YMP/CM-0011

U.S. DEPARTMENT OF ENERGY

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

SITE CHARACTERIZATION PROGRAM BASELINE

REVISION 1

VOLUME 2 OF 5

MARCH 1991

UNITED STATES DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

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WBS No. 1.2.3
QA Level Yes

PROJECT BASELINE DOCUMENT

YUCCA MOUNTAIN SITE CHARACTERIZATION PROGRAM BASELINE (SCPB) VOLUME 2

CHANGES TO THIS DOCUMENT REQUIRE PREPARATION AND APPROVAL OF A CHANGE REQUEST IN ACCORDANCE WITH PROJECT AP-3.3Q

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

UNITED STATES DEPARTMENT OF ENERGY
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT OFFICE

Y-AD-057
9/90

YUCCA MOUNTAIN PROJECT
CHANGE DIRECTIVE (CD)

1 CR No. 91/052

SECTION I. IDENTIFICATION

2 Title of Change:

Submittal of the "Site Characterization Program Baseline, Rev. 1," for CCB Control

3 Change Classification:

☐ Class 1 ☐ Class 3
☒ Class 2

SECTION II. DISPOSITION

4 CR Disposition:

☐ Approved ☐ Disapproved
☒ Approved with Conditions

5 Conditions: *(if applicable)*

The next revision of this document should incorporate the following items:

1. The term "Exploratory Shaft Facility" should be replaced by "Exploratory Studies Facility" throughout the document.

2. The term "repository" should be replaced by "potential repository" throughout the document.

(See Change Documentation Continuation Page ___)

Implementation Direction: *(if applicable)*

1. This Change Request (CR) is approved for CCB Baselining as the "Site Characterization Program Baseline, Revision 1," and is assigned Controlled Document number YMP/CM-0011.

2. The Director, Regulatory and Site Evaluation Division is responsible for ensuring the above listed conditions are incorporated into the next revision of Document YMP/CM-0011.

(See Change Documentation Continuation Page 2)

SECTION III. CONCURRENCE

7 Quality Assurance Organization Concurrence

Name: D. G. Horton (print) Org.: PQA (print)

Signature: N Waldura for DG Horton Date: 3/28/91

8 Disposition Authority

Name: M. B. Blanchard (print) Title: CCB Chrprsn (print)

Signature: Robert [illegible] For Maxwell Blanchard Date: 3/28/91

9 Effective Date:

3/28/91

5 Implementation Direction (continued)

3. The CCB Secretary shall ensure that the Cover Page and the Title Page for Document YMP/CM-0011, Revision 1, are prepared.

4. The Document Originator shall provide a Print Ready Copy of YMP/CM-0011, Revision 1, to the CCB Secretary. The Document Number and Revision Number will be identified on each page of the Publication Ready Document, YMP/CM-0011.

5. The CCB Secretary shall ensure that YMP/CM-0011, Revision 1, is prepared in accordance with this Change Directive (CD). The CCB Secretary shall ensure the Document Change Notice (DCN), indicating changes made in the document, is prepared. The DCN will be attached to the front of the Print Ready Copy of the document. The CCB Secretary shall also prepare a Controlled Document Issuance Authorization (CDIA) to transmit this CD, the DCN, and YMP/CM-0011, Revision 1, to the Project Document Control Center (DCC) in accordance with AP-1.5Q.

6. Per AP-3.3Q, each TPO and Project Office Division Director will complete an Affected Document Notice (ADN) as notification of completion of implementation planning for this CD.

7. The CCB Secretary shall ensure that the Configuration Information System (CIS) and the CCB Register are updated to reflect Revision 1 to YMP/CM-0011.

8. Any changes to document YMP/CM-0011, Revision 1, will require submittal of a CR to the Project CCB.

9. Upon release of YMP/CM-0011, Revision 1, all Project Participants will be required to use YMP/CM-0011, Revision 1, in performing duties applicable to this document.

Y-AD-059
9/90

YUCCA MOUNTAIN PROJECT
DOCUMENT CHANGE NOTICE (DCN) RECORD

1 Document Title: Site Characterization Program Baseline

2 Document Number: YMP/CM-0011

The document identified in Blocks 1 and 2 has been changed. The changed pages attached to this DCN are identified in Block 7 opposite the latest DCN number in Block 3. The original issue of this document as modified by all applicable DCN's constitutes the current version of the document identified in Blocks 1 and 2.

3 DCN NO.	4 CR NO.	5 DOCUMENT Rev./ICN #	6 CR TITLE	7 AFFECTED PAGES	CHANGE	ADD	DELETE	8 DATE
001	91/052	Rev. 1	Submit SCPB, Rev. 1 for CCB Control (complete revision of information related to ESF design)	All	X			4/5/91

Yucca Mountain Site Characterization
Project Office
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WBS 1.2.9
QA: N/A

MAR 20 1991

Distribution

RENAMING OF EXPLORATORY SHAFT EFFORT

As a consequence of the instructions from Dr. John W. Bartlett, Director of the Office of Civilian Radioactive Waste Management, on February 12, 1991, about the redirection of Yucca Mountain Site Characterization Project efforts associated with the Exploratory Shaft Facility design effort, it has become apparent that retaining the name of Exploratory Shaft would be somewhat misleading when the current design studies are focusing upon ramps, and a shaft is only being considered as a possible backup.

Therefore, after considerable discussion with many parties about selecting a new name, I have concluded that the most appropriate approach for now is to change the name of Exploratory Shaft Facility (ESF) to Exploratory Studies Facility (ESF). As you can observe, the acronym remains the same but "Shaft" becomes "Studies."

For all future communication, I request that you use this new name for this very important facility. We do not plan on modifying any completed documents or sending out errata sheets. I do request that all new communications within the U.S. Department of Energy's program now refer to this facility as the Exploratory Studies Facility. I thank you for your cooperation.

Carl P. Gertz
Project Manager

YMP:MBB-2814

Distribution—Memorandum dated MAR 20 1991

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YMP/CM-0011, Rev. 1

The numbering scheme used in this table of contents reflects that the numbering of the Site Characterization Plan has been preserved to maintain consistency among related documents. Sections 8.5 and 8.6 have been intentionally excluded.

 YMP/CM-0011, Rev. 1

TABLE OF CONTENTS

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

YMP/CM-0011, Rev. 1

TABLE OF CONTENTS (continued)

Page

YMP/CM-0011, Rev. 1

LIST OF FIGURES

YMP/CM-0011, Rev. 1

LIST OF FIGURES (continued)

YMP/CM-0011, Rev. 1

LIST OF FIGURES (continued)

YMP/CM-0011, Rev. 1

LIST OF FIGURES (continued)

 YMP/CM-0011, Rev. 1

LIST OF TABLES

YMP/CM-0011, Rev. 1

LIST OF TABLES (continued)

YMP/CM-0011, Rev. 1

LIST OF TABLES (continued)

 YMP/CM-0011, Rev. 1

8.3.1.3 Overview of the geochemistry program: Description of the present and expected geochemical characteristics required by the performance and design issues

Summary of performance and design requirements for geochemical information

Performance allocation is being used in developing the issue resolution strategy for the performance and design issues and to determine what geochemical information must be developed during site characterization. Performance allocation is an iterative process incorporating sensitivity analysis to determine data needs. Specifically, an identification of a data need by a performance or design issue results in a request for that information to be generated by the geochemical program. Supporting data must be obtained to provide the necessary information to satisfy the requested data need. These data will be used to develop the conceptual and numerical model to be used in understanding geochemical processes and evaluating subsystem performance.

Figure 8.3.1.3-1 shows the performance and design issues that call for geochemical data, summarizes the data needed, and indicates the relevant model for each data need. The models will be discussed in detail later and are shown in the figure as an introduction. The specific data needs by the performance and design issues are as follows:

1. Issue 1.1 (total system performance, Section 8.3.5.13) calls for retardation factors for radionuclides in the rock units along the flow paths under expected and unexpected conditions for 10,000 to 100,000 yr. Issue 1.1 also calls for major ion water chemistry, dispersion coefficients, and matrix diffusion coefficients.

2. Issue 1.2 (individual protection, Section 8.3.5.14) calls for the same data as Issue 1.1, except only for expected conditions and only for 1,000 yr. In addition, data on gas phase transport is requested.

3. Issue 1.3 (ground-water protection, Section 8.3.5.15) again calls for the same data as Issue 1.1, except only for expected conditions and only for 1,000 yr.

4. Issue 1.5 (engineered-barrier system release rates, Section 8.3.5.10) calls for changes in geochemical conditions to serve as input to scenarios, and for radionuclide sorptive and transport properties of the host rock.

5. Issue 1.6 (ground-water travel time, Section 8.3.5.12) calls for geochemical data relevant to determining the extent of the disturbed zone, specifically, data on silica mobilization as it affects permeability.

6. Issue 1.8 (NRC siting criteria, Section 8.3.5.17) calls for data on geochemical conditions and processes at the site for the evaluation of the presence or absence of the favorable and potentially adverse conditions and analysis of geochemical effects on subsystem/system performance.

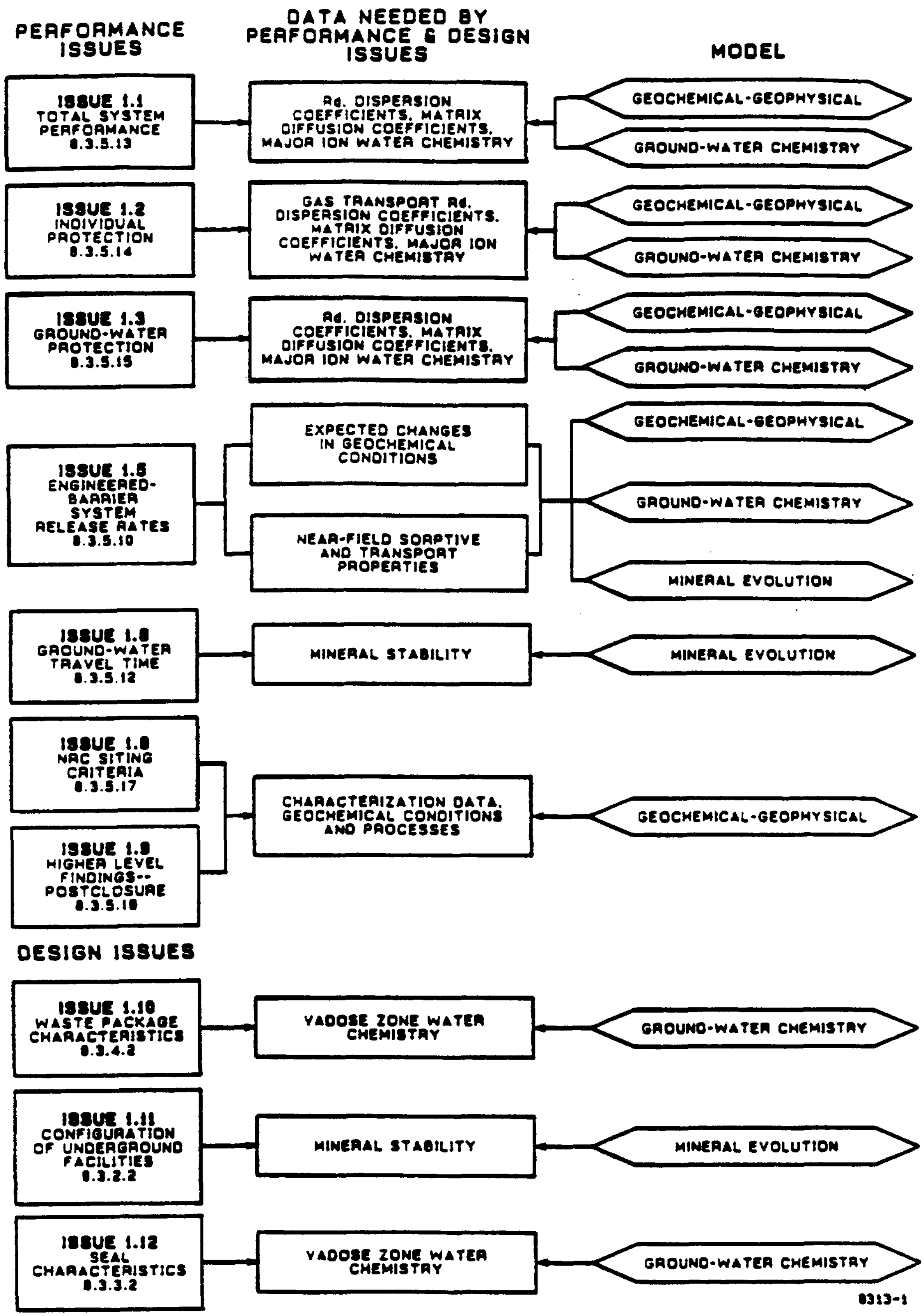

Figure 8.3.1.3-1. Parameter calls and corresponding model from geochemistry test program.

YMP/CM-0011, Rev. 1

7. Issue 1.9a (higher level findings--postclosure system and technical guidelines, Section 8.3.5.18) calls for geochemical data for making the higher level finding on the technical guideline on geochemistry.

8. Issue 1.10 (waste package characteristics--postclosure, Section 8.3.4.2) requests data on the vadose zone water chemistry to support the waste package design and testing programs.

9. Issue 1.11 (configuration of underground facilities--postclosure, Section 8.3.2.2) requests data on mineral stability to support testing to determine the stability of mined openings and the thermal response of the host rock.

10. Issue 1.12 (seal characteristics, Section 8.3.2.2) requests data on the vadose zone water chemistry to support the testing of ground water-seals materials interactions.

Table 8.3.1.3-1 shows the progression from performance and design issue needs for geochemical data to the parameters that define the testing program (activity parameters on Table 8.3.1.3-1). The left hand column shows the issues that require geochemical data. These issues are linked to appropriate common parameter categories. The common parameter category is chosen as a general subject area under which related parameters, including closely related performance parameters, can be grouped. The common parameter categories, in turn, are linked to activity parameters that represent the focus of the testing programs (given as the SCP sections) that address the data included in the common parameter categories. These activity parameters will become characterization parameters when test bases are finalized for them. As an example of the progression shown on Table 8.3.1.3-1, consider the requirement for radionuclide retardation factors (R_fs) for Issue 1.1. Sorption data for the unsaturated zone is included in the common parameter category called unsaturated zone geochemical properties. The program to supply the sorption data is built around laboratory testing of sorption as functions of the important variables, summarized as the activity parameters on Table 8.3.1.3-1. These activity parameters will become characterization parameters when test basis are developed to determine the testing goals and confidences needed to satisfy the performance parameter allocations.

The logic of the geochemistry program is described later. Justification is also provided for the secondary and supporting data that must be obtained to provide the necessary information to satisfy the requested data needed by the various performance or design issues.

<u>Approach used to satisfy performance and design requirements</u>

In a broad sense, the geochemistry program must characterize and evaluate the effectiveness of the geochemical "barrier." The program of geochemical testing described in this section concerns characterizing the far-field geochemistry at the site. The geochemical studies concerned with characterizing the waste package environment and engineered barrier system performance are discussed in Section 8.3.4.2 and 8.3.5.9, respectively. Section 8.3.5.13, through the use of performance allocation, presents an evaluation that describes the far-field geochemical "barrier" as a reserve barrier in a total systems performance assessment. The geochemical barrier

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 1 of 6)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geochemistry characterization program: Activity parameter	Response by geochemistry characterization program: SCP activity
1.1, Total system performance	8.3.5.13	Unsaturated zone geochemical properties (sorptive)	Sorption as a function of solid phase composition	8.3.1.3.4.1.1
			Sorption as a function of sorbing element concentration	8.3.1.3.4.1.2
			Sorption as a function of groundwater composition	8.3.1.3.4.1.3
			Sorption on particulates and colloids	8.3.1.3.4.1.4
			Statistical analysis of sorption data	8.3.1.3.4.1.5
			Biological sorption and transport	8.3.1.3.4.2
		Unsaturated zone geochemical properties (solubility of radionuclides)	Solubilities of compounds bearing radionuclides having significant representation in the inventory and half-lives > 20 yr	8.3.1.3.5.1.1 through 8.3.1.3.5.1.3 8.3.1.3.5.2.1 8.3.1.3.5.2.2
		Saturated zone geochemical properties (sorptive)	Sorption mechanics for radionuclides	8.3.1.3.4.1.1
			Sorption as a function of solid phase composition	8.3.1.3.4.1.1
			Sorption as a function of sorbing element concentration	8.3.1.3.4.1.2
			Sorption as a function of groundwater composition	8.3.1.3.4.1.3
			Sorption on particulates and colloids	8.3.1.3.4.1.4

YMP/CM-0011, Rev. 1

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 2 of 6)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geochemistry characterization program: Activity parameter	SCP activity
1.1, Total system performance (continued)	8.3.5.13	Saturated zone geochemical properties (sorptive) (continued)	Statistical analysis of sorption data	8.3.1.3.4.1.5
			Biological sorption and transport	8.3.1.3.4.2
		Saturated zone geochemical properties (diffusive)	Effective diffusivities for saturated tuff	8.3.1.3.6.2.1
		Saturated zone geochemical properties (solubility of radionuclides)	Solubilities of compounds bearing radionuclides having significant representation in the inventory and half-lives > 20 yr	8.3.1.3.5.1.1 through 8.3.1.3.5.1.3 8.3.1.3.5.2.1 8.3.1.3.5.2.2
		Rock unit characteristics (mineralogy-petrology)	3-dimensional mineral distribution	8.3.1.3.2.1
		Fracture characteristics (mineralogy-petrology)	3-dimensional mineral distribution	8.3.1.3.2.1
		Fault characteristics (mineralogy-petrology)	3-dimensional mineral distribution	8.3.1.3.2.1

YMP/CM-0011, Rev. 1

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 3 of 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.1, Total system performance (continued)	8.3.5.13	Saturated zone hydrologic properties and conditions (transmissive)	Longitudinal diffusion, crushed tuff	8.3.1.3.6.1.2
		Saturated zone hydrologic properties and conditions (groundwater chemistry)	Major ion chemistry	8.3.1.2.1.3.5
		Saturated zone hydrologic properties and conditions (dispersive)	Dispersion characteristics for crushed tuff	8.3.1.3.6.1.1
			Hydrodynamic dispersion for solid rock column	8.3.1.3.6.1.2
			Heterogeneity, solid rock	8.3.1.3.6.1.2
			Hydrodynamic dispersion for fractured tuff	8.3.1.3.6.1.4
			Channeling--non-Fickian dispersion	8.3.1.3.6.1.4
		Unsaturated zone hydrologic properties and conditions (dispersion)	Permeability as a function of pressure (matrix potential)	8.3.1.3.6.1.3
			Matrix potential of the unsaturated tuff	8.3.1.3.6.1.3

YMP/CM-0011, Rev. 1

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 4 of 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.1, Total system performance (continued)	8.3.5.13	Unsaturated zone hydrologic properties and conditions (fluid chemistry)	Major ion chemistry	8.3.1.2.2.4.8
1.2, Individual protection	8.3.5.14	Same as Issue 1.1	Same as Issue 1.1	
1.3, Ground-water protection	8.3.5.15	Same as Issue 1.1	Same as Issue 1.1	
1.5, Engineered barrier system release rates	8.3.5.10	Changes in geochemical radionuclide conditions, sorptive and transport properties of the near-field host rock	Sorption as a function of solid phase composition	8.3.1.3.4.1.1
			Sorption as a function of sorbing element concentration	8.3.1.3.4.1.2
			Sorption as a function of ground-water composition	8.3.1.3.4.1.3
			Sorption on particulates and colloids	8.3.1.3.4.1.4
			Statistical analysis of sorption data	8.3.1.3.4.1.5
			Biological sorption and transport	8.3.1.3.4.2

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 5 of 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.5, Engineered barrier system release rates (continued)	8.3.5.10		Solubilities of compounds bearing radionuclides having significant representation in the inventory and half-lives > 20 yr	8.3.1.3.5.1.1 through 8.3.1.3.5.1.3 8.3.1.3.5.2.1 8.3.1.3.5.2.2
			Major ion chemistry	8.3.1.2.2.4.8
1.6, Ground-water travel time	8.3.5.12	Rock unit characteristics (mineralogy-petrology)	Mineral stability	8.3.1.3.2.2.2
1.8, NRC siting criteria	8.3.5.17	Same as Issue 1.1	Same as Issue 1.1	
1.9, DOE siting guidelines	8.3.5.18	Same as Issue 1.1	Same as Issue 1.1	
1.10, Waste package characteristics (post-closure)	8.3.4.2	Unsaturated zone hydrologic properties (fluid chemistry)	Major ion chemistry	8.3.1.2.2.4.8
		Rock unit characteristics (mineralogy-petrology)	Mineral stability	8.3.1.3.2.2.2

YMP/CM-0011, Rev. 1

Table 8.3.1.3-1. Activity parameters provided by the geochemistry program that support performance and design issues (page 6 of 6)

Calls by performance and design issues			Response by geochemistry characterization program	
Issue	SCP section	Parameter category	Activity parameter	SCP activity
1.11, Configuration of underground facilities (postclosure)	8.3.2.2	Rock unit characteristics (mineralogy-petrology)	Mineral stability	8.3.1.3.2.2.2
1.12, Seal characteristics	8.3.3.2	Unsaturated zone hydrologic properties (fluid chemistry)	Major ion chemistry	8.3.1.2.2.4.8

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

is an important factor. Thus, the geochemistry test program must test the assumptions and provide confidence in and give support to the release rates determined by the solute transport calculations of Section 8.3.5.13, as well as evaluate alternative conceptual models of the site geochemistry. The goal for the retardation parameter in the solute transport calculations is a value of one, implying that "no credit" is taken for geochemical retardation processes. However, these processes are included in the strategy for demonstrating system compliance by virtue of the inclusion of a retardation factor in the equations. The geochemistry program is directed at quantifying the retardation factor, which is expected to exceed a value of one. Any value greater than one will supply added confidence to the calculations of transport to the accessible environment based on advective/dispersive transport calculations.

The calculations of the total site performance, as shown in Section 8.3.5.13, are based on equivalent porous media transport through the matrix with adsorptive retardation. The geochemistry test program must provide the sorption data as well as the supporting geochemical information required for the total system modeling approach used for Issue 1.1. A combination of laboratory experiments and modeling will be used by the geochemistry program to support the use of R_fs and the one-dimensional system model described in Section 8.3.5.13. In addition to providing the requested data to the performance issues, the results of the geochemistry program must prove with reasonable assurance that, for the far-field

1. Sorption, expressed in terms of K_d, as a function of water composition, radionuclide concentration, and rock type is sufficient for meeting the performance objectives.

2. The sorptive phases will remain stable under the conditions expressed in Issue 1.1 for 10,000 yr.

3. The ground-water composition is predictable over the time and conditions called for in Issue 1.1.

4. No "short circuit" of the sorptive barrier exists (i.e., transport by particulates, colloids, or by microbes).

Additionally, the program results must

1. Define the relative role of physical retardation processes such as dispersion and matrix diffusion.

2. Determine the solubility and speciation of radionuclides to support the K_d tests and analyses of transport when sorption is not considered.

3. Provide information for analysis of gaseous transport.

A summary logic diagram for the geochemistry program is given in Figure 8.3.1.3-2. The data generated by the investigations will be used to develop conceptual and numerical models on ground-water chemistry, mineral evolution, sorption, and a geochemical-geophysical model of Yucca Mountain. These models and their supporting data will provide the basis for the analy-

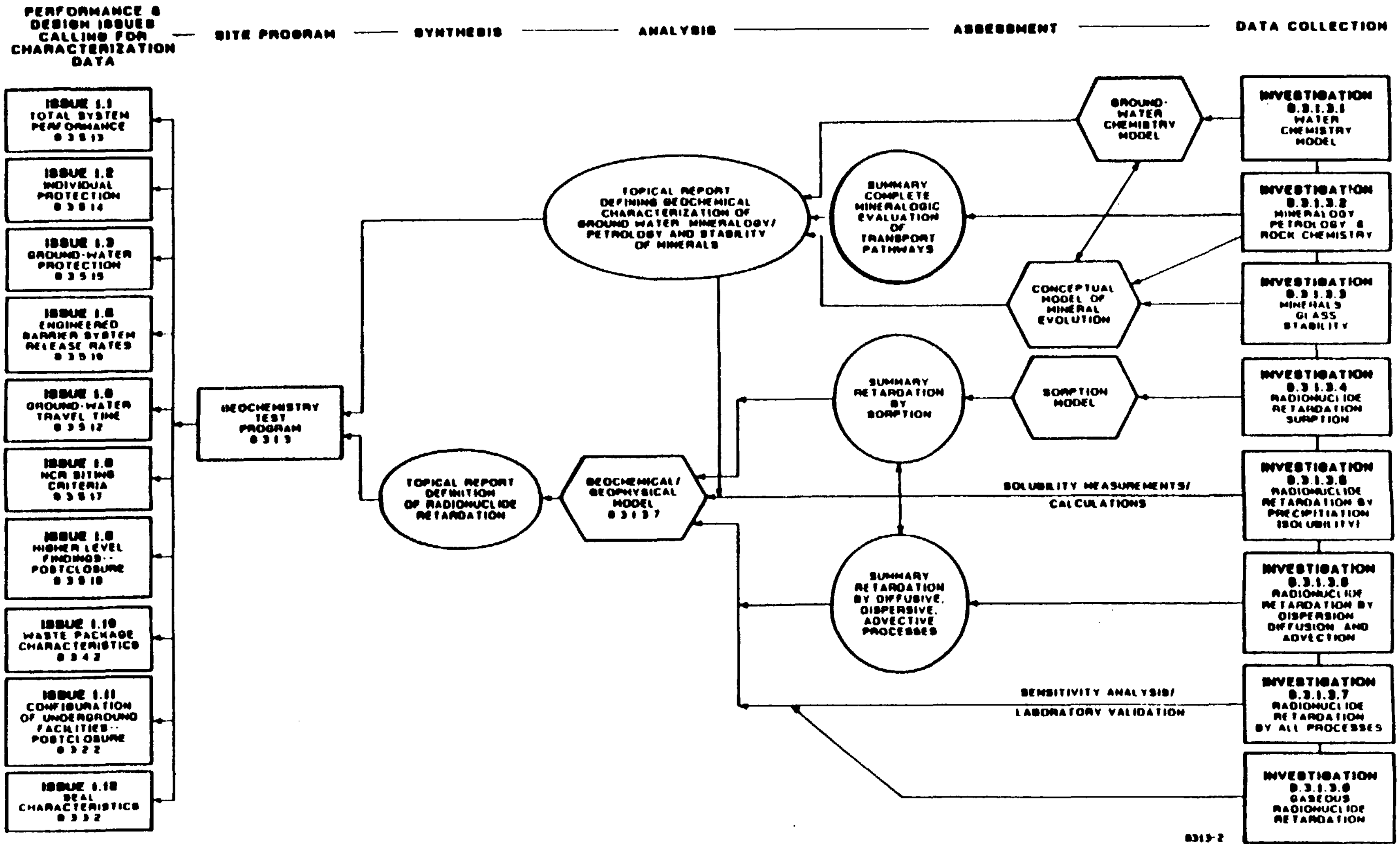

Figure 8.3.1.3-2. Logic diagram for geochemistry program 8.3.1.3

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

ses just described, thus satisfying the performance and design requirements. Detailed logic diagrams for each investigation will be described in the following section.

The applicability of the data obtained in the laboratory investigations to total system performance will have to be established. The interactions and relative importance of the physical and chemical retardation processes are being evaluated in Investigation 8.3.1.3.7 (radionuclide retardation investigations). This investigation will identify the significant physical and chemical retardation processes that need to be included in the one-dimensional system performance model used in Section 8.3.5.13.

The applicability of extrapolating the laboratory data to field scale will also have to be established. The elements to be considered in developing the strategy for this are described in Study 8.3.1.3.7.2. The elements include scaling testing, field testing, conservative and reactive tracer testing in the c-wells, and natural analogs, where applicable.

The geochemical program will provide information on the geochemical processes defining potential changes in the near-field mineralogy relevant to the definition of the disturbed zone. This information is important to Performance Issue 1.6 (ground-water travel time, specifically Information Need 1.6.5 (disturbed zone boundary)), and Repository Design Issue 1.11 (configuration of underground facilities--postclosure), which must develop a predictive model assessing the stability of underground openings. Data on the vadose zone water chemistry will support the waste package design, testing, and modeling of engineered-barrier system release rates. The ground-water chemistry model will be a starting point for predicting the vadose zone water chemistry changes due to waste emplacement, and the conceptual model of mineral evolution will be the basis for the analysis of future mineral stability. Finally, the basic characterization data on geochemical conditions and processes that support the system and subsystem performance Issues 1.1, 1.2, 1.3, and 1.5 are also used to support performance Issues 1.8 and 1.9.

Alternative Conceptual Models

The intent of Table 8.3.1.3-2 is (1) to present the current conceptual understanding of the geochemical conditions and processes active at the site and how they are expected to function as the geochemical barrier to radionuclide migration during the repository performance period and (2) to present alternative hypotheses that could be supported based on the uncertainty in existing information and understanding. These two aspects are further developed in the table by identifying the performance parameters, or design needs, that may be affected by the results of site characterization work to determine if the current conceptual understanding, or an alternate hypothesis, is correct. The needed confidence in these performance parameters is given (based on system or subsystem performance allocation tables in the SCP), along with an estimated sensitivity of the performance assessments to the alternative hypotheses and the uncertainty involved. The specific studies are aimed at quantifying the geochemical processes, limiting uncertainty, or distinguishing between alternate representations of expected behavior of the site.

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 1 of 8)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
RETARDATION MODEL	Radionuclide mobility is substantially retarded by (1) sorption, (2) solubility, and (3) dispersion/diffusion/filtration	High--mechanisms of transport and and retardation are only generally known	Retardation is largely by-passed by flow field characteristics (i.e., rapid along fractures) One retardation process dominates Retardation processes in the natural situation are too complex to model reliably	NA[a]	NA	NA	NA	8.3.1.3.7--retardation, all processes
Gaseous pathway	Gaseous radionuclide release from the near field is upward through the unsaturated zone, rate and amount of transport can be bounded by engineered barrier system performance assessments and data on vapor phase transport collected in the pre-emplacement time frame	High--site data very limited, calculational models not tested with field data	Vapor transport cannot be modeled adequately	NA	NA	NA	NA	8.3.1.3.7--retardation, all processes

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 2 of 8)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Dispersion/ diffusion	Dispersion/ diffusion provide some retardation	High--site data very limited	Vapor phase movement too rapid along preferred flow paths to model adequately Dispersion ineffective as a retardation mechanism	Gaseous radionuclide release to accessible environment	High	High	High	8.3.1.3.8--gaseous transport 8.3.1.2.2.6--gaseous phase movement in unsaturated zone 8.3.1.2.2.7.1--gaseous phase chemistry
Isotopic exchange	Isotopic exchange with the liquid phase in the unsaturated zone provides some retardation for carbon-14	High--site data very limited	Isotopic exchange not effective due to rapid vapor phase transport	Gaseous radionuclide release to accessible environment	High	High	High	8.3.1.3.8--gaseous transport 8.3.1.2.2.6--gaseous phase movement in unsaturated zone 8.3.1.2.2.7.1--gaseous phase chemistry
Liquid pathway	Predominant release pathway is in the liquid phase, movement is downward and laterally from the repository. Retardation provided by chemical and physical processes	Low to medium--current hydrologic data support downward movement. Current data base is not extensive enough	Rapid groundwater movement bypasses chemical and physical retardation processes	NA	NA	NA	NA	NA

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 3 of 8)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Sorption	Sorption is an element-specific function of water composition, solids, redox condition, pH, temperature, rock texture, hydrologic properties	Medium to high--some uncertainty over site-specific conditions for individual element behavior	Site specific behavior for specific radionuclides is too complex to predict with confidence Sorption "barrier" bypassed by physical conditions, rapid fracture flow, colloidal transport	Geochemical retardation	High	High	High	8.3.1.3.4.3--sorption models 8.3.1.2.3.1.7--C-hole reactive tracer test
- Sorption as a function of substrate, water chemistry, and sorbate concentration	Sorption controlled by these parameters	Medium to high--some uncertainty in site conditions	Sorption cannot be modeled as a function of these parameters	Subset of sorption model element; overall ranking given with sorption element above				8.3.1.3.2.1--3-D mineral distribution 8.3.1.3.4.1.1--sorption as a function of solid phase composition 8.3.1.3.4.1.2--sorption as a function of sorbing element concentration 8.3.1.3.4.1.3--sorption as a function of ground-water composition 8.3.1.3.4.1.5--statistical analysis

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 4 of 8)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
- Sorption as a function of substrate, water chemistry, and sorbate concentration (continued)								8.3.1.3.6.1.1--crushed tuff column experiments 8.3.1.3.6.1.2--mass transfer kinetics 8.3.1.3.6.1.3--unsaturated tuff column experiments
- Sorption on particulates and colloids	Sorption on particulates/colloids expected to be minor and filtration would further reduce effects	Low--mobile particulates not expected in the far field	Particulate transport may be possible in a flow field dominated by rapid fracture flow	Subset of sorption model element; overall ranking given with sorption element above				8.3.1.3.4.1.4--sorption on colloids and particulates
- Microbial activity	Not thought to be a significant transport mechanism	Low--microbial activity expected to be low. Consistent with existing field data	No credible alternative	Subset of sorption model element; overall ranking given with sorption element above				8.3.1.3.4.2--biological sorption and transport
Solubility	Solubility limits levels of radionuclides through far field and solubility limited by equilibrium thermodynamic relations and/or precipitation rates	Medium to high--in element thermodynamic data and in site chemical environment	Radionuclide concentrations not limited by thermodynamic relations due to colloid formation; thermodynamic data unavailable; nucleation unfavorable Sorption processes dominate; saturation is not approached	Geochemical retardation	Medium (saturated zone) High (unsaturated zone)	Low to medium--sorption expected to control radionuclide concentrations	Medium	8.3.1.3.5--retardation by precipitation

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 5 of 8)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
- Precipitation (aqueous speciation and solubility modeling)	Radionuclide concentrations in the far field are limited by solubility/precipitation constraints	Medium to high--limited data on actinides under site conditions	Solubility/precipitation relationships cannot be modeled reliably	Subset of solubility model element; overall ranking given with solubility element above				8.3.1.3.5.1--dissolved species concentration limits
- Colloid formation and stability	Colloid formation is limited under far field site conditions for most radionuclides and filtration would limit transportation	Medium--some uncertainty exists about behavior under site conditions	Colloids form for some radionuclides and transport is possible for rapid groundwater movement along fractures	Subset of solubility model element; overall ranking given with solubility element above				8.3.1.3.5.2--colloid behavior 8.3.1.3.7.2--applicability of laboratory data to repository transport
Dispersion/diffusion/filtrations	Retardation of radionuclide transport by physical processes along pathways for matrix-dominated flow field and for some conditions of fracture flow	High--flow mechanism is not well established at the site, data on physical retardation mechanisms very sparse	Flow is dominated by rapid fracture-flow pathways and retardation mechanisms bypassed Data on physical retardation mechanism cannot be obtained for reliable quantification	Geochemical retardation	Medium (saturated zone) High (unsaturated zone)	Low to medium--sorption expected to control radionuclide concentrations	Moderate	8.3.1.3.6.1.4--fractured tuff column studies 8.3.1.3.6.1.5--filtration 8.3.1.3.6.2--diffusion

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 6 of 8)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
WATER CHEMISTRY MODEL	Ground-water chemistry is a controlling factor in retardation by sorption and solubility. Ground-water composition controlled by water-rock interactions trending toward equilibrium	Low to medium--some uncertainty in ground-water composition and thermodynamic modeling of rock/water interactions	Kinetics of rock-water interactions are too slow to alter composition of recharge water and flow is dominated by rapid fracture flow--thermodynamic modeling therefore cannot model ground-water composition and evolution predictably	Ground-water chemistry contribution to retardation factors	High	High	High	8.3.1.3.7--retardation, all processes
Saturated zone	Saturated zone ground-water composition is controlled by rock-water interactions along flow paths. No unexpected changes in ground-water chemistry along pathway to accessible environment	Low--current data are adequate to explain saturated zone ground-water composition	No credible alternative	Saturated zone residence times and retardation processes (If fluid flow is controlled by rapid fracture flow through the unsaturated zone, retardation in the saturated zone must be included in performance assessment of releases to the accessible environment)	High--direct evidence of residence times in saturated zone and origins of water	Medium--some compensation for chemical conditions is possible	Low--saturated zone barrier is backup. Also produces additional lines of evidence for flow path/velocity	8.3.1.3.1.1--ground-water chemistry model 8.3.1.2.3.2--saturated zone hydrochemical characterization

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 7 of 8)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Unsaturated zone	Unsaturated zone ground-water composition is surface recharged, modified by rock water interaction	High--very few data available	Unsaturated zone water composition reflects deep sources in the saturated zone (i.e., former stands of ground-water table, upwelling leading to perched water	Unsaturated zone water residence times and fluid chemistry as it affects dissolution of waste and retardation processes	High	High	High	8.3.1.3.1.1--ground-water chemistry model 8.3.1.2.2.7--hydrochemical characterization of unsaturated zone
MINERAL EVOLUTION MODEL	Tuff secondary mineralogy reflects alteration of tuffs immediately after deposition followed by slower alteration and formation of secondary minerals with surface recharge waters. Alteration predictable from thermodynamic relationships	Low to medium--data base somewhat limited, current data in agreement with theoretical relationships	Mineralogy is metastable kinetics are too slow and rock-water reactions are too complex to predict temporal changes over the performance period	Solid phase contribution to retardation factor	High	High	High	8.3.1.3.2--retardation, all processes 8.3.1.3.3.3--conceptual model of mineral evolution
Mineral alteration history	3-D distribution of mineral zonation from early alteration is predictable (i.e., alteration processes can be understood) at the site and a vertical and lateral stratigraphy can be developed	Medium--current data are not areally extensive enough to develop the stratigraphy	Alteration processes are too complex on the repository scale for a mineralogic stratigraphy to be developed	Retardation factor	High	Medium--sorptive phases are secondary minerals formed by alteration processes	Low--alternative hypothesis not supported by existing data	8.3.1.3.2.1--mineralogy and petrology along transport pathways 8.3.1.3.2.2--mineral alteration history

Table 8.3.1.3-2. Current representation and alternative hypotheses for geochemical model for site geochemistry program (page 8 of 8)

Current representation		Uncertainty in current understanding	Alternative hypothesis and significance					Tests to distinguish hypothesis and reduce uncertainty
Model element	**Current representation**	**Uncertainty and rationale**	**Alternative hypothesis**	**Performance measure design or performance parameter**	**Needed confidence in parameter or performance measure**	**Sensitivity of parameter or performance measure to hypothesis**	**Need to reduce uncertainty**	**Studies or activities to reduce uncertainty**
Mineral stability	Secondary mineralogy along flow paths (particularly sorptive minerals) will remain stable under post-emplacement conditions or, at least, their alteration is predictable based on thermodynamic considerations	Medium--thermodynamic data are not extensive and low temperature alteration processes are difficult to quantify experimentally	Alteration rates are controlled by local conditions (interfaced processes) and are too complex to model reliably	Retardation factor	High	High	Low--alternate hypothesis not supported by existing data	8.3.1.3.3--stability of minerals and glasses

*NA = not applicable.

YMP/CM-0011, Rev. 1

The geochemical understanding of site behavior is intimately connected to the characterization of the hydrologic regime at the site. These two aspects cannot be handled separately; the flow regime at the site (flow dominated by matrix or fracture flow or a combination of both) will determine the effectiveness of the geochemical "retardation barrier." The relative role of retardation processes will vary as a reflection of the ground-water flow regime at the site.

For example, under a matrix dominated flow system at low velocities the role of dispersion/diffusion and filtration would be more important in retarding radionuclide movement than in a flow system dominated by relatively faster ground-water movement in a fracture flow dominated system. In terms of the performance assessment strategy for total systems performance (Issue 1.1), the role of the geochemical "retardation barrier" may become more important in a hydrologic system dominated by relatively faster fracture flow than a slower matrix flow dominated flow regime because ground-water travel times would decrease and geochemical retardation then may be relied on more heavily to retard radionuclide migration.

The geochemistry program described in this section is focused on the far-field portion of the waste isolation system. As such, it is aimed at supplying data needed to predict radionuclide retardation and releases to the accessible environment (Issue 1.1). The program of geochemical work needed to address near-field performance is described in the waste package program (Section 8.3.4.2.4). Some of the geochemical site data collected in the far-field program contribute to the characterization of the waste package environment by establishing the pre-emplacement geochemical conditions.

As mentioned earlier, the hydrologic setting of the site is intimately bound to the geochemistry program. Hydrologic investigations are intended to define the nature of the flow mechanisms (matrix versus fracture flow in both the saturated and unsaturated zones). The geochemistry program will collect data relevant to both flow mechanisms so that the role of geochemical retardation can be assessed for the present hydrologic setting of the site and for possible changes in the hydrologic setting during the repository performance period. Although the geochemistry and geohydrology programs are intimately connected, the geochemistry program is in this sense independent of the geohydrology program. To determine the relative weighting given to various geochemical retardation processes in a total system analysis, the two efforts are brought together.

The organization of the information presented in Table 8.3.1.3-2 is hierarchal in nature. Three conceptual model headings are given, the retardation model, the ground-water chemistry model, and the mineral evolution model. Under each of these models all subordinated elements are listed that describe components of the conceptual models. For example, the ground-water chemistry model considers both the saturated and unsaturated zones. For the larger retardation model, a further subdivision is made based on processes involved in the model components. The retardation model considers pathways for gaseous and liquid movement as the two major elements. Retardation processes expected to be involved are subordinated under these headings. A further subdivision is given for aspects of these processes that can be conveniently separated.

YMP/CM-0011, Rev. 1

All three models are closely related. The retardation model is the most important from the perspective of predicting site performance and integrates information from all the models. It is recognized that radionuclide retardation is a partial function of the chemistry of the far field rock/ground-water system. The ground-water chemistry is controlled, at least in part, by the rock-water interactions. The mineral evolution model must be integrated with the water chemistry model to understand the present geochemical conditions and the anticipated conditions during the repository performance period, at the site. The results of this understanding is then integrated into the retardation model to predict the behavior of any radionuclides carried into this rock/ground-water system during the repository performance period.

The retardation model considers the gaseous pathway and the liquid pathway (ground-water transport). For the gaseous pathway, dispersion and diffusion processes may supply some retardation, and isotopic exchange with the aqueous phase may contribute additional geochemical retardation, depending on the velocity of vapor-phase movement. For releases to the ground water, three broad categories of retardation are given as mentioned earlier. The relative importance of these retardation processes will vary dependent on the hydrologic regime. In addition to this interface with other site characterization activities, the experimental approach taken to investigate retardation processes determines, at least in part, the confidence that can be associated with the results. As a specific example, sorption testing can be done from a purely empirical approach, involving large numbers of tests determined simply by parameter variation, or an approach tailored exclusively on understanding the controlling sorption mechanisms. These "end-member" approaches generate significantly different testing programs. The approach taken in the geochemistry program is a blend of both, the exact mix determined by the current understanding of element-specific behavior and the overall need to predict the behavior a given radionuclide within the context of the total system (near and far field) performance. The test describing the testing matrices, methods, and approaches supplies further detail on these questions. In addition, testing is included to determine the behavior of radionuclides for mechanisms that, if active at the site, could effectively bypass the sorption barrier, such as sorption on colloid or particulate material. The current understanding of the site indicates that these processes are not expected to be significant but the alternative hypotheses must be tested.

As mentioned previously, the ground-water chemistry and mineral evolution models are supportive to the retardation model. These two models address the questions of determining the stability of the sorptive mineralogy during the repository performance period and the potential evolution of ground-water composition. These two models also have some application to design needs described in more detail elsewhere. More specifically, a mineral stratigraphy for the host rock will be developed from studies of the alteration history of the rocks. This "alteration stratigraphy" based on mineral zonations can be used in designing the layout of repository drifts.

A major effort in the geochemistry program is the integration of all the retardation, alteration, and transport processes into a unified picture of predicted site behavior. The integration effort is described in Section 8.3.1.3.7. This modeling activity is an overview attempt to integrate modeling studies to understand sorption processes (Section 8.3.1.3.4.3),

YMP/CM-0011, Rev. 1

solubility processes (Section 8.3.1.3.5.1.3), etc., within the geochemistry program. The modeling activity is the vehicle that integrates the results of all the testing, determines the relative importance of individual retardation and transport mechanisms for various flow regimes (determining the effects of alternate hypothesis), and ultimately supports the assumptions and data uses in the overall total system performance assessments. This system level modeling is shown at the highest level for each of the three models described in Table 8.3.1.3-2. Modeling work to understand individual processes such as sorption and precipitation are included in the lower level activities cited in column nine of the table.

Interrelationships of the geochemical investigations

Eight investigations are included in the geochemical characterization program. These investigations are summarized in the following paragraphs, and logic diagrams are given for each investigation. Information will be passed between these investigations; this is indicated on the logic diagrams by the "other investigations" box.

Investigation 8.3.1.3.1 (Figure 8.3.1.3-3) addresses water chemistry within the potential emplacement horizon and along potential flow paths to the accessible environment. Performance Issue 1.5 (engineered barrier system release rates, Section 8.3.5.10) and design Issues 1.10 (waste package characteristics, Section 8.3.4.2) and 1.11 (configuration of underground facilities, Section 8.3.2.2) require that the unsaturated zone water chemistry be well known. The design requirements include a certain tolerance for ground-water composition changes. If the variation in concentration of certain aqueous species (i.e., Cl and F) in the unsaturated zone is outside the constraints of the waste package design then the design may have to be adjusted. Issue 1.5 also uses the ground-water composition constraints to assess performance of the engineered barrier system, including the waste form and container. However, once the present ground-water composition is well defined and the design is set, the performance issue would have to use a ground-water chemistry model to assess ground-water or vadose zone chemistry changes and the effects of the changes on the performance of the waste package.

Investigation 8.3.1.3.1 will use the ground-water chemistry data already available and to be obtained in Activities 8.3.1.2.3.2.2 and 8.3.1.2.3.2.3 (saturated zone) and data from the ground-water chemistry activities in Activity 8.3.1.2.2.7.2 (unsaturated zone). These data will be incorporated into the conceptual-predictive ground-water chemistry model. This model will explain the present ground-water chemistry, the composition defined by the interactions of the ground water with minerals in the rock. This model will then be able to predict future variations in ground-water chemistry given a thermal component introduced by waste emplacement or an increase in flux through the unsaturated zone induced by climatic changes. These predictions are important to Issue 1.5, which must assess the engineered barrier system performance. Furthermore, the future ground-water chemistry is important in understanding the sorption and solubility processes in supporting Issues 1.1 to 1.3.

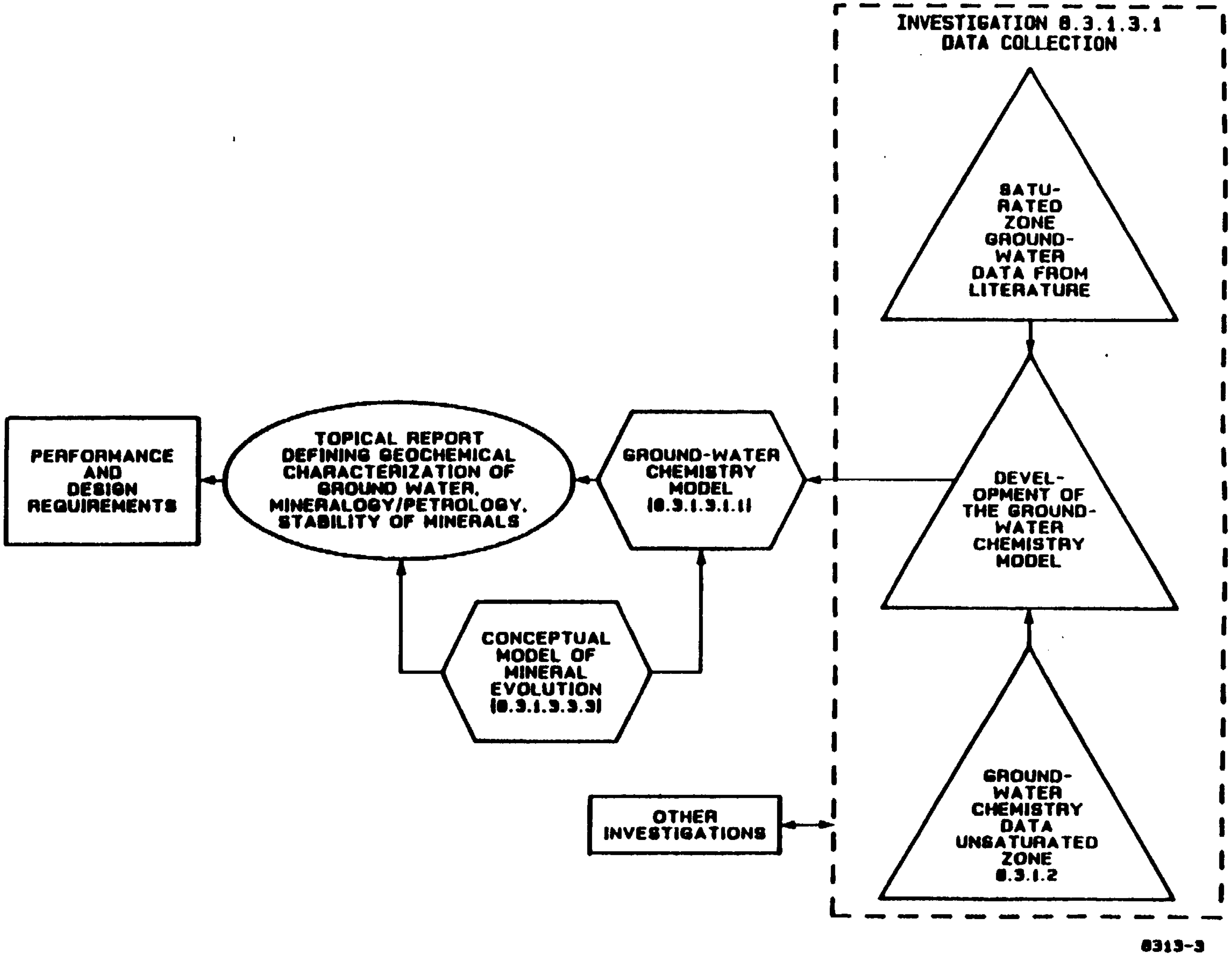

Figure 8.3.1.3-3. Logic diagram for Investigation 8.3.1.3.1 (ground-water chemistry along flow paths to the accessible environment).

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

Investigation 8.3.1.3.2 (Figure 8.3.1.3-4) addresses mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths to the accessible environment. This investigation addresses two major questions: (1) how are the mineral distributions at Yucca Mountain going to affect radionuclide retardation by sorption and (2) what processes account for the minerals found at Yucca Mountain and are the processes still operating and likely to alter the mineralogy in the next 10,000 yr enough to alter sorption behavior at the site? This investigation will provide the descriptive baseline for mineralogy-petrology data for other investigations in this program and for the performance and design issues. To answer the questions, a three-dimensional distribution of minerals will be developed and will aid in developing a sorption model and also will include a description of the fracture mineralogy along potential flow paths. This investigation will also provide the data necessary to understand past mineral alteration. All these data are important for determining the impact of repository development on the host rock, the extent of the disturbed zone, and the potential geochemical changes beyond the disturbed zone.

Issue 1.1 (Section 8.3.5.13) is relying on mineralogically based stratigraphic units at Yucca Mountain (i.e., vitric and zeolitic) for waste isolation. Therefore, the mineralogy, petrology, and rock chemistry must be well known for the stratigraphic units along flow paths to the accessible environment. This investigation also ties to other investigations in this program such as Investigations 8.3.1.3.4 (sorption) and 8.3.1.3.6 (dynamic transport).

Investigation 8.3.1.3.3 (Figure 8.3.1.3-5) addresses the stability of minerals and glasses. Issue 1.1 requires distribution coefficients for all units in the saturated and unsaturated units below the repository in the controlled zone. Therefore, it is important that the stability of the sorptive minerals in these units be investigated to determine the natural alteration rate over time and alteration due to the thermal pulse from waste emplacement. The waste package and engineered barrier system design (Issues 1.10 and 1.11, Sections 8.3.4.2 and 8.3.2.2) will also need mineral stability information so that impacts on sorptive minerals can be assessed. The conceptual model will support this design need and also support the definition of the disturbed zone (Issue 1.6, Section 8.3.5.12, change in hydrologic parameters due to mineral alteration).

A conceptual model of mineral and glass evolution at Yucca Mountain is needed to predict future mineral evolution by natural processes and repository induced thermal loading. This investigation is designed to develop such a conceptual model. Natural analog environments will be studied to understand better the origin of altered minerals at Yucca Mountain and improve the predictive capabilities of geochemical modeling codes. Other studies include obtaining data on the kinetics of glass and silica polymorph transitions and their relationship to aqueous silica activity, which influences zeolite stability. Thermodynamic data on stable and metastable mineral assemblages, specifically the zeolite, analcime, and albite data will also be obtained. These studies are the experimental basis for determining the overall mineral stability at Yucca Mountain.

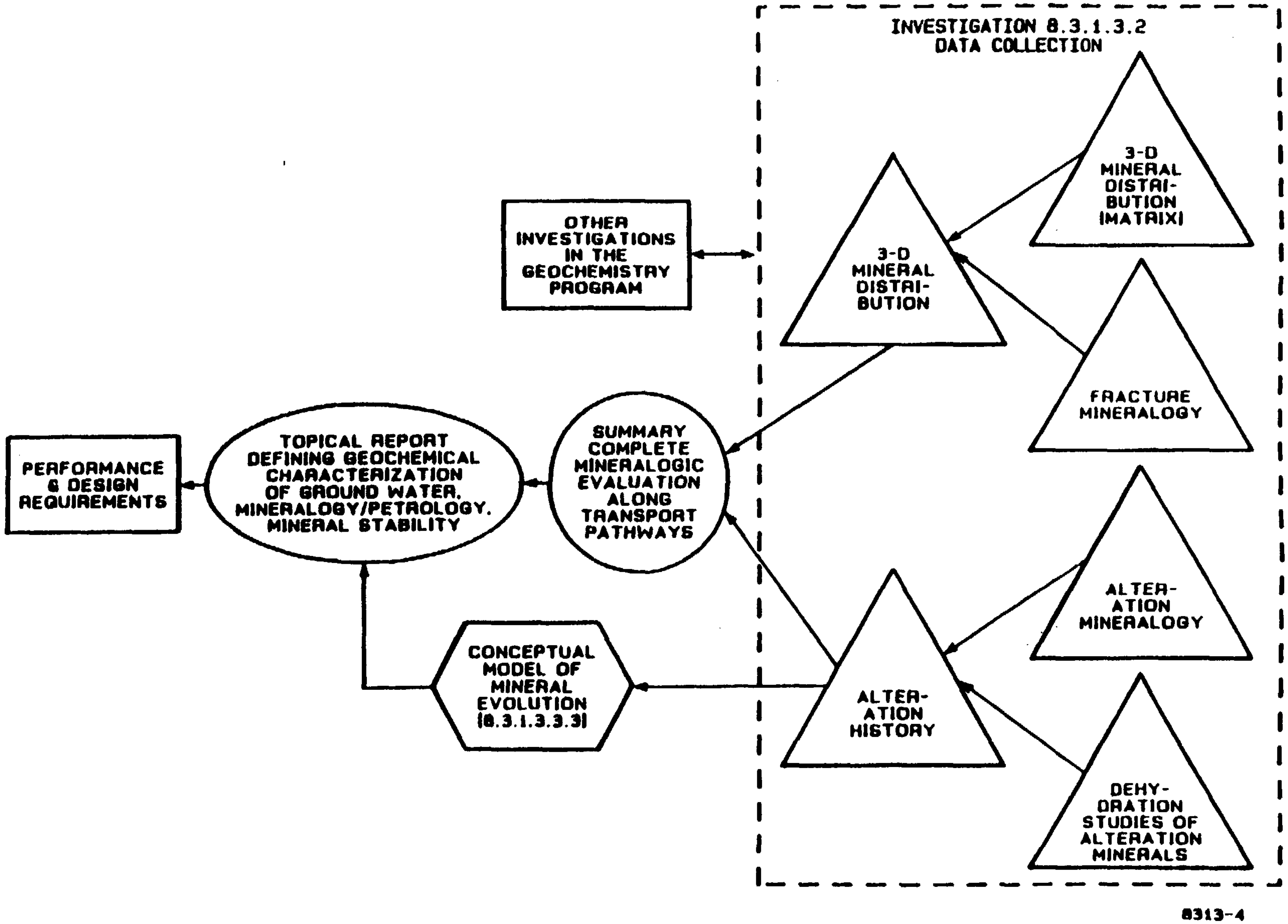

Figure 8.3.1.3-4. Logic diagram for Investigation 8.3.1.3.2 (mineralogy, petrology, and rock chemistry along flow paths to the accessible environment).

YMP/CM-0011, Rev. 1

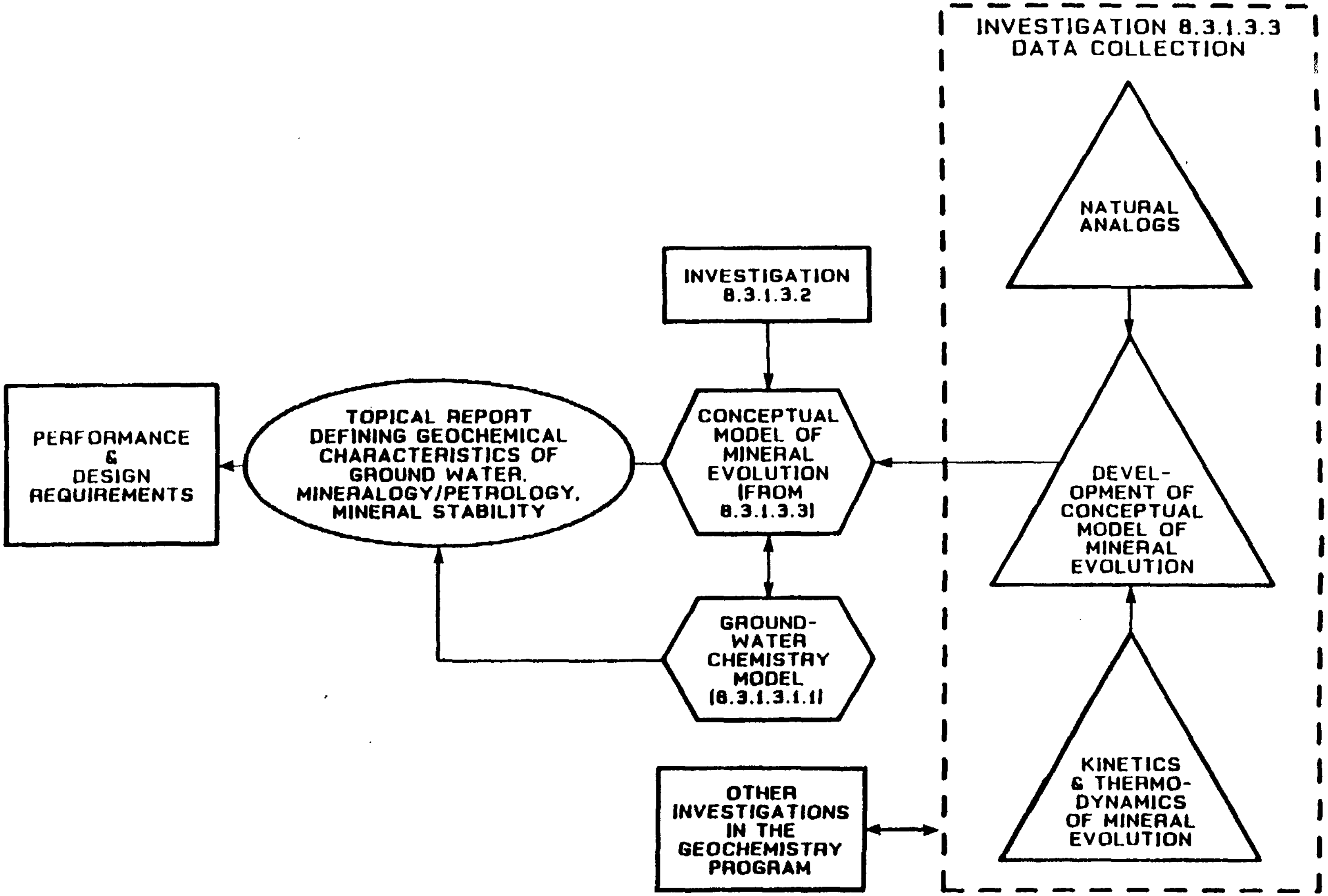

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Figure 8.3.1.3-5. Logic diagram for Investigation 8.3.1.3.3 (stability of minerals and glasses).

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

Investigation 8.3.1.3.4 (Figure 8.3.1.3-6) addresses radionuclide retardation by sorption processes along flow paths to the accessible environment. Sorption in the far field (beyond the disturbed zone) at Yucca Mountain will be studied in the investigation. Performance Issue 1.1 (Section 8.3.5.13) has called for retardation factors for each species known to be chemically sorbing and for each rock unit in the saturated and unsaturated zone in the controlled area under the range of water and rock chemical conditions expected for each unit. Mechanistic and empirical data will be collected on sorptive behavior, and a sorption model will contribute to the understanding of the expected behavior of key radionuclides in the site system.

Because numerous variables can affect sorption, the potentially very large amount of laboratory testing must be constrained by experiments designed to identify significant system variables and quantify their effect on radionuclide transport. The radionuclides of primary concern are identified in Section 4.1.3.1.1 as the key radionuclides, based on waste inventories and projected chemical behavior of the system. Issue 1.1 has required information on specific radionuclides: strontium, cesium, plutonium, americium, carbon, uranium, neptunium, technetium, zirconium, iodine, and curium. The radionuclides of strontium and cesium have been investigated and are well understood (Chapter 4); therefore, actinide sorption will be emphasized in laboratory experiments because of the complexity of actinide aqueous chemistry, sorptive behavior, and waste inventories. Of lesser importance for sorption studies are radionuclides expected to be in a poorly sorbable anionic form such as carbon-14 or technetium-99. Sorptive behavior will be determined as a function of mineral composition and as a function of the sorbing element concentrations (isotherms). Sorption mechanisms and adsorption kinetics also will be studied. Further scoping will be done by considering the ground-water composition and expected radionuclide concentrations. Preliminary testing will also help define future testing needs; thus, radionuclides showing consistently high sorption coefficients in initial testing may not need extensive testing. A part of this investigation will also include study of microbial effects on radionuclide sorption and transport. Another independent activity is the study of radionuclide sorption on particulates and colloids.

Investigation 8.3.1.3.5 (Figure 8.3.1.3-7) addresses radionuclide retardation by precipitation along flow paths to the accessible environment. This investigation will produce results that will supply limits on the concentration of dissolved waste elements and limits on natural colloid concentration that might occur under expected conditions.

Issue 1.1 (Section 8.3.5.13) has identified the need for the determination of solubility limits of chemical species associated with the i^{th} radionuclide (i.e., mean and variance) for the range of expected water-and-rock chemical conditions. Furthermore, information is required on the precipitate that forms when the solute exceeds its solubility. Issue 1.1 will use the solubility and precipitation data as possible input to, and support for, the system performance model for radionuclide transport.

This study is organized to define and implement experiments to measure the solubility and speciation of important waste elements. Geochemical modeling codes, EQ 3/6, will be used to assess the sensitivity of several parameters that might control solubility. Colloid formation as well as

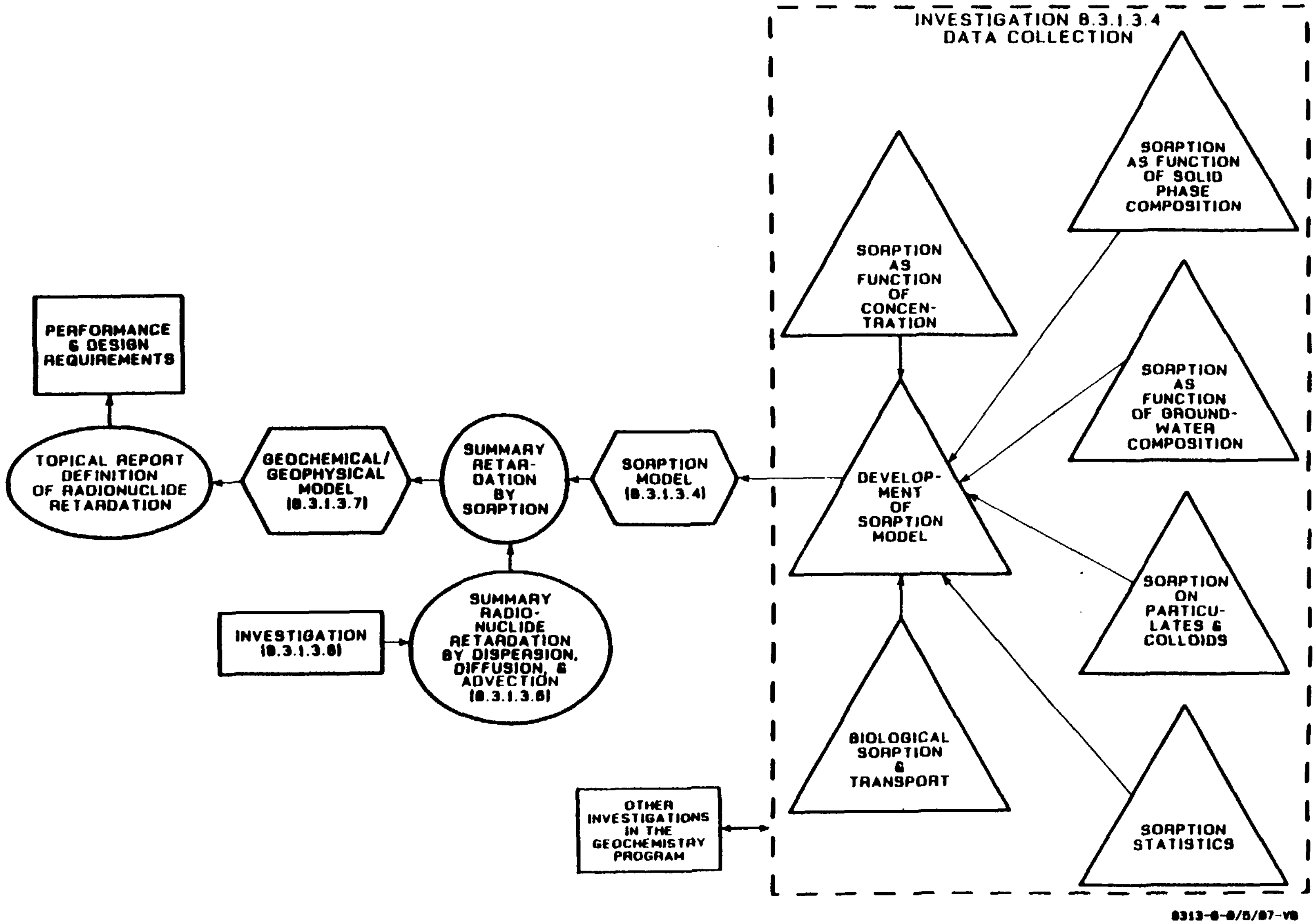

Figure 8.3.1.3-6. Logic diagram for Investigation 8.3.1.3.4 (radionuclide retardation by sorption processes along flow paths to the accessible environment).

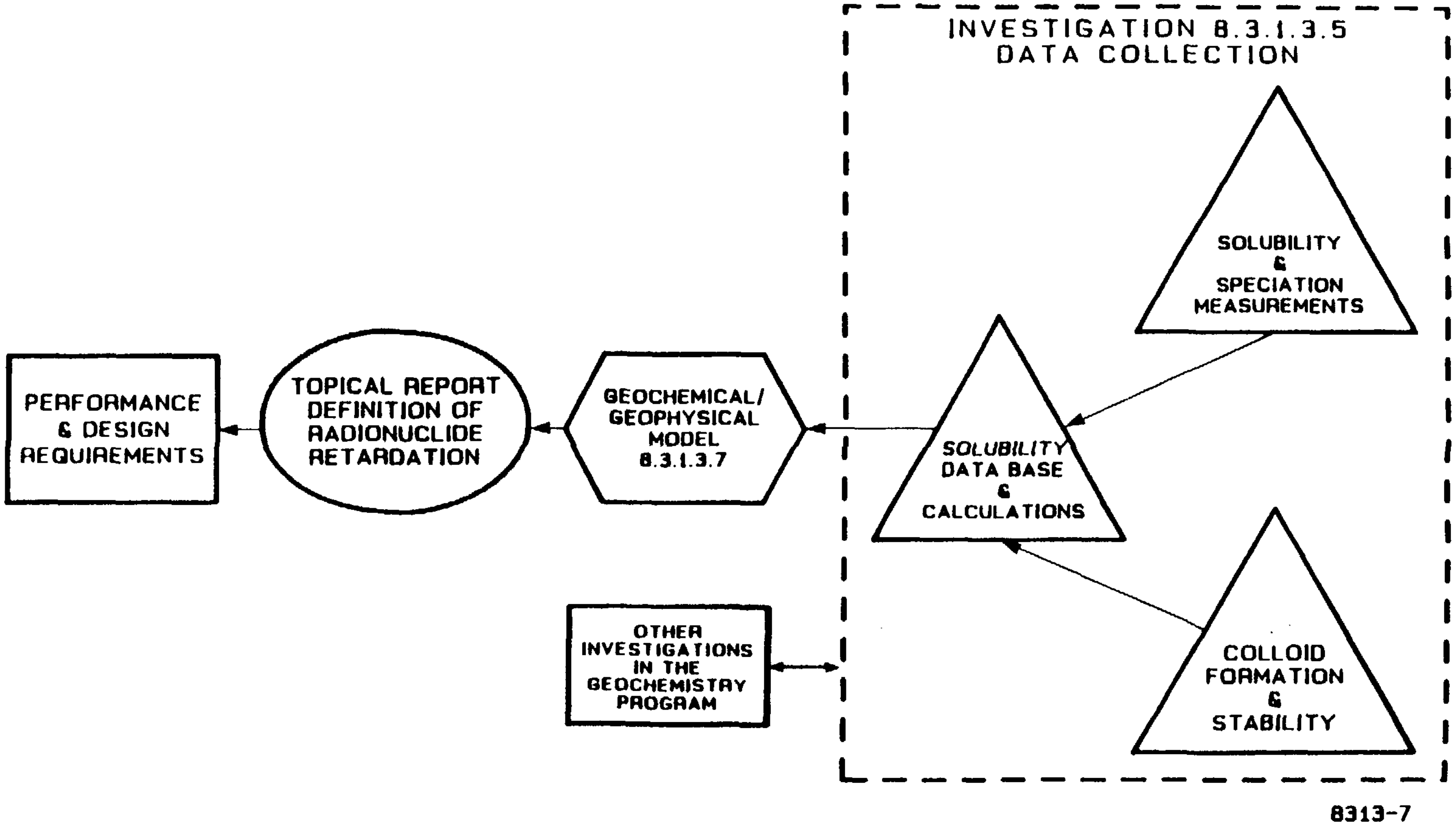

Figure 8.3.1.3-7. Logic diagram for Investigation 8 3 1 3 5 (radionuclide retardation by precipitation processes along flow paths to the accessible environment)

 YMP/CM-0011, Rev. 1

characterization and stability are other aspects of this investigation that will be studied as additional data necessary to understand the potential for transport of a precipitate through tuff. Colloid formation and stability are important because colloid transport is a possible mechanism for bypassing the sorptive barrier. These data are also required by Investigation 8.3.1.3.6 where the determination of the actual transport potential of colloids, precipitates, and particulates will be determined.

Investigation 8.3.1.3.6 (Figure 8.3.1.3-8) addresses radionuclide retardation by dispersive, diffusive, and advective transport processes along the flow paths to the accessible environment. This investigation will determine experimentally the rate of movement and effective retardation of radionuclides by dispersive, diffusive, and advective processes. Specifically, Issue 1.1 requires experimental evidence that could confirm or deny the theory of advective-diffusive coupling of solute concentrations in matrix and fracture flows that is currently embodied in the transport model of TOSPAC. Issue 1.1 states that this information is crucial in establishing the credibility of transport phenomenology embodied in any models used to assess the consequences of the release scenarios associated with the water pathways. Investigation 8.3.1.3.6 will provide to the total system performance the effective diffusivity of species in the matrix of each rock unit in the saturated and unsaturated zones. The parameter called for by total system performance is an empirical parameter measuring the effective diffusivity of the fracture matrix interface (constrictivity-tortuosity factor) for the saturated and unsaturated zone. This investigation will also (1) provide information on the transport of colloids and adsorption kinetics, (2) evaluate and support the use of the batch distribution coefficients by total system performance in an advective system, and (3) support the use of data produced in saturated systems for application to an unsaturated system.

Investigation 8.3.1.3.6 is divided into the diffusion study and the dynamic transport column study. The diffusion study will investigate matrix diffusion in a nonadvective system and the dynamic transport column study will investigate matrix diffusion and other processes in an advective system. The column study includes five activities that use an advective (tuff column) system: (1) crushed tuff column tests, (2) mass transfer kinetics, (3) unsaturated tuff column tests, (4) fractured tuff column tests, and (5) filtration tests. All these activities essentially measure the breakthrough or elution curve for tracers through tuff columns. The elution curve can be characterized by the time of arrival and the broadness or dispersion of the curve. These two properties depend on several process parameters such as distribution coefficients, speciation, colloids, kinetics, matrix diffusion, longitudinal diffusion, hydrodynamic dispersion, channeling, and heterogeneity. This investigation will decouple these processes so that the information needs of Issue 1.1 (Section 8.3.5.13) can be resolved. The technical rationale section of Investigation 8.3.1.3.6 and the discussion of each study and activity within the investigation will develop further the dynamic transport testing strategy to quantify the variables operating in the five testing activities.

Investigation 8.3.1.3.7 (Figure 8.3.1.3-9) addresses radionuclide retardation by all processes along flow paths to the accessible environment, and the question of establishing that laboratory data can be reliably extrapolated to field conditions. The modeling portion of this investigation will

YMP/CM-0011, Rev. 1

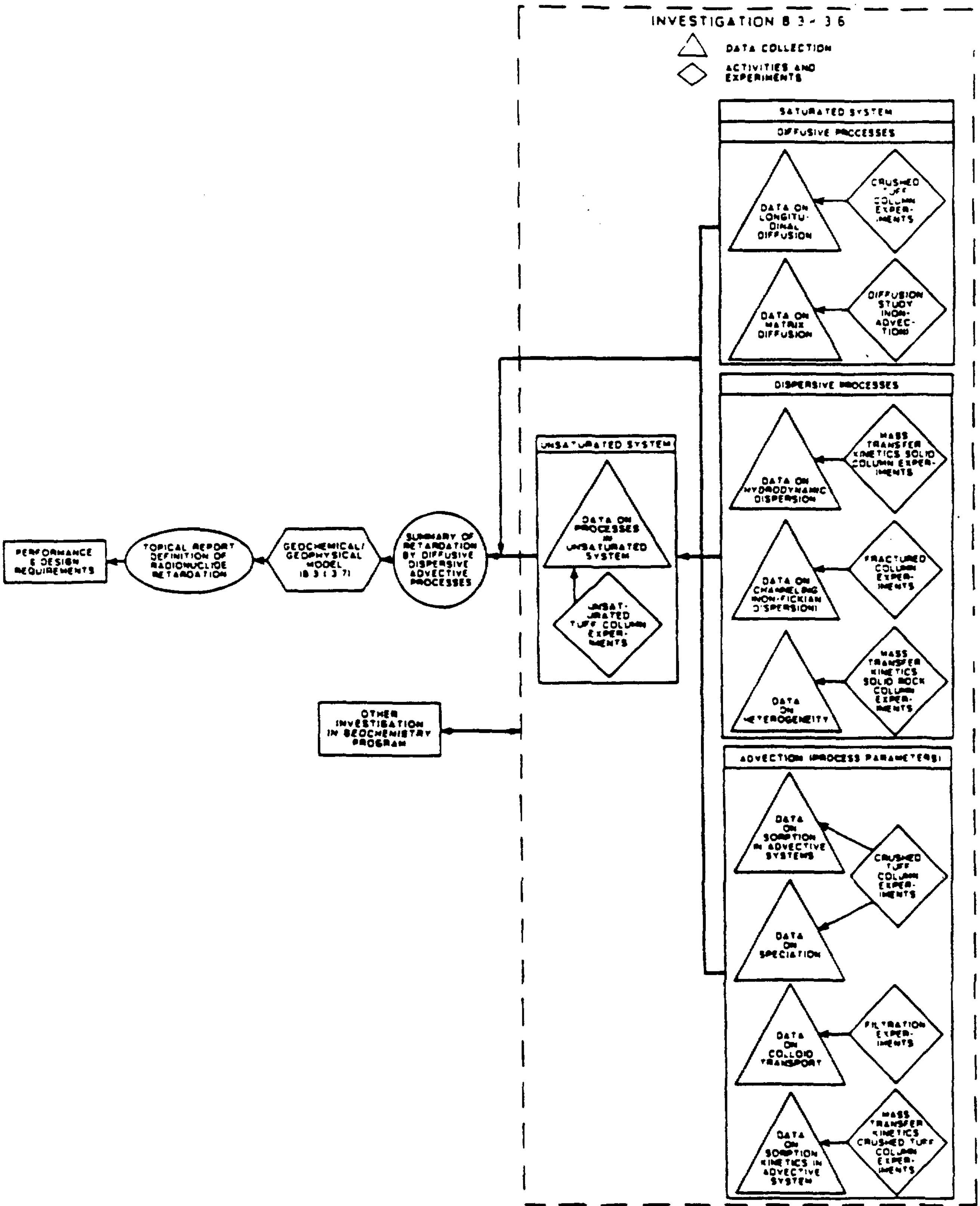

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Figure 8.3.1.3-8. Logic diagram for Investigation 8 3 1.3 6 (radionuclide retardation by dispersive, diffusive and advective transport processes along flow paths to the accessible environment).

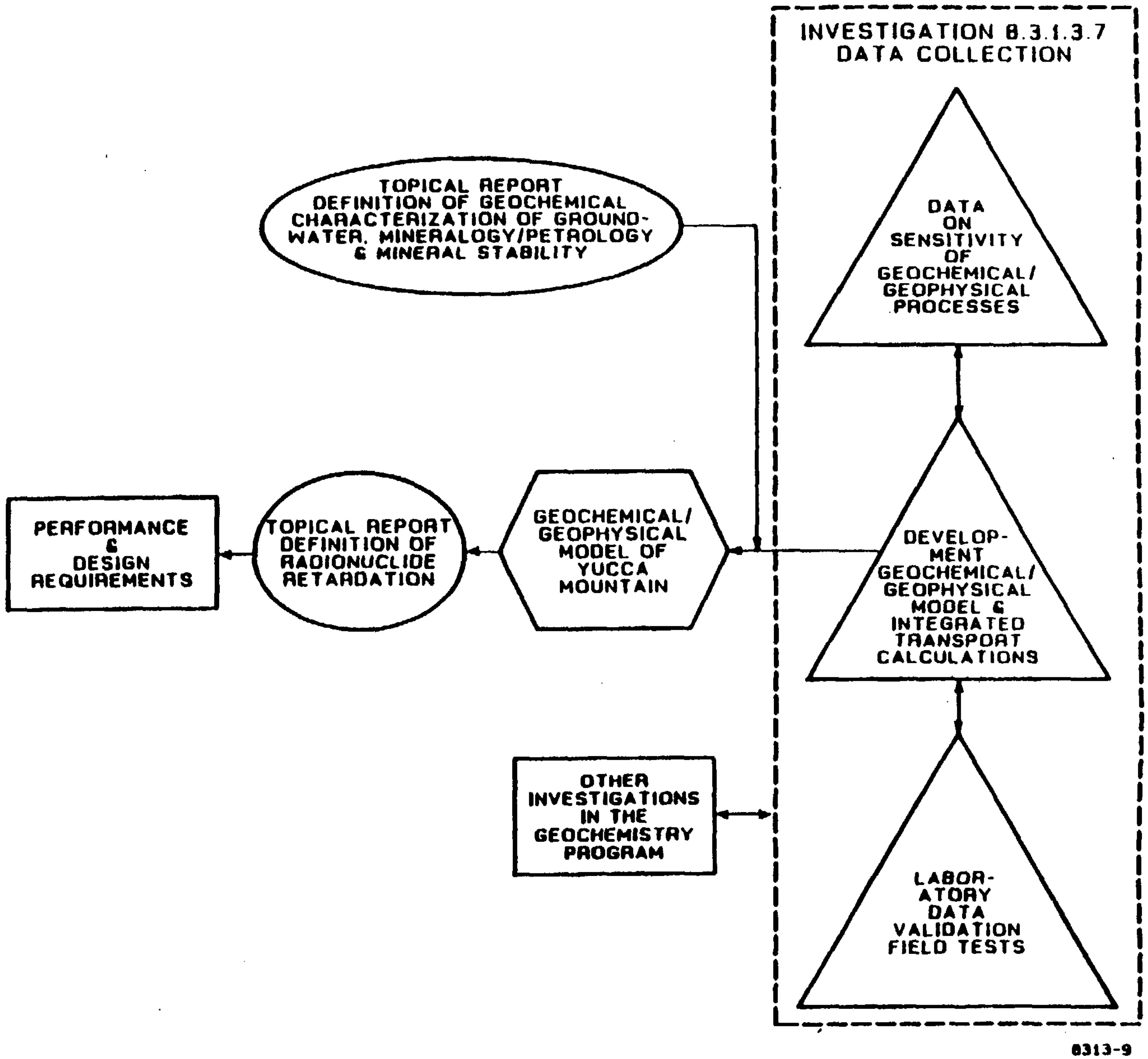

Figure 8.3.1.3-9. Logic for diagram for Investigation 8.3.1.3.7 (radionuclide retardation by all processes along flow paths to the accessible environment)

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

use a three-dimensional transport model and other multidimensional process codes to determine, characterize, and quantify the cumulative effects of all significant processes, physical and geochemical, acting on or controlling radionuclide transport at Yucca Mountain, thus providing an evaluation of the effectiveness of the geochemical barrier. This will support Issue 1.1 by validating the simplifying assumptions and identifying the processes that can be ignored in the system performance assessments. The integrated transport calculations will use the geochemical information obtained from all the investigations under this geochemistry program and other specific geophysical data needed to do complete calculations. The results of this investigation will provide support and give confidence to the systems performance calculations of performance Issue 1.1. Issue 1.1 requires calculational models of radionuclide transport in the unsaturated and saturated zone that are capable of representing the effects of flow in at least two dimensions on the transport of dissolved, reactive solutes and of testing the theory embodied in the one-dimensional systems-level model used by the performance issue.

The retardation sensitivity study (8.3.1.3.7.1) will interface with the sorption and transport investigations and provide input into the design and interpretation of the experimental work and geochemical field tests. Study 8.3.1.3.7.2 outlines the field test strategy, large block tests, large scale experiments, geochemical field tests, nuclide migration studies at the NTS, and natural analog studies that will be used to demonstrate that the results of this program are applicable to the release calculations of system performance assessment.

Investigation 8.3.1.3.8 (Figure 8.3.1.3-10) addresses retardation of gaseous radionuclide along the flow paths to the accessible environment. This investigation outlines the scientific plan that may be needed if Issue 1.1 (Information Needs 8.3.5.13.1, 8.3.5.13.4, and 8.3.5.13.5) indicates that gaseous transport of radionuclides should be investigated. Preliminary calculations of the rates of transport of gaseous radionuclide species will be done. A calculational model will be used to calculate transport and possibly identify the potential retardation mechanism. An experimental program will be used to verify the calculational results if needed.

Issue 1.1 requires a model calibration and validation of gas-phase carbon-14 transport in the overburden of the unsaturated zone units. The results of Investigation 8.3.1.3.8, if needed, will be useful to Issue 1.1. Gaseous radionuclide transport also will have to be considered for the evaluation of radionuclide releases to the environment for 100,000 yr after repository closure (10 CFR 960.3-1-5; Section 8.3.5.18).

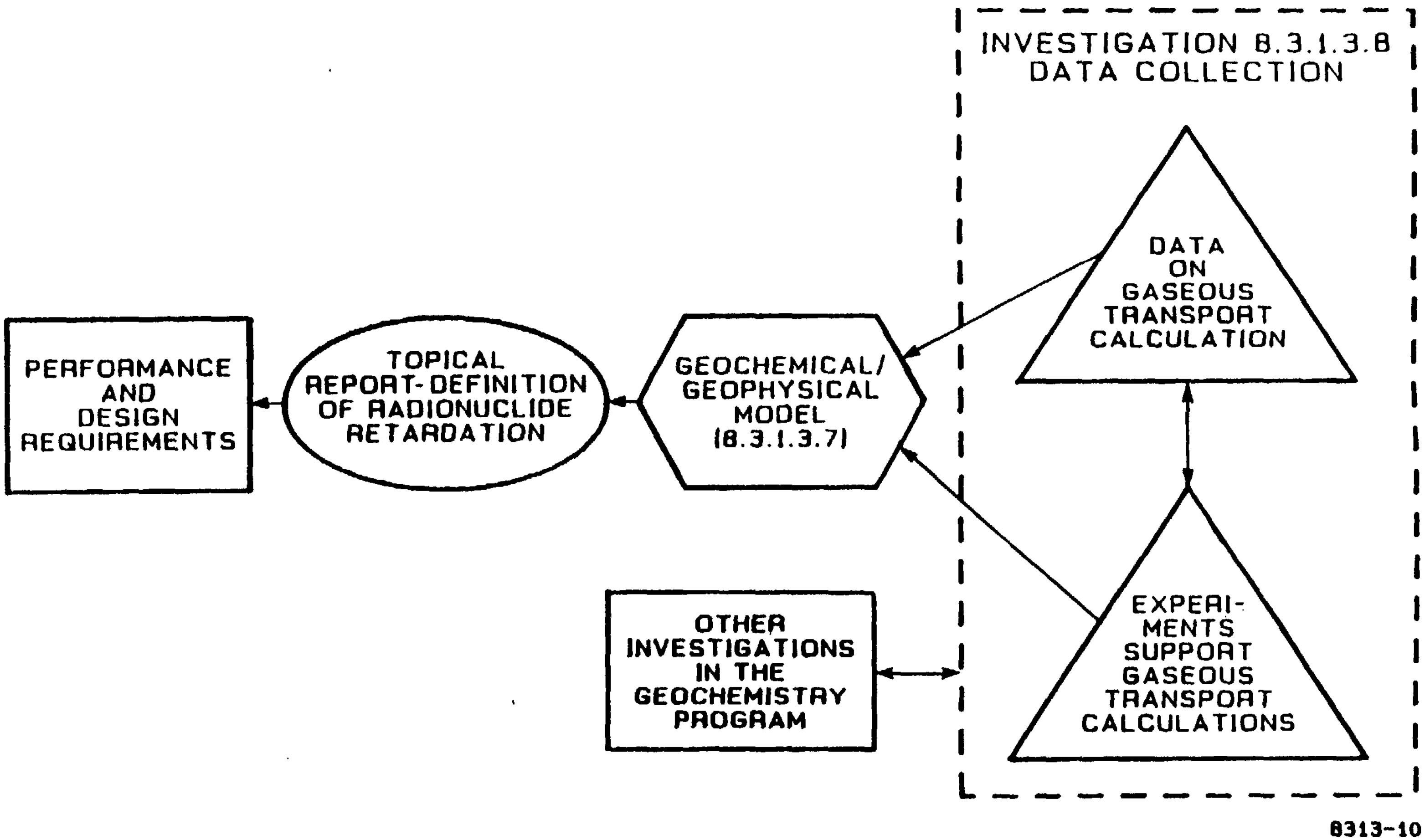

Figure 8.3.1.3-10. Logic diagram for Investigation 8.3.1.3.8 (radionuclide retardation by gaseous transport processes along flow paths to the accessible environment)

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

8.3.1.3.1 Investigation: Studies to provide information on water chemistry within the potential emplacement horizon and along potential flow paths

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
4.1.2	Ground-water chemistry
4.1.2.1	General description of the hydrochemistry
4.1.2.6	Background radioactivity
4.1.2.7	Particulates and colloids
4.1.2.9	Mineralogical controls on water composition
7.4.1.7	Rock-water interactions
7.4.1.1	Stability of borehole openings
7.4.1.3	Reference water for experimental studies

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Saturated and unsaturated zone ground-water chemistry.
2. Ground-water chemistry model development.

Purpose and objectives of the investigation

The goal of this investigation is to provide a ground-water chemistry model that would (1) explain the present ground-water composition as a result of interactions of the ground water with minerals, (2) be able to predict future variations in ground-water chemistry under anticipated and unanticipated conditions, as required by Issue 1.1 (Section 8.3.5.13), that would alter radionuclide flux through the saturated and unsaturated zone, and (3) support and be integrated with other modeling efforts within the geochemistry program (Section 8.3.1.3).

Issues 1.5, 1.10 and 1.11 (Sections 8.3.5.10, 8.3.4.2, and 8.3.2.2, respectively) also require that the ground-water chemistry surrounding the waste package and engineered barrier system be understood so that the design and performance of these system components of the repository can be assessed. Furthermore, other investigations within this test program require the conceptual model of ground-water chemistry, namely, Investigations 8.3.1.3.3 (stability of minerals and glasses), 8.3.1.3.4 (sorption), and 8.3.1.3.5 (solubility), and Study 8.3.1.3.7.1 (retardation sensitivity analysis).

The ground-water composition at Yucca Mountain and the surrounding area has been determined for the saturated zone (Chapter 4). Saturated zone stud-

YMP/CM-0011, Rev. 1

ies (Section 8.3.1.2) will continue but, more importantly, the unsaturated zone ground-water compositions must be obtained. The unsaturated zone ground-water compositions are necessary data to evaluate waste element speciation, solubility, and source term concentrations because the unsaturated zone ground-water compositions will partially define the starting conditions and rates of corrosion of the canister, and dissolution of the waste form. Furthermore, the water compositions are needed to assess the overall retardation of waste elements (Investigations 8.3.1.3.4 (sorption), 8.3.1.3.5 (solubility) and Section 8.3.1.3.7 (retardation sensitivity analysis)) from the repository to the accessible environment under expected and unexpected conditions.

A necessary prerequisite for understanding the overall retardation of radionuclides is the development of a ground-water chemistry model. This model must use the ground-water chemistry data, include the processes that control ground-water compositions, and determine their relative importance. The relative importance of the processes controlling ground-water composition will be useful for understanding the present variations in the ground-water compositions and predicting future variations.

Technical rationale for the investigation

The rationale for this investigation is to develop an understanding of the processes controlling the natural variability in ground water, and use this understanding to predict present and future variations. Mineral stability studies, mineralogy-petrology studies, and input from the climate and tectonics programs on rates and magnitudes of future processes and events will serve as the basis for establishing the ground-water chemistry conceptual model.

8.3.1.3.1.1 Study: Ground-water chemistry model

Objectives

The goal of this study is to develop a ground-water chemistry model that will initially describe pre-emplacement conditions. The model will integrate the unsaturated and saturated zone data with the processes of water infiltration, water flow, and mineralogic changes in order to develop a mechanistic description of the current ground-water chemistry. Future changes in these properties and processes will then be considered, including changes in infiltration as influenced by climatic conditions; long-term mineralogic changes, particularly those influenced by the thermal pulse from emplaced waste; and changes in the material properties due to the emplaced waste, or possible igneous activity. This model of post-emplacement ground-water chemistry will be used to evaluate the chemistry of water interacting with the emplaced waste in the post-emplacement period. This model will be integrated with several investigations in the geochemistry program. In particular, the conceptual model of mineral evolution (Section 8.3.1.3.3) will be supported by and integrated with the ground-water chemistry model. Furthermore, solubility modeling efforts (Section 8.3.1.3.5) as well as sorption modeling efforts (Section 8.3.1.3.4) will also rely on and be integrated with the ground-water chemistry model. Finally, the ground-water

 YMP/CM-0011, Rev. 1

chemistry model will provide needed information to retardation sensitivity analyses and associated integrated transport calculations (Section 8.3.1.3.7).

The ground-water chemistry model will be used to provide information requested by Information Need 1.1.1 (Section 8.3.5.13.1) in its total systems performance model calculations and by Issue 1.5 (engineered-barrier system release rates, Section 8.3.5.10). The latter must assess the waste package design by determining the significance of a potential change in the ground-water compositions in the waste package environment.

Parameters

The data needed are as follows:

1. Processes that control ground-water composition and their relative importance.

   a. Mineral stability (Investigation 8.3.1.3.3, Activity 8.3.1.3.2.2.2)

2. Mineralogy and petrology (Investigation 8.3.1.3.2).

3. Spatial distributions of thermal and mechanical properties (Investigation 8.3.1.4.2)

4. Saturated zone ground-water compositions (Section 8.3.1.2).

5. Unsaturated zone ground-water composition (Section 8.3.1.2).

6. Range of future climatic conditions (Investigation 8.3.1.5.1).

7. Rates and magnitudes of potential igneous activity (Investigation 8.3.1.8.1).

The data obtained are as follows:

1. Analysis. Evaluations of present water chemistry. Predictions of future variations in ground-water compositions between the repository and the accessible environment.

2. Models. Ground-water chemistry model.

Description

The ground-water chemistry model is considered to be conceptual with numerical support. The computational support will be provided by the code EQ3/6. Other codes may be used to verify results of EQ3/6. Prior work defining the dissolved chemical constituents of water in the underlying saturated zone between the repository and the accessible environment provides sufficient data for assessments of potential radionuclide transport, as discussed in Chapter 4 of this document. These data include major, minor, and trace element concentrations, pH and redox state, and the concentration of dissolved gases. A current report (Kerrisk, 1987) summarizes and evalu-

 YMP/CM-0011, Rev. 1

ates the most recent information on the saturated zone ground-water chemistry at Yucca Mountain and the surrounding area. Further work on the characterization of the saturated zone water chemistry is planned in Study 8.3.1.2.3.2

Limited data on the unsaturated zone water chemistry are available. The activities involving the characterization and evaluation of the unsaturated zone ground-water chemistry are found in Activity 8.3.1.2.2.7.2 (aqueous phase chemical investigation of the unsaturated zone). Data will also be obtained from Activity 8.3.1.2.2.4.8 (exploratory-shaft facility and investigations--hydrochemistry tests in the exploratory shaft). Under these activities, water chemistry data will be obtained primarily to determine apparent ages of gas and water in the unsaturated zone and investigate the extent of water-rock interactions. Furthermore, Study 8.3.4.2.4.1.3 will characterize the unsaturated zone ground water in order to predict the compositional changes in the water near the waste package. Data on mineralogy and petrology (Investigation 8.3.1.3.2), stability of minerals and glasses (Investigation 8.3.1.3.3), spatial distributions of thermal and mechanical properties (Investigation 8.3.1.4.2), natural analogs (Investigation 8.3.1.3.3), the range of future climatic conditions (Investigation 8.3.1.5.1), and the rates and magnitudes of potential igneous activity (Investigation 8.3.1.8.1) will also be used in the ground-water chemistry model.

Details of the model development and the consideration and/or development of alternative models will be described thoroughly in the study plan for the ground-water chemistry model, as well the computational support provided for this work.

8.3.1.3.2 Investigation: Studies to provide information on mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections of the data chapters and support documents provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
4.1.1.2	Analytical techniques
4.1.1.3.1	The potential host rock
4.1.1.3.2	Surrounding units
4.1.1.4	Mineral stability
4.2.2.1	Hydrothermal alteration of zeolites
4.2.2.2	Hydrothermal alteration of smectites

YMP/CM-0011, Rev. 1

SCP section	Subject
4.2.2.3	Hydrothermal alteration of rhyolite glasses
4.4.2	Potential effects of natural changes

Parameters

The following parameters will be measured, calculated, or obtained as a result of the site studies planned to satisfy this investigation:

1. Mineral distributions in bulk rock.
2. Mineral distributions in fractures.
3. Bulk rock chemistry.
4. Chemistry of fracture deposits.
5. Mineral origins and alteration history.
6. Data on dehydration of smectites, zeolites, and glasses.

The following parameters are needed to satisfy this investigation:

1. Hydrologic conditions.
2. Geometry of the flow paths.

Purpose and objectives of the investigation

This investigation will provide the baseline set of data and understanding of the natural environment in which geochemical and other processes interact. Two studies are proposed and designed to provide the data needed as represented by the parameters just listed. The first study will provide a three-dimensional distribution of mineral types, rock and mineral compositions, and mineral abundances within the potential host rock and along potential flow paths to the accessible environment. The second study will determine the history of mineralogic and geochemical alteration at Yucca Mountain.

The three-dimensional distribution of mineral types and abundances at Yucca Mountain must be known to use the data on mineralogic controls of sorption (Investigation 8.3.1.3.4) for transport calculations. Investigation 8.3.1.3.7 will use this information in integrated transport calculations and sensitivity analyses, and Issue 1.1 (Section 8.3.5.13) will evaluate this work to assess the contribution of geochemical retardation along flow paths in the total system performance calculations. This information will also be used to evaluate the potential correlation between mineral distributions and former water-table elevations.

The purposes of the second study (history of alteration) are the following:

1. Determination of the impact of repository development on the host rock, which requires the following information:

   a. Host rock mineralogic and chemical variability and internal stratigraphy for Investigation 8.3.1.4.2.

YMP/CM-0011, Rev. 1

b. Evaluation of any hazardous mineral occurrences (fibrous zeolites) in the intervals to be mined for Information Need 4.2.1 (Section 8.3.2.4.1).

c. Evaluation of any past evidence for rock dissolution for Program 8.3.1.7.

2. Definition of the disturbed zone (Information Need 1.6.5, Section 8.3.5.12.5), which requires the following information:

   a. Studies of the amounts and types of mineralogic responses to elevated temperatures in the past; these data will also help to address Information Need 1.11.6 (Section 8.3.2.2.6).

   b. Quantitative analysis of sorptive mineral distributions in the potential repository horizon and on the surrounding rocks for evaluation of mineral stability.

3. Projecting the geochemical changes beyond the disturbed zone throughout the life of the repository for Issue 1.1 (Section 8.3.5.13), which requires the following information:

   a. The assessment of past hydrothermal alteration in terms timing and temperature.

   b. The assessment of past hydrothermal alteration in terms of analogous changes that may be anticipated due to repository emplacement.

   c. The evaluation of mineral and glass assemblages (stable and metastable) present at Yucca Mountain as a baseline for comparing accelerated or deviant geochemical changes anticipated around a repository.

Technical rationale for the investigation

The three-dimensional mineral work already completed shows that there may be large differences between minerals that occur in the bulk rock and minerals that occur along fractures. Since hydrologic conditions affect the extent to which matrix and fracture lining minerals are exposed to radionuclides by the ground water, it will be necessary to obtain data on hydrologic properties (Investigations 8.3.1.2.2 and 8.3.1.2.3) when considering sorptive mineralogy for performance assessment. The final application of these data will also depend on the geometry of flow paths from the disturbed zone to the accessible environment (Information Need 1.6.3, Section 8.3.5.12.3).

The history of alteration study will investigate what processes account for the minerals found at Yucca Mountain, whether those processes have been completed or are still operating, and the impact of projected processes on the potential repository at Yucca Mountain. The geochemical history of Yucca Mountain can be studied from the minerals present, where conditions and times of formation can be obtained. These data will be used in three different contexts at Yucca Mountain: (1) to estimate the impact of repository development on the host rock, (2) to assist in determining the extent of the dis-

 YMP/CM-0011, Rev. 1

turbed zone, and (3) to estimate the rates and directions of geochemical changes beyond the disturbed zone throughout the life of the repository. Each of these three contexts are related to the several specific performance and design activities listed in the previous section.

There are two studies under this investigation: (1) the study of three-dimensional mineral distributions at Yucca Mountain (three activities) and (2) the study of geochemical processes at Yucca Mountain inferred from mineralogy (two activities). These studies have relevant surface-based and exploratory shaft facility tests.

8.3.1.3.2.1 Study: Mineralogy, petrology, and chemistry of transport pathways

The goals of this study are (1) to determine the three-dimensional distribution of mineral types, compositions, abundances, and petrographic textures within the potential host rock and (2) to determine the three-dimensional distribution of mineral types, composition, and abundances in rocks beyond the host rock that provide pathways to the accessible environments. This study will provide input into the assessment of retardation by sorption (Investigations 8.3.1.3.4 and 8.3.1.3.7), the geologic framework of Yucca Mountain (Investigation 8.3.1.4.2), and the definition of the disturbed zone (Information Need 1.6.5, Section 8.3.5.12.5). The analysis of mineral types, abundances and distributions beneath Yucca Mountain is required by each of these information needs and investigations. There are three activities within this study.

8.3.1.3.2.1.1 Activity: Petrologic stratigraphy of the Topopah Spring Member

Objectives

The goal of this activity is to determine the petrologic variability within the devitrified Topopah Spring Member at Yucca Mountain and to define the stratigraphic distribution of variability.

Parameters

The data needed are as follows:

1. Descriptions of the Topopah Spring Member from core samples, from outcrop, and from the exploratory shaft facility.

The data gathered are as follows:

1. Model distributions of phenocrysts and textural features in the devitrified Topopah Spring Member.

2. Quantitative x-ray diffraction (XRD) studies of the devitrified Topopah Spring Member.

YMP/CM-0011, Rev. 1

3. Chemical analyses of the devitrified Topopah Spring Member.

4. Statistical interpretations of these data.

Description

Studies of the distribution of phenocrysts and rock matrix textures in this member have been shown to be useful for defining stratigraphic position within the devitrified Topopah Spring Member (Byers, 1985; Byers and Moore, 1987). Matrix textures apparently account for some of the variation in thermomechanical properties within the Topopah Spring Member (Price et al., 1985; Blacic et al., 1986). Preliminary studies using quantitative XRD data show that mineral abundances in drill core samples, particularly the distributions of silica phases, vary systematically with stratigraphic depths within the devitrified portion of the Topopah Spring Member. Chemical data for the Topopah Spring Member show little variability within the devitrified portion below the quartz-latite caprock. However, the available chemical analyses are limited, particularly in the distribution and abundance of trace elements.

This investigation has so far used data only from the cored holes at Yucca Mountain (drillholes USW G-1, USW G-2, USW GU-3, USW G-4, and UE-25a#1). Future cored holes will also be used. Current data collected are derived from samples collected approximately every 20 m along each drill core. Samples also reflect collection sequences that closely bracketed major stratigraphic contacts. Sample density will be at least as frequent in future drill cores; however, the sample density may be subject to change depending on statistical requirements.

A plan to develop an integrated drilling program for acquisition of site-specific subsurface information is being developed and is described in Investigation 8.3.1.4.1. Sampling requirements for this investigation will be integrated with the drilling program. Of particular importance will be the study of samples from the exploratory shaft facility where larger samples with well-constrained stratigraphic relations can be obtained and where lateral variability within the host rock horizon will be assessed.

8.3.1.3.2.1.2 Activity: Mineral distributions between the host rock and the accessible environment

Objectives

Using the data provided as site characterization progresses, this activity will attempt to determine the three-dimensional distribution chemistry and the total abundance of all major rock-matrix minerals, between the host rock and the accessible environment. The analysis of the three-dimensional stratigraphy will be most heavily weighted toward those units that will first be encountered along potential flow paths away from the repository (i.e., Calico Hills) as identified by Issue 1.1 (Section 8.3.5.13).

 YMP/CM-0011, Rev. 1

Parameters

The data needed are as follows:

1. Determination of probable flow paths between the host rock and the accessible environment.

The data gathered are as follows:

1. Quantitative x-ray diffraction (XRD) data studies of samples from deep drillholes within and around the repository block.

2. Special XRD studies (e.g., study of glycolated clay-mineral separations).

3. Chemical analyses of strata between the host rock and the accessible environment.

4. Statistical interpretation of these data.

Description

This activity will provide a three-dimensional model for the distributions and abundances of all major minerals and of the chemistry of these minerals and their host rocks that occur beneath Yucca Mountain, for potential flow paths between the repository and the accessible environment. Statistical evaluation of this model, such as analysis to estimate natural variability, to extrapolate between boreholes, and to determine sample density in boreholes, will be an important part of the activity. This analysis is currently coupled to the functional stratigraphy put forth by Sandia National Laboratories; and a variety of approaches including kriging will be tested. The basic data for the activity are provided from cored and drilled holes within the boundaries of the accessible environment at Yucca Mountain. These data consist of quantitative XRD determinations of mineral abundances, x-ray fluorescence (XRF) determinations of major and trace element abundances in bulk rocks, and electron microprobe analyses of mineral compositions. An ongoing part of this activity is the reevaluation and reanalysis of XRD patterns already collected and stored, as the precision and accuracy of quantitative XRD methods is improved. The current XRD data are derived from samples collected approximately every 66 ft (20 m) along each drill core. Samples are also collected to closely bracket major contacts. Sample density will be comparable in future drill cores. However, sample density is subject to change depending on statistical requirements. These data will ultimately be used in Investigation 8.3.1.3.4 (sorption) and as support to the performance and design issues. However, the variability of mineral paragenesis with depth and the variations in mineral structures (e.g., smectite-illite intergrowths) are important in determining the history of alteration at Yucca Mountain (see Activity 8.3.1.3.2.2.1).

 YMP/CM-0011, Rev. 1

8.3.1.3.2.1.3 Activity: Fracture mineralogy

Objectives

The objective of this activity is to determine the distributions of minerals within fractures at Yucca Mountain, within all significant rock masses that might provide transport pathways with some component of fracture flow.

Parameters

The data needed are as follows:

1. Model of unsaturated zone hydrologic flow.
2. Model of saturated zone hydrologic flow.

The data gathered are as follows:

1. Distribution and identity of mineral species.
2. Petrographic and chemical characteristics of fracture fillings.

Description

The minerals that occur in fractures can be very different from those that occur in the adjacent rock matrix. This difference can have important consequences for retardation by sorption (Investigation 8.3.1.3.4), particularly in situations where fracture flow becomes significant. Some potentially important sorptive minerals occur only in fractures of stratigraphic horizons where they are otherwise absent (e.g., mordenite in devitrified tuffs). Manganese minerals in fractures have potential impact as sorptive phases, and the types and distributions of manganese minerals will be determined. Hydrous minerals, including zeolites and opal, may occur in fractures that cross the potential repository horizon; water contents and thermal evolution of water from these minerals will be determined. Fracture samples have been collected from drill cores and will be collected from future drill cores from the exploratory shaft facility ramps and drifts at both the Topopah Spring and Calico Hills levels. In particular, this task requires core exhibiting fractures from depths to 3,000 ft (914 m). Samples from the exploratory shaft facility will be particularly important for determining cross-cutting vein relations and the distribution of faults and fractures with mineralogy that permits aqueous transport. Sample density in detail will depend on fracture mineral abundance and variability. Data will be collected by binocular microscope studies and petrographic thin section studies of fractures. Scanning electron microscope (SEM) studies will be made of fracture mineral morphologies and chemistries. Data will also be collected by electron microprobe where possible. Minerals scraped from fractures will be studied by x-ray diffraction (XRD) and neutron activation analysis when knowledge of trace chemistry is necessary. The nature of mineral distributions in fractures will also provide information relevant to alteration history (Study 8.3.1.3.2.2).

YMP/CM-0011, Rev. 1

8.3.1.3.2.2 Study: History of mineralogic and geochemical alteration of Yucca Mountain

The goal of this study is (1) to determine the timing, temperatures, and hydrologic conditions of past alteration at Yucca Mountain and (2) to study experimentally the dehydration of smectite, zeolite, and glass. Processes to be studied range from deep-seated past hydrothermal alteration to shallow mineral deposition along fractures and faults. Near-surface alteration studies on trench faults can be found under Activity 8.3.1.5.2.1.5. Alteration episodes will be defined, and the constraints on times and temperatures of alteration will be used to evaluate future alteration in the natural state as opposed to alteration due to the repository's thermal load. This study will provide input for the definition of the disturbed zone (Information Need 1.6.5, Section 8.3.5.12.5), for mineral stability (Investigation 8.3.1.3.3), and for models of past hydrologic processes within Investigation 8.3.1.2.3. This study encompasses a large number of parameters that are required to integrate multiple lines of research by assessing the timing, temperatures, and processes of mineralogic alteration at Yucca Mountain.

8.3.1.3.2.2.1 Activity: History of mineralogic and geochemical alteration of Yucca Mountain

Objectives

Deep-seated alteration of a hydrothermal and epigenetic nature must be studied to constrain the timing of such activities, in order to answer the question of whether such processes pose any future threat to the repository. The temperature interpreted from the alteration mineral assemblages can also be used to estimate the long-term thermal stabilities of important sorptive phases, such as clinoptilolite, and of the silica polymorphs that can influence water composition, precipitation, and the stabilities of other silicate minerals.

Shallower alteration around the host rock is not as extensive as deep-seated alteration but is particularly important for answering questions about the timing and temperatures of past fluids that have left deposits in voids and fractures of the host rock. The fluids that have passed through the host rock can be inferred from the minerals deposited. Temperatures can be inferred from mineral assemblages, from stable isotope ratios, or from fluid inclusions. Relative timing or sequence of alteration events can be inferred from some textures (e.g., geopetal structures) and the timing may be determined by uranium-series, uranium-trend, potassium-argon, or electron spin resonance (ESR) dating.

Parameters

The data needed are as follows:

1. Stable isotope data from authigenic minerals.

2. Uranium-thorium and rubidium-strontium isotopic data for authigenic minerals.

YMP/CM-0011, Rev. 1

3. Uranium-series and uranium-trend ages of authigenic minerals.

4. Model of unsaturated zone hydrologic flow.

5. Model of saturated zone hydrologic flow.

The data gathered are as follows:

1. Ages (potassium-argon, ESR), temperatures, and distributions of past hydrothermal alteration around Yucca Mountain.

2. Ages (potassium-argon, ESR), temperatures, and distributions of past hydrothermal and diagenetic alteration in and near the host rock.

Description

Several types of past alteration are being studied at Yucca Mountain. They include multiple episodes of hydrothermal and diagenetic alteration within the host rock and in surrounding units.

Study activities will include petrologic analysis of alteration sequences and structures (e.g., tilting of geopetal structures and bubble homogenization temperatures determined from fluid inclusions). Electron microprobe analyses will be made of minerals representing growth sequences; drill core, drill cutting, outcrop, and exploratory shaft samples will be used.

X-ray diffraction (XRD) data will be collected on authigenic mineral occurrences at and near Yucca Mountain. Paleotemperatures will be estimated from clay-mineral interstratifications, from fluid inclusions and from stable isotope compositions. The ages of alteration events will be estimated using two experimental techniques: (1) potassium-argon dating of clays and zeolites and (2) ESR dating of quartz and calcite. Uncertainties in the proposed methods and alternate experimental approaches will be discussed in the study plan. Approximately 250 samples will be used in all petrographic and XRD studies combined under this activity.

Samples from the exploratory shaft, from its lateral drifts, and, in particular, from the portion of the shaft that passes through the bottom of the Topopah Spring Member and into the tuff of Calico Hills are particularly important to this study. These underground exposures will provide large oriented samples of alteration products. If found, samples of natural gel will be collected from the exploratory shaft.

8.3.1.3.2.2.2 Activity: Smectite, zeolite, manganese minerals, glass dehydration, and transformation

Objectives

The goal of this activity is to determine how minerals and glasses important in the rocks at Yucca Mountain will dehydrate and transform under anticipated thermal loads and to investigate the ability of zeolites and

 YMP/CM-0011, Rev. 1

smectites to rehydrate after the peak in temperature. These transformations and alterations will influence sorption and rock stability immediately below the host rock. The hydrous minerals clinoptilolite-heulandite and smectite are of the greatest importance because of their proximity (several tens of meters to a few hundred meters) to the potential repository horizon. Although less abundant, the hydrous manganese minerals are also important to retardation modeling. Vitrophyre glass and vitric, nonwelded glass also occur in this zone. The hydrous minerals have well-documented rehydration properties in recovery from short-term heating, but prolonged-heating data at low temperatures (80 to 150°C) are not available. The hydrous glasses may not simply rehydrate, but may irreversibly dehydrate and collapse or transform to other phases. The nature of these transitions and the rates and amounts of water loss from unsaturated glass must be studied. This study will also provide input to the assessment of retardation by sorption (Investigation 8.3.1.3.4), and the definition of the disturbed zone (Information Need 1.6.5; Section 8.3.5.12.5).

Long-term heating experiments in unsaturated to saturated conditions will be conducted. This activity will study the dehydration and reaction behavior of long-term (minimum of 5 yr), low-temperature (50 to 250°C) heating of minerals and glasses.

Thermogravimetric and differential thermal analyses of hydrous minerals and glasses will be conducted to determine the time-temperature behavior of zeolites, smectites, and glasses relevant to a repository at Yucca Mountain.

Parameters

The data needed are as follows:

1. Literature information on dehydration, rehydration and low temperature hydrothermal reactions.

The data gathered are as follows:

1. Mineralogic characterization of reaction products from long-term saturated and unsaturated heating experiments.

2. Time-temperature data.

Description

Study of long-term dehydration and transformation reactions at low temperatures will be carried out in a series of solid-state controlled, low temperature ovens held at temperatures between 50 and 250°C. Reaction vessels for the experiments will consist of Teflon™ vessels and stainless steel, Teflon™ -lined Parr bombs. Reactions will be carried out with samples either in contact with liquid water, water-saturated air, or in room air to approximate a range of water vapor pressures. Dry, room-air experiments will be conducted in conventional porcelain dishes or on silica glass slides. Samples used will be natural vitrophyre and vitric, nonwelded glasses from Yucca Mountain, natural zeolites and smectites from Yucca Mountain, and cation-exchanged pure zeolites and smectites. The cation-exchanged minerals will provide critical information on the role of interlayer or exchangeable

YMP/CM-0011, Rev. 1

cations in determining dehydration or reaction behavior. Preliminary data suggest that partial loss of rehydration ability does occur in long-term dry heating of magnesium-saturated smectite and sodium-rich clinoptilolite. The experiments will be maintained for a minimum of 5 yr but can be continued longer with very little additional effort. Samples will be examined every six months to evaluate changes.

Time-temperature data will be obtained at varied heating rates (1 to 20°C/min) and isothermally using thermogravimetric analysis (TGA). Variable water vapor pressures will be used in TGA analyses to assess the effects of P_{H_2O} on dehydration. Enthalpy effects associated with dehydration (and perhaps rehydration) and oxidation-reduction for zeolites and smectites will be studied by differential scanning calorimetry (DSC). These data will be obtained on natural glasses, zeolites, and smectites from Yucca Mountain and on cation-exchanged pure minerals. The cation-exchanged minerals will provide data for interpreting the effect of interlayer or exchangeable cations on dehydration-rehydration behavior.

8.3.1.3.3 Investigation: Studies to provide information required on stability of minerals and glasses

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the data chapters and support documents provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
4.1.1.4	Mineral stability
4.2.2	Hydrothermal alteration of sorbing minerals and glasses
4.4.2	Potential effects of natural changes
7.4.1.7	Rock-water interactions

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Data on mineral and water compositions in natural hydrothermal systems.

2. Data on kinetics of silica phase transformations and correlation to silica phase transformations.

3. Data to construct thermodynamic models of clinoptilolite, analcime, and albite.

YMP/CM-0011, Rev. 1

4. Conceptual model for past and future mineral alteration at Yucca Mountain.

Purpose and objectives of the investigation

The goal of this investigation is to determine the stability of minerals and glasses along the flow paths to the accessible environment in order to assess impacts of waste emplacement on mineral stability and the resulting effect on radionuclide retardation. Three studies are part of this investigation: (1) Study 8.3.1.3.3.1, (natural analogs), (2) Study 8.3.1.3.3.2 (kinetics and thermodynamics of mineral evolution), and (3) Study 8.3.1.3.3.3 (conceptual model of mineral evolution).

The conceptual model of mineral evolution will integrate the results of the first two studies and will use the descriptive and experimental work on mineral alteration found in Study 8.3.1.3.2.2, the three-dimensional mineral distribution of Study 8.3.1.3.2.1, and the ground-water conceptual model of Study 8.3.1.3.1.1. The information from this investigation will be used in Issue 1.5 (Section 8.3.5.10) to understand the near-field environment of the waste package and engineered barrier system by Information Need 1.6.5 (disturbed zone, Section 8.3.5.12.5) and in Issue 1.1 (Section 8.3.5.13) to assess geochemical retardation for the total system performance calculations. Furthermore, this information is important to Issue 1.8 (NRC siting criteria, Section 8.3.5.17) and to Investigation 8.3.1.3.7 (retardation by all processes).

Technical rationale for the investigation

The minerals and glasses present in Yucca Mountain today reflect (1) the volcanic processes that originally created the primary (igneous) phases and (2) the interaction of ground waters and atmospheric gases with these phases over the past 11 million years. Construction and operation of a repository in Yucca Mountain will result in some modification of the nature and extent of ground-water-atmosphere-rock interactions. The thermal pulse resulting from waste emplacement will be particularly important in this regard. A conceptual model of mineral and glass evolution (Study 8.3.1.3.3.3) in Yucca Mountain must be developed to allow prediction of the nature and extent of the potential modification.

Active hydrothermal systems in welded ash-flow tuffs offer natural analogs to the types of rock-water interactions that are likely in the near-field of the proposed repository in Yucca Mountain. Studies of natural analogs (Study 8.3.1.3.3.1) are needed because these systems provide insight into the effects of water-rock interactions on devitrified welded ash-flow tuffs over periods of hundreds of thousands of years.

The determination of stable mineral assemblages is also needed because solid-solid transitions are slow at the temperatures of interest and metastable reaction products are common. It is difficult to determine the stable assemblages through direct experimentation; rather, thermodynamic data (for zeolites), which can be developed from solid-liquid reactions, solid-solid reactions at higher temperatures, and calorimetric data, are needed to predict the stable assemblages (Study 8.3.1.3.3.2). These data can also be used to identify controlling reactions that determine the rate of evolution of

 YMP/CM-0011, Rev. 1

larger mineral assemblages. Kinetic studies will be needed on rate controlling mineral reactions (evolution of silica polymorphs and relation to evolution of aqueous silica activity) (Study 8.3.1.3.3.3).

There are three studies under this investigation: analog study of hydrothermal systems in tuff, kinetics and thermodynamics of mineral evolution, and conceptual model of mineral evolution.

8.3.1.3.3.1 Study: Natural analog of hydrothermal systems in tuff

Objectives

The goals of this study are (1) to improve the reliability of long-term predictions regarding hydrothermal rock alteration in devitrified welded ash-flow tuff, (2) test the capabilities of the EQ3/6 geochemical code (Section 7.4.4) through modeling of alteration mineral assemblages in natural systems, and (3) to provide a better understanding of the origin of alteration mineral assemblages found in Yucca Mountain at present. This study will also help in development of the conceptual model for mineral evolution in Yucca Mountain and will aid substantially in guiding the laboratory studies. This study will investigate the origin and evolution of secondary mineral assemblages produced in active hydrothermal systems in rock types similar to those which compose Yucca Mountain.

Parameters

The data needed are as follows:

1. Literature Survey:

    a. Water compositions.
    b. Temperatures of hydrothermal systems.
    c. Secondary mineral assemblages and paragenesis.

2. EQ3/6 computer code.

The data gathered are as follows:

1. Petrographic description of core.

2. Microprobe analyses of alteration products.

3. Mineral solid solutions.

4. Reaction path calculations.

5. Document discrepancies between predicted and observed mineral assemblages.

6. Implications of results to Yucca Mountain.

 YMP/CM-0011, Rev. 1

Description

This study (presently in a conceptual phase) will (1) select and describe a hydrothermal system in tuffaceous rocks in the continental United States that could be studied as a geologic analog to the near-field of the proposed repository in Yucca Mountain, (2) evaluate the paragenesis of hydrothermal minerals in this system, (3) evaluate the chemical variability of surface and subsurface ground waters in this system to derive compositions appropriate for modeling purposes, (4) carry out preliminary calculations to test the capabilities of the EQ3/6 geochemical code in modeling of alteration reactions in natural hydrothermal systems in welded ash-flow tuffs, (5) use EQ3/6 (see Sections 8.3.5.10.3.2.1 and 8.3.5.10.3.2.2 for discussions of development of EQ3/6) to explore the possibility that hydrothermal systems can provide useful thermodynamic constraints on the stabilities of minerals for which reliable thermodynamic constants are presently lacking (e.g., zeolites and clays), and (6) provide a preliminary evaluation of how data from natural geothermal systems could add to our predictive capabilities with regard to geochemical modeling, experimental studies, and the overall performance of the proposed repository at Yucca Mountain.

8.3.1.3.3.2 Study: Kinetics and thermodynamics of mineral evolution

The goals of this study are (1) to investigate the kinetics of glass and silica polymorph transitions and their relationship to aqueous silica activity and (2) to provide thermodynamic data for clinoptilolite/heulandite and albite and analcime. A kinetic study of zeolite and related framework silicates is not planned; however, the technical basis for the development of experimental activities is discussed in the following text.

Silica activity has been identified as an important parameter in controlling mineral stability in Yucca Mountain. This parameter adds uncertainty to the understanding of mineral stability because the rate of evolution of silica activity is not well understood. Considerable uncertainty exists regarding the origin of alteration minerals in rock matrices and fractures in Yucca Mountain. These minerals could have formed early in the history of the Topopah Spring Member from elevated emplacement temperatures, or they could have formed from more recent, and perhaps ongoing, interaction of ground water with glassy tuffs. If the latter is true, the alteration minerals would react to changes in ground-water conditions over time (e.g., changes in pH may cause an increase in the rate of silica phase transformation; and therefore, more rapid decrease in the aqueous silica activity). These changes would then have to be documented to assess their effect on the temporal stability of sorptive minerals along potential transport pathways. However, if the minerals can be shown to have formed early after the formation of the tuff, and not to have been affected by subsequent exchange reactions, significant interaction with ground water would be ruled out. This is particularly important because mineral alteration unrelated to the repository thermal pulse could cause changes in sorptive capacity.

Understanding the mineral stability and evolution at Yucca Mountain will depend on the quality of the thermodynamic data base available; therefore, the gathering of thermodynamic data is fundamental to this study. This data

YMP/CM-0011, Rev. 1

will be especially important in verifying the relationship between silica activity and mineral stability, particularly that of the framework silicates such as the zeolites. Clinoptilolite-heulandite, albite and analcime, along with the silica polymorphs, are principal components of important mineral reactions observed to have taken place in Yucca Mountain. Both thermodynamic data for the end-members of these minerals and a description of solid-solution and order-disorder phenomena are needed.

Clinoptilolite and some other zeolites are thought by some to be metastable. The disappearance of clinoptilolite from the geologic column in rock more than a few hundred million years old supports this. However, clinoptilolite is thought to be stable at metastably high silica activity and its disappearance controlled by the evolution of silica activity, which is in turn probably controlled by the evolution of the silica polymorphs. This is supported by the observation that clinoptilolite generally forms from initially glassy rocks and is generally accompanied by cristobalite (or opal-c). If field and thermodynamic studies do not ultimately support this view, or if it is found that there may be rapid evolution of aqueous silica activity to quartz saturation, kinetic studies of zeolite and other mineral reactions will become important to assess the temporal stability of the sorptive minerals. Present kinetic studies being carried out by the geologic community chiefly are directed at the kinetics of dissolution. Such studies would certainly represent part of the work needed here, but there is a need to understand precipitation kinetics and the other mechanisms controlling the rates of mineral reactions.

8.3.1.3.3.2.1 Activity: Kinetic studies of zeolite and related framework silicates

Objectives

The goal of this activity is to predict the rates of possible transformation of silica polymorphs in Yucca Mountain and the effect such transformations would have on aqueous silica activity. This information will be combined with information from other activities and studies, particularly activities 8.3.1.3.3.2.2 and 8.3.1.3.3.2.3 and Study 8.3.1.3.2.1 to assess the effects of silica polymorph evolution on the stability of other minerals, particularly clinoptilolite, in Yucca Mountain.

Parameters

The data needed are as follows:

1. Literature survey of kinetic data.

The data gathered are as follows:

1. Aqueous silica activity as a function of reaction progress, temperature, and pH.

YMP/CM-0011, Rev. 1

Description

Literature data will be used to develop a model for the kinetics of evolution of silica phases and aqueous silica activity. This model will be compared with observations at Yucca Mountain and with field data on other vitric tuffs in the literature to estimate possible changes in silica for experimental work on aqueous silica activity. Thermodynamics and solubilities of cristobalite and opal-c are similar enough that initial experimentation will focus on hydrothermal alteration of cristobalite to quartz and observation of the aqueous silica activity as a function of reaction progress. Important variables that are likely to affect the rate of reaction are temperature, pH, and composition of the ground water.

8.3.1.3.3.2.2 Activity: Determination of end-member free energies for clinoptilolite-heulandite, albite, and analcime

Objectives

The goal of this activity is to determine end-member free energies from solubility measurements. This activity will provide enthalpy of formation data which will then be used to determine the thermodynamic stability of these silicates.

Parameters

The data needed are as follows:

1. Pure mineral samples of clinoptilolite-heulandite, albite, and analcime.

The data gathered are as follows:

1. Solubility measurements.
2. Free energy calculations.

Description

The solubilities of clinoptilolite-heulandite, albite, and analcime with known compositions, and for albite with a known state of order, will be measured. The solubility measurements will be used as a means to collect data from which free energies can be calculated because a relatively rapid approach to equilibrium is more probable than with reactions among solid phases. The equilibrium solution compositions will then be combined with knowledge of the thermodynamics of the aqueous phase (primarily from the EQ3/6 data base to be consistent with other data used in the Yucca Mountain Project) to calculate mineral free energies for the specific compositions studied.

 YMP/CM-0011, Rev. 1

8.3.1.3.3.2.3 Activity: Solid solution descriptions of clinoptilolite-heulandite and analcime

Objectives

The goal of this activity is to provide descriptions of the thermodynamics of the clinoptilolite-heulandite and analcime solid solutions in support of the development of the mineral stability model. The thermodynamic descriptions developed will be tied to the thermodynamics of discrete compositions of clinoptilolite and analcime determined in Activity 8.3.1.3.3.2.2 but will extend the thermodynamic description to the entire range of possible compositions.

Parameters

The data needed are as follows:

1. Crystallographic information.
2. Pure mineral samples.

The data gathered are as follows:

1. Solubility measurements on minerals of intermediate compositions.
2. Elemental analyses.
3. Theoretical models (for configurational entropy).

Description

Solid solution descriptions will be based primarily on theoretical models for configurational entropy with support from solubility measurements. This activity will involve solubility measurements on intermediate compositions of clinoptilolite/heulandite and analcime. A theoretical approach to the entropy of mixing will be used. Configurational entropy will be linked to crystallographic information, particularly, the available cation sites, the cations that would occupy those sites, and information on the coupling between ions that occupy the sites.

8.3.1.3.3.3 Study: Conceptual model of mineral evolution

Objectives

A conceptual model will be produced to explain the observed distributions of minerals in Yucca Mountain. Emphasis will be placed on the evolution of framework silicates (feldspars, zeolites, and silica polymorphs). The model will address the general chemical evolution of vitric tuffs. This model will also be used to predict future mineral evolution in the mountain due to both natural processes and as a result of a repository emplacement.

This model will be a significant contribution to Issue 1.1 (Section 8.3.5.13) in its transport calculation and to the waste package issue (Issue 1.4, Section 8.3.5.9) and engineered barrier system issue (Issue 1.5, Section 8.3.5.10). This model is intimately tied to the ground-water

YMP/CM-0011, Rev. 1

chemistry model (Investigation 8.3.1.3.1) and to the three-dimensional mineralogic distribution at Yucca Mountain (Investigation 8.3.1.3.2).

Parameters

The data needed are as follows:

1. Data from Studies 8.3.1.3.3.1 and 8.3.1.3.3.2.
2. Three-dimensional model (Study 8.3.1.3.2.1) of mineral distribution.
3. Ground-water model (8.3.1.3.1).

The data gathered are as follows:

1. Conceptual model of mineral evolution.

Description

Data from Studies 8.3.1.3.3.1 (natural analogs), 8.3.1.3.3.2 (kinetics and thermodynamics), 8.3.1.3.2.1 (three-dimensional mineralogic distribution, specifically, Activity 8.3.1.3.2.2.2, alteration of zeolites), and 8.3.1.3.1.1 (ground-water chemistry model) will be used for this conceptual model. Codes will be developed as needed. These codes will be based primarily on routines from the Common Los Alamos Mathematical Software (CLAMS) as listed in Study 8.3.1.3.3.2.

8.3.1.3.4 Investigation: Studies to provide the information required on radionuclide retardation by sorption processes along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the site characterization plan data chapters and support documents provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
4.1.3.3.1	Sorption data for tuff
4.1.3.3.2	Sorption data from batch experiments
4.1.3.3.3	Sorption data from crushed tuff column experiments
4.1.3.3.4	Sorption data from circulating system experiments
4.1.3.3.5	Comparison of sorption ratios from batch, circulating system, and column measurements

 YMP/CM-0011, Rev. 1

4.1.3.3.6 Sorptive behavior as a function of stratigraphic position and mineralogy

4.1.3.3.7 Sorptive behavior as a function of ground-water composition

4.1.3.4.4 Solubilities of waste elements on Yucca Mountain water

4.1.3.6.1 Transport of suspended solids

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Sorption coefficients as a function of

   a. Ground-water composition.
   b. Mineralogy and surface structure.
   c. Sorbing species.
   d. Waste element concentration.
   e. Atmosphere (if needed).
   f. Temperature (if needed).
   g. Colloidal material (sorption on).
   h. Organic complexation (if needed).

2. Sorption kinetics.

3. Biological sorption and transport.

Data analysis is to include the following:

1. Statistical analysis to evaluate critical parameters and gaps in data.

Model development is to include the following:

1. Modeling of whole-rock sorption isotherms.
2. Modeling of sorption mechanisms.

Data supplied from other investigations are as follows:

Investigation	Subject
8.3.1.2.2	Site unsaturated zone hydrologic system
8.3.1.2.3	Site saturated zone hydrologic system
8.3.1.2.1	Water chemistry (specifically Activity 8.3.1.2.1.3.5)
8.3.1.3.2	Mineralogy, petrology, and rock chemistry

 YMP/CM-0011, Rev. 1

Investigation	Subject
8.3.1.3.3	Stability of minerals and glasses
8.3.1.3.5	Solubility
8.3.1.3.6	Sorption from dynamic transport column experiments (specifically Study 8.3.1.3.6.1)

Purpose and objectives of the investigation

The purpose of this investigation is to obtain data on the sorption behavior of key radionuclides as required by Issue 1.1 (Section 8.3.5.13). Specifically, Issue 1.1 requires that, for each key radionuclide species known to be chemically sorbing and for each rock unit in the controlled area except for the overburden, estimates should be provided of the mean and standard deviation of the distribution coefficients $K_d(i)$, under the range of water-rock chemical conditions expected for the unit in question. The key radionuclides identified by Issue 1.1 are isotopes of americium, carbon, cesium, curium, iodine, neptunium, plutonium, strontium, technetium, uranium, and zirconium.

The objectives of this investigation are to carry out three separate but related studies. These are (1) to obtain laboratory batch sorption coefficients for the key radionuclides as a function of the parameters listed above, to statistically evaluate these coefficients, and to develop an understanding of sorption mechanisms for each of the key radionuclides; (2) to evaluate the significance of biological sorption and transport; and (3) to develop a capability for the prediction of the sorption behavior of key radionuclides under conditions not assessed in the experimental program.

Technical rationale for the investigation

The degree to which a given radionuclide in solution is sorbed by a solid substrate is controlled by many variables, the most important of which are the composition and structure of the substrate, the composition and temperature of the solvent (e.g., ground water), the concentration of the radionuclide in solution, and the degree to which sorption equilibrium is achieved. To evaluate the potential influence of each of these variables, many individual experiments must be conducted. By carrying out sets of experiments in which all but one of the variables are held constant, the influence of each of the variables can be evaluated separately. For instance, the composition of the solvent (i.e., ground water) and the composition and structure of the substrate could be held constant while the concentration of the radionuclide in solution is varied in separate experiments over a range anticipated in the proposed repository environment. Other sets of experiments could involve variations in solvent (i.e., ground water) or substrate compositions, or in substrate structure (e.g., amorphous versus crystalline iron oxyhydroxides). For the laboratory data to be defensible, they must be shown to be statistically significant; therefore, statistical methods and isotherm equations are needed for the evaluation of variance in the experimental results.

YMP/CM-0011, Rev. 1

Although varying the concentration of a given radionuclide in solution is generally as simple as adding more of a ready made stock solution to the experimental charge, varying the composition of the solvent and/or the substrate can be more involved. For instance, to maintain a certain pH (acidity) or Eh (oxidation/reduction potential) condition in the solvent, the composition of the atmosphere in contact with the experimental charge may need to be controlled.

If the entire range of conditions and concentrations anticipated in the proposed repository environment is to be included in the experimental program, it is clear that a large number of experiments must be conducted. If sorption kinetics are to be investigated as well, an even larger number of experiments will be required. In order to restrict the number of experiments to a realistic value, the emphasis in the experimental program should be on gaining an understanding of the basic mechanisms involved in the sorption reactions. Once the mechanisms have been identified, independently derived models and data can be used to calculate the influence of variables such as the solvent composition over ranges outside of those included in the experimental program.

8.3.1.3.4.1 Study: Batch sorption studies

The goal of the batch sorption experiments will be to obtain sorption coefficients for key radionuclides as a function of the parameters listed above and discussed in the individual studies below. These studies will use statistical analysis to evaluate the experimental results (Activity 8.3.1.3.4.1.5) and will provide the data base for the development of models to allow prediction of sorption coefficients under conditions not directly addressed by the experimental program. The experimental emphasis will be on the elements americium, neptunium, plutonium, technetium, and uranium. Results for the alkali and alkaline earth elements are discussed in Chapter 4 and are assumed to be adequate for performance assessment calculations. The values for sorption coefficients obtained in this study will be used to interpret the results obtained in crushed-tuff column experiments (Activity 8.3.1.3.6.1.1).

The activities included in this study are

SCP section	Description
8.3.1.3.4.1.1	Batch sorption measurements on rocks and minerals
8.3.1.3.4.1.2	Sorption as a function of sorbing element concentrations (isotherms)
8.3.1.3.4.1.3	Sorption as a function of ground-water composition
8.3.1.3.4.1.4	Sorption on particulates and colloids
8.3.1.3.4.1.5	Statistical analysis of sorption data

YMP/CM-0011, Rev. 1

Sorption coefficients and their dependence upon the variables studied will be used in Investigation 8.3.1.3.6 (radionuclide dispersion, diffusion, and advection) to aid in predictions of flow, particularly fracture flow; in calculation of retardation by various mechanisms (Investigation 8.3.1.3.7, radionuclide retardation investigations); and in performance assessment calculations for Issue 1.1.

8.3.1.3.4.1.1 Activity: Batch sorption measurements as a function of solid phase composition

Objectives

This activity will focus primarily on determining sorption coefficients for radionuclides on tuffs of the Calico Hills zeolitic and vitric units, on devitrified tuffs, and on pure minerals representative of the minerals present in the rock and fractures of the repository block. Data will be obtained on sorption coefficients ($K_d(i)$) for each of the key radionuclides on whole-rock samples and pure mineral separates under the range of rock-water conditions anticipated in the repository block. The results on pure minerals will be used to interpret the whole-rock data and to derive insight into sorption mechanisms (surface complexation and ion exchange mechanisms). Further insight into sorption mechanisms and sorption kinetics will be provided by comparison of these results with the results of crushed-rock column experiments (Activity 8.3.1.3.6.1.1).

Parameters

The data needed are as follows:

1. Mineral abundance and composition of samples from the tuffaceous beds of Calico Hills and other tuffs of similar composition used in the tests, and of fracture fillings in the repository block (Section 8.3.1.3.2.1).

2. Chemical composition of the pure minerals used (Section 8.3.1.3.2.1).

3. Physical properties and cation exchange capacity of the solids used.

4. Ground-water composition.

5. Radioactive tracers (same tracers used as in Investigation 8.3.1.3.6).

6. Speciation data for key radionuclides in chosen ground-water compositions.

YMP/CM-0011, Rev. 1

The data gathered are as follows:

1. Surface properties of pure mineral separates.

2. Structure and distribution of surface complexes of the key radionuclides on pure minerals representative of the proposed repository block.

3. Isotherms describing the detailed sorption behavior of selected radionuclides in pure minerals of interest.

4. Sorption coefficients as a function of solid substrate composition.

5. Correlations of sorption coefficients with mineralogy.

6. Comparisons of batch data with crushed tuff column data (Activity 8.3.1.3.6.1.1).

Description

The test matrix will focus primarily on plutonium, neptunium, americium, and uranium because of their presence as key radionuclides and their complex aqueous chemistry. Zirconium and nickel may also be studied based on their importance in spent fuel inventories. Sorptive behavior of cesium, strontium, and barium are well characterized by existing data; however, they may be used to validate the testing procedures and to fill any existing data gaps. Zeolitic, vitric, and devitrified samples from the tuffaceous beds of Calico Hills will be the focus of the activity. Other tuffs of similar mineralogic composition will be used to supplement the limited availability of Calico Hills material. Some measurements will also be done using Topopah Spring tuff and tuffs from the saturated zone because these rocks are considered as sorptive barriers held in reserve.

Sorption will also be measured on pure minerals of composition ranges bracketing those in the Yucca Mountain rocks. Clinoptilolite, mordenite, and smectite will be the primary focus, with some additional testing using calcite and Fe and Mn oxyhydroxides such as, goethite, hematite, and pyrolusite. Both sorption and desorption ratios will be measured, using standardized techniques.

The sorption studies on pure minerals will consist of two areas of investigation: (1) sorption by surface complexation and (2) ion exchange. A mechanistic understanding of the sorptive process is sought through these two efforts.

The mechanism for actinide sorption is unknown. It is known that iron and manganese oxyhydroxides, such as goethite, hematite, and pyrolusite, strongly sorb actinides; therefore, sorption on these minerals must be considered. Initially the surface properties of these minerals will be determined by acid titration. Sorption experiments with these oxyhydroxides and the actinides and technetium will be conducted and the structure and distribution of surface complexes of the nuclides on the oxyhydroxide surfaces will be determined by extended x-ray adsorption fine structure (EXAFS). This technique is developed and has been applied to similar systems as described in Hayes et al. (1987) and Brown et al. (1987). The EXAFS technique also will characterize (identify) the oxyhydroxide minerals present in the tuff as will further characterization work in Section 8.3.1.3.2. Further details regarding this technique can be found in the study plan.

The ion exchange mechanism will be studied by developing isotherms describing the sorption of selected radionuclides in pure minerals. These isotherms will be analyzed using an inversion technique of regularization. Selectively coefficients for the studied radionuclides will be obtained for each of the different sorptive sites in the mineral. This site-specific information will be correlated with structural data for the reactive sites in the mineral and will be used to obtain information on the relationship between sorption and structural properties of the sorbing solid. The results obtained in this manner will be used to attempt prediction of the spatial variation of sorption in Yucca Mountain using mineralogic composition.

A minimum of 200 tests are anticipated for this activity, however, additional testing may be required based on the analyses of the data and on performance assessment calculations. A testing matrix is given in Table 8.3.1.3-3 summarizing the elements and solid phases addressed by this activity. The effects of variations in surface area on sorption will be examined by a limited number of bounding experiments. If significant effects are observed, more detailed testing will be considered.

Table 8.3.1.3-3. Testing matrix for batch sorption measurements as a function of solid phase composition

Elements[a,b]	Solid phase
U	Calico Hills tuff:
Pu	
Np	- zeolitic
Am	- vitric
Tc	- devitrified
U	
Zr	
Ni	Topopah Spring tuff[c]
Cs	
Sr	Tuff from saturated zone[c]
Ba	

YMP/CM-0011, Rev. 1

Table 8.3.1.3-3. Testing matrix for batch sorption measurements as a function of solid phase composition (continued)

Elements[a,b]	Solid phase
Pure mineral phases:	- clinoptilolite - mordenite - smectite - calcite - Fe and Mn oxyhydroxides (such as goethite, hematite, and pyrolusite)

[a]Sorption measurements are planned for elements in the first column on the solid phases in the second column.
[b]Tests will be run at only one concentration.
[c]Two samples from different locations.

Actinide tracers in known, stable, and well-characterized oxidation states are needed for use in this study and for use in Investigation 8.3.1.3.6. Most actinide elements in near-neutral solutions and at expected repository conditions can exist in more than one oxidation state, each of which may exhibit different sorption and transport behavior. To characterize these behaviors, sources of the individual species must be available. Plutonium and other actinides (key radionuclides expected to be present, Investigation 8.3.1.3.5) will be prepared in specific oxidation states in a carbonate buffer approximating the carbonate concentration of well J-13 water. The concentration prepared will be the lowest possible in which the species present can be identified (normally by spectroscopy). These solutions will be diluted and immediately used in sorption measurements. The remaining stock solution will be monitored during the course of the sorption experiments to assess the stability of the prepared oxidation state. It is important to be able to measure the distribution of redox species for studied elements in the experimental solutions, but the stability of the oxidation states, while desirable, is not critical. When satisfactory techniques are developed, quality assurance technical procedures will be written and implemented.

Computer codes to be used include RAYGUN, GAMANAL, and SPECANAL, which are all standard Los Alamos gamma ray data analysis codes.

 YMP/CM-0011, Rev. 1

8.3.1.3.4.1.2 Activity: Sorption as a function of sorbing element concentrations (isotherms)

Objectives

The purpose of this activity is to characterize the dependence of sorption coefficients upon the concentration of the element being sorbed by developing isotherms for the radionuclide. These measured values of K_d will be compared with the requirements of Issue 1.1 as they are developed. This activity will develop isotherms for the radionuclides to be tested. These isotherm data will be incorporated into the sorption data base, for use in determining element concentration levels at which precipitation begins to contribute to the measured sorption ratio, and in modeling sorption (Investigation 8.3.1.3.7) to predict retardation along flow paths. Since the concentration of waste elements is expected to change along potential flow paths, accurate sorption predictions must account for these changes, if significant. Batch techniques and procedures will be used as described in Activity 8.3.1.3.4.1.1.

Parameters

The data needed are the same as Activity 8.3.1.3.4.1.1.

The data gathered are the sorption coefficients as a function of sorbing element concentration.

Description

The concentration ranges studied will try to reach an apparent concentration limit (i.e., the highest concentration the solution can maintain when all other variables are held constant) so that it can be shown that precipitation is not contributing to the sorption ratio. The primary waste elements to be studied include uranium, plutonium, neptunium, and americium, with concentrations ranging from 10^{-12}M to an apparent concentration limit approximately 10^{-4} molar, if possible (Table 8.3.1.3-4). The experiments will be run with eight different concentrations within this range. The number of concentrations studied may change once the minimum number of points necessary for adequate isotherms is determined. Tuffs with mineralogy similar to Calico Hills zeolitic (T_z), to vitric (T_v), and to devitrified (T_{dv}) tuffs will be used. Test procedures are as for Activity 8.3.1.3.4.1.1. A general test matrix is given in Table 8.3.1.3-4. More elaboration is provided in the study plan on radionuclide retardation. Approximately 96 tests performed in duplicate are anticipated. This number will be adjusted based on initial testing results. The effects of variations in surface area on sorption will be examined by a limited number of bounding experiments. If significant effects are observed, more detailed testing will be considered.

YMP/CM-0011, Rev. 1

Table 8.3.1.3-4. Sorbing element concentrations of primary waste elements[a,b]

Elements	Solid phase[c,d]	Approximate concentration range[e,f] (M)
U	$T1_z$ $T2_v$ $T3_{dv}$	10E-12 to 10E-4
Pu	$T1_z$ $T2_v$ $T3_{dv}$	10E-12 to 10E-4
Np	$T1_z$ $T2_v$ $T3_{dv}$	10E-12 to 10E-4
Am	$T1_z$ $T2_v$ $T3_{dv}$	10E-12 to 10E-4

[a]Experiments run under ambient laboratory conditions. The liquid phase for all experiments was well J-13 water.

[b]Later studies not presently included in this investigation may run combinations of the actinides to measure the effects of competition among these radionuclides.

[c]$T1_z$ = zeolitic tuff; $T2_v$ = vitric tuff; $T3_{dv}$ = devitrified tuff.

[d]Oxyhydroxides, clays, and zeolites listed in Table 8.3.1.3-3 are also part of this matrix. The isotherm development (ion exchange in Section 8.3.1.3.4.1.1) is based on measurements at different sorbing element concentrations.

[e]E-12 is exponential notation (10^{-12}).

[f]Number of concentrations within given range was approximately eight.

8.3.1.3.4.1.3 Activity: Sorption as a function of ground-water composition

Objectives

The goal of this activity is to measure sorption coefficients as a function of ground-water compositions anticipated along potential travel paths and to determine if the values of K_d are above the goals set by Issue 1.1 (Section 8.3.5.13) as they are developed. Ground-water composition can control the waste radionuclide oxidation state, speciation, and solubility, and therefore, can have a great effect on the measured sorption ratio. These data will contribute to the sorption data base and support the sorption model development and performance assessment calculations. Batch techniques and procedures will be used as described in Activity 8.3.1.3.4.1.1.

Parameters

The data needed are as follows:

1. Same parameters as for Activity 8.3.1.3.4.1.1.

2. Ground-water compositions and samples from wells at Yucca Mountain.

3. Artificially prepared ground waters.

 YMP/CM-0011, Rev. 1

4. Composition of unsaturated zone ground waters (Investigation 8.3.1.3.1).

The data gathered are as follows:

1. Sorption coefficients as a function of ground-water composition.

Description

Batch sorption coefficients will be measured in ground waters of varying compositions and will be compared with the results obtained using well J-13 ground water (Activity 8.3.1.3.4.1.1). Ground water from two Yucca Mountain wells, USW H-3 and UE-25p#1, will be used in these tests along with artificially prepared ground water made by spiking well J-13 water with salts to give compositions simulating and possibly bounding vadose water compositions. The actinides uranium, plutonium, neptunium, and americium will be tested with cesium, barium, strontium, tin, and europium for validation of testing procedures and to fill gaps in the existing data base. Batch techniques and procedures will be used as described in Activity 8.3.1.3.4.1.1. A general test matrix is given in Table 8.3.1.3-5. More elaboration is provided in the radionuclide retardation study plan. A minimum of 60 tests performed in duplicate are anticipated. This number will be adjusted based on examination of the initial testing results. The effects of variations in surface area on sorption will be examined by a limited number of bounding experiments. If significant effects are observed, more detailed testing will be considered.

Although not part of the present investigation, additional testing may be necessary in future studies to evaluate the effects of waste package degradation products in altering sorption characteristics in the ground-water chemistry of the far field. Other studies may be initiated at a later time to measure the effects of competition and interaction among radionuclides, such as possible increases in iron and zirconium concentrations.

8.3.1.3.4.1.4 Activity: Sorption on particulates and colloids

Objectives

The goal of this activity is to determine if sorption of important radionuclides occurs on particulates or colloids that may be present in ground waters along potential transport pathways. This is an interactive effort with others described under Investigations 8.3.1.3.5 (solubility) and 8.3.1.3.6 (dynamic transport). Batch techniques, modified to accommodate the much smaller sample sizes, will be used to measure sorption. If any sorption is measured, then the use of sorption coefficients alone may not accurately predict the transport of sorbed radionuclides. Experiments investigating the transport of radiocolloids and particulates will be done under Investigations 8.3.1.3.6. Activity 8.3.1.3.6.1.5 (filtration) will investigate how this transport occurs through porous matrix and through fractured columns. The results of these experiments will direct the scope of this sorption activity. Data generated in this activity will not only support Investigation 8.3.1.3.6 but will contribute to the sorption data base and be used to support transport calculations by performance assessment.

Table 8.3.1.3-5. General test matrix to be used in measuring batch sorption coefficients in ground waters of varying compositions[a]

Element	Solid phase[b,c]	Sources of ground water[d,e]		
U	$T1_z$ $T2_v$ $T3_{dv}$	USW H-3	UE-25p#1	AW1,2,3
Pu	$T1_z$ $T2_v$ $T3_{dv}$	USW H-3	UE-25p#1	AW1,2,3
Np	$T1_z$ $T2_v$ $T3_{dv}$	USW H-3	UE-25p#1	AW1,2,3
Am	$T1_z$ $T2_v$ $T3_{dv}$	USW H-3	UE-25p#1	AW1,2,3

[a]All experiments done under ambient laboratory conditions. Data to be compared with results using well J-13 water (Activity 8.3.1.3.4.1.1).
[b]$T1_z$ = zeolitic tuff; $T2_v$ = vitric tuff; $T3_{dv}$ = devitrified tuff.
[c]Zeolites, clays, and oxyhydroxides listed in Table 8.3.1.3-3 may be included in this testing matrix, if needed.
[d]USW H-3 and UE-25p#1 are wells near Yucca Mountain; AW1, 2, 3 refers to artificially prepared ground water made by spiking well J-13 water.
[e]To evaluation potential effects of waste package degradation products, future tests may involve well-13 water spiked with probable contaminants (e.g., iron and zirconium) from the near field.

Parameters

The data needed are as follows:

1. Particulates from Yucca Mountain.
2. Identification of particulate composition.
3. Size distribution of particulates.
4. Estimate of size limit for transportable particulates (Investigation 8.3.1.3.6).

The data gathered are as follows:

1. Sorption coefficients on particulates.

Description

This activity involves the following steps: (1) collection of particulate and colloid material and its identification and (2) sorption measurements on the particulates. Particulate (and colloid) material will be obtained by filtering ground waters pumped from well J-13 and any other working wells available at the time of collection. This material will be identified by x-ray diffraction (XRD) and scanning electron microscope (SEM) analysis. Because of very limited sample availability, batch testing over the range of radionuclide concentrations and oxidation states, ground-water compositions and other variables measured in previously described batch

YMP/CM-0011, Rev. 1

studies, may not be practical. On the basis of the analyses of results from other batch tests, the values of these variables showing the most conservative sorption, but still consistent with site conditions, can be selected in order to set up a smaller test matrix for the particulate tests. Transport experiment results (Investigation 8.3.1.3.6) and transport calculations will also be used to limit the testing activities. The particulate-colloid sorption tests will not be initiated until preliminary testing and analysis is completed for Activities 8.3.1.3.4.1.1 through 8.3.1.3.4.1.3 and Investigation 8.3.1.3.6 to allow definition of the test matrix. More elaboration on this activity will be given in the study plan.

8.3.1.3.4.1.5 Activity: Statistical analysis of sorption data

Objectives

The goal of this activity is to produce statistical correlations and error estimates. Various statistical approaches will be used on the sorption data base, as provided by the statistical analysis system for Los Alamos National Laboratory, to (1) determine those variables (e.g., mineralogy, ground-water composition, and atmosphere) having the most profound effect on the sorption coefficients; (2) predict sorption coefficients as a function of mineralogy and, perhaps, ground-water composition; (3) estimate errors associated with predicted sorption coefficients; and (4) identify gaps in the experimental data. The results of these analyses will be used to bound sorption coefficients to be used in Investigation 8.3.1.3.7 and for performance assessment in Issue 1.1 (Section 8.3.5.13).

Parameters

The data needed are as follows:

1. Sorption coefficients as a function of numerous variables (Activities 8.3.1.3.4.1.1 through 8.3.1.3.4.1.4 and Study 8.3.1.3.4.2).

2. Mineralogy of tuff samples (Investigation 8.3.1.3.2).

3. Ground-water composition (Investigation 8.3.1.3.1).

The data gathered are as follows:

1. Correlations of sorption with numerous variables.
2. Bounds on sorption coefficients under various conditions.
3. Estimates of errors on predicted sorption coefficients.

Description

Regression techniques will be used to investigate factors that may significantly influence sorption ratio estimates. The statistical analysis system package is being used on a trial basis for these analyses. The computer packages of SOSI; data base management (sorting) and DATATRIEVE, a data management package will also be used.

 YMP/CM-0011, Rev. 1

8.3.1.3.4.2 Study: Biological sorption and transport

Objectives

The objective of this study is to determine what effects microorganisms have on the movement of radioactive waste (i.e, effects on sorption) and to determine if microbial activities play a role significant enough to be included in a performance calculation for Yucca Mountain. This study will identify the quantity, location, and characteristics of past and future organic materials used at the site and their susceptibility to microbiological degradation. The effect that these microorganisms will have on the movement of actinides will be determined through analysis of their effect on ground-water quality, colloid formation, effect on solubility, or by direct sorption of the actinides.

This study is being undertaken because (1) large amounts of biodegradable organic materials have been, or will be, introduced into or near the potential repository area, (2) microorganisms isolated from the NTS are capable of biodegrading these organic materials and have been shown to bind plutonium-239 exhibiting an R_d of 10,000, and (3) the mobility of the microorganisms through the tuff and their effect on the solubility of radioactive wastes is unknown.

Data generated will be included in the sorption data base and used to support work in Activity 8.3.1.3.6.1.5 (filtration) and to support transport calculations (Investigation 8.3.1.3.7 and Issue 1.1, Section 8.3.5.13).

Parameters

The data needed are as follows:

1. Ground-water chemistry (Investigation 8.3.1.3.1).

2. Flow rates and directions of water flows in the unsaturated and saturated zone.

3. Sorption of actinides on crushed tuff (Study 8.3.1.3.4.1).

The data gathered are as follows:

1. Sorption on microorganisms and data on steady state, v-max, actinide speciation, and cellular location.

2. Data indicating potential for the transport of radioactive wastes by microorganisms and microorganism by-products. Data on colloidal properties and mobility of microorganisms.

3. Understanding of magnitude of microbial activity on retardation and transport of radionuclides.

4. Identification of microorganisms.

 YMP/CM-0011, Rev. 1

Description

The following tasks are included in this study: (1) determination of the growth of microorganisms on fluid (e.g., drilling fluid); (2) evaluation of the influence of microorganisms on the movement of actinides, such as colloidal agglomeration and chelation; and (3) determination of the binding constant of microorganisms to actinides. Before sorption testing can be done, bacteria must be isolated and cultured in the laboratory. To isolate the bacteria, samples are taken from soils that have received discharges of drilling fluids during the course of the drilling operations and are, therefore, considered likely to contain microorganisms capable of biodegrading drilling fluids (USW G-1 and UE-25c#2).

The samples are placed in sterile bottles and immediately returned to the laboratory for analysis. A mineral salts medium is used to culture these microorganisms. A controlled amount of drilling fluid is added as the only energy source for microorganism growth. Solid media are inoculated with washings of the soil samples. After aerobic or anaerobic incubation at room temperature, isolated bacterial colonies growing on the medium are transferred to fresh media and incubated to obtain pure colonies. Colony morphology and microscopic characteristics and viscosity can then be determined. The growth of microorganisms indigenous to tuff from Yucca Mountain will also be studied utilizing exploratory shaft samples.

This study will determine the sorption ratio of radionuclides on bacteria. A steady-state sorption ratio for the bacteria and radionuclides will be determined. This is necessary to affix a value to bacterial sorption of radionuclides. The cellular location (internal versus external) of actinide sorption will be investigated to determine the stability of sorption. Furthermore, this study will determine if microorganisms preferentially sorb different oxidation states of a radionuclide. Sorption testing will be done primarily with plutonium, americium, and neptunium on core samples from USW G-4 (1,501 ft) using well J-13 water. Samples from the exploratory shaft will be used when they become available.

The previously unstudied effects of microorganisms on the movement of actinides through fractured and unfractured tuff will be examined by determining the movement of plutonium, americium, and neptunium sorbed to bacteria. This work will determine if the movement is a function of the biological mobility or the colloidal dispersion of the bacteria. Furthermore, the movement of radionuclides chelated by bacterial metabolites (i.e., siderophores) through fractured and unfractured tuff will be determined.

8.3.1.3.4.3 Study: Development of sorption models

Objectives

The purpose of this study is to model the sorption experiments on rocks and minerals representing the proposed repository block and to derive a capability to predict sorption coefficients for key radionuclides under water-rock conditions not included within the experimental program. This information will be used in Performance Issue 1.1 (Section 8.3.5.13), by Investi-

YMP/CM-0011, Rev. 1

gation 8.3.1.3.7, and by Investigation 8.3.1.3.6 as part of the description of radionuclide movement from the repository to the accessible environment.

Parameters

The data needed are as follows:

1. Sorption isotherm data for the key radionuclides on representative whole-rock samples and pure mineral separates (Sections 8.3.1.3.4.1.1 and 8.3.1.3.4.1.3).

2. Surface properties of pure mineral separates (Section 8.3.1.3.4.1.1).

3. Ground-water compositions in the proposed repository block (Section 8.3.1.3.1.1).

4. Speciation data for key radionuclides in representative ground-water compositions (Section 8.3.1.3.5.1.2).

5. Chemical compositions of the pure minerals (Section 8.3.1.3.2.1).

6. Mineral abundance and composition in rock samples and fracture fillings found in the proposed repository block (Section 8.3.1.3.2.1).

7. Structure and distribution of surface complexes of the key radionuclides on pure minerals representative of the proposed repository block (Section 8.3.1.3.4.1.1).

The data gathered are as follows:

1. Models describing the sorption of key radionuclides in the proposed repository block as a function of the mineralogic composition of the host rocks or fracture fillings, ground-water composition, radionuclide concentration, and temperature.

Description

This study will develop the best possible capability for the prediction of sorption coefficients for key radionuclides in the proposed repository block based on the available data. The predictive capability will be based on ion exchange and surface complexation models and data obtained in Studies 8.3.1.3.4.1, 8.3.1.3.4.2, and 8.3.1.3.4.3.

8.3.1.3.5 Investigation: Studies to provide the information required on radionuclide retardation by precipitation processes along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

 YMP/CM-0011, Rev. 1

The following sections of the data chapters and support documents provide a technical summary of existing data relevant to this information need:

SCP section	Subject
4.1.3.4.1	Processes affecting radionuclide concentrations and speciation in solution
4.1.3.4.2	Solubility and speciation data
4.1.3.4.3	Solubility modeling

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Solubility or concentration limits of important waste elements.

2. Ability of waste elements to form natural colloids.

3. Measurements of solubility as outlined by a NRC technical position "Determination of Radionuclide Solubility in Ground Water for Assessment of High-Level Waste Isolation" (NRC, 1984a).

4. Sensitivity of solubility limits to variation in controlling parameters (theoretical).

5. Speciation of waste elements.

6. Models that provide theoretical framework for understanding solubility, speciation and colloid formation.

Parameters that control solubility and speciation include the following:

1. Water chemistry (dissolved constituents, pH, redox state).
2. Water temperature.
3. Radiation field.

Purpose and objectives of the investigation

The purpose of this investigation is to supply input data for calculations of radionuclide transport along potential transport pathways from the repository to the accessible environment at the Yucca Mountain site. These calculations are required to address the overall system performance objective for radionuclide release in 10 CFR 60.112 (Issue 1.1, Section 8.3.5.13) and in making findings on the postclosure system guideline and the technical guidelines for geochemistry in 10 CFR 960.4 (Issue 1.9, Section 8.3.5.18), and in the siting criteria of 10 CFR 60.122 (Issue 1.8, Section 8.3.5.17).

 YMP/CM-0011, Rev. 1

Specifically, Issue 1.1 requires estimates of the means and standard deviations of the solubility limits of radionuclide-bearing compounds under anticipated water chemistry conditions.

There are two ways that radionuclides can be transported with water moving through the repository toward the accessible environment. Radionuclides can travel as dissolved species in the water and as particulate material carried by the water. This investigation will supply data and models that can be used to calculate concentration limits (solubilities) of dissolved waste elements in local water at the Yucca Mountain site; these concentration limits will be used directly by performance assessment models of radionuclide transport. This investigation will also supply data and models describing the formation and stability of natural radionuclide colloids in local water. This information will be used in assessing the likelihood of colloid transport (Section 8.3.1.3.7) and by Issue 1.1 in the total systems performance calculation. Radionuclide solubility and speciation data and models will also be used to support modeling of sorptive behavior as a function of water chemistry and waste element chemistry (Section 8.3.1.3.4).

Technical rationale for the investigation

It is not practical to measure solubilities of all waste elements that may exist in radioactive waste under all conditions that may occur at the repository or along flow paths to the environment. The technical approach used to select waste elements for solubility measurements and to select the conditions of these measurements is based on three criteria:

1. Select waste elements that have radionuclides present in large quantities relative to their EPA release limits (40 CFR 191, Appendix A, Table I).

2. Select waste elements that are likely, based on present knowledge of waste element chemistry and expected repository conditions, to have solubility limits during transport.

3. Select conditions for solubility experiments that will bound expected conditions at the repository or along flow paths to the environment.

The radionuclides of primary concern are discussed in Section 4.1.3.1.1. A review of the chemistry of important waste elements is also given in Section 4.1.3.4. These sections, along with descriptions of the expected water chemistry (Section 4.1.2) and changes in water chemistry resulting from waste emplacement (Section 4.2) form the basis for the selections of solubility experiments discussed below. The initial emphasis is on americium, plutonium, and neptunium solubility and speciation; measurements are also planned for uranium, thorium, radium, zirconium, tin, and nickel. These latter elements are included in the testing program so that the concentrations can be used as upper bounds for transport assessments, since sorption work is not planned for these elements except uranium at present.

Consideration has also been given to the generic technical position entitled "Determination of Radionuclide Solubility in Ground Water for

 YMP/CM-0011, Rev. 1

Assessment of High-Level Waste Isolation" (NRC, 1984a) in the selection of these experiments. This technical position serves as guidance in the preparation of detailed plans for waste element solubility experiments. It requires that any site that elects to use solubility to limit waste element release must design experiments to determine the solubility under site-specific conditions. The experiments discussed in this section are meant to satisfy the requirements of this technical position.

The various parameters that influence solubility can be divided into three groups:

1. Those parameters that define the conditions controlling solubility (water chemistry, temperature, and radiation field).

2. Those parameters that define element behavior (waste-element chemistry, colloid behavior, and kinetic data).

3. Those parameters necessary to understand precipitation processes (models).

The primary areas of choice in designing solubility experiments involve the conditions of the experiment and the elements chosen. For solubility conditions, five specific parameters have been considered in designing the experiments: (1) water compositions including pH and redox (speciation of redox sensitive radionuclides), (2) temperature, (3) identity of the solid controlling solubility, (4) the presence of other solids, and (5) radiation effects such as radiolysis. Solubilities that represent upper limits on waste element concentrations are of primary concern in defining the experiments. However, solubility data without an understanding of the basic processes involved are of only limited value. Thus, the results that will aid in understanding and in solubility modeling are stressed.

An important part of this investigation is the modeling of solubility and speciation of waste elements (Section 4.1.3.4). Modeling will be used for two purposes: to assess the importance of the various parameters that influence solubility and speciation (e.g., water composition) and to calculate solubilities under conditions not directly covered by the solubility experiments. Modeling of solubility and speciation of waste elements has concentrated on equilibrium methods; this emphasis will continue. Equilibrium models require thermodynamic data for solids that are likely to precipitate and for aqueous species that may be present in the water. These data are being developed from literature sources and from the solubility and speciation data collected as part of this investigation. If nonequilibrium or kinetic models are found necessary to describe some aspects of waste element solubility, they will be used as needed.

Movement of natural radionuclide colloids represent a transport mechanism that may be active under site conditions, and may not act to limit the effectiveness of the sorption barrier in retarding migration. To assess the potential for colloid transport (Section 8.3.1.3.4), information is needed about the likelihood of colloid formation under water conditions at the Yucca Mountain site and the stability of colloids once formed. Two waste elements that may form stable colloids under these conditions have been identified;

YMP/CM-0011, Rev. 1

they are plutonium and americium (Section 4.1.3.4). Because these elements also contribute significant activity to the waste inventory, colloid formation and stability experiments are planned with them.

8.3.1.3.5.1 Study: Dissolved species concentration limits

The goal of this study is to provide solubility or concentration limits for dissolved species of important waste elements under conditions that are characteristic of the repository and along flow paths toward the accessible environment. The importance of solubility has been highlighted by the NRC technical position entitled "Determination of Radionuclide Solubility in Ground Water for Assessment of High-Level Waste Isolation" (NRC, 1984a). The experiments described under this study are meant to satisfy the requirements of this technical position.

The results of this study will be used in the assessment of radionuclide releases to the accessible environment and to assess the existence of favorable or potentially adverse conditions at the site.

8.3.1.3.5.1.1 Activity: Solubility measurements

Objectives

The goal of this activity is first to specify the conditions under which solubility experiments will be carried out and then to measure solubilities or concentration limits of important waste elements under these conditions.

Parameters

The data needed are as follows:

1. Water chemistry (composition, pH, redox state, oxidation-reduction).
2. Water temperature.
3. Radiation environment.

The data gathered are as follows:

1. Solubilities (concentration limits).
2. Identity of solids controlling solubility.
3. Oxidation states and speciation of the dissolved species in solution.

Description

Solubility measurements are planned in three water compositions, a neutral electrolyte, well J-13 water, and drillhole UE-25p#1 water. These compositions range from a simple system with no complexing except hydrolysis through well J-13 water (sodium bicarbonate water), which is expected to be

YMP/CM-0011, Rev. 1

close to water compositions in the unsaturated zone, to drillhole UE-25p#1 water (calcium bicarbonate water), which is from the carbonate aquifer and has the highest solute concentration of any water observed in the vicinity of Yucca Mountain. Table 8.3.1.3-6 shows the test conditions for water used in measuring the solubility of waste elements.

Table 8.3.1.3-6. Test conditions for water used in solubility measurements[a]

Water	pH	Temperature (°C)
J-13	6, 7, 8.5	25, 60, 90
UE-25p#1	6, 7, 8.5, 9.5	25, 60
Neutral electrolyte	6, 7, 8.5	25, 60

[a]Waters will be oxygen saturated.

The pH of the waters will be varied for the measurements (neutral electrolyte at pH 6, 7, and 8.5; well J-13 water at pH 6, 7, and 8.5; drillhole UE-25p#1 water at pH 6, 7, 8.5, and 9.5). Solubility experiments will be performed at 25, 60, and 90°C for well J-13 water, and at 25 and 60°C for drillhole UE-25p#1 water and the neutral electrolyte. These temperatures cover the range of expected conditions where liquid water may be present. All measurements will be done under oxidizing conditions (oxygen saturated) to simulate the conditions found in most waters from Yucca Mountain and vicinity; this procedure will result in solubilities that are equal to or greater than solubilities that would be measured under reducing conditions. Data from tests measuring changes in water chemistry resulting from interaction with the host rock or waste package materials indicate only minor compositional changes (Section 4.1). No solubility measurements are planned in which the water compositions are modified to account for these effects. If future data from experiments involving Yucca Mountain water and local minerals or waste package material show significant water composition changes, this decision will be reviewed.

An attempt will be made to approach steady state in the solubility measurements from both undersaturation and oversaturation. Tests approaching steady state from oversaturation will be done first and the solids that precipitate will be characterized. Where possible, these solids will be prepared and used for experiments that approach steady state from undersaturation. This procedure has the advantage of not specifying the solid that controls solubility, but of allowing the system under investigation to determine the solid that will precipitate.

There are no plans in the present investigation to include other solids such as tuff from Yucca Mountain in the solubility experiments. The presence of tuffs may compromise the ability to obtain meaningful data on the solubil-

YMP/CM-0011, Rev. 1

ity of radionuclides. Including tuffs in the tests greatly increases the complexity of the solubility work because it may not be possible to deconvolute the effects of two operative processes, sorption and precipitation. When sufficient data have been gathered to generate a fundamental understanding of solution chemistry, then the Project will consider expanding the scope and complexity of the testing to include solubility experiments with tuff. The potential effects of solids on solubility will be addressed in Study 8.3.1.3.6.1.

There are no plans to perform solubility experiments in the presence of gamma radiation. The effects of gamma radiation should not be significant by the end of the containment period. A number of the waste elements have radionuclides with high specific alpha activities. The effects of alpha-radiation will be investigated by performing solubility experiments with two isotopes of plutonium (Pu-239 and Pu-242) and americium (Am-241 and Am-243) that have different specific activities.

The choices of waste elements for the solubility experiments are based on the importance of each waste element (Section 4.1.3.1.1) and the likelihood of solubility having an influence on transport (Section 4.1.3.4). Solubility measurements will first be done for americium, plutonium, and neptunium. At a later date, measurements will begin for uranium, thorium, radium, zirconium, tin, and nickel. Solubility measurements are not planned for technetium, cesium, iodine, or strontium. Although radionuclides of these elements make important contributions to the activity of waste, they may have high solubilities under conditions at the Yucca Mountain site; thus solubility might not limit their transport.

8.3.1.3.5.1.2 Activity: Speciation measurements

<u>Objectives</u>

The goal of this activity is to identify important aqueous species of waste elements under conditions described in Activity 8.3.1.3.5.1.1 and determine their formation constants. This will be done when important data are unavailable from any other source outside the Yucca Mountain Project. This activity is concurrent with the measurement of concentration limits in Study 8.3.1.3.5.1, and is intended to fill any data gaps so that this solubility data can be explained by the thermodynamic modeling (Activity 8.3.1.3.5.1.3).

<u>Parameters</u>

The data needed are as follows:

1. Important waste elements for which speciation measurements are needed (Activity 8.3.1.3.5.1.3).

2. Experimental conditions (Activity 8.3.1.3.5.1.1).

3. Water samples (Investigation 8.3.1.3.1).

 YMP/CM-0011, Rev. 1

The data gathered are as follows:

1. Determination of the identity and measurement of the formation constants of aqueous species of waste elements.

Description

For this activity, experiments will be performed with waste elements in solution to determine the identity of the aqueous species formed and their concentrations under conditions that can be used to determine their formation constants. Under the conditions expected at Yucca Mountain, carbonate is expected to play an important role in plutonium and americium speciation. Initially, plutonium and americium carbonate speciation will be studied.

8.3.1.3.5.1.3 Activity: Solubility modeling

Objectives

The goal of this activity is to develop the thermodynamic models and data needed to calculate waste element solubilities over the range of conditions expected at the site.

Parameters

The data needed are as follows:

1. Computer code EQ3/6 (see Sections 8.3.5.10.3.2.1 and 8.3.5.10.3.2.2 for discussions on development of EQ3/6).

2. Thermodynamic data from literature and from Activity 8.3.1.3.5.1.1 and Activity 8.3.1.3.5.1.2.

The data gathered are as follows:

1. Models and data to calculate waste element solubilities (both equilibrium and nonequilibrium or kinetic models).

Description

This activity will collect thermodynamic data from the literature and apply existing chemical equilibrium models to the solubility data developed in Activity 8.3.1.3.5.1.1 and to data from any other pertinent solubility experiments in order to test the applicability of the models and data. Where data on the existence of formation constants of aqueous species are found to be inadequate, recommendations for measurements will be made to Activity 8.3.1.3.5.1.2. If equilibrium models are found to be inadequate to describe any solubility data, nonequilibrium models that involve kinetic behavior (nucleation, precipitation, dissolution, or oxidation-reduction kinetic models) will be developed. These models will be used to test the consistency of experimental data and to assess the sensitivity of the solubilities to variations in controlling parameters such as water composition.

 YMP/CM-0011, Rev. 1

8.3.1.3.5.2 Study: Colloid behavior

The goal of this study is to determine the stability of waste element colloids under expected site-specific conditions that might be encountered at the repository or along flow paths toward the accessible environment. The results of this study will be used in the assessment of radionuclide releases to the accessible environment and to assess the existence of favorable or potentially adverse conditions at the site.

8.3.1.3.5.2.1 Activity: Colloid formation characterization and stability

Objectives

The objective of this activity is to determine the formation and stability of waste element colloids. Two waste elements that may form colloids have been identified; they are plutonium and americium (Section 4.1.3.4). Although only plutonium and americium will be investigated during the initial phase of the study of waste element colloids, work will be extended to other radionuclides if performance assessments of engineered barrier system performance and other field and laboratory data show other radionuclides are potentially important in colloid formation. This information will be used by performance Issue 1.1 (Section 8.3.5.13) and Investigations 8.3.1.3.4 and 8.3.1.3.6.

Parameters

The data needed are as follows:

1. Experimental conditions (Activity 8.3.1.3.5.1.1).
2. Water samples (Investigation 8.3.1.3.1).

The data gathered are as follows:

1. Waste elements that form natural colloids.
2. Specific condition under which colloids form.
3. Physical and chemical characteristics of the colloids.
4. Stability of colloids.

Description

Plutonium and americium have been reported to form natural colloids. Because these elements also contribute significant activity to the waste inventory, colloid formation and stability experiments are planned for these elements. The conditions likely to promote colloid formation, the stability of the colloids, and the disposition of the waste element species as the colloids break up will be described. Colloid breakup involves the redissolution or degradation of the colloid and the eventual fate of the component radioactive element(s).

 YMP/CM-0011, Rev. 1

The conditions to be studied for colloid formation, stability, and break up will include pH, redox state, temperature, concentration of the element, etc. The effect of these conditions on colloid size, density, composition, charge, and chemical reactivity will be studied.

8.3.1.3.5.2.2 Activity: Colloid modeling

Objectives

The objective of this activity is to develop models and model parameters to calculate natural colloid concentrations and stability and to describe the disposition of the waste element species as the colloids break up. Data collected for plutonium colloids indicate that true equilibrium is not obtained in solutions with colloids present because of alpha radiolysis products. A preliminary kinetic model involving oxidation and reduction of soluble plutonium species and plutonium colloids has been partially successful in describing this behavior, but further model development is needed. An americium colloid model will also be required.

Parameters

The data needed are as follows:

1. Experimental data on colloid behavior (Activity 8.3.1.3.5.2.1).

The data gathered are as follows:

1. Models and model parameters to calculate natural colloid concentrations and stability.

Description

This activity will use techniques for modeling chemical and physical systems to describe the data collected in Activity 8.3.1.3.5.2.1.

8.3.1.3.6 Investigation: Studies to provide the information required on radionuclide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters and support documents provide a technical summary of existing data relevant to this investigation:

 YMP/CM-0011, Rev. 1

SCP section	Subject
4.1.3.5.2	Retardation by matrix diffusion during fracture flow
4.1.3.6	Radionuclide transport
4.1.3.6.1	Transport of suspended solids

Parameters

The following parameters will be measured, calculated, or derived as a result of the site studies planned to satisfy this investigation:

1. Data on diffusion.

   a. Longitudinal diffusion.
   b. Matrix diffusion.

2. Data on diffusion without advection.

3. Data on adsorption.

4. Data on dispersion.

   a. Hydrodynamic dispersion.
   b. Channeling.

5. Data on anion exclusion.

6. Data on speciation.

7. Data on sorption kinetics.

8. Data on heterogeneity.

9. Data on colloidal movement.

10. Data on flow in fractured tuff.

Data needed from other investigations are as follows:

1. Hydrologic conditions.
2. Geometry of flow paths.
3. Results of radionuclide sorption in batch tests.

Purpose and objectives of the investigation

The goal of this investigation is to experimentally determine the rate of movement and effective retardation of radionuclides by dispersive, diffusive, and advective processes. Specifically, Issue 1.1 (Section 8.3.5.13) needs experimental evidence that could confirm or deny the theory of advective-diffusive coupling of solute concentrations in matrix and fracture

 YMP/CM-0011, Rev. 1

flow. This theory is embodied in the transport model for fracture flow currently used in the transport model of TOSPAC (described in Issue 1.1). Issue 1.1 states that this information is crucial in establishing the credibility of transport phenomenology embodied in any models used to assess the consequences of the release scenarios associated with the water pathways.

This investigation will provide the effective diffusivity of radionuclide species in the matrix of each rock unit in the saturated and unsaturated zones to the total system performance Issue 1.1. The parameter called for by Issue 1.1 is an empirical parameter measuring the effective diffusivity of the matrix-fracture interface (constrictivity-tortuosity factor) for the saturated and unsaturated zones. Issue 1.6 (Section 8.3.5.12), which must determine the pre-waste-emplacement ground-water travel time is also calling for diffusion data from this investigation. Furthermore, permeabilities at the matrix-fracture interfaces are required by Issue 1.1. An understanding of dispersion processes and the contributions of sorption to radionuclide retardation in an advective system is necessary to develop the required parameters for Issue 1.1. Issue 1.1 also requires distribution coefficients for the rock matrix in the saturated and unsaturated zone beyond the disturbed zone. The bulk of the sorption data will be gathered in Investigation 8.3.1.3.4, but if these data are to be used in a dynamic system, sorption (distribution coefficients) must be evaluated in this dynamic system. This investigation will provide that evaluation and support of the use of the sorption data by Issue 1.1. The results of this investigation, however, will first be assessed by Investigation 8.3.1.3.7 before being used in Issue 1.1. Finally, Issue 1.1 requires knowledge of whether a precipitate (colloid) can be transported through the porous and fractured rock.

Technical rationale for the investigation

This investigation is divided into two studies that have been designed to understand how radionuclides are transported (retarded) by advective, diffusive, and dispersive processes. These studies are the (1) dynamic transport column study (Study 8.3.1.3.6.1) and (2) diffusion study (Study 8.3.1.3.6.2). The dynamic transport column study includes five activities: crushed tuff column tests (Activity 8.3.1.3.6.1.1), mass transfer kinetics (Activity 8.3.1.3.6.1.2), unsaturated tuff column (Activity 8.3.1.3.6.1.3), fractured tuff column (Activity 8.3.1.3.6.1.4), and filtration (Activity 8.3.1.3.6.1.5).

The dynamic transport and diffusion study test matrix is shown in Table 8.3.1.3-7. This table represents all the tests and analyses that will be conducted as part of this investigation and presents the processes for which measured and derived data will be gathered by this task. The matrix shows which tasks will produce primary data (p) on each process listed and where effects of processes are observed but not used as a primary source of data (a).

The following text will briefly describe each test represented in the matrix. The first six tests listed represent activities and tests under the dynamic transport column study (Study 8.3.1.3.6.1). The last test listed is Study 8.3.1.3.6.2 (diffusion).

Table 8.3.1.3-7. Dynamic and diffusion study test matrix

	R^d	Speciation	Colloids	Kinetics	Matrix diffusion	Longi-tudinal diffusion	Hydro-dynamic dispersion	Channeling	Hetero-geneity
Crushed tuff columns	p	p	a	a	n	a	a	n	n
Mass transfer kinetics									
Sorption kinetics	a	a	a	p	n	p	a	n	n
Solid tuff columns	a	a	a	a	a	a	p	n	p
Unsaturated tuff columns	a	a	a	a	n	a	a	a	a
Fractured tuff columns	a	a	a	a	a	n	p	p	p
Filtration	n	n	p	n	n	n	a	n	n
Diffusion studies	a	a	a	a	p	n	n	n	n

Key:

a = effect will be observed, but parameter will be fit or derived from other experiment.
n = negligible effect.
p = primary source of data.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

The crushed tuff column activity (Activity 8.3.1.3.6.1.1) will measure the rate of movement of radionuclides relative to tritiated water and other well-defined chemical species or colloids through crushed tuff columns. The primary data resulting from this test are sorption coefficients and evidence of speciation. Kinetic, matrix diffusion, longitudinal diffusion, and hydrodynamic dispersion effects will also be observed in these tests. These tests will be used to support the use of K_ds produced from the batch experiments (Investigation 8.3.1.3.4), by Issue 1.1. Differences between this study and the batch studies will be investigated in Study 8.3.1.3.6.1. Speciation information will be used to provide elucidation relative to other processes such as diffusion and dispersion and will be used to reinterpret batch distribution coefficients. The process of anion exclusion is significant because it could reduce the transport time of the anionic radionuclides through the zeolitic tuff. The observation of colloid breakthrough in this study will establish the need to treat colloidal movement (Activity 8.3.1.3.6.1.5 (filtration)).

The mass transfer kinetic activity (Activity 8.3.1.3.6.1.2) will investigate the kinetics of sorption as a function of water velocity. The mass transfer kinetic activity will provide data to validate or support the use of retardation factors based on static measurements by performance Issue 1.1. The activity has two parts: tests run with crushed tuff columns and tests run with solid rock columns. The crushed column tests will evaluate sorption kinetics. The primary data from these tests will be kinetic data and data on longitudinal diffusion, which is diffusion in the direction of flow. Sorption coefficients, speciation, hydrodynamic dispersion effects and potential colloid transport will be observed. The solid tuff column tests will provide primary information on hydrodynamic dispersion and effects of heterogeneity on mass transfer kinetics. The other effects listed previously will also be observed.

Dispersion can be a factor when trying to elucidate the processes of diffusion and sorption kinetics. Dispersion is important to transport processes because high dispersivity broadens the breakthrough front of the radionuclide migration and, therefore, leads to earlier arrival times. Dispersion may also affect sorption by creating lower aqueous phase concentrations. The apparent dispersion (broadening of the elution curve) depends on such parameters as diffusivity, water velocity, kinetic rates, and hydrodynamic dispersivity including channeling (non-Fickian dispersion). The solid rock column tests will measure the dispersion for nonsorbing tracers that will be sensitive to hydrodynamic dispersion. Hydrodynamic dispersion can be defined as the velocity distribution due to laminar flow through pores combined with the effect of tortuous flow paths. The hydrodynamic dispersion of the solid rock columns is expected to be greater than the crushed tuff columns due to the solid rock heterogeneity. Sorbing tracers will be used to test the ability to predict the broadening effects of the combined processes just discussed. Dispersion in the solid rock column will be smaller than the dispersion data used in performance calculations; however, the laboratory experimental data will provide dispersion data in tuff at a small scale that may be useful in examining the scale dependent nature of dispersion.

There are no primary data being obtained from the unsaturated tuff column activities; however, all the effects of the processes listed in the test matrix will be observed except for matrix diffusion. Total system

YMP/CM-0011, Rev. 1

performance calculations (Section 8.3.5.13) will be determining radionuclide travel-time calculations through the unsaturated zone using data gathered from experiments performed under saturated conditions. Therefore, the unsaturated tuff column tests are critical for understanding how the geochemical-physical processes in a saturated system can be applied to an unsaturated system.

The fractured tuff column tests will provide primary data on hydrodynamic dispersion, channeling (non-Fickian dispersion), and heterogeneity. All other process effects will be observed except for longitudinal diffusion. Performance Issue 1.1 calls for an empirical measure of diffusivity to be used in a fracture flow scenario. The effective diffusivities measured in the column experiments in this investigation will be based on a limited set of tracers. Empirical diffusivities can be obtained by using the measured diffusion of these tracers to derive diffusivities for the other radioelements. The empirical diffusivities can only be useful in Issue 1.1 if the information is derived using knowledge of the diffusive and dispersive processes from this activity and the tests in this investigation. Specifically, channeling in fractures (non-Fickian dispersion) leads to only a small diffusive flux since channels contribute to a small proportion of the surface area of the fractures. The non-Fickian dispersion could have a velocity component that would cause the apparent dispersion to be increased by mass transfer kinetics (sorption kinetics).

The filtration activity will provide primary data on whether colloidal material can be filtered or transported through tuff. Radionuclides that may form natural colloids will be identified in Activity 8.3.1.3.5.2.1. The formation of radiocolloids, however, may reduce the transport time of affected radionuclides independent of the sorption capabilities of the zeolitic tuff.

The diffusion study will elucidate diffusive processes and provide primary data on matrix diffusion for performance Issue 1.1. Effects of sorption, speciation, colloids, and kinetics also will be observed in these tests. Diffusion data will be collected independently of advective and dispersive processes by looking at moving species in a nonadvective flow regime. Specifically, matrix diffusion associated with fracture flow is of particular importance to the performance of the repository because diffusion is one of the two mechanisms that enables radionuclides to contact and, therefore, interact with sorbing minerals beyond the surface of the fractures. Effects of matrix diffusion will also be observed in the previously described solid rock column tests under mass transfer kinetics and in the fractured tuff column tests.

8.3.1.3.6.1 Study: Dynamic transport column experiments

All the experiments in the dynamic transport column experiment study measure the breakthrough or elution curve for tracers through tuff columns. The elution curves can be characterized by (1) the time of arrival and (2) the broadness or dispersion of curve.

The time of arrival depends on the retardation factor, that, in turn depends on the R_d. For flow through fractures the arrival time also depends

 YMP/CM-0011, Rev. 1

on matrix diffusion. Significant deviations (those larger than expected based on sampling variability) in the arrival time for a radionuclide from that predicted on the basis of the batch R_d indicates one of the following problems that must be addressed in performance assessment:

1. The presence of more than one chemical species with different selectivities in the tuff minerals, which are not readily exchanged.

2. The presence of colloid or pseudo-colloid containing the tracer.

3. Extremely slow adsorption kinetics. (Note that the residence time for sorbing tracers is generally longer in the column studies than in the batch measurements.)

4. For solid tuff columns, the process of crushing tuff has altered the mineral surfaces responsible for sorption.

5. Matrix diffusion in the case of fractured tuff.

6. Solubility effects attributable to the presence of solids.

The broadness or apparent dispersion of the curve depends on the following:

1. Longitudinal diffusion.
2. Hydrodynamic dispersion due to laminar flow.
3. Sorption kinetics.
4. Channeling.
5. Heterogeneity.
6. Matrix diffusion.

The physical form of the tuff changes the sensitivity of the experiment to the above processes. For example, crushed tuff minimizes the sensitivity to channeling, heterogeneity, and differences in mineral composition and texture between batch measurement and column experiments. A series of experiments, varying a single parameter, such as water velocity, permits the measurement of a single process because the parametric dependencies of the processes are different. For example, the velocity dependence of kinetics is different from the velocity dependence of hydrodynamic dispersion.

8.3.1.3.6.1.1 Activity: Crushed tuff column experiments

Objective

The purpose of this activity is to measure the rate of movement through crushed tuff columns of radionuclides relative to tritiated water and other well-defined chemical species or colloids. The observation of differences in the sorption ratios measured by the batch technique (Investigation 8.3.1.3.4) versus the column technique will indicate the presence of more than one chemical species of a radionuclide if all other factors listed previously are constant. Comparisons with well-characterized anions, cations, and colloids will determine the charge or colloidal form of the unknown species. By also

YMP/CM-0011, Rev. 1

performing these measurements on pure minerals, the minerals responsible for the sorption of single species can be identified.

Results of the crushed tuff column activity have several applications: (1) the observation of multiple species will be used in Investigation 8.3.1.3.4 to reinterpret batch distribution coefficients, (2) the retardation factors from column measurements will be used in performance assessment as either lower limits for distribution coefficients or to confirm the validity of the batch distribution coefficients, and (3) the observation of the movement of colloids through crushed-rock column experiments will establish the need to treat particulate movement in performance assessment. The contribution to the understanding of the mechanisms of interactions between single species and individual minerals will improve the confidence level and reduce uncertainties in the application of laboratory sorption data in performance assessment calculations.

The probable crushed tuff columns that will be used for these experiments are

1. Two Topopah Spring Member tuffs.
2. Two Calico Hills tuffs (zeolitic and vitric).
3. One Prow Pass Member tuff.
4. Aluminum-poor clinoptilolite.
5. Aluminum-rich clinoptilolite.
6. Aluminum-poor mordenite.
7. Aluminum-rich mordenite.
8. Montmorillonite.
9. Illite.
10. Two feldspars.

The tracers that will be used for this activity and Activities 8.3.1.3.6.1.2 through 8.3.1.3.6.1.4 and Study 8.3.1.3.6.2 are

1. HTO (tritiated water).
2. Iodine-131.
3. Fluorescent polystyrene sols.
4. Dyes.

Cations with single oxidation states and with known solubilities are

1. Cesium-137.
2. Strontium-85.
3. Barium-133.

Key radionuclides include

1. Technetium.
2. Plutonium.
3. Americium.
4. Neptunium.
5. Uranium.

 YMP/CM-0011, Rev. 1

Nonradioactive tracers include

1. Fluoride.
2. Chloride.
3. Sulfate.
4. Nitrate.
5. Bromide.
6. Polystyrene latex.

For most of the activities, the anions will be run in a mixed batch (together). Tritium will always be run alone. The anions, tritium, and technetium column experiments will last approximately one week. The radionuclide experiment durations vary depending on the sorption capacity of the radionuclides. The cations cesium, barium, and strontium have already been done and the results are similar to the batch experimental results (Treher and Raybold, 1982).

The crushed-tuff column experiment is composed of three parts: (1) to characterize the columns, (2) to determine sorption ratios, and (3) to infer speciation.

The retention volume and intrinsic dispersivity of the crushed tuff columns that will be used for the other parts of this activity will be determined. Sorption ratios will then be determined by comparing the crushed tuff column results with the batch sorption results determined in Investigation 8.3.1.3.4. The differences observed may verify the presence of more than one chemical species of a radionuclide or other known tracers. Comparison of column and batch technique using pure minerals will also be conducted. Finally, should the presence of more than one chemical species containing the radionuclide be observed, speciation can be inferred. This is done by comparing the elution curves of well characterized cations, anions, and colloids to determine the charge or the colloidal form of the unknown species.

<u>Parameters</u>

The data needed are as follows:

1. Batch sorption data from Investigation 8.3.1.3.4.

The data measured are as follows:

1. Column characterization: retention volumes and intrinsic dispersivity.

2. Retardation factors and retention volumes of tracers.

3. Dispersion in shape of the breakthrough curve.

4. Elemental analysis of exchangeable cations.

YMP/CM-0011, Rev. 1

The data derived are as follows:

1. Sorption ratios for cations and key radionuclides.

2. Comparison of sorption ratios between crushed tuff column studies and the batch technique.

3. Charge of unknown species.

4. Colloidal form of unknown species.

5. Significance of anion exclusion.

Description

Tuff samples from the same lot as Investigation 8.3.1.3.4 will be used for the crushed tuff columns. The tuff samples were chosen to have mineralogies and sorptive properties that are representative of minerals located along flow paths to the accessible environment. Furthermore, the actinide tracers used for this activity will be obtained from Investigation 8.3.1.3.4.

Tritiated water (a nonsorbing tracer) is used to determine the intrinsic dispersivity of the crushed tuff columns. This requires measuring the void volume to determine the column porosity. All nonsorbing tracers are not equivalent because anions and other large molecules are excluded from the intracrystalline pore space in zeolites and clays.

Sorption ratios for cations and key radionuclides will be determined. Speciation may be observed as the listed cations and key radionuclides elute. Sorption ratios may also be determined for column experiments using pure minerals and these ratios will be compared to the equivalent batch technique results. Minerals responsible for the sorption of single species can then be identified.

Actinides have been observed to have a fraction that elutes through crushed rock columns earlier than expected (Olofsson and Allard, 1986). Subsequently, the determination of the species of the actinides is important. The species determination is extremely difficult, particularly for americium and plutonium, because of the low solubility of both the actinides in near neutral solutions. For example, the extinction coefficients for plutonium in a +6 oxidation state limit the measurement to approximately 10^{-6} molar. The tracer experiments (batch, column) are performed at lower concentrations; for this reason, indirect evidence must be used to infer the solution species. One piece of data that can be used to infer this information is the column behavior since negatively charged ions (anion exclusion) and large molecules are eluted earlier than tritiated water. Furthermore, colloidal matter can be eluted even earlier through a mechanism known as hydrodynamic chromatography. Therefore, comparing the known species (e.g., chlorine, known colloids) with the unknown species will allow inferences about the charge and/or colloidal form of the species. This information will be used in evaluating the results from the batch sorption tests of Investigation 8.3.1.3.4, including the sorption of single species on pure mineral samples. In particular, it has been observed that only minor amounts of technetium are adsorbed in a tuff column. In general, it is thought that technetium does not adsorb;

YMP/CM-0011, Rev. 1

however, this observation is not consistent with batch measurements where sorption is observed. Detailed work may be needed to reconcile the batch versus column results and may include redesigning the batch sorption experiments.

8.3.1.3.6.1.2 Activity: Mass transfer kinetics

Objectives

The goal of this activity is to determine the elution rate of radionuclides as a function of water velocity. The adsorption of radionuclides, like any chemical reaction, is a dynamic process and has a reaction rate. The reaction rate can be very rapid as in a simple ion exchange process or slowed by some intermediate step. If the residence time is short compared with the reaction rate, the apparent sorption ratio will decrease. These measurements will establish the mass transfer kinetics limitation and yield information that can elucidate the sorption mechanism. The elution rate of cations and key radionuclides as a function of water velocity will be determined for crushed tuff columns (homogeneous system), solid rock columns (heterogeneous system), and for pure mineral samples.

Mass transfer coefficients (sorption K_ds) will be used by performance assessment as a basis for establishing the validity of retardation factors based on static measurements in scenarios involving rapid water movement such as fracture flow. Mass transfer coefficients will also be used by Investigation 8.3.1.3.7. Diffusion coefficients for cations will also result from this activity. These results along with the results from Study 8.3.1.3.6.2 will be used by Investigation 8.3.1.3.7 and Issue 1.1 (Section 8.3.5.13).

Parameters

The data needed are as follows:

1. Dispersion characteristics for crushed tuff (intrinsic dispersivity) (Activity 8.3.1.3.6.1.1)

The data measured are as follows:

1. Retardation factors and retention volume of tracers.
2. Dispersion in shape of the breakthrough curve.
3. Elemental analysis of exchangeable cations.

The data derived are as follows:

1. Sorption ratios.
2. Kinetic rate constants.
3. Velocity limit to which sorption values are valid.

Description

To establish mass transfer kinetics for a homogeneous system (crushed tuff columns), this activity will determine sorption rate constants and will

 YMP/CM-0011, Rev. 1

establish the mass transfer kinetic limitation by determining a velocity limit to which the sorption values are valid. The dispersivity of the crushed tuff column must be well characterized to distinguish mass transfer from dispersion. The crushed tuff columns used will be the same columns used in Activity 8.3.1.3.6.1.1. The tracers used will be cesium, barium, strontium, uranium, plutonium, neptunium, americium, and technetium. The anions will not be used in these tests. For strongly sorbing cations or actinides, shorter crushed columns will be used.

To establish mass transfer kinetics in a heterogeneous system (solid rock column), this activity will determine sorption rate constants and will establish the mass transfer kinetics limitation by determining the velocity limit to which sorption values are valid. This activity will determine whether the mechanism of mass transfer exhibits a dependence on the heterogeneity of the rock column (i.e., mineral dependence). Two solid rock core samples without fractures from the Topopah Spring Member, possibly two from the Calico Hills (zeolitic and vitric), and one from the Prow Pass Member will be used. The mass transfer kinetics experiments will be done using an apparatus that produces an advective flow through the solid rock column. This apparatus is in a developmental stage. The tests will be conducted using the uranium, plutonium, neptunium, americium, technetium, and anion tracers.

Mass transfer kinetics limitations will similarly be established for systems of pure minerals. This test will provide information on the kinetics of adsorption on select sorbing minerals and will assist in elucidating the mass transfer kinetic data of the previous tests. The minerals to be used are clinoptilolite, mordenite, montmorillonite, and illite. An analcime column test may be conducted if it is established that the geochemical-physical retardation of radionuclides in flow paths at greater depths are important to the total system transport calculations (Section 8.3.5.13).

8.3.1.3.6.1.3 Activity: Unsaturated tuff columns

Objectives

This activity will measure the relative migration rate of radionuclides through partially unsaturated rock columns. The present approach to modeling chemical interactions in unsaturated rock is to treat the chemistry in a way identical to that of saturated rock, except for modifying the effective porosity. Although dispersion is expected to vary with saturation state, the chemistry should not alter over the range of saturation states anticipated in Yucca Mountain. This assumption about dispersion and sorption must be verified through experiment. Most of the adsorption isotherms, as discussed in Chapter 4, show linear behavior. It is unclear whether or not the rock-water ratio affects radionuclide sorption. The nonlinear behavior exhibited by some adsorption isotherms may be explained by irreversible adsorption on small numbers of sites, such that increasing the rock-water ratio effectively increases the K_d. Conversely, zeolites generally show a decrease in K_d as the rock-water ratio increases. This may be an experimental artifact related to the difficulty of separating phases. At any rate, the effects of varying rock-water ratio will be investigated and details will be in the study plans.

YMP/CM-0011, Rev. 1

The summary report (Daniels et al., 1982) discussed the effect of rock-water ratio on sorption isotherms. Until the chemical composition of pore water in the unsaturated zone is determined (Section 8.3.1.2.2), there is no evidence to suggest that there would be a difference in the chemical interaction in the unsaturated rock due to pore water chemical composition.

The results of the unsaturated tuff column experiments will be used in Investigation 8.3.1.3.7 and ultimately in performance assessment to validate models used to calculate unsaturated flow and transport. Also, the retardation factors, if different from saturated tuff experiments, will be used in performance assessment calculations for unsaturated zone transport calculations.

Parameters

Data and models based on saturated tuff are needed. Work on the development of an unsaturated column for laboratory scale testing is needed. Data measured are retardation factors or retention volumes.

The data derived are as follows:

1. Permeability as a function of pressure (matric potential).

2. Saturation as a function of pressure (matric potential).

3. Matric potential of the unsaturated tuff.

4. Sorption ratios.

5. Support or nonsupport of transport or flow models based on a saturated system.

Description

This activity will develop the unsaturated tuff column apparatus and the hydrologic properties of the column will be characterized. An unsaturated tuff column apparatus similar to that used in soil physics will have to be developed. Because the suction potential of tuff is much larger than that of soils, this apparatus will have to be designed to operate at high internal pressure. Conventional porous plates may be adapted for this apparatus, but other types may have to be tested.

The tuff samples used will be limited to a few Topopah Spring Member samples and one Calico Hills sample. The unsaturated tuff columns will be characterized, providing rock characteristics information and characteristic curves for hydrologic modeling and for the laboratory work in this investigation. Specifically, the matric potential of the unsaturated tuff will be characterized and the migration of cations and radionuclides in the unsaturated tuff columns will be studied. Sorption ratios for tritiated water, chloride, and only weakly sorbing cations will be determined; use of more highly sorbing cations would hinder completion of this activity in a timely manner. Results of these tests will ensure the applicability of sorption values of saturated flow in tuff to an unsaturated system. These tests are high risk experiments; however, it may be even more difficult to guarantee

 YMP/CM-0011, Rev. 1

success of geochemical field tests in the unsaturated zone (Study 8.3.1.3.7.2). Alternate experimental approaches will be discussed in the study plan that will be developed for this study.

8.3.1.3.6.1.4 Activity: Fractured tuff column studies

Objectives

This activity will measure the transport and diffusion of radionuclides through naturally fractured tuff. Although there is a great body of research supporting the modeling of contaminant transport through homogeneous porous media from the column chromatography literature, such support does not exist for the transport of contaminants through fractures. The tests in this activity will examine the movement of tracers through naturally fractured Yucca Mountain cores to test the transport models. Because fracture flow may be a significant component of flow under some conditions, the movement of radionuclides along fractures in the tuffs must be understood and quantified. The quantification is particularly important so that estimates of radionuclide transport and retardation under porous and fracture flow regimes can be compared in the system assessments. Specifically, the coupling of flow in fractures and diffusion into the matrix must be described and, more importantly, dispersion due to heterogeneity and channeling must be evaluated.

The results of fracture flow experiments will be used by Investigation 8.3.1.3.7 and performance assessment to validate models describing transport in fractures. The effective retardation and diffusivities of radionuclides will be used by performance assessment to calculate radionuclide migration in the saturated zone and in scenarios involving fracture flow. Also, the movement of nonsorbing tracers in fractures can be used as a reference to aid the interpretation of carbon-14 dates in ground water. Finally, the information on the effective retardation of nonsorbing tracers in fracture flow may be used in calculations of pre-waste-emplacement ground-water travel time (Issue 1.6, Section 8.3.5.12).

Parameters

The data needed are as follows:

1. Diffusivities (gained from diffusion Study 8.3.1.3.6.2).

The data measured are as follows:

1. Fracture permeability.
2. Porosity.
3. Fracture surface topography.
4. Elution curve (tracer concentration as a function of time).
5. Elemental analysis of cations.

The data derived are as follows:

1. Fracture aperture.

 YMP/CM-0011, Rev. 1

2. Retardation factors for tracers and retention volumes.

3. Dispersion, diffusion into the rock matrix, and sorption ratios.

4. Evaluate retardation in a fracture flow system for retardation sensitivity analysis (8.3.1.3.7.1) to determine effective retardation for a fracture flow system.

Description

At present six fractured-core columns are operating. They include four Topopah Spring Member tuffs, one Bullfrog Member tuff, and one Tram Member tuff. Samples are limited by the availability of fractured core. There are no good fractured cores of Calico Hills tuff available at this time. If and when they are available, this activity will include samples from the Calico Hills in the tests. Some nonsorbing tracers and cesium, barium, strontium, technetium, uranium, plutonium, americium, and neptunium will be used as tracers for these tests. This activity will validate sorption processes in a fractured system. The fractured tuff column will be characterized by determining the fracture characteristics such as fracture aperture and fracture permeability. Fracture apertures will be determined from permeability measurements and inferred using Darcy's Law. The surface topography of the fractured tuff also will be determined using optical techniques. The method for measuring permeability will be described in technical procedures not yet available.

The effective diffusivities measured in these experiments will be based on a limited set of tracers; therefore, empirical diffusivities for the other tracers of interest will be obtained by applying the known diffusion of the limited set of tracers.

The effective retardation for a fracture flow system factor or diffusivity will be determined by measuring the radionuclide elution curve and fitting the curve to curves generated either with the analytic solution described in reports referenced in Chapter 4 or when necessary by the TRACR3D (see Investigation 8.3.1.3.7) computer code. Dispersion will also be derived. All chemical analyses will be done using standard analytical techniques, as in Study 8.3.1.3.6.1.

8.3.1.3.6.1.5 Activity: Filtration

Objectives

The tuffs of Yucca Mountain may provide a natural barrier by acting as an efficient filter for particulate matter. This study will attempt to quantify the filtration of colloids and particulates by the tuff as a function of particle or pore size. The filtration of various particle sizes will be measured using solid tuff cores and fractured cores. The results of the filtration experiments will provide an experimental basis to decide whether or not particulate transport of radionuclides needs to be considered in the final performance assessment or if colloid and particulate transport can be ruled

YMP/CM-0011, Rev. 1

out on the basis of filtration. The data will also be used by Investigation 8.3.1.3.7 to aid in this assessment.

Solid tuff cores will be used to determine whether Yucca Mountain tuff is an effective filter given matrix (porous) flow. The same solid core used by Activity 8.3.1.3.6.1.2 will be used in this activity. Synthetic colloids, natural colloids, and colloids from Study 8.3.1.3.5.2 will be characterized in terms of size distributions and then used in the tuff column test. This activity will also use fractured tuff core to determine whether filtration of particulates or colloids in a fractured tuff core and matrix diffusion will occur. The same fractured tuff core used for Activity 8.3.1.3.6.1.4 will be used.

Parameters

The data measured are size distribution and surface charges of particulates, and the data derived are effective pore sizes and filtration profiles.

Description

As in the activity describing the solid rock column mass transfer kinetics (Activity 8.3.1.3.6.1.2), an apparatus will be developed that produces advective flow through the solid rock column at pressures between 2,000 to 3,000 psi. For both the solid tuff core and the fractured tuff core, the same particulate tracers will be used. There are many standard particulate tracers available that require different techniques for detection. The tracers of choice have not been investigated for transport in tuff as yet. Possibly plutonium and americium polymers, a synthetic colloid, or a polystyrene sol will be used. Fluorescent particles are available that can be detected by fluorometry. Gold colloids can be detected by plasma emission spectrometry or neutron activation. In sufficiently high concentration, all particulate tracers can be analyzed by conventional light scattering (nephelometry).

The particle size distribution of tracers will be determined by dynamic light scattering. The colloids will also be determined by dynamic light scattering to ensure that relevant sizes of tracers are used. The dynamic light scattering, also known as autocorrelator photon spectroscopy, is a state-of-the-art technique. There will be a need to do some development to extract the theoretical limit of information contained in the measurement. The development is primarily one of producing a better code for inverting integral equations.

8.3.1.3.6.2 Study: Diffusion

This study will measure the diffusivity and kinetics of adsorption in a purely diffusive system (i.e., no advection). This study supports Activity 8.3.1.3.6.1.4 and overlaps with Activity 8.3.1.3.6.1.2 by providing confirmatory results. The measured diffusivities will be used by Investigation 8.3.1.3.7 and Issue 1.1 (Section 8.3.5.13). Kinetic rate constants and effective diffusivities will be measured from the uptake of radionuclides on intact tuff as a function of time. Scaling studies will also be conducted to

 YMP/CM-0011, Rev. 1

determine up to what scale the matrix diffusion model can be applied with confidence. Technetium, uranium, plutonium, americium, neptunium, cesium, barium, and strontium will be used in this study.

Three experimental techniques are developed in the following activities using beakers fabricated from tuff wafers and rock slabs.

8.3.1.3.6.2.1 Activity: Uptake of radionuclides on rock beakers in a saturated system

Objectives

This activity will measure the uptake of radionuclides by rock beakers as function of time. By using rock beakers, extraneous components introduced from other types of vessels are removed. The geometry of the beaker requires a numerical rather than an analytic solution. These results will provide a baseline for the following activities on diffusion through a saturated tuff slab and diffusion in an unsaturated tuff block.

Parameters

The data needed are ionic diffusivities, and the data measured are elemental analysis of key radionuclides and cations.

The data derived are as follows:

1. Apparent diffusivity as a function of time.
2. Kinetic rate constants as a function of time.
3. Sorption ratios for cations and key radionuclides.

Description

The problem of sorption of actinides, particularly americium, on vessels made of plastic or glass can be eliminated by using saturated rock beakers. The procedure for making the rock beakers from Yucca Mountain tuff is not yet available; the rock beakers will initially be made of Topopah Spring Member tuff and then the experiments will be extended to Calico Hills tuff. The interior of the rock beaker will be relatively smooth. If the sorption of actinides is principally on the external surfaces of tuff, it would be expected that a lower K_d would be observed in these experiments than in batch sorption experiments.

The uptake of radionuclides as a function of time will be fit to a diffusion model with reactions (sorption) to determine the diffusivities and rate constants. For a linear reversible reaction, an analytic solution exists. In the event of a more complex reaction mechanism, higher order, irreversible reactions, or both will be added to the computer code TRACR3D (Investigation 8.3.1.3.7).

YMP/CM-0011, Rev. 1

8.3.1.3.6.2.2 Activity: Diffusion through a saturated tuff slab

Objectives

This activity is designed to measure the diffusion of radionuclides in a purely diffusive system, no advection. The kinetic rate constant as a function of time and the effective diffusivity as a function of thickness will be measured. A scaling study will be made by varying the thickness of the tuff slab or wafer. The saturated slabs will be made of Topopah Spring Member tuff and Calico Hills zeolitic tuff. The results of Activity 8.3.1.3.6.2.1 will be used to interpret the results.

Parameters

The data needed are as follows:

1. Ionic diffusivities.

The data measured are as follows:

1. Porosity.
2. Pore tortuosity.
3. Pore constrictivity.
4. Elemental analyses of cations and key radionuclides.

The data derived are as follows:

1. Kinetic rate constants.
2. Sorption ratios for cations and key radionuclides.
3. Effective diffusivities.

Description

A saturated tuff slab or wafer will separate two solutions, one with tracers and one without. The migration of radionuclides due to pure diffusion will be studied. The scaling studies are done by varying the thickness of the wafer. A thick wafer will produce higher diffusivities. The grain orientation may affect the diffusion and this would provide some geometric information in interpreting diffusion in the field. For a thin wafer, diffusion times would be shorter, thus, the kinetics will be on a rapid time scale. Kinetics may be limited by a scaling dependence.

8.3.1.3.6.2.3 Activity: Diffusion in an unsaturated tuff block

Objectives

This activity will determine the distribution of radioactivity in the unsaturated tuff matrix, using an unsaturated tuff block of the Topopah Spring Member or Calico Hills.

The uptake of radionuclides as a function of time will be fit to a diffusion model with reactions (sorption) to determine the diffusivities and

 YMP/CM-0011, Rev. 1

rate constants. For a linear reversible reaction, an analytic solution exists as has been shown for the simple cations. In the event of more complex reaction mechanisms, higher order and irreversible reactions will be added to the computer code TRACR3D (Investigation 8.3.1.3.7).

Parameters

The data needed are as follows:

1. Ionic diffusivities.

The data derived are as follows:

1. Apparent diffusivity.
2. Kinetic rate constants as a function of time.
3. Sorption ratios for cations and key radionuclides.
4. Effective porosity.
5. Pore tortuosity and constrictivity.

Description

The method used for studying the distribution of radioactivity entails drilling a small hole in the unsaturated tuff block and injecting tracers. This design is used to minimize vapor phase convection. The diffusion or distribution of the radionuclides will be determined by sectioning the tuff block using cryogenic methods to minimize drying of the saturated slab and thus preventing the radionuclides from moving.

8.3.1.3.7 Investigation: Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters and support documents provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
4.1.2	Ground-water chemistry
4.1.3.3	Sorption
4.1.3.4	Processes affecting radionuclide concentrations and speciation in solution
4.1.3.5	Matrix diffusion
4.1.3.6	Radionuclide transport

 YMP/CM-0011, Rev. 1

SCP section	Subject
4.1.3.7	Geochemical retardation in the host rock and surrounding units--anticipated conditions
4.1.3.8	Geochemical retardation in the host rock and surrounding units--unanticipated conditions
4.2.1	Anticipated thermal conditions resulting from waste emplacement
4.2.4	Effects of the thermal pulse on radionuclide migration

Parameters

The following parameters will be measured or calculated as a result of the site studies planned as part of this investigation:

1. Significance and relative importance of physical and geochemical processes affecting transport.

2. Geochemical-geophysical model of Yucca Mountain.

3. Integrated transport calculations.

4. Transport models and related support.

Purpose and objectives of the investigation

The purpose of this investigation is to support the total systems performance calculations of Issue 1.1 (Section 8.3.5.13). Issue 1.1 requires calculational models of radionuclide transport in the unsaturated and saturated zone that are capable of representing the effects of flow in at least two dimensions on the transport of dissolved, reactive solutes and of testing the theory embodied in the one-dimensional systems-level model used in Issue 1.1. The goal of this investigation is to use the three-dimensional transport model and other multidimensional process codes to support Issue 1.1 and to determine, characterize, and quantify the cumulative effects of all significant processes, physical and geochemical, acting on or controlling radionuclide transport at Yucca Mountain. In using the three-dimensional model to support the simpler system performance model in Issue 1.1, it must be demonstrated that the laboratory generated data described in previous investigations can be reliably transferred to anticipated field conditions. The second study of this investigation is intended to address this concern. This investigation must synthesize all the field characterization data and the experimental geochemistry data of this test program together with the geochemical field test data gathered in other test programs and as part of this investigation (Study 8.3.1.3.7.2).

Technical rationale for the investigation

The first study (Study 8.3.1.3.7.1) involves the following three principal activities: (1) determine the significance and importance of the geo-

 YMP/CM-0011, Rev. 1

chemical and physical processes affecting transport, (2) compile a conceptual geochemical-geophysical model of Yucca Mountain and use it as a basis for integrated transport calculations (3-D), and (3) support and maintain the transport models. The second study (Study 8.3.1.3.7.2) outlines the elements of a strategy to address the question of validating the extrapolation of laboratory data to field conditions. As site characterization proceeds, the strategy will be evolved and presented in SCP updates, followed by reports on the results of this work.

To support Issue 1.1 and to calculate the best and most realistic estimates of radionuclide transport at Yucca Mountain, the significance and relative importance of each physical and geochemical process needs to be assessed. The assessment will include evaluating the following: (1) geochemical transport processes, (2) physical transport processes, (3) experimental support and development, (4) particulate transport, (5) coupled phenomena, and (6) heat load effects.

If a particular process is known to impact transport generally but is found to be unimportant in controlling transport at Yucca Mountain, then it can be excluded from the integrated transport calculation and performance assessment calculations. However, this assessment must be based on the results from investigations into (1) the significance of the physical and geochemical processes and (2) the limits of applicability of the physical and geochemical models thought to affect transport. The laboratory and field data must be integrated into, and correlated with a determination of the significance and importance of transport processes and transport calculations in order to present the most realistic picture of potential transport.

8.3.1.3.7.1 Study: Retardation sensitivity analysis

As a baseline set of input data for the integrated transport calculations (information item in this investigation), a conceptual geochemical-geophysical description of Yucca Mountain is needed based on the results, data, and information generated from the geochemistry, mineralogy-petrology, hydrology, and other pertinent Yucca Mountain Project tasks. From this compilation of baseline data, a determination can be made as to what data may be inadequate or insufficient to make the cumulative, integrated transport calculations needed to meet the NRC and EPA regulations. The calculations will be made during the fulfillment of Information Needs 1.1.4, and 1.1.5 (Sections 8.3.5.13.4 and 8.3.5.13.5).

The integrated transport calculations are to be used to determine and quantify the cumulative and individual effects of all physical and geochemical processes controlling transport. The effects that may be important in limiting or increasing the total integrated radionuclide release rates can then be identified. With a completed baseline set of integrated transport calculations the following can be assessed: (1) the potential effects of favorable and potentially adverse conditions; (2) the determination that the site is not disqualified and is not likely to be disqualified; (3) the determination that the site meets the qualifying conditions and is likely to continue to meet the qualifying conditions; and (4) probabilistic estimates of

 YMP/CM-0011, Rev. 1

the radionuclide releases to the accessible environment considering anticipated and unanticipated scenarios.

Computer models are used to calculate transport and investigate the significant processes affecting transport. The geologic system and the transport processes at Yucca Mountain are very complex (e.g., being unsaturated and fractured media). To model such a system, the most efficient numerical tools need to be used. The models must be verified (assuring that a computer code correctly performs the operations specified in the numerical model and the computational algorithms used to solve the governing equations are accurate) and validated (assuring that the theoretical foundation of the code describes the actual system behavior). Alternative numerical approaches in computer models will be implemented wherever feasible. These alternative numerical models will include all significant transport processes and possibly increase computational efficiency and numerical stability. Identification of the important contributors to uncertainty and those parameters for which variation within favorable limits have little or no influence on results from retardation calculations will allow estimates of model sensitivities and uncertainties to be made. Once sensitivities are identified, unnecessary complexity in the systems models can be reduced (Information Need 1.1.3), thereby facilitating the probabilistic simulations of systems performance to be made in fulfilling Information Need 1.1.5.

The following three activities are intended to be interactive efforts with each other and with the laboratory and field programs presented in other investigations and the following study (Study 8.3.1.3.7.2).

8.3.1.3.7.1.1 Activity: Analysis of physical/chemical processes affecting transport

Objectives

This activity will analyze all the processes that may affect transport; geochemical transport processes, physical transport processes, particulate transport, heat-load effects, and coupled phenomena. Results of this study will be used to support and develop those laboratory experiments designed to examine the physical and geochemical processes affecting radionuclide transport and other experimental activities under this program and the exploratory shaft tests (i.e., diffusion experiments). A correlation and validation of results obtained from laboratory, exploratory shaft, and field experimental results with transport calculations will also be done.

The investigation of the geochemical processes affecting transport will be used (1) to interpret sorption, solubility, water chemistry, and precipitation data; (2) to design future experiments; (3) to examine and define the limits of the applicability of laboratory-measured sorption values to the field situation at Yucca Mountain; and (4) to verify the applicability of using parameter values obtained in the laboratory under saturated conditions in calculations of transport through the unsaturated zone. The investigation of the physical processes (dispersion, matrix diffusion, and advection) affecting transport will be used (1) to interpret results obtained under Investigation 8.3.1.3.6, (2) to examine and define the limits of the applic-

 YMP/CM-0011, Rev. 1

ability of laboratory-measured diffusion and constrictivity values to the field situation at Yucca Mountain, (3) to examine the impact that fracture versus matrix flow has on transport, and (4) to correlate the results obtained from the C-well field tests (Investigation 8.3.1.2.2) and other field tests (Study 8.3.1.3.7.2) with results obtained from laboratory testing and modeling activities. The investigation of particulate transport will be used by performance assessment (Issue 1.1) to establish a need to treat particulate transport, and a determination of the impact of microbiological activity on radionuclide transport will be made. The particulate transport investigations will also be used for the experimental design and interpretation of results from colloid transport experiments conducted under Investigation 8.3.1.3.6.

The investigation on the heat-load effects will be used by performance assessment to establish a need to treat all or some of the heat-load effects, and in the waste package activities to establish a need to treat all or some of the heat-load effects in waste package design and for calculations of radionuclide release from the engineered barrier system.

The investigation into coupled phenomena will be used to improve the integrated geochemical-geophysical description of Yucca Mountain (Activity 8.3.1.3.7.1.2), and to interpret experimental results and develop future experiments, and to develop and perform calculations under Activities 8.3.1.3.7.1.1 and 8.3.1.3.7.1.3.

Parameters

The data needed are as follows:

1. Data from the following investigations and activities:

Investigation	Subject
8.3.1.2.2	Site unsaturated zone hydrologic system
8.3.1.2.3	C-well tracer tests
8.3.1.3.1	Water chemistry
8.3.1.3.2	Mineralogy-petrology information
8.3.1.3.3	Mineral-glass stability
8.3.1.3.4	Radionuclide sorption, microbial activity
8.3.1.3.5	Radionuclide precipitation, solubility, speciation
8.3.1.3.6	Physical processes: dispersion, matrix diffusion, advection (derived values), filtration/transport of particulates, evidence of speciation, kinetics of chemical processes (sorption), effects of flow processes on transport (fracture, matrix)

 YMP/CM-0011, Rev. 1

Investigation	Subject
8.3.1.3.8	Gaseous radionuclide retardation
8.3.1.3.7.2	Applicability of laboratory data to repository transport calculations

The data gathered are as follows:

1. Significance and importance of

   a. Geochemical processes.
   b. Physical processes.
   c. Particulate transport.

2. Extents of

   a. Microbial activity.
   b. Heat-load effects.
   c. Changes in stress and fractures.
   d. Gaseous transport.

3. Effects of coupled processes.

Description

This activity will involve verifying the applicability of using sorption measurements performed under saturated conditions, in calculations of transport through the unsaturated zone. This activity will also examine the limits of applicability of conceptual geochemical models (such as the distribution coefficient, Study 8.3.1.3.4.3). The limits of the applicability of laboratory-measured sorption values to field situation will also be assessed. Data on sorption (Investigation 8.3.1.3.4), speciation (Investigations 8.3.1.3.5 and 8.3.1.3.6), precipitation-solubility (Investigation 8.3.1.3.5), ground-water chemistry (Investigation 8.3.1.3.1), and thermodynamic data will be used in the assessments. Data from Investigation 8.3.1.3.6 will also provide input for this assessment by determining how the physical processes of dispersion, diffusion, and advection will affect radionuclide transport. This activity will (1) examine the limits of applicability of laboratory-measured diffusion and constrictivity values to the field situation, (2) examine the extent to which matrix versus fracture flow processes contribute to radionuclide transport, and (3) correlate the results obtained from the laboratory, field, and modeling investigations and activities.

Particulate transport (Activity 8.3.1.3.6.1.5, filtration) will be investigated using numerical models. The relative importance and significance of particulate transport to radionuclide transport, and the extent to which microbiological activity (Study 8.3.1.3.4.2, biological sorption) may also have an effect on transport will be determined. Heat-load effects on hydrology and transport near the repository will be modeled by examining changes in stress and fractures, and possibly by examining the extent of gaseous transport (Investigation 8.3.1.3.8). Furthermore, the effects of coupled processes on transport of radionuclides will be studied to determine

 YMP/CM-0011, Rev. 1

which of the possible coupled processes should be taken into account by the total systems performance Issue 1.1 (Section 8.3.5.13).

In particular, the computer codes TRACR3D, COLLOID, TRANQL, WAFE, FEHMS, and HDOC will be used. TRACR3D is a finite difference three-dimensional flow and transport code that incorporates geochemical (sorption) and physical processes and data along with hydrologic and geologic data to do integrated transport calculations (Activity 8.3.1.3.7.1.2). The COLLOID code will investigate particulate and colloid transport and the contribution of microbial activity to this transport. The TRANQL code will specifically assess the geochemical processes (sorption, speciation, precipitation, solubility, thermodynamics effects) and how they may affect transport. The WAFE code incorporates a thermal component into the flow and transport code, and TRACR3D will assess the geochemical-physical conditions under a thermal regime similar to a repository environment. FEHMS is a finite element code that couples heat, mass, and stress changes, and assesses their effects on transport. Finally, HDOC is a code that uses the dynamics of contour methods to model flow and transport. It is a numerically efficient transport code that will be used comparatively with the other more complex and involved codes. This code could be very efficient and economical if it can be shown to replicate sensitivity studies presently performed by other more computationally intensive codes. This code then is quite robust and could be beneficial if used by performance assessment.

The codes all have user's manuals or referenceable procedures or Yucca Mountain Project milestones associated with them. They are listed here.

Code	Citation
TRACR3D	Travis, Bryan J., "TRACR3D: A Model of Flow and Transport in Porous/Fractured Media," LA-9667-MS, Los Alamos National Laboratory (May, 1984).
TRANQL	Cederberg, G. A., R. L. Street, and J. O. Leckie, "A Groundwater Mass Transport and Equilibrium Chemistry Model for Multicomponent Systems," Water Resources Research, 21(8), 1095-1104 (1985).
HDOC	Travis, Bryan J., and L. Eric Greenwade, "A One-Dimensional Numerical Model of Two-Phase Flow and Transport in Porous Media using the Dynamics of Contours Methodology," Milestone C717, Los Alamos National Laboratory (October, 1985).
FEHMS	Zyvoloski, G., and S. Kelkar, "FEHMS: A Finite Element Heat-Mass-Stress Code for Coupled Geological Processes," Milestone R346, Los Alamos National Laboratory, Los Alamos, NM (March 31, 1987).
COLLOID	Nuttall, H. E., "Population Balance Model for Colloid Transport," Milestone R318, LA-UR-86-1914, Los Alamos National Laboratory (June, 1986). Submitted to Water Resources Research.
WAFE	Travis, Bryan J., "WAFE: A Model for Two-Phase, Multicomponent Mass and Heat Transport in Porous/Fractured Media," LA-10488-MS, Los Alamos National Laboratory (October, 1985).

 YMP/CM-0011, Rev. 1

8.3.1.3.7.1.2 Activity: Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations

Objectives

The objective of this activity is to perform calculations of radionuclide transport from the repository to the accessible environment using, as a basis, an integrated, conceptual geochemical-geophysical model of Yucca Mountain. The geochemical model of Yucca Mountain and the integrated geochemical transport calculations will be used for site characterization, the environmental assessment, and to resolve Issues 1.1 and 1.8 (Sections 8.3.5.13 and 8.3.5.17). The results will also be used by the performance assessment subtask to establish the need to treat all or some of the geochemical and physical processes.

Parameters

The data needed are as follows:

1. Geohydrologic characteristics (Section 8.3.1.2). Recharge rates, location of water tables, flow paths and fluxes of water and gases in the unsaturated and saturated zones.

2. Rock characteristics (Sections 8.3.1.4 and 8.3.1.15). Stratigraphy and structural characteristics, spatial distribution of thermal conditions and mechanical properties.

3. Engineered barrier characteristics (Issue 1.5, Section 8.3.5.10). Boundaries of the reference engineered barrier system (EBS), release rates from the EBS assuming both anticipated and unanticipated processes and events.

4. Release rate from the waste forms after the contaminant barrier is breached (Issue 1.4, Section 8.3.5.9).

5. Geochemical characteristics (this program). Water chemistry (Investigations 8.3.1.3.1 and 8.3.1.2.2); mineralogy-petrology and rock chemistry (Investigation 8.3.1.3.2); sorption processes (Investigation 8.3.1.3.4); precipitation processes (Investigation 8.3.1.3.5); dispersive, diffusive, and advective processes (Investigation 8.3.1.3.6).

6. Potential effects of erosion (Section 8.3.1.6).

7. Potential effects of future climatic conditions (Section 8.3.1.5).

8. Potential effects of igneous and tectonic activity (Section 8.3.1.8).

9. Data from the C-well tracer tests.

10. Data from the field tests (geochemistry) of Study 8.3.1.3.7.2.

YMP/CM-0011, Rev. 1

The data gathered are as follows:

1. Geochemical-geophysical model.
2. Integrated radionuclide transport calculations.

Description

This activity will first construct an integrated, conceptual geochemical/geophysical description of Yucca Mountain based on the results, data, and information generated from the geochemistry, mineralogy-petrology, hydrology, and other pertinent Yucca Mountain Project tasks. From this complete description of Yucca Mountain, an assessment of the areas and specific items needing further and more intensive investigation can be made. This compilation activity should occur at regular intervals. A technical integrating committee may need to be formed to review the information in the reference information base and issue a Yucca Mountain Project assessment of that data in the form of a geochemical-geophysical model similar to the one produced by this activity. This committee may also be the correct forum for determining the Yucca Mountain Project positions on such things as which hydrologic flow models will be used.

Second, integrated transport calculations on radionuclides from the repository to the accessible environment will be performed using the geochemical-geophysical model as a basis for the calculation. The integrated transport calculations will be used to determine and quantify the cumulative and individual effects of all geochemical and physical processes controlling transport. The effects that may be important in limiting or increasing the total radionuclide release rates can then be identified. These calculations serve Activity 8.3.1.3.7.1.1 and are interactive with that activity. Furthermore, these calculations will support and give confidence to the assumptions made by performance assessment (Issue 1.1, Section 8.3.5.13) in its use of a one-dimensional system model for radionuclide transport and the resulting cumulative frequency distribution curves for radionuclide releases to the accessible environment.

The integrated transport calculations can be used to assess the potential effects of favorable conditions and potentially adverse conditions resulting from changes in future climatic conditions, erosion, and igneous and tectonic effects, on the transport and retardation of radionuclides from the waste package to the accessible environment. This activity primarily will use the transport codes TRACR3D, WAFE, and possibly HDOC, described in Activity 8.3.1.3.7.1.1. The WAFE code will be used as necessary based on requests by and continued cooperation with Lawrence Livermore National Laboratory. These particular codes will be improved and new models or methods may be developed or employed depending upon the specific problems requiring investigation. Specifically, stochastic methodology may be used to account for random variations in parameters along the transport paths and imperfect knowledge of parameters, and to estimate the most likely transport histories.

 YMP/CM-0011, Rev. 1

8.3.1.3.7.1.3 Activity: Transport models and related support

Objectives

The objective of this activity is to verify the computer codes and to validate the models used in this study and to identify important contributors to the uncertainties in retardation calculations (sensitivity analyses). Because of the special quality assurance requirements placed on the codes and models used to estimate the performance of a repository, it is expected that they will require some degree of verification and validation (Section 8.3.5.20.2). Sensitivity analyses will identify the important contributors to uncertainty in retardation model calculations. Once model sensitivities are identified, unnecessary complexity in the total systems models can be reduced, thereby facilitating the probabilistic simulations of systems performance to be made in fulfilling Issue 1.1. The results of the sensitivity analysis will be used by Activities 8.3.1.3.7.1.1 and 8.3.1.3.7.1.2 and Investigations 8.3.1.3.1 through 8.3.1.3.6.

Computer models are used to investigate the physical and geochemical processes affecting transport and estimate the integrated transport of radionuclides (Activity 8.3.1.3.7.1.2). The geologic system and the transport processes at Yucca Mountain are very complex due to the unsaturated, fractured nature of the porous media. For quality assurance, the models must be verified, validated, and the important contributors to model uncertainty and those parameters for which variation within favorable limits have little or no influence on model results should be identified. While this activity is closely linked to Activities 8.3.1.3.7.2.1 and 8.3.1.3.7.2.2, the results of this activity are critical, and therefore, this activity is recognized as being distinct.

Inherent in this activity and in previous Activities 8.3.1.3.7.1.1 and 8.3.1.3.7.1.2 is the implementation of alternative conceptual models. As appropriate, alternative conceptual models will be considered in order to identify the significant processes in the transport calculation. Alternative numerical methods that increase computational efficiency and numerical stability will also be examined.

Parameters

The data needed are as follows:

1. Computer model results from all models used in the Yucca Mountain Project (hydrologic and transport).

2. Results from Activity 8.3.1.3.7.1.1 and Study 8.3.1.3.1.2.

Description

To comply with the Quality Assurance procedure SOP-03-02 (Software Quality Assurance) the codes being used and generated under this study must be verified and the models validated.

Verification of a code is defined as the assurance that a computer code correctly performs the mathematical operations specified in the numerical

 YMP/CM-0011, Rev. 1

model. One way of verifying a computer code is to compare the numerical results with analytic solutions of the same problem. Documented benchmarking and other documented comparisons with independently derived results are also acceptable forms of verification (SOP-03-02). Validation of a model is defined as the assurance that a model correctly represents the physical processes embodied in it and the software is applicable to the problem. Plans for verification and validation are discussed in Section 8.3.5.20.2.

The sensitivity analysis will identify the important contributors to uncertainty in retardation model calculations among parameters used in constructing the transport models and quantify the influence of these parameters on model results. Parameters for which variation within foreseeable limits has little or no influence on results of calculations will be identified. This analysis will be closely tied to Study 8.3.1.3.7.1.1. For example, if a model is very sensitive to relatively small changes in one specific parameter value, then that parameter must be well-defined with low uncertainties. These two tasks will be iterative.

The following codes will be used

Code	Citation
TRACR3D	Travis, Bryan J., "TRACR3D: A Model of Flow and Transport in Porous/Fractured Media," LA-9667-MS, Los Alamos National Laboratory (May, 1984).
TRANQL	Cederberg, G. A., R. L. Street, and J. O. Leckie, "A Groundwater Mass Transport and Equilibrium Chemistry Model for Multicomponent Systems," Water Resources Research, 21(8), 1095-1104 (1985).
HDOC	Travis, Bryan J., and L. Eric Greenwade, "A One-Dimensional Numerical Model of Two-Phase Flow and Transport in Porous Media using the Dynamics of Contours Methodology," Milestone C717, Los Alamos National Laboratory (October, 1985).
FEHMS	Zyvoloski, G., and S. Kelkar, "FEHMS: A Finite Element Heat-Mass-Stress Code for Coupled Geological Processes," Milestone R346, Los Alamos National Laboratory (March 31, 1987).
COLLOID	Nuttall, H. E., "Population Balance Model for Colloid Transport," Milestone R318, LA-UR-86-1914, Los Alamos National Laboratory (June, 1986). Submitted to Water Resources Research.
WAFE	Travis, Bryan J., "WAFE: A Model for Two-Phase, Multicomponent Mass and Heat Transport in Porous/Fractured Media," LA-10488-MS, Los Alamos National Laboratory (October, 1985).

 YMP/CM-0011, Rev. 1

8.3.1.3.7.2 Study: Demonstration of applicability of laboratory data to repository transport calculations

Objectives

The goal of this study is to outline the strategy that will be used to demonstrate the validity of the laboratory generated geochemical data and the validity of transport calculations using that data. In particular, the data to be validated is from the Geochemistry Program (8.3.1.3) and the transport model is the code TRACR3D (8.3.1.3.7.1). This study will also support the total system performance calculations described in Section 8.3.5.13.

Parameters

The strategy will include modeling and a combination of large-scale laboratory experiments, field studies, consideration of natural analogs, information from processes in the soil zone, and peer review. Examples of activities for each of these factors and its applicability to the goal of this study are briefly described below.

Description

Modeling

The integrated transport calculations being performed in Study 8.3.1.3.7.1 will be used to determine and quantify the cumulative and individual effects of all physical and geochemical processes controlling transport. The major contributing factors to uncertainty in transport calculations and factors to which the transport calculations are the most sensitive will be identified. The results of these calculations, which identify the important parameters, will be used to aid in the planning and interpretation of the larger scale experiments and field tests described below. The tests themselves may then serve to partially validate the transport models.

Large scale laboratory experiments

The use of the data from experiments, such as those described in the following text, to establish the applicability of laboratory data to repository transport calculations will be evaluated in this study.

Experiments at a scale larger than are currently being conducted in 8.3.1.3.6.1 (dynamic transport column experiments) are necessary to investigate scaling phenomenon. Intact tuff blocks may also be removed from areas where other surface based testing may occur, for example, that described in the third activity in this section (field-scale tests). A tuff block (1 m by 1 m) would be removed from the Calico Hills unit. Blocks with discrete fractures would be preferred in order to resolve the question whether the Calico Hills unit would have open or closed fractures. Furthermore, zeolites are abundant in this unit and the unit is considered to be the primary natural barrier to nuclide migration.

The intact tuff blocks would be sent to the geochemical laboratory in Canada supported by the Canadian waste repository program where an existing facility is available to do these larger scale flow and transport experiments

YMP/CM-0011, Rev. 1

on rock blocks. Information would be gained regarding flow paths, scale and effective retardation. This effort to scale up the experiments is an important step to doing field-scale transport experiments.

Field testing

Field testing may be the only way to establish the applicability of laboratory data in system performance transport calculations. Furthermore, validation of unsaturated zone flow and transport models is necessary. There are three activities that make up the overall field test strategy. The first activity is planned intermediate scale flow and transport experiments in caissons at the Los Alamos National Laboratory. The second activity is geochemical field tests to be conducted in a surface facility outside the Yucca Mountain exploratory block. The third activity is aimed at utilization of nuclide migration and transport data from the Nevada Test Site.

Several field-scale studies are already described in Chapter 8. Sections 8.3.1.2.3.1.5 through 8.3.1.2.3.1.8 describe testing of the C-wells with both conservative and reactive tracers. These tests are in the saturated zone and will be used to measure the physical and chemical properties of the geological media in the saturated zone that will affect radionuclide retardation in the Yucca Mountain vicinity. In addition, the results will be used to test numerical codes being used for predicting flow and transport.

A. Intermediate scale tests (caisson tests)

The goal of the caisson test is to provide data that will exercise the physics embodied in three-dimensional models of flow and transport in unsaturated porous media. Modeling of the data by Yucca Mountain Project participants will answer questions concerning validity of unsaturated zone flow and transport models.

A caisson is basically a galvanized highway culvert 3 m in diameter and 6 m deep put on its end on a concrete floor. The caissons are clustered around a central access caisson with six experimental caissons composing a single cluster. These intermediate-scale experiments offer many of the advantages of laboratory scale experiments over field experiments, while allowing for a much larger experimental scale. These advantages are as follows:

1. Known porous materials are used so that heterogeneities can be controlled and material characteristics are more well defined.

2. Instrumentation can be placed in desirable positions at the time of construction.

3. Input and boundary conditions can be more easily controlled.

These factors all help to minimize characterization problems in data analysis. Disadvantages of intermediate-scale experiments include

1. The effects of natural heterogeneities cannot be investigated.

 YMP/CM-0011, Rev. 1

2. The scale of the facility may not be sufficient for scale-dependent processes to be exhibited.

Therefore, while intermediate-scale experiments cannot replace field experiments for model validation because the effects of system heterogeneities and scale-dependent processes must be identified, they serve as a mechanism to move from laboratory-scale to field-scale experiments because scale-up effects can be studied independent of system heterogeneities.

The proposed experiment will be conducted at the intermediate-scale caisson facility located at the Engineering Experimental Test facility as Los Alamos National Laboratory. Six experimental caissons are clustered around a central access caisson at the facility. Access ports are located between the experimental and access caissons that allow instruments such as solution sampling devices, neutron probe access tubes, and tensiometers to be inserted with depth. When filled with a porous medium, the caissons can be used to conduct well-controlled, well-monitored experiments of flow and transport in either saturated or unsaturated porous media.

For the proposed experiment, the caissons will be filled with crushed Bandelier tuff, which has been used as the porous medium in several previous caisson studies and has been extensively characterized mineralogically, chemically, and hydraulically. A flux will be applied over a small area at the top boundary of the caisson so that a three-dimensional flow and transport region will develop. The flux will be applied at a rate that is low enough to avoid saturated conditions but high enough to maintain tensions above a 500-cm level, which is necessary to avoid operational difficulties with tensiometers and solution samplers. Pre-experimental modeling exercises will be used to determine the design flux, the inflow area, and the placement of the monitoring instruments for the experiments.

The study plan to be developed for the caisson tests will include information on previous caisson experiments, the characterization of the Bandelier tuff, experimental constraints (limitations of the experimental apparatus and facilities), and the experimental design and test implementation.

B. Field-scale tests

The purpose of field-scale tests is to study tracer migration in the Calico Hills unit, to determine if fracture flow is possible in the unit, to validate the laboratory generated geochemical data, and to validate transport codes being used to model nuclide migration in the unsaturated tuffs at Yucca Mountain. A field scale test outside the exploratory block at a surface facility, an audit in the Calico Hills unit, is recommended. It is very important to be able to characterize and test this primary barrier at the field scale. The adequacy of unsaturated tuff in Yucca Mountain as a barrier must be sufficiently proven, and as yet, there are relatively few data on this system.

The adit would be designed such that several different field tests could be conducted, such as diffusion tests, in situ single fracture tests, and flow tests in complex fractures (by injection or infiltration). These tests would answer some key questions:

 YMP/CM-0011, Rev. 1

1. In the absence of moving water, what are the rates of diffusion of specific elements into the pore system of the Calico Hills tuff?

2. In fractures containing flowing water, what mechanisms control the movement of specific elements?

3. What is the fracture network in the Calico Hills, and what is the fracture/matrix coupling?

The field test proposal is only in a conceptual phase. The study plan for proposed tests will include the design of the surface facility (adit), the details of each proposed geochemical test, and details of preliminary modeling work.

C. Field studies at the Nevada Test Site

There is a tremendous potential for scientific study of radionuclide migration at the Nevada Test Site. Because of weapons tests, nuclide migration and particulate transport can be studied in a geologic setting that is similar to the repository area. The site represents an opportunity to study migration from tests on a field scale, in situ, that in some instances are 20 yr old. Interaction with the hydrology/radionuclide migration program already established by the Nevada Operations Office of the DOE has been initiated (Blanchard and Elle, 1988). The possibility for utilizing this information source will be investigated, consistent with the limitations imposed by the need to maintain appropriate national security measures.

Natural analogs

A complimentary approach to laboratory testing, field testing and geochemical modeling is the study of natural analogs. Natural analogs provide a tool for evaluating the operation of potentially important geochemical processes over geologic time. These studies have not received major attention in the geochemical site characterization program for Yucca Mountain. The geochemical studies, which are described in Chapter 4, have been concerned largely with developing an understanding of the basic geochemistry of radionuclide transport. However, as these studies progress and the site characterization activities for geochemistry become better understood, detailed models will be developed for the geochemical environment of Yucca Mountain. These models will be based on laboratory and field data, and the extrapolation of these data to the Yucca Mountain site will be through computer modeling as part of the retardation sensitivity task. As these models are refined, it will be possible to identify key elements of the geochemical system that affect strongly site performance and must be understood with a high degree of confidence. Furthermore, it is possible that inferences relative to the sorption behavior of selected radionuclides in the rock-water system at Yucca Mountain can be obtained from analyses of some U-Th decay chain daughters in ground water. This additional natural analog approach will be considered during site characterization and used, if appropriate. The information that will be needed to validate the application of performance modeling can be provided in part through studies of carefully chosen natural analogs.

 YMP/CM-0011, Rev. 1

A primary benefit of natural analog studies that is unique is the time perspective. Field studies of processes of radionuclide migration are time limited and are restricted to small volumes of rock compared with the site. These limitations may restrict the use of highly sorptive tracers; may not adequately represent scaling problems; may not allow complete evaluations of fracture networks and the relative importance of down-gradient, geometric variations in fracture systems; and may not allow adequate extrapolation of results for the required 10,000 yr containment period. Studies of natural analogs provide one means to evaluate the impact of these limitations. Natural analogs can be chosen that provide data concerning the operation of geochemical and geochemical rock systems for periods of tens to hundreds of thousands of years.

There are, however, some limitations to natural analog studies. The most important is past work involving natural analogs was concerned with systems that are no longer active. Complete information may not be available concerning the geochemical environment of the system or the hydrologic system that controlled radionuclide migration. Natural analog systems must be as similar as possible to the hydrological and geochemical environment of the Yucca Mountain site to provide useful information for site characterization and model validation. Studied natural analog systems must be carefully chosen so that useful information can be provided for the Yucca Mountain site or attempts must be made to extract analog information from the Yucca Mountain site. Two possible study directions for natural analogs are proposed. First, analog studies can be restricted to currently active systems where information can be obtained for geochemical and hydrological processes. Second, considerable technical progress is being made in the development of radiometric methods for estimating processes of radionuclide migration. In addition to the more conventional isotope systems (U-Th decay series, T, D, oxygen-18, carbon-14), new progress has been made with other systems such as chlorine-36, iodine-129, and the noble gases. These isotopic systems may allow inferences or bounds to be developed concerning the operation of geochemical and hydrologic processes in the analog environment. Innovative applications of studies of natural isotope systems can be applied to analog environments and to Yucca Mountain itself.

The role of natural analog studies for the characterization of the Yucca Mountain site at this time cannot be described with certainty. However, studies using information from natural analogs will probably be required for several geochemical topics. These include (1) validation of sorption models for individual waste radionuclides, (2) evaluation of the retardation models for elements showing complex and variable geochemical behavior in the natural environment (actinides), (3) validation of transport models involving flow through fracture networks, and (4) validation of SiO_2-kinetics models concerning the stability of secondary alteration minerals in Yucca Mountain (Study 8.3.1.3.3.1).

Soil zone data

There is a large and growing body of literature on the movement of contaminants in the near surface or soil zone and a substantial amount of the literature deals with the unsaturated zone. As a start, a literature search is proposed to determine availability and applicability of this type data. Focus will be placed on the proposed INTRAVAL field tests, particularly those

 YMP/CM-0011, Rev. 1

being conducted by the University of Arizona. Investigative overlap with Yucca Mountain Project studies will be identified. A study plan will be developed based on the evaluation and literature review.

Peer review

An important and critical part of establishing the credibility of the results of this study is peer review. The peer review process will be considered for use during all stages of this investigation, from conceptualization of the experiments to the review of the final results. Peer review can also become technical arbitor where no appropriate combinations of laboratory, field, and literature data can be identified to support the extension of lab data to the field.

8.3.1.3.8 Investigation: Studies to provide the required information on retardation of gaseous radionuclides along flow paths to the accessible environment

Technical basis for obtaining the information

Link to the technical chapters and applicable support documents

The following sections of the site characterization plan data chapters and support documents provide a technical summary of the existing data relevant to this information need:

SCP section	Subject
4.1.3.6.2	Gaseous transport

Parameters

The parameters obtained from other investigations are

1. Identification of the gaseous species.
2. Composition of the unsaturated zone gas phase.
3. Mechanism for gaseous transport.
4. Flow paths available in unsaturated zone.
5. Water chemistry.
6. Physical state of the water in the unsaturated zone.

The parameter obtained from this investigation is gaseous radionuclide transport calculations.

Purpose and objectives of the investigation

The purpose of this investigation is to supply input data for calculations of gaseous radionuclide transport from the repository to the accessible environment at the Yucca Mountain site. These calculations are required to address the overall system performance objective for radionuclide release in

YMP/CM-0011, Rev. 1

10 CFR 60.112, Issues 1.1, 1.2, and 1.3 (Sections 8.3.5.13, 8.3.5.14, and 8.3.5.15), and in making findings on the postclosure system guideline and the technical guidelines for geochemistry in 10 CFR Part 960, Issue 1.9 (Section 8.3.5.18). Specifically, Issue 1.1 requires an estimate of the standard deviation of the residence time in the repository overburden of the C-14 nuclei released at the repository level. The objective of this investigation is to provide the data necessary for developing a chemical model that can be used to calculate this residence time. The residence time can then be used to calculate the rates of transport of gaseous radionuclide species between the repository and the accessible environment, and to verify experimentally the models of gaseous radionuclide transport and retardation that are used to assess radionuclide release.

Technical rationale for the investigation

The location of the repository in the unsaturated zone presents the possibility that radionuclides that can exist as gases can be transported toward the environment through gaseous flow paths in the unsaturated zone. Gaseous transport driven by concentration gradients (diffusion) or by convective flow is possible. Activity 8.3.1.2.2.7.1 (gaseous-phase chemical investigation) is focused on understanding the nature of the gas transport processes within the unsaturated zone. There are several mechanisms, however, that can retard the rate of radionuclide transport in the gas phase. The two most likely to be effective are isotopic exchange between the gas phase and aqueous phase, and the solubility of the gaseous species in the aqueous phase.

The initial approach to studying the retardation of gaseous species along flow paths is to do preliminary calculations of the rates of transport of gaseous radionuclide species considering the various driving forces that may exist and without consideration of possible retardation mechanisms. The mechanisms that can affect transport of gaseous species will be identified and calculated rates of interphase transport between the gas and aqueous phases will be used to evaluate the various retardation mechanisms. This analysis depends on a knowledge of the chemical nature of the gaseous radionuclides (the most important being carbon-14 as carbon dioxide and iodine-131 as iodine gas), the quantity, distribution, and chemistry of water that can contact the gas phase in the unsaturated zone, the nature of the driving force for transport (convection or diffusion), and the nature of the flow paths for gas in the unsaturated zone (porous flow or fracture flow). Information about hydrology (water quantity and distribution), gaseous flow paths, and the importance of connection in the unsaturated zone will be obtained from Investigation 8.3.1.2.2.

A program of experimental measurements of gas transport in unsaturated zone rock may be required to verify the calculational models used for this analysis. A decision to plan and initiate an experimental program will be made based on the results of the analysis described above.

Information from the activities just described will be combined to calculate the rates of gaseous species transport under expected repository conditions in the modeling in Investigation 8.3.1.3.7. From these results the contribution of gaseous releases to the total system releases will be determined.

YMP/CM-0011, Rev. 1

8.3.1.3.8.1 Study: Gaseous radionuclide transport calculations and measurements

The goal of this study is (1) to calculate the rates of transport of gaseous radionuclide species (Activity 8.3.1.3.8.1.1) between the repository and the accessible environment considering the various driving forces and retardation mechanisms that may exist and (2) to experimentally verify potential existing models of gaseous radionuclide transport and retardation that are used to assess radionuclide release to the environment. The need for the second goal will depend on the results of the gaseous radionuclide transport calculation (Activity 8.3.1.3.8.1.1). The results of Activity 8.3.1.3.8.1.1 will be used to plan a series of experimental measurements (Activity 8.3.1.3.8.1.2) of radionuclide transport in unsaturated tuff if the calculations do not provide sufficient assurance of radionuclide containment. If calculated results with their associated uncertainties are adequate to assess the release of gaseous radionuclides for performance assessment calculations, Activity 8.3.1.3.8.1.2 may not be required. The results will be used to determine radionuclide releases to the accessible environment and to evaluate the existence of potentially adverse conditions.

8.3.1.3.8.1.1 Activity: Physical transport mechanisms and rates--retardation mechanisms and transport with retardation

Objectives

The goal of this activity is to determine the manner in which gaseous species are transported in the unsaturated zone and to calculate transport rates without retardation. This activity will then identify the retardation mechanisms that can affect the transport of gaseous species through the unsaturated zone and model these processes so that the effects on transport rates can be evaluated.

Parameters

The data needed are as follows:

1. Gaseous radionuclide species (Issue 1.1).

2. Gas phase composition (Investigation 8.3.1.2.2).

3. Mechanism of gaseous transport (Investigation 8.3.1.2.2 and Information Need 8.3.2.2.6).

4. Flow paths for gaseous transport (Investigation 8.3.1.2.2).

5. Water chemistry (Investigations 8.3.1.3.1 and 8.3.1.2.2).

6. Physical state of the water (Investigation 8.3.1.2.2).

 YMP/CM-0011, Rev. 1

The data gathered are as follows:

1. Rates of gaseous transport without retardation.

2. Identification of retardation mechanisms that affect gaseous transport.

Description

This activity will calculate gaseous species transport in the absence of retardation mechanisms by applying gas transport models for convective flow and diffusion to the physical description of the system. These models will be obtained from the literature if they exist. This activity also will survey the literature on processes such as isotopic exchange and gas solubility to identify those processes that can affect gas transport. Processes that appear effective will be modeled to assess their influence on transport of gaseous radionuclide species in the unsaturated zone. Gas transport rates with retardation will be calculated.

8.3.1.3.8.1.2 Activity: Gas transport measurements

Objectives

The goal of this activity is to measure experimentally gas transport rates under typical unsaturated zone conditions to verify calculational models of gas transport and retardation if they exist.

Parameters

The data needed are as follows:

1. Identity of the gaseous species (Investigation 8.3.1.3.5).

2. Gas phase composition (Investigation 8.3.1.2.2).

3. Gas transport mechanism (Investigations 8.3.1.3.5 and 8.3.1.2.2 and Section 8.3.2.2.6).

4. Water chemistry (Investigation 8.3.1.3.1).

5. Physical state of the water (Investigation 8.3.1.2.2).

The data gathered are as follows:

1. Measurement of gas transport rates.

2. Verification of calculational models of gas transport and retardation.

YMP/CM-0011, Rev. 1

Description

This activity will perform experimental measurements of gaseous transport rates and retardation processes in order to verify calculational models of these processes if they exist. The exact nature of the experimental measurements are not determined at this time. Examples of the kinds of measurements that may be needed are (1) measurements of isotopic exchange rates of carbon between carbon dioxide and aqueous carbonate under flow or diffusion conditions typical of the unsaturated zone or (2) measurements of interphase transport rates of carbon dioxide or iodine between the gas phase and an aqueous phase in pores or fractures.

 YMP/CM-0011, Rev. 1

8.3.1.4 Overview of the rock characteristics program: Description of the present and expected rock characteristics required by performance and design issues

Summary of performance and design requirements for rock characteristics information

Compliance with performance and design criteria for a geologic repository will require information about the rock characteristics of the Yucca Mountain site. This information will be used in the design of underground repository facilities and to support assessments of site performance related to ground-water travel time, waste-package lifetime, radionuclide releases from the engineered-barrier system (EBS), and radionuclide releases to the accessible environment. The various regulatory requirements are concerned with rock characteristics, conditions, and processes in different subsurface regions within and around Yucca Mountain. The rock characteristics are also an important component of model validation, particularly for establishing the boundary and initial conditions and the geometry of the model.

The siting criteria discussed in 10 CFR 60.122 must also be evaluated, including the favorable condition for waste emplacement at a minimum depth of 300 m and characterization of structural, stratigraphic, and geomechanical conditions to determine if potentially adverse conditions are present. Design criteria for the underground facility, seals of shafts and boreholes, and waste packages are also evaluated in the context of the natural rock properties of the site. Assessments of whether the performance objectives, siting criteria, and design criteria can be met will rely on information about the stratigraphy and structure of the Yucca Mountain site, the properties of the rock units occurring at the site, and the temperature and stress conditions before excavation of underground openings.

Approach to satisfy performance and design requirements

The geologic and geophysical site characterization activities described in this section provide an important category of information needed to develop a three-dimensional physical property model, i.e., the geometry associated with the material properties of the rock at the Yucca Mountain site. The objective of the three-dimensional model is to provide a computer-based representation of the physical properties of the rocks at the site. The data base for the model will contain the distribution of parameters (physical properties) within property-dependent units. An important function of the computer-based model will be to provide input for numerical computer analyses that involve hydrologic, thermal, thermomechanical, and geochemical processes.

The three-dimensional physical properties model is a representation of the Yucca Mountain repository site containing various kinds of data on its geologic, geohydrologic, thermal, mechanical, and geochemical properties. The model will allow predictions of how a physical property changes spatially within and across the boundaries of the model. The boundaries represent distinct changes in a property.

 YMP/CM-0011, Rev. 1

The location of the physical property boundaries will be based on three sources of information: (1) geologic studies, (2) geophysical studies, and (3) the physical property data. The physical properties model could be developed based entirely on the samples from site characterization. However, the geologic complexity of the Yucca Mountain site may cause large amounts of uncertainty associated with the variability of the properties between sample locations. Therefore, the physical property data will be correlated with the geologic and geophysical data to reduce the uncertainty between sample locations. The nature and number of site characterization studies to be conducted will be determined by the current understanding of the site and by the level of confidence required for the physical properties and the numerical models in which they are being input.

Figure 8.3.1.4-1 provides the overall logic for developing the three-dimensional physical property model. The geologic, hydrologic, geochemical, and thermal/mechanical properties are the fundamental information to be contained in the model. The geologic framework serves as the geometric framework for the physical property model. The hydrologic, geochemical, and thermal mechanical properties will be developed in Sections 8.3.1.2, 8.3.1.3 and 8.3.1.15 respectively. These separate categories of properties are called on in this section in order to integrate them into the physical properties model. Table 8.3.1.4-1 serves as the first step in the correlation of parameter requests from design or performance issues (e.g., performance or design parameters in sections 8.3.5.12, 8.3.5.13, 8.3.2.2, and 8.3.3) and results from data gathering activities (activity parameters and associated characterization parameters). The parameter categories listed in Table 8.3.1.4-1 are topical categories that are used to translate data requests for types of design and performance information into similar types of site data to be collected. Because of the diversity and volume of data needs called for in the design and performance issues and data provided by characterization activities, it is inappropriate to expect a one-to-one correspondence between a requested performance parameter and an activity parameter. Rather, a given characterization parameter in almost every case will require data reduction and analysis to transform them into the information directly used in design or performance analysis. In order to improve the confidence in the results from a characterization activity, data from related activities will be analyzed for corroboration.

Characterization parameters commonly will take the form of maps and ther two- or three-dimensional illustrations, such as isopach maps, isopleth maps and structure contour maps, or diagrams displaying statistical distributions of activity parameters throughout the site. Many parameters will also include a spatial or unit-specific component such as an isopach map of a specific stratigraphic unit within a specified area. The eventual formulation of an appropriate testing basis for each characterization parameter will include the identification of (1) tentative parameter goals, (2) current estimate of parameter values, (3) current confidence level, and (4) needed confidence level. For example, if an isopach map of the thermomechanical unit TSw2 within the boundary of the repository perimeter drift is identified as a characterization parameter, then the tentative parameter goal may be that contours are accurate to within ±30 m. Current estimates of the

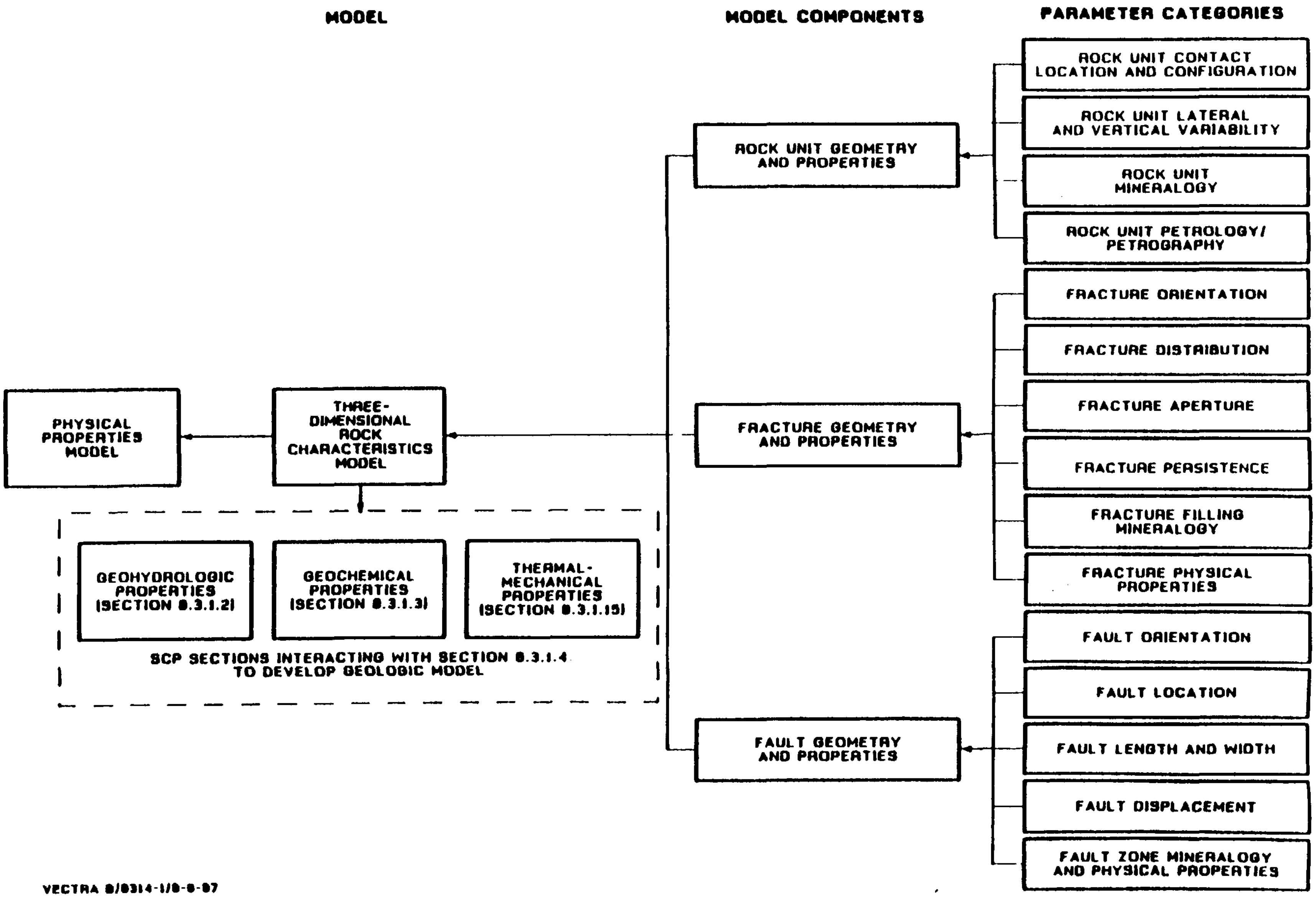

Figure 8.3.1.4-1. Logic diagram for the three-dimensional physical properties model.

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 1 of 12)

Calls by performance and design issues		Parameter category	Response by rock characteristics program	
Issue	SCP section		Activity parameter	SCP activity
			ROCK UNIT GEOMETRY AND PROPERTIES	
1.1	8.3.5.13	Rock-unit contact location and configuration	Attitude, ash-flow zones	8.3.1.4.2.2.1
1.6	8.3.5.12		Attitude, bedded-tuff zones	8.3.1.4.2.2.1
1.11	8.3.2.2		Attitude, lithostratigraphic units	8.3.1.4.2.1.1
1.12	8.3.3.2		Borehole diameter	8.3.1.4.2.1.3
4.4	8.3.2.5		Color, lithostratigraphic units	8.3.1.4.2.1.1
			Contacts, flow units	8.3.1.4.2.1.5
			Contacts, lithostratigraphic units, nature	8.3.1.4.2.1.1
			Correlatable sequences	8.3.1.4.2.1.1
			Depth, lithostratigraphic units	8.3.1.4.2.1.1
			Geophysical signature, lithostratigraphic markers	8.3.1.4.2.1.3
			Key marker beds	8.3.1.4.2.1.1
			Lateral continuity of horizons	8.3.1.4.2.1.2
			Lithology, stratigraphic sequence	8.3.1.4.2.2.4
			Locations, bedded tuff units	8.3.1.4.2.1.1
			Magnetic property changes, core samples	8.3.1.4.2.1.5
			Petrographic changes, core samples	8.3.1.4.2.1.4
			Seismic velocities	8.3.1.4.2.1.3
			Spontaneous potential	8.3.1.4.2.1.3
			Stratigraphic sequence, Topopah Spring welded unit	8.3.1.4.2.2.4
			Stratigraphic sequence, lithostratigraphic units	8.3.1.4.2.1.1
			Thickness, flow units	8.3.1.4.2.1.5
			Thickness, lithostratigraphic units	8.3.1.4.2.1.1

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 2 of 12)

Calls by performance and design issues		Parameter category	Response by rock characteristics program	
Issue	SCP section		Activity parameter	SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Vertical distribution, lithostratigraphic units	8.3.1.4.2.1.2
1.1	8.3.5.13	Rock-unit lateral and vertical variability	Acoustic velocity, core samples	8.3.1.4.2.1.4
1.6	8.3.5.12		Age, potassium-argon, lithostratigraphic units	8.3.1.4.2.1.1
1.11	8.3.2.2			
1.12	8.3.3.2		Areal extent, exposed bedrock	8.3.1.4.2.2.1
4.4	8.3.2.5		Density, bulk, in situ	8.3.1.4.2.1.3
			Density, grain and bulk, core samples	8.3.1.4.2.1.4
			Density, variations	8.3.1.4.2.1.2
			Depositional characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Depositional units, Topopah Spring Member	8.3.1.4.2.1.5
			Electrical conductivity	8.3.1.4.2.1.3
			Electrical resistivity, core samples	8.3.1.4.2.1.4
			Electromagnetic properties, variations	8.3.1.4.2.1.2
			Emplacement history, ash-flow tuffs	8.3.1.4.2.1.1
			Extent, lithostratigraphic units	8.3.1.4.2.1.1
			Gravitational field, variations	8.3.1.4.2.1.2
			Hydraulic conductivity, core samples	8.3.1.4.2.1.4
			Induced polarization, core samples	8.3.1.4.2.1.4
			Laboratory/in situ rock property correlation, surface and subsurface geophysics	8.3.1.4.2.1.4
			Lateral continuity, horizons	8.3.1.4.2.1.2

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 3 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Lateral continuity, repository host horizon	8.3.1.4.2.2.4
			Lateral extent, ash-flow zones	8.3.1.4.2.2.1
			Lateral extent, bedded-tuff zones	8.3.1.4.2.2.1
			Lateral variability, lithostratigraphic units, exploratory shaft facility drifts	8.3.1.4.2.2.4
			Lithic fragments, concentration variations, subunit contacts	8.3.1.4.2.1.5
			Lithic fragments, type and abundance, lithostratigraphic units	8.3.1.4.2.1.1
			Lithic-rich subzones, locations, flow units	8.3.1.4.2.1.5
			Lithologic uniformity, relations to density, seismic velocity, porosity, and resistivity	8.3.1.4.2.1.4
			Lithophysal zone characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Lithophysal zones, geophysical signatures	8.3.1.4.2.1.3
			Magnetic field intensity, total	8.3.1.4.2.1.2
			Magnetic field, variations	8.3.1.4.2.1.2
			Magnetic susceptibility	8.3.1.4.2.1.3, 8.3.1.4.2.1.5
			Porosity, core samples	8.3.1.4.2.1.4
			Porosity, variations	8.3.1.4.2.1.3

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 4 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Pumice characteristics, lithostratigraphic units	8.3.1.4.2.1.1
			Pumice clasts, concentration variations, subunit contacts	8.3.1.4.2.1.5
			Pumice clasts, concentrations, flow units	8.3.1.4.2.1.5
			Rock characteristics, changes, Topopah Spring Member	8.3.1.4.2.1.5
			Seismic velocity, contrasts	8.3.1.4.2.1.2
			Statistical analysis crossplots, geophysical measurements	8.3.1.4.2.1.3
			Thickness, ash-flow zones	8.3.1.4.2.2.1
			Thickness, bedded-tuff zones	8.3.1.4.2.2.1
			Thickness, volcanic section, from electromagnetic surveys	8.3.1.4.2.1.2
			Transport history, ash-flow tuffs	8.3.1.4.2.2.1
			Variability, lateral, lithostratigraphic units	8.3.1.4.2.1.1
1.1 4.4	8.3.5.13 8.3.2.5	Rock-unit mineralogy and petrology	Alteration history, ash-flow tuffs	8.3.1.4.2.2.1
			Alteration, degree and type, lithostratigraphic units	8.3.1.4.2.1.1
			Clay concentrations, from induced polarization data	8.3.1.4.2.1.4
			Compositional changes, anomalous, subunit contacts	8.3.1.4.2.1.5
			Cooling history, ash-flow tuffs	8.3.1.4.2.2.1

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 5 of 12)

Calls by performance and design issues		Parameter category	Response by rock characteristics program	
Issue	SCP section		Activity parameter	SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Curie temperature	8.3.1.4.2.1.5
			Demagnetization, alternating field	8.3.1.4.2.1.5
			Demagnetization, thermal	8.3.1.4.2.1.5
			Depositional breaks, locations, flow units	8.3.1.4.2.1.5
			Essential minerals, abundance	8.3.1.4.2.1.1
			Gamma-radiation intensity temperature, relative	8.3.1.4.2.1.3
			Glassy intervals, lithostratigraphic units	8.3.1.4.2.1.1
			Grain size, bedded-tuff intervals, lithostratigraphic units	8.3.1.4.2.1.1
			Grain size, variations, flow units	8.3.1.4.2.1.5
			Induced polarization	8.3.1.4.2.1.3
			Isotopes, gamma-ray spectrometry	8.3.1.4.2.1.1
			Magnetic minerals, composition	8.3.1.4.2.1.5
			Magnetic minerals, grain size	8.3.1.4.2.1.5
			Magnetic minerals, grain size variation	8.3.1.4.2.1.5
			Magnetic minerals, relative abundance	8.3.1.4.2.1.5
			Magnetization, anhysteritic remanent	8.3.1.4.2.1.5
			Magnetization, isothermal remanent	8.3.1.4.2.1.5
			Magnetization, remanent, orientation and magnitude	8.3.1.4.2.1.5
			Magnetization, saturation	8.3.1.4.2.1.5
			Mineral phases, diagenetic, bedded tuffs	8.3.1.4.2.1.1

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 6 of 12)

Calls by performance and design issues		Parameter category	Response by rock characteristics program	
Issue	SCP section		Activity parameter	SCP activity
		ROCK UNIT GEOMETRY AND PROPERTIES (continued)		
			Mineral phases, diagenetic, bedded tuffs	8.3.1.4.2.1.1
			Mineral phases, distinctive morphologies	8.3.1.4.2.1.1
			Mineralogy, bedded-tuff units	8.3.1.4.2.1.1
			Mineralogy, lithostratigraphic units	8.3.1.4.2.1.1
			Paleomagnetic directions, lithostratigraphic units	8.3.1.4.2.1.5
			Petrography, lithostratigraphic units	8.3.1.4.2.1.1
			Potassium, uranium, thorium content	8.3.1.4.2.1.3
			Primary crystallization, lithostratigraphic units	8.3.1.4.2.1.1
			Smectite-rich intervals, geophysical signatures	8.3.1.4.2.1.3
			Sorting, bedded-tuff units	8.3.1.4.2.1.1
			Sorting, lithostratigraphic units	8.3.1.4.2.1.1
			Spherulitic zones, lithostratigraphic units	8.3.1.4.2.1.1
			Textural variation, across flow-unit boundaries	8.3.1.4.2.1.5
			Texture, lithostratigraphic units	8.3.1.4.2.1.1
			Welding characteristics, anomalous, subunit contacts	8.3.1.4.2.1.5
			Welding, lithostratigraphic units	8.3.1.4.2.1.1
			Zeolite-rich intervals, geophysical signatures	8.3.1.4.2.1.3
			Zeolites, concentrations, from induced polarization	8.3.1.4.2.1.4

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 7 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
			FRACTURE GEOMETRY AND PROPERTIES	
1.1	8.3.5.13	Fracture distribution	Fractal analysis	8.3.1.4.2.2.2
1.6	8.3.5.12		Fracture characteristics, spatial variation	8.3.1.4.2.2.5
1.11	8.3.2.2		Fracture distribution, spatial	8.3.1.4.2.2.2
1.12	8.3.3.2		Fracture frequency, apparent, lateral variability	8.3.1.4.2.2.3
4.4	8.3.2.5		Fracture frequency, variation with depth	8.3.1.4.2.2.3
			Fracture frequency, variation with lithostratigraphic unit	8.3.1.4.2.2.3
			Fracture location	8.3.1.4.2.2.3
			Fracture network geometry	8.3.1.4.2.2.2
			Fracture network, three-dimensional distribution, exploratory shaft facility	8.3.1.4.2.2.4
			Fracture networks	8.3.1.4.2.2.2
			Fracture patterns, local, variations	8.3.1.4.2.2.2
			Fracture, spatial distribution	8.3.1.4.2.2.4
			Fractures, subsurface, near fault zones, lateral variability	8.3.1.4.2.2.3
			Seismic properties, relation to fracture properties	8.3.1.4.2.2.5
			Seismic shear-wave amplitudes	8.3.1.4.2.2.5
			Seismic shear-wave polarizations	8.3.1.4.2.2.5
			Seismic shear-wave travel times	8.3.1.4.2.2.5
			Seismic-wave propagation characteristics	8.3.1.4.2.2.5

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 8 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
1.6 1.11 4.4	8.3.5.12 8.3.2.2 8.3.2.5	Fracture orientation	Fracture attitude, statistical distribution	8.3.1.4.2.2.3
			Fracture attitude, variation with depth	8.3.1.4.2.2.3
			Fracture attitude, variation with lithostratigraphic unit	8.3.1.4.2.2.3
			Fracture orientation	8.3.1.4.2.2.2
			Fracture orientation, statistical distribution	8.3.1.4.2.2.2
			Fracture strike direction, lateral variability	8.3.1.4.2.2.3
1.6 1.11 4.4	8.3.5.12 8.3.2.2 8.3.2.5	Fracture aperture	Fracture aperture	8.3.1.4.2.2.2, 8.3.1.4.2.2.3, 8.3.1.4.2.2.4
1.6 1.11 4.4	8.3.5.12 8.3.2.2 8.3.2.5	Fracture persistence	Fracture connectivity	8.3.1.4.2.2.2
			Fracture dimension	8.3.1.4.2.2.3
			Fracture intersections, distribution	8.3.1.4.2.2.2
			Fracture persistence	8.3.1.4.2.2.2
			Fracture persistence, statistical distribution	8.3.1.4.2.2.4
1.11 4.4	8.3.2.2 8.3.2.5	Fracture-filling mineralogy and physical properties	Fracture mineralization, degree	8.3.1.4.2.2.3
			Fracture roughness	8.3.1.4.2.2.2, 8.3.1.4.2.2.3
			Fracture surface profile	8.3.1.4.2.2.4

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 9 of 12)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by rock characteristics program: Activity parameter	SCP activity
			FRACTURE GEOMETRY AND PROPERTIES (continued)	
			Fracture surface profile	8.3.1.4.2.2.3
			Fracture types	8.3.1.4.2.2.3
			Fracture-filling mineralogy	8.3.1.4.2.2.2, 8.3.1.4.2.2.3, 8.3.1.4.2.2.4
			FAULT GEOMETRY AND PROPERTIES	
1.1	8.3.5.13	Fault location	Fault location	8.3.1.4.2.2.3
1.6	8.3.5.12		Fault trends, from electromagnetic surveys	8.3.1.4.2.1.2
1.11	8.3.2.2		Structural domains	8.3.1.4.2.2.4
4.4	8.3.2.5		Structural rotations, magnitude from paleomagnetic directions	8.3.1.4.2.1.5
			Tectonic style, faults	8.3.1.4.2.2.4
			Tectonic style, faults, Ghost Dance fault	8.3.1.4.2.2.4
1.1	8.3.5.13	Fault orientation	Fault and fault-zone attitude	8.3.1.4.2.2.1
1.6	8.3.5.12		Fault orientation	8.3.1.4.2.2.4
1.11	8.3.2.2		Structural rotations, magnitude from paleomagnetic directions	8.3.1.4.2.1.5
4.4	8.3.2.5			
1.1	8.3.5.13	Fault length and width	Fault and fault-zone length	8.3.1.4.2.2.1
1.6	8.3.5.12		Fault-zone width	8.3.1.4.2.2.1, 8.3.1.4.2.2.3
1.11	8.3.2.2			
4.4	8.3.2.5			

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 10 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		FAULT GEOMETRY AND PROPERTIES (continued)		
1.11 2.3 4.4	8.3.2.2 8.3.5.5 8.3.2.5	Fault displacement	Fault displacement, deep-seated faults, indication from lateral discontinuities	8.3.1.4.2.1.2
			Fault displacement, faults and fault zones	8.3.1.4.2.2.1
			Strike-slip faults, indications from lateral discontinuities	8.3.1.4.2.1.2
			Structural domains	8.3.1.4.2.2.4
			Tectonic styles, faults	8.3.1.4.2.2.4
			Tectonic styles, faults, Ghost Dance fault	8.3.1.4.2.2.4
4.4	8.3.2.5	Fault-zone mineralogy and physical properties	Alteration characteristics, fault zones	8.3.1.4.2.1.2
			Fault and fault-zone characteristics, near-surface faults and zones	8.3.1.4.2.2.1
			Fault physical characteristics	8.3.1.4.2.2.4
		GEOLOGIC FRAMEWORK		
1.1 1.6 1.11 1.12 4.4	8.3.5.13 8.3.5.12 8.3.2.2 8.3.3.2 8.3.2.5	Geologic framework	Correlation diagrams, lithostratigraphic units	8.3.1.4.2.3.1
			Correlation of laboratory values and in situ values for rock properties	8.3.1.4.2.3.1

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 11 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
			GEOLOGIC FRAMEWORK (continued)	
			Cross sections, lithostratigraphic units	8.3.1.4.2.3.1
			Fractures, spatial distribution	8.3.1.4.2.3.1
			Geologic model, three-dimensional	8.3.1.4.2.3.1
			Interpretation of depositional and and diagenetic history of rock units	8.3.1.4.2.3.1
			Interpretation of distribution of lithology, petrology, petrography, and mineralogy of rock units	8.3.1.4.2.3.1
			Isopach maps, lithostratigraphic units	8.3.1.4.2.3.1
			Isopleth maps, rock property values	8.3.1.4.2.3.1
			Relations between geologic and geophysical characteristics of rock units	8.3.1.4.2.3.1
			Rock properties, three-dimensional distribution	8.3.1.4.2.3.1
			Structure contour maps, lithostratigraphic units	8.3.1.4.2.3.1
			Surface geologic maps	8.3.1.4.2.3.1
			GEOLOGIC MODEL	
1.1	8.3.5.13	Geologic model synthesis	Age, fracturing	8.3.1.4.2.2.4
1.6	8.3.5.12		Chronology, faulting	8.3.1.4.2.2.1
1.11	8.3.2.2		Chronology, faulting, relative	8.3.1.4.2.2.3

YMP/CM-0011, Rev. 1

Table 8.3.1.4-1 Activity parameters provided by the rock characteristics program that support performance and design issues (page 12 of 12)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by rock characteristics program: Activity parameter	Response by rock characteristics program: SCP activity
		GEOLOGIC MODEL (continued)		
1.12	8.3.3.2		Faulting chronology	8.3.1.4.2.2.1
4.4	8.3.2.5		Fracture chronology, fracture development	8.3.1.4.2.2.2
			Fracture chronology, relative changes due to tectonism--see tectonism studies	8.3.1.4.2.2.3 8.3.1.8.2
			Fracture chronology, relative changes due to erosion--see erosion studies	8.3.1.6.4.1
			Saturation	8.3.1.4.2.1.3
			Water content	8.3.1.4.2.1.3
			Relationships among hydrologic test results, VSP fracture data and lithologic data	8.3.1.4.2.2.5
			Relationships among geochemical test results, VSP fracture data, and lithologic data	8.3.1.4.2.2.5
			Poisson's ratio	8.3.1.4.2.1.3
			Young's modulus	8.3.1.4.2.1.3
			Relationships among geomechanical test results, VSP fracture data, and lithologic data	8.3.1.4.2.2.5

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

parameter will be obtained from information or references in Chapter 1 of the Site Characterization Plan (SCP). Needed confidence levels will indicate how important this information is to design and performance issues. Current levels of confidence will, in most cases, be low.

The grouping of performance parameters into categories is a necessary first step because individual parameter requests commonly differ with respect to such things as specific spatial locations, stratigraphic units, and associated goals, in some cases for the same parameter type within a given category. Thus, the parameter categories are defined to properly correlate sets of related design or performance parameters with corresponding sets of characterization parameters.

Table 8.3.1.4-1 lists activity parameters associated with each parameter category that incorporates information provided by the rock characteristics program. The following explanation is provided to summarize the types of design and performance parameters encompassed by each category.

The table entries labeled "rock unit geometry and properties," "fracture geometry and properties," "fault geometry and properties," and "geologic framework" each represents a broad group of geologic and geophysical information (Figure 8.3.1.4-1). "Rock unit geometry and properties" is divided into three parameter categories: rock unit contact location and configuration; rock unit lateral and vertical variability; and rock unit mineralogy and petrology. The performance and design parameters associated with "rock unit contact location and configuration" include such items as unit contact attitudes for geohydrologic, geochemical, thermomechanical, and lithologic units; thickness of the Topopah Spring and other rock units; lateral extent of thermomechanical units; attitudes of various units; and depths to various unit contacts. Rock unit lateral and vertical variability includes such performance and design parameters as spatial correlation scales for hydrologic and geochemical properties, and extent and abundance of lithophysal cavities in the Topopah Spring Member. The category "rock unit mineralogy and petrology" combines requests for site information on such parameters as calcite cementation above the repository, radionuclide concentrations, and mineralogy around the waste packages.

The second group of parameter categories, "fracture geometry and properties," addresses information about the fracture network of Yucca Mountain. It includes five parameter categories. The first, "fracture distribution," includes design and performance requests primarily for fracture frequency, spacing, and abundance, as well as for spatial distribution to aid classification of fracture and joint sets. The second category, "fracture orientation," is self explanatory and provides a rare one-to-one match with performance and design requests. The next category in this group, "fracture aperture," includes requests for fracture widths and their local spatial distribution. The category for "fracture persistence" includes requests for persistence, as well as fracture length. The last category in this group, "fracture filling mineralogy and physical properties," includes parameter requests for such items as roughness of fracture walls, distribution and concentrations of fracture fillings in the repository, and fracture weathering information in the Topopah Spring Member.

 YMP/CM-0011, Rev. 1

The next broad group of parameters categories, "fault geometry and properties," deals with the characteristics of faults and fault zones. The first four of these categories are self-explanatory and summarize design and performance requests for information on fault locations, orientations, length and width, and displacement. The fifth and last entry, "fault zone mineralogy and physical properties," has no specific corresponding requests from design and performance issues that are directly addressed by the characterization program for rock characteristics. The hydrological, thermomechanical, and geochemical properties of rock materials within fault zones are requested, but are listed under parameter categories for the type of property (e.g., permeability or retardation coefficient) in the appropriate characterization program (Sections 8.3.1.2, geohydrology program; 8.3.1.3, geochemistry program; and 8.3.1.15, thermal and mechanical properties program). Also, several requests for information relating to faulting potential and to location of faults with such potential are not listed here but are addressed in the sections on postclosure tectonics (Section 8.3.1.8) and in preclosure tectonics (Section 8.3.1.17).

The last general category of parameters, "geologic framework," represents a set of synthesized parameters that will eventually constitute "characterization parameters." The form and content of these parameters are under development but will provide a vehicle for reducing the data represented by "activity parameters" to a proper form for transfer to uses in design and performance analysis.

As previously mentioned, a three-dimensional model could be developed based only on physical property data from core samples. Various interpolation methods can be used to estimate the variation in the value of a property of the rock between the locations of the samples. The use of the rock property data determines the degree to which it is important to know precisely how a particular property varies with the distance from the sample location. For example, if a hydrologic numerical model for calculating ground-water travel time requires a value for the effective permeability, several considerations will determine how well effective permeability must be known. First, the question of what level of uncertainty on travel time is acceptable should be addressed. Second, the sensitivity of the travel-time calculation to the effective permeability must be determined. If the travel time is very sensitive to permeability and the uncertainty associated with the calculation must be small, activities to obtain additional information to better describe the spatial variability of the parameter are justified. The planned geologic and geophysical studies are intended to identify correlations between the properties of interest that can be directly measured and other properties that must be estimated. The results of the geologic studies will therefore be used to calibrate the geophysical data and provide additional sources for correlating parameter information.

Alternative conceptual models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses that are

YMP/CM-0011, Rev. 1

also consistent with available data and that may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) the activities or studies designed to discriminate between alternative hypotheses or to reduce uncertainty. Integration of information from different disciplines increases confidence in the data and is often necessary to comprehensively evaluate alternative hypotheses. The inductive reasoning process based on the results of hypothesis tests will be used to validate models for assessing the long-term performance of the site (Section 8.3.5.20). Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate. Table 8.3.1.4-2 is the hypothesis-testing table for the site rock characteristics program.

To help ensure comprehensiveness of the hypotheses considered in Table 8.3.1.4-2, hypotheses for modeling site rock characteristics have been divided into elements or components that describe the geological domain covered by the model, the stratigraphic geometry that affects the behavior of the model, and the structure elements that affect the model. These elements are listed in column one.

The second column of the table lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Table 8.3.1.4-2 provides a judged level of uncertainty designated high, medium, or low associated with the current representation for each element. A brief rationale for the judgment is also given.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Column six gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of the performance parameters in column five to the selection of hypotheses in columns two and four for that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 1 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Geologic domain	Area encompassing controlled area and defined by major structural boundaries to west, north, and east, and arbitrarily by a few km outside controlled area to south	Low--properties and processes outside model domain unlikely to affect rock properties within controlled area	None	Ground-water travel time (GWTT); radionuclide release to accessible environment, repository design	High	Low--geologic domain encompasses likely extent of controlled area	Low--existing data indicate that geologic domain is not likely to change	Investigation 8.3.1.4.2--geologic framework
	Vertical extent includes entire Tertiary section	Low-medium--properties of rock below Tertiary unlikely to be significant influence on design	Vertical extent includes Tertiary section plus upper part of underlying Paleozoic	GWTT; radionuclide release to accessible environment	High	Low--repository, all facilities and primary barrier (unsaturated zone) are entirely within upper part of Tertiary section	Low--performance or design not likely to be affected by properties below Tertiary section	8.3.1.4.2.1, 8.3.1.4.3.1
Stratigraphic geometry	First-order vertical variability imparted by east-dipping layered volcanic and volcaniclastic sequences	Medium--distinct changes in lithology, including welding of ash flows, correspond to well-defined stratigraphic units, however vertical variation within units are less well defined and may be as important	Laterally anisotropy due to variation in primary crystallization and secondary alteration of individual layers	GWTT; ground quality, thermal/mechanical response, radionuclide releases to accessible environment, depth to lower boundary of primary barrier, geochemical retardation properties of host rock and underlying units	High	High--vertical variability defines GWTT and radionuclide migration	Low-medium--more adequate characterization of unit contacts and vertical variability within units needed	8.3.1.4.2.1, 8.3.1.4.3.1
	Second-order vertical variability in rock properties imparted by	Medium--geometry of mineralogical alteration zones not well known	Mineralogical alteration does not affect rock properties of interest	Same as above	High	High--GWTT and radionuclide migration	High--more adequate characteristics of the upper boundary of	8.3.1.3.2.1, 8.3.1.3.2.2, 8.3.1.3.4.1, 8.3.1.4.2.1, 8.3.1.4.3.1

YMP/CM-0011, Rev. 1

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 2 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Strati- graphic geometry (continued)	mineralogical alteration in distinct quasi-horizontal zones transecting primary unit contacts		Mineralogical alteration is geometrically random and cannot be mapped				mineralogical alteration is very important	
	First-order lateral variability within layered rock units imparted by volcanic and volcaniclastic depositional processes related to distance to source, i.e., properties within units are non-stationary	Medium--site data and numerous analyses strongly indicate lateral change in rock properties and magnitude of changes is related to coefficient of variation and is unknown	No systematic lateral change in rock properties occur in layered volcanic and volcanistic sequences	Same as above	High	Medium--lateral variability has less effect on GWTT and radionuclide migration	High-medium--magnitude of lateral changes need to be better characterized before effect on performance and design can be evaluated	8.3.1.4.1.3, 8.3.1.4.2.1, 8.3.1.4.3.1
	Lateral and vertical variability of rock properties is heterogeneous and geostatistical analysis techniques (variogram, autocorrelation) are adequate for characterizing heterogenity	Medium-high--local small-scale variability may be so great that units may be considered homogeneous, i.e., nugget effect is large relative to variance at sill	Variability of parameters within the units is purely homogeneous Other Markovian processes can be used to characterize heterogeneity such as fractal analysis, Fourier analysis, and others	Same as above	High to medium	Medium--model used significantly affect resulting GWTT and radionuclide migration calculations and design	Low--for performance assessment because modeling scale will be set conservatively equal to or larger than the variogram range Medium--for design since local failures may depend on small-scale variogram structure	8.3.1.4.2.1, 8.3.1.4.3.1, 8.3.1.4.3.2

YMP/CM-0011, Rev. 1

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 3 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Structure	First-order lateral anisotropy imparted to rock mass by tectonic faults and fractures that increase in abundance to south	Low--available data indicate faults and fractures are zonally distributed	Faults and fractures are uniformly distributed in geologic domain	GWTT (depth to water table, gradient fracture permeability), usable area	High	Medium--GWTT in saturated zone may be dependent on fracture distribution	Medium--effects of structural anisotropy on performance needs better understanding	8.3.1.4.1.3, 8.3.1.4.2.1, 8.3.1.4.2.3, 8.3.1.4.3.1, 8.3.1.4.3.2
	Intact blocks are inclined and rectangular in cross-section and are bounded by imbricate normal faults that continue at depth as parallel faults	High--faults are curvlinear in plan; they may curve and flatten with depth	Intact blocks are lensoid in all dimensions due to imbricate normal faults that anasiomose and flatten with depth	Usable area, ground quality, potential for significant displacement, drifts and accesses usable for 100 yr, rockfall	High	High--alternative interpretation of geometry of fault blocks could affect usable area of repository	High--effects of fault geometry on usable area of repository needs evaluation	Same as above
	Fractures along some interconnected pathways are open	Low--drillhole data indicate many fractures are open in upper km	Fractures are essentially closed	GWTT; radionuclide release to accessible environment	High	High--open fractures would significantly effect GWTT, especially in the saturated zone	Medium--saturated-zone GWTT depends on fracture aperture, but is backup barrier, unsaturated-zone GWTT depends on matric potential more than aperture	Same as above
			Fractures apertures correlated with orientation and magnitude of principal stresses	Same as above				
	Vertical and lateral variation in degree of alteration	Medium--preliminary data support current representation	Converse	Same as above	High	High--openess of fractures would significantly affect GWTT and radionuclide migration	Medium--saturated-zone GWTT depends on fracture aperture, but is backup	Same as above

YMP/CM-0011, Rev. 1

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 4 of 5)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
							barrier, unsaturated-zone GWTT depends on matric potential more than aperture	
	Open fractures are coated with secondary minerals	Medium--preliminary data support current representation	Converse	Same as above	Medium	Medium--secondary coating of open fractures not expected to significantly affect GWTT or radionuclide migration	Medium--additional data needed on nature of secondary minerals coating open fractures	8.3.1.3.2.1.3, 8.3.1.4.2.2, 8.3.1.4.2.3, 8.3.1.4.3.1, 8.3.1.4.3.2
	Fracture aperture is very sensitive to small changes in stress and to applied hydraulic loading	Low-medium--variation in tectonic stress not likely in 10,000 years	Fracture aperture is not sensitive to stress changes	Same as above	High	Low--probability of changes in stress and significant hydraulic loading is low	Medium--effect on GWTT not significant for pre-waste emplacement in controlled area, but radionuclide migration of 10,000 yr may be significant	8.3.1.17.4.8

YMP/CM-0011, Rev. 1

Table 8.3.1.4-2. Current representation and alternative hypotheses for models for the rock characterization program (page 5 of 5)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Structure (continued)			Lateral variation in fracture aperture correlated with lateral variation in in situ stress	Same as above	High	Medium--heterogeneity in distribution of aperture could affect GWTT	Medium--additional data needed on possible correlation between aperture and stress	8.3.1.17.4.8
Rock characteristics	The repository block does not contain a large number of faults that will result in localized failures throughout the repository when subjected to expected conditions (i.e., temperature, excavation and thermally induced stress)	Medium--current estimates of the in situ stress state and assumed distribution, orientation, and properties of faults precludes inducing movement along a majority of the faults when excavation and thermally induced stresses are introduced	Converse	Emplacement borehole stability (retrieval, container lifetime), room stability (worker safety), permeability (GWTT, radionuclide migration), seal performance	High	High--GWTT; radionuclide migration	High--alternative hypothesis questions suitability of site	8.3.1.4.2.2, 8.3.1.8.2.1, 8.3.1.8.3.3, 8.3.1.15.2.1, 8.3.1.17.2.1, 8.3.1.17.4.8
	Localized failure along numerous fracture zones when subjected to expected conditions (i.e., temperature, excavation and thermally induced stress	Medium--stable openings indicated by empirical and numerical analysis	Converse	Same as above	High	Same as above	Same as above	8.3.1.4.2.2, 8.3.1.4.2.3, 8.3.1.8.2.1, 8.3.1.8.3.1, 8.3.1.8.3.2, 8.3.1.8.3.3, 8.3.1.17.2.1, 8.3.1.17.4.8

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

The final column identifies the characterization studies or activities that will discriminate among alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

Interrelationships of rock characteristics investigations

This characterization program has been divided into three investigations: (1) development of an integrated drilling program and integration of geophysical activities, Investigation 8.3.1.4.1; (2) geologic framework of the Yucca Mountain site, Investigation 8.3.1.4.2; and (3) development of three dimensional models of rock characteristics at the repository site, Investigation 8.3.1.4.3. Feeding into Investigation 8.3.1.4.3 will be the results of investigations in Section 8.3.1.2 (geohydrology), Section 8.3.1.15 (thermal and mechanical rock properties) and Section 8.3.1.3 (geochemistry).

8.3.1.4.1 Investigation: Development of an integrated drilling program and integration of geophysical activities

This investigation is composed of two planning and evaluation activities. The first activity is designed to provide a mechanism for overall integration of the surface-based activities to be conducted during site characterization. Integration is important to ensure that the data needed to improve site models for use in performance assessment and repository design are obtained in an efficient and cost-effective manner. The second activity is designed to provide a focal point for integration of all geophysical site characterization activities. Because geophysical activities provide data to a number of site programs, as well as to both performance and design issues, it is important that the planned activities are periodically reviewed to determine if the data base being developed is adequate for the range of planned uses.

8.3.1.4.1.1 Activity: Development of an integrated drilling program

Objectives

The objectives of this activity are to

1. Ensure representativeness of data acquired during surface-based site characterization activities and that data represent the range of phenomena and structural characteristics needed for performance assessment.

2. Integrate and prioritize surface-based activities to produce a schedule that best addresses representativeness and efficacy concerns, given budgetary constraints. Monitor conformance with plans, especially with respect to site performance impact (particularly the nature and extent of surface disturbance, fluid use, and penetrations of the unsaturated zone and the repository horizon). Review planned activities with respect to methodology,

YMP/CM-0011, Rev. 1

monitor activities in progress, and provide a means to effect changes if necessary. Address sample and data requirements through linkage and integration with other activities.

3. Maintain a system of technical element baseline approval and control. Such a system is needed to ensure conformance with planning and integration, and to control changes to plans that have the potential to adversely impact site performance; testing interference; or data and samples exchanged between activities.

Parameters

There are no parameters for this activity.

Description

Drilling is an integral part of many of the surface-based investigations planned to obtain information needed for repository design and performance assessment. The specific activities and proposed boreholes are summarized in Section 8.4 and each program investigation. More specific and updated technical data on these activities are provided in the Surface Based Investigation Plan (in draft). Boreholes have been sited to satisfy two different strategies: (1) characterize anomalies and gather data on subsurface conditions to sample known or inferred features of interest and (2) characterize the statistical distribution of needed parameters to obtain samples representative of an entire volume of interest. Consistent with the requirements of 10 CFR 60(c)(4), the location and drilling of the exploratory boreholes are being coordinated with the repository design. More details of this coordination, particularly with regard to the potential impact of site characterization activities on repository performance, are provided in Section 8.4.

To this end, the integration of surface-based borehole siting, sampling, and testing will be optimized by (1) coordinating sampling and testing programs to reduce redundant sampling and testing; (2) minimizing both the potential alteration of ambient surface and subsurface conditions within the repository environment and the creation of possible preferential pathways caused by drilling boreholes that need to be sealed as required by 10 CFR 60.134; (3) ensuring that drilling and sampling methods are well matched to applicable technical, regulatory, and scientific requirements; (4) maximizing cost-effectiveness of drilling program; and (5) maximizing information obtained by increasing both the sampling of the subsurface rock mass and the data obtained from in situ monitoring activities. Each drillhole proposed in various site characterization programs (see Section 8.4 and specific program investigations) represents a source of data intended to answer a particular requirement of design or performance assessment. Where feasible, objectives for separate, currently planned holes may be combined, if appropriate data can be obtained from a single hole. The process of integrating the drilling program as site characterization proceeds may include the addition of new drillholes or deletion of previously scheduled holes as a result of preliminary results of early studies and activities.

YMP/CM-0011, Rev. 1

Planned surface-based field activities have been integrated to a significant degree. Examples of such integration are (1) all planned penetrations of the repository horizon in the immediate vicinity of the site will meet the criteria of the systematic drilling program to reduce the total number of penetrations; (2) the prototype unsaturated-zone drilling activity will support selection of drilling methods for the multipurpose boreholes (MPBH) (presently being reevaluated), the unsaturated-zone boreholes, the systematic drilling program, and the site vertical borehole study; (3) a series of tracer tests in the C-hole complex will determine if existing drillholes across the site will suffice for saturated-zone characterization instead of additional multi-well complexes; and (4) the drilling schedule is based on prioritization of surfaced-based testing activities, which is linked to generally recognized performance assessment requirements.

An initial program of surface-based activities will be evaluated and baselined. Additional detail on the drilling and borehole testing proposed in the SCP is provided in the Surface Based Investigation Plan (SBIP). The effect of this integration activity will be two-fold: (1) the program of activities will be evaluated and modified, as necessary, to ensure that interference between activities and potential effects on site performance will either be eliminated or mitigated to the extent practical and (2) the program will be subject to a technical change-control procedure pertaining to surface-based testing that will ensure that changes to activities will not have an adverse impact on site performance or adjacent activities. Activities in the SCP will be evaluated to identify proposed sampling and to identify any changes needed to the existing drilling program to satisfy sampling requirements that are not attached to specific boreholes.

Revisions resulting from evaluations of representativeness of data, potential test interference, site performance, advanced conceptual design, and license application design impacts will be described in the semiannual progress reports. Likewise, new data, analyses, or topical information will be made available in order to continue the process of integration. This process will develop, using the above information, new priorities and schedules to be used for near-term and long-term field activities planning. The SBIP will be updated at regular intervals to maintain current information on the updated activity plans for drilling and borehole testing.

8.3.1.4.1.2 Activity: Integration of geophysical activities

<u>Objectives</u>

This activity will provide a mechanism for information exchange, an analysis of data and other technical information, and an overview of planned geophysical site characterization activities. The objectives for geophysics integration are to increase (1) the effectiveness of planned geophysical surveys through consideration of past efforts both within and outside the Yucca Mountain Project and (2) the overall effectiveness of geophysical exploration by analysis of how each planned survey addresses specific information requirements for site licensing.

YMP/CM-0011, Rev. 1

Parameters

No activity or characterization parameters are produced by this activity.

Description

Planned geophysical surveys will collect different types of data that will be used to support geologic, hydrologic, and tectonic models of the site. These models serve as the basis for certain performance assessment and design analyses. The models are identified in Sections 8.3.1.2 through 8.3.1.17. Much of the geophysical information obtained will not directly provide parameters for use in probabilistic assessments. Rather, performance assessment and design are supported by the use of such geophysical information to ensure that the range of variability of site characteristics considered in calculations is representative of actual site conditions. Similarly, geophysical applications such as fault detection are a form of nonprobabilistic support for the representativeness of site data.

This integration activity will review and evaluate planned geophysical surveys for (1) consistency with the results from past surveys, (2) direct or supportive uses of the data for licensing, (3) the likelihood that useful data will be generated, (4) the need for the planned effort with respect to alternate methods for obtaining the data, and (5) scheduling with respect to other studies and the overall priorities for site characterization. An ongoing component of this activity involves planning, study plan review, monitoring performance of field activities, review of applicability of various geophysical activities, and development of an overall strategy for application of geophysical methods.

An additional component of this activity will involve detailed review and evaluation of particular applications for geophysical methods, including feasibility studies when appropriate. Methodological information, including results from past geophysical activities at Yucca Mountain, will be reviewed to ensure the effectiveness of planned activities. Existing geologic and hydrologic information, and interpretations from past geophysical activities, will be evaluated to identify specific needs to be addressed. Information needs identified through the performance allocation process for technical areas, such as tectonics, mineral resources, rock characteristics, and hydrology, will be further defined and assessed for common objectives. The following applications of geophysical methods will be reviewed: (1) intermediate depth structural characterization of Yucca Mountain and vicinity (Study 8.3.1.17.4.7), (2) detection and characterization of fractures and the extent of fault zones within the conceptual perimeter drift boundary and immediate vicinity (Study 8.3.1.4.2.2), (3) depth to the water table in the vicinity of the site (Study 8.3.1.2.3.1.2), and (4) detection of potentially economic mineral deposits (Study 8.3.1.9.2.1). As the reviews and evaluations progress, changes in planned activities will be reported in semiannual progress reports.

YMP/CM-0011, Rev. 1

8.3.1.4.2 Investigation: Geologic framework of the Yucca Mountain site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of Chapter 1 of this document summarize available data relevant to the Yucca Mountain stratigraphy and structure, and identify areas of insufficient or inconclusive information:

SCP section	Subject
1.2.2.2	Cenozoic rocks (stratigraphy and lithology at Yucca Mountain)
1.3.2.2.2	Structures and structural history of Yucca Mountain
1.8.1.2	Stratigraphy and lithology
1.8.1.3	Structural geology and tectonics
1.8.2.1	Relation of geology to repository design

Parameters

Table 8.3.1.4-1 summarizes the geologic characteristics that will be measured or calculated as a result of the studies planned for this investigation. The geologic characteristics provided through this program will be used in developing the hydrogeologic stratigraphy in Section 8.3.1.2, and the geochemical stratigraphy in Section 8.3.1.3. The geologic characteristics will also be combined with the data developed in Investigations 8.3.1.15.1 and 8.3.1.15.2 and in Site Programs 8.3.1.2 and 8.3.1.3 to develop three-dimensional models of thermal, mechanical, hydrologic, and geochemical properties in Study 8.3.1.4.3.2.

Purpose and objectives of the investigation

The objectives of this investigation are three-fold and, in general, cover those studies and activities that will allow an understanding of the large-scale variation in stratigraphy and structure in support of design and performance assessment calculations. First, this investigation will provide primary data on the lateral and vertical variations in site stratigraphy through acquisition of borehole cores and cuttings and surface geologic mapping. Second, it will provide information that will allow three-dimensional modeling (through the use of borehole and surface geophysical surveys) of the variation in properties of interest between points of primary data. Lastly, it will provide information on the lateral and vertical variation of structural elements that may affect in situ properties of interest (e.g., fracture-related flow) in conjunction with site characterization investigations on geohydrology, geochemistry, postclosure tectonics, and seismicity (i.e., preclosure tectonics) (Sections 8.3.1.2, 8.3.1.3, 8.3.1.8, and 8.3.1.17).

Technical rationale for the investigation

Development of a comprehensive, three-dimensional description of geologic and geophysical characteristics of the site requires integration of information from subsurface investigations, geologic mapping, surface-based and subsurface geophysical surveys, and geologic studies in the exploratory shaft and underground drifts. This model provides the geologic constraints for developing quantitative three-dimensional models of rock properties in Investigation 8.3.1.4.3. Such a model must be compatible with the stratigraphic, structural, and tectonic setting of the region, and must incorporate genetic models that address depositional, thermal, and alteration histories of local volcanic rock units, part of which are developed under Site Program 8.3.1.8.

On the basis of structural considerations, the areal extent of geologic investigations at Yucca Mountain can be divided into two areas, repository perimeter drift and site, as defined below (Figure 8.3.1.4-2). The perimeter drift defines an area where a significantly lower concentration of faults has been mapped relative to surrounding areas. This area is bounded on the north and northeast by Drill Hole Wash. The Solitario Canyon fault zone marks its western border, and a belt of small-scale structural features north of Abandoned Wash limits its eastern and southeastern extents. The site area boundary is located outward approximately 4 to 12 km from the boundaries of the perimeter drift. The northern, eastern, and southern limits of the region of investigation around the site are selected primarily on the basis of differences in structural styles inferred from existing geologic maps (Scott and Bonk, 1984; Maldonado, 1985). They include Prow Pass (Claim Canyon Caldron), Fortymile Wash, and a northeast-trending lateral fault south of Busted Butte. The western boundary of the study region has been selected at the Windy Wash fault zone on the basis of maintaining a similar amount of lateral distance from the perimeter drift.

The site geologic investigations can be divided into three principal investigations: (1) development of an integrated drilling program (8.3.1.4.1), (2) geologic framework of the Yucca Mountain site (this investigation), and (3) development of three-dimensional models of rock characteristics at the repository site (8.3.1.4.3). The area of investigation will include a larger area than the site as the understanding of the characteristics of each lithostratigraphic unit on a regional scale will allow a higher level of confidence when using deterministic information to interpolate between drillholes, shafts, and surface exposures within the site area. Integration of these investigations requires continual correlation at all levels from data collection to analysis and interpretation. These investigations will provide geologic, geomechanical, geothermal, geohydrologic, and geochemical information for the data base needed by the performance and design issues (Table 8.3.1.4-1).

Geophysical surveys may play a major role in providing information on the gross spatial distribution of bulk properties. They also will be used at particular drillholes to interpolate between depth intervals from which cores or other samples were acquired. Geophysical surveys will be evaluated, and if proven effective, will be used to detect possible rock property contrasts between drillholes. Surveys not proven to be effective will be eliminated from the investigations program. The results of direct in situ measurements

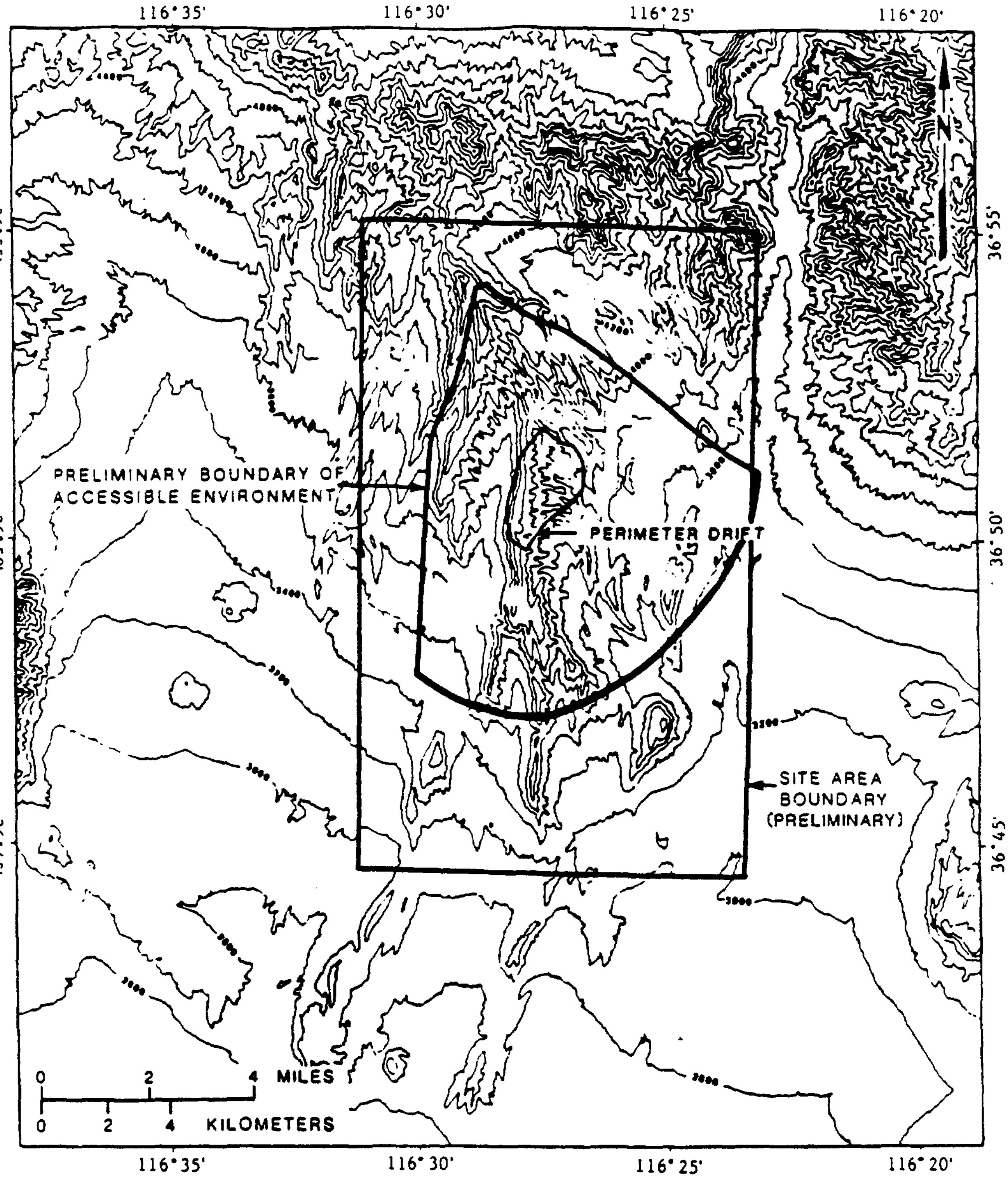

Figure 8.3.1.4-2. Areas of geologic investigation at Yucca Mountain

YMP/CM-0011, Rev. 1

made from drillholes and from the exploratory shaft facility, will be used to analyze data from methods such as seismic or electrical tomography to develop quantitative and empirical relationships needed to characterize subsurface variability between shafts and drillholes. A fundamental element of stratigraphic studies is the development of a data base of rock sample analyses collected from holes drilled for geologic and hydrologic purposes. Continuously cored geologic drillholes will continue to be used to establish the reference stratigraphic framework to currently planned depths of 1,828 m from which comparative studies between geophysical and geologic characteristics can be made. Geophysical relationships that are established in core studies can then be applied to the stratigraphic study of rotary drillholes (where rock samples are limited to drill bit cuttings and sidewall samples) and to the geologic interpretation of data derived from surface-based and subsurface geophysical surveys. With the incorporation of additional stratigraphic data collected from surface field studies, a more complete stratigraphic data base will be used to map the distribution of intrinsic lithologic characteristics within Yucca Mountain. Primary geologic parameters that influence the distribution of rock properties include chemical composition, degree of welding, primary crystallization, and type and degree of alteration. Surface and subsurface mapping of lithologic characteristics within stratigraphic units aids in interpreting the transportation, emplacement, cooling, and alteration histories of major ash-flow tuff sheets. In turn, these interpretations will aid in the prediction of physical properties in parts of the repository block where relatively few subsurface samples will be collected. Stratigraphic investigations are grouped under Study 8.3.1.4.2.1.

Characterization of the structural setting of the site requires detailed study of local fault and fracture systems and their relation to the local and regional stratigraphic, tectonic, and geophysical framework. Recognition of small-scale structures within and near the site area is achieved through detailed mapping of zonal features of exposed ash-flow stuffs and interpretation of detailed surface and subsurface geophysical surveys. An understanding of the fracture network at the site requires the application of innovative approaches because the fracture system (1) is poorly exposed at the surface, (2) is predominantly composed of steeply dipping (high-angle) fractures, (3) includes fractures induced by both tectonic and cooling processes, and (4) includes strata-bound subsystems. Lateral components of the system are studied principally by mapping and analyzing surface exposures. Characterization of the vertical component of the fracture system will largely be achieved through detailed study of the exploratory shaft and drifts, and to a lesser degree, by examination of drillhole walls and core samples. In addition, borehole geophysics, particularly surface-to-borehole seismic profiling, cross-hole seismic surveys, and borehole-to-surface electrical resistivity methods may provide information regarding bulk distribution of fractures. Structural investigations are grouped under Study 8.3.1.4.2.2.

Stratigraphic and structural information will be used in Investigation 8.3.1.4.3, to constrain the interpretation of thermal and mechanical properties (Investigation 8.3.1.15.1), the in situ thermal and stress conditions

 YMP/CM-0011, Rev. 1

(Investigation 8.3.1.15.2), geohydrologic properties (Investigations 8.3.1.2.1 and 8.3.1.2.2), and geochemical properties (Investigation 8.3.1.3.2). The final product (Study 8.3.1.4.3.2) is a three-dimensional model of rock characteristics of Yucca Mountain, which will be used in verifying the design of the underground facility and assessing performance.

8.3.1.4.2.1 Study: Characterization of the vertical and lateral distribution of stratigraphic units within the site area

The objective of this study is to determine the vertical and lateral variability and emplacement history of stratigraphic units and lithostratigraphic subunits within the Yucca Mountain site area.

Geologic mapping, geophysical surveys, borehole evaluations, and geologic sampling, testing, and analysis will be used to gather pertinent geologic data, develop lithologic correlations, and describe the geologic stratigraphy of the site area. Surface-based mapping and borehole activities will be complemented by geologic mapping and testing in the exploratory shaft and drifts (Activity 8.3.1.4.2.2.4).

Activities planned for this study include (1) surface and subsurface stratigraphic studies of the host rock and surrounding units, (2) surface-based geophysical surveys, (3) borehole geophysical surveys, (4) petrophysical properties testing, and (5) correlation of stratigraphy and rock magnetic properties.

8.3.1.4.2.1.1 Activity: Surface and subsurface stratigraphic studies of the host rock and surrounding units

Objectives

The objective of this activity is to determine the spatial distribution, history, and characteristics of stratigraphic units within the Paintbrush Tuff, tuffaceous beds of Calico Hills, Crater Flat Tuff, and possibly older volcanic rocks within the site area.

Parameters

The characterization parameters for this activity are

1. Welding and primary crystallization characteristics of lavas and ash-flow tuffs.

2. Petrographic characteristics.

3. Pumice characteristics.

4. Type and abundance of lithic fragments.

5. Characteristics of lithophysal zones.

6. Degree and type of alteration.

7. Depth, thickness, attitude, and extent of lithostratigraphic units.

8. Location and general characteristics of bedded tuff intervals, including grain size and sorting characteristics, diagenetic mineral phases, and depositional characteristics.

Description

Characterization of the stratigraphic sequence within the site area will use (1) borehole drilling and coring, (2) sampling, lithologic examination, and analysis of drill-bit cuttings and core, (3) borehole video surveys and logging, (4) surface-outcrop mapping; (5) petrographic and geochemical analysis of drillcore, cuttings, and outcrop samples, and (6) surface and borehole geophysical surveys.

Geologic and geophysical data derived from existing holes and additional holes will provide information to aid in the development of three-dimensional rock characteristics models of the proposed repository area.

Pending the integration of the drilling program, three additional continuously cored holes may be drilled (Figure 8.3.1.4-3) in the vicinity of the site to better explain inferred geologic and geophysical anomalies and to help determine the lithologic variability in the Paintbrush Tuff, tuffaceous beds of Calico Hills, and Crater Flat Tuff. One hole (USW G-5) would be located along the northeast flank of Yucca Mountain, to determine if abrupt changes in lithologies of underlying units or changes in structural style within Yucca Wash are factors that influence the steeper gradient in the potentiometric surface north of drillhole USW G-1. Another hole (USW G-6) is planned along the northwest flank of Yucca Mountain in the vicinity of Windy Wash. This hole is expected to provide representative stratigraphic data for this area and allow correlation of thicknesses of key stratigraphic units across the site area. A third hole (USW G-7) may be located about 5 km southwest of Busted Butte in the southern part of Yucca Mountain. Within this area the Paintbrush Tuff is extremely thin and appears to on lap an inferred high point in the preexisting topography. This hole will be used to determine the nature of this feature and its effect on ground-water travel times and potential flow paths in southern Yucca Mountain for saturated zone flow modeling (Section 8.3.1.2.3.3). These holes will allow interpolation of lithologic characteristics between the repository area where more densely spaced holes may be drilled (Investigations 8.3.1.4.1 and 8.3.1.4.3) and the preliminary boundary of the accessible environment.

Studies of the hydrology of the unsaturated and saturated zones include plans for borehole drilling and coring (Section 8.3.1.2). The total suite of holes drilled by the DOE will provide an opportunity to study the lateral variability of the Topopah Spring Member, other members of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, Crater Flat Tuff, and other units, and will provide samples for geologic evaluation.

YMP/CM-0011, Rev. 1

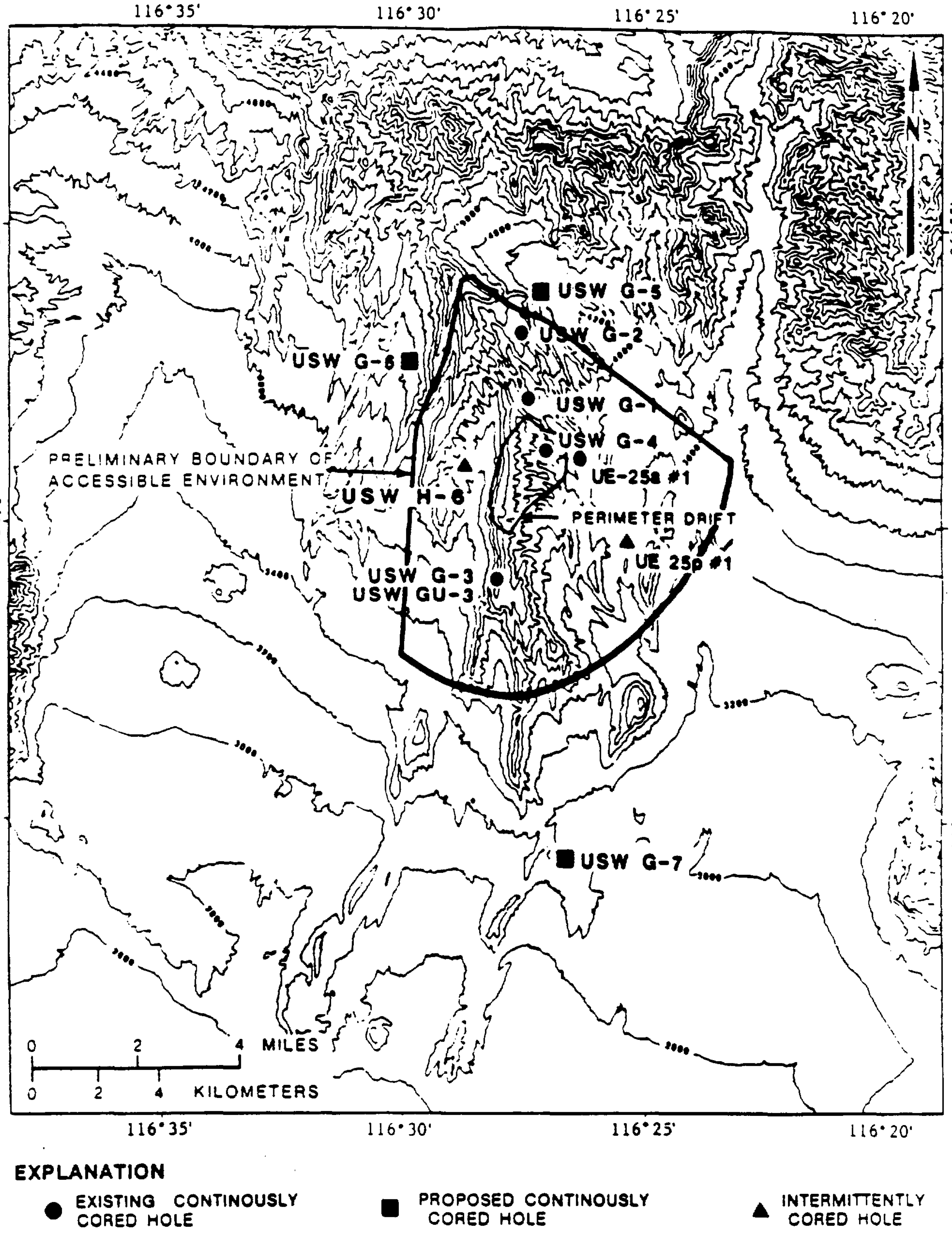

Figure 8.3.1.4-3. Locations of existing and proposed continuously cored holes at Yucca Mountain

YMP/CM-0011, Rev. 1

the lithostratigraphic subunits between the ground surface and the upper part of the tuffaceous beds of the Calico Hills. The distribution of lithophysal zones within the Topopah Spring Member will be mapped in the exploratory shaft facility.

Bedded tuffs that divide major ash-flow tuffs commonly range in thickness from less than 1 m to about 61 m (Table 8.3.1.4-3) and include a variety of lithologies that range from fine-grained tuffaceous sandstone to very coarse ash-fall tuff. Core recovery is typically poor in the unsaturated zone; consequently nearby outcrops will be sampled in the northern part of Yucca Mountain to fill gaps in the data. This study will aid in identifying stratigraphic lateral continuity and inhomogeneities that may act as potential lateral flow paths.

Video camera surveys will be performed in all holes drilled in the vicinity of Yucca Mountain. The textural and tonal contrasts that are seen on camera logs will provide valuable information about key stratigraphic features such as the vertical distribution of lithophysal cavities, thin-reworked and ash-fall tuff intervals, non- to partially welded zones, lithic-rich zones, spherulitic zones, glassy intervals, relative degree of sorting, relative sizes of pumice clasts, and nature of contacts between units. Video-camera observations will be correlated with core, drill bit-cuttings, and geophysical logs to interpret the subsurface characteristics of rock units.

The ability to predict lateral variability of the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff beyond the perimeter drift can be enhanced by conducting a study of outcrops in highlands surrounding the site area. Stratigraphic sections of sufficient thickness will be described and measured principally within the southwest quadrant of the NTS and in Crater Flat. Areas of particular interest will include northern Crater Flat, Calico Hills, Fortymile Canyon, Little Skull Mountain, Skull Mountain, and the northernmost part of Yucca Mountain. Efforts will focus on identifying and correlating lateral variations of subunits of the Topopah Spring Member (Figure 8.3.1.4-4). Additional thickness data also will be collected for the Yucca Mountain and Pah Canyon members, tuffaceous beds of Calico Hills, and Prow Pass and Bullfrog members (Figure 8.3.1.4-5).

Rock samples will be examined megascopically as well as with hand lens and binocular microscope. Samples of particular interest will be selected for further petrographic, mineralogical, and isotopic analyses. Samples also will be selected for detailed petrographic and geochemical analyses (see activities described in the geochemistry program (Section 8.3.1.3)). Megascopic descriptions, coupled with analyses of selected thin sections and grain mounts, will focus on identifying distinctive lithologies, key marker beds, and correlatable sequences. Scanning electron microscopy (SEM) will be used to characterize distinctive morphologies and interpret modes and environments of deposition. X-ray powder diffraction and microprobe analyses on selected samples will be used to identify relative abundance of mineral phases.

On the basis of the mineralogical studies by Los Alamos National Laboratory (Section 8.3.1.3, geochemistry) of core from Yucca Mountain, about 100 intervals (samples) of mordenite-bearing or suspected mordenite-bearing core

YMP/CM-0011, Rev. 1

Table 8.3.1.4-3. Volcanic stratigraphy at Yucca Mountain

Potassium-argon dating method age (million years)	Magnetic polarity[b]	Rock unit[a]	Range in thickness (m)
10.2	ND[c]	Basalt dikes	ND
		* Timber Mountain Tuff	ND
11.3		* Rainier Mesa Member	0-46
		Bedded tuff	0-61
		* Paintbrush Tuff	ND
12.5	R	* Tiva Canyon Member	69-148
		Bedded tuff	1-15
	R	* Yucca Mountain Member	0-29
		Bedded tuff	0-47
	R	* Pah Canyon Member	0-71
		Bedded tuff	0-9
13.1	N	* Topopah Spring Member	287-359
		Bedded tuff	1-17
13.4[d]		Tuffaceous beds of Calico Hills	27-289
		Bedded tuff	0-21
		* Crater Flat Tuff	ND
	N	* Prow Pass Member	80-193
		Bedded tuff	2-10
13.5	N	* Bullfrog Member	68-187
		Bedded tuff	6-22
	R	* Tram Member	190-369
		Bedded tuff	3-50
	N	Dacite lava and flow breccia	0-249
		Bedded tuff	0-14
	I	* Lithic Ridge Tuff	ND
		Bedded tuff	3-7
13.9		Older volcanic rocks and volcanogenic sedimentary rocks	345+

[a]Names and rankings of some units do not conform to U.S. Geological Survey usage. Formally recognized names are preceded by asterisks.

[b]Polarity symbols: R = reversed, N = normal polarity, I = intermediate between reversed and normal.

[c]ND = not determined.

[d]Age determined from associated lava flow.

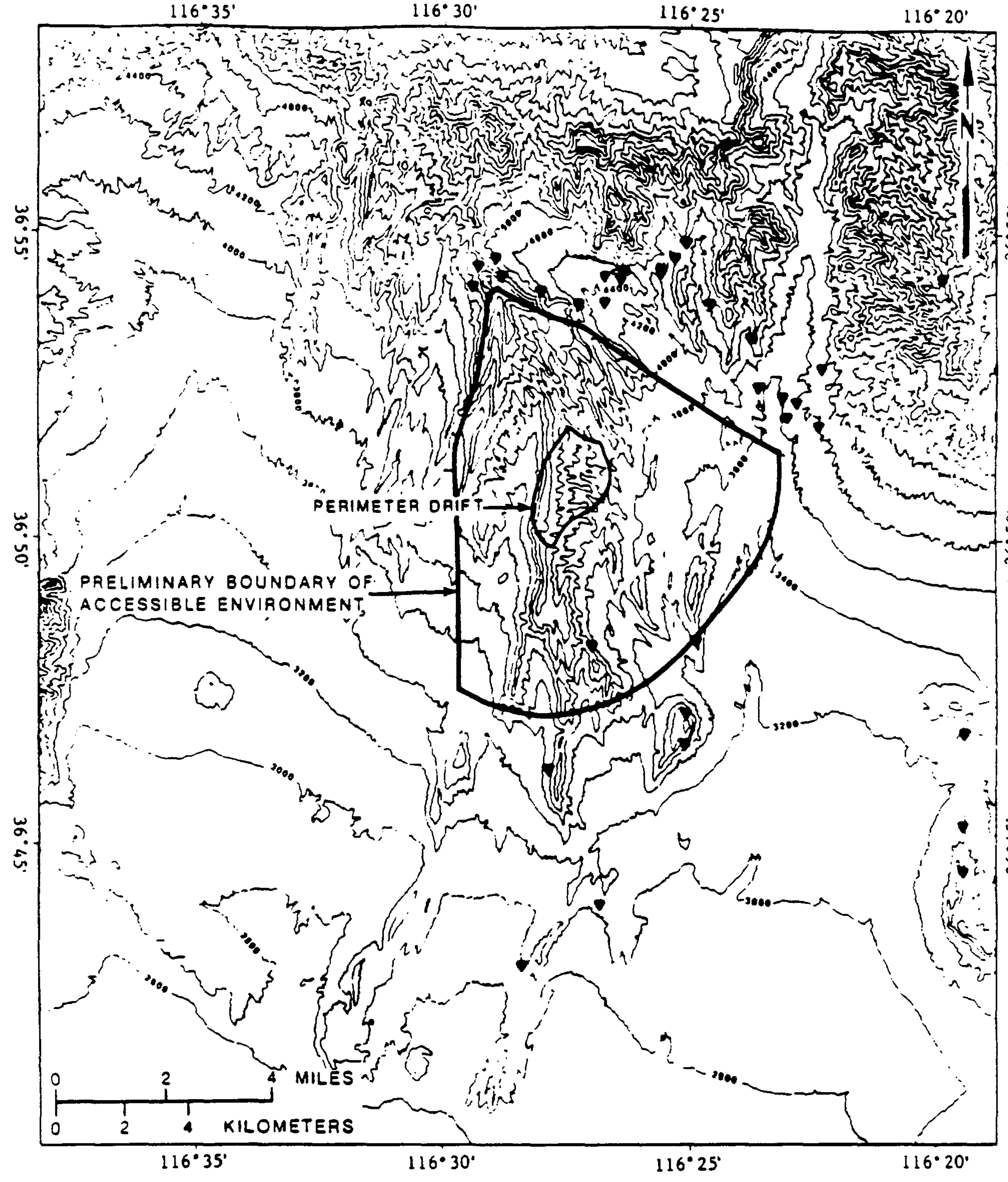

Figure 8.3.1.4-4. Approximate locations of additional surface stratigraphic studies of the Topopah Spring Member of the Paintbrush Tuff

YMP/CM-0011, Rev. 1

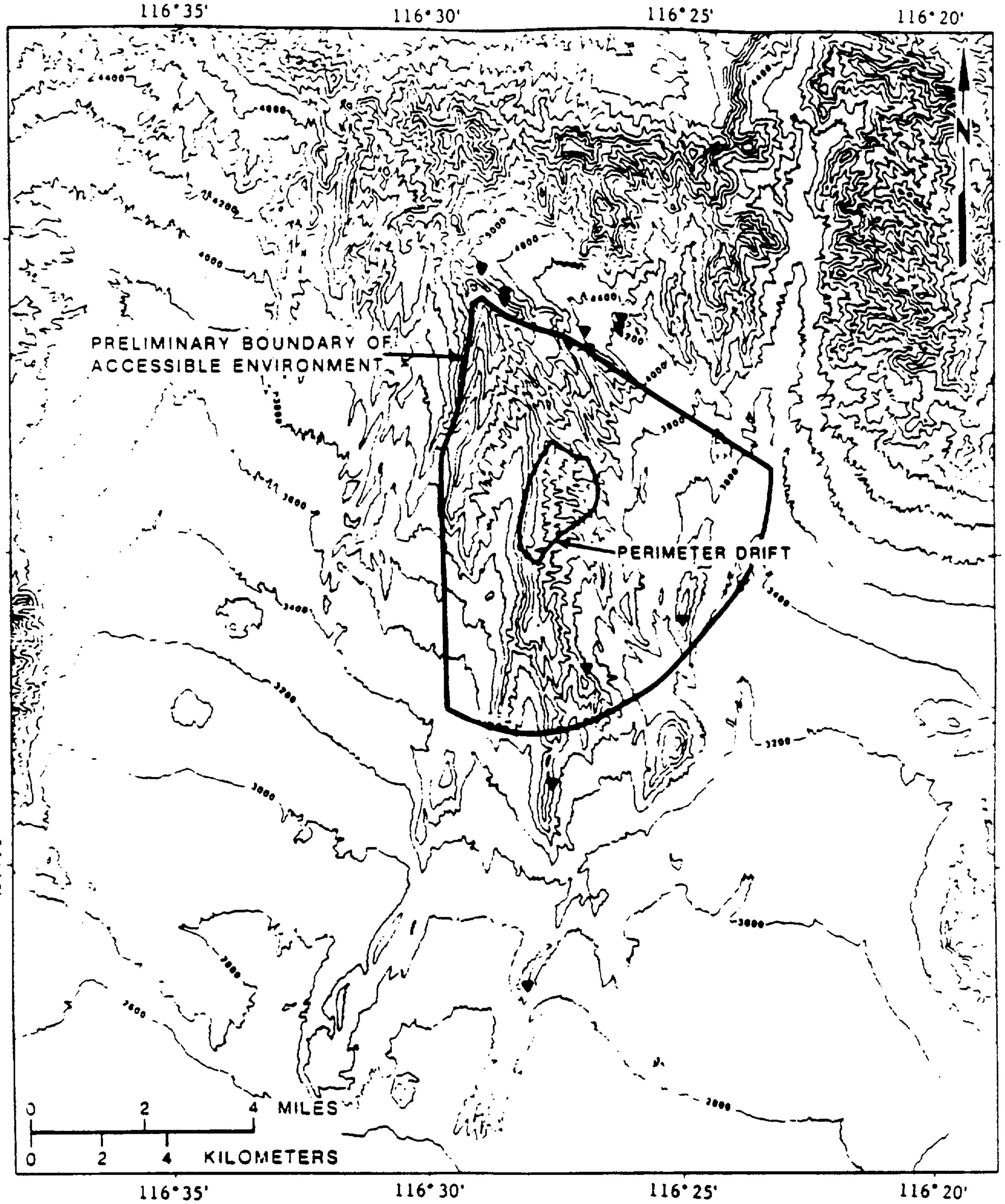

Figure 8.3.1.4-5. Approximate locations of additional surface stratigraphic studies of the Yucca Mountain and Pah Canyons Members of the Paintbrush Tuff, tuffaceous beds of the Calico Hills and Prow Pass and Bullfrog Members of Crater Flat Tuff

YMP/CM-0011, Rev. 1

from drillholes USW G-1, USW G-2, USW G-4, and UE-25b#1h will be selected for additional studies. All samples will be from the Crater Flat Tuff, tuffaceous beds of Calico Hills, and the lower part of the Paintbrush Tuff. The mineralogy of each sample will be determined by X-ray powder diffraction. Results of these determinations will provide the abundance of mordenite (a zeolite) in each sample and will be the basis for further selecting of certain samples for additional investigation by optical microscopy of these sections and grain mounts, SEM, and electron microprobe analysis. Studies by optical microscopy and SEM will provide information on the morphology and zonation of the various zeolite minerals that may act as sorbing agents for radionuclides during the postclosure time frame.

Data obtained from geologic mapping, borehole drilling, coring, video surveys, sampling and petrographic analysis and geophysical studies will be compiled into stratigraphic and lithologic models. This information will be used with geophysical data (Activities 8.3.1.4.2.1.2 and 8.3.1.4.2.1.3) petrophysical data (Activity 8.3.1.4.2.1.4), rock magnetic properties (Activity 8.3.1.4.2.1.5), and data from investigation of tectonics and igneous processes (Site Programs 8.3.1.8 and 8.3.1.17) to formulate the site geologic model in Study 8.3.1.4.2.3. These models will provide the geologic framework for use in the development of models of the vertical and lateral variability of subsurface rock properties.

8.3.1.4.2.1.2 Activity: Surface-based geophysical surveys

Objectives

The objective of this activity is to improve confidence in stratigraphic models of Yucca Mountain by incorporating geophysical constraints.

Parameters

The parameters of this activity are

1. Seismic velocity contrasts, seismic attenuation, seismically reflective horizons, density variation, local variations in magnetic field orientation and strength, and variations in electrical properties which are associated with vertical or lateral changes in lithology.

2. Lateral continuity of horizons defined by geophysical surveys.

Description

Surface-based geophysical surveys will be used to help define the lateral and vertical distribution of the stratigraphic units and lithostratigraphic subunits of the Yucca Mountain tuffs. These tests will be integrated under Activity 8.3.1.4.2.1.6 with surface-based geophysical surveys being performed in other site characterization programs. Table 8.3.1.4-4 summarizes the geophysical techniques that will be used to study the vertical and lateral continuity of rock units. The table provides information on the location and scope of the survey and is divided into two parts. The first part describes geophysical surveys to be used by

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 1 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
			ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2		
Seismology					
Vertical seismic profiling	8.3.1.4.2.2.5	Repository block and vicinity	15 to 25 geotomographic profiles, 0.2 to 2 km in length, cross-hole and surface-down-hole surveys. Directional shear and compression energy sources	Decision to proceed (DTP) after feasibility test DTP after calibration in shaft and drifts	Used to map 3-dimensional network of rock mass fractures. 20-m per pixel geometry.
Intermediate depth seismic refraction	8.3.1.4.2.1.2	E-W line across Yucca Mountain, N of block	Explosive sources; shotholes	None	See Sutton (1985)
Paleomagnetism					
Site	8.3.1.4.2.1.5	Yucca Mountain	Orient drill core as it becomes available. Establish reference orientation through study of outcrop samples. Determine magnetic character of outcrop samples to aid in interpretation of aeromagnetic data	None	See Rosenbaum (1983), Rosenbaum and Rivers (1984), Rosenbaum and Snyder (1985), Rosenbaum (1985)
Borehole geophysical methods					
Geophysical logging					
Borehole gravimetry	8.3.1.4.2.1.3	Yucca Mountain	15 water-table (WT) drillholes, existing deep holes that can be made available, and all new holes that reach the base	None	Already have data in H-1, P 1, C 1, G-3, and G-4. Data will be used to model structure in the immediate vicinity of each borehole, to study

YMP/CM-0011, Rev. 1

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 2 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2 (continued)					
Borehole gravimetry (continued)			of the Topopah Spring Member (Tpt)		lithophysal zones, and to model the Paleozoic surface beneath Yucca Mountain. See Robbins et al. (1982), Healy et al. (1984), and Healey et al. (1986)
Borehole magnetic logs	8.3.1.4.2.1.3	Yucca Mountain	15 WT drillholes, and new drillholes before casing operations	None	Used to determine mappable magnetic events for studying structural integrity of Yucca Mountain, and to supplement paleomagnetic and lithophysal studies. See Hagstrum et al. (1980).
Induced potential logs	8.3.1.4.2.1.3	Yucca Mountain	Test in one or two drillholes	Evaluate for effectiveness after 1 or 2 drillholes	Feasibility study to determine if the method can be used to map zeolitized rock
Commercially available logs	8.3.1.4.2.1.3	Yucca Mountain	All existing unlogged drillholes, all new holes, and relog selected holes	None	To obtain parameters for hydrologic, geologic, and geophysical models, and to determine uniformity and lateral distribution of rock properties within the stratigraphic units. See Spengler et al. (1979), Maldonado et al. (1979), Daniels and Scott (1981), Hagstrum et al. (1980), Daniels et al. (1981), Muller

YMP/CM-0011, Rev. 1

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 3 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
		ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2 (continued)			
Commercially available logs (continued)					(1982), Muller and Kibler (1983 and 1984), Spengler and Chornack (1984), Muller (1985), and Muller and Kibler (1985)
Borehole radar logs	8.3.1.4.2.2.3	Yucca Mountain	Drillholes that penetrate the base of the Topopah Spring Member	Evaluate for effectiveness after 1 or 2 drillholes	Primarily used for fracture detection or to demonstrate the absence of fractures in the unsaturated zone
Acoustic televiewer logs and TV camera logs	8.3.1.4.2.2.3	Yucca Mountain	All Yucca Mountain drillholes	None	For fracture and fault zone detection, and stratigraphic and lithologic correlation. See Healy et al. (1984), Stock et al. (1984), Stock and Healy (1984), Stock et al. (1985)
Large spacing electromagmetic (EM) and resistivity logs	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	To determine accurate large-volume in situ values for studying fracture and lithophysal zones and for interpreting anomalies detected with surface and borehole data
Borehole to surface methods					
Resistivity and EM methods	8.3.1.4.2.1.3, 8.3.1.4.2.2.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole data	For fracture studies in the unsaturated zone, to obtain detailed structure in areas of anomalous surfac

YMP/CM-0011, Rev. 1

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 4 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
ACTIVITIES DESCRIBED IN STUDIES 8.3.1.4.2.1 AND 8.3.1.4.2.2 (continued)					
Resistivity and EM methods (continued)					geophysical data and in critical locations such as the shaft site and surface facilities locations, and to verify projected faults at critical locations. See Daniels and Scott (1981)
High resolution P and S wave seismic	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as previous, and to obtain parameters for designing effective, deeper-penetrating seismic surveys
Surface to hole seismic refraction	8.3.1.4.2.1.3	Yucca Mountain	Selected drillholes	After evaluation of surface and borehole surveys	Same as two previous, and for critical fault location and bed tracing
Borehole to borehole methods	8.3.1.4.2.2.5	Yucca Mountain close-spaced holes for hydrologic testing and for surface facilities studies	Selected drillholes	None	Geotomography to map fractures and demonstrate mappability of features that intersect the drillholes using resistivity, EM, radar, and high resolution P and S seismic (Yo Yo) methods
Petrophysics	8.3.1.4.2.1.4	Yucca Mountain	Selected core from cored drillholes	None	To verify geophysical log accuracy, calibrate computed logs, determine properties that are not or cannot be measured in situ, and to model and interpret surface geophysical studies

YMP/CM-0011, Rev. 1

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 5 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2					
Seismology					
Deep refraction	8.3.1.17.4.3.1	E-W transect, Indian Spring-Stovepipe Wells (Figure 8.3.1.-17-12)	Reversed profiles and cross-profiles, shot-points 8- to 20-km spacing	None	Existing surveys shown in Figure 8.3.1.17-13. See Pankratz (1982), Mooney et al. (1982), Hoffman and Mooney (1983), Hoover et al. (1982), Monfort and Evans (1982), and Sutton (1984)
Shallow (Bison) refraction and shear wave refraction and reflection	8.3.1.17.4.4.1 and others	Quaternary faults, Yucca Mountain and vicinity	250-500 m traverses, portable instruments, sledgehammer energy source. Shear wave method uses 12 (or more) geophones, 3-m spacing	Number and location to be decided on the basis of geologic mapping	Maximum depth of penetration 100 m. Used to detect offset in surficial deposits. Shear wave method capable of detecting 30 cm offset
Evaluation of proposed deep reflection survey	8.3.1.17.4.3.1	Proposed survey 15km test located to the south of Amargosa Valley or southwest of Beatty	To be determined	DTP after evaluation of preliminary tests (15 km recon. line) and peer review	COCORP survey extending northward into southern Death Valley produced marginal quality data, although data in the upper one second are locally good. Five- and ten-second reflections were imaged with fair continuity. See de Voogd et al. (1986).

YMP/CM-0011, Rev. 1

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 6 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)					
Intermediate reflection and intermediate refraction	8.3.1.17.4.7.1	Controlled area, Yucca Mountain	Evaluate previous results, assess potential for application of this method to Yucca Mountain, plan new application if appropriate	None	This is a planning activity only. Previous reflection survey using Vibroseis at Yucca Mountain failed (McGovern, 1983). More recent surveys using air gun at Mid Valley produced useful results (McArthur and Burkhard, 1986). See also Hoover et al. (1982).
Shallow (Mini-sosie) reflection	8.3.1.17.4.7.8 and others	Crater Flat, Jackass Flats (Figure 8.3.1.17-8)	7 to 1 profiles, 1 to 5 km in length, hand carried instruments. Energy from battery of hand-operated tampers	DTP after evaluation of two preliminary profiles selected from profiles indicated in Figure 8.3.1.4-8	Maximum depth of penetration 1 km. Used to map shallow structural and stratigraphic features. Additional Mini-sosie surveys at Yucca Mountain are planned in Activity 8.3.1.4.2.1.1
<u>Gravity investigations</u>					
Regional maps	8.3.1.17.4.12.1	Yucca Mountain and vicinity	Beatty 1:100,000 quad, Pahute Mesa 1:100,000 quad, NTS 1:100,000 map area, Yucca Mountain, 1:48,000 map area	None	Field work complete, compilation complete, final results not yet available. See Snyder and Oliver (1981), Ponce (1981), Ponce and Oliver (1981), Hoover et al. (1982), Ponce and Hanna (1982), Jasma et al. (1982), Ponce (1984), and Snyder and Carr (1984).

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 7 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)					
Site area map	8.3.1.17.4.7.2	Yucca Mountain	1:24,000 map of site and vicinity, 200 ft spacing of stations along E-W lines spaced 500 ft apart (where topography permits)	None	Will require as many as 7,500 additional stations. Useful for establishing strati-graphic variability of repository host rock and fault location and offset. See Snyder (1981), Snyder and Carr (1982), Jansma et al. (1982), Kane et al. (1981), Ponce et al. (1985)
Detailed surveys, deep reflection profiles and shallow reflec-tion profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Moun-tain, Indian Springs. Pre-cise location to be deter-mined.	Gravity determinations along profiles at 500 ft (150 m) spacing	DTP only if seis-mic surveys run	Assists interpretation of seismic results
Magnetic methods					
Regional aero-magnetic maps	8.3.1.17.4.12.1	Yucca Mountain and vicinity	Beatty, Pahute Mesa, Indian Springs, and Pahranagat 1:100,000 quadrangles to be compiled from exis-ting surveys	None	Field investigations com-plete; compilation 80% (?) complete. See Kane et al. (1981), Hoover et al. (1982), Kane and Bracken (1983), U.S. Geological Survey (1984), Ponce (1984)
Site aeromag-netic maps	8.3.1.17.4.7.3	Yucca Mountain	1:12,000 scale map of site and vicinity, continuous aeromag-netic survey along	None	1:62,500 scale map com-plete (U.S. Geological Survey, 1984). See also Jansma et al. (1982),

YMP/CM-0011, Rev. 1

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 8 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)					
Site aeromagnetic maps (continued)			E-W flight lines spaced 1/16 mile (0.1 km)		Bath et al. (1982), Kane et al. (1982), Kane and Bracken (1983), and Bath and Jahren (1984)
Ground magnetic survey, deep reflection profiles and shallow reflection profiles	8.3.1.17.4.3.1	Stovepipe Wells, Yucca Mountain, Indian Springs. Precise location to be determined.	Magnetic determinations along profiles at 10 to 20 ft (3 to 6 m) spacing where accessible by truck, 50 to 100 ft (15 to 30 m) spacing elsewhere	DTP only if seismic surveys run	Assists interpretation of seismic results
Site ground magnetic surveys	8.3.1.17.4.7.4	Yucca Mountain (Figure 8.3.1.4-9)	Ground magnetic surveys at (1) known and inferred structures, (2) vicinity of drillholes, (3) vicinity of shaft and surface facilities, (4) anomalies detected. Surveys to be semicontinuous: 10 to 20 ft (3 to 6 m) spacing	Number and location to be determined through evaluation of geologic and geophysical mapping	Primary purpose is to locate concealed extensions of faults. See Bath and Jahren (1984), Scott et al. (1984), and Bath and Jahren (1985)
Curie isotherm	8.3.1.8.5.2.1	Yucca Mountain region	Analysis of existing regional aeromagnetic data	None	Purpose is to map configuration of Curie isothermal surface, and to compare areas of shallow isotherms with areas of high heat flow and recent volcanism. See Connard et al. (1983).

YMP/CM-0011, Rev. 1

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 9 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)					
Electrical methods					
Regional magnetotelluric (MT)	8.3.1.17.4.3.1	Yucca Mountain, Crater Flat, Jackass Flats, Amargosa Desert, Death Valley (Figure 8.3.1.17-12)	Detailed survey with stations at 3 to 5 km spacing of Yucca Mountain, Crater Flat, and northern Amargosa Desert. Reconnaissance survey with stations at 10 km spacing in remainder of area	None	Previous survey by Furgerson (1982) shows mappable conductivity contrasts in 1 to 15 km depth range. See also Kauahikaua (1981), and Hoover et al. (1982)
Surface geoelectric investigations (airborne EM, slingram, VLF, dc resistivity, EM soundings, tensor audio magnetotelluric and telluric profiling filing)	8.3.1.17.4.7.5	Yucca Mountain	Assess potential for application of these methods, evaluate previous results, plan new applications if appropriate, conduct prototype tests	DTP with full-scale application of selected methods only if warranted by results of prototype testing	Applied to structural and stratigraphic problems at the site by Flanigan (1981), Smith and Ross (1982), Fitterman (1982), Hoover et al. (1982), Senterfit et al. (1982), Scott et al. (1984), Frischkenecht and Raab (1984). Other studies in region include Zablocki (1979), Anderson (1982), Smith et al. (1981), Greenhaus and Zablocki (1982).
Radiometric and remote sensing methods					
Surface and airborne gamma ray investigations	8.3.1.17.4.7.6	Yucca Mountain	Assess potential for application of these methods with preliminary survey over known faults using ·ic ground measure-	DTP with full-scale application of airborne methods only if warranted by results of preliminary survey	Could detect percolation of radon through fault zones (gamma emitting daughter bismuth-214)

YMP/CM-0011, Rev. 1

Table 8.3.1.4-4. Summary of geophysical studies for Site Program 8.3.1.4 (rock characteristics) (page 10 of 10)

Method	SCP section	Location	Scope	Decision points	Comments
			SUMMARY OF GEOPHYSICAL STUDIES FROM OTHER INVESTIGATIONS CONTRIBUTING TO SITE GEOLOGY STUDIES 8.3.1.4.1.2 AND 8.3.1.4.2.2 (continued)		
Thermal infrared investigations	8.3.1.17.4.7.7	Yucca Mountain	Assess potential for application of aircraft and satellite thermal infrared imagery in mapping of fracture network	DTP based on evaluation of cost and expected results	Method depends on detection of surface temperature variation, which are largely dependent on soil moisture content, which in turn is in part related to infiltration along fractures.
Thematic Mapper Satellite Imagery	8.3.1.17.4.3.5	Yucca Mountain and vicinity	Tapes of the four Thematic Mapper V scenes encompassing the Yucca Mountain Region (Beatty, Indian Springs, Pahute Mesa, and Pahranagat 1:100,000 quads) to be used to produce spectral and spectral ratio maps, from which areas containing distinctive patterns of lineations will be delineated.	None	Used to define structural domains, areas of well-developed desert varnish, and areas of hydrothermal alteration.
<u>Paleomagnetism</u>					
Region	8.3.1.17.4.3.2	Little Skull Mountain, Crater Flat, Skull Mountain, southern Yucca Mountain, eastern Yucca Flat.	10 to 20 sites at Little Skull Mountain will be sampled. If useful results are obtained, other sites as listed may be sampled.	DTP only if useful results obtained at Little Skull Mountain, and if suitable strata are present.	Preliminary results at Yucca Mountain indicate 30 degrees rotation (Scott and Rosenbaum, 1986)

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

Characterization Program 8.3.1.4, and the second part identifies geophysical surveys that are used primarily for Characterization Program 8.3.1.17 (preclosure tectonics) and Characterization Program 8.3.1.8 (postclosure tectonics) but will be used to develop the geologic model. Geophysical surveys will also aid in determining favorable sites for drillholes. These detailed geophysical surveys will include (1) seismic refraction, (2) seismic reflection, (3) gravity and magnetics, and (4) electromagnetic soundings.

A seismic refraction profile will be acquired in the Yucca Wash area (Figure 8.3.1.4-6). This profile will be used to investigate significant velocity contrasts in the volcanic section that are associated with abrupt lateral changes in lithology, and that may be the result of structural displacement or alteration associated with a steep gradient in the potentiometric surface north of drillhole USW G-1 and in the vicinity of proposed corehole USW G-5.

After proof-of-technique trials, as many as 15 seismic reflection profiles may be performed using a shallow penetrating, high-resolution method called Mini-sosie (Barbier, 1983). This technique will be used to study the position of marker-horizons that have a sufficient contrast in seismic velocity and is expected to be useful to a maximum depth of about 1,000 m. Of specific interest are possible marker horizons that may be buried beneath Yucca Wash and Midway Valley (Figure 8.3.1.4-7). Information collected will also be used to trace individual faults by studying the lateral continuity of reflecting horizons. This technique differs from previous reflection studies because it is designed to penetrate only the upper geologic section.

Two detailed ground magnetic and gravity surveys will be performed across Yucca Wash (near USW G-5) and south of Busted Butte (near USW G-7) (Figure 8.3.1.4-8) in association with proposed geologic coreholes USW G-5, USW G-6, and USW G-7. In situ magnetic and density variations will be used to map the local vertical and lateral distribution of lithostratigraphic units.

A number of geophysical surveys that will be performed for tectonics Investigation 8.3.1.17.4 will also provide information for evaluation of stratigraphy and structure. These surveys and methods are indicated in the second part of Table 8.3.1.4-4. Many of these methods have not been tried at the Yucca Mountain site and will be tested before application for data collection purposes.

Shallow seismic refraction and shear wave refraction and reflection, will be used for investigation of faults in the vicinity of Yucca Mountain, using sledgehammer and shear wave sources. The number and location of the traverses will be based on the results of detailed geologic mapping. These surveys are more completely described in Activities 8.3.1.17.4.4.1 and 8.3.1.17.4.4.4. In addition, a program of intermediate seismic reflection in the vicinity of Yucca Mountain is planned in Activity 8.3.1.17.4.7.1, using such sources as vibrators, explosives, and air guns. The locations of these seismic lines will be determined after further acquisition and analysis of tectonic data using criteria that will include obtaining the requisite stratigraphic information needed to input to the geologic model of the site.

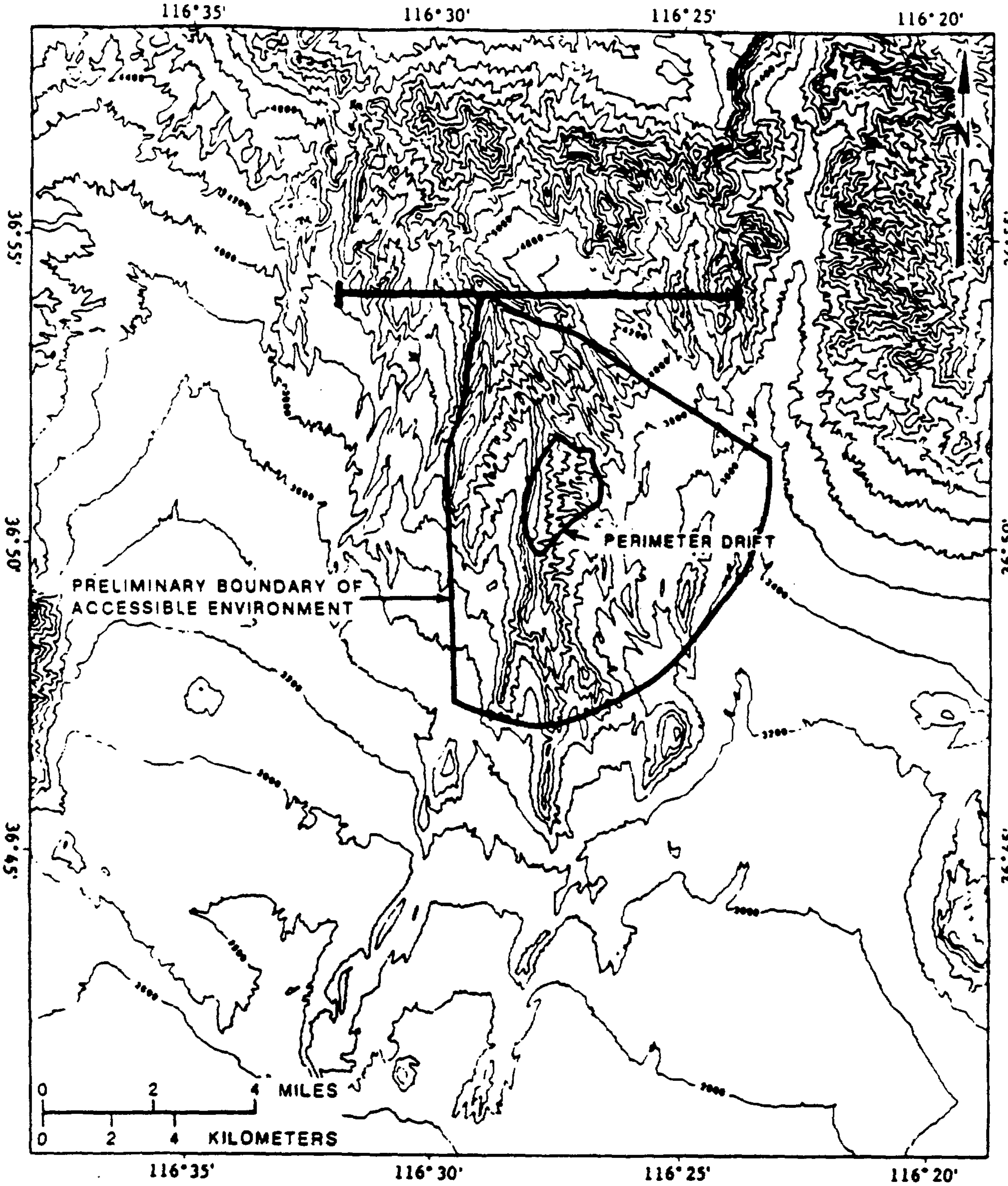

Figure 8.3.1.4-6. Approximate location of proposed seismic refraction survey across Yucca Wash

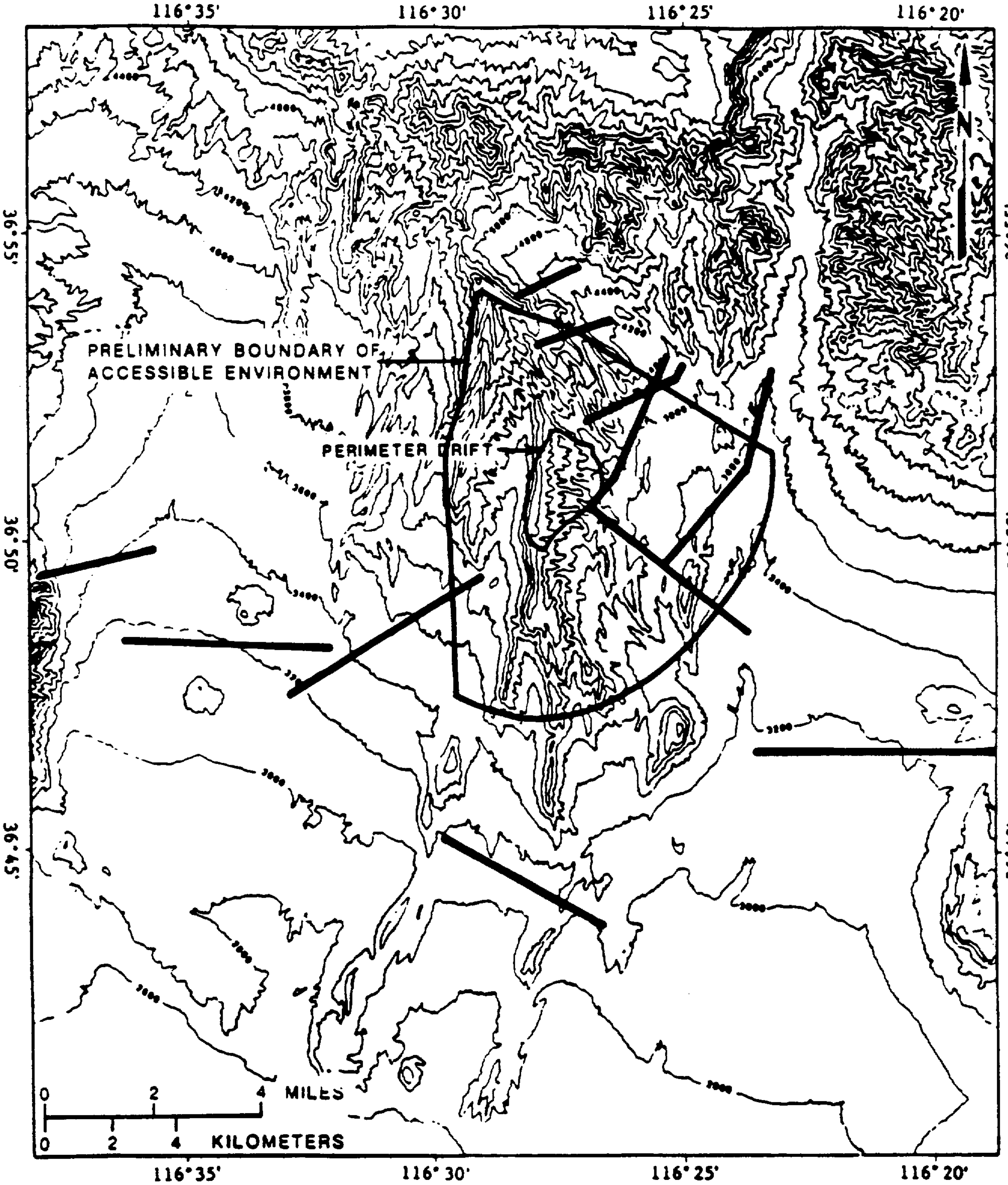

Figure 8.3.1.4-7. Approximate location of proposed seismic reflection surveys at Yucca Mountain.

YMP/CM-0011, Rev. 1

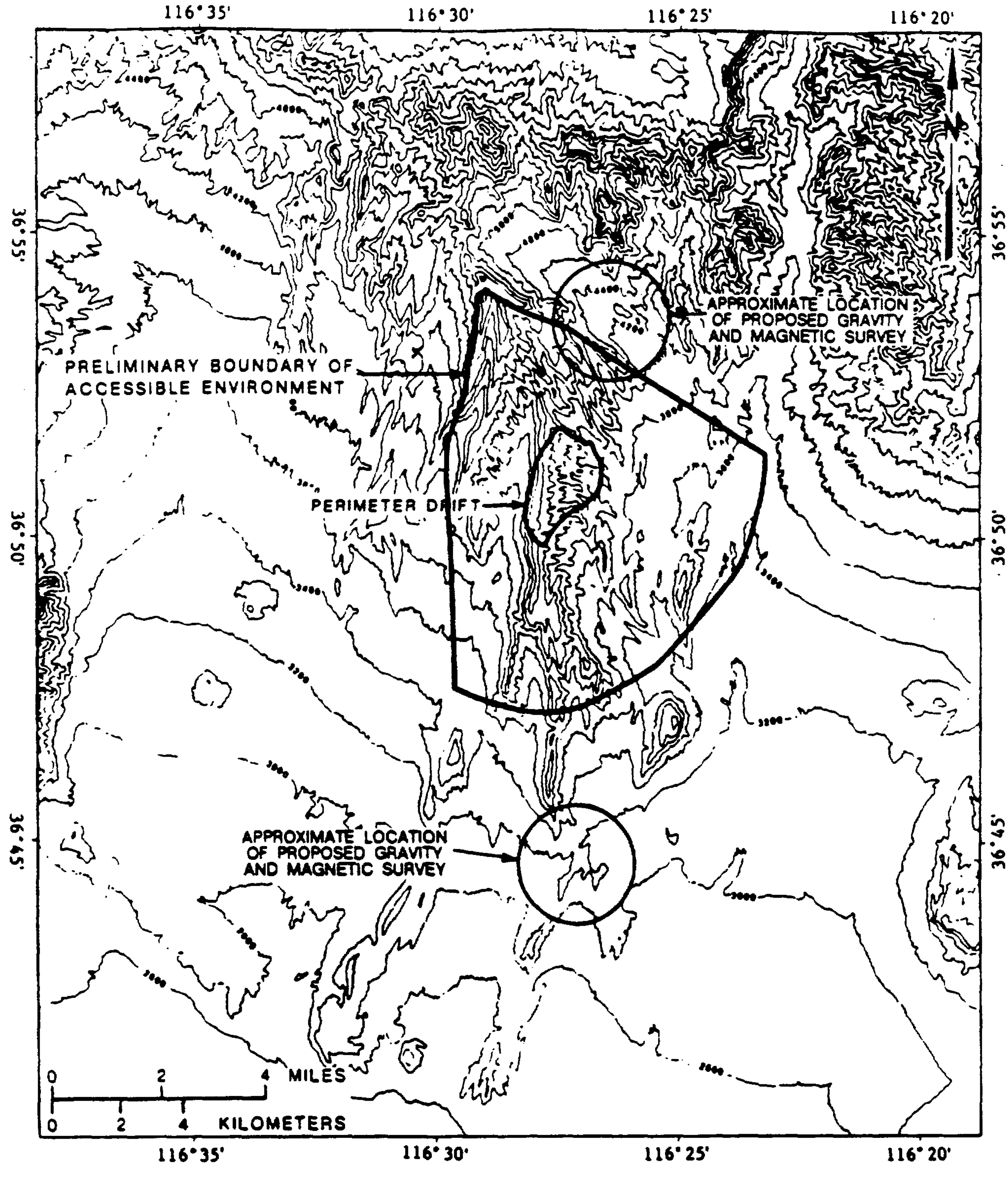

Figure 8.3.1.4-8. Approximate locations of proposed gravity and magnetic surveys near proposed coreholes

YMP/CM-0011, Rev. 1

Gravity and magnetic data will be acquired at 500-ft intervals along the same surface profiles as the intermediate seismic data and shallow seismic surveys. In addition, a site gravity map at a scale of 1:24,000 is proposed (Activity 8.3.1.17.4.7.2), for which as many as 7,500 gravity stations would be required. The stations would be located at 200-ft intervals along lines spaced about 500 ft apart. An aeromagnetic survey is proposed which would produce a higher resolution map (1:24,000 scale) than previous surveys (Bath et al., 1982; Jansma et al., 1982; Kane and Bracken, 1983; Bath and Jahren, 1984), but over a smaller region. Additional gravity and ground magnetic surveys may be performed to investigate aeromagnetic anomalies, the location of proposed shafts and repository surface facilities.

Various electrical methods including airborne electromagnetic (EM) surveys, EM soundings, tensor audio magnetotellurics, telluric profiling, and direct current resistivity will be evaluated for application to tectonic, structural, and stratigraphic problems in Activity 8.3.1.17.4.7.5. In addition, radiometric (airborne gamma intensity) and remote sensing methods (thermal infrared scanner and Thematic Mapper V) will be evaluated in Activities 8.3.1.17.4.7.7 and 8.3.1.17.4.3.5 for application to detection of faults and fractures at the surface. Radiometric or surface temperature anomalies may be associated with radon emanation or water infiltration, respectively, along faults or fractures. Application of these electrical and remote sensing methods for site characterization will depend on the outcome of feasibility tests.

Electromagnetic surveys will be performed to investigate the thickness of the volcanic section and fault trends in Yucca Wash (near USW G-5). Alteration zones associated with fault zones will be evaluated and may provide evidence of hydraulic connectivity of the inferred fault system.

8.3.1.4.2.1.3 Activity: Borehole geophysical surveys

Objectives

The objectives for this activity are (1) to aid in the definition and refinement of the location and character of lithostratigraphic units and contacts between units and (2) to determine the distribution of rock properties within lithostratigraphic units.

Parameters

The parameters for this activity are the direct measurements and quantities derived from geophysical logs, statistical analysis, cross plots, and correlation with core data, including the borehole diameter, in situ bulk density, electrical conductivity, resistivity, spontaneous potential, gamma radiation intensity, temperature, induced polarization, porosity, saturation, potassium-uranium-thorium (K-U-Th) content, water content, seismic velocities, deformation moduli, magnetic susceptibility, and total magnetic field intensity.

YMP/CM-0011, Rev. 1

Description

A suite of commercially available geophysical logs will be obtained in future holes drilled in the vicinity of Yucca Mountain. Additional experimental geophysical logs also will be obtained in selected boreholes. Geophysical log data will be correlated with measurements of properties such as porosity, saturation, water content, seismic velocity (in the unsaturated zone), deformation moduli, magnetic susceptibility, total magnetic field intensity, K-U-Th content, and hydraulic conductivity.

Compensated-density, induction, resistivity, and spectral-gamma logs will be used most frequently for lithologic correlations, although other logs may be used such as caliper, spontaneous potential, temperature, neutron, and induced polarization. Signatures of compensated-density logs will provide information to identify dominant lithophysal zones in boreholes where only drill bit-cutting samples will be available, or where poor resolution exists on borehole video-camera logs. Induction, resistivity, and spectral-gamma logs are expected to serve as indicators of smectite- and zeolite-rich intervals. These logs also will be used to identify key stratigraphic markers at the top and base of major ash-flow tuffs, which commonly show an increase in alteration.

Borehole samples, borehole video-camera logs, and geophysical logs will be correlated to help determine the vertical and lateral continuity of the lithostratigraphic units. Geophysical log data will provide rock property data for the unsaturated and saturated zone hydrology models and mechanical and thermal models of the host rock and surrounding units.

Borehole gravimetry will be used in available boreholes to obtain bulk density and structural information for the region around each hole. In addition, data from this technique will be used to study lithophysal zones, and to model the Tertiary-Paleozoic surface at the site. Gravimeter logs have been obtained for several holes (UE-25p#1, UE-25c#1, and USW H-1) including several which were continuously cored (USW G-3 and USW G-4). Additional logs will be acquired from as many as 15 of the existing and proposed water table holes which are nearest the site, existing deep holes as available, and all of the proposed holes which penetrate the base of the Topopah Spring Member.

Large spacing electromagnetic (EM) and resistivity logging will be tested and evaluated to determine applicability for studying fracture and lithophysal zones, and for interpreting anomalies detected by means of other borehole and surface geophysical methods. The application of these methods to acquisition of site characterization data will depend on the outcome of preliminary testing.

 YMP/CM-0011, Rev. 1

8.3.1.4.2.1.4 Activity: Petrophysical properties testing

Objectives

The objective of this activity is to provide geophysical and rock property data to be used in the interpretation of surface-based and borehole geophysical surveys.

Parameters

The parameters for this activity are

1. Electrical resistivity and bulk density of core samples containing in situ pore waters.

2. Electrical resistivity, induced polarization, bulk density, grain density, porosity, seismic velocities, and hydraulic conductivity on resaturated samples.

Description

Rock property testing will provide data for use in the interpretation of surface and borehole geophysical surveys (Activities 8.3.1.4.2.1.2 and 8.3.1.4.2.1.3). Laboratory measurements will be made on core samples obtained from boreholes drilled in the area of interest. Mechanical and thermal properties determined by those testing activities described in Investigation 8.3.1.15.1 and other activities under Investigation 8.3.1.4.2 (this investigation) will also be used in interpretation of geophysical surveys.

This activity will provide data on (1) the degree of water saturation within the rock above the static water level, (2) the moisture flux through the rock matrix, (3) preferential paths for water flow, (4) the potential for contaminant transport by means of diffusion processes, (5) concentrations of clays and zeolites within the measured stratigraphic section, (6) statistical relationships of various rock properties to provide information on the degree of welding, alteration, and compositional uniformity, and (7) rock property variation for integration in a three-dimensional geophysical model of the site.

8.3.1.4.2.1.5 Activity: Magnetic properties and stratigraphic correlations

Objectives

The objectives of this activity are to

1. Provide magnetic property data to aid the interpretation of volcanic stratigraphy and structure of rock units within the Yucca Mountain site area.

YMP/CM-0011, Rev. 1

2. Use paleomagnetic directions to provide orientations for drill core segments.

3. Assess the rotation of rock units in relation to the geologic structures of Yucca Mountain from paleomagnetic indications.

Parameters

Three categories of parameters are required for this activity.

1. Measured magnetic parameters:

   a. Orientation and magnitude of remnant magnetism.
   b. Magnetic susceptibility.
   c. Curie temperature.

2. Measured properties of flow units:

   a. Textural variations across boundaries.
   b. Grain size variations.
   c. Pumice clast concentrations.
   d. Locations of lithic-rich subzones.
   e. Nature of contacts between flow units.

3. Inferred properties of flow units:

   a. Locations of deposition breaks.
   b. Thicknesses of individual flow units.

Description

Natural remanent magnetization (NRM) and magnetic susceptibility exhibit systematic variation that correlates with depositional breaks within several major ash-flow tuffs. Data will be collected to help understand the observed mineralogical variations that produce the observed changes in magnetic susceptibility and remnant magnetization. Empirical relationships will be developed between depositional breaks and variations in these magnetic properties to provide information for the three-dimensional geologic model.

Lithologic relationships will be developed based on observations of the following rock properties: (1) measurement of NRM, (2) measurement of anhysteritic remanent magnetization (ARM), (3) measurement of isothermal remanent magnetization (IRM), (4) measurement of saturation magnetization (M_{sat}), (5) measurement of magnetic susceptibility, (6) alternating field demagnetization, (7) thermal demagnetization, and (8) curie temperature determination.

Oriented samples for rock magnetic properties testing will be collected from surface outcrops in the vicinity of Yucca Mountain. Sampling sites will be selected where geologic evidence indicates that the area is relatively undisturbed and the identity of the unit sampled is well known. These sites are used to establish reference paleomagnetic directions for geologic units.

YMP/CM-0011, Rev. 1

Other sites will be selected where rotations of the geologic structure will be evaluated. Data from these sites will be used to assess the magnitudes of the rotations.

Samples have been collected from drill core segments at 3-m intervals from throughout drillholes USW G-1, USW G-2, USW GU-3, and USW G-3. Samples also have been collected from throughout the sections penetrated by two drillholes located on Crater Flat (VH-1 and VH-2). Further sampling from drill core will be obtained from oriented core segments.

Variations in magnetic properties determined in the laboratory will be used to collect intervals of core from drillholes USW G-1, USW G-2, USW GU-3, and USW G-3 for detailed petrographic studies. Studies will focus on identifying subtle variations across contacts that separate subunits of major ashflow tuffs. These features include textural changes, localized concentrations of pumice clasts and lithic fragments, anomalous welding characteristics, and subtle compositional changes that may correlate with abrupt changes in magnetic properties.

Measurement of NRM and remanent magnetization will be determined with a spinner magnetometer after at least one level of alternating field demagnetization. Progressive alternating field and thermal demagnetization will help assess mineralogical variations within the rock. Additional rock magnetic measurements (ARM, IRM, M_{sat}) will be used to help assess variation in the composition, relative abundance, and magnetic grain size of magnetic minerals. Selected samples are subjected to progressive thermal demagnetization in order to determine blocking temperature spectra and to assess whether samples possess multiple components of remanent magnetization. Curie temperatures will be determined from rock chips of mineral separates to help define the magnetic minerals present in the samples.

Measurements of the relative magnitude of magnetic susceptibility will be obtained using a hand-held magnetic susceptibility meter. This meter will provide relative values, and will help limit the size of intervals of core selected for petrographic studies. If this technique proves to be successful, the instrument will be used in continuously cored holes.

To measure total intensity and magnetic susceptibility variation with depth, borehole magnetic surveys using an experimental flux-gate magnetometer, proton-spinner magnetometer, and susceptometer will be performed as described in Activity 8.3.1.4.2.1.3. These logs will be correlated with available geologic data. Geologic correlations will focus on identifying depositional units and rock characteristics changes in the Topopah Spring Member.

8.3.1.4.2.1.6 Activity: Integration of geophysical activities

Objectives

This activity will provide a mechanism for information exchange, analysis of data and other technical information, and review of planned geophysical site characterization activities. The operating principles for

YMP/CM-0011, Rev. 1

geophysics integration are that (1) the effectiveness of planned geophysical surveys can be increased through consideration of past efforts both within and outside the Yucca Mountain Project; and (2) the overall effectiveness of geophysical exploration can be increased by analysis of how each planned survey addresses specific information requirements for site licensing. The objectives of the geophysics integration activity are then to optimize the effectiveness of geophysical activities for providing data that support site licensing, from cost and technical perspectives.

Parameters

No activity or characterization parameters are provided by this activity.

Description

Planned geophysical surveys will collect different types of data, which may be used to support geologic, hydrologic, and tectonic models of the site. (In this context, model refers to interpretation of the history of causative processes giving rise to the present state, based on observations and inference.) Such models are identified as steps in the issue resolution strategies of Sections 8.3.1.2 and 8.3.1.4, although the form and content are not described explicitly. Much of the information contained is expected to be nonquantitative and therefore will not directly support probabilistic assessments. However, performance assessment is supported by the use of such information to ensure that the range of variability of the site characteristics included in performance calculations is representative of actual site conditions. Similarly, geophysical applications such as fault detection are a form of nonprobabilistic support for the representativeness of site data.

8.3.1.4.2.2 Study: Characterization of the structural features within the site area

The objective of this study is to determine the frequency, distribution, characteristics, and relative chronology of structural features within the Yucca Mountain site area.

Surface and subsurface structural studies will be performed to identify and characterize fracture-fault systems within the site area. Detailed geologic mapping of zonal features in ash-flow tuffs that crop out at the surface of Yucca Mountain will provide the necessary stratigraphic control for identifying small-scale faults. Lateral variability of fracture networks will be studied by detailed mapping and pavement analysis. Subsurface distribution and geologic characteristics of fracture-fault zones will be studied by analysis of core samples, borehole evaluations, exploratory shaft facility studies, and application of geophysical techniques. Results of these studies will be integrated with hydrologic study results described in Section 8.3.1.2 to provide information for the development of geologic models of the site (Study 8.3.1.4.2.3).

 YMP/CM-0011, Rev. 1

Geologic mapping of the exploratory shaft facility ramp and drifts will include detailed fracture mapping and photogeologic recording. Borehole evaluations in the exploratory shaft facility after drilling and coring will include video, geophysical and vertical seismic profiling surveys. Fracture-filling mineralogy studies in the ramps, drifts, and boreholes will be conducted to evaluate the chronology of fracture development.

Preparation of a three-dimensional geologic model (Study 8.3.1.4.2.3) requires discrimination between natural fractures and those induced by excavation and construction-related activities. The photographic methods discussed in Activity 8.3.1.4.2.2.4 (Geologic mapping of the exploratory shaft facility) are useful in documenting the existing fracture network but may have difficulty in discriminating natural from induced fractures. Geologic mapping in the underground can aid in recognizing blast-induced fractures, by, for example, noting the absence of mineralization or by tracing the fracture back to the point of origin at a shot point.

In addition to the characterization of structural features, the geological mapping of the ramps and drifts will include mineralogic, petrologic, and petrographic studies as described in Section 8.3.1.3.2.1.

Activities planned for this study include (1) geologic mapping of zonal features in the Paintbrush Tuff at a scale of 1:12,000, (2) surface-fracture network studies, (3) borehole evaluation of fractures and faults, (4) geologic mapping of the exploratory shaft facility ramps and drifts, and (5) vertical seismic profiling studies.

8.3.1.4.2.2.1 Activity: Geologic mapping of zonal features in the Paintbrush Tuff

Objectives

The objectives of this activity are (1) to map zonal variations within exposed tuffs that will aid in the identification of structural displacements at a scale of 10 m or less, and (2) to detect subtle changes in structural styles.

Parameters

The parameters for this activity are

1. Thickness, attitudes, and lateral extent of zones within ash-flow and bedded tuff intervals, areal extent of exposed bedrock.

2. Attitudes, lengths, displacements, and near-surface characteristics of faults and fault zones.

Description

Geologic mapping of zonal variations in ash-flow sheets and structural features that are exposed over much of the site area has been completed and published at a scale of 1:12,000. The mapped area forms an irregular pattern, the boundaries of which roughly coincide with prominent topographic features (Figure 8.3.1.4-9, Area A). The northernmost limit of the map is Prow Pass; the northeastern boundary is Yucca Wash; the eastern limit is Fortymile Wash; the southern extent is the southernmost exposure of Fran Ridge; and the western limit is Windy Wash.

Mapping will extend outward from the western and southern boundaries of the mapped area to include areas east of longitude 116° 32′ and areas north of latitude 36° (Figure 8.3.1.4-9, Area B). The mapping will identify thickness, attitude, and lateral extent of zones within ash-flow tuffs and bedded tuff intervals; areal extent of exposed bedrock; and attitudes, lengths, displacements, and near-surface characteristics of faults and fault zones. Northern, northeastern, and eastern limits of the map area will not be extended because rock units of interest are poorly exposed in those areas. The need for larger scale mapping (e.g., 1:2,400) in the immediate vicinity of the repository facilities will be assessed.

Geologic information that is initially documented on aerial photographs during field mapping will be transferred to stable topographic base maps by using high-precision photogrammetric techniques.

8.3.1.4.2.2.2 Activity: Surface-fracture network studies

Objectives

The objective of this activity is to provide measurements and analyses of fracture networks to support modeling of hydrologic potential flowpaths, particularly in unsaturated zones. Applications are also expected to aid development of tectonic models and determination of the mechanical response of fractured rock to excavation and thermal loading. The analyses will provide quantitative data for determining spatial distribution of fractures, chronology of fracture development, and parametric characteristics of fractures. Applications are expected to aid in the development of tectonic models and possibly to aid in the determination of the bulk response of fractured rock in the context of excavation and loading.

Parameters

The parameters for this activity are fracture orientation, frequency, aperture, roughness, persistence, spatial distribution, fracture-filling mineralogy, relative age, and tectonic style.

Description

The characterization of fracture networks on the surface of Yucca Mountain will be carried out through a phased program of detailed studies of outcrops (either natural or cleared). Because analyses of fractures in drillholes (Activity 8.3.1.4.2.2.3) and fractures exposed in the exploratory shaft (Activity 8.3.1.4.2.2.4) are based on relatively small samples that emphasize the vertical dimension, analyses based on surface exposures of fractures provide a unique opportunity to understand lateral variations and

YMP/CM-0011, Rev. 1

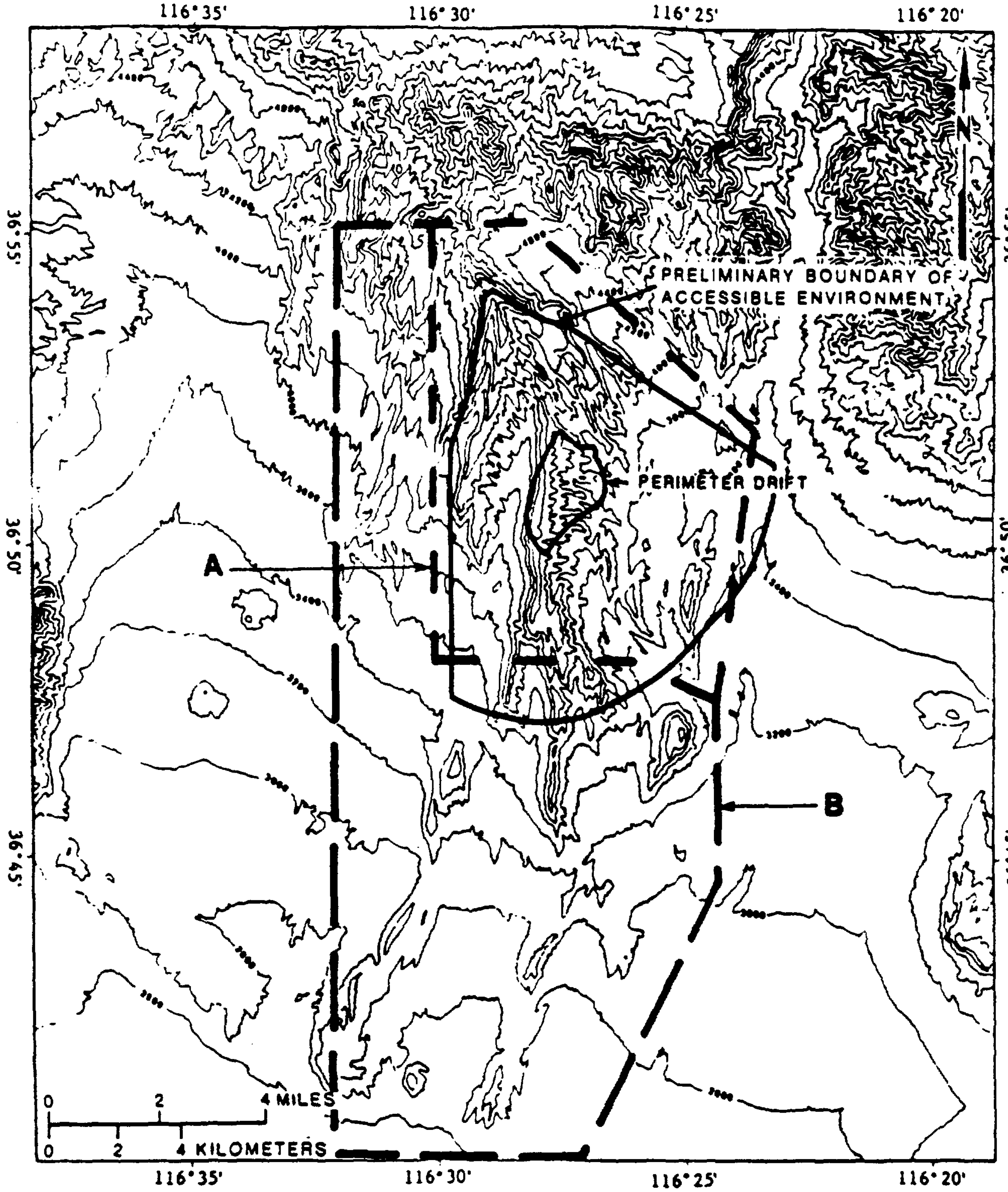

Figure 8.3.1.4-9. Approximate areal limits of mapped area (A) and area of additional mapping (B).

YMP/CM-0011, Rev. 1

other fracture characteristics in different stratigraphic units. The applicability of data from fracture studies and fracture networks projected to the subsurface will depend largely on the comparison of the data with the result of fracture analyses conducted in the exploratory shaft facility.

Detailed studies included in this activity will provide site-specific data from outcrops on Yucca Mountain. This activity will focus primarily on the Paintbrush Tuff, and to a lesser extent, the tuffaceous beds of Calico Hills units exposed within the site area boundary (at Prow Pass). Stratigraphically lower units, such as the Crater Flat Tuff, do not crop out in the site area boundary but are exposed within several miles of the site. If preliminary studies in the site area clearly establish that there is a need for additional fracture network data from offsite outcrops, preliminary evaluations of the transferability of data from offsite outcrops will be performed. If these studies demonstrate that these data are convincingly transferable to the site (e.g., apparently good correlation with fractures mapped in exploratory shaft facility ramps and drifts), additional fracture data may be derived from exposures in such areas as the southern part of Yucca Mountain, Little Skull Mountain, northern Crater Flat, and along U.S. Highway 95.

As no detailed surface-fracture network study of this scope involving comparable rocks has been attempted, extensive innovation in measurement and analytical procedures will be required. Throughout this activity a phased approach will be employed whereby the results from sites already studied in a given unit will be considered in determining the need for additional data.

Preliminary work indicates that most fractures are strata-bound. Therefore, fluid-flow paths through fractures depend to a large degree on the changes of fracture networks within lithostratigraphic units. Outcrop locations will be chosen to provide lateral coverage and vertical sampling through the stratigraphic section exposed at the surface of Yucca Mountain. The outcrops will provide two-dimensional surfaces through three-dimensional fracture networks.

Three methods are planned for surface fracture studies: (1) bedrock-pavement (pavement method), (2) uncleared-outcrop method (outcrop method), and (3) photogeologic method. For the pavement method, cleared bedrock surfaces are mapped, and fracture parameters are recorded. For the outcrop method, fracture parameters are recorded from incompletely exposed natural outcrops. For the photogeologic method, linear features are mapped from aerial photographs by means of a stereoplotter. Differences between the uncleared outcrop methods and the pavement method hinge on the degree of exposure (and, therefore, mappability) and the number of parameters that can be measured by each method.

Aerial photographs of 1:2,400 scale were used to test the photogeologic method (Throckmorton, 1987). Results of this study showed that most fracture traces were not discernible because of poor exposures and inadequate (too small) photographic scale. In addition, trace bearings and trace lengths measured on the photos differed from those measured in the field, indicating that many traces mapped from the photos represented lineations other than fractures. On the basis of these results, the photogeologic method was rejected, but may be tested again with larger-scale photographs.

 YMP/CM-0011, Rev. 1

Data collected on parameters listed previously will be analyzed in various ways. Fracture orientations (strike and dip) of each network will be plotted onto lower hemisphere equal-area projections. Frequency distributions of fracture trace-lengths, aperture, and surface roughness will be plotted and characterized for fracture networks. Other statistical-geometric methods will be applied to the fracture data base where appropriate. In addition to other analytical methods, a fractal analysis of each pavement will quantify the spatial distribution of fracture traces and fracture trace intersections. Fractal geometry will be used as a means of statistically determining scaling characteristics of fracture networks (Barton et al., 1986). Fractal analysis may offer a technique to characterize the complex three-dimensional fracture systems in the repository block (Barton and Larson, 1985; Barton et al., 1985).

8.3.1.4.2.2.3 Activity: Borehole evaluation of faults and fractures

Objectives

The objectives of this activity are to

1. Assess the reliability and usefulness of available borehole techniques for identifying and characterizing the subsurface fracture distribution.

2. Determine vertical and lateral variability and characteristics of subsurface fractures.

3. Identify subsurface characteristics of fault zones.

Parameters

The parameters for this activity are

1. Fracture location, dimension, type, orientation, relative chronology, aperture, degree of mineralization, mineralogy of fillings, surface profile, roughness, and apparent frequency.

2. Lateral variability in apparent fracture frequencies and strike directions of fractures within lithostratigraphic units, and subsurface fracturing closely associated with fault zones.

Description

Analysis and interpretation of subsurface characteristics of faults and fractures in the site area will, in part, be based upon (1) core sampling and fracture logging, (2) borehole video camera logging, and (3) acoustic televiewer surveys and logging.

Fracture and fault studies in continuous core will help determine the relative spatial relationships of these features. Measurements will include relative chronology, apertures, and fracture surface characteristics (such as surface profile and roughness), degree of mineralization, and mineralogy of

YMP/CM-0011, Rev. 1

fillings. Attitudes of fractures and faults will be obtained by analysis of oriented cores and by orienting segments of core based on reorientation using paleomagnetic techniques (Activity 8.3.1.4.2.1.5).

The term "roughness" is used to represent the condition of joint roughness, which can be parameterized in different ways including the joint roughness coefficient of Barton and Choubey (1977). The term "roughness coefficient" is used exclusively to refer to this parameterization; whereas the usage "roughness" is more general.

Careful reconstruction and analysis of core segments will not eliminate many of the sampling limitations that are inherent to the study of fractures in near-vertical coreholes, particularly at Yucca Mountain where vertical fractures dominate. Characterization of fractures in core provides only one dimension of the total fracture network and will be integrated with surface studies that provide information from other sampling orientations to help understand sample bias in corehole data. The relatively small sample size of core also precludes the study of fracture dimensions. No distinction can be made between large, through-going fractures and fractures that have very short trace lengths. Future coreholes will be used to aid in planning studies in the exploratory shaft facility ramps and drifts (Activity 8.3.1.4.2.2.4) where more accurate observations of three-dimensional fracture networks can be made.

A continuous visual display of borehole walls will be obtained in future holes drilled in the vicinity of Yucca Mountain by using an instrument assembly that includes a borehole television camera, compass, light source, and digital depth readout. Video-camera tapes will be reviewed and the location, orientation, and relative abundance of fractures will be recorded. Fracture data will be compiled to show changes in the apparent frequency of fractures as a function of depth, stratigraphic unit, and lithostratigraphic unit. Directional orientation histograms will be constructed that illustrate distribution of strike and dip directions within appropriate lithostratigraphic and stratigraphic units. These types of compilations will provide a means for estimating the degree of lateral variability in apparent fracture frequencies and strike directions of subhorizontal fractures within lithostratigraphic units, and provide a means for estimating subsurface fracturing closely associated with fault zones. Variability of vertical fractures will be compiled from mapping in the drifts and horizontal boreholes in the exploratory shaft facility.

Acquisition of a continuous record of fractures intersecting a borehole is the primary advantage of using oriented borehole television to map fractures in the subsurface. However, several limitations of the method can be identified that limit the characterization of fracture networks. They include the following:

1. Data are biased because vertical fractures are not adequately sampled as in core studies.

2. Only one dimension of the fracture network is sampled.

YMP/CM-0011, Rev. 1

3. Inaccuracies in identifying and measuring the toes and heels of fracture planes that cut the borehole limit data acquisition from borehole television to strike and dip directions only; the amount of dip of fracture planes often cannot be confidently measured and, therefore, true fracture spacings cannot be obtained.

4. Important fracture parameters that are useful for characterizing fracture sets, such as persistence, roughness, and mineral coatings, cannot be measured directly from borehole television images.

The significance and validity of subsurface fracture analyses based on core and television camera logging will depend largely on comparison with results of fracture analyses conducted in the exploratory shaft facility.

Acoustic televiewer logging is an additional technique that can be used to study the distribution of fractures in the saturated zone by inspection of borehole walls. The televiewer provides an oriented image of the acoustic scattering profile of the borehole, in the form of a continuous log. The borehole is displayed on the log as if it were split vertically along magnetic north and unrolled onto a vertical plane. Nonvertical fractures form distinctive sinusoidal features that can be used to measure strike and dip directions as well as the amount of dip.

Fracture attitudes will be measured from existing televiewer logs as well as from logs of future holes. Data sets will be compiled to show the vertical variations as a function of depth and lithostratigraphic units. As in the analysis of fractures from video-camera observations, data will be displayed on direction orientation histograms. This will allow comparative analyses between drillholes. Unlike the video-camera log, the amount of dip often can be calculated from the televiewer log at depths where accurate determinations of hole diameters can be made from existing caliper logs. Acquisition of these data will allow application of statistical methods such as stereonet contouring to determine the significance of any preferential spatial distributions.

Several other borehole geophysical methods, including borehole-to-borehole techniques, will be evaluated in available drillholes at the site. These methods will include borehole radar, crosshole resistivity, crosshole EM, crosshole radar, and high resolution crosshole seismic surveys (Table 8.3.1.4-4). Evaluations also will involve comparative studies of the various methods used to identify subsurface fractures. Stratigraphic intervals for which fracture data are available for several subsurface techniques will be analyzed to assess the utility of each method.

8.3.1.4.2.2.4 Activity: Geologic mapping of the exploratory shaft facility

Objectives

The objectives of this activity are to

YMP/CM-0011, Rev. 1

1. Determine the vertical and horizontal variability of fracture networks in the exploratory shaft facility ramps, drifts, and boreholes.

2. Characterize major faults and fault zones in the subsurface.

3. Map the lithostratigraphic features of the subunits, and the abundance and character of lithophysal zones.

4. Assist in evaluation of test locations in the exploratory shaft facility.

Parameters

Three categories of parameters are required for this activity.

1. Fault parameters:

   a. Geometry.

   b. Physical characteristics.

   c. Tectonic styles of faults bounding the repository on the northeast and east, and of the Ghost Dance fault.

2. Fracture parameters:

   a. Orientation.
   b. Aperture.
   c. Roughness.
   d. Fracture persistence.
   e. Surface characteristics.
   f. Mineralogy.
   g. Relative ages.
   h. Spatial distribution.

3. Stratigraphic parameters:

   a. Hand-specimen lithology of Yucca Mountain stratigraphic sequence.

   b. Lateral variability of repository host horizon.

Description

Major subsurface structural features, such as the Drill Hole Wash and imbricate normal fault zones near the northeastern and eastern boundaries, respectively, of the repository will be directly studied in the exploratory shaft facility. The character of the Ghost Dance fault within the repository will be investigated and lateral variability of the lithologic character of the repository host rock will be determined. Data obtained from fracture mapping in the ramps and drifts will be combined with surface studies to describe the three-dimensional fracture network within the exploratory shaft facility.

 YMP/CM-0011, Rev. 1

Geologic mapping of the exploratory shaft facility ramps and drifts will take place after new wall exposures are cleared and surveyed.

Mapping in the ramps and drifts can provide a detailed description of stratigraphic, lithologic, and structural features and will provide data as required by 10 CFR 60.21(c) for inclusion in the safety analysis report. Descriptions of fracture networks and intersections are enhanced by continuous observation because fracture spacing and attitude commonly vary over distances of tens to hundreds of meters. Both objectives can be met in a timely manner by a two-tiered approach to the mapping: (1) analysis of stereoscopic photographs (photogrammetric geologic mapping) and (2) continuous detailed mapping along reference lines (detailed line surveys).

Stereoscopic photographs will be taken of exposed surfaces in the exploratory shaft facility ramps and in the walls and crown of drifts in the exploratory shaft facility, as mining progresses; floors and working faces will not be mapped unless anomalous geologic features are exposed. Geologic maps will include discontinuities such as faults, fractures, breccia zones, and other features of interest including lithologic and stratigraphic features. These features will be identified based in part, but not exclusively, on predetermined criteria. The maps will be prepared from stereoscopic photographs using close-range photogrammetry and direct observation.

Stereophotography and in situ mapping of the ramps and drifts will be done routinely as fresh rock is exposed. Close-range photogrammetry will provide continuous data in the ramps and drifts. In the ramps, detailed in situ measurements will be made of geologic features along horizontal reference lines. In the drifts, line surveys will be done continuously along one wall, or more as required at significant changes of geologic features.

Detailed mapping will be emphasized in the areas adjacent to the exploratory shaft facility tests at both the Topopah Spring and Calico Hills levels, areas near major geologic structures within the repository, and across geologic structures near the borders of the repository. In addition, investigators will make detailed maps of test rooms and will log cores from holes drilled for hydrologic, geomechanical, and geochemical tests in the ESF main test level and at the Calico Hills level.

If unusual zones of alteration or fracture-filling minerals are encountered, representative samples will be acquired in conjunction with geologic mapping, as appropriate for mineralogical and age determinations. The location of origin of such samples, and the observed relationships between fracture mineralization and fracture orientation, will be recorded. Petrographic and x-ray diffraction analysis, and uranium-thorium disequilibrium dating, will be performed on collected samples by scientists working on other activities.

Fracture coatings are more commonly preserved underground than near the surface, and are protected to a greater degree from isotopic exchange. Uranium-thorium disequilibrium dating of calcite and uraniferous opal will be performed as a part of other activities (Investigation 8.3.1.3.2). Electron

 YMP/CM-0011, Rev. 1

spin resonance (ESR) dating of quartz and potassium-argon dating of clay fracture coatings from subsurface samples will also be performed as a part of Investigation 8.3.1.3.2.

Studies of fracture-filling mineralogy by other activities will be used to determine formation of the filling minerals to help infer the ages of fracturing and to estimate rates of tectonism. This information will be used in assessments of the potential for and likely character of additional fracturing and seismic activity at Yucca Mountain. The results of these analyses will be integrated with the evaluations planned for postclosure and preclosure tectonics and repository design.

Analyses of the ages of fracture mineralogy also provide information to aid in the interpretation of past fracture hydrologic-mineralogic processes in the repository host rock and surrounding units. These studies will be integrated with fracture mineralogy evaluations in unsaturated zone hydrology and mineralogic and geochemical activities.

Products derived from this activity will include (1) a stereophotographic record of the geologic features exposed on the ramp walls and on the walls and crown of drifts; (2) geologic maps (combination in situ and photogrammetric) of lithologic, stratigraphic, and structural features including fracture networks as exposed on the ramp walls and on the walls and crown of drifts; (3) fracture orientations and statistical distributions; (4) fracture persistence and statistical distributions; (5) fracture roughness and statistical distributions; (6) fracture apertures and statistical distributions; (7) fracture infilling percentage and statistical distributions; (8) fracture intersection data; (9) two- and three-dimensional expression of fracture density; (10) three-dimensional estimate of fracture network characteristics and variability (fractal analysis); (11) structural domains; (12) tectonic style; (13) paleostresses as suggested by displacements along faults; (14) lithology and stratigraphy; (15) an assessment of the lateral variability of geologic features within the ramp and drifts; and (16) representative lithologic and mineralogic samples.

8.3.1.4.2.2.5 Activity: Seismic tomography/vertical seismic profiling

<u>Objectives</u>

The objectives of this activity are to

1. Investigate, and if successful, provide a means for broadly detecting and characterizing the subsurface fracture network in regions between the surface, boreholes, and underground workings.

2. Calibrate and relate the seismic propagation characteristics of the host rock to the fracture patterns observed in boreholes and underground workings, and to extrapolate the observed fracture patterns to the surrounding region.

 YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are travel time, amplitudes, and polarizations of the direct, reflected, and refracted compressional and shear waves (SH and SV), as well as other wave propagation characteristics identified by investigating the relationship of wave propagation characteristics to fracture properties.

Description

Tomographic vertical seismic profiling (VSP) techniques may be used to study the degree and character of fracturing of the rock mass. Feasibility studies will be performed to establish whether these techniques are applicable to the unsaturated zone at Yucca Mountain. If they are successful, then multi-offset, multisource (P, SV, and SH) VSP surveys would be conducted between the surface and existing drillholes, and between the surface and the underground excavations of the exploratory shaft facility, to detect and map spatial variation of seismic propagation characteristics in the repository area. Seismic characteristics are expected to correlate in a useful manner with observed fracture characteristics. The objective will be to derive a series of maps of the fracture characteristics of the subsurface, to be used in development of a three-dimensional descriptive model of fracturing at Yucca Mountain. From previous VSP studies, it is estimated that significant spatial variation of seismic propagation characteristics may be detected using pixels with dimensions as small as 20 m. The velocities, amplitudes, and polarizations of seismic phases recorded on three-component sensors may be used to broadly characterize fracture orientations, density, and spacing. Tomographic analysis using the travel times, amplitudes, and shear wave polarization may be used to relate seismic characteristics to the fracture characteristics. Three-component sensors will be placed in available boreholes with the compressional and shear wave sources placed at the surface. Interpretation of surveys in boreholes will be augmented by performing similar surveys in drifts at the Topopah Spring and Calico Hills levels where more direct observations of fracture characteristics can be obtained. The hydrologic, geochemical, and geomechanical test results obtained in the exploratory shaft facility will be evaluated in terms of the fracture information from the VSP surveys. If successful, the VSP approach may provide a means for extrapolating important characteristics of the site directly measured at select locations to the greater region encompassed by VSP studies.

The following steps are proposed for the VSP work. First, structural and fracture domains with similar properties will be selected and defined in the exploratory shaft facility after geologic mapping has been conducted. Second, appropriate sensors will be installed in drillholes into the drift walls, providing a vertical array of sensors that can then be used to carry out the VSP work with the P- and S-wave sources at the surface. Finally, after the instrumentation has been emplaced, the VSP survey will be conducted.

YMP/CM-0011, Rev. 1

Laboratory analysis of core samples will be performed to observe and measure seismic propagation effects needed for interpreting the characteristics of the in situ rock mass. Fractured and unfractured specimens will be subjected to seismic excitation at test conditions (frequency, strain amplitude) representative of field test conditions.

8.3.1.4.2.3 Study: Three-dimensional geologic model

Objectives

The objective of this study is to develop a three-dimensional geologic model of the site area. In doing so, much of the study will involve synthesis of the results of other studies in the investigation to develop a model that will be integrated into the three-dimensional rock characteristics model described in Study 8.3.1.4.3.2 of Investigation 8.3.1.4.3.

8.3.1.4.2.3.1 Activity: Development of a three-dimensional geologic model of the site area

Objectives

The objective of this activity is to develop a three-dimensional geologic model of the Yucca Mountain site that incorporates stratigraphic, structural, geophysical, and rock properties information pertinent to site characterization, and design and performance assessment activities.

Parameters

The parameters of this activity fall into three categories.

1. Stratigraphy-lithology (lateral and vertical variations in lithostratigraphic units):
    a. Depth.
    b. Thickness.
    c. Attitude.
    d. Welding and crystallization.
    e. Alteration.
    f. Petrography.
    g. Lithophysal zones in Topopah Spring Member.
    h. Geophysical characteristics.
2. Faults:
    a. Distribution.
    b. Displacements.
    c. Orientations.
    d. Age relationships.
    e. Physical features.

 YMP/CM-0011, Rev. 1

f. Geophysical characteristics.
g. Tectonic styles.

3. Fractures:

a. Spatial distribution.
b. Frequencies.
c. Persistence.
d. Orientations.
e. Age relationships.
f. Surface characteristics.
g. Interconnectedness.
h. Aperture.
i. Filling mineralogy.
j. Mineral infilling distribution.
k. Geophysical characteristics.

Description

Geologic data that are collected from coreholes, drillholes, outcrops, and geophysical studies will be used to construct isopach maps, structural contour maps, correlation diagrams, and cross sections. These illustrations will show the distribution and lithologic variability of stratigraphic units that underlie the site and surrounding areas such as Crater Flat and Jackass Flats. Principal scales of compilations will be 1:48,000, 1:24,000, and 1:12,000.

As stratigraphic, structural, and geophysical studies progress from data collection and documentation phases into interpretation phases, important sources of information will be reviewed, assessed, and integrated into a model that describes all relevant aspects of the site geology. This descriptive model will also incorporate geologic constraints discovered during development of models of the depositional and diagenetic histories of units.

8.3.1.4.3 Investigation: Development of three-dimensional models of rock characteristics at the repository site

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections summarize available data relevant to the development of three-dimensional models of rock characteristics for the repository area and the immediate vicinity.

YMP/CM-0011, Rev. 1

SCP section	Subject
1.2.2.2	Cenozoic rocks (stratigraphy and lithology at Yucca Mountain)
1.3.2.2.2	Structures and structural history of Yucca Mountain
1.8.1.2	Stratigraphy and lithology (summary of significant results)
1.8.1.3	Structural geology and tectonics (summary of significant results)
1.8.2.1	Relation of geology to repository design
2.9.1.1	Geoengineering properties (summary)
2.9.1.2	Relationship of data to performance objectives
2.9.1.3	Preliminary evaluation of data uncertainty
3.6.1	Hydrogeologic units
3.10.1	Summary of significant results (hydrogeology)
4.5	Summary of significant results (geochemistry)

Parameters

The principal result of this investigation will be the development of computer-based representations of the three-dimensional distribution of physical property data. Contour maps or cross sections will show the spatial distribution of such parameters as rock compressive strength, thermal conductivity, or gas permeability. Specific parameters to be modeled include those rock characteristics parameters requested as input to design or performance assessment information needs. As an intermediate step in the three-dimensional modeling process, this investigation will provide data such as porosity, saturated hydraulic conductivity, and saturation to provide a basis for defining the detailed spatial variability of the tuff rock mass upon which all rock characteristic distributions depend. Analysis of the core obtained by this study will also provide data pertaining to the following:

1. Location of geologic contacts.

2. Basic rock descriptions including degree of welding, types of pumice or lithic fragments, abundance of lithophysae, gross mineralogy, and alteration.

3. Subsurface characteristics of faults.

4. Fracture frequencies and orientation.

5. Rock quality designation.

YMP/CM-0011, Rev. 1

The core will be available for more detailed examination of lithology, fractures, faults or other geologic features by other studies and investigations (particularly Investigation Section 8.3.1.4.2, geologic framework). As additional information from detailed study of core, geophysical logs, and other investigations becomes available, the three-dimensional model will be modified to reflect the new data.

Purpose and objectives of the investigation

The purpose of developing three-dimensional, computer-based models of rock characteristics at the Yucca Mountain site is two-fold: (1) to summarize information gained during the course of Investigations 8.3.1.4.2 (geologic framework), 8.3.1.2.1 through 8.3.1.2.3 (hydrologic material properties), (thermal/mechanical properties) and (2) to provide a mechanism for transfer of this integrated information to the design and performance assessment issues.

Specifically, performance assessment and design issues have called for quantitative information regarding the spatial distribution of various rock characteristics (Table 8.3.1.4-1). Numerous investigations have been designed to acquire the basic quantitative data or to develop the geologic framework that must be considered in the development of a three-dimensional model of rock characteristics.

Technical rationale for the investigation

This investigation consists of activities that integrate information collected by numerous other investigations. These diverse types of field and laboratory data are presented in the form of three-dimensional models of rock characteristics--models that have been requested by, and that will be utilized directly by, design and performance assessment studies.

Construction of a three-dimensional block model of rock properties that represents actual rock characteristics at the Yucca Mountain site is much more than the arbitrary "plugging" of quantitative values for some rock property into the proper "box" in three-dimensional space. Interpolation algorithms are numerous, yet application of different procedures may yield vastly differing interpretations of identical input values. The critical factor for developing a model that is representative of in situ conditions is the extent to which the quantitative determinations of some rock property value are constrained by the geologic framework (Investigation 8.3.1.4.2) of the Yucca Mountain area. A porosity model that does not respect constraints imposed by geologic knowledge of the eruptive and depositional history of the rocks involved, the general vertical and lateral variability of similar rocks elsewhere, and the observed displacement of original rock units by faulting will not be generally accepted and therefore will not be useful to a performance assessment analyst or design engineer.

The essential philosophy of model development will be to use detailed information regarding the spatial structure of selected rock characteristics (e.g., porosity, saturated hydraulic conductivity) obtained by Study 8.3.1.4.3.1 (systematic drilling program) and less abundant, quantitative rock characteristics data obtained by Investigations 8.3.1.2.1. through 8.3.1.2.3, 8.3.1.3.2 and 8.3.1.15.1 in order to determine the spatial corre-

 YMP/CM-0011, Rev. 1

lation structure of the rock characteristic(s) under current consideration. Quantitative descriptions of the identified spatial structure will be compared with descriptions of the geologic framework of Yucca Mountain (Investigation 8.3.1.4.2), and major discrepancies will be resolved. The quantitative descriptive data will then be interpolated and projected using a standard mathematical algorithm to create a model of the desired property(ies) as requested by performance assessment and design issues.

8.3.1.4.3.1 Study: Systematic acquisition of site-specific subsurface information

Only one activity is planned under this study.

8.3.1.4.3.1.1 Activity: Systematic drilling program

Objectives

This activity will acquire physical rock samples, analytical data, and basic descriptions of the subsurface geology of the repository site on a systematic basis. These samples and information are important for characterizing the three-dimensional distribution of rock characteristics, and hydrologic and geochemical variables, for the unsaturated zone at Yucca Mountain. Other information and samples will also be provided because of this access to the shallow saturated zone.

Borehole locations and drilling methods used by this activity are technically and programmatically integrated with other activities, including 8.3.1.2.2.3.2 (site vertical boreholes study), 8.3.1.2.3.1.1 (Solitario Canyon fault study in the saturated zone), and 8.3.1.2.3.1.2 (site potentiometric-level evaluation). Consistent with the requirements of 10 CFR 60(d)(4), the location and drilling of the boreholes in the systematic drilling program are being coordinated with the repository design. More detail on this coordination effort (particularly regarding the potential impact on repository performance of site characterization activities in general and the systematic drilling program in particular) is provided in Section 8.4. The integration and coordination of these activities will be accomplished in Activity 8.3.1.4.1.1, development of an integrated drilling program.

Parameters

Parameters to be provided through the acquisition of samples and data by this activity include the following:

1. Locations of contacts of geologic and thermal-mechanical stratigraphic units (Ortiz et al, 1985).

2. Lithologic and petrologic descriptions of core or cuttings, including welding and primary crystallization characteristics.

 YMP/CM-0011, Rev. 1

3. Locations and characteristics of lithophysal zones and other altered zones.

4. Locations and characteristics of faults.

5. Fracture frequency and orientation.

6. Core recovery data, including rock quality designation (RQD).

7. Matrix porosity.

8. Unsaturated matrix hydraulic conductivity.

9. Matrix saturation and in situ potential.

The sample logging, wireline logging, and laboratory testing needed to investigate these parameters will be conducted under the associated geologic, hydrologic, and geochemical activities. The strategy for locating boreholes is based on the requirements of the three-dimensional rock characteristics model (Study 8.3.1.4.3.2), and on other studies that involve analysis of spatial variability (e.g., Activity 8.3.1.2.2.3.1, matrix hydrologic properties testing). The objectives of this strategy are to provide areal coverage within and immediately adjacent to the perimeter drift and to provide information for the evaluation of the geostatistical approach for characterizing spatial variability and obtaining representative data.

Description

Surface based testing planned for site characterization may be categorized according to two different approaches: the "feature sampling" program or the systematic program. The feature sampling approach tests specific hypotheses about behavior of the site; boreholes are located where anomalous behavior is expected or proximal to important structures controlling variability. The systematic approach uses only certain information for locating boreholes, and thus, is unbiased with respect to what is known about the site. Representative (conditionally unbiased) sampling may yield smaller predictive uncertainty if known anomalies are avoided, or greater uncertainty if extreme behavior is not restricted to known anomalies. The systematic approach relies on the feature sampling approach, and thus on hypothesis testing, for characterizing extremes. The systematic approach involves more closely spaced boreholes in the immediate site area than the feature sampling approach. Both approaches provide the sampling coverage needed for engineering design and performance assessment calculations.

The systematic drilling program consists of twelve boreholes, located in conjunction with the feature sampling program, including (1) seven boreholes to provide areal coverage and (2) five boreholes to provide information for evaluation of the geostatistical approach. The systematic drilling program is intended to provide samples and data for evaluating the variability of hydrologic, geochemical, geomechanical, and other characteristics as discussed in Section 8.4.2.1.5. This information, in conjunction with that from the feature sampling program, will be used to evaluate the current understanding of unsaturated-zone flow and transport and alternative hypotheses for flow processes. The most pervasive data needs are for the immediate site area

 YMP/CM-0011, Rev. 1

where such processes as gaseous transport lateral diversion, fracture-matrix interaction, nuclide sorption in the unsaturated zone, and geomechanical rock mass response could significantly affect site performance. The systematic drilling program, therefore, focuses on the immediate site area; additional information from outside the area will be obtained from various existing and planned boreholes of the feature sampling program.

If feature(s) are discovered, characterization plans will be reevaluated and may be modified. It is expected that the feature sampling program would be modified, for example, by adding drillholes to the site vertical boreholes study of the unsaturated zone to investigate newly discovered features. However, the systematic drilling program could also be modified by changing the location of a planned borehole or adding a new one. Data from the feature sampling program and the systematic program will be reevaluated on an ongoing basis during site characterization, as discussed in Investigation 8.3.1.4.1 (development of an integrated drilling program). All drilling plans are flexible and can be modified as the result of ongoing evaluation.

The unsaturated portion of each borehole will be drilled dry, without the use of water or other conventional drilling circulation liquids, to preserve sample quality and prevent damage to the formation to the extent practicable. Each borehole will be drilled to a depth of approximately 100 m below the water table; the unsaturated zone will be protected by casing or other means from water produced while drilling below the water table. Other drilling criteria are (1) continuous core sampling capability; (2) penetration to at least 2,600 ft; (3) monitoring of circulation air for immediate detection of perched water in the unsaturated zone; (4) modest drill pad requirements (i.e., approximately 200 ft in the largest dimension); and (5) incorporation of borehole standoff from repository drift into the borehole siting. Borehole locations were selected according to the areal coverage and spacing criteria described below, and then modified slightly where necessary to provide better access in rugged terrain, thus reducing surface disturbance. The selection of a drilling method is linked to the results of prototype drilling, which is associated with the site vertical boreholes study (Activity 8.3.1.2.2.3.2).

Areal Coverage

Seven boreholes, USW SD-1 through USW SD-7, are located within or just outside of the conceptual perimeter drift boundary (CPDB) (Figure 8.3.1.4-10). These seven holes, when combined with planned USW boreholes UZ-2, UZ-3, UZ-7, UZ-8, and H-7 of the feature sampling program, result in approximately uniform areal coverage of the area within the CPDB at an effective borehole spacing of roughly 3,000 ft. Figure 8.3.1.4-10 shows the planned borehole locations with circles of a 1,500-ft radius centered at each borehole; deviations from regular coverage result from a requirement for reasonable access in the rugged terrain. Two quantities were considered in adopting the 3,000-ft spacing: (1) the correlation length for variability of basic physical properties (e.g., matrix porosity; pneumatic conductivity) and (2) the minimum number of boreholes in the feature sampling program with which data from the systematic program will be compared for detection of bias.

YMP/CM-0011, Rev. 1

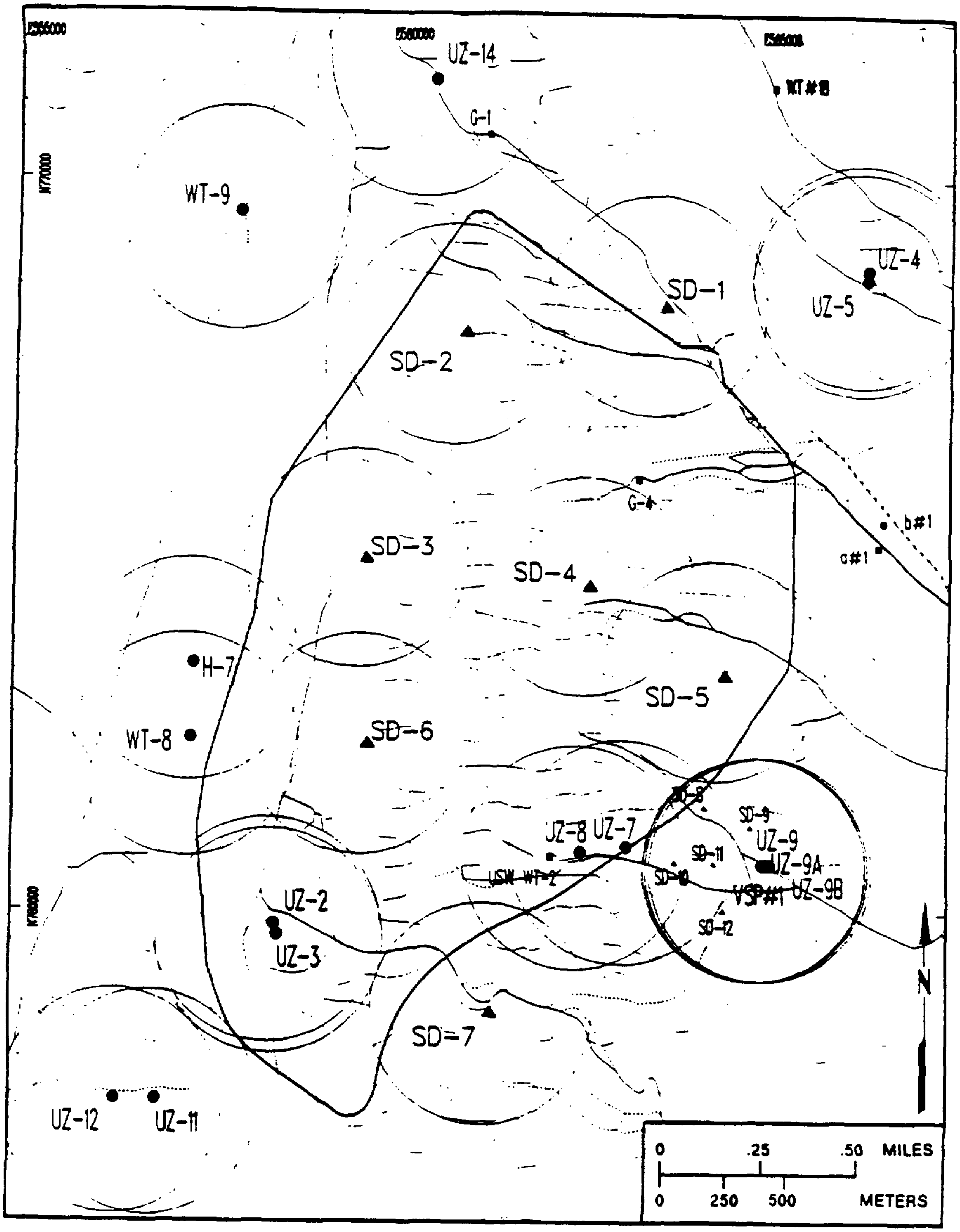

Figure 8.3.1.4-10a. Yucca Mountain systematic drilling program– areal coverage scheme. See Figure 8.3.1.4-10b for legend.

LEGEND

- ▲ SYSTEMATIC DRILLING PROGRAM
- ● FEATURE SAMPLING PROGRAM INTEGRATED WITH SYSTEMATIC PROGRAM
- • EXISTING HOLES SUITABLE FOR RESAMPLING
- ◯ 500 FOOT BUFFER

- LIGHT DUTY ROADS
- UNIMPROVED ROADS
- TRAILS
- POWERLINES
- PERIMETER DRIFT BOUNDARY

SOURCES:

50 M ELEVATION CONTOURS – USGS 1:100,000 BEATTY QUAD

1956 1:24,000 USGS TOPOGRAPHIC MAPS

1976 1:24,000 USGS ORTHOPHOTO MAPS

1983 1:100,000 USGS TOPOGRAPHIC MAPS

7/1986 AND 9/1987 1:24,000 AERIAL PHOTOGRAPHY

GRID TICKS BASED ON NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE

PERIMETER DRIFT BOUNDARY – SNL DRAWING R07003A

MAP COMPILED IN AUGUST 1988

NOTE: THE FOLLOWING DRILL HOLES SHOWN ON FIGURE 8.3.1.4-11a ARE WITHIN THE NEVADA TEST SITE BOUNDARY AND ARE DESIGNATED WITH PREFIX UE25: a#1, b#1, WT#18, UZ-4, UZ-5, UZ-9A, UZ-9B, SD-9, AND VSP#1. ALL THE REST ARE DESIGNATED WITH THE PREFIX USW.

Figure 8.3.1.4-10b. Legend for Figure 8.3.1.4-10a

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

The tuffaceous beds of the Calico Hills have been designated as a primary barrier for waste isolation in the performance allocation process described in Section 8.1. A review of selected physical properties data (porosity and air permeability) available for the tuffaceous beds of the Calico Hills unit indicated that the maximum range of spatial correlation for this unit was roughly 3,000 ft. This 3,000-ft distance is a preliminary estimate of the distance over which these properties can be interpolated using the geostatistical approach. These preliminary results suggest that one or more boreholes should be less than 3,000 ft away from any given location to reduce the uncertainty (relative to taking the mean and standard deviation of all the data). The 3,000-ft spacing also provides that for 87.2 percent of the area within the CPDB, any given point within the CPDB will be less than 1,500 ft away from at least one borehole. The integrated feature sampling and systematic drilling programs will thus provide acceptable areal coverage of the area within the CPDB. If a geostatistical model with correlation length of about 3,000 ft or more is used in conjunction with performance assessment, then reduction of statistical uncertainty throughout the site area would result without additional drilling.

An alternative basis for the number of boreholes in the areal coverage scheme is to approximate the minimum number of similar boreholes in the feature sampling program, with which statistical comparison can be used for detection of bias. The number of such boreholes in the feature sampling program has been set by plans for hypothesis testing. Five such boreholes are planned in the immediate site vicinity including USW holes UZ-2, UZ-3, UZ-7, UZ-8, and H-7 (Activities 8.3.1.2.2.3.2 and 8.3.1.2.3.1.1). Other such boreholes are also available at slightly greater distances from the site. In general the number of boreholes in the "unbiased" set should be comparable to the number of other boreholes, for statistical comparison. This rationale assumes that the Calico Hills unit will eventually be investigated by borehole penetration or excavation at the exploratory shaft facility location.

Geostatistical evaluation

The systematic drilling program is intended to provide sufficient data for meaningful evaluation of the geostatistical approach to modeling spatial variability, particularly for basic matrix properties including porosity, saturation, and saturated hydraulic conductivity. Preliminary plans for new drilling, combined with data from existing boreholes, will provide information about the spatial variation of certain rock characteristics at the site.

The information needed to evaluate the geostatistical approach consists of sufficient numbers of pairs of observations (boreholes) separated by various distances ranging from about 1,000 ft up to about 10,000 ft. The lower separation value corresponds roughly to the upper spacing limit of sampling in the ESF and associated boreholes. The upper value approximates the maximum dimension of the CPDB.

Trend analysis is typically required for geostatistical evaluation. Data trends with depth or borehole location may be related to such factors as distance to the eruptive source of a tuff unit, or stratiform lithologic differentiation that occurs during welding and cooling (Section 8.4.2.1.5.4). Methods used for trend fitting usually require data from outside the study area (e.g., outside the CPDB) to constrain the trend model at the edges of the

 YMP/CM-0011, Rev. 1

study area. A wide distribution of boreholes, is therefore, needed for detection and modeling of data trends within the site area. For hydrologic state information (e.g., matrix saturation), this control will be provided by a number of planned boreholes outside the perimeter drift (including UE25 holes UZ-4, UZ-5, UZ-9, UZ-9A, and UZ-9B, and USW holes UZ-10, UZ-11, UZ-12, UZ-13, UZ-14, WT-8, and WT-9). The same boreholes may be used for modeling trends in stratigraphy or physical properties, and additional control may be obtained from numerous existing boreholes (including UE25 holes a#1, b#1, c#1, c#2, c#3, and WT#18, and USW holes H-1, H-3, H-6, G-1, G-2, G-3, GU-3, WT-1, WT-7, and UZ-1).

Gridded locations provide the maximum density of borehole pairs at discrete spacings; however, the need to control surface disturbance at Yucca Mountain, and the integration of systematic drilling with the feature sampling program, make a gridded program impractical. Instead, a standard approach is used whereby borehole pairs are grouped in spacing ranges. A rule of thumb for geostatistical analysis holds that the number of pairs in each spacing range should be at least 30. The actual number of pairs that is acceptable for each spacing range will depend heavily on the data values. However, the rule is a valid basis for planning the systematic drilling program, because insufficient information is available (especially at the smaller spacings) to indicate otherwise.

According to statistical principles, the borehole pairs used for statistical modeling should reside within a domain where it is physically reasonable to use a single model for prediction, and where certain statistical properties of variability are uniform. For the systematic drilling program, the domain is taken as the area within the perimeter drift and immediate vicinity. It would be impractical to drill the entire domain at 1,000-ft spacing, and so the small spacings are investigated in a limited area. The assumption that this area is representative of the domain will be evaluated from the results of the twelve planned boreholes, and other boreholes of the feature-sampling program, and possibly investigated further in additional systematic drilling.

Boreholes SD-8 through SD-12 on Figure 8.3.1.4-11 are located just outside the southeastern part of the CPDB. They are clustered in reasonably accessible locations near USW UZ-7, USW UZ-8, and the UE25 UZ-9/9A/9B complex of boreholes, which increases the number of spacings. The distribution of different spacings possible from the systematic drilling program (USW holes SD-1 through SD-8 and SD-10 through SD-12, and UE25 SD-9), plus the other planned penetrations indicated on Figure 8.3.1.4-10, is shown by the histogram of Figure 8.2.1.4-12. The spacings in this figure are sorted in ranges of 1,000 ft, but may be redefined if appropriate for geostatistical modeling. Several existing boreholes within the perimeter drift or immediate vicinity are accessible for relogging and resampling; if these holes (USW holes UZ-6, UZ-6S, H-6, G-1, G-3, GU-3, G-4, and WT-Z; and UE25 holes a#1, b#1, c#1, c#2, and c#3) are included in the spacing compilation, the histogram of Figure 8.3.1.4-13 results. The two figures show that the systematic drilling program, together with existing boreholes and additional planned drilling, results in greater than 30 borehole pairs in spacing ranges up to 10,000 ft. Thus the systematic drilling program meets the requirements for geostatistical evaluation, and will provide significant additional information for a subset of rock characteristics if integrated with existing boreholes.

YMP/CM-0011, Rev. 1

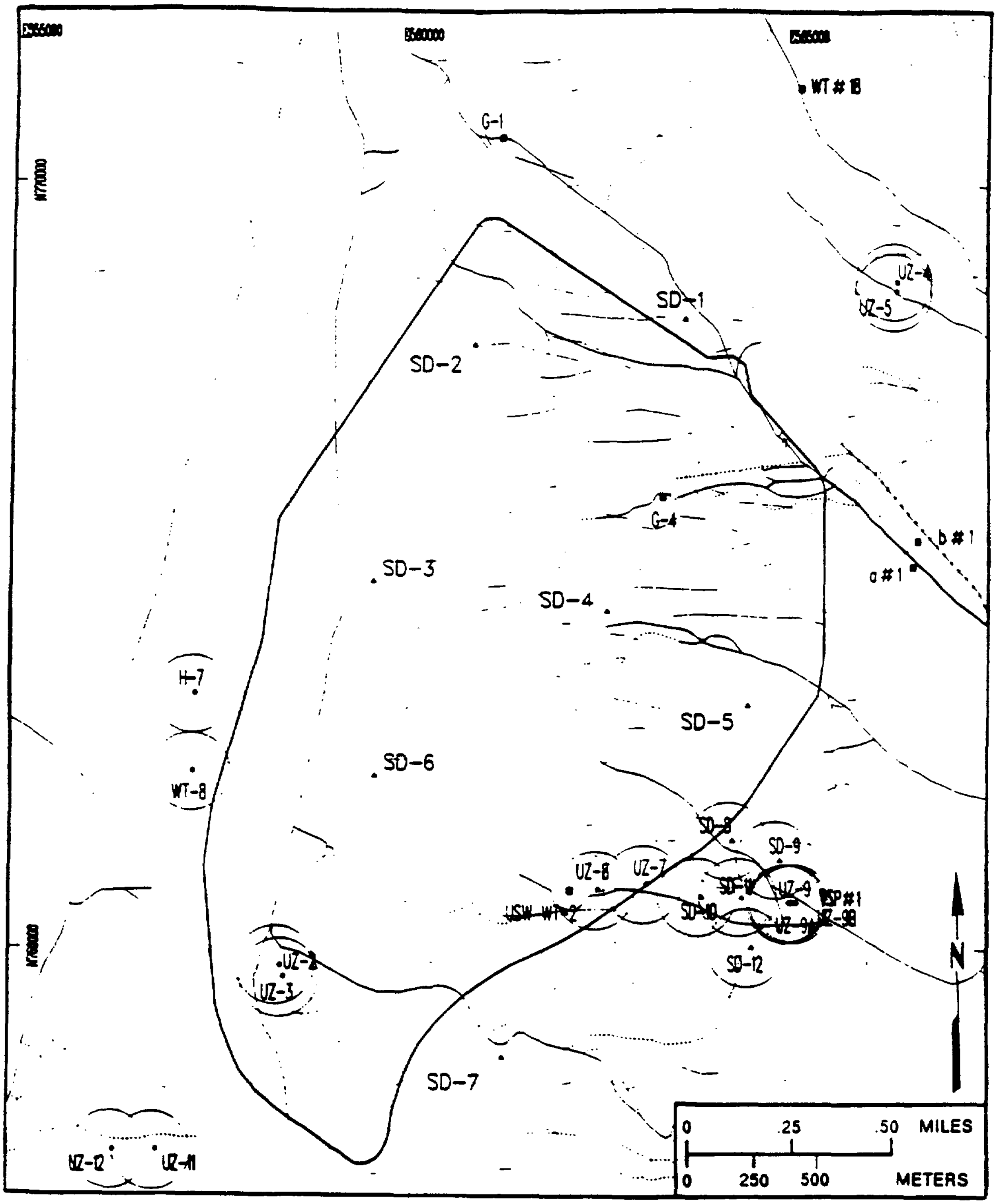

Figure 8.3.1.4-11a. Yucca Mountain systematic drilling program– small scale variability test drill hole location. See Figure 8.3.1.4-11b for legend.

LEGEND

- ▲ SYSTEMATIC DRILLING PROGRAM
- ● FEATURE SAMPLING PROGRAM INTEGRATED WITH SYSTEMATIC PROGRAM
- • EXISTING HOLES SUITABLE FOR RESAMPLING
- ◯ 500 FOOT BUFFER

- LIGHT DUTY ROADS
- UNIMPROVED ROADS
- TRAILS
- POWERLINES
- PERIMETER DRIFT BOUNDARY

SOURCES:

50 M ELEVATION CONTOURS - USGS 1:100,000 BEATTY QUAD

1956 1:24,000 USGS TOPOGRAPHIC MAPS

1976 1:24,000 USGS ORTHOPHOTO MAPS

1983 1:100,000 USGS TOPOGRAPHIC MAPS

7/1986 AND 9/1987 1:24,000 AERIAL PHOTOGRAPHY

GRID TICKS BASED ON NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE

PERIMETER DRIFT BOUNDARY - SNL DRAWING R07003A

MAP COMPILED IN AUGUST 1988

NOTE: THE FOLLOWING DRILL HOLES SHOWN ON FIGURE 8.3.1.4-12b ARE WITHIN THE NEVADA TEST SITE AND ARE DESIGNATED WITH THE PREFIX UE25: a#1, b#1, WT#18, UZ-4, UZ-5, UZ-9, UZ-9A, UZ-9B, SD-9, AND VSP#1. THE REMAINING DRILL HOLES (OUTSIDE THE BOUNDARY) ARE DESIGNATED WITH THE USW PREFIX.

Figure 8.3.1.4-11b. Legend for Figure 8.3.1.4-11a.

YMP/CM-0011, Rev. 1

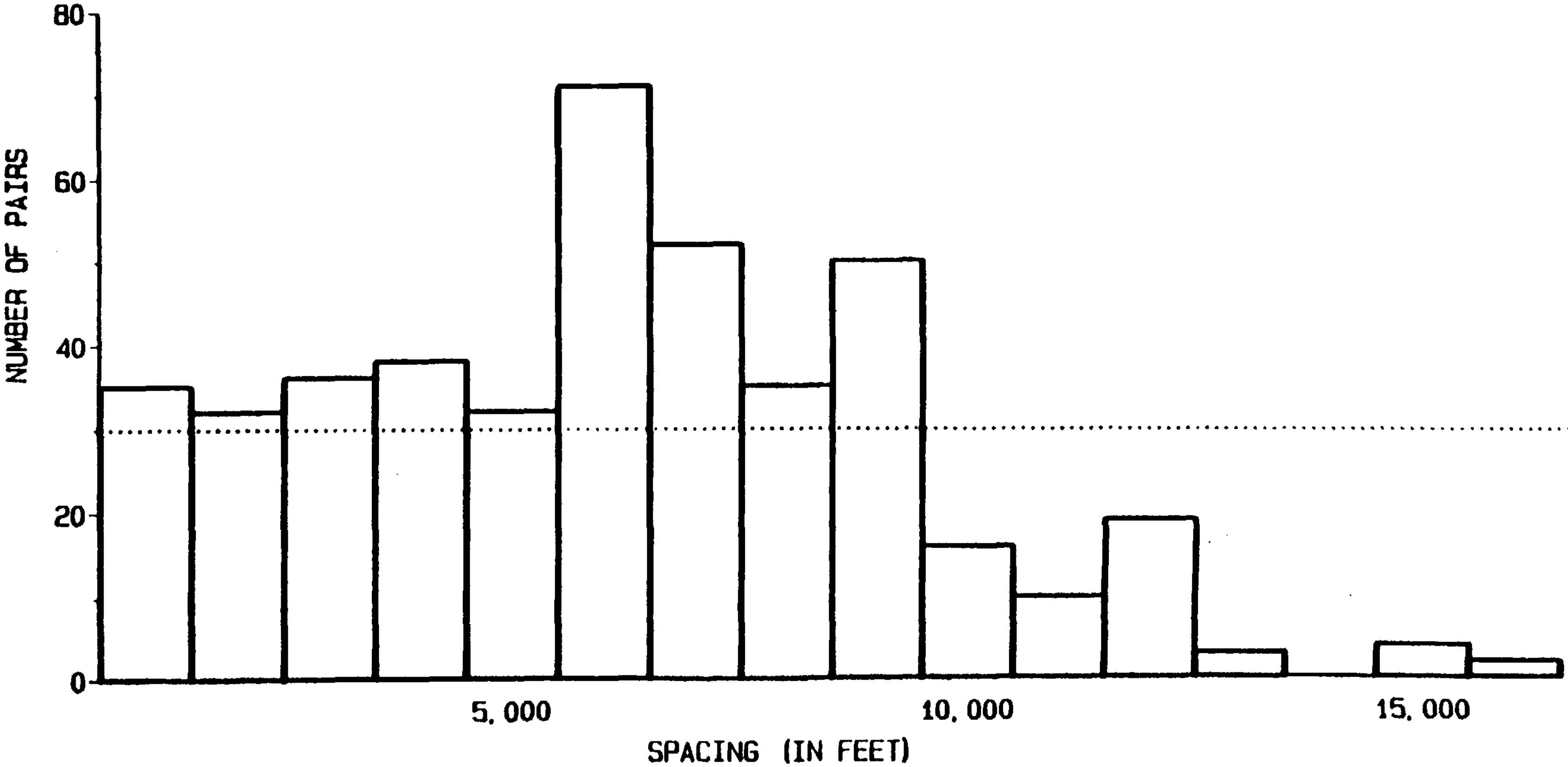

Figure 8.3.1.4-12. Histogram of data pairs for geostatistical analysis Based on systematic drilling program, plus selected proposed boreholes from the site vertical boreholes study, site potentiometric level monitoring activity, and Solitario Canyon Fault study in the saturated zone

YMP/CM-0011, Rev. 1

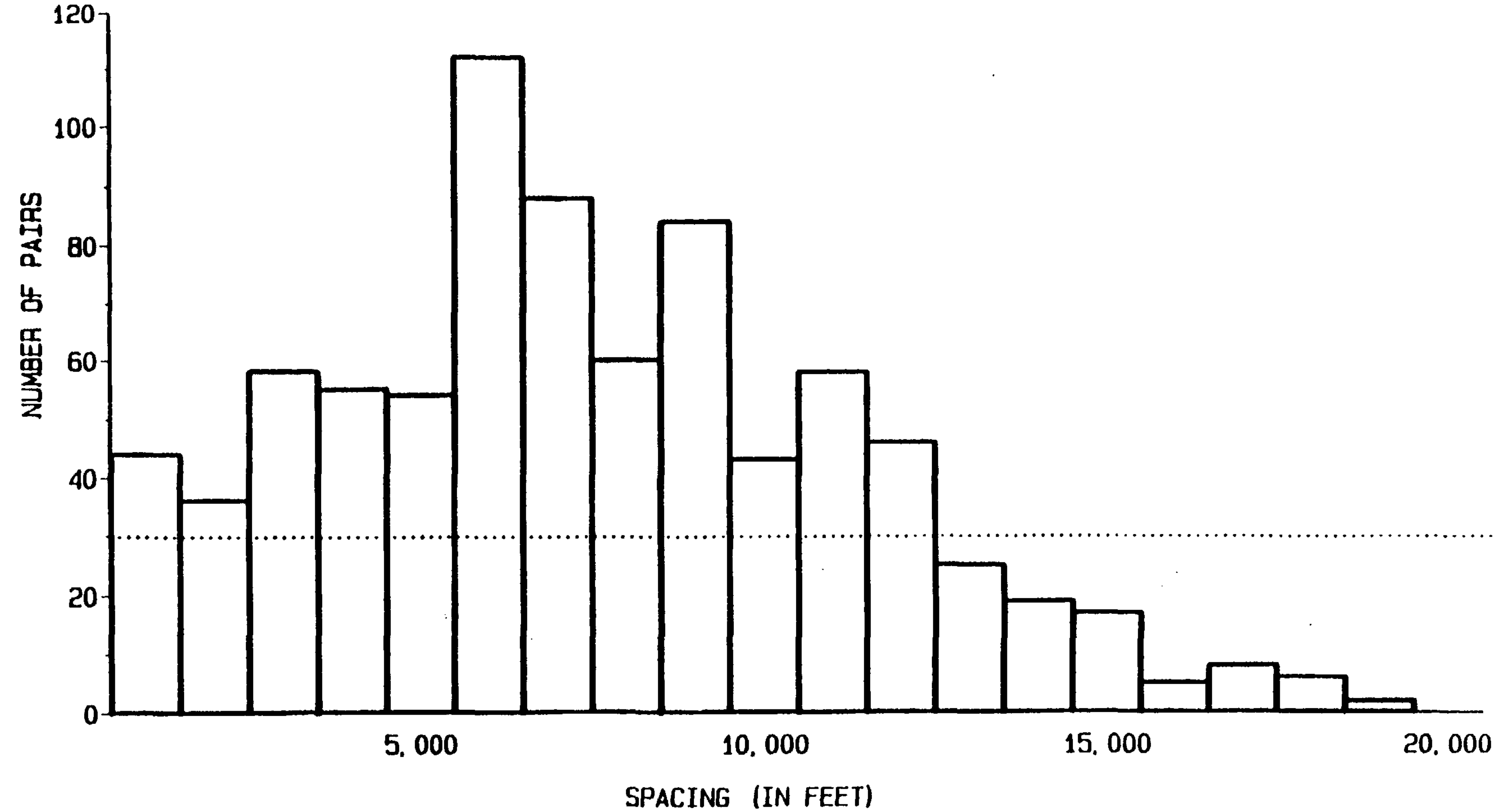

Figure 8.3.1.4-13. Histogram of data pairs for geostatistical analysis. Based on systematic drilling program, plus selected existing and proposed boreholes from the feature sampling program.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

Some loss of information may be incurred from separate use of boreholes located in clusters, for generating larger spacings. For example, the USW UE25 USW UZ-9 complex of boreholes (spaced about 100 ft apart) will be used in conjunction with USW holes SD-8, SD-10, SD-11, and SD-12; and UE25 SD-9 for generating multiple spacings of 1,000 ft or more. This effect depends on the correlation structure, and on persistence of residual trends in the data set. When the data from the boreholes just listed become available, the effect will be evaluated to determine the extent to which it causes bias in the evaluation of the geostatistical approach.

Analysis and sampling strategy

All available core will be described, photographed, and logged graphically for unit contacts, fracture parameters, and gross engineering indicators such as RQD. A small suite of matrix properties including porosity, saturation, and saturated conductivity will be intensively analyzed for spatial dependence. The underlying logic is that the basic spatial correlation patterns determined in this manner can probably be correlated statistically to the spatial distribution of other rock characteristics. Measurement of these parameters is relatively inexpensive and can be extended to a large number of samples, increasing confidence. Rock characteristics such as unsaturated matrix conductivity are much more costly to measure and cannot be similarly repeated. Once a common correlation structure has been established, the set of more frequent measurements can be used directly for estimating the sparse set.

Subsequent to logging, the recovered material will be sampled systematically according to a predetermined scheme. This scheme is designed to support statistically representative measurements of the following basic properties saturation, porosity, and saturated hydraulic conductivity. After basic measurements are completed, the same samples (along with other samples according to the scheme) will be analyzed by different studies, culminating in measurements that require destructive testing. Determination of multiple properties from the same specimens is important for correlating variability of different parameters with nonuniform measurement support. Figure 8.3.1.4-14 summarizes in a conceptual manner the coordination of multiple sampling efforts for the same specimens. The scheme that is actually used will be determined through further planning and the integration function of the Project Sample Overview Committee.

The sampling program for sample group A (sampled for porosity, saturated hydraulic conductivity, and saturation) will be conducted in the Sample Management Facility according to the predetermined scheme. In this conceptual scheme, porosity and saturation data are measured on samples collected every 1.5 m (5 ft); saturated conductivity would be measured for alternating samples, or every 3 m (10 ft). A secondary sampling program would be undertaken in at least two intervals within each unit to sample close-order variability. This secondary program is represented schematically on the left-hand side of Figure 8.3.1.4-14.

 YMP/CM-0011, Rev. 1

Sample group B (Figure 8.3.1.4-14) may be collected to investigate rock characteristics that do not require the same intensity of sampling as group A. This may be because less confidence in the parameter is required by the performance allocation, or because the cost of a single measurement is many times the cost of a porosity or saturation test. Similarly, sample groups C and D would be collected for investigation of properties with different requirements. All the sample groups are referred back to the basic matrix properties, because all the samples were originally tested in the same way. The statistical model for variability of each group can be enhanced (at least in principle) through the use of the model for basic properties.

8.3.1.4.3.2 Study: Three-dimensional rock characteristics models

8.3.1.4.3.2.1 Activity: Development of three-dimensional models of rock characteristics at the repository site

<u>Objectives</u>

The objective of this activity is to develop computer-based three-dimensional models that integrate quantitative and semiquantitative data on rock characteristics in light of constraining information developed by studies of the geologic framework of the Yucca Mountain site (Investigation 8.3.1.4.2).

<u>Description</u>

This study will serve as the process whereby the majority of location-specific site characterization data describing rock characteristics is summarized and interpreted in light of a constraining geologic framework (Investigation 8.3.1.4.2) for Yucca Mountain. This study also will result in models that will be the means by which these data pass from site characterization investigations to design and performance assessment studies. Because the rock characteristics data and the geologic framework information both will be represented as three-dimensional computer-based models that are closely linked to the Yucca Mountain Project Technical Data Base, representations of the model may take many forms depending upon the use of the information. For example, information from the model may be represented as contour (isopleth) maps, cross sections, level plans, "3-D" perspective illustrations, statistical distributions (histograms, means, variances), and as numerical data files for direct input to computer codes used for performance assessment or design analyses. The primary requirement of input data for the three-dimensional rock property models is systematic and statistically valid (unbiased) sampling at scales adequate to allow quantitative characterization of the spatial variability of the parameters of interest at Yucca Mountain. Characterization of spatial variability will depend heavily upon geostatistical techniques. Determination of sampling intervals and parameters will rely upon geostatistical analysis in conjunction with sensitivity studies conducted by the associated performance assessment or design information needs.

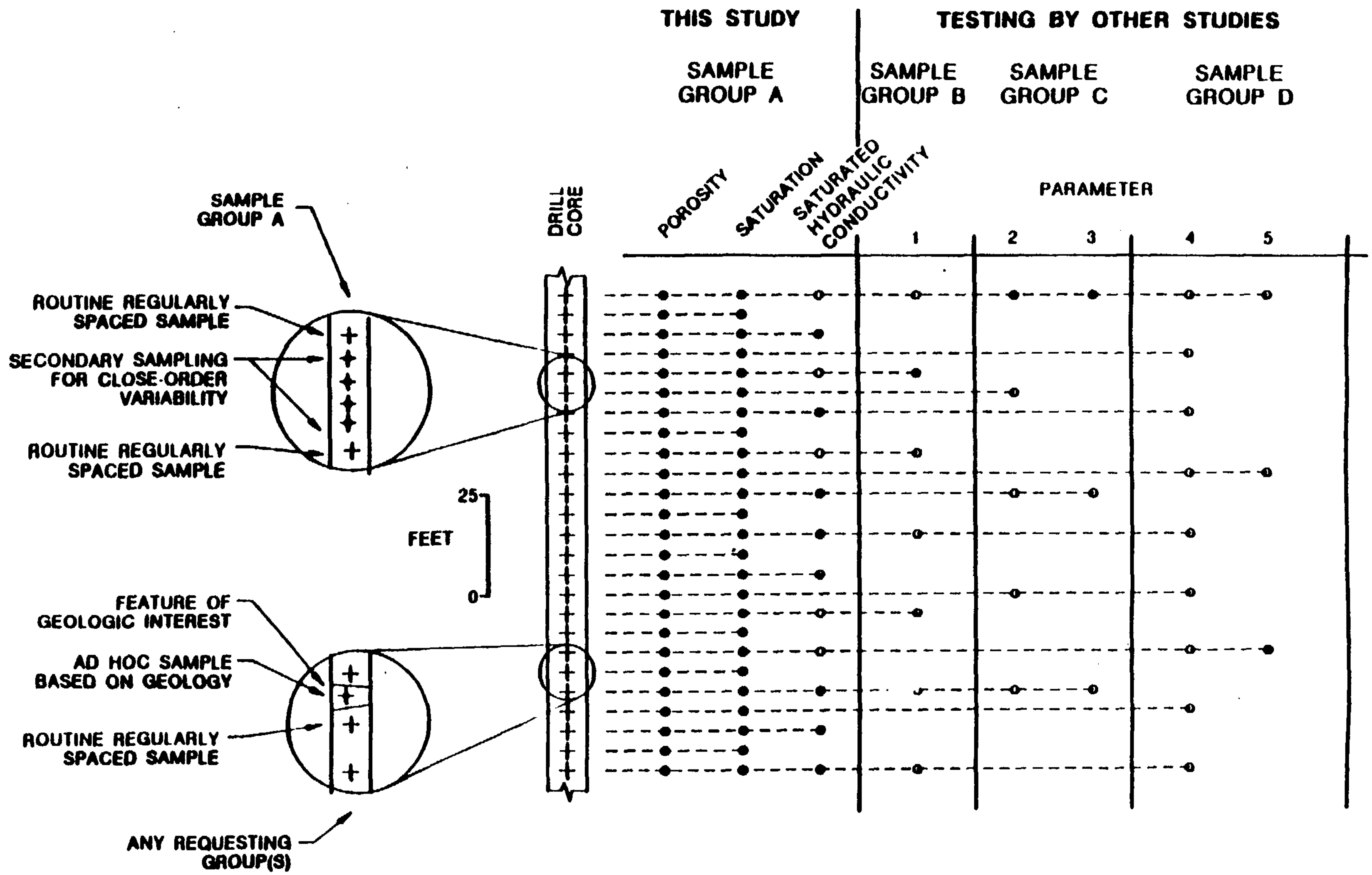

Figure 8.3.1.4-14. Possible systematic sampling program.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

Much of the analysis of the spatial variability will depend upon detailed knowledge of a few selected rock characteristics (e.g., porosity, saturated hydraulic conductivity, saturation) that will be obtained as part of the integrated drilling program described by Investigation 8.3.1.4.1. These parameters will serve as surrogates in determining the spatial variability of several other parameters needed by performance assessment and design issues in preliminary stages of the analyses. Because the basic spatial distribution of properties of the rock mass at Yucca Mountain is that produced by the processes of volcanic eruption, transport, deposition, and post-depositional alteration (including welding and devitrification), the quantitative description of the distribution should correspond to parameters that derive their distribution from some part of those emplacement and alteration processes.

The measured values of parameters from which the final modeling activities will be conducted, will come largely from Site Programs 8.3.1.2 (geohydrology), 8.3.1.3 (geochemistry), and 8.3.1.15 (thermal and mechanical properties).

The models typically will be constructed as follows. First, measured values of the hydrogeologic, geochemical, or thermal/mechanical parameters of interest (from drillholes and the exploratory shaft facility) will be mapped into their proper three-dimensional location in model space. Second, geologic framework information (the altitude of geologic contacts, fault locations and offsets, etc.), from Investigation 8.3.1.4.2 also will be mapped into three-dimensional model space. The spatial structure of the observed values (actual measurements) will be determined by geostatistical techniques (variogram or covariance analysis). The spatial structure of a group of related parameters may be further refined by study of the cross-covariances among those quantities. Conflicts between the observed spatial structure of quantitative data and the structure implied by the geologic framework will be resolved (e.g., identification of a concealed fault, reinterpretation of volcanic source area or flow path, or identification of some previously unknown alteration phenomenon). Surface-based and borehole geophysical interpretations will also provide a constraint upon subsurface modeling. The geostatistical techniques of covariance analysis and kriging will be used to determine when the spatial structure of a parameter of interest is sufficient.

Hydrologic, thermal/mechanical, and geochemical rock property measurements then will be interpolated into unsampled areas constrained by the observed values at sampling points, by the faulted stratigraphy, and by the identified spatial structure. The most detailed approach to this phase of modeling involves the formulation of a three-dimensional block model, wherein the site is divided into numerous orthogonal blocks and each block is sufficiently small that the parameter of interest may be treated as constant within the block. Once the structure of the data is determined, the values of unsampled blocks are estimated (interpolated) by techniques such as kriging (or cokriging). Geostatistical techniques provide estimates of the uncertainty associated with each parameter within each block. Estimates of the probability that the true value in each block exceeds some predetermined limit or is within some range of values (specified by the corresponding performance assessment or design issue) are also possible.

 YMP/CM-0011, Rev. 1

8.3.1.5 Overview of the climate program: Description of future climate conditions, required by the performance and design issues

Summary of performance and design requirements for climate information

Certain performance and design issues address requirements that climate and climate-related factors be determined for past, present, and future conditions (Investigation 8.3.1.5.1) and that the effects of future climate on hydrology be determined (Investigation 8.3.1.5.2). The results of Investigation 8.3.1.5.1 are necessary inputs to Investigation 8.3.1.5.2. Pertinent available data on recent climate, meteorology, and paleoclimate are presented in Chapter 5 along with a discussion of methods for predicting future climate. Similarly, available hydrology data pertinent to Yucca Mountain are presented in Chapter 3. The general conclusions from Chapters 3 and 5 are that more data are required than are presently available on the paleohydrology, paleoclimate, and modern climate of the Yucca Mountain area in order to adequately predict future climate and its possible effect on site hydrology relative to repository performance.

Plans for two investigations making up the climate program are given in Sections 8.3.1.5.1 and 8.3.1.5.2. Other plans for site investigations requiring climate information include those for the erosion program (Section 8.3.1.6), the geochemistry program (Section 8.3.1.3), the preclosure hydrology program (Section 8.3.1.16), and the geohydrology program (Section 8.3.1.2). The relationship between the climate program and the design and performance issues is shown in Figure 8.3.1.5-1.

The climate program consists of investigations designed to provide data on past, present, and future climate conditions and to determine the effects of climate change on surface, unsaturated-zone, and saturated-zone hydrology. Specifically, determining the effects of future climate on geohydrology helps to satisfy the following performance and design issues.

Issue	Short title	SCP section
1.1	Total system performance (the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR Part 60 and 40 CFR 191.13)	8.3.5.13
1.8	NRC siting criteria (the favorable and potentially adverse conditions of 10 CFR Part 60)	8.3.5.17
1.9a	Higher level findings (postclosure) of 10 CFR Part 960: (1) 960.4-2-1, qualifying condition for geohydrology, (2) 960.4-2-4, qualifying condition for climate	8.3.5.18

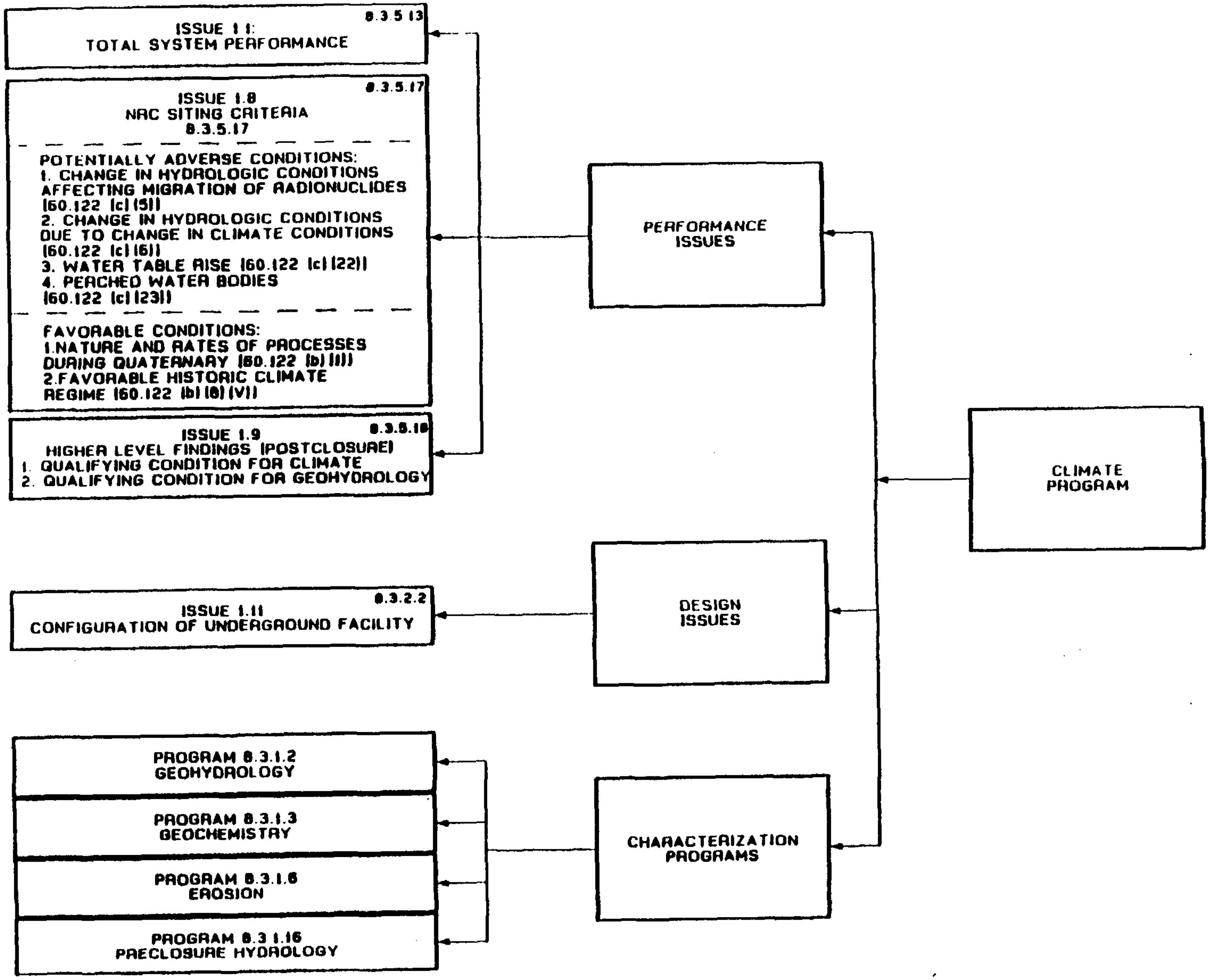

Figure 8.3.1.5-1. General logic diagram showing ties between climate program and other characterization programs, design issues, and performance issues.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

Issue	Short title	SCP section
1.9b	Comparative evaluation over next 100,000 yr	8.3.5.18
1.10	Waste package characteristics (postclosure)	8.3.4.2
1.11	Configuration of underground facilities (postclosure)	8.3.2.2
1.12	Seal characteristics	8.3.3.2

For the 10,000-yr period (Issues 1.1, 1.8, 1.9a, 1.10, 1.11, and 1.12), it has been determined that information needed to satisfy Issue 1.1 will be sufficient to address Issues 1.8, 1.9a, 1.10, 1.11, and 1.12. However, to satisfy Issue 1.9b (the comparative evaluation over the next 100,000 yr), additional information is required within the climate program, including additional data and slightly different modeling strategies (Section 8.3.1.5.1.6.2).

Table 8.3.1.5-1 lists the specific repository performance scenarios related to climatic change in the "initiating event or process" column. These scenarios have been identified as being of concern to Issues 1.1 and 1.9b. Each scenario has a related performance measure, as shown in column 2. Each performance measure has two performance parameters in the third column, related to either the 10,000-yr or 100,000-yr period. Each performance measure has an additional parameter assigned as the quantitative bound on the expected magnitude of the performance parameter. Following the performance parameters are the tentative goals and corresponding confidence levels needed to meet the total system performance objectives.

The primary climatic variables that have an effect on the performance measures include magnitude and intensity of precipitation, storm types as they influence initial runoff and snow accumulation, and snowmelt and evapotranspiration. The relationship between the performance parameters and the related climate investigations is presented in the next section.

Approach to satisfy performance and design requirements

The investigations, studies, and activities within the climate program are designed to provide estimates of future climatic conditions and estimates of the effects of future climate on hydrologic conditions. Figure 8.3.1.5-2 traces the flow of information to show how data-gathering activities lead to modeling and synthesis activities to finally result in a determination of the effects of future climate on unsaturated-zone, saturated-zone, and surface-water hydrology to satisfy Performance Issues 1.1 and 1.9b (and subsequently Issues 1.8, 1.10, 1.11, and 1.12) as discussed in the previous section. This figure ties into Table 8.3.1.5-2.

Table 8.3.1.5-1. Initiating events or processes and associated performance measures (for climate program) (page 1 of 2)

Initiating event or process	Intermediate performance measures	Performance parameters	Tentative goal	Needed confidence
Climatic changes cause increase in infiltration over C-area[a]	Radionuclide transport time through UZ[b], given fixed UZ thickness, rock hydrologic properties, and geochemical properties	Expected magnitude of flux change due to climatic changes over next 10,000 yr (to satisfy Issue 1.1)	Show expected flux change will be < 5 mm/yr	High
		Expected magnitude of flux change due to climatic changes over 100,000 yr (to satisfy Issue 1.9b)	Show expected flux change will be < 5 mm/yr	High
Climatic changes cause an increase in altitude of water table	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Expected magnitude of change in water-table level due to climatic changes over next 10,000 yr (to satisfy Issue 1.1)	Show expected magnitude of change in water-table altitude will be <+100 m	High
		Expected magnitude of change in water-table level due to climatic changes over next 100,000 yr (to satisfy Issue 1.9b)	Show expected magnitude of change in water-table altitude will be <+100 m	Moderate
Climatic change causes an increase in the gradient of the water table within the C-area	Radionuclide transport time through SZ[c], given fixed distances to accessible environment boundary	Expected magnitude of change in water-table gradient due to climatic change over the next 10,000 yr (to satisfy Issue 1.1)	Show change will be $< 2 \times 10^{-3}$	Moderate

YMP/CM-0011, Rev. 1

Table 8.3.1.5-1. Initiating events or processes and associated performance measures (for climate program) (page 2 of 2)

Initiating event or process	Intermediate performance measures	Performance parameters	Tentative goal	Needed confidence
		Expected magnitude of change in water-table gradient due to climatic change over next 100,000 yr (to satisfy Issue 1.9b)	Show change will be $< 2 \times 10^{-3}$	Moderate
Climatic change causes appearance of surficial discharge points within C-area	Radionuclide transport time through SZ, given fixed SZ rock hydrologic and geochemical properties	Expected locations of surficial discharge points within C-zone over the next 10,000 yr; magnitudes of discharges at each location (to satisfy Issue 1.1)	Show that no significant surficial discharge points could appear within C-area, given a water-table rise <+160 m	Moderate
		Expected locations of surficial discharge points within the C-zone due to climatic change over the next 100,000 yr (to satisfy Issue 1.9b)	Show that no significant surficial discharge points could appear within C-area, given a water-table rise <+160 m	Moderate

[a]C-area = controlled area.
[b]UZ = unsaturated zone.
[c]SZ = saturated zone.

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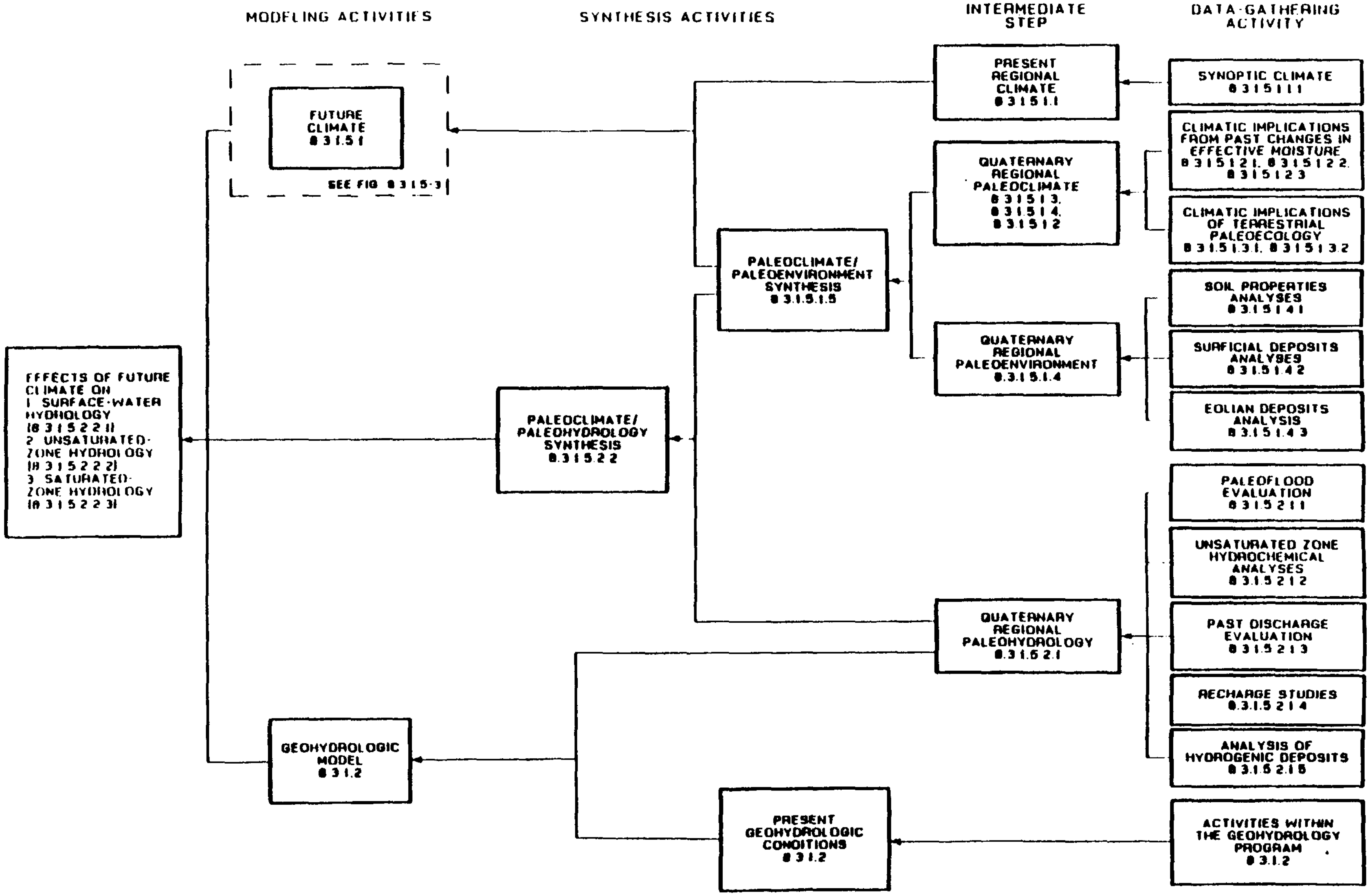

Figure 8.3.1.5-2. Logic diagram for climate program.

YMP/CM-0011, Rev. 1

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 1 of 6)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by climate characterization program: Activity parameter	Response by climate characterization program: SCP activity
1.1, 1.9b	8.3.5.13, 8.3.5.18	Present regional climate	Monthly and annual values for temperature	8.3.1.5.1.1.1
			Monthly and annual values for precipitation	8.3.1.5.1.1.1
			Monthly and annual values for wind-velocity	8.3.1.5.1.1.1
			Spatial and temporal variation of precipitation	8.3.1.5.1.1.1
			Spatial and temporal variation of air temperature	8.3.1.5.1.1.1
1.1, 1.9b	8.3.5.13, 8.3.5.18	Quaternary regional paleoclimate	Paleontology (ostracodes, diatoms, aquatic palynomorphs, etc.) in marsh, lake, and playa deposits	8.3.1.5.1.2.1
			Lithostratigraphy of marsh, lake, and playa deposits	8.3.1.5.1.2.2
			Clastic sedimentology of marsh, lake, and playa deposits	8.3.1.5.1.2.2
			Chemical sedimentology of marsh, lake, and playa deposits	8.3.1.5.1.2.2
			Major element analyses of bulk sediments from marsh, lakes, and playas	8.3.1.5.1.2.2
			Carbonate mineralogy of bulk sediments from lakes, marshes, and playas	8.3.1.5.1.2.3

YMP/CM-0011, Rev. 1

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 2 of 6)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by climate characterization program: Activity parameter	Response by climate characterization program: SCP activity
1.1, 1.9b (continued)	8.3.5.13, 8.3.5.18 (continued)	Quaternary regional paleoclimate (continued)	Non-carbonate mineralogy of bulk sediments from lakes, playas, and marshes	8.3.1.5.1.2.3
			Stable isotope analyses of bulk sediments from lakes, playas, and marshes	8.3.1.5.1.2.3
			Ages of playa, lake, and marsh deposits	8.3.1.5.1.2.4
			Pack-rat midden compositions	8.3.1.5.1.3.1
			Pack-rat midden distributions	8.3.1.5.1.3.1
			Pack-rat midden ages	8.3.1.5.1.3.1
			Pollen and spore compositions	8.3.1.5.1.3.2
			Pollen and spore distributions	8.3.1.5.1.3.2
			Pollen and spore ages	8.3.1.5.1.3.2
			Pollen-climate transfer functions	8.3.1.5.1.3.3
			Vegetation-climate and pollen-climate response surfaces	8.3.1.5.1.3.3
1.1, 1.9b	8.3.5.13, 8.3.5.18	Quaternary regional paleoenvironment	Soil morphology and distribution	8.3.1.5.1.4.1
			Soil physical properties	8.3.1.5.1.4.1
			Soil chemical properties	8.3.1.5.1.4.1

YMP/CM-0011, Rev. 1

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 3 of 6)

Calls by performance and design issues		Parameter category	Response by climate characterization program	
Issue	SCP section		Activity parameter	SCP activity
1.1, 1.9b (continued)	8.3.5.13, 8.3.5.18 (continued)	Quaternary regional paleoenvironment (continued)	Dust physical properties	8.3.1.5.1.4.1
			Dust chemical properties	8.3.1.5.1.4.1
			Soil water holding capacity	8.3.1.5.1.4.1
			Soil partial pressure of CO_2	8.3.1.5.1.4.1
			Movement of soil solutions	8.3.1.5.1.4.1
			Rates of carbonate translocation in soils	8.3.1.5.1.4.1
			Ages of soils	8.3.1.5.1.4.1
			Physical properties of surficial deposits	8.3.1.5.1.4.1, 8.3.1.5.1.4.2
			Soil mineralogical properties	8.3.1.5.1.4
			Ages of surficial deposits	8.3.1.5.1.4.1, 8.3.1.5.1.4.2
			Soil water chemistry	8.3.1.5.1.4.1
			Distribution of surficial deposits	8.3.1.5.1.4.2
			Thickness of surficial deposits	8.3.1.5.1.4.2
			Chemical properties of surficial deposits	8.3.1.5.1.4.2
			Mineralogical properties of surficial deposits	8.3.1.5.1.4.2
			Ages of eolian deposits	8.3.1.5.1.4.3
			Trace element geochemistry in eolian deposits	8.3.1.5.1.4.3
			Trace element geochemistry in alluvium	8.3.1.5.1.4.3
			Paleowind velocity	8.3.1.5.1.4.3

YMP/CM-0011, Rev. 1

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 4 of 6)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by climate characterization program: Activity parameter	SCP activity
1.1, 1.9b	8.3.5.13, 8.3.5.18	Paleoclimate paleo-environmental synthesis	Paleoprecipitation distributions	8.3.1.5.1.5.1
			Paleoprecipitation intensities	8.3.1.5.1.5.1
			Paleotemperature patterns	8.3.1.5.1.5.1
			Paleoevaporation rates	8.3.1.5.1.5.1
			Time series of paleoprecipitation at key locations	8.3.1.5.1.5.1
			Time series of paleoevaporation rates at key locations	8.3.1.5.1.5.1
			Time series of paleotemperature at key locations	8.3.1.5.1.5.1
			Magnitude of high paleoprecipitation	8.3.1.5.1.5.1
			Duration of high paleoprecipitation periods	8.3.1.5.1.5.1
			Occurrence of high paleosnowmelt	8.3.1.5.1.5.1
			Magnitude of low paleotemperatures	8.3.1.5.1.5.1
			Magnitude of low paleoevaporation	8.3.1.5.1.5.1
1.1, 1.9b	8.3.5.13, 8.3.5.18	Future climate	Future seasonal distribution and average annual rainfall	8.3.1.5.1.6.3
			Future type and intensity of storms	8.3.1.5.1.6.3
			Future distribution and average annual snowfall and rapidity of snowmelt	8.3.1.5.1.6.3
			Future evapotranspiration	8.3.1.5.1.6.3
			Future cloud cover	8.3.1.5.1.6.3
			Future temperature	8.3.1.5.1.6.3
			Future wind speed and direction	8.3.1.5.1.6.3

YMP/CM-0011, Rev. 1

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 5 of 6)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by climate characterization program: Activity parameter	Response by climate characterization program: SCP activity
1.1, 1.9b	8.3.5.13, 8.3.5.18	Quaternary regional paleohydrology	Paleoflood magnitudes	8.3.1.5.2.1.1
			Paleoflood frequencies	8.3.1.5.2.1.1
			Paleoflood hydraulic characteristics	8.3.1.5.2.1.1
			Paleoflood debris movement quantities	8.3.1.5.2.1.1
			Paleoflood debris movement characteristics	8.3.1.5.2.1.1
			Travel times from Cl^{36} and C^{14}	8.3.1.5.2.1.2
			Unsaturated zone water isotopic characteristics	8.3.1.5.2.1.2
			Unsaturated zone water chemical characteristics	8.3.1.5.2.1.2
			Past evapotranspiration rate	8.3.1.5.2.1.3
			Past potentiometric head	8.3.1.5.2.1.3
			Location, type, and extent of hydrogeologic units	8.3.1.5.2.1.3
			Transmissivity	8.3.1.5.2.1.3
			Discharge of paleoseeps and paleosprings	8.3.1.5.2.1.3
			Locations of paleoseeps and paleosprings	8.3.1.5.2.1.3
			Analog infiltration rate	8.3.1.5.2.1.4
			Analog recharge rate	8.3.1.5.2.1.4
			Analog site effective moisture	8.3.1.5.2.1.4

YMP/CM-0011, Rev. 1

Table 8.3.1.5-2. Activity parameters provided by the climate program that support performance and design issues (page 6 of 6)

Calls by performance and design issues		Parameter category	Response by climate characterization program	
Issue	SCP section		Activity parameter	SCP activity
1.1, 1.9b (continued)	8.3.5.13, 8.3.5.18 (continued)	Quaternary regional paleohydrology (continued)	Mineralogy of calcite-silica deposits	8.3.1.5.2.1.5
			Petrology of calcite-silica deposits	8.3.1.5.2.1.5
			Morphology of calcite-silica deposits	8.3.1.5.2.1.5
			Paleontology of calcite-silica deposits	8.3.1.5.2.1.5
			Chemistry of calcite-silica deposits	8.3.1.5.2.1.5
			Ages of calcite-silica deposits	8.3.1.5.2.1.5
			Isotopic concentrations of calcite-silica deposits	8.3.1.5.2.1.5
1.1, 1.9b	8.3.5.13, 8.3.5.18	Paleoclimate/ paleohydrology synthesis	Relationship between climate (e.g. precipitation, temperature, evapotranspiration) and infiltration and recharge	8.3.1.5.2.1.1, 8.3.1.5.2.1.2, 8.3.1.5.2.1.3, 8.3.1.5.2.1.4, 8.3.1.5.2.1.5

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

Table 8.3.1.5-2 provides a direct link between the climate-related performance parameters (Table 8.3.1.5-1) and the activities in the climate characterization program by using "parameter categories." Each parameter category represents a group of activities (and the parameters to be addressed by those activities) that will be used to evaluate the climate-related performance parameters. There are seven parameter categories: present regional climate, Quaternary regional paleoclimate, Quaternary regional paleoenvironment, paleoclimate-paleoenvironmental synthesis, future climate, Quaternary regional paleohydrology, and paleoclimate-paleohydrology synthesis. From Table 8.3.1.5-1, there are essentially four types of performance parameters relating to changes in ground-water flux, changes in the elevation of the water table, changes in the gradient of the water table, and the potential for surface discharge points for ground water in the controlled area. All the parameter categories represent activities that provide information, directly or indirectly, to each of these performance parameters. The most direct link is between the future climate and the paleohydrology-paleoclimate synthesis parameter categories; however, the other categories are linked indirectly to the performance parameters through these categories.

The parameter categories listed in the table, which group the activity parameters, correspond to many of the square boxes on Figure 8.3.1.5-2. Two boxes, "present geohydrologic conditions" and "geohydrologic model," are not represented in the table because these activities do not take place within the climate program. The activity parameters represent either field or measured data or are directly calculated from field or measured data. These activity parameters are generally the output from their associated SCP activity listed in the next column. For data-gathering activities (far right on logic diagram), the associated parameter category is generally just a study-level grouping. For synthesis activities, which analyze data from multiple studies and activities, the parameter categories correspond exactly to the synthesis activities, and the associated activity parameters are the output from the synthesis activity. Modeling activities also have a direct correlation to parameter categories.

In all instances the calls by performance and design issues listed in the first column are derived from Issues 1.1 and 1.9b, and will also be used to satisfy Issues 1.8, 1.9a, 1.10, 1.11, and 1.12.

The following discussion follows the logic diagram and table and ties the climate program to the design and performance issues:

The first data-gathering activity (8.3.1.5.1.1.1) is designed to contribute to the characterization of the present regional synoptic climate along with temporal and spatial variations. This characterization is used to calibrate models of future climate as shown in the figure. The table shows the activity parameters (or data) gathered in this activity along with the parameter category associated with this study (modern regional climate).

The next two data gathering studies, 8.3.1.5.1.2 and 8.3.1.5.1.3, are designed to contribute to a chronology of paleoclimate. These studies draw upon evidence from lake, playa, and marsh sediments and terrestrial ecology (pollen and pack rat middens) to develop a qualitative interpretation of the Quaternary regional paleoclimate. The activity parameters associated with

 YMP/CM-0011, Rev. 1

these activities are shown in the table and fall under the category "Quaternary regional paleoclimate." These studies form the basis for further activities within the climate program.

Complementing the paleoclimate history will be four data-gathering activities (8.3.1.5.1.4.1 to 8.3.1.5.1.4.4) leading in the same manner to a chronology of paleoenvironment. These activities draw upon lines of evidence from soils, surficial deposits, eolian deposits, and geomorphology. The paleoclimate and paleoenvironmental activities are to be integrated ultimately into a paleoclimate-paleoenvironmental synthesis (Activity 8.3.1.5.1.5.1). It is expected that the principal line of evidence for the synthesis will be the paleoclimate history and that the paleoenvironment history will serve to complement the paleoclimate chronology. This synthesis is necessary for the assessment of long-term variability of paleoclimate and to provide a basis for the estimation of future climatic episodes. In addition, the results of this synthesis activity will be used to determine the potential effects of future climatic conditions on hydrologic conditions. The specific output from this synthesis activity includes an assessment of paleoclimatological conditions, which will be used in the future climate modeling activities and in the paleohydrology activities.

Activities pertaining to the modeling of future climate are shown on Figure 8.3.1.5-3. Activity 8.3.1.5.1.6.1 contains the plans for global climate modeling and does not require input from any previously discussed site activities. The feasibility activity for regional numerical modeling requires information on present regional climate. The purpose of this activity is to determine if a regional numerical model is likely to provide timely and scientifically valid results. An additional empirical modeling activity (8.3.1.5.1.6.4) uses the integrated paleoclimate-paleoenvironmental chronology from Activity 8.3.1.5.1.5.1 to project past climatic episodes into the future. In the empirical modeling approach, the climatological values for past climatic regimes will provide estimates for ranges that may occur in the future. Therefore, the activity parameters listed under the category "future climate modeling" will be derived from either a linked global-regional modeling approach (8.3.1.5.1.6.3), a separate empirical modeling approach (8.3.1.5.1.6.4), or both. This model output will be used to determine the effects of future climate on geohydrology.

Five activities (8.3.1.5.2.1.1 to 8.3.1.5.2.1.5) will generate the data to be used to determine the Quaternary regional ground-water flow system. These activities include estimating severe paleorunoff and paleofloods, determining relationships between paleoinfiltration and paleorecharge, identifying areas of paleorecharge and paleodischarge in the Yucca Mountain region, and assessing the conditions and rates of recharge in that region. The specific activity-level parameters, which consist of measured or collected data, are shown in the table and are used to develop a picture of the paleohydrology at Yucca Mountain.

The data generated to determine the Quaternary regional paleohydrology will then be used along with the paleoclimate-paleoenvironmental data to determine the relationships between paleoclimate and paleohydrology. This synthesis work is not an independent study or activity but rather occurs within each of the paleohydrology activities. The parameter category, "paleoclimate-paleohydrology," contains one activity parameter, "relation-

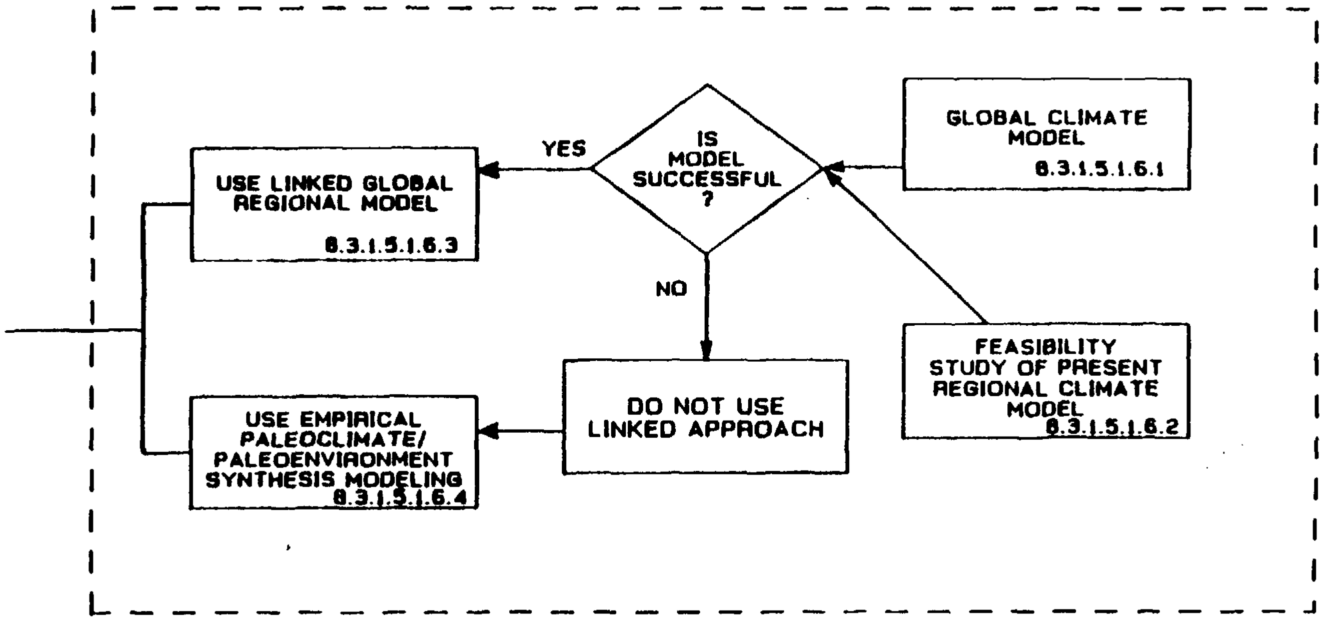

Figure 8.3.1.5-3. Detail of the climate model step (Study 8.3.1.5.1.6) in logic diagram.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

ships between paleoclimate and paleoinfiltration and paleorecharge," that is an additional output from each paleohydrology activity.

Activities within the geohydrology program (8.3.1.2) will proceed in parallel with the above mentioned climate program activities. Specifically, studies addressing the unsaturated- and saturated-zone hydrologic system (8.3.1.2.2.10 and 8.3.1.2.3.2) will be used to develop models of the flow systems in both the unsaturated and saturated zones. These models will be used to assist in the evaluation of baseline hydrologic conditions.

At this point, information will be available (1) on future climatic conditions, (2) on the relationships between paleohydrology and paleoclimate, and (3) from the geohydrology program (models of flow systems of the unsaturated and saturated zones and the surface water system) as shown in Figure 8.3.1.5-2. These three sources of information will be used by climate program Study 8.3.1.5.2.2 to characterize future regional hydrologic conditions based on the estimated climatic changes. The result of this study will be an estimate of the impact of future climate changes on the overall hydrologic system. The first activity (analysis of future surface hydrology) will result in a determination of future precipitation-runoff relationships to be used by the erosion program (8.3.1.6). The next activity (analysis of future unsaturated-zone hydrology) will provide quantitative estimates of future infiltration, percolation, and saturation of the unsaturated zone due to climatic changes, which are essentially some of the performance parameters listed in Table 8.3.1.5-1 used to satisfy the performance objectives of Issues 1.1 and 1.9b. The final activity will provide estimates of future water-table altitude, ground-water flow rates, and ground-water velocity, corresponding to other performance parameters listed in Table 8.3.1.5-1. The performance parameters listed in Table 8.3.1.5-1 will address the performance objectives of Issues 1.1 and 1.9b and therefore Issues 1.8, 1.9a, 1.10, 1.11, and 1.12.

The information presented in Table 8.3.1.5-2 is a step toward the development of "characterization parameters" for the climate program. Characterization parameters will be a specific limited set of parameters for which quantitative testing bases will be established. These testing bases will express, through parameter goals or degree of accuracy, how well a particular parameter important to the climate program needs to be understood. Characterization parameters will be developed from the individual activity parameters in the following parameter categories: paleoclimate-paleoenvironment synthesis, future climate, and paleoclimate-paleohydrology synthesis. An example of one such characterization parameter is future precipitation. Initial sensitivity analyses performed on the hydrologic models will provide an idea as to how well future precipitation is needed to be known and what ranges of values are significant. This process will help to guide the future climate modelers as to how well they need to determine future precipitation and aid in prioritizing the activities within the climate testing program.

Alternative Conceptual Models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled

YMP/CM-0011, Rev. 1

and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses that are also consistent with available data and that may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) the activities or studies designed to discriminate between alternative hypotheses or to reduce uncertainty. Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate. Tables 8.3.1.5-3, 8.3.1.5-4, and 8.3.1.5-5 summarize the current status of regional climate, paleoclimate, and paleohydrologic modeling, respectively, that is being performed as part of the climate site program.

To help ensure comprehensiveness of the hypotheses considered in Tables 8.3.1.5-3, 8.3.1.5-4, and 8.3.1.5-5 hypotheses involved in climate modeling have been divided into elements or components that describe the physical domain defined by the model, the driving forces/processes that influence the behavior of the model, the boundary conditions that affect the model, the system geometry of the physical components of the model, and the system response dynamics of the model in response to its driving forces, boundary conditions and system geometry. These elements are listed in column one.

The second column of the table lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Tables 8.3.1.5-3, 8.3.1.5-4, and 8.3.1.5-5 provides a judged level of the uncertainty designated "high," "moderate," "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Column six gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of the performance parameters in column five to the selection of hypotheses in columns two and four for that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

Table 8.3.1.5-3. Current representation and alternative hypotheses for regional model for the climate program (page 1 of 4)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Physical domain	Great Basin and parts of surrounding continental land mass and eastern Pacific Ocean, between 24°N latitude and 50°N latitude; 3,000 km by 3,000 km, with center near Yucca Mountain	High--degree of spatial resolution obtainable in this region is unknown; effects of boundary conditions are unknown	Larger area is appropriate to reduce boundary effects Smaller area is appropriate to obtain needed degree of spatial resolution	Flux in unsaturated zone Thickness of unsaturated zone Flux in saturated zone Length of flow path in saturated zone	High High Low Low	Medium	High--need high resolution capable of providing site-specific characteristics at Yucca Mountain	8.3.1.5.1.5.1, 8.3.1.5.1.6.2, 8.3.1.5.1.6.3
Driving forces/ processes	Regional climate is driven principally by the broader global climate, as established by conditions at regional-global model boundaries Regional climate is modified by conditions within the region, including land-surface roughness, stability of atmosphere, low-level winds, and temperature and humidity gradients (affected by possible lakes that may form in playa basins in periods of increased effective moisture)	High--although boundary conditions are expected to be the principal driving forces for regional climate, relative significance of regional factors is uncertain	None identified	Same as above	Same as above	High--performance parameters are directly influenced by factors that affect climate	High--need to understand factors that affect regional climate to predict future climate accurately	8.3.1.5.1.1.1, 8.3.1.5.1.5.1, 8.3.1.5.1.6.1, 8.3.1.5.1.6.2

YMP/CM-0011, Rev. 1

Table 8.3.1.5-3. Current representation and alternative hypotheses for regional model for climate program (page 2 of 4)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Boundary conditions	Boundaries within region include -Topography (effects of mountain and lowlands) -Land use/albedo -Vegetation distribution -Distribution of sea-surface temperatures External boundaries with global system include fluxes of momentum, heat, and vapor	High--although boundaries have been identified, the effects of boundary conditions on climate in the region have not been defined	None identified	Same as above	Same as above	High--specific climatic predictions are highly dependent on nature of boundary conditions	High--need to determine which boundary conditions are most influential and their rates of variation	8.3.1.5.1.6.2, 8.3.1.5.1.6.3
	Boundaries are variable in time	Low--geologic record indicates variations in some boundary conditions during the past 100,000 yr	None identified	Same as above	Same as above	High--climatic predictions are highly dependent on degree of variability in boundary conditions	Low--based on low uncertainty	8.3.1.5.1.6.2, 8.3.1.5.1.6.3
System Geometry	Present land-sea configuration and topography will not change significantly during the 10,000-yr isolation period	Low--rates of change are low enough that no significant alteration of geometry is expected	None identified	Same as above	High--geometry of system significantly affects climatic conditions	High	Low--based on uncertainty	8.3.1.5.1.6.2, 8.3.1.5.1.6.3

YMP/CM-0011, Rev. 1

Table 8.3.1.5-3. Current representation and alternative hypotheses for regional model for climate program (page 3 of 4)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
System response/ dynamics	During the 10,000-yr isolation period, natural and anthropogenic processes will cause changes in sea-temperature patterns, composition of atmosphere, and orbital parameters; as a result, shifts in temperature, precipitation, wind, and evapotranspiration will occur	High-preliminary modeling has shown a wide range of possible future climates	See subsets of alternative hypotheses below	Same as above	High	High	High--hydrologic conditions during the 10,000-yr isolation period are greatly dependent on climatic conditions	8.3.1.5.1.6.2 8.3.1.5.1.6.3
	During first 1,000 yr, warming trend (2-4°C) will occur, with significantly increased precipitation (greenhouse effect)	Same as above	Greenhouse effect will have little impact in this region; thus, no significant increase in precipitation is expected during next 1,000 yr	Same as above	High	High	Same as above	Same as above
				Subset of model element; overall ranking given with element above				

YMP/CM-0011, Rev. 1

Table 8.3.1.5-3. Current representation and alternative hypotheses for regional model for climate program (page 4 of 4)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
System response/ (continued)	After 1,000 yr, cooling trend will occur with significantly decreased precipitation (natural trend toward glacial period)	Same as above	Glacial/interglacial climatic shifts are slow enough that no significant changes in temperature or precipitation are expected in 10,000-yr isolation period	Same as above	High	High	Same as above	Same as above
				Subset of model element; overall ranking given with element above				

YMP/CM-0011, Rev. 1

Table 8.3.1.5-4. Current representation and alternative hypotheses for paleoclimate modeling for the climate program (page 1 of 4)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Physical domain	Southern Great Basin is the appropriate domain for paleoclimate studies	Low--area to be examined for paleoclimate evidence needs to be regional in scope, but constrained to general area of interest	Western U.S. (west of 100° W longitude) and eastern Pacific Ocean (to include data from deep-sea sediment cores) is appropriate domain	Future: Flux in the unsaturated zone Thickness of the unsaturated zone Flux in the saturated zone Lengths of flow paths in the saturated zone	 High High Low Low	Low--values of parameters are not dependent on size	Low	8.3.1.5.1.1, 8.3.1.5.1.2, 8.3.1.5.1.3, 8.3.1.5.1.4, and 8.3.1.5.1.5
Driving forces/ processes	Analogs exist in the paleoclimatic record of present climates; future climates will be determined by the same driving forces and processes that operate today and that operated in the past	Medium--a wide spectrum of paleoclimatic conditions is reflected in the geologic record, and probably encompasses present and future conditions	No analogs exist; present and future conditions are unique due to anthropogenic effects	Same as above	Same as above	Low--values of parameters do not depend on existence of analogs	Medium--need to have assurance that geologic record can be used to evaluate paleoclimate, in order to guide and check climate models	8.3.1.5.1.1, 8.3.1.5.1.2, 8.3.1.5.1.3, 8.3.1.5.1.4, 8.3.1.5.1.5, and 8.3.1.5.1.6
	Major long-term (10^4 - 10^5 yr) paleoclimate variations have been periodic, driven by periodic orbital variations of the earth	Low--earth's orbital variations are known and have been correlated with geologic evidence of climate variations	Major long-term (10^4 - 10^5 yr) paleoclimate variations have been quasi-periodic. They are predominantly driven by climate changes that are	Same as above	Same as above	High--values of parameters depend on future climate, which is sensitive to orbitally induced variations in atmospheric conditions	Low--existing data are sufficient to establish periodic nature of paleoclimate variations in the geologic record	8.3.1.5.2, 8.3.1.5.3, 8.3.1.5.4, 8.3.1.5.5, and 8.3.1.5.6

YMP/CM-0011, Rev. 1

Table 8.3.1.5-4. Current representation and alternative hypotheses for paleoclimate modeling for the climate program (page 2 of 4)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Driving forces/ processes (continued)			abrupt and occur only when thresholds in sea-surface temperature are exceeded					
	Biospheric components have significantly affected past atmospheric conditions and climate	Low--present existence of forests, marine plankton populations, and mammal populations affect atmospheric compositon and albedo, and thus climate	None identified	Same as above	Same as above	High--values of parameters depend on future climate, which is sensitive to biospheric components	Medium--need to identify geologic evidence of paleoclimates that were similar to expected CO_2-induced climate, as a guide and check for climate models	Same as above
Boundary conditions	Boundaries that affected paleoclimates in the region are similar to those of modern climates and include Solar radiation Atmospheric composition Ice-sheet location Topography Extent of sea ice Surface albedo	Low--these are generally recognized boundaries that can be assumed to apply to past as well as present climates	None identified	Same as above	Same as above	Low--values of parameters do not depend on definition of past boundaries	Low	8.3.1.5.1.1, 8.3.1.5.1.2, 8.3.1.5.1.3, 8.3.1.5.1.4, and 8.3.1.5.1.5

YMP/CM-0011, Rev. 1

Table 8.3.1.5-4. Current representation and alternative hypotheses for paleoclimate modeling for the climate program (page 3 of 4)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Boundary conditions (continued)	Boundary conditions for paleoclimates during the Quaternary were at times substantially different from those of today	Medium--although boundary conditions probably were different, magnitudes of changes are uncertain	In the southern Great Basin, boundary conditions during the Quaternary were not substantially different from those of today	Same as above	Same as above	Low--values of parameters do not depend on degree of difference between past and present climatic boundary conditions	Medium--need improved understanding of past boundary conditions to guide and check climate models	8.3.1.5.1.1, 8.3.1.5.1.2, 8.3.1.5.1.3, 8.3.1.5.1.4, and 8.3.1.5.1.5
System geometry	The Quaternary paleoclimatic record consists of paleontologic and stratigraphic evidence and the distribution of Quaternary surficial deposits and geomorphic features within the physical domain	Low--generally, the Quaternary paleoclimate system can be adequately described in this framework	Deep sea cores from the eastern Pacific Ocean are a significant component of the record needed to understand southern Great Basin paleoclimates	Same as above	Same as above	Low--values of parameters do not depend on definition of Quaternary paleoclimatic system geometry	Low	8.3.1.5.1.2, 8.3.1.5.1.3, 8.3.1.5.1.4, and 8.3.1.5.1.5
System response/ dynamics	Quaternary climatic conditions produced an identifiable record from which these conditions can be interpreted	Medium--some geologic features are known to be climatic indicators (e.g., plant macrofossils in pack rat middens), but record is sparse, and other signatures may be too subtle to identify and interpret	Short-term or minor climatic fluctuations leave no discernable record	Same as above	Same as above	Low--values of parameters do not depend on the nature of the geologic record of Quaternary climatic conditions	Medium--need to be able to recognize and interpret the geologic record of Quaternary climatic conditions to correlate with paleoclimate models	8.3.1.5.1.2, 8.3.1.5.1.3, 8.3.1.5.1.4, and 8.3.1.5.1.5

YMP/CM-0011, Rev. 1

Table 8.3.1.5-4. Current representation and alternative hypotheses for paleoclimate modeling for the climate program (page 4 of 4)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
System response/ dynamics (conditions)			The geologic record is too altered or too complex to be interpreted in terms of paleoclimate	Same as above	Same as above	Same as above	Same as above	Same as above
	During the Quaternary, climatic conditions were at times substantially different from modern climates; only during the last interglacial period were conditions as warm globally, including the southern Great Basin	High--Evidence indicates that different climatic conditions existed during the Quaternary, but the magnitudes of the differences are uncertain	In the southern Great Basin, no substantially different climates occurred during the the Quaternary	Same as above	Same as above	Medium--values of parameters depend on future climate; climatic conditions during Quaternary are likely to be repeated in the future	High--need to understand magnitude of climatic changes in the Quaternary, in order to relate to paleohydrology and to guide and check climate modeling	8.3.1.5.1.2, 8.3.1.5.1.3, and 8.3.1.5.1.4

YMP/CM-0011, Rev. 1

Table 8.3.1.5-5. Current representation and alternative hypotheses for paleohydrology modeling for the climate program (page 1 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
Physical domain	Hydrogeologic study area and nearby surrounding southern Great Basin is the appropriate domain for paleohydrology studies	Low--area to be examined for paleohydrologic evidence needs to be regional in scope and defined in part by regional ground-water flow system	Larger (or smaller) area is appropriate for paleohydrology studies	Present and future: Flux in the unsaturated zone Thickness of unsaturated zone Flux in the saturated zone Lengths of flow paths in the saturated zones	 High High Low Low	Low--values of parameters are not dependent on size of area studied	Low	8.3.1.5.2.1
Driving forces/ processes	Progressive late Tertiary and Quaternary tectonic lowering of Death Valley, combined with generally increasing aridity, caused a net lowering of the regional water table	Medium--large elevation difference between modern water table and spring deposits at Furnace Creek and Ash Meadows indicates a decline in the water table; the relative influence of tectonics and climate change in lowering the decline is uncertain	None identified	Same as above	Same as above	Medium--future trends in water-table altitude depend in part on extrapolation of past trends and their controlling factors	Medium--need to understand causes of past trends to predict future trends accurately	8.3.1.5.2.1.3, 8.3.1.5.2.1.5, 8.3.1.8.3.2, 8.3.1.17.4.9, 8.3.1.17.4.12
	Quaternary paleoclimate fluctuations were principally responsible for changes in hydrologic conditions; Quaternary tectonic, thermal, and volcanic processes had minor roles	High--relative roles of climate, tectonic, thermal, and volcanic processes are not well understood	Tectonic events and thermal processes were primarily responsible for Quaternary hydrologic changes; climate forces were minor	Same as above	Same as above	Low--actual values of performance parameters not greatly affected by cause of Quaternary conditions	High--need to understand cause of hydrologic changes to Quaternary to predict future conditions accurately	8.3.1.5.2.1, 8.3.1.8.3.1, 8.3.1.8.3.2, 8.3.1.8.3.3, 8.3.1.5.1.2, 8.3.1.5.1.3, 8.3.1.5.1.4, and 8.3.1.5.1.5

YMP/CM-0011, Rev. 1

Table 8.3.1.5-5. Current representation and alternative hypotheses for paleohydrology modeling for the climate program (page 2 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
Driving forces/ processes (continued)	Pedogenic processes are responsible for the hydrogenic deposits observed in Trench 14	Medium--all data are consistent with a pedogenic origin, but none proves it	Deposits were formed by discharge of ground water from a formerly much higher regional water table	Same as above	Same as above	Low--actual values of performance parameters are not affected by cause of hydrogenic deposits in Trench 14	High--need to understand cause of deposits in Trench 14 to evaluate likelihood of future occurrence	8.3.1.5.2.1.5
			Deposits in Trench 14 were formed from deep-seated ground water forced upward by seismic pumping or other tectonic/thermal process	Same as above	Same as above	Same as above	Same as above	8.3.1.5.2.1.5
			Deposits in Trench 14 were were formed from discharging perched water	Same as above	Same as above	Same as above	Same as above	8.3.1.5.2.1.5
	Deposits that are physically similar to those in Trench 14 were formed by the same processes as those observed in Trench 14	High--too few data are available for other deposits near Yucca Mountain to adequately test hypothesis	Same as above	Same as above	Same as above	Same as above	Same as above	Same as above

YMP/CM-0011, Rev. 1

Table 8.3.1.5-5. Current representation and alternative hypotheses for paleohydrology modeling for the climate program (page 3 of 6)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Boundary conditions	The upper, lower, and lateral hydrologic boundaries that defined the paleohydrologic system in the Quaternary are approximately the same as those that define the modern system	Low--no major changes in the hydrologic system are recognized from the geologic record that would result in a redefinition of boundaries	The boundaries that defined the hydrologic system during the Quaternary were substantially different from those of today, because of major differences in hydrogeologic framework and/or climate between then and now	Same as above	Same as above	Low--the actual values of performance parameters are not greatly affected by the definition of Quaternary boundaries	Low	8.3.1.5.2.1
	The principle of uniformitarianism applies; past hydrologic conditions can be correctly interpreted from the geologic record, and future conditions can be accurately predicted, because past and future relationships were and will be the same as those of today; thus, among the approaches to paleohydrology investigations,	Low--this is a widely accepted principle that is used to guide geologic interpretation	Plant and animal adaptations to environmental changes make using fossil evidence tenuous in interpreting past or predicting future hydrologic conditions	Same as above	Same as above	Low--actual values of performance parameters do not depend on validity of principle of uniformitarianism	Low--assume uniformitarianism applies, but recognize possible errors that may result and adjust for known departures	8.3.1.5.1.2 through 8.3.1.5.1.5, and 8.3.1.5.2.1
			Modern geohydrologic relationships include many complexly interrelated variables that are not discernable in the geologic record;	Same as above	Same as above	Same as above	Same as above	8.3.1.5.1.2 through 8.3.1.5.1.5, and 8.3.1.5.2.1

YMP/CM-0011, Rev. 1

Table 8.3.1.5-5. Current representation and alternative hypotheses for paleohydrology modeling for the climate program (page 4 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Boundary conditions (continued)	it is appropriate to include the study of analog recharge sites, analyses of rainfall-runoff relationships, and interpretation of fossil evidence		therefore, use of that record to interpret past and predict future conditions is inappropriate					
	The locations of hydrologic boundaries (recharge/discharge sites, altitude of water table, lower boundary) and the values of water fluxes were at times during the Quaternary substantially different from those of today	Medium--although boundary locations and fluxes are believed to have been different, magnitudes are uncertain	Hydrologic boundary locations and fluxes during the Quaternary were the same or only slightly different from those of today	Same as above	Same as above	Low--actual values of performance parameters are not greatly dependent upon whether conditions in the past were substantially different from those of today	Medium--need to know boundary locations and fluxes to predict future conditions accurately	8.3.1.5.2.1, 8.3.1.8.3.1, 8.3.1.8.3.2, 8.3.1.8.3.3, 8.3.1.2.1.4, and 8.3.1.2.3.3
System geometry	The Quaternary paleohydrologic system consists principally of Quaternary surficial and hydrologic deposits and current features such as aquifers, aquitards, and structural boundaries	Low--with some exceptions (such as evidence of formerly higher water tables in the form of fracture coatings), the Quaternary paleohydrologic system can be adequately described in this framework	None identified	Same as above	Same as above	Low--actual values of performance parameters do not depend on definition of Quaternary paleohydrologic system geometry	Low	8.3.1.5.1.2 through 8.3.1.5.1.5, 8.3.1.5.2.1, and 8.3.1.2.3.2

YMP/CM-0011, Rev. 1

Table 8.3.1.5-5. Current representation and alternative hypotheses for paleohydrology modeling for the climate program (page 5 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
System geometry (continued)	None selected	High--either (1) greater fluxes and higher water-table altitudes during the Quaternary resulted in substantially different flow pathways; or (2) differences in hydrologic conditions were not sufficient to alter flow paths signficantly	Ground-water flow pathways during the Quaternary were different from or about the same as those of today	Same as above	Same as above	Medium--actual performance parameters are not greatly dependent on Quaternary flow pathways, unless those pathways have since been modified by geologic processes	High--need to establish what the Quaternary pathways were, and any modifications, to predict future pathways accurately	8.3.1.2.1.4, 8.3.1.2.3.3, and 8.3.1.8.3.3
System response/ dynamics	Quaternary hydrologic conditions produced an identifiable geologic record from which those conditions can be interpreted	Medium--some aspects of modern hydrologic processes are known to create a geologic record (e.g., spring deposits, flood deposits), but other signatures may be too subtle to identify and interpret	Short-term fluctuations of hydrologic conditions leave no discernable record The geologic record is too altered or too complex to be interpretable in terms of paleohydrology	Same as above	Same as above	Low--actual values of performance parameters do not depend on the nature of the geologic record of Quaternary hydrologic conditions	High--need to be able to recognize and interpret the geologic record of Quaternary hydrologic conditions to predict future conditions accurately	8.3.1.5.1.2 through 8.3.1.5.1.5, 8.3.1.5.2.1, and 8.3.1.3.2.1
Response to climate	The hydrologic changes that resulted from Quaternary climate fluctuations were substantial	High--evidence indicates that different hydrologic conditions existed during the Quaternary, but the relative magnitudes resulting from various causes are uncertain	The hydrologic system adjusted rapidly to Quaternary climate changes, with no major changes in the flow system	Same as above	Same as above	Medium--actual performance parameters are not greatly dependent on magnitude of changes of changes caused by Quaternary climate, although values could be affected because cyclical nature of climate change	High--need to understand magnitude and cyclicity of hydrologic changes caused by Quaternary climate, in order to predict future conditions accurately	8.3.1.5.1, 8.3.1.5.2.1

YMP/CM-0011, Rev. 1

Table 8.3.1.5-5. Current representation and alternative hypotheses for paleohydrology modeling for the climate program (page 6 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Response to tectonics	Quaternary faulting produced short-term, local, and small-magnitude changes on the hydrologic system	High--evidence indicates that different hydrologic conditions existed during the Quaternary, but the relative magnitudes resulting from various causes are uncertain	Quaternary faulting significantly altered the hydrologic system	Same as above	Same as above	Medium--values of performance parameters are dependent in part on changes in hydrogeologic framework that occurred during Quaternary tectonism	High--need to understand the response of the hydrologic system to tectonism, as evidenced in part by the Quaternary record	8.3.1.8.3.1, 8.3.1.8.3.2, 8.3.1.8.3.3
Response to thermal forces	Thermally driven convection did not have a signficant effect on ground-water flow during the Quaternary	High--some evidence exists of thermally driven convection under present conditions; cyclic tectonic/thermal processes could have affected hydrologic conditions during the Quaternary, but magnitude is uncertain	Thermally driven convection had a significant effect on ground-water flow during the Quaternary	Same as above	Same as above	Medium--potential cyclic nature of tectonic/thermal processes could result in past conditions affecting performance parameters	Medium--need to understand response of hydrologic system to thermal effects, although distinguishing thermal effects from others in the Quaternary geologic record is likely to be difficult	8.3.1.8.3.1, 8.3.1.8.3.2, 8.3.1.8.3.3, 8.3.1.5.2.1.4, 8.3.1.5.2.1.5
Response to volcanism	Quaternary volcanism had only localized effects on hydrologic conditions	Low--localized and sparse nature of Quaternary volcanism likely had little regional effects on hydrologic conditions	Effects of Quaternary volcanism had far-reaching effects on hydrologic conditions	Same as above	Same as above	Low--actual values of performance parameters are not greatly dependent on extent of effects of Quaternary volcanism	Low--although need to understand effects of volcanism on hydrologic conditions should such an event occur at Yucca Mountain	8.3.1.8.3.1, 8.3.1.8.3.2, and 8.3.1.8.3.3

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameter, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The final column identifies the characterization studies or activities that will discriminate between alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

Interrelationships of climate investigations

Investigation 8.3.1.5.1 is designed to address the data, parameters, and processes that can be used to derive a model of future climatic change. This model is needed to predict potential future climatic changes that may (through the hydrologic regime) alter the long-term waste isolation capability of the Yucca Mountain site.

Data will be collected to characterize the present regional climate (Study 8.3.1.5.1.1) including the spatial and temporal variation. A study of the climatic inferences from paleolake, playa, and marsh sediments (Study 8.3.1.5.1.2) will draw upon the paleontology, stratigraphy, sedimentology, geochemistry, and chronology of these deposits. A study of the climatic implications of terrestrial paleoecology (Study 8.3.1.5.1.3) will draw upon evidence from pack rat midden macrofossils, palynology, and vegetation-climate relations. A paleoenvironmental study of the Yucca Mountain site (Study 8.3.1.5.1.4) will draw upon investigations into rates and conditions of soil development, distribution and geomorphology of surficial deposits, and the eolian history of the region. The paleoclimate history (from Studies 8.3.1.5.1.1 through 8.3.1.5.1.3) and the paleoenvironment history (8.3.1.5.1.4) will cross-check and complement each other and will be combined to create a final paleoclimate-paleoenvironment synthesis (Study 8.3.1.5.1.5), an integrated chronology, and a description of paleoclimate episodes at Yucca Mountain and environs.

The chronology produced in Study 8.3.1.5.1.5 will serve as the data base for the culmination of Investigation 8.3.1.5.1, modeling of future climates (Study 8.3.1.5.1.6). This study will employ a parallel approach of empirical modeling and numerical modeling to describe the timing and meteorology of future climate scenarios. This output will be used in Investigation 8.3.1.5.2 to estimate responses of the hydrologic regime to future climate.

Investigation 8.3.1.5.2 is designed to address the potential effects of future climatic conditions on hydrologic conditions. The characterization of Quaternary regional hydrology (Study 8.3.1.5.2.1) has the overall objective of defining relations between paleohydrology and paleoclimate, in order to understand how the hydrologic regime will respond to future climatic conditions. The study is planned to evaluate regional paleoflooding (Activity 8.3.1.5.2.1.1) and to assess both infiltration and percolation in the unsaturated zone and also ground-water potentiometric levels during the Quaternary (Activity 8.3.1.5.2.1.2). Isotopic composition and chemistry of water in the unsaturated zone will be analyzed to assess the Quaternary

YMP/CM-0011, Rev. 1

infiltration and recharge history of Yucca Mountain. An evaluation of paleodischarge areas and an evaluation of past water levels in carbonate caverns (Activity 8.3.1.5.2.1.3) will be completed to determine past discharge areas and regional ground-water levels. Potential modern analogs to pluvial climates at Yucca Mountain will be studied (Activity 8.3.1.5.2.1.4) to estimate conditions and rates of ground-water recharge at Yucca Mountain during the Quaternary. The hydrologic origin and significance of calcite and silica deposits in faults and fractures in the vicinity of Yucca Mountain (Activity 8.3.1.5.2.1.5) will be factored into this evaluation.

A study is planned to characterize the future regional hydrology taking into account future climatic changes (Study 8.3.1.5.2.2). A precipitation-runoff model is planned to simulate paleoconditions of precipitation and runoff (Activity 8.3.1.5.2.2.1). The model will then be used to estimate future precipitation-runoff conditions from scenarios for future climatic change. In addition, the unsaturated zone hydrologic model will be used to predict the potential changes in infiltration, percolation, and the degree of saturation due to future climatic change (Activity 8.3.1.5.2.2.2).

Finally, a synthesis of future hydrologic characteristics due to climatic changes will be completed (Activity 8.3.1.5.2.2.3). The objective of this study will be to integrate data on paleoclimatic and paleohydrologic conditions to complete a reconstruction of paleoclimatic conditions. The paleoclimatic reconstruction will be used, together with the meteorology of future climate scenarios and models of the present ground-water regime from Section 8.3.1.2 (geohydrology program), to predict the impacts of future climatic change on the unsaturated and saturated zone hydrologic system at Yucca Mountain. This study will involve incorporating paleohydrologic data into models to estimate potential changes in the altitude and gradient of the water table caused by future climatic change.

8.3.1.5.1 Investigation: Studies to provide the information required on nature and rates of change in climatic conditions to predict future climates

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this information need:

SCP section	Subject
5.1	Recent climate and meteorology
5.2.1.1	Quaternary global paleoclimate
5.2.1.2	Quaternary regional paleoclimate
5.2.2.1	Components of the climate system
5.2.2.2	Climatic variations

YMP/CM-0011, Rev. 1

SCP section	Subject
5.2.2.3	Climate prediction methods
5.2.3	Site paleoclimatic investigations
5.3.1	Significant results

Parameters

The following parameters will be collected, measured, or calculated as a result of the site studies planned as part of this investigation:

1. Recent meteorological data.

2. Great Basin historical climatic data--spatial and temporal variability of precipitation, wind, temperature, cloud cover.

3. Selected Great Basin hydrologic data--stream discharge, lake level.

4. Age, fossil content, sedimentary characteristics, mineral content, chemical content, and magnetic properties of lake, playa, and marsh sediments.

5. Age and paleontologic characteristics of pack rat midden macrofossil assemblages.

6. Vegetation-climate calibrations--response surfaces, transfer functions.

7. Prehistoric variation in lake levels over the Quaternary.

8. Synoptic "snapshots" of prehistoric climate extremes.

9. Analysis of Quaternary soil and surficial deposit properties, and Quaternary geomorphic characteristics of surfaces and drainages.

10. Forecasts (a general estimation, not a specific parameter or variable) of climatic variables for the next 100,000 yr in southern Nevada.

Other site studies that supply information to support the determination of the previous parameters are as follows:

Study	Subject
8.3.1.12.1.1	Characterization of the regional meteorology
8.3.1.2.2.1	Characterization of unsaturated zone infiltration
8.3.1.5.2.1	Characterization of Quaternary regional hydrology
8.3.1.6.1.1	Distribution and characteristics of past erosion

Purpose and objectives of the investigation

Investigation 8.3.1.5.1 provides information to help satisfy performance and design Issues 1.1, 1.8, 1.9a and b, 1.10, 1.11, and 1.12. Recent meteorological data and Great Basin historical climate data will be used to cali-

YMP/CM-0011, Rev. 1

brate (using present conditions) and validate (using past conditions) models of future climate. A paleoclimate-paleoenvironment synthesis will be derived from lake, playa, and marsh sediments, pack rat middens, vegetation calibrations, and soil and surficial deposits. This synthesis will provide time-sequential reconstructions for the modeling activities as well as for Investigation 8.3.1.5.2. These models will attempt to forecast climatic variables for the next 100,000 yr to determine climatic conditions.

Technical rationale for the investigation

The arid climate of the southern Great Basin is one of several factors making Yucca Mountain potentially attractive for the long-term disposal and isolation of radioactive waste. The persistence of arid conditions (and an accompanying thick unsaturated zone) in the region through the postclosure period would be advantageous to waste isolation. However, paleoclimatic studies in the surrounding region indicate that the modern degree of aridity is atypical of the past few hundreds of thousands of years. Shallow groundwater recharge occurred in southern Nevada between 20,000 and 10,000 yr ago (Claassen, 1985), when major climatic changes created vast lakes in many of the valleys of Nevada, Utah, and eastern California (Section 5.2). Although such high magnitude events may be cyclic on a time scale of 100,000 yr, most of the intervening periods appear to have been wetter than today (Smith, G.I., 1983).

When viewed on a scale of hundreds to thousands of years, climate is constantly changing, and future climatic fluctuations may significantly affect the hydrologic regime and erosion rates at Yucca Mountain. Thus, climate change must be considered when evaluating the suitability of the repository site.

If data are discovered within the Quaternary geologic period that document the above objectives, they will be studied. The exact studied time interval will be flexible depending upon the completeness of the recovered stratigraphic data. However, the late Quaternary will be emphasized.

Climatic scenarios of concern. Our present understanding of past climates suggests that there are primarily two recurring large-scale circulation patterns which may result in higher levels of effective moisture in southern Nevada. The future occurrence of either pattern could have a negative impact on the proposed repository. The first pattern is associated with the growth of continental ice sheets during glacial periods. Under modern conditions, the westerlies and the associated jet stream are strongest and in their most southerly position during winter, when cold arctic air is in close proximity to warm tropical air. During glacial periods, arctic air masses reached farther south than today in all seasons, but tropical air did not contract towards the equator to any significant degree (because orbitally induced variations in insolation have little effect in low latitudes). Thus, polar and tropical air masses would interact with each other year round in a region farther south than today, thereby potentially increasing frontal activity (storminess) and precipitation in the NTS region. An increase in frontal activity through the year would increase precipitation and reduce evaporation, factors that have the potential to increase recharge.

YMP/CM-0011, Rev. 1

The second pattern involves an orbitally induced variation in insolation that results in higher than modern summer temperatures over land in the middle and high latitudes of the northern hemisphere. Under such conditions about 9,000 yr ago, the increased temperature contrast between land and sea brought moist tropical air masses (monsoons) into North Africa and the Indian subcontinent. The resulting increased rainfall and reduced evaporation turned now desert areas into savannas and woodlands (Kutzbach and Otto-Bleisner, 1982). Similar changes have been postulated to have occurred in the NTS region (Spaulding and Graumlich, 1986) and may occur again in modified form if future increases in atmospheric CO_2 concentrations cause a "greenhouse effect" on global climate.

In addition to the two patterns described above, both associated with extremes in glacial and solar insolation boundary conditions, it appears that other, more moderate, configurations of boundary conditions may result in high levels of effective moisture in the region of southern Nevada. For example, within 150 km of Yucca Mountain moderate to high lake levels were maintained for much of the period between the last interglacial (about 125,000 yr before present) and the last glacial maximum (about 20,000 yr before present) (G. I. Smith, 1983).

Paleoclimatic studies at Yucca Mountain will attempt to determine the past frequency and timing of occurrences of the scenarios listed above and to identify other patterns of past climatic circulation that led to high levels of effective moisture. Future climatic studies will attempt to estimate the probability of occurrences of these and other scenarios over the next 10,000 to 100,000 yr.

Paleoclimatic studies. The primary objectives of the paleoclimatic studies are to

1. Determine the magnitude, duration, and timing of past major periods effectively wetter than modern conditions in and near southern Nevada.

2. Provide data to establish the relationships between paleoclimate change and corresponding paleohydrologic responses.

3. Establish, where possible, the relationships between past climatic changes near Yucca Mountain and predictable elements of larger scale (global or northern hemispheric) climatic changes, such as those induced by changes in the earth's orbit.

4. Provide the basis for the testing of numerical climate models.

Constituent studies. The studies under the paleoclimatic investigation are

1. Study 8.3.1.5.1.1--Characterization of modern regional climate. The modern climate is the baseline for establishing the relationships between climatic variables (such as precipitation or temperature) and the various proxy data (such as plant distributions or lake size or chemistry). Thus, understanding modern climate is essential to reconstructing the past and predicting the future.

 YMP/CM-0011, Rev. 1

2. Study 8.3.1.5.1.2--Paleoclimate study: lake, playa, marsh deposits. Paleontological, stratigraphic-sedimentologic, and geochemical indicators preserved in lacustrine sediments provide the principal record of paleohydroenvironments, which for most shallow water systems are also sensitive paleoclimate records and the only available long records of climate change. These records will provide relative estimates of climate properties and in some instances may provide quantitative estimates of climate.

3. Study 8.3.1.5.1.3--Climatic implications of terrestrial paleoecology. Plant macrofossil assemblages from pack rat middens and fossil pollen spectra from stratigraphic deposits will provide the basis for reconstructing vegetation change near Yucca Mountain and in the surrounding region. Numerical methods (response surfaces, transfer functions) will translate these vegetation records into quantitative estimates of past changes in precipitation, temperature, and other climatic variables.

4. Study 8.3.1.5.1.4--Paleoenvironmental history. Investigations of soils and surficial deposits at Yucca Mountain are necessary to define the responses of local depositional and erosional regimes to climatic change.

5. Study 8.3.1.5.1.5--Paleoclimatic-paleoenvironmental synthesis. The various lines of evidence will be synthesized into chronologies of paleoclimatic changes in formats suitable for input into the paleohydrologic studies and the future climates studies.

6. Study 8.3.1.5.1.6--Characterization of the future regional climate and environments. Future climate will be estimated for the next 100,000-yr period, with emphasis on the next 10,000 yr. Quantitative estimates of climatic parameters will result from using numerical and/or empirical models. Paleoclimatic data can empirically suggest possible boundary conditions. Linked global-regional numerical models may provide the needed climate estimates for Yucca Mountain.

Spatial scale. Investigators working within the paleoclimate program will attempt to discover any available evidence of past periods of greater than modern effective moisture in as close proximity to Yucca Mountain as possible. Data bearing on this problem that are available near the proposed repository include (1) plant assemblages from pack rat middens; (2) micropaleontological, geochemical, and sedimentological data from playa and paleomarsh sediments; (3) terrestrial pollen data; and (4) vertebrate paleontological data from outcrops, pack rat middens, and paleomarsh sediments. (Refer to Tables 5-13 and 5-14 and Figure 5-24 for an analysis of currently available data.) In addition to these data, the age and nature of surficial deposits and soil development will be assessed, as appropriate, to develop an understanding of the paleoclimatic record at Yucca Mountain.

The characteristics of local playa and marsh records are planned to be evaluated in terms of climatic sensitivity, sediment accumulation rates, and preservation of paleontologic and mineralogic climatic indicators.

 YMP/CM-0011, Rev. 1

These records

1. Represent available aquatic record of Quaternary climatic and hydrologic events near Yucca Mountain.

2. Have direct bearing on hydrologic models and the tie between regional climatic change and local hydrologic changes.

3. Can be related to regional framework of climatic and hydrologic changes developed through regional paleoclimatic studies (discussed below). In this light, local aquatic records will provide evidence on climatic episodes that have resulted in significant hydrologic responses in this area but are of much less importance regionally.

Climate is operative on a regional scale, and no single station or paleoclimatic site can provide an adequate record of past variability or be representative of the climate over the entire recharge area. The same characteristic applies to paleoclimatic records, which, on a regional scale, are necessary to provide a check on the continuity of the local records thereby reducing the uncertainty involved in identifying major past periods of higher effective moisture. Regional records, especially from extant lakes and wet playas, should provide thicker stratigraphic sections and greater temporal resolution for dating past periods of major recharge. The potential for missing portions of the record through deflation, etc. will be minimized by studying such sites. Regional scale data are also necessary for describing variations in past storm track positions, and for testing hypotheses on temporal and spatial patterns of climatic change. These aspects would require a spatial network of sites for key time periods in the past. The sources of paleoclimatic proxy data available on a regional scale are the same as on the local scale, with the notable addition of permanent lakes as sources of micropaleontological, geochemical, and sedimentological data.

Temporal scale. Over the last 50,000 yr, the climate of the Northern Hemisphere has changed from "interstadial glacial" (about 65,000 to 35,000 yr B.P.), to "full-glacial" conditions (about 20,000 to 18,000 yr B.P.), to conditions warmer than today (about 9,000 to 6,000 yr B.P.), to modern conditions. This period thus offers examples of extreme configurations of global climatic boundary conditions, and the effects of these changes in southern Nevada are planned to be studied in detail. Available techniques for dating paleoclimatic changes are also most precise over this period and "synoptic snapshots" of paleoclimatic conditions at appropriate times in southern Nevada can be constructed for numerical model evaluation.

The global climates of the next 10,000 to 100,000 yr may include a transition from the current interglacial, to moderate glacial, to full-glacial conditions. To understand the ramifications of this change, the last 200,000 yr are planned to be studied in moderate detail to provide examples of the climatic effects of such global changes on the Yucca Mountain region.

Over the last 500,000 to 1,000,000 yr, climatic conditions have varied enough to allow boreal small mammals such as the bog-lemming to live in wet seeps on Yucca Mountain. Some knowledge of these seemingly very different conditions is required to predict the possible magnitudes of future wet episodes at Yucca Mountain.

 YMP/CM-0011, Rev. 1

Future climate investigations. Forecasts of future climatic conditions at Yucca Mountain will be made primarily through numerical models of the climate system. A general circulation model (GCM) of global climate will be used to describe the expected responses of global climate to future variations in glacial ice extent, orbital parameters (which affect the distribution of incoming solar radiation on the earth's surface), atmospheric chemistry, and other climatic boundary conditions. If proven feasible, a regional-scale mesoscale model will be linked to the GCM to provide the spatial resolution necessary for forecasting the future climatic conditions at Yucca Mountain.

Before numerical models can be used to forecast future climatic conditions, they must incorporate evidence of past climatic change as reconstructed from paleoclimatic proxy data in the region on time scales commensurate with the periodicity of earth-sun orbital relations. This refinement is necessary because of the effects of complicated feedback systems, lag times, and topographic barriers on climate. It is performed by comparing paleoclimate records with model results and by improving the model so that it simulates known past climates more accurately.

The models will be calibrated and checked using present-day and historical data sets that will be evaluated in simulations of climates of key historic times such as periods of high lake stands, desiccation, vegetative change, or ground-water recharge.

Following successful model testing exercises, scenarios will be developed that include boundary conditions to account for inputs from natural and human activities to the atmosphere. The possible effects of volcanic dust, aerosol, and carbon dioxide on future climate conditions will be examined.

If the approach of linked global-regional numerical models does not prove feasible, then an alternative approach of empirical modeling paleoclimatic data to estimate future climate is planned.

8.3.1.5.1.1 Study: Characterization of modern regional climate

The objective of this study is to provide a baseline and a background for the interpretation of climatic variation. Characterization of the synoptic climate will result in the determination of modern spatial and temporal variations in precipitation, air temperature, cloud cover, and other meteorological variables. These data will be used in the development of modern vegetation-climate calibration relationships, in the assessment of lake-climate relationships, and in the development and testing of climate circulation models and in specifying relationships between global-scale circulation patterns and the regional and local climate features of relevance to site performance coordinated by the overview activity in Section 8.3.1.12.1.2.

 YMP/CM-0011, Rev. 1

In cooperation with meteorology program (8.3.1.12) and geohydrology program (8.3.1.2), efforts will be made to relate modern storms (and their trajectories) to the isotopic signatures of infiltrating ground water. This analysis will be assisted by modeling of the carbon isotope systematics in ground water. These data may provide insight into past air-mass trajectories and will be available to the climatology program.

8.3.1.5.1.1.1 Activity: Synoptic characterization of regional climate

Objectives

The objectives of this activity are to

1. Provide the basis for developing vegetation-climate relationships, lake-climate relationships, and climate-circulation models (meteorological data).

2. Provide an understanding of spatial and temporal variation in climate (synoptic climate).

3. Determine the climate conditions (i.e., time, temperature, seasonality, and air masses) under which recharge occurs (isotopic data).

Parameters

The parameters for this activity are

1. Meteorological data, such as monthly and annual values for temperature, precipitation, wind velocity, from a regional network of sites.

2. Synoptic climate, such as spatial and temporal variation of precipitation, air temperature, cloud cover, and wind velocity.

Description

Meteorological data will be compiled from U.S. Weather Service stations from the southern Great Basin and surrounding region. The synoptic climate of the Great Basin region will be determined through statistical correlations with larger scale climate information. These correlations will include the longest usable climatic record, including possible use of tree ring data if applicable, and will be used to identify patterns of specific weather system development and to determine how the systems affect areas of particular interest within the Great Basin.

A network of weather stations will be set up in the region, in cooperation with meteorology program 8.3.1.12 and geohydrology program 8.3.1.2. Each station will include a precipitation collector for oxygen-18 and deuterium samples, a tipping bucket, and a temperature probe connected to a data logger. Temperature data will be collected every 15 to 20 min; water samples will be collected whenever possible within 24 hrs of a storm event.

The data will be statistically analyzed to determine the relation of oxygen-18 to deuterium to storm track, air temperature, altitude, and season. Results of the analysis will be used in Study 8.3.1.5.1.2 (paleolacustrine studies) to assist in estimating the source and seasonality of recharge that occurred in the Quaternary in the Yucca Mountain region and in Activity 8.3.1.5.2.1.2 (Quaternary unsaturated zone hydrochemical analysis).

8.3.1.5.1.2 Study: Paleoclimate study: lake, playa, marsh deposits

This study will establish the nature, timing, duration, and amplitude of paleoclimate changes based on analyses of paleontologic, geochemical, and stratigraphic-sedimentologic data obtained from lacustrine sediments in or near southern Nevada (Figure 8.3.1.5-4). Planned locations of the marsh, playa, and lake sampling sites may change as data are collected and analyzed. The sampling strategy and any such changes will be reported in the study plan and SCP progress reports. In addition, information will be collected on paleolake levels and sizes to identify the timing and extent of paleoclimate events. These analyses will provide estimates of past changes in precipitation, temperature, relative moisture balance, and other climatic parameters. These estimates, when integrated regionally for particular climatic episodes, will aid in identifying the particular pattern of atmospheric circulation (air-mass interactions) responsible for the observed variations. Moreover, these estimates will provide the basic data to be used for analyzing past climatic periodicity and for validating climate models.

Because climate variability may contribute significantly to the hydrologic system, especially in terms of recharge and discharge, the results of this study will also be central to the paleohydrologic studies of this area (Section 8.3.1.5.2). The degree to which past climatic and past hydrologic changes are linked will provide a basis for comparing or linking the outputs of models that predict future climatic and hydrologic variability.

8.3.1.5.1.2.1 Activity: Paleontologic analyses

Objectives

The objective of this activity will be to assemble and interpret, in paleoclimatic terms, detailed records of ostracodes, diatoms, and pollen, along with other types of fossils as warranted by specific paleoclimatic questions. This record will involve collection, identification, enumeration, and interpretation of paleontologic data that emphasizes the past 50,000 yr in great detail, the past 200,000 yr in moderate detail, and the past 1,000,000 yr in some detail. Calcareous fossils will also be collected for geochemical and age analyses of their carbonate.

Parameters

The parameters for this activity include paleoenvironmental interpretations of ostracodes, diatoms, aquatic palynomorphs, and other paleobiotic remains.

YMP/CM-0011, Rev. 1

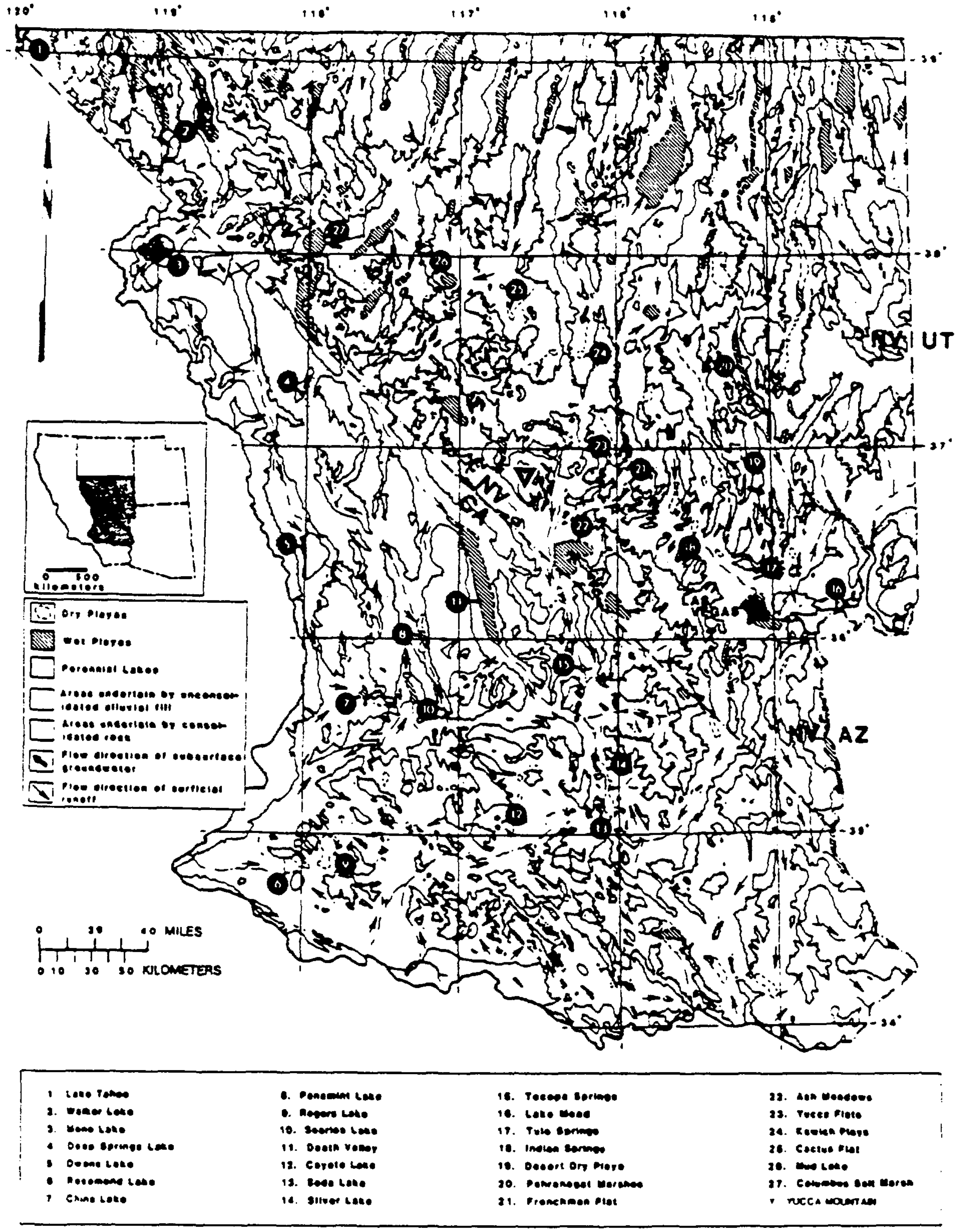

Figure 8.3.1.5-4. Possible sampling sites for paleoclimate studies. Modified from Bedinger et al. (1984)

 YMP/CM-0011, Rev. 1

Description

Ostracodes. Ostracodes are minute crustacea with bivalved calcite carapaces that can be identified to the generic or specific levels. They are largely benthic animals, living at or just below the sediment-water interface. Ostracode life-cycles range from about 3 weeks to well over a year, and their ecology is therefore centered upon annual or seasonal phenomena. Ostracodes live in virtually all oxygenated water bodies that persist for more than about a month. They attain their highest population densities in quiet or gently flowing water and are most commonly preserved in circumneutral to alkaline water.

Nonmarine ostracodes are divided into two major ecologic groups: those that live in surface waters (epigean) and those that live in ground water (hypogean). Epigean taxa may be further divided ecologically into those living in ground-water discharge environments and those that live in lacustrine environments. Both ground-water discharge and lacustrine taxa may be further subdivided into groups of taxa that only live in very particular environments such as continuously cold water (cryobionts) or continuously warm water (thermobionts), or water that is warm for at least a given period during the year (thermophilic). Ostracodes are very sensitive to water chemistry, with the distribution of some taxa determined by the major dissolved ion content of the water. Other parameters, such as turbidity, oxygen levels, and biotic factors appear to influence ostracode productivity rather than their presence or absence.

Most ostracode species have well-defined biogeographic ranges that appear to be limited by seasonal variations in water temperature and chemistry. Ostracodes are capable of entering new environments through the transport of adult ostracodes or eggs by birds, insects, or wind. Similarly, as environments change, some species will no longer be able to survive and will become locally extinct. Thus ostracodes may rapidly expand or contract their geographic ranges in response to changing hydroenvironmental and climatic conditions. Ostracodes will be collected in conjunction with Activity 8.3.1.5.2.1.3 (evaluation of past discharge areas).

Diatoms. Diatoms are single-celled algae that produce an opaline silica frustule, which provides precise taxonomic information. Various species of diatoms cover a range of aquatic habitats from the sediment-water interface to the open-water epilimnion. Diatoms are short-lived organisms and therefore can respond by increasing species abundance to environmental phenomena operating on weekly time scales.

Particular diatom species are known from all aquatic environments within the photic zone. Diatom species are especially sensitive to water quality, including parameters such as solute composition, salinity, and pH. They are also extremely sensitive to the availability of nutrients such as nitrogen, phosphorous, silica, and dissolved organic compounds.

Diatoms have an excellent fossil record, and, unlike ostracodes, diatoms are commonly preserved in acidic environments or any environment low in HCO_3 activity. Where both groups of organisms are preserved, the diatoms may provide useful information on short-term environmental phenomena that may have no obvious impact on the ostracode population. Conversely, ostracodes

YMP/CM-0011, Rev. 1

appear to be better suited to recognizing what may be termed the general environmental aspects of an aquatic environment such as temperature or water composition.

Aquatic palynomorphs. The pollen record of emergent or submergent macrophytes and the remains of certain algae provide important information about the chemical, and to a lesser extent thermal, properties of the water in which they lived. The response of aquatic plants to their general chemical environment is quite similar to the response of diatoms and ostracodes discussed above. In addition, aquatic macrophytes are sensitive to the stability of a water mass. For example, emergent plants such as cattails require that local water level remain within a specified range or they will drown from rising water levels or desiccate from falling levels. The stability of a water body on a seasonal to annual scale is an important hydrologic and climatic property.

Other biotic remains. Other fossils, ranging from terrestrial vertebrates to aquatic chrysophyte cysts and branchiopods, may prove vital to understanding the nature of a particular climate record. The way in which climate interpretations would be made from other kinds of fossils generally follows the format given above for ostracodes, diatoms, and pollen. Other types of fossils can be used to evaluate and refine the climatic interpretations derived from the principal organisms and may offer information not available from these organisms. For example, the occurrence of branchiopod fossils together with ostracodes implies a wet-playa hydrology whereas the presence of branchiopods without ostracodes implies a dry-playa hydrology. The recognition of a wet and dry playa record from cores in the modern day dry playas near Yucca Mountain would have climatic significance.

Paleoclimatic interpretations of aquatic records. The ecologies of ostracodes, diatoms, and other aquatic organisms are necessarily related to the properties of the water in which they live. To extract climatic information from the fossil record of aquatic organisms, a relationship between aquatic parameters and climate parameters must be established.

Shallow wet-playa lakes, marsh ponds, and spring pools from shallow aquifers are surface-water features that are common today and were common in the past in southern Nevada. The water columns in each of these environments will typically be thermally coupled to the daily or weekly changes in air temperature over the water body (Forester, 1987). Furthermore, the water temperature of spring vents from shallow aquifers provide good estimates of mean annual air temperature. The seasonal variability in water temperature of standing bodies or the constant value of spring vents provides a thermal habitat that determines occurrence and abundance of all aquatic organisms, but especially ostracodes. New taxa appear as the thermal habitat changes with changing climate, while others become locally extinct. Thus knowledge about the thermal ecology and biogeography of aquatic taxa provides direct information about water temperature that may then be interpreted in terms of air temperature. These interpretations may be qualitative, based on empirical observations; semiquantitative, based on multivariate analyses techniques; or quantitative, based on statistical analyses and organism physiology.

YMP/CM-0011, Rev. 1

Climate may play an important role in determining water chemistry when water with a given input composition is evaporatively coupled to the atmosphere over the basin. Wet periods result in dilution or flushing of dissolved salts from the basin. Dry periods result in concentration and solute evolution due to selective mineral precipitation and other processes. The chemistry of the surface water body is thus coupled to the atmospheric moisture balance over the water body. The chemical character of the water establishes a chemical habitat that determines organism occurrence and abundance. As the chemical habitat changes with changing climate, new taxa appear or become locally extinct and thus provide a record of the paleochemistry. Thus knowledge about the chemical ecology of aquatic taxa, especially diatoms and ostracodes, provides direct information about paleohydrochemistry that may be interpreted in terms of moisture balance. As with paleotemperature, these interpretations may be qualitative, semiquantitative, or quantitative.

The response of water chemistry to climate is operative on all time scales and for basins of all sizes whereas the response of water temperature to climate may be most sensitive in shallow water bodies that remain thermally mixed in all seasons. Aquatic records, whether they provide only hydrologic or both hydrologic and climatic information, are important to any study that seeks to understand past climate, because they are integrating climate processes that are operating on seasonal or annual scales rather than the much coarser scales common to other records.

8.3.1.5.1.2.2 Activity: Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits

Objectives

The objectives of this activity are to

1. Identify and characterize the general physical and chemical properties of sedimentary units from outcrops, shore deposits, and cores. This information will provide a physical and relative temporal framework within which various paleoenvironmental studies will be made.

2. Determine the specific environment of deposition for the sedimentary units using the principles of clastic and chemical sedimentology.

Parameters

The parameters for this activity are

1. Lithostratigraphy of marsh, lacustrine, and playa deposits.

2. Clastic and chemical sedimentology of marsh, lacustrine, and playa deposits.

YMP/CM-0011, Rev. 1

Description

Reconnaissance coring, trenching, and seismic techniques will provide information about sample sites, access to sediments that cannot be sampled in outcrop, and general information about subsurface stratigraphy for all forms of analyses. This will minimize needed samples and maximize the climatic information obtained from the samples.

Lithostratigraphy involves the lithologic characterization of sedimentary units in order to define sedimentary units and to place these units in space and time. Investigations will describe sediment thickness, color, grain size, texture, bedding, magnetic susceptibility, bulk elements, mineralogy, and other properties deemed necessary for accomplishing this task.

Clastic and chemical sedimentology involves identifying and describing the chemical and physical nature of the sedimentary units identified by lithostratigraphy in order to define the nature of the depositional environment. Properties such as grain size, composition, bedforms, nature of contacts between sediment units or other properties that will aid in interpreting deposition environment will be investigated. Sedimentologic data provide general paleoclimatic information together with general environmental boundary conditions for other studies.

8.3.1.5.1.2.3 Activity: Geochemical analyses of lake, marsh, and playa deposits

Objectives

The objective of this activity is to provide a detailed chemical and mineralogic characterization of all sediments to provide information about the chemistry of the water from which the minerals precipitated and to determine sediment provenance.

Parameters

The parameters for this activity are

1. Element analyses of bulk sediments.
2. Carbonate mineralogy.
3. Noncarbonate mineralogy.
4. Stable isotope analyses.
5. Other chemical parameters.

Description

Element analyses of bulk sediments. Element analyses of bulk sediments involves determining the kind and quantity of elements present in sediment samples taken as a time series from a core. These data are subjected to a variety of multivariate analyses to characterize the data set in terms of origins of particular element groups. This information provides important insights into chemical processes (endogenic and authigenic (diagenetic))

 YMP/CM-0011, Rev. 1

operating within the local environment as well as processes (allogenic) that contribute materials from the surrounding region. These types of data are important for characterizing past climate because the endogenic-authigenic processes provide information about water chemistry that may be related to moisture balance whereas the allogenic record provides information about stream input and other factors that may characterize wet periods.

Carbonate mineralogy. Endogenic carbonate mineralogy is related to the Mg/Ca ratio of the water from which the carbonate precipitated. As lake water evaporates, the Mg/Ca ratio increases or conversely, as lake water is diluted or flushed, the ratio decreases resulting in a different suite of carbonate minerals. The expected mineral sequence from dilute water to concentrated water is low-Mg calcite, high-Mg calcite, aragonite (or dolomite), and monohydrocalcite. Thus, knowledge about the carbonate mineral sequence through a sedimentary deposit may provide evidence for wet and dry cycles. Moreover, biogenic carbonate, principally the shells of ostracodes or snails, may provide information about the temperature and salinity of the water in which the carbonate was precipitated. The Mg/Ca ratio of biogenic calcite is known to be closely related to the temperature at which the carbonate precipitated, whereas the Sr/Ca ratio appears to be related to the salinity of the water. Temperature and salinity are important climate indicators in climatically sensitive aquatic environments.

Noncarbonate mineralogy. Noncarbonate minerals such as salts and silica minerals (opals, clays) provide information about the composition of the parent body of water, about the diagenetic postdepositional environment, or both. The former provides information about moisture balance, whereas the latter provides an indication of the degree of alteration of a sedimentary unit.

Stable isotopes. Stable isotopes, principally of oxygen and carbon, but also of strontium, sulfur, deuterium/hydrogen, provide information about the source/temperature of precipitation, water salinity, water temperature, and other forms of environmental information. This information, as with aquatic microfossils, provides a means of evaluating the moisture balance or temperature of the atmosphere over the water body.

Other chemical parameters. Other types of geochemical analyses may prove necessary in some situations. Marsh sediments, for example, may be especially rich in organic compounds or other components not common in playas.

8.3.1.5.1.2.4 Activity: Chronologic analyses of lake, playa, and marsh deposits

Objectives

The objective of this activity is to obtain an accurate, precise chronologic framework for the paleoclimatic information acquired in this study. Moreover, all age information should, whenever possible, be tested with other techniques to reduce uncertainties.

 YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are ages of biostratigraphic indicators and sediments using the following techniques: carbon-14, amino acid, thermoluminescent dates, uranium-series, uranium-trend, paleomagnetism, tephrachronology, fossils, and others.

Description

Carbon-14. Radiocarbon analyses will be conducted on organic rich sediments, on terrestrial organic matter deposited in aquatic sediments, or on biogenic carbonate using conventional or tandem accelerator methodologies. Radiocarbon can provide age information in the age range from modern to 50,000 yr before present, but is subject to decreasing confidence with decreasing sample size, increasing age, and errors due to contamination.

Amino acids. Amino acid analyses may be applied to well-preserved mollusc or ostracode shells. Particular amino acids are known to change from one state to another as a function of time and temperature. Thus when temperature is known to have been relatively constant, amino acid analyses may provide age, but when thermal histories are variable amino acid data may be used for relative age or as a correlation tool.

Thermoluminescent dating. This technique is in the experimental stage at this time, but may prove useful for dating aquatic sediments in the age range of 2,000 to 250,000 yr before present. The value of this method over most others is that it is usually not dependent on local geochemistry.

Uranium-series. Uranium-series analyses are conducted largely on inorganic or biogenic carbonates. This method is useful for obtaining ages on materials that incorporate uranium but no thorium at the time of crystallization, and remain closed to uranium and its daughter products throughout their history. The age range of this method is from about 5,000 to approximately 350,000 yr before present.

Uranium-trend. Uranium-trend analyses will be conducted largely on surface sediments such as marsh outcrop or soil sequences. It may be applicable to playa cores under some circumstances. This method is an open-system dating method based on uranium-series decay and the migration of daughter products of U-238 through a soil or sediment column. The method is most effective on samples in the range of 60,000 to 600,000 yr.

Paleomagnetism. Paleomagnetic analyses will be applied to core and trench sediments to establish the remanent magnetism. Except for geologically short intervals, the past 700,000 yr has exhibited normal polarity. In most instances, the discovery of reversed polarity sediments indicates they were deposited before this date.

Tephrachronology. This method involves the comparison of the chemical and physical characteristics of volcanic ashes with those of ashes of known ages. Included in this activity will be potassium-argon dating of volcanic materials intercalated with lake, playa, and marsh deposits.

 YMP/CM-0011, Rev. 1

Fossils. The geologic history of many terrestrial and aquatic organisms are well known so that the occurrence of these organisms provides an age range for the sediment. Moreover, the timing of the expansion or contraction of biogeographic ranges for some organisms, largely rodents, is known so that the occurrence of such taxa in a particular area offers a more refined age than the geologic range of the species.

Other chronological methods. Techniques such as stratigraphic position, sediment accumulation rates, soil development, degree of weathering, or presence of artifacts may offer needed age estimates. Moreover, some forms of isotopic analyses, such as strontium isotopes, may provide a way of recognizing sediments deposited from different waters and thus offer a relative age.

Additional records that may be utilized include tree-ring data that have been collected in central and western Nevada as discussed in Chapter 5. These data may be interpreted to determine relationships between tree-ring widths and seasonal fluctuations in climate on the scale of 10 to 1,000 yr. This interpretation may be useful in the development of paleoclimatic transfer functions.

8.3.1.5.1.3 Study: Climatic implications of terrestrial paleoecology

This study will provide quantitative estimates of changes in climatic variables (e.g., precipitation and temperature) for the southern Great Basin. Plant macrofossils from pack rat middens will provide coverage for the last 50,000 yr (Activity 8.3.1.5.1.3.1), while fossil pollen from land plants recovered from cores of lacustral sediments will cover at least the last 150,000 yr (Activity 8.3.1.5.1.3.2). Transfer functions, response surfaces, or both will be developed through the statistical comparisons of modern climate to the vegetation data, and these equations will be used in the reconstructions of past climates from the paleovegetation data (Activity 8.3.1.5.1.3.3).

8.3.1.5.1.3.1 Activity: Analysis of pack rat middens

Objectives

The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in plant macrofossil assemblages preserved in ancient pack rat middens.

Parameters

The parameters for this activity are

1. Macrofossil assemblages collected from pack rat middens in the southern great basin and surrounding region.

 YMP/CM-0011, Rev. 1

2. Radiocarbon age estimates.

3. Other data--vertebrates, insects, isotopic data.

Description

Pollen studies (discussed in activity 8.3.1.5.1.3.2) are generally carried out in permanently wet environments, but pack rat midden analysis is restricted to the semiarid and arid deserts of western North America. In this method, past vegetation is reconstructed from plant remains preserved in middens deposited in rock cavities by rodents of the genus Neotoma (pack rats, wood rats, or trade rats). The plant remains can often be identified to the species level, and the assemblages are believed, based on the contents of modern middens, to represent vegetation growing within a radius of 30 m of the midden at the time of accumulation.

Pack-rat middens are collected by extracting kilogram-sized samples of material from different levels of the deposit. These are soaked in water to dissolve the cementing material and sieved to concentrate the plant remains (e.g., stems, needles, leaves, and seeds). When dry, the plant material is sorted and counted or weighed to produce a quantified record of the different plant taxa present.

Selected plant macrofossils or other materials from each midden are submitted for radiocarbon analysis. This dating method provides an estimate of the age of the midden assemblage, accurate to within a few hundred years. in instances where more precise dating is required, multiple samples from the same midden are submitted for radiocarbon dating. The paleobotanical data from the individual midden assemblages are compiled to create time series of vegetational change from a given area and vegetational setting. Replication of pack rat chronologies from sites with similar settings ensures that site-specific phenomena do not introduce bias into the interpretation of the data set.

In addition to plant macrofossils, pack rat middens are rich sources of vertebrate and insect remains, pollen, and cellulose for isotopic investigations. The data may be analyzed to elucidate certain paleoclimatic signals. This activity will be carried out in conjunction with Activity 8.3.1.5.2.1.4 (analog recharge studies).

8.3.1.5.1.3.2 Activity: Analysis of pollen samples

Objectives

The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in the stratigraphic record of fossil pollen grains.

YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are

1. Pollen assemblages collected from lacustrine, marsh, and playa sediments (and other sedimentary deposits) in the southern Great Basin.

2. Radiocarbon dates, tephrochronology, and other chronological markers.

Description

Studies of fossil pollen in stratified deposits have been used extensively to reconstruct fluctuations in temperature and precipitation over the last 20,000 yr. The applicability of the method has been limited in the western united states by the relative scarcity of bogs and small lakes, the optimal settings for most types of pollen studies. However, paleoclimatological insights have been gained from studies of the fossil pollen contained in sediments deposited in western pluvial lakes, alpine lakes, caves, rock shelters, and alluvium. Pollen records, in general, provide quasi-continuous records of regional vegetational change. While the majority of these studies are restricted to the Holocene, palynological studies of pluvial lake, marsh, and playa sediments also provide information over the period of 10 to several hundreds of thousand years ago.

Pollen is extracted from samples by dissolving unwanted mineral and organic matter in the sample with strong acids and bases. The pollen is comparatively resistant and will remain and become concentrated after dissolution. The pollen is stained to enhance its microstructural detail and mounted on microscope slides for examination. Pollen grains of known plant taxa are identified, tabulated, and plotted stratigraphically according to absolute concentration (per gram or cubic centimeter of sediment) or relative percentages. The stratigraphic plots are interpreted in terms of increasing or decreasing amounts of plant taxa responsible for the various pollen types, taking into account the relative pollen production of individual plant groups, the ease by which pollen is distributed, and the processes by which it is incorporated into the sediment and preserved.

In some instances, pollen studies will be conducted at the same sites as those for paleolacustrine investigations (Study 8.3.1.5.1.2), because lake sediments may contain well preserved pollen and represent more or less continuous deposition. However, because of exposure and oxidation, playa deposits may be unsuitable for pollen analysis. Pack rat middens also contain pollen, particularly from the local vegetation surrounding the midden site, and its analysis can be helpful in determining the nature of the pollen rain (the pollen coming from and falling on any region) in areas where lakes and marshes are few.

 YMP/CM-0011, Rev. 1

8.3.1.5.1.3.3 Activity: Determination of vegetation-climate relationships

Objectives

The objective of this activity is to translate the vegetational records provided by pack rat midden and palynological investigations and available dendroclimatological data into quantitative estimates of past climatic variables.

Parameters

The parameters for this activity are

1. Vegetation-climate, pollen-climate response surfaces, or both.
2. Pollen-climate transfer functions.

Description

Palynological and pack rat midden studies together provide a regional network of time series of vegetational change spanning the last few tens of thousands of years. Much of the evidence for past climatic variations comes from such paleoecological records of past vegetation. Tree-ring data that have been collected in central and western Nevada may be interpreted to determine relationships between tree-ring widths and seasonal fluctuations in climate on the scale of 10 to 1,000 yr. This analysis will be conducted in conjunction with similar analyses in Activity 8.3.1.5.1.2.4 and supplemented by absolute and relative dating techniques. The interpretation of these paleoecological records in climatic terms requires information on the modern relationships between vegetation and climate. Given the understanding of such relationships, and with certain assumptions, it is possible to infer the nature of the climatic variations responsible for the vegetation changes recorded by the fossil evidence.

Relationships between modern vegetation and climate are also required for evaluating of climate simulation models. To judge the ability of the model to simulate correctly the past climate, modern vegetation-climate relationships are used to transform model simulations of past climates into estimates of past vegetation; these can then be compared with the observed fossil record.

There are two related approaches for constructing statistical relationships between modern vegetation and climate data: (1) a transfer function approach in which individual climate variables are expressed as a function of several vegetation predictor variables (e.g., the percentages of different pollen types) and (2) a response function approach in which the relative abundances (or the presence or absence) of individual taxa are expressed as nonlinear functions of one or more environmental variables.

The transfer function approach usually makes use of a multiple regression analysis to construct a relationship between a particular climate variable and a number of predictor variables, which are generally the percentages of individual pollen types. In practice, a data set of paired observations of modern surface pollen samples and climate is required for calibration of

YMP/CM-0011, Rev. 1

the equation. The resulting equation is then applied to fossil pollen data to interpret them in climatic terms.

In the response function approach, the relative abundance or probability of occurrence of different taxa is expressed as a nonlinear (usually polynomial) function of one or more environmental variables. The resulting functions are usually displayed as "response surfaces" that show how the abundance or probabilities vary in the space defined by the environmental variables. For relative abundance data, the response functions are fit using linear regression, while for presence-absence data, the surfaces are fit using logistic regression.

Because response functions illustrate the environmental preferences of different taxa, they can provide guidance in the qualitative interpretation of fossil data in climatic terms. Quantitative reconstruction is possible as well, using response functions of several taxa to determine the environmental conditions necessary to give rise to a particular fossil assemblage.

Application of response functions for climate model validation is relatively straightforward. The relative abundance or the presence or absence of different taxa can be simulated by applying response functions to the values of climate variables simulated by climate models. The simulated vegetation variables can then be compared with the observed. In a typical example, the climate model would be set up to simulate some specific paleoclimate, and the simulated vegetation would be compared with the observed fossil record.

8.3.1.5.1.4 Study: Analysis of the paleoenvironmental history of the Yucca Mountain region

The objective of this study is to evaluate the paleoenvironmental record at Yucca Mountain and surroundings in the light of the inferred paleoclimate history of the southern Great Basin. It also provides information to distinguish between effects resulting from surficial processes, as opposed to tectonic activity, and to evaluate the age of tectonic events. The chronology of the erosional and depositional responses to climatic changes at Yucca Mountain will be used to cross-check and supplement the reconstruction of paleoclimate. A detailed paleoenvironmental history is needed to distinguish short- and long-term tectonic effects from local climatic controls on surficial processes. Therefore, dated deposits in this study will be used to constrain ages and recurrence intervals of fault movements.

The paleoenvironmental history of the Yucca Mountain region is a record consisting of surficial deposits and landforms resulting from a combination of specific climatic and tectonic conditions. Surficial processes involving weathering, water, and wind are dominantly controlled by climatic conditions. In surficial deposits with well-constrained ages, specific indicators of paleoclimate can be compared with the regional paleoclimatic history. Less specific indicators of paleoclimate at Yucca Mountain can be reconstructed from soils of different ages and from depositional environments of surficial deposits.

 YMP/CM-0011, Rev. 1

Although the characteristics of the diverse arid-region surficial deposits at Yucca Mountain and surroundings do not allow the precise determination of such climatic parameters as temperature and precipitation, they contain a valuable record of paleoclimate data pertinent to the site itself. The surficial deposits provide a tool for understanding how the Yucca Mountain region has responded to Quaternary climatic episodes and climatic change in the southern Great Basin, in that they suggest that the types and intensities of different erosional and depositional processes have changed throughout the Quaternary. To ascertain whether the climatic responses at Yucca Mountain have been synchronous with those of the rest of the Great Basin, it will be necessary to compare the paleoenvironmental record at Yucca Mountain (from surficial deposits data) with the regional paleoclimate history. If the responses have not been synchronous, it will be necessary to examine other factors besides regional paleoclimate to explain the history of erosional and depositional response at Yucca Mountain. Thus, the paleoenvironmental history serves as both a cross-check on the regional paleoclimate history, as well as a means by which the effect of past hydrologic and erosional episodes upon the Yucca Mountain landscape can be quantified. In addition, this history bears on assessing the influence of local and regional tectonic processes on the surficial processes operating at Yucca Mountain.

The modeling of soil properties at Yucca Mountain will result in a definition of the relation of the properties of late Holocene soils to modern climatic parameters, the comparison of paleoclimate scenarios to soil properties, and the quantification of soil development over time for use as a dating technique. Investigation of modern soils forming under soil moisture conditions similar to wetter paleoclimates at Yucca Mountain will result in the ability to characterize soil properties resulting from past pluvial conditions. Mapping of the surficial deposits of the Yucca Mountain area will aid in the evaluation of the influence of paleoclimate on their genesis and the history of erosion and landform development. Reconstruction of the eolian history of Yucca Mountain will result in an understanding of the role of eolian deposition and erosion in the paleoenvironment and aid in defining the Quaternary paleoclimates at Yucca Mountain.

8.3.1.5.1.4.1 Activity: Modeling of soil properties in the Yucca Mountain region

Objectives

The objectives of this activity are to

1. Determine the relations among properties of late Holocene soils and modern climatic parameters.

2. Compare properties of selected soils at Pahute Mesa and areas near Tonopah, which have formed under conditions similar to those that may have existed at Yucca Mountain during pluvial conditions of Pleistocene glacial climatic cycles.

3. Compare properties of early Holocene and Pleistocene soils to paleoclimatic models that are reconstructed from other lines of

 YMP/CM-0011, Rev. 1

evidence, such as paleolimnology and terrestrial paleoecology, as a check on these models.

4. Frame climatic scenarios as a function of the depth, distribution, and quantity of pedogenic carbonate and other soil parameters.

5. Quantify rates of soil development in specific climates for use as a dating tool for Quaternary deposits and ages of fault movements.

Parameters

The parameters for this activity are

1. Soil morphology and physical and chemical properties of Holocene and Pleistocene soils formed on a variety of parent material lithologies, under modern climates similar to Yucca Mountain at present and during the latest glacial maximum (the Pahute Mesa and Tonopah climatic analog sites).

2. The understanding of how airborne dust contributes to the development of soils on parent materials containing a high proportion of gravels.

3. Physical and chemical analyses of dust.

4. Field measurements of soil partial pressure of carbon dioxide (pCO_2) and available water-holding capacity (AWC).

5. Movement and composition of soil solutions as determined by lysimeter studies.

6. Rates of carbonate translocation in soils of known composition, texture, and pCO_2, under different climatic regimes and rates of accumulation of dust.

7. Rates of soil development from physical and chemical properties of dated soils, including field-described properties (color, texture, structure, clay content, and consistency) and laboratory measured properties (clay mineralogy, major elements, bulk density, soluble salts, carbonates, and extractable iron oxides).

8. Ages of soils at study sites (using cation ratios of rock varnish, potassium-argon, radiocarbon, uranium-trend, uranium-series, and thermoluminescence dating techniques). Experimental isotopic dating techniques such as beryllium-10 and chlorine-36, may be used if they are proved useful and reliable.

Description

One aim of this activity will be to compare theoretical carbonate distributions, resulting from computer modeling under various simulated climatic conditions, with real carbonate distributions in sampled soils. This will result in a line of evidence that can be used as a check on paleoclimate models as reconstructed from other lines of evidence (paleo-

 YMP/CM-0011, Rev. 1

limnology and terrestrial paleoecology). Another check on the paleoclimatic history of Yucca Mountain will be provided by comparison of the properties of analog soils formed under the modern climates at Pahute Mesa and Tonopah with late Pleistocene and older soils formed at Yucca Mountain. The analog soils have formed under approximately the same moisture levels as Yucca Mountain and the surrounding region during pluvial conditions of Pleistocene glacial climatic cycles. Another aim of the activity is to apply the rates of soil development calculated from the physical and chemical properties of dated soils to undated soils in order to estimate the ages of undated soils. These ages will be important in the estimations of ages of Quaternary deposits and fault movements at Yucca Mountain and surroundings.

Soil properties are a function of time and climate. In particular, the distribution and concentration of calcium carbonate and other soluble salts are linked to temperature and precipitation. This relation can be quantified if other factors such as the available water-holding capacity (AWC) of the soil and the composition and influx rate of dust are known. Computer modeling of soils under various climatic regimes can simulate the distribution (depth) and concentration of carbonate in soils. This information, when compared with the movement of carbonate as measured by lysimeters and with carbonate distribution in soils of known age, will permit the evaluation and cross-checking of paleoclimate models proposed for the Yucca Mountain area from paleolimnology and terrestrial paleoecology. Paleoclimate models can be modified if the actual distribution of soil carbonates conflicts with distributions predicted by these models.

Rates of soil development will be calculated for dated surficial deposits, using measured physical and chemical properties. The result of these calculations will be the quantification of the development of some soil properties over time. Knowing the rates at which certain features of a soil develop will allow the dating of previously undated soils, through the examination and measurement of the same properties and the application of known rates. It is expected that this method of dating surficial deposits will also be applied to bracketing ages of fault movement in the Yucca Mountain area.

Backhoe trenches will be excavated in soils developed on surficial deposits of known or inferred ages. The sites will be classified according to deposit age. Soil profiles at a minimum of two sites for each age category will be sampled and described. Sites under consideration in California include Silver Lake and the Cima volcanic field. These particular sites may provide information to the soil modeling effort. They are localities that are characterized by relatively complete stratigraphic sections that contain multiple well-developed paleosols of various ages. The chronology of the paleosols at these localities is well established by radiometric age dates and may provide a relatively complete record of soil development during Quaternary time. Proposed sites in Nevada include Kyle Canyon, Beatty, Fortymile Wash, Pahute Mesa, and a location near Tonopah.

A regional network of dust traps has been set up in a variety of climatic, lithologic, and geomorphic settings. The purpose of the network is to collect airborne dust in marble traps to simulate dust additions to soils developed in gravelly parent materials. Samples will be collected at least once a year. Dust-collection data are required for input for the computer

 YMP/CM-0011, Rev. 1

modeling of carbonate translocation and are not available in the existing soils literature.

Soil and dust samples will be analyzed in the laboratory for physical and chemical properties related to climate and age. The properties that may be measured include, but are not limited to, (1) particle size distribution, (2) organic matter content, (3) carbonate and silica content, (4) soluble salts, (5) extractable chemistry, (6) major and minor element chemistry, (7) soil water, (8) density, (9) mineralogy, and (10) morphology.

Available water-holding capacity and pCO_2 is measured in gravelly desert soils of a variety of ages at various locations in the vicinity of Yucca Mountain. These data are required as input for the computer modeling of ground-water transport of carbonate and are not available in the existing soils literature. Also, the movement and composition of soil solutions in soils near Yucca Mountain will be measured by lysimeters. This data will be compared with the movement of soil solutions predicted by computer modeling.

Therefore, a computer program has been developed to model the movement of carbonates in solution through soils of varying texture and AWC under varying climatic conditions. This computer program is based on a compartment model that considers a soil to be a vertical stack of compartments; each compartment has physical properties that affect the development of calcic horizons (Arkley 1963; McFadden and Tinsley, 1985; Mayer et al., 1988). Physical properties can differ between, but not within, compartments, and water and solutes can move from upper to lower compartments. The program will be used to simulate carbonate development in soils according to the paleoclimatic conditions developed from paleolimnologic and terrestrial paleoecologic evidence. Simulated soil conditions will be compared with real soil conditions at Yucca Mountain to evaluate the paleoclimate history and, if necessary, modify it.

8.3.1.5.1.4.2 Activity: Surficial deposits mapping of the Yucca Mountain area

Objectives

The objectives of this activity are to

1. Determine the distribution, age, genesis, soil properties, and physical properties of surficial deposits at Yucca Mountain and surroundings.

2. Evaluate the influences of climate and tectonics on the genesis of surficial deposits.

3. Provide a map of surficial deposits for facility placement planning, geomorphic studies, engineering property studies, and surface infiltration studies.

4. Determine the distribution of major concentrations of calcite-silica vein deposits at or near the ground surface at Yucca Mountain.

YMP/CM-0011, Rev. 1

Parameters

Among the parameters under consideration are the following:

1. Distribution, spatial relationships, and thicknesses of the various types of surficial deposits (e.g., fluvial, eolian, and colluvial).

2. Chief physical properties of surficial deposits, including lithology, stone content, particle size distribution, bulk density, soil moisture content, texture, color, and depositional features.

3. Chemical and mineralogical properties of surficial deposits and soils may include, but are not limited to, clay mineralogy, calcium carbonate content, amount of amorphous silica, amounts and types of soluble salts, amounts and types of extractable iron, and soil water chemistry.

4. Chief soil characteristics, including the profile, color, structure, texture, stone content, secondary clay amounts, calcium carbonate content, secondary silica content, consistency, and plasticity.

5. Ages of surficial deposits and soils.

6. Interpreted paleotemperatures during carbonate deposition.

7. Distribution of major outcropping or near-surface calcite-silica vein deposits at Yucca Mountain.

Description

The distribution, spatial relationships, and thicknesses of the various surficial deposits of the Yucca Mountain area will be defined; the definition will be aimed at identifying the geomorphic settings of the various deposits (e.g., fluvial, eolian, and colluvial), the areal extents and proportion of each type of deposit within the region, their thicknesses, and their vertical and horizontal stratigraphic relations. The distribution of surficial deposits will be determined by mapping the deposits on aerial photographs and possibly on satellite imagery. The contacts of the deposits will be verified in the field by examining trenches and natural exposures. Field descriptions of surficial deposits and soils will focus upon characteristics and parameters that will aid in determining their age and genesis, as well as the influences of past climate and tectonics. The area of investigation is shown in Figure 8.3.1.5-5. This activity will be carried out in conjunction with Activity 8.3.1.6.1.1.1 (development of geomorphic map of Yucca Mountain). This activity will also interface and complement the work done in Section 8.3.1.14.2 (studies to provide soil and rock properties at potential locations of surface facilities).

To supplement the mapping (particularly with regard to deposit thicknesses, but more importantly for the description and sampling of the surficial deposits and soils), shallow trenches will be excavated by backhoe, bulldozer, or both at key sites. In addition to the detailed description of the stratigraphy, soil morphology, and other physical characteristics of the

YMP/CM-0011, Rev. 1

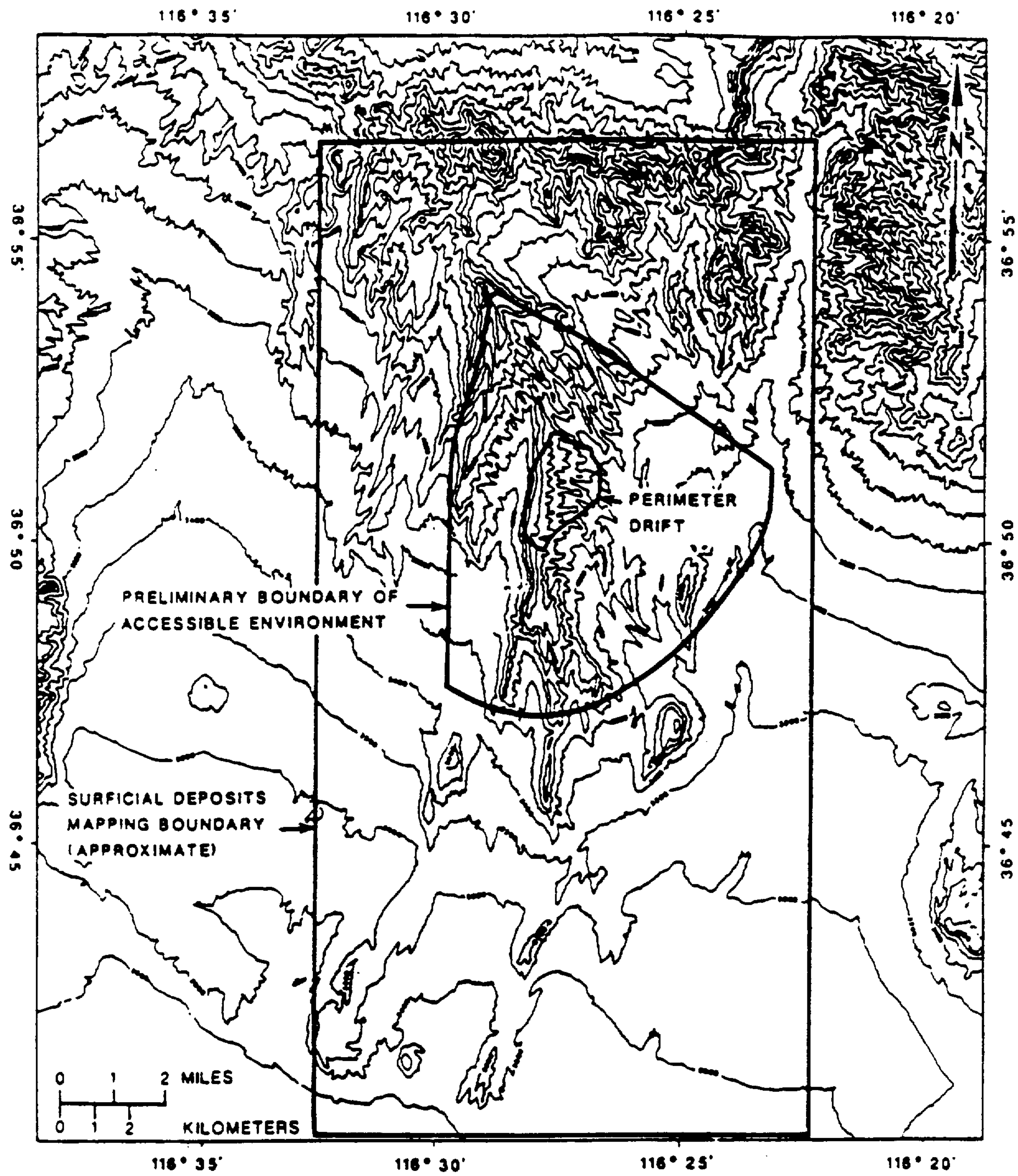

Figure 8.3.1.5-5. Approximate boundaries of Yucca Mountain surficial deposits mapping

YMP/CM-0011, Rev. 1

surficial deposits, samples will be collected for physical, chemical, and ineralogic analysis and for stable isotope analysis and dating. Another supplemental procedure for the mapping will be the compilation and interpretation of lithologic logs of previously drilled shallow drillholes to determine the thickness and other physical properties of surficial deposits encountered in drilling. This information will be correlated with results of the mapping and trenching procedures.

Soil water samples will be collected at selected sites for chemical analysis. Chemical data for modern soil water will aid in determining the paleoclimatic implications of the relative abundance, form, and distribution of secondary calcium carbonate and amorphous silica in the various surficial deposits. Also, this data will aid in applying the findings of the soil moisture analog study to the interpretation of paleosoil moisture conditions in the Yucca Mountain area.

Laboratory analysis of surficial deposits and soils will be conducted to determine a variety of physical, chemical, and mineralogical properties. These properties may include, but are not limited to, (1) particle size distribution, (2) bulk density, (3) soil moisture content, (4) clay mineralogy, (5) calcium carbonate content, (6) amounts of amorphous silica, and (7) amounts and types of soluble salts and extractable iron. Data from these analyses will provide a basis for characterizing key physical, chemical, and mineralogic properties of the surficial deposits and soils, and will aid in the determination of their genesis and relative ages.

The surficial deposits will also be dated to aid in correlation of depositional events with Pleistocene glacial and interglacial climatic cycles and the periods of transition between these cycles. Dating techniques will include uranium-series, uranium-trend, radiocarbon, thermoluminescence, and cation ratio dating. Dating will also contribute to the effort to correlate paleoecological evidence with the paleoenvironmental (erosional and depositional) history of Yucca Mountain area.

The uranium-series dating technique has been a useful tool in estimating the ages of crystallization of secondary carbonates. This technique can potentially be used on any materials that incorporate uranium but no thorium at the time of crystallization, and remain closed to uranium and its daughter products throughout their history (Bradley, 1985).

Preliminary analysis (Knauss, 1981) suggests that Quaternary secondary silica should be an ideal material for uranium-series disequilibrium methods. Dates on amorphous (opaline) silica would provide minimum limiting ages for their host sediments, and dates on buried opals would provide maximum limiting ages for overlying sediments. Secondary carbonates occur in a wide variety of forms in the Yucca Mountain area. Many have developed in surficial deposits; others occur as root casts in eolian-alluvial-colluvial "sand-ramp" deposits, as fracture-fill materials, and as throughflow seep deposits. Two important characteristics of these carbonates make them suitable materials for deriving paleoclimatic information: (1) they may have been deposited by meteoric waters and thus would reflect in part the temperature of crystallization in the near-surface environment and (2) they are datable by uranium-series disequilibrium methods. Uranium is quite soluble in meteoric waters that pass through uranium-bearing minerals, especially in near-surface envi-

YMP/CM-0011, Rev. 1

ronments characterized by oxidizing conditions. Trace amounts of uranium are thus carried through soils, unconsolidated materials in water, or both and coprecipitated with calcium carbonate. In contrast, thorium is characterized by extreme insolubility in near-surface environments and thus does not coprecipitate with uranium because it is not leached from thorium-bearing minerals. This is significant because, with time, the amount of thorium-230 will increase by radioactive decay of uranium-234. The ratios of the activity of thorium-230 to its parent uranium-234 and its grandparent uranium-238 are used to calculate the date of crystallization of the carbonate. At present, this method is useful back to about 350,000 yr.

Uranium-trend dating is an open-system dating method based on uranium-series decay and the migration of daughter products of uranium-238 through a soil or sediment column. In the Yucca Mountain area, the uranium-trend dating method has thus far been limited mainly to alluvial deposits because they are the most extensive Quaternary sediments. Because one of the pertinent questions to be answered in geologic investigations of Yucca Mountain is the rate of hillslope erosion (Section 8.3.1.6), accurate dating of colluvial deposits is desirable. Dating of eolian sediments is also useful, because such deposits are significant from a paleoclimatic point of view. If uranium-trend dating is feasible on colluvial and eolian deposits, the derived ages should be consistent with the relative ages. Such a test is only a partial check on the suitability of the method, because consistent relative ages may result but may be incorrect in terms of absolute age. A further check is provided by the linearity of the uranium-trend plots; plots that show poor linearity indicate that the material is unsuitable for dating and little confidence can be placed in the derived absolute ages. Good linearity and consistent relative ages strongly suggest correct absolute ages. Alluvial deposits in this area generally show excellent linearity on uranium-trend plots. A final and more rigorous test of the suitability of the method would be to compare derived uranium-trend ages with independent absolute dating methods such as conventional closed-system uranium-series dates on secondary carbonates that occur in the same deposits or potassium-argon dates on volcanic rocks that underlie the deposits. This uranium-trend method is most effective on samples in the range of 60,000 to 600,000 yr (Rosholt et al., 1985).

Isotopic analyses of secondary carbonates will be performed to determine paleotemperatures from proportions of stable isotopes. The results of these analyses will include isotopic composition of secondary carbonates (oxygen-16 to oxygen-18 and carbon-13 to carbon-12 ratios), differences between crystallization temperatures of secondary carbonates and Holocene average temperatures of crystallization, and dates of crystallization of secondary carbonates. One of the primary factors controlling the oxygen isotope composition of secondary carbonates in near-surface environments is temperature of crystallization. Theoretical and empirical studies have shown that the ratio of oxygen-18 to oxygen-16 varies systematically with temperature in carbonates if the oxygen isotope compositions of the source waters are similar. Departure of carbonate crystallization temperatures from the present value can be determined using oxygen isotope compositions of Pleistocene samples in comparison with isotope composition of Holocene samples. Paleotemperatures thus determined can be very useful in testing the hypothesis that pluvial periods were caused at least in part by cooler temperatures and reduced rates of evapotranspiration. In addition, since there is a regular change in oxygen

 YMP/CM-0011, Rev. 1

isotope composition of carbonates with temperature, the magnitude of temperature change can be estimated. Empirical studies have shown that carbon isotopic composition of soil carbonates is controlled to a great extent by the type of plant community. Because temperature is one of the controlling factors in plant geography, determination of the former vegetation type will serve as an independent, qualitative check on the paleotemperature determinations.

Erosional landforms ("nivation basins") above 2,200 m in the high mountain ranges near the Nevada Test Site reflect the past occurrence of perennial snowfields (Dohrenwend, 1984). Although the time of formation of these features is not yet known with certainty, they are presumably of Late Wisconsin age. The occurrence of perennial snowfields provides evidence on the past climate at the upper reaches of the recharge areas for Yucca Mountain. Investigations of these features will focus on their geographic and elevational distribution, their age, and the paleoclimatic inferences that can be drawn from their occurrence.

The distribution of those calcite-opaline silica accumulations whose stratigraphic relations and areal locations suggest possible derivation from major calcite-opaline silica vein deposits will be noted. Stratiform bodies of secondary calcite opaline silica of pedogenic origin are associated with all older soils at Yucca Mountain. Calcite-opaline silica within the vein deposits is physically somewhat similar, but forms steeply dipping veins within faults and fracture systems. The veins may have formed through downward infiltration of solutions associated with pedogenic processes, or they may have formed though a variety of other processes (see discussion of calcite-opaline silica vein deposits, Activity 8.3.1.5.2.1.5). Distinction between these alternative hypotheses may have significant hydrologic implications, hence information on the distribution of these deposits will be collected as part of the surficial deposits mapping of Yucca Mountain, and supplied to Activity 8.3.1.5.2.1.5 (studies of calcite and opaline silica vein deposits) for further analysis.

8.3.1.5.1.4.3 Activity: Eolian history of the Yucca Mountain region

Objectives

The objectives of this activity are

1. Document eolian erosion and deposition in the Yucca Mountain area during the last 750,000 yr.

2. Determine paleoenvironmental conditions during times of eolian deposition and intervening times of surface stability and soil formation.

3. Determine source areas of sand and silt.

 YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are

1. Age of eolian sediments and soils developed on eolian deposits by uranium-series methods, thermoluminescence, and volcanic ash identification.

2. Textural characteristics of sediments.

3. Mineralogy of sediments.

4. Paleowind directions--directly determined from faceted bedrock surfaces, or determined from cross-bedding azimuth measurements of dune deposits.

5. Paleowind velocities--indirectly determined by measuring platelet spacing on the surface of abraded quartz grains.

6. Concentrations of thorium, titanium, zirconium, yttrium, and niobium in alluvial and eolian sands and in alluvial and eolian silts.

Description

Eolian deposits are widespread in the Yucca Mountain area. Thick deposits of sand have been blown against Fran Ridge, Busted Butte, and southern parts of Yucca Mountain, and veneers of eolian silt mantle nearly all flat and gently sloping surfaces and ridge tops in the area. These deposits range in age from at least 740,000 yr to only a few thousand years old. Thus, the great spatial and temporal distribution of eolian deposition and erosion, and the intervening episodes of surface stability and soil formation, record a long history of climatically influenced conditions at Yucca Mountain. Dating of eolian deposits is also important to the reconstruction of Quaternary fault movements at Yucca Mountain, because several major north-south trending faults offset these eolian deposits.

Eolian sands will be dated primarily by identifying volcanic ashes that are interbedded in sand ramps, and by uranium-series dating of secondary carbonates in the soils developed on these deposits. Paleoenvironmental conditions that have well-constrained ages can then be compared with other paleoclimatic reconstructions, most notably the lacustrine records developed under Activity 8.3.1.5.1.2.1. Because the paleoclimate record derived from pack rat middens in the Yucca Mountain area is limited to the age range of radiocarbon dating (about 50,000 yr before present), dated eolian deposits are one of the few sensitive paleoclimatic indicators available for reconstructing paleoenvironments older than 40,000 yr.

The Bishop ash has already been observed in the sand ramps, indicating that eolian deposition in the Yucca Mountain region began before 740,000 yr B.P (Izett, 1982). Volcanic ashes of Lava Creek (610,000 yr B.P.) and Lathrop Wells basaltic core (the late Quaternary) occur in the Yucca Mountain area and may occur in the sand ramps.

 YMP/CM-0011, Rev. 1

Uranium-series dating of the sand ramps is possible because these sediments contain secondary carbonates of two distinct types. The first type takes the form of rhizoliths or root casts; these features form as sheaths and casts of plant roots in sandy calcareous sediments. The presence of a plant cover implies that the sediments have been stabilized and that little or no deposition is taking place. The second type of carbonate deposit found in the sand ramps is laminar calcrete. Studies conducted elsewhere in the southwestern United States indicate that most laminar calcretes are of pedogenic origin and take a considerable amount of time to form after stabilization of the geomorphic surface (Gile et al., 1965). Uranium-series dating of rhizoliths yields a close minimum age for the time of stabilization of a sand ramp surface. Uranium-series dating of laminar calcretes yields a minimum age for the underlying sediments, but also a maximum age for overlying sediments. Thus, by dating both types of carbonates, bracketing uranium-series dates can be obtained for many of the sand ramp sediments; for the uppermost units, close minimum ages can be obtained.

Fine-grained eolian silt is an ideal geologic material for dating by thermoluminescence analysis over a time range of the last 100,000 yr. Silt-rich eolian deposits mantle gently dipping surfaces and may represent one or more episodes of eolian deposition. Preliminary thermoluminescence dating of vesicular A horizons from the Yucca Mountain area indicates that deposition of the fine silt fraction took place in the mid-Holocene (Whitney et al., 1986).

The distribution and thickness of these dated eolian deposits, both sand and silt, will be mapped to aid in the reconstruction of paleowind directions and in the identification of sediment source areas. Regional wind directions can be reconstructed from the position of dunes with respect to topographic barriers, and by regional comparison of the geometry, cross-bedding azimuths, and thickness of the deposits. Paleowind directions will also be measured from the orientation of wind-abraded bedrock surfaces on hills and mountains.

The geochemistry of immobile trace elements will be studied in eolian sediments to identify sediment source areas. Sand and silt-rich soil A horizons, typically with vesicular structure, are common surface horizons in soils of arid regions, including most soils in the Yucca Mountain area. Investigators who have studied these features in other parts of the southwestern United States have concluded that many such features are (1) primarily eolian in origin and (2) of Holocene age (McFadden et al., 1986). Particle size analyses of vesicular A horizons from the Yucca Mountain area indicate that these features have modal sizes in the fine sand and fine silt fractions, suggesting that (1) the features are probably eolian and (2) two sources of sediment may be involved, one local (fine sands) and one distant (fine silts). If the source of the fine silts can be identified, it may be possible to reconstruct the mid-Holocene paleowind pattern. The most likely candidates as distant sources for the fine silts are unvegetated playa surfaces found in the structural basins of southern Nevada. Identification of the source basin or basins is possible by analysis of playa fine silts and vesicular A horizon fine silts for immobile trace element concentrations. The term immobile here refers to elements that are usually chemically immobile under surface conditions. Such elements (thorium, titanium, zirconium, yttrium, and niobium) are not leached from crystal lattice positions under subaerial conditions and hence can serve as signatures for basins with

YMP/CM-0011, Rev. 1

distinctive lithologies. The five trace elements to be measured are those that have been used most extensively by igneous petrologists in classifications of volcanic rocks of different origins; their use here is appropriate because most of the basins in southern Nevada receive sediments eroded primarily from Tertiary volcanic rocks. In a similar fashion, local sources of the fine sands found in the vesicular A horizons can be identified using the same trace elements. Collectively, the data should identify the sources of sediment in soil A horizons and allow reconstruction of local and synoptic-scale paleowind patterns in the mid-Holocene.

Investigations of sand mineralogy will be performed to augment both sediment source identification and to search for volcanic ashes. Textural characteristics of the eolian deposits will be analyzed to aid in reconstructing eolian conditions and to determine how much sand has been reworked by alluvial processes. Bimodal grain-size distributions, for example, exist in the silt mantles, indicating two sources of sediment in the deposit.

Terrestrial paleoecologic studies will be done on pollen, teeth, bones, rootcasts, and burrows where such evidence is found and can be determined to indicate local paleoenvironmental conditions. Tests will be done to determine whether or not the pollen preserved in sand ramp sands and interbedded soils is of local or regional origin. This information can then be compared with paleoenvironmental information derived from macrofossil studies of local pack rat middens (Study 8.3.1.5.1.3). Soils analyses undertaken as part of the surficial deposits mapping of Yucca Mountain (see description of Activity 8.3.1.5.1.4.2) will yield paleotemperature information from oxygen isotopic analyses, and ranges of paleotemperatures and precipitation based on modeling of several soil properties (Activity 8.3.1.5.1.4.1).

Paleowind velocities will be measured indirectly by studying the surface textures of eolian quartz grains with a scanning electron microscope. The frosting of quartz grains is known to be caused by abrasion, and at the microscopic level this frosting is seen to be the formation of a series of parallel plates. The spacing between individual plates is related to the velocity of the wind that last transported the grains. Measurements of plate spacing on grains from different age deposits will allow comparison of paleowind velocities with those of present winds.

8.3.1.5.1.5 Study: Paleoclimate-paleoenvironmental synthesis

This study consists of one activity and will compare the paleoclimatic estimates from the various proxy data sets and provide data syntheses in the formats required for future climate and paleohydrology investigations.

 YMP/CM-0011, Rev. 1

8.3.1.5.1.5.1 Activity: Paleoclimate-paleoenvironmental synthesis

Objectives

The objective of this activity is to provide summaries of the paleoclimatic data in formats that can be utilized by investigations of future climatic changes and paleohydrology.

Parameters

The parameters for this activity are

1. Synoptic snapshots of climatic conditions during key time periods in the past.

2. Time series (chronologies) of changes in climatic variables (e.g., precipitation and temperature).

3. Estimates of magnitude, timing, and duration of major past periods of high effective moisture.

Description

Paleoclimatic data will be used (1) in future climate investigations to evaluate numerical climate models, (2) to establish the relationships between past periods of high levels of effective moisture in southern Nevada and global climate states, and (3) to provide input into paleohydrological models. The paleoclimatic estimates from paleolacustrine investigations, terrestrial paleoecology, and paleoenvironmental investigations must be compared and synthesized into the forms required by these other studies.

The first use of the synthesized paleoclimatic data is in evaluating numerical climate models. The numerical climate models will be constructed on the basis of modern climatic data, and paleoclimatic investigations will provide independent data for model evaluation. This exercise will require mapped arrays of paleoclimatic estimates (synoptic snapshots) for key time periods in the past (primarily over the last 50,000 yr). The periods will be selected to provide a range of differing boundary conditions, such as global ice maxima versus minima, and will demonstrate the validity and sensitivity of the models to changes in these conditions.

The second application of the paleoclimatic data is to support a second approach to predicting aspects of future climatic variations in southern Nevada will involve identifying the global climate states (e.g., glacials, interglacials, and interstadials) that accompanied regional periods of high effective moisture. Estimates of the characteristics, magnitudes, and durations of such periods will provide guidance in estimating the climatic infiltration parameters that would occur at Yucca Mountain, if, for example, a glacial climate occurred in the next 10,000 to 100,000 yr. The paleoclimate data base may be adequate to identify periodic components in past climatic variations to provide a basis for estimating the timing of future changes. This approach will require time-series data of variations in climatic parameters.

 YMP/CM-0011, Rev. 1

Mapped summaries of paleoclimatic estimates will be compared with paleohydrologic data to establish the relationships between climatic phenomena and changes in hydrologic parameters. These maps will be similar to those required for model validations, but will be centered on Yucca Mountain and will be on finer, smaller spatial and temporal scales. Ongoing scientific work that bears directly on these modeling efforts is being carried out under the COHMAP project (Webb et al., 1987), a joint venture including Brown University, the University of Wisconsin, and the National Center for Atmospheric Research (NCAR). The COHMAP project includes mapping of general circulation model (GCM) simulated climates (from the NCAR Community Climate Model) at 3,000-yr intervals back to full glacial. The simulations are then compared with conditions inferred from paleoclimate indicators (e.g., fossil pollen). The results of the COHMAP project are expected to be extremely useful in implementing the site characterization plans, and COHMAP activities will be integrated with the SCP activities wherever appropriate.

8.3.1.5.1.6 Study: Characterization of the future regional climate and environments

The objective of this study is to estimate values for climatic parameters for the Yucca Mountain area over the next 100,000 yr, with special emphasis on the next 10,000 yr. The values for these parameters will be used in the hydrologic modeling of the ground-water regime at Yucca Mountain (Investigation 8.3.1.5.2) and in the investigation of the effects of future climate on erosion at Yucca Mountain (Investigation 8.3.1.6.2). Estimates for future precipitation, temperature, evapotranspiration, and other parameters will result from the modeling of certain climate scenarios expected to occur in the southern Great Basin over the next 100,000 yr.

Modeling of future climate requires the development of a procedure for quantitatively evaluating the characteristics of future climate scenarios. This study will employ a dual approach to modeling: a numerical approach (Activities 8.3.1.5.1.6.1 through 8.3.1.5.1.6.3) and an empirical approach (Activity 8.3.1.5.1.6.4). Both approaches first require the establishment of an integrated time series of paleoclimate change and the selection of expected future climate scenarios based on the nature and timing of climate scenarios in the Quaternary. In the numerical modeling approach, a linked global-regional numerical model will be employed to calculate the future meteorological parameters. The regional model will use boundary conditions for future scenarios as derived from a global climate model as well as from paleoclimate evidence from corresponding similar episodes in the Quaternary. In the empirical modeling approach, values of climate parameters for future scenarios will be estimated from evidence in the paleoclimate record for corresponding similar episodes in the Quaternary.

Both the numerical and the empirical approaches to modeling future climate are descriptive methods. They are two different ways of describing the meteorology of future climate scenarios, and both are based on the paleoclimate history of the region. This history will include the timing, duration, and meteorologic nature of Quaternary climatic episodes. The prehistorical record of climate must extend far enough back into the past and be dated with enough precision to allow the reconstruction of an integrated

YMP/CM-0011, Rev. 1

time series of paleoclimate from paleolacustrine, terrestrial paleoecologic, and paleoenvironmental evidence (Study 8.3.1.5.1.5).

As an integral part of this study, two advisory panels will be formed. These panels, made up of specialists in areas of climate modeling, will be used to assess the specific details of the two climate modeling efforts (i.e., the global modeling and the regional modeling, if the feasibility study determines that regional modeling is appropriate), with particular attention to be given to (1) the development of criteria to evaluate the different models available and the different techniques used, (2) the establishment of boundary conditions, (3) the expected and realistically attainable output from each model, and (4) the ability of the two models to interact with each other. The potential use of the advisory panels is identified in the following discussion of the activities to be conducted under this study.

8.3.1.5.1.6.1 Activity: Global climate modeling

Objectives

The objectives of this activity are to

1. Identify and estimate factors controlling global climate.

   a. Develop a sequence of "snapshots" of possible climate scenarios at intervals of up to 1,000 yr over the next 10,000 yr.

   b. Develop a set of anticipated global climate scenarios over the next 100,000 yr.

2. Compute the configuration and extent of ice sheets at regular intervals of time over the next 100,000 yr to determine the effects of such ice volume changes upon the climatic system.

3. Provide boundary conditions, including precipitation, temperature, cloud cover, evapotranspiration, and wind velocity for regional climate models through the use of general circulation models.

Parameters

The output from the global climate modeling, to be used as boundary conditions for the regional modeling includes means and ranges of the following parameters:

1. Surface temperature.
2. Cumulative precipitation rate.
3. Condensed moisture.
4. Fractional cloud amount.
5. Averaged solar flux absorbed at surface.
6. Averaged solar flux absorbed by earth and atmosphere.
7. Averaged infrared flux upward at surface.
8. Averaged longwave flux at top of atmosphere.

 YMP/CM-0011, Rev. 1

9. Averaged total albedo of surface and atmosphere.
10. Shortwave heating rate.
11. Longwave heating rate.
12. Convective temperature change.
13. Sensible heat flux at surface.
14. Latent heat flux at surface.
15. Wind velocity.

Description

The paleoenvironmental record for the Quaternary Period suggests that significant variations in climate have occurred in the past and are likely to occur in the future. Modeling future global and regional climate will help determine whether such variations in climate can significantly affect the proposed repository at Yucca Mountain. General circulation models (GCMs) can provide three-dimensional simulations of the atmosphere at too coarse a spatial resolution to provide meaningful results for specific sites. Regional mesoscale models are capable of disaggregating GCM output to represent explicitly the physical processes that govern the hydrologic balance. Therefore, the goal of this study is to link a GCM with a regional model to predict future climate.

The prediction of future global climate rests largely on calculation of extreme climatic conditions (scenarios) that can be anticipated to occur in the future. A coupled ice sheet-energy balance modulus expected to be used to identify the scenarios pertinent to hydrology that are associated with repository performance. At present, the following scenarios have been identified as being of concern:

1. Natural variability under modern conditions.

2. Glacial periods that may correspond to pluvial conditions in the southern Great Basin.

3. A "super" glacial and resulting conditions in the southern Great Basin.

4. A "super" interglacial, in which increases in carbon dioxide and other trace gases lead to significant global warming.

5. A "super-long" period of changed climate, that, by virtue of its duration, could adversely affect site performance.

In addition, future climate for the next 10,000 yr will be modeled in time intervals of up to 1,000 yr in duration. Additional scenarios and time periods will be run as required by results of the energy balance model runs or other sources.

The best known changes in the global climate system during the Quaternary Period accompanied the growth and decay of major ice sheets. These glacial-interglacial cycles have been shown to correlate with the variations in orbital parameters of the earth (i.e., longitude of perihelion, obliquity, and eccentricity (Hays et al., 1976)).

 YMP/CM-0011, Rev. 1

One goal of climate modeling is to demonstrate that these ice volume variations follow deductively from a simple set of mathematical statements or forcing functions. Computer codes have been developed to simulate climate change based upon these forcing functions. These climate drivers will provide (1) estimates of the probability of certain climate scenarios, (2) timing of climate scenarios of concern, and (3) rough estimates of future climate states.

The first major step in the modeling activity involves estimating configurations of each major ice sheet on the globe at regular intervals of time over the next 100,000 yr. Although orbital variations may induce glacial-interglacial cycles, one of the important factors helping to maintain ice ages is the extensive ice sheets which increase the albedo of the earth. Therefore, a two-dimensional ice sheet model will be developed in this activity and will be calibrated to output from the global climate drivers.

General circulation models (GCMs) are sensitive to the volume and distribution of glacial ice covering the earth as well as variations in the orbital parameters of the earth. These scenarios of interest will be determined by an expert panel after examination of the simulated evolution of boundary conditions as produced by the climate-driver models possibly augmented by an energy-balance model. The scenarios of interest may not be limited to extreme boundary conditions, but may include situations which, because of their temporal persistence or other characteristics, are potentially relevant to site performance. Therefore, output from the climate driver and ice sheet models will be used as boundary conditions for GCM runs at the time periods or for the scenarios of interest. Additional boundary conditions for runs of GCMs include the locations and elevations of continental areas, the locations and elevations of continental ice, the locations and temperature of sea ice, surface albedo, and sea-surface temperature.

Since uncertainties exist in specifying or computing factors such as CO_2 level or sea surface temperatures, the model simulations will include a sensitivity analysis of climate response to a plausible range of variables that may contribute to global climate change.

Present plans for the GCM modeling will use the CCM at the National Center for Atmospheric Research. This approach has been approved by the advisory panel mentioned earlier. A version of the CCM under development includes an oceanic circulation component and should result in documented, well-tested codes by FY 1989.

Initial model simulations are designed to determine the sensitivity of climate to uncertainties in the specified boundary conditions. These simulations will be done with fixed sea surface temperatures. Future simulations will be designed to incorporate the full seasonal cycle. Output data will include estimates of precipitation, temperature, cloud cover, evapotranspiration and wind velocity. Regional processors will be developed to manipulate the data that surrounds the Yucca Mountain site in coordination with the regional modeling activity. Input to the regional models will be in the form of boundary conditions.

YMP/CM-0011, Rev. 1

Published model results (CLIMAP Project Members, 1981) for the last glacial maximum will provide a set of benchmarks in the early stages of the activity. Some examination of the appropriateness of the model results can be obtained from the comparisons to the various time horizons represented in the geologic record.

The documentation of all the computer codes and mathematical and numerical models will follow NRC guidelines for documentation of codes (NRC, 1983a). The codes will be evaluated through an examination of the ability of the coded procedures to reproduce accurately the modern circulation patterns and those reconstructed for the last glacial maximum and other time horizons (where data are available). All model results will be reviewed by the advisory panel at regular intervals during the characterization process.

8.3.1.5.1.6.2 Activity: Regional climate modeling

Objectives

The objective of this activity is to establish the feasibility of using a regional scale numerical climate model for predicting future climatic conditions at Yucca Mountain. If this task is accomplished, the model will be calibrated against modern climatic data and validated with paleoclimatic data.

Parameters

The parameters for this activity are

1. Calibration of a regional-scale numerical climatic model (with historic data).

2. Evaluation of a regional-scale model (with paleoclimatic data).

Description

A feasibility study will be initiated to evaluate the applicability of numerical regional climate modeling in accomplishing the climate prediction requirements of the Yucca Mountain Project within appropriate time and cost constraints. Regional numerical modeling is used to describe the meteorology of expected future climate scenarios resulting from the interpretation of the paleoclimate record. A numerical regional model is a mathematical description of the dynamics of the earth's atmospheric circulation, based upon the equations of fluid flow and specific boundary conditions. The model describes how the earth's atmosphere responds to imposed boundary conditions, with the output of the model being in the form of calculated values of meteorological parameters (precipitation, temperature, etc.) for discrete geographic areas--rectangles created by gridding the earth's surface parallel to latitude and longitude. Reducing grid size increases the spatial resolution of the model at the cost of increased computational load. The practicality of small grids will be studied.

YMP/CM-0011, Rev. 1

The feasibility of a regional modeling approach would first be established by demonstrating that current climate conditions can be adequately simulated over the southern Great Basin. This exercise would emphasize amounts and seasonal patterning of precipitation and other surface climatological conditions. If it is successful in these simulations, the model would be tested against Quaternary paleoclimatic conditions for periods with adequate observational characterization of surface climate. If these efforts were also successful, the model would be deemed suitable for generating future climate scenarios for the proposed repository site at Yucca Mountain and would be so employed.

The development of a numerical atmospheric model will be pursued only if the proposed feasibility study indicates that the numerical modeling approach would be an effective and timely method of accomplishing the Yucca Mountain Project climate prediction objectives. If the feasibility study does not produce encouraging results in terms of the resolution desired and computational efficiency regarding regional numerical modeling, as determined from criteria established by an expert panel, then the characterization of future regional climate and environments will be based essentially on the empirical modeling approach.

8.3.1.5.1.6.3 Activity: Linked global-regional climate modeling

Objectives

The objectives of this activity are to

1. Formulate reasonable hypotheses for scenarios of future climate in the southern Great Basin and Yucca Mountain over the next 100,000 yr, with emphasis on the next 10,000 yr.

2. Model meteorological parameters of expected climate scenarios for the southern Great Basin.

3. Use the quantitative meteorologic descriptions resulting from the modeling of future climate scenarios to derive measurements of climate parameters to be used in hydrologic modeling of the Yucca Mountain area and in investigating the effects of climate on erosion at Yucca Mountain.

Parameters

The parameters for this activity are

1. Estimates of the nature, timing, and probability of occurrence of future climate scenarios.

2. Meteorologic parameters of expected future climate scenarios: average annual rainfall, seasonal distribution of rainfall, type and intensity of storms, average annual snowfall, distribution and duration of snow cover, rapidity of snowmelt, evapotranspiration, cloud cover, and temperature.

 YMP/CM-0011, Rev. 1

3. The values of meteorologic parameters over requisite time spans, to be used in the hydrologic modeling of Yucca Mountain and in erosion investigations.

Description

Following the testing period for the regional climate model, it will be decided if such a modeling approach is within the time and cost constraints of the Yucca Mountain Project. In addition, the defensibility of the model on its own will be analyzed as well as its ability to link with the global climate model. If the regional numerical model receives approval from an expert panel, it will be linked with a GCM (Section 8.3.1.5.1.6.1) to simulate future climatic conditions at Yucca Mountain. The outputs of the global future climate modeling activity will be used as boundary conditions on regional climate model runs to simulate future climate conditions at Yucca Mountain.

8.3.1.5.1.6.4 Activity: Empirical climate modeling

Objectives

The objectives of this activity are to

1. Formulate reasonable hypotheses for scenarios of future climate in the southern Great Basin and Yucca Mountain over the next 100,000 yr, with emphasis on the next 10,000 yr.

2. Model meteorological parameters of expected climate scenarios for the southern Great Basin.

3. Use the quantitative meteorologic descriptions resulting from the modeling of future climate scenarios to derive measurements of climate parameters to be used in hydrologic modeling of the Yucca Mountain area and in investigating the effects of climate on erosion at Yucca Mountain.

Parameters

The parameters for this activity are

1. Estimates of the nature, timing, and probability of occurrence of future climate scenarios.

2. Meteorologic parameters of expected future climate scenarios over requisite time spans: average annual rainfall, seasonal distribution of rainfall, type and intensity of storms, average annual snowfall, distribution and duration of snow cover, rapidity of snowmelt, evapotranspiration, cloud cover, wind speed and direction, and temperature.

YMP/CM-0011, Rev. 1

Description

The empirical approach to climate modeling will be the direct application of meteorological values estimated for paleoclimate episodes to the description of analogous scenarios expected to occur in the future. For a given scenario, values of precipitation, temperature, and other parameters would be estimated directly from the paleolacustrine, terrestrial paleoecologic, and paleoenvironmental evidence. A simplistic example would be the following: statistical examination of the paleoclimate record might show that there is a moderate-to-high probability of another period of higher-than-present precipitation and lower-than-present temperatures (a pluvial), spanning several thousand years, occurring at some time between 80,000 and 100,000 yr from the present. To characterize the meteorology of this expected episode, the values of meteorologic parameters for prior pluvial episodes are assembled from the physical evidence of the palecolimate record. The averages, seasonality, ranges, and areas of uncertainty for the parameters are synthesized in a form usable as input for hydrologic modeling. It should be noted that this approach of directly applying paleoclimate data to expected future scenarios is based directly on physical evidence, and on the assumption that climatic episodes within the next 100,000 yr in the southern Great Basin will resemble events in the Quaternary paleoclimate history of the area. The record of past climatic variations can thus provide a guide to the range of climatic conditions foreseeable in the future, providing that the large-scale controls of climate remain similar to those that prevailed in the past. The increase of CO_2 concentrations in the atmosphere in the future (due to the burning of fossil fuels, etc.) makes it likely that the large-scale controls of climate in the future may differ from those experienced during the Quaternary. As a result, numerical approaches to the prediction of future climate may be required to supplement the empirical methods.

The time series of paleoclimate will then be statistically examined for possible periodic components in climatic variation, including an examination for the presence of astronomical forcing of atmospheric circulation (the influence of changes in the earth's orbital relations to the sun on global air mass circulation). The present state of our knowledge of Great Basin climate history, as evidenced by the highstands of paleolake systems, suggests periodic components in climatic episodes of higher-than-present effective moisture in the Great Basin. Should this be confirmed statistically, it will then be possible to apply this periodic forcing function to estimating the timing of possible future pluvial episodes over the next 100,000 yr. This exercise will be aided by the fact that the variations in orbital parameters (eccentricity, obliquity, and precession) governing astronomical forcing can be estimated over the next 10,000 to 100,000 yr, and thus changes in insolation in that period are predictable.

If a periodicity in the climate record can be established, a sequence of expected future climate scenarios can be formulated for the next 100,000 yr, possibly accompanied by estimates of probabilities of occurrence for different climatic scenarios over this period. Should a periodicity not be clearly established, it will become necessary to use an alternative approach to estimating the timing of future climate scenarios. Such an approach would likely be a statistical description of the probabilities of certain climate scenarios recurring over the next 100,000 yr.

 YMP/CM-0011, Rev. 1

8.3.1.5.2 Investigation: Studies to provide the information required on potential effects of future climatic conditions on hydrologic characteristics

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
3.7.4	Paleohydrology (regional)
3.9.8	Paleohydrology (site)
5.2.1	Paleoclimatology
5.2.2	Future climatic variation
5.2.3	Site paleoclimatic investigations

Parameters

The following parameters will be measured, estimated, or calculated as a result of the site studies planned as part of this investigation:

1. Relationship between climate and infiltration.

2. Past and future surface water characteristics--locations, frequency, and hydraulic properties of past and future flood events.

3. Past and future unsaturated-zone hydrologic characteristics--hydrochemical characteristics as an indication of past hydrology and prediction of future ground-water flow conditions.

4. Past and future saturated-zone hydrologic characteristics--water table altitude, and recharge and discharge locations and rates.

Other site studies that provide information that support the determination of the previous parameters include the following:

SCP section	Study
8.3.1.2.1.2	Characterization of the regional surface water (present-day surface-water conditions)
8.3.1.2.1.3	Characterization of the regional ground-water flow system (present-day regional geohydrology)
8.3.1.2.1.4	Regional hydrologic system synthesis and modeling (present-day regional hydrology)
8.3.1.2.2.1	Characterization of unsaturated zone infiltration (present-day infiltration at the site)

 YMP/CM-0011, Rev. 1

SCP section	Study
8.3.1.2.2.3	Characterization of percolation in the unsaturated zone (present-day unsaturated-zone flux at the site)
8.3.1.2.2.7	Hydrochemical characterization of the unsaturated zone (present-day unsaturated-zone flux at the site)
8.3.1.2.2.8	Flow in unsaturated, fractured rock
8.3.1.2.2.9	Site unsaturated zone modeling, synthesis, and integration (present-day unsaturated zone geohydrology)
8.3.1.2.3.1	Characterization of the saturated zone ground-water flow system (present-day saturated zone geohydrology)
8.3.1.2.3.2	Characterization of the saturated zone hydrochemistry
8.3.1.2.3.3	Saturated zone hydrologic system synthesis and modeling (present-day saturated zone geohydrology)
8.3.1.5.1.1	Characterization of the modern regional climate (present-day regional climatic conditions)
8.3.1.5.1.2	Regional paleolimnologic studies (past regional climatic conditions)
8.3.1.5.1.3	Regional terrestrial paleoecologic studies (past regional climatic conditions)
8.3.1.5.1.4	Analysis of paleoenvironmental history of the Yucca Mountain region (past environments at the site)
8.3.1.5.1.6	Characterization of the future regional climate and environments (future climatic conditions at the site)
8.3.1.16.1.1	Site flood and debris hazards studies (present-day flood potential at the site)

Purpose and objectives of the investigation

This investigation (8.3.1.5.2) provides information to help satisfy performance and design Issues 1.1, 1.8, 1.9a and b, and 1.10. Reconstructions from Investigation 8.3.1.5.1 along with past surface water, and unsaturated- and saturated-zone characterizations will lead to an understanding of the Quaternary regional hydrologic regime. This information along with models of future climate conditions and estimates of future meteorological conditions from Investigation 8.3.1.2.1, and models of the unsaturated and saturated zones from the geohydrology program (Section 8.3.1.2) will help determine the effects of climate change on geohydrology. This will require the development of a relationship between climate and infiltration and recharge.

YMP/CM-0011, Rev. 1

Technical rationale for the investigation

Climatic, igneous, tectonic, and erosional processes may potentially change the geohydrologic setting at Yucca Mountain. The purpose of this investigation is to determine the hydrologic conditions during the Quaternary that have differed significantly from present conditions due to changes in the climatic processes. This information will be used to evaluate the likelihood of recurrence over the next 100,000 yr of episodic conditions that may affect the regional flow system. Of specific interest are (1) the maximum altitude of the water table during pluvial periods of the Pleistocene Epoch, (2) the effects of water-table rises on shortening of ground-water flow paths to discharge areas, and (3) the magnitude of increases in recharge during pluvial periods. With this information, questions such as the following can be addressed: "What is the possibility of the repository flooding due to a rising water table during a return of pluvial conditions?" and "How large an infiltration flux might move through the repository in the future?" These potential future hydrologic conditions resulting from changing climatic conditions will be predicted through the use of numerical model sensitivity analyses. These sensitivity analyses (which are discussed in detail in each appropriate activity) will involve assessing the sensitivity of flow in the unsaturated and saturated zones to variations in infiltration and recharge.

The relationship between climate and infiltration and recharge will be developed on the basis of studies conducted under this testing program. Once this relationship is developed, the results of the sensitivity analyses will be used to identify the climatic parameters needed for assessing future conditions in the unsaturated and saturated zones. This information can then be used by the future climate modeling study (Section 8.3.1.5.1.6) to simulate the necessary scenarios that describe the conditions and occurrence of significant periods of climatic variation. Subsequently, the hydrologic models will use these predicted climatic conditions to simulate future infiltration to the unsaturated zone and recharge to the saturated zone.

Recurring pluvio-glacial climate conditions could shorten the time for radionuclide transport from the repository to the accessible environment if it is shown that percolation flux is increased through the repository block. The velocity increase produced by increased infiltration will be predicted by site-scale modeling. Also of significance is the maximum water-table rise that might accompany a recurring pluvio-glacial climatic condition, travel time be shortened by reducing the thickness of unsaturated zone below the repository (Czarnecki, 1985).

The water-table altitude beneath the repository block reflects an interaction of many factors, including (1) the local recharge rate, (2) the lateral flux in the saturated zone resulting from recharge in upgradient areas, (3) vestiges from prior climatic regimes that persist because of storage effects, (4) distance to and altitude of regional discharge boundaries, and (5) especially, the distribution of conductivities and structures in the saturated zone. Computer models can functionally relate these conditions. A water-table change can be predicted due to a change of any one (or more) variable, if the model has been calibrated and checked against known conditions. Obtaining reliable predictions of water-table change will require knowledge of past changes of recharge distribution and discharge positions as well as sufficient detailed geometry and conductivities of units in the entire flow

 YMP/CM-0011, Rev. 1

field. The studies of this investigation include (1) the interpretation of geomorphic and stratigraphic evidence of paleofloods; (2) the evaluation of analog recharge sites to estimate past, and, therefore, future, infiltration characteristics (ground-water recharge); (3) the search for hydrochemical evidence of waters that infiltrated in the past; and (4) the location of past points of ground-water discharge as evidenced by former springs, mineral vein fillings, and cave deposits recording higher water levels in the past. These studies have been formulated to provide the information required to predict the water-table fluctuations.

Paleoflooding will be investigated to improve the knowledge of severe surface runoffs during prehistoric times and to ascertain the relationships between those floods and paleoclimates. The investigation will examine alluvial deposits, debris-flow scars and deposits, severe erosion scars, and stone-stripe deposits to improve the understanding of the processes that formed them, and to determine whether these features have modern analogs that were formed or are forming under present climatic conditions. Results will provide a perspective on differences and similarities between past and present floods, and the relations to different climates. In addition, an improved understanding of the relation between paleoclimate and past floods will supplement predictions of future flooding based on rainfall-runoff modeling (Section 8.3.1.2.1.3).

The increased recharge that would occur under a return to pluvial conditions would depend upon a variety of interrelated factors. These factors include not only the amount of increase in average annual precipitation, but also the seasonal distribution and type of precipitation; the amount and rate of snowmelt; and changes in evapotranspiration, runoff characteristics, and soil and plant cover. Modern settings analogous to past climatic conditions at Yucca Mountain will be identified, instrumented, and studied to determine the infiltration versus precipitation relationships that relate to past and future climates. These modern settings, referred to as analog recharge sites, will be identified based on the rock-soil-vegetation cover, geology, topography, meteorological conditions, and hydrochemical properties of the precipitation, surface water, and soil moisture. Then, by evaluating the characteristics of each site, the conditions and rates of ground-water infiltration and recharge representative of past and future pluvial conditions will be estimated.

To gain a further understanding of the Quaternary ground-water conditions at Yucca Mountain, the discharge area of the ground-water basin will be studied for evidence of prior water-table elevation, discharge, and temperature. The potentiometric surface in the regional carbonate aquifer is gentle in slope due to the high transmissivity (Section 3.6). Provided that tectonic deformation can be ruled out, prior gradients obtained from paleospring elevations are related linearly to prior discharge. Slope extrapolation to the site and to recharge areas may provide estimates of prior potentiometric altitudes. A study of paleospring deposits and fossils contained in them will indicate altitudes of former discharge points and suggest paleodischarge rates. These studies are justified on the same basis as are efforts to interpret the fossil record and the paleohydrology of recharge areas. Both boundary conditions need to be defined for any one time modeled. Redundant and confirmatory data, such as the detailed study of zeolites for

 YMP/CM-0011, Rev. 1

evidence of fossil saturation levels, will help substantiate the hydrologic model predictions.

Remote sensing and field survey methods will be used to locate structural features presently or formerly controlling regional flow and discharge areas. Biologic and fossil evidence will be assessed for past discharge rates and climatic implications. Carbonate deposits will be sampled in caves, where they formed at various levels reflecting different water-table elevations. Carbon and oxygen isotope ratios in such minerals reflect the age and climate of the waters that formed them; thus, cyclic history may be recorded for regional interpretation of the basin hydrology. Past discharges will also be estimated in discharge areas from measured conductivities and computed gradients.

On the basis of current knowledge of hydrogeologic properties, fluxes, hydraulic heads, and estimated recharge rates, past water-table altitudes will be calculated. To further reduce uncertainty in these results, additional information about past water tables will be sought. Hydrochemistry will be used to produce a second line of evidence for paleosaturation altitudes. Hydrochemical analyses have the potential of identifying waters of an age and oxygen-18/oxygen-16 ratio consistent with infiltration during a past pluvial period, thereby providing information on flow velocities and paths. In principle, a sufficiently refined model can then predict future fluctuations in the water-table altitude if adequate boundary conditions are provided for the various climatic regimes.

8.3.1.5.2.1 Study: Characterization of the Quaternary regional hydrology

The objective of this study is to characterize the distribution of surface water, the unsaturated zone infiltration and percolation rates, and the ground-water potentiometric levels during the Quaternary Period in the vicinity of Yucca Mountain.

Activities planned for the study are (1) an evaluation of regional paleofloods, (2) an analysis of unsaturated zone hydrochemistry, (3) an evaluation of past regional discharge areas, (4) an analog recharge study, and (5) an assessment of calcite-silica vein deposits.

8.3.1.5.2.1.1 Activity: Regional paleoflood evaluation

Objectives

The objectives of this activity are to

1. Identify the locations and investigate the hydraulic characteristics of paleoflood events, and compare this evidence with the locations and characteristics of modern flooding and geomorphic processes. These findings and comparisons will improve knowledge of the relationships between climate and flooding.

 YMP/CM-0011, Rev. 1

2. Assess the character and severity of paleoflood and debris hazards to assess the potential of flood and debris hazards for the repository during the preclosure period.

Parameters

The parameters for this activity are

1. Magnitudes, frequencies, areal extent, and hydraulic characteristics of paleoflood flows.

2. Quantities and characteristics of debris movement during paleofloods.

Description

Two trenches have been dug in the north fork of Coyote Wash; one cross-channel trench and one T-shaped trench. These trenches have exposed deposits recording a complex sequence of debris-flow and flood-flow events that occurred during the late Quaternary Period. The trenches have been mapped and analyzed to determine the interpretable characteristics of the paleofloods. Additional trenching, mapping, and stratigraphic analyses of alluvial deposits in neighboring stream channels north and south of Coyote Wash, and throughout the region surrounding Yucca Mountain and the Nevada Test Site will be performed to improve understanding of past flooding in the Yucca Mountain region.

Erosion scars, stone stripes, and other debris deposits will be evaluated with regard to the geomorphic processes responsible for their formation (Investigation 8.3.1.6.1). Areas and drainages of concern will be reconnoitered for erosion scars and hillslope deposits. The features that may be the products of past extreme surface-water runoffs will be examined and recorded. Attempts will be made to develop criteria for dating the features to increase the value of these data with regard to ages and frequencies of debris movement. The widespread presence of stone stripes on hillslopes at and around Yucca Mountain may be evidence of paleofloods and related landslope failures. The presence of these large deposits of cobbles and boulders over substantial areas of steeply sloping terrain poses the concern that they could become entrained in future landslope failures and become incorporated within fluvially transported debris. Improved knowledge of the age and genesis of these deposits should confirm or allay concerns regarding their potential for contributing to future debris hazards. Results will be used in analyses of flooding and debris hazards (Investigation 8.3.1.16.1).

Attempts will be made to date alluvial surfaces and unconsolidated stream-channel deposits. Much of the unconsolidated debris underlying alluvial surfaces and comprising stream-channel deposits was deposited by surface runoff. A determination of the ages of these alluvial surfaces will provide valuable knowledge of past floods. Specifically, it will date the recency of severe flooding at the sites of the deposits, and collectively, these ages may suggest whether severe runoff events of the Yucca Mountain area might be episodic or relatively continuous during recent geologic time. Relative ages of the surfaces will be determined from geomorphic mapping, and absolute ages might be determined using the newly developed technique of

 YMP/CM-0011, Rev. 1

rock-varnish dating. A field and photo reconnaissance of areas of concern should help dictate the techniques to be applied in dating the surfaces.

The evidence of paleoflooding will be compared with the magnitudes and frequencies of historical floods. The streamflow and runoff information collected as part of the activities called "surface-water runoff monitoring" and "transport of debris by severe runoff" will be compared to assess the frequencies and magnitudes of present-day flooding in and around the Nevada Test Site. Available evidence and knowledge of paleofloods will be compared with knowledge developed on current flooding to determine whether present-day flooding is more or less frequent and larger or smaller than past flooding. Modern geomorphic channel and slope processes and their resultant sediment deposits will be compared with fluvial and slope deposits of the past to determine similarities and dissimilarities between modern and paleo processes.

8.3.1.5.2.1.2 Activity: Quaternary unsaturated zone hydrochemical analysis

Objectives

The objectives of this activity are to

1. Determine the past and infiltration percolation history at Yucca Mountain by analyzing the isotopic and chemical characteristics of water from the unsaturated zone.

2. Understand the past unsaturated-zone hydrologic system by modeling vadose-water hydochemistry to help predict the future hydrologic system.

Parameters

The parameters for this activity are the isotopic composition and chemistry of unsaturated-zone water; travel times (chlorine-36, carbon-14, tritium), flow paths (oxygen-18/oxygen-16 ratios, deuterium/hydrogen ratios), and sources of past recharge in the unsaturated zone.

Description

One methodology for characterizing the unsaturated-zone hydrology of Yucca Mountain during the Quaternary in terms of residence times, flow paths and mechanisms, and sources of infiltration will be from the chemical and isotopic characteristics of present-day vadose gas and water. Chlorine-36 and carbon-14 dating of ground water, and carbon-14 dating of carbon-dioxide gas in the unsaturated zone, combined with flow paths determined for stable-isotope ratios (oxygen-18/16, deuterium/hydrogen, and carbon-13/12) and chemical compositions (major cations, anions, and trace elements), should permit the calculation of water or gas travel times. If caliche dissolution is occurring at Yucca Mountain, carbon-14 age corrections should be made using carbon isotopic data on caliche water bicarbonate and carbon dioxide gas (see unsaturated-zone hydrochemistry study plan for details). There will be no direct data collection as part of this activity. The chemical and

 YMP/CM-0011, Rev. 1

isotopic data will be collected in Activities 8.3.1.2.2.7.1, 8.3.1.2.2.7.2, and 8.3.1.2.2.4.8. The interpretations of these data on flow paths and travel times will be compared with those parameters obtained by chemical hydraulic methods.

The results of other investigations associated with paleohydrology and paleoclimate, from which past vadose-water movement may be inferred, will be used in conjunction with the hydraulic parameters and hydrochemical and isotopic data of surface and subsurface waters for the interpretations of the Yucca Mountain recharge history.

All pore-water samples, if enough water can be obtained, will be analyzed for (1) carbon-14, tritium, and chlorine-36 isotopic activity; (2) oxygen, hydrogen, and carbon isotope ratios; and (3) water chemistry. If perched water is encountered in boreholes or the exploratory shaft facility, water samples will also be collected for chemical and isotopic analysis. Carbon-14 and chlorine-36 activities will be determined by tandem-accelerator mass spectrometry. Tritium activity will be analyzed using low-level gas counters or liquid scintillation counters. Stable isotope ratios will be determined using isotope-ratio mass spectrometry. Water chemistry, cations and anions, will be analyzed using inductively coupled plasma and ion chromatography. These tests will be performed in conjunction with other hydrochemical tests conducted in Activity 8.3.1.2.2.4.8.

8.3.1.5.2.1.3 Activity: Evaluation of past discharge areas

Objectives

The objectives of this activity are to

1. Determine the location, type, and extent of hydrogeologic units in the ground-water discharge areas of the Amargosa Desert and Death Valley.

2. Understand the past quantity and quality of water in the discharge areas of Franklin Lake, Amargosa Desert-River, and Peter's Playa and to determine the paleohydrologic significance of Peter's Playa and Franklin Lake as discharge areas.

3. Determine the location and hydrogeologic characteristics of paleo-spring deposits in the discharge area.

4. Determine the location and amount of discharge by evapotranspiration that has occurred at past discharge sites.

5. Understand the past and present discharge areas of the regional hydrologic system in order to predict the future saturated zone hydrologic system at Yucca Mountain.

6. Determine past ground-water levels in carbonate caverns as evidence of past hydrologic conditions.

 YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are

1. Past rates of evapotranspiration
2. Hydrogeologic units (location, type, and extent) in discharge areas.
3. Location of past discharge areas.
4. Past discharge of springs and seeps.
5. Past potentiometric head.

Description

Remote sensing techniques will be used to identify lineaments, fracture zones, types of vegetative cover and types of surficial units so that their hydrologic implications can be determined. The types of remote sensing techniques being considered for use include (1) Landsat multispectral scanner (MSS) and thematic mapping (TM) spectral bands; (2) high-and low-altitude aerial photography (black and white, color, and color infrared); (3) low-altitude predawn thermal data taken before, during, and after storm events; and (4) side-looking airborne radar. Remote sensing will be done in conjunction with Investigation 8.3.1.8.2. A literature search will be conducted to gather information about previous studies using these remote sensing techniques, and appropriate data bases will be collected from national agencies and private contractors. If necessary, new surveys will be run to supplement the existing information.

Linear features such as lineaments and fracture zones, will be mapped to identify areas of interaquifer connection. Existing geologic, geophysical, geochemical, hydrologic, and seismic activity data will be used to supplement the remote sensing data. Evidence of paleotectonic activity such as a facies change, and thickening or thinning of sedimentary units, will be identified from geologic data. Evidence of crystalline-basement discontinuities (structural or lithologic) will be identified by analyzing the geophysical data. Hydrologic and geochemical data will be compared with the lineament map to determine where linear structural or stratigraphic features appear to affect ground-water flow.

The characteristics of the vegetative cover and surficial units will also be identified using remote sensing techniques and categorized into units of equal infiltration-discharge capacity. Reflective and thermal-spectral characteristics will be used to identify the types, spatial distribution, and density of the vegetation and surficial units. The soil moisture content will also be evaluated using reflective and thermal scanner data. Field inspections will be made to verify the remote sensing data. The correlation between the hydrologic and spectral properties of the surficial materials will be evaluated.

Past evapotranspiration rates will be estimated from modern evapotranspiration rates in the study area (Study 8.3.1.2.1.3), the modern rates determined for analog sites (this study), and changes in rates that may result as a function of changes in climate (Investigation 8.3.1.5.1). Variables to be quantified for the study area and analog areas include climate, runoff, vegetative cover, depth to water table, soil type, and infiltration. Once the effects of their variability as a function of climate has been deter-

YMP/CM-0011, Rev. 1

mined, past and future evapotranspiration can be estimated on the basis of predicted climate change.

The infiltration-discharge characteristics of the surficial units and the areas of interaquifer connections will be incorporated into the three-dimensional hydrologic flow model of the regional ground-water-flow system (Activity 8.3.1.5.2.2.3).

Where possible, discharge from springs and seeps will be measured. Water-level measurements will be made in existing wells, caverns, and springs in addition to those collected under Investigations 8.3.1.2.1 and 8.3.1.2.3. Approximately five sites will be selected and recorders installed to provide a record of discharge.

Carbonate caverns located in the ground-water discharge areas south of Yucca Mountain provide a convenient window to the regional carbonate aquifer. The caverns will be mapped, sampled, and analyzed. Previous studies of deposits from these caverns suggest a possible 300,000-yr record of carbon and oxygen isotope variation (Winograd et al., 1985) that may provide information about the Quaternary geohydrologic and paleoclimatologic conditions at these sites and at Yucca Mountain. Deposits on the cavern walls provide a record of water-level changes in the regional carbonate aquifer dating back through the Quaternary. Biologic evidence from the cavern deposits also provides an association with ground-water chemistry.

Where possible, several available caverns will be entered, mapped, and sampled. Approximately 50 samples of the carbonate layers that are exposed on the cavern walls will be collected. The water in these caverns will also be sampled.

The samples will be analyzed to determine mineralogic and biologic composition and age. Information such as ostracode and diatom biology will be used to provide data about mode and environment of occurrence, including water chemistry. Up to 150 thin-sections of carbonate samples will be analyzed to determine mineralogic variations that provide evidence of varying ground-water conditions. Scanning electron microscope (SEM) and x-ray techniques will also be used on up to 100 of the thin-sections to determine the microscopic structure and composition of the banded carbonate units. Chemical, physical, and isotopic analyses will be run on up to 50 samples to determine the age of the water in the aquifer.

Shallow test holes will be rotary drilled or hand augered in the ground-water discharge area south of Yucca Mountain to obtain samples of the subsurface materials. Up to 50 rock-mineral and water samples will be analyzed to determine radiometric dates. The dating method used will depend on the sample type and amount of sample available. Thin-sections will be made from the collected samples and analyzed to determine the mineralogic makeup of the materials. Samples will also be analyzed using x-ray, SEM, particle induced x-ray emission (PIXE), inductively coupled plasma (spectrometer) (ICP), and chemical analyses to provide additional mineralogic information that will be used to support the chemical, geologic, and hydrologic studies. The drill cuttings and core will be evaluated for biological indicators, such as ostracodes, diatoms, and opal phytoliths, using standard methods such as screening and washing of samples and microscope analysis of residue. Samples

 YMP/CM-0011, Rev. 1

will be analyzed to determine the species and the environmental conditions under which the biologic indicator lived.

Studies of ostracode ecology along with studies of ostracode-valve chemistry will be conducted at selected sites to provide detailed information about the thermal and chemical properties of both discharging ground-water and also of the pools, ponds, and marshes supported by that water. This modern ecologic study conducted in conjunction with Study 8.3.1.5.1.2 will use about 30 ground-water discharge environments surrounding Yucca Mountain. The selection of sites will be based upon acquiring water upwelling from the regional aquifers, water from or near recharge sites in the mountains, and water derived from perched ground water in the valleys. Site selection will emphasize thermal and chemical diversity of modern discharging ground water as well as the aquatic environments supported by the discharging ground water. The selected sites will be sampled on at least a quarterly basis and a few key sites may be sampled more frequently. Sampling at each site will include multiple samples of each local subenvironment such as spring vents, spring pools, and marshes, as well as the ground water itself at some sites. The expected sample set will be approximately 400 samples. The study and calibration of the magnesium-calcium and strontium-calcium ratios in biogenic carbonate will be based on living material collected from a limited number of sites as well as on laboratory cultures of material from those sites.

The data derived from the previous collections will be organized in two ways: (1) a record of all environmental parameters (temperature, hydrochemical) associated with a species living at the time of collection and (2) the absolute and relative abundances of all adult ostracodes found in one or more quantitative sediment samples taken from each environment. Both sets of information will be evaluated statistically as well as qualitatively and will form the baseline information needed to properly interpret any taxa found in the fossil record. The ostracode-valve chemistry data will be used to establish magnesium/calcium and strontium/calcium partitioning coefficients for common species to determine the potential temperature and salinity resolution of this method. Ecological and chemical data from the ostracodes will be correlated with the modern ground-water hydrology to establish process relationships between all ostracode environmental data and known ground-water hydrology, thereby providing the basis for evaluating the nature of past discharge areas.

Results of this activity are expected to provide estimates of the past ground-water levels in the vicinity of Yucca Mountain during the Quaternary to be used in conjunction with past ground-water level data derived from evaluations at other regional discharge areas.

8.3.1.5.2.1.4 Activity: Analog recharge studies

Objectives

The objective of this activity is to estimate the conditions and rates of ground-water recharge (infiltration) during the Quaternary in the vicinity of Yucca Mountain.

YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are

1. Recharge rates of analog sites.
2. Infiltration rates of analog sites.
3. Effective moisture of analog sites.
4. Relationships between climate and infiltration and recharge.

Description

Four or five localities will be evaluated to determine if they are suitable as late Pleistocene analog recharge sites. This evaluation will consist of characterizing the rock types, vegetation types and coverage, precipitation amounts, and topography. Sites will be selected that include a range of climatic conditions postulated to have existed on Yucca Mountain during the past pluvial climatic regimes of the late Pleistocene; data will be collected and used to determine paleorecharge rates.

At each selected site, the infiltration rate will be evaluated, and this value will establish the upper limit on recharge at that site. Water samples will be collected from the vadose-water zone to determine the local infiltration quantity and chemistry. To estimate infiltration rates from the samples, hydrochemical technique that uses the mobile chloride ion as a tracer through the hydrologic cycle will be used (Claassen 1986). The plant community and its relationship to recharge and soil moisture will be studied to estimate an infiltration rate for the whole basin. Remote sensing techniques will be used to determine type, spatial distribution, and density of vegetation. Soil temperatures also will be collected on a continuous basis. Evaluation of soil characteristics to determine their hydrologic properties and effect on consumptive water use will be evaluated if needed.

The temporal and spatial variability of chloride deposition will be calculated or measured at each of the selected sites. To accomplish this task, samples of precipitation, surface water, and moisture content of soils from the vadose water zone will be collected and analyzed. The integrated precipitation samples will be collected four times per year using a bulk sampler. Surface-water samples will also be collected from creeks and springs. Soil-moisture samples will be analyzed for ionic concentrations and for hydrogen and oxygen isotope ratios. A computer code will be developed to calculate the chloride chemistry in the recharge water.

Stream gaging measurements may be made at each of the selected sites and continuous-stage recording instruments installed where appropriate when necessary. Crest-stage gages will be used to back up the peak runoff measurements made by the continuous recorders. These stream measurements will be used to aid in the development of a local basin water budget.

Field investigations will be conducted to locate and collect contemporary pack rat middens from each selected site. The contemporary plant communities and pack rat collecting habits also will be investigated in the field and by field experiments in conjunction with Activity 8.3.1.5.1.3.1 (analysis of pack rat middens). Plant macrofossil assemblages will be col-

 YMP/CM-0011, Rev. 1

lected in the field and sent to the laboratory for identification. These modern biological indicators will be interpreted and compared with similar macrofossil data that were collected in the vicinity of Yucca Mountain.

8.3.1.5.2.1.5 Activity: Studies of calcite and opaline silica vein deposits

Objectives

The objective of this activity is to determine the ages, distribution, origin, and paleohydrologic significance of calcite and opaline silica deposits along faults and fractures in the vicinity of Yucca Mountain.

Parameters

A list of possible parameters includes

1. Mineralogy--including minerals present, degree of crystallinity, and chemical composition.
2. Petrology--including textures and mineral paragenesis.
3. Morphology--including large scale structure and vertical and areal extent.
4. Paleontology--including species present and absolute and relative abundances.
5. Chemistry--including major, minor, and trace element contents of bulk samples and mineral separates.
6. Hydrology--including modeling of possible flow paths.
7. Geochronology--including uranium-series, uranium-trend, potassium-argon dating method, and fission-track ages of fracture-filling and fracture-hosting materials.
8. Isotopic compositions of hydrogen, carbon, oxygen, strontium, and lead.

Description

Cryptocrystalline calcite, with and without opaline silica, fills many faults and fractures in the vicinity of Yucca Mountain. These fillings may have originated by one or more mechanisms including pedogenic, perched-water spring, deep-seated spring, hydrothermal spring, or hydrotectonic processes similar to those described by Kopf (1982). Each possible origin may have significant implications for the paleohydrology at repository depth, and thus, knowledge of the origin is important for predicting anticipated and unanticipated events that may act on the repository in the future.

 YMP/CM-0011, Rev. 1

Plans for this activity are flexible because results obtained by many different methods will need to be integrated. Additionally, results from one method may either obviate or necessitate tests by other methods. Finally, before initiating the investigations, a detailed plan will be subjected to critical review by an external peer panel and will be modified according to suggestions of the review committee.

The general approach will be to gather data through a multidiscipline approach that will include field investigations, mineralogy, geochemistry, fluid-inclusion studies, geochronology, tracer-isotope, stable-isotope studies, paleontology, and hydrology. Materials that will be studied include not only fault and fracture fillings found in trenches, natural exposures, and drill cores, but also possible analog deposits such as cold spring, hydrothermal spring, and pedogenic deposits. Some of the materials collected by this broad approach are expected to have applications to other activities. For example, some data and raw sample material will likely be applicable to seismotectonic activities, and thus close cooperation with these aspects of the program will be necessary.

Field investigations of the deposits will be accomplished through a combination of trenching and drilling. Veins exposed in trench walls will be mapped in detail. Samples will be collected such that any changes in character as a function of lateral extent or vertical extent will be represented. If trenching does not expose the maximum depth of at least one vein deposit, a series of shallow vertical holes may be drilled so as to intersect the fracture containing the vein deposit at successively greater depths. If a base for the deposit is not found by a depth of 20 m, an angle hole may be drilled to an approximate depth of 80 m to attempt to ascertain the depth limit of the deposit.

Standard mapping techniques will also be used (as part of Activity 8.3.1.5.1.4.2) to determine the location and areal distribution of calcite and opaline silica deposits in the vicinity of Yucca Mountain. This datum will constrain possible origins for the deposits and will be a critical point for modeling of the paleo and possible future hydrologic flow systems. If field mapping locates an unfaulted calcite and opaline silica deposit at a bedrock-colluvium contact, that deposit will be thoroughly investigated as a possible analog to the fracture filling exposed in trench 14, a trench located near the proposed surface facility rate.

Fracture-filling materials, wallrock of the fractures, and samples of possible analog materials will be subjected to mineralogic study by such techniques as petrographic microscopy, x-ray diffraction, scanning electron microscopy, and standard clay-mineral analysis. Precise knowledge of mineral assemblages, degree of crystallinity of diagnostic phases, and mineral paragenesis of the fracture-filling materials may provide constraints on the origin of the deposits. In addition, alteration and reaction textures (or lack thereof) in the wallrock of the fractures may further constrain theories of origin.

Geochemical investigations will be used in support of and in conjunction with mineralogic studies. Major, minor, and trace-element compositions of whole-rock samples and of samples from specific phases from fracture-filling and analog materials may prove to be diagnostic for certain possible modes of

YMP/CM-0011, Rev. 1

origin. The final choice of analytical methods will depend on sample sizes available, necessary precision, and detection limits. Anticipated methods include x-ray fluorescence, instrumental neutron activation analysis, and electron microprobe analysis. If any of the geochemical data reveal information of possible economic interest, samples will be referred to those investigating this aspect of the site (Section 8.3.1.9, human interference program).

Fluid inclusions (trapped samples of the liquids from which crystals grew) are common in carbonate and silicate minerals that crystallized in a variety of environments. Such inclusions, if present, will be analyzed in the fracture-filling materials as well as in samples from possible analogs. If fluid inclusions are of more than one phase, they will be heated to the homogenization temperature that represents a minimum estimate of the temperature of deposition.

Ages of fracture-filling materials will be determined by a number of different methods. These ages will be important in the understanding of sequential changes in the paleohydrology and in the determination of chronology for paleotectonics. The data will then be used to predict future hydrology and tectonics. Uraniferous calcite and opaline silica that behaved as closed systems can best be dated by uranium-series techniques. Uranium-series dating techniques on calcite and opaline silica may further constrain the age of these deposits if the uranium in these minerals behaves as a closed system. If suitable samples of volcanic ash can be obtained from within the fracture zones, potassium-argon dating will be attempted. Fission-track dating of apatite crystals separated from the wallrocks of the fractures will be attempted to see if temperatures were high enough to reset or lower apparent ages of the volcanic rocks.

The isotopic compositions of strontium and lead in the calcite-silica deposits and in samples from possible analog materials will be determined to see if these data can provide constraints on the origin of the calcite and opaline silica deposits. These isotopic compositions should be dependent on the isotopic compositions of the rocks through which the depositing fluid flowed and thus if the fluids passed through isotopically distinct units like those known to exist below Yucca Mountain, the data may identify paleohydrologic flow paths.

The isotopic compositions of oxygen, carbon, and hydrogen in the fracture-filling materials depend on temperature of deposition and isotopic compositions in the depositing fluid. If fluid inclusions can be found and analyzed, a unique temperature of deposition can be determined. Alternatively, the isotopic compositions of phases that crystallize in equilibrium with one another can be used to estimate the composition of the depositing fluid and the temperature of deposition. If the fact that equilibrium existed cannot be established, comparison of the data with data from possible analogs will at least constrain possible modes of origin.

Virtually all surface and many subsurface waters contain aquatic organisms and some of these become preserved as fossils in chemically precipitated deposits. The organisms present in a given body of water are determined by a large number of factors including temperature and chemical composition of the water. If organisms such as ostracodes are preserved within the fracture-

YMP/CM-0011, Rev. 1

filling material, their species and the trace-element composition of their calcareous remains can be compared with hydrologic and biologic data for present-day analogs to tightly constrain possible modes of origin.

The final phase of this activity will be to test possible modes of origin for consistency with hydrologic flow models (Section 8.3.1.2.1).

8.3.1.5.2.2 Study: Characterization of the future regional hydrology due to climate changes

The objective of this study is to characterize the impacts of potential future climate changes on the regional and site surface-water system, the site unsaturated-zone hydrology, and the regional and site saturated-zone hydrology.

8.3.1.5.2.2.1 Activity: Analysis of future surface hydrology due to climate changes

Objectives

The objectives for this activity are to

1. Simulate past changes in runoff and surface-water storage (lakes) resulting from past climatic change.

2. Use the relationship between paleoclimate and paleo surface-water conditions to predict the impact of future climatic conditions on surface-water hydrology at the site.

Parameters

The parameters for this activity are past and future runoff and surface-water storage.

Description

Precipitation-runoff relations of modern surface-water conditions and basin characteristics will serve as the basis for the development of a present-day precipitation-runoff model (or models) for the Yucca Mountain site. Sufficient data will be collected through the current precipitation and streamflow gaging programs (Activity 8.3.1.2.1.2.1 and Section 8.3.1.12) and rainfall-runoff modeling in Fortymile Wash basin (Activity 8.3.1.2.1.3.3) to allow modeling of modern-day, precipitation-runoff relationships. The model will be run to simulate estimated paleoconditions derived from other activities such as precipitation, snowpack conditions, soil evaporation, interception of precipitation by vegetation, and transpiration. These model runs will be used to validate the model against inferred conditions derived from past proxy records. The model will be used to simulate future runoff conditions resulting from hypothesized climatic change based on results of the paleorunoff simulations.

 YMP/CM-0011, Rev. 1

8.3.1.5.2.2.2 Activity: Analysis of future unsaturated zone hydrology due to climate changes

Objectives

The objective of this activity is to predict quantitatively the potential effects of future climatic conditions on infiltration, percolation, and the degree of saturation of the unsaturated zone at Yucca Mountain.

Parameters

The parameters for this activity are

1. Relationship between climate and infiltration.

2. Time-dependent spatial distributions of moisture potential, pore-gas pressure, saturation, and moisture flux.

Description

The unsaturated-zone hydrologic model, to be developed in Activity 8.3.1.2.2.9.3, will provide a calibrated model of present-day flow conditions and processes. The model will be calibrated using initial and boundary conditions, and geohydrologic material properties. The results of artificial infiltration studies will be incorporated into the model development (Activity 8.3.1.2.2.1.3). Sensitivity studies will be performed on a sequence of transient simulations over the next 10,000 yr during which the rate of net land-surface infiltration will be varied over time and space. These mathematical simulations will investigate the effects of scenarios chosen to represent infiltration rates resulting from probable climatic changes extrapolated from paleoclimatologic and paleohydrologic conditions. The set of simulations will delimit the sensitivity of the moisture-potential, saturation, perched-water, and moisture-flux distributions within the natural, unsaturated-zone flow system to changes in infiltration arising from climatic variations.

8.3.1.5.2.2.3 Activity: Synthesis of effects of possible future recharge due to climate changes on hydrologic characteristics of the Yucca Mountain saturated zone

Objectives

The objectives of this activity are to

1. Reconstruct paleohydrologic conditions at Yucca Mountain and use these conditions together with the paleoclimatic conditions reconstructed under Investigation 8.3.1.5.1 as a basis to predict the impact of future climatic conditions on the saturated-zone hydrologic system.

 YMP/CM-0011, Rev. 1

2. Synthesize the existing paleohydrologic data through the use of numerical simulation techniques to determine the effects that greater recharge would have on water-table altitude, ground-water flow paths, and hydraulic gradients between Yucca Mountain and the accessible environment.

Parameters

The parameters for this activity are

1. Relationship between climate and recharge.
2. Distribution of potentiometric head (past, present, and future).

Description

Records of past climates for the Yucca Mountain area indicate that conditions wetter and cooler than modern day have occurred in the past (Section 5.2.1). These conditions may have led to higher water levels in the past (Winograd and Szabo, 1986). Correlations between past climatologic and geohydrologic conditions, including past recharge rates, will be inferred using paleowater levels determined from the study of past discharge areas and analog recharge sites. Past climate changes will be correlated with geologic and biologic evidence of paleohydrologic conditions (Activities 8.3.1.5.1.2.1 and 8.3.1.5.1.3.1).

A three-dimensional numerical ground-water flow model of the regional flow system (developed under Activity 8.3.1.2.1.4.4.) will be calibrated using modern-day conditions. The higher water levels inferred for the past will be simulated to estimate the magnitude of past recharge.

The simulation of wetter conditions will be used to assess potential changes in water-table altitude, ground-water flow rates, and ground-water flow directions. Recharge will be varied from modern conditions up to the maximum probable amount to be expected in the next 10,000 yr. Sensitivity analyses will be done to determine the appropriate time periods needed for model input.

Results of previous modeling (Study 8.3.1.2.1.4) will be the basis for future work. Recharge boundary fluxes applied to both two- and three-dimensional models for regional ground-water saturated flow (Czarnecki, 1985; Sinton and Downey, 1986) were based on the best estimates of recharge believed to occur either as throughflow into the area or as a really distributed recharge. Principal areas where significant a really distributed recharge may occur are Pahute Mesa, Rainier Mesa, Timber Mountain, and Fortymile Wash.

New data on climatic conditions and recharge mechanisms under various scenarios (monsoon versus thunderstorm versus snowfall precipitation and corresponding vegetation changes) will be incorporated into the simulation of increased-recharge conditions.

 YMP/CM-0011, Rev. 1

8.3.1.6 Overview of the erosion program: Description of the future erosional rates required by the performance and design issues

Summary of performance and design requirements for erosion information

The following summarizes the requirements for erosion data from the design and performance issues:

1. The surface characteristics program (8.3.1.14) requires information on the expected magnitude and locations of erosion both on bedrock and alluvial-colluvial surfaces.

2. Issue 1.12 (Section 8.3.3.2, seal characteristics) requires information on the erosion potential (rates) near shafts to support the design of seals.

3. The human interference program (8.3.1.9) requires information on erosion to determine the most suitable locations for the surface markers and monuments of the warning system.

Existing regional data indicate that erosion will not affect the minimum burial depth (200 m) required by 10 CFR 960.4-2-5(b). Using the maximum erosion rates presented in Section 1.1 (Table 1-3) of 40 cm/1,000 yr, the amount of erosion that will occur over the next 10,000 yr (4 m), or even 100,000 yr (40 m), is much less than the total burial depth. Therefore, even an increase in erosion rates by a factor of two or three would have no impact on burial depth relative to the 200 m disqualifying condition.

Large-scale mass wasting (e.g., rock slides and debris flows) does not appear to pose a significant hazard to waste isolation at Yucca Mountain. Eolian processes and plans to investigate them within the climate program are discussed in Section 8.3.1.5.1.4.3. The erosion test program concentrates on fluvial and hillslope erosion.

Approach to satisfy performance and design requirements

The general strategy used in developing the postclosure erosion program is to identify the site-specific geomorphic parameters and data that are needed to satisfy the design and performance issues and to ensure that the 200 m disqualifying condition is not exceeded. As discussed in Chapters 1, 3, and 5, the desert environment of the southern Great Basin is one of the factors that has made Yucca Mountain potentially advantageous for the long-term disposal of high-level radioactive waste. From the standpoint of waste containment, the comparative aridity of the climate and the relatively low rates of tectonic uplift (relative stability of the tectonic setting) during the Quaternary period have kept the long-term erosion rates low. The future persistence of tectonic stability coupled with the semiarid-to-arid climatic conditions would result in continued low erosion rates through the post-closure period, and assist in the isolation of the waste. Thus, erosional processes are not believed to pose a hazard to waste isolation at Yucca Mountain.

 YMP/CM-0011, Rev. 1

For the integrity of the repository to be at risk from erosional breaching, a combination of highly unlikely topographic, climatic, and tectonic conditions would be required. Climatic change in the postclosure period to relatively wetter semiarid conditions would result in a sustained period of higher precipitation and runoff, possibly increasing the average upland erosion rate above the present level. Although data presented in Chapter 1 indicate that Quaternary erosion rates during wetter climates were not substantially greater than present-day rates, an increase of precipitation and runoff could result in slightly higher erosion rates at Yucca Mountain. The erosion rates could also be aggravated by a period of sustained tectonic uplift, if uplift rates were to greatly exceed those estimated for the Quaternary period. It must be emphasized, however, that the probability of this hypothetical scenario occurring is extremely low. The relative vertical tectonic adjustment has been less than 3 cm/1,000 yr during the late Cenozoic (Miocene to present), and the average maximum downwasting rate was estimated to be 2 cm/1,000 yr (Section 1.1). It is highly unlikely that climatic or tectonic changes during the postclosure period will significantly change the rate of downwasting. Additionally, increased erosion of hillslope and uplands would result in increased aggradation on piedmonts and lowlands which would decrease local stream gradients and the potential for further hillslope and upland erosion.

Because erosion is not expected to pose a hazard to the isolation of waste at Yucca Mountain (Issue 1.1, Section 8.3.5.13), very few performance and design issues request information from the erosion program. Only Issue 1.12 (Section 8.3.3.2, seal characteristics), the surface characteristics program (Section 8.3.1.14), and the human interference program (Section 8.3.1.9), require input from the erosion program. In addition, the preliminary performance allocation for the surface system element (1.1.1) (Section 8.3.2.5) has established tentative goals for several parameters dealing with erosion at surface facilities. Table 8.3.1.6-1 lists the parameters requested by these issues and programs.

Issue 1.12 (seal characteristics, Section 8.3.3) requests information on the erosion potential near shaft entry locations. This information will be provided through Investigation 8.3.1.6.1, which will determine the current rates of erosion at the site and through Investigations 8.3.1.6.2 and 8.3.1.6.3, which will investigate alternative conceptual models for erosion, i.e., the potential effects of future tectonic activity and climatic conditions on erosion at the site. The surface characteristics program (8.3.1.14) requires information on the present locations and rates of erosion. This information will be provided by Investigation 8.3.1.6.1.

The human interference program (8.3.1.9) requires information on erosion that will support the determination of the reliability and survivability of surface markers and monuments. Although erosional processes are not expected to pose a hazard to waste containment and isolation, the effects of rapid stream incision needs further study because of its potential consequences to surface markers and monuments. Markers need to be placed in areas of limited erosion or deposition to aid survivability. The data obtained from studies of stream incision will be used in the design of the warning system, and will augment those studies being undertaken in support of the surface characteristics program (Section 8.3.1.14). Investigations 8.3.1.6.2 and 8.3.1.6.3

Table 8.3.1.6-1. Parameters provided by the erosion program that support performance and design issues

Issue requesting parameter	SCP section number	Performance or design parameter	Tentative goal	Desired confidence	Characterization parameter	Testing basis: Current estimate of parameter range	Testing basis: Current confidence	Testing basis: Needed confidence	Study number
1.12 (Seal characteristics)	8.3.3.2	Erosion potential at shaft entry locations	< 1 m of preferential erosion of bedrock at shaft entry locations over 1,000 yr	Low	Long term erosion rates at shaft entry locations	40 cm/ 1,000 yr	Very low	Low	8.3.1.6.1.1 8.3.1.16.1.1
1.1 (Total system performance) through human interference program	8.3.5.13, 8.3.1.9	Locations of low erosion or deposition for surface markers	Identify geomorphologically stable areas along controlled-zone boundary	Low	Long term rates of erosion, deposition at proposed marker locations	40 cm/ 1,000 yr	Very low	Low	8.3.1.6.1.1 8.3.1.16.1.1
4.4 Technical feasibility) through surface characteristics program	8.3.2.5, 8.3.1.14	Scour potential along Fortymile Wash at bridge locations; erosion potential along proposed roads	< 13 m of scour at bridge foundations over 100 yr; < 5 m of bed erosion in channel over 100 yr; < 1 m sheet erosion on roadways over 100 yr	Low	Rates of soil, bedrock erosion at bridge locations over 100 yr; erosion along roads and channel beds	40 cm/ 1,000 yr	Very low	Low	8.3.1.6.1.1 8.3.1.16.1.1

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

will provide information on the potential effects of future tectonic and climate activity on erosion at the site. This information will also be used to locate surface markers and monuments in areas with potential for low rates of future erosion to enhance survivability.

The relationship between the investigations performed under this characterization program and the issues and programs that require information on erosion locations, rates, and processes is shown in Figure 8.3.1.6-1.

Interrelationships of erosion investigations

Four investigations have been developed to provide the data required by the performance and design issues. Many of the necessary parameters have been obtained and evaluated as part of the ongoing scientific studies at the Nevada Test Site (NTS) in support of the weapons testing program. In most instances, data are not site specific and, therefore, not adequate to satisfy the performance and design issues. Studies will be carried out during site characterization to satisfy these remaining data needs.

Investigation 8.3.1.6.1 will collect site-specific data on Quaternary erosion and stream incision rates that will be used to calculate average erosion rates on Yucca Mountain and to develop a history of the downcutting episode(s) of Fortymile Wash. Investigation 8.3.1.6.2 includes studies to assess the potential effects of future climatic changes on locations and rates of erosion. Previously established regional erosion rates suggest that future changes in the climatic regime will not significantly affect upland and hillslope erosion rates. Local erosion data on Yucca Mountain and an evaluation of the relationship of increased runoff in Fortymile Canyon, Fortymile Wash, and their tributaries to localized stream incision rates are needed for Information Need 2.7.1 (Section 8.3.2.3.1). Investigation 8.3.1.6.3 will evaluate the effects of tectonic activity on rates of erosion.

Investigation 8.3.1.6.4 addresses the potential effects of erosion on the baseline hydrologic, geochemical, and rock characteristics at Yucca Mountain. Because the effects of erosional processes on the baseline conditions are not expected to pose any hazard to waste isolation and are not expected to affect the postclosure ground-water travel time, no further studies or activities are planned. These topics will be addressed in a topical report that will present the discussion supporting termination of the erosion program.

Other investigations will provide data in the form of input parameters to the erosion program. Investigations 8.3.1.5.1 and 8.3.1.8.2 will provide data on the nature and extent of future climatic changes and tectonic activity, respectively. Data obtained to date on regional tectonic and climatic activity during the Quaternary Period suggest that very little change will occur in the erosional regime at Yucca Mountain during the postclosure period as a result of these processes (Chapters 1 and 5). Limited site-specific studies will be completed to determine quantitatively, on the basis of Quaternary erosion rates, the extent of potential stream incision that could result from future tectonic activity and climatic changes.

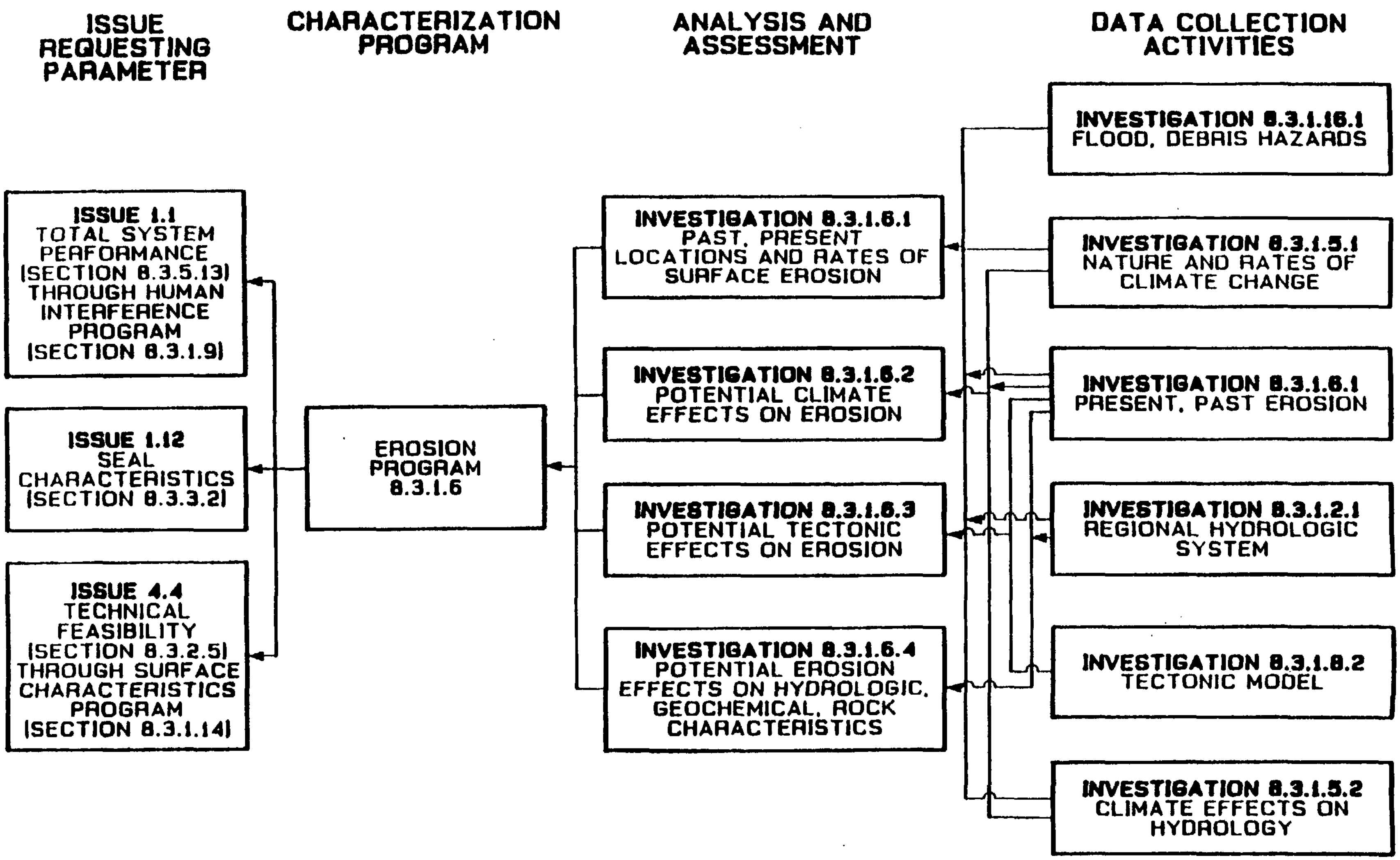

Figure 8.3.1.6-1. Relationship between erosion program and investigations.

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

Although the long-term average upland and hillslope erosion rates have been established for the southern Great Basin, they may not be representative of actual erosion rates on Yucca Mountain or of the short-term episodes of stream incision that may occur when a critical process threshold is exceeded. Fortymile Canyon, Fortymile Wash, and their tributary channels located on the eastern flanks of Yucca Mountain may be subject to critical threshold (complex) response (the reaction of a fluvial system to a disruption of the equilibrium of the system). As discussed in Chapter 1, Sec- tion 1.1.3.2, very little site-specific information is presently available that would allow for the quantification of erosional processes at Yucca Mountain. Those data needs will be satisfied during site characterization.

8.3.1.6.1 Investigation: Studies to determine present locations and rates of surface erosion

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Sections 1.1 (geomorphology), 3.2.1 (flood history and potential for future flooding), and 5.1 (modern climate and meteorology) summarize existing data relevant to this investigation. As discussed in these sections, site-specific data are not available for rates and locations of erosion, especially along Fortymile Canyon, Fortymile Wash, and their tributaries.

Parameters

Three groups of parameters will be measured or calculated as a result of the site studies planned for this investigation:

1. A geomorphic map of Yucca Mountain that defines areas of active erosion and areas of no erosion (i.e., geomorphic stability).

2. Rates, locations, and causes of incision in Fortymile Wash and its tributaries.

3. Average rates of hillslope erosion on Yucca Mountain.

Other site studies will provide data to support the determination of these parameters. Activities in support of Investigation 8.3.1.2.1 will supply data on the regional meteorology and surface water system. Investigation 8.3.1.5.1 will provide geomorphic information on surficial deposits and geomorphic interpretation of Quaternary history. Investigation 8.3.1.5.2 will provide paleoflood evaluations. Site flood and debris hazard data will be provided from Investigation 8.3.1.16.1.

Purpose and objectives of the investigation

The objectives of this investigation are to obtain the site-specific data needed to calculate average Quaternary hillslope erosion rates and accurate average short-term erosion rates associated with episodic erosion. This investigation will perform three activities and use information from the

 YMP/CM-0011, Rev. 1

climate (Section 8.3.1.5) and geohydrology (Section 8.3.1.2) programs to support these objectives. Figure 8.3.1.6-2 shows how these data-collection sections will support the determination of present rates and locations of surface erosion. Three kinds of data will be obtained to characterize past distribution of hillslope and alluvial deposits, and surfaces of different ages will be shown on a geomorphic map of Yucca Mountain. First, the map will show the extent to which modern erosion has affected an essentially Pleistocene landscape. Second, local stream incision rates will be calculated by dating incised stream terraces and sand ramps by uranium-trend, uranium-series, radiocarbon, and cation ratio (rock varnish) dating methods. Third, average erosion rates on hillslopes will be calculated from dated hillslope surfaces by the rock varnish dating method.

Desert geomorphic processes acting in conjunction with extensional tectonism have molded the present topography of the Yucca Mountain area, and these processes continue very slowly to modify the landscape. The predominantly semiarid-to-arid climates of the past and present have helped to preserve the landscape of the region surrounding Yucca Mountain. Weathering in arid environments proceeds more slowly than in more humid environments, and materials on most of the bedrock slopes of the mountain appear to be only slightly weathered. Available data suggest that the region surrounding Yucca Mountain has been geomorphically stable during much of the middle and late Quaternary, and that rates of geomorphic processes are likely to remain generally low during the next 10,000 yr.

The locations of modern erosion are best shown on aerial photographs and large-scale topographic maps of Yucca Mountain where the drainage networks are clearly defined. Erosion on hillslopes is visible on aerial photographs because the recently stripped slopes are much lighter in color than adjacent deposits, which are coated with dark desert varnish. The amount and distribution of modern erosion is of very limited extent when compared with the vast areas of stable Pleistocene deposits in the Yucca Mountain area. The contrast between limited areas of modern upland and hillslope erosion versus large stable areas is a strong argument for low erosion rates at the proposed repository site.

Average late Tertiary and Quaternary erosion rates for local areas of the southern Great Basin and northern Mojave Desert have been inferred from height differences between active and relict basalt-capped erosion surfaces. Estimates based on this approach for several widely separated upland areas range between 1.2 and 4.7 cm per 1,000 yr for periods of 1.1 to 10.8 million years, and the differences in these average rates show no apparent relation to regional variations in late Tertiary and Quaternary vertical tectonic activity. Degradation of upland areas in the Yucca Mountain region is relatively slow, with average downwasting rates over the last 1 to 5 million years probably between 0.5 to 2.0 cm per 1,000 yr on lower hillslopes nd proximal piedmont areas and less than 0.5 cm per 1,000 yr in middle and distal piedmont areas. Thus, it would appear that the general degradation of upland areas in the region surrounding Yucca Mountain is proceeding relaively slowly.

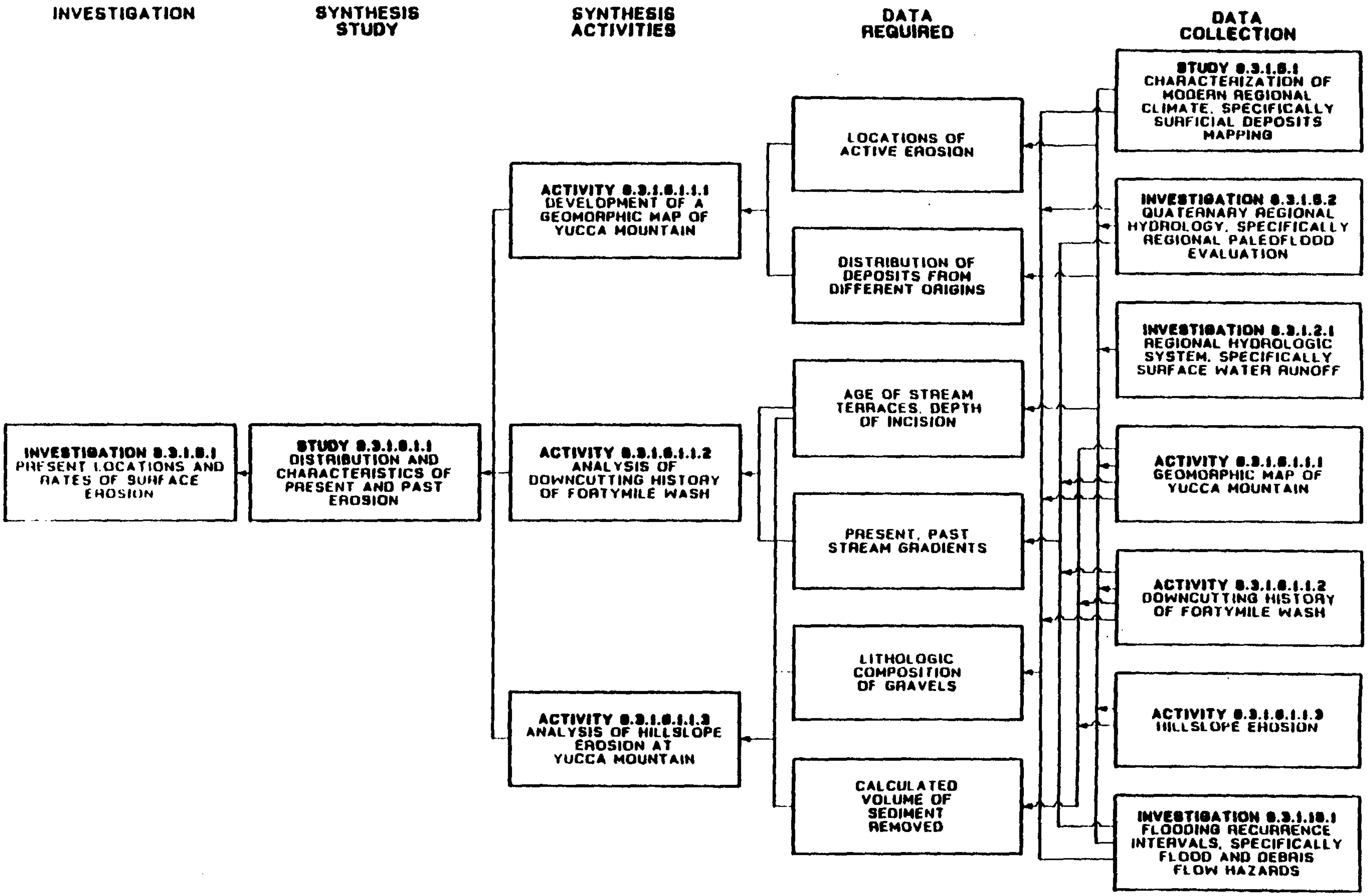

Figure 8.3.1.6-2. Logic diagram for Investigation 8.3.1.6.1.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

The sporadic nature and limited areal extent of individual precipitation events are major impediments to an accurate characterization of present-day erosion. Few data have been collected in the Great Basin to correlate individual storm events with corresponding volumes of sediment transported out of a basin with the associated storm runoff. Because the storms can be of very limited areal extent, a single storm may cause measurable hillslope erosion and flooding in one tributary while not providing sufficient precipitation to an adjacent tributory to cause runoff. Furthermore, the next storm to cause measurable erosion on the same hillslope may occur in the same month, or not for several years or even decades. The sporadic nature of these storms causes the complex response of the fluvial systems.

Complex response is a term applied to the reaction of a fluvial system to a disruption of the equilibrium of the system. Such disruptions can be due to base-level lowering, tectonic uplift or tilting, climatic change, or human activity. The disruption of equilibrium causes a critical threshold to be exceeded (Chapter 1, Section 1.1), and the system does not respond uniformly throughout. The lower-order tributary streams of the system do not respond at the same rate as the main channel (e.g., Fortymile Wash and its tributaries). In the example of base-level lowering, a pulse of erosion along the main channel will result in rejuvenation of the tributaries. The influx of sediment from the rejuvenated tributaries can result in aggradation on the main channel, and downcutting may stop until such a time when the aggraded material has been removed. When the system has removed the aggraded material, another episode of erosion may occur. Thus, erosion is episodic and depends on the response of the entire system (Matthusen, 1986).

Direct measurement of present rates of erosion at Yucca Mountain may be difficult to obtain over the next several years of site characterization. Stream gaging equipment has been installed and more stations are planned, but there is no guarantee that a variety of storms will take place over these specific drainages during the next few years. Even if storm events do occur, the characterization of erosion locations and calculated rates of erosion may be based on limited observations and collected discharge and sediment data, and may not accurately reflect long-term erosion rates.

Indirect measurements are thus necessary to supplement direct measurements to better characterize recent hillslope erosion and floods. These measurements include the evaluation of flood and debris-flow hazards from Holocene deposits and discharge volumes of paleofloods calculated from maximum particle size and engineering analysis techniques. These activities are all included within the description of the regional surface-water system (Study 8.3.1.2.1.2), the characterization of regional meteorology (Section 8.3.1.2.1.1), geomorphic studies (Section 8.3.1.5.1), paleoflood evaluation (Activity 8.3.1.5.2.1.1), and site flood debris-hazards studies (Activity 8.3.1.16.1.1).

One study, consisting of three activities, will be performed in support of Investigation 8.3.1.6.1. The study will focus on the identification and quantification of active erosional processes. Data on these processes and stream-incision rates will be used to determine the cause of downcutting in Fortymile Wash.

 YMP/CM-0011, Rev. 1

8.3.1.6.1.1 Study: Distribution and characteristics of present and past erosion

The objectives of this study are to identify the erosional processes that have been operating in the Yucca Mountain area during the Quaternary, to identify the specific locations of past erosion, and to quantify the rates of the different processes and assess their relative importance.

A geomorphic map of the Yucca Mountain area will delineate erosionally active and stable areas, and will correlate the various surficial deposits with those geomorphic processes responsible for their origin. Investigation of the downcutting history of Fortymile Wash will yield ages of stream terraces, depths of stream incision, steam gradients, and lithologies of stream gravels, which will aid in identifying the controls on local stream incision.

8.3.1.6.1.1.1 Activity: Development of a geomorphic map of Yucca Mountain

Objectives

The objectives of this activity are to (1) determine the areal distribution of active erosional areas and geomorphically stable areas and (2) determine the spatial distribution of the different types of geomorphic processes and associated deposits.

Parameters

The parameters for this activity are

1. The locations of areas of active erosion.

2. The locations of geomorphically stable areas and the distribution of deposits originating from different geomorphic processes.

Description

The distribution of landforms and areas of present and past erosion at Yucca Mountain will be shown on a geomorphic map of the area. The map will show areas of modern erosion and the stable areas that are largely unaffected by modern erosion. Accurate distribution of areas of modern erosion is important for calculation of present and future erosion rates.

The geomorphic map will be a derivative map of the surficial deposits map (Activity 8.3.1.5.1.4.2). The surficial deposits map will show the types and ages of surficial deposits on the landscape. The geomorphic map will show landforms (both bedrock and surficial deposits) and the types of past and present geomorphic processes that are chiefly responsible for their formation. Ages of deposits can be used to infer the relative stability or instability of the landforms. The geomorphic map will be constructed from much of the aerial photographic interpretation and field checking of deposits and map-unit contacts that will be undertaken during preparation of the surficial deposits map (Activity 8.3.1.5.1.4.2). Dating of surficial deposits will

YMP/CM-0011, Rev. 1

also be accomplished in the surficial deposits map activity. The geomorphic interpretation of the surficial deposits will be primarily based upon the interpretations of origins from other paleoenvironmental studies of Yucca Mountain (Study 8.3.1.5.1.3) and reported in the synthesis of the Quaternary history of Yucca Mountain (Activity 8.3.1.5.1.5.1).

8.3.1.6.1.1.2 Activity: Analysis of the downcutting history of Fortymile Wash and its tributaries

Objectives

The objectives of this activity are to (1) determine stream-incision rates on Fortymile Wash and selected tributaries and (2) determine the cause(s) of the major downcutting episode(s) on Fortymile Wash.

Parameters

The parameters for this activity are

1. The ages of stream terraces.
2. The depths of stream incision.
3. Present and past stream gradients.
4. The lithologic composition of stream gravels.

Description

Fortymile Wash is a major geomorphic feature situated about 3 km east of the proposed repository site. The wash flows south out of the Timber Mountain caldera drainage basin, about 680 km^2 in size, and is incised 20 to 25 m into Quaternary deposits along its course east of Yucca Mountain. Dune, Sevier, and Yucca Washes are incised from 2 to 25 m into Quaternary deposits. These washes and their tributaries are incised as much as 100 m into bedrock dip slopes along the fault and fracture zones on the east side of Yucca Mountain.

Rates of stream incision are greater than surface degradation rates, and the downcutting of the Fortymile Canyon represents the highest localized erosion rates for the Yucca Mountain area. The average rate of stream incision below the main stream terrace is about 8.5 cm per 1,000 yr. However, the age of the stream terrace is based not on a direct radiometric age, but on the correlation to isotopically dated deposits with similar soil development. In this activity, all major stream terraces on Fortymile Wash will be dated by either uranium-trend, uranium-series, rock varnish (cation ratios), or radiocarbon methods. By dating all terraces, average incision rates can be refined for specific intervals of downcutting between episodes of valley aggradation and subsequent terrace formation. Terraces on Fortymile Wash tributaries will be dated in an effort to refine the youngest episodes of valley aggradation and incision. These site-specific incision rates will be used to calculate future erosion rates near the repository. This information may also be valuable for interpreting the paleoenvironmental history of Yucca Mountain (Study 8.3.1.5.1.4).

 YMP/CM-0011, Rev. 1

Another aspect of this activity is to determine the cause or causes for the downcutting of Fortymile Canyon, which is unusually deep compared with other canyons in Great Basin piedmonts and basins. To identify contributing factors to this unique geomorphic feature, former stream gradients will be reconstructed from stream terrace profiles, and stream gravel lithologic compositions will be examined to identify any changes in upper basin source areas. These two activities will help in deciding if stream capture was a major factor in the formation of Fortymile Wash. Also, all relevant subsurface information, including both drillhole and geophysical data, will be examined to decide if Fortymile Wash is situated along a fault or fault zone.

8.3.1.6.1.1.3 Activity: An analysis of hillslope erosion at Yucca Mountain

Objectives

The objectives of this activity are to (1) determine the average rates of Quaternary hillslope erosion on Yucca Mountain in bedrock and surficial deposits and (2) determine the genesis and the rates of movement of hillslope deposits.

Parameters

The parameters that will be obtained by this activity are

1. The absolute ages of the rock varnish coatings of bedrock and surficial deposits.

2. Maximum incision depth of hillslopes and adjacent dated surfaces.

3. Descriptions of the textures, grain size distributions, and sedimentary structures of the surficial deposits.

4. The calculated volume of sediment removed from hillslopes by erosional processes.

Description

The calculation of site-specific erosion rates will be accomplished using a new rock-varnish dating technique. Rock varnish, also called desert varnish, is nearly ubiquitous in arid and semiarid regions. Rock varnish is a thin coat of ferromanganese oxides, clay minerals, and biologic materials accreted on rocks in a variety of environmental settings. Varnished deposits and surfaces can be dated because several mobile cations in the varnish are depleted with time. The ratio of mobile to immobile cations (K+Ca/Ti) decreases with time, providing a relative age sequence for varnishes in a given area (Section 8.3.1.17.4.9.1).

Absolute age estimates have been determined by calibrating the cation-leaching curve with cation ratios from potassium-argon-dated volcanic rocks in Crater Flat and uranium-trend-dated alluvial deposits along the flanks of Yucca Mountain and within the surrounding washes and canyons (Harrington and Whitney, 1987). Maximum incision parallel to the dated hillslope deposits

YMP/CM-0011, Rev. 1

and bedrock surfaces will be measured, and volumes of denuded sediment will be calculated where possible. Erosion rates for both bedrock and surficial deposits will be used to estimate future erosion rates during the postclosure period.

8.3.1.6.2 Investigation: Potential effects of future climatic conditions on locations and rates of erosion

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Sections 1.1.3 and 5.2.2 of the SCP data chapters provide a technical summary of existing data relevant to this investigation. Section 1.1.3 addresses the influence of climate on geomorphic processes, average erosion rates in the region surrounding Yucca Mountain, and significant late Quaternary geomorphic processes in the Yucca Mountain area. Future climatic variations and conceptual models used to investigate future climatic variation are presented in Section 5.2.

Parameters

This investigation will synthesize the results of studies undertaken in support of Investigations 8.3.1.5.1 (nature and rates of climate change) and 8.3.1.6.1 (present locations and rates of surface erosion). Thus, the parameters themselves are the results and conclusions from these studies. The parameters that will be used as input to this investigation are (1) predicted climate of the Yucca Mountain region over the next 1,000 to 100,000 yr, including the predicted timing of climatic changes, and the nature and duration of predicted climatic episodes; (2) the present locations and rates of surface erosion; and (3) the distribution and characteristics of past erosion.

Purpose and objectives of the investigation

An estimate of the potential effects of future climate on locations and rates of erosion will be derived in this investigation from converging lines of evidence. Figure 8.3.1.6-3 shows how information from Investigation 8.3.1.5.1 and from the activities within Investigation 8.3.1.6.1 will be used to determine potential effects of future climatic conditions on locations and rates of erosion. A projected sequence of climatic episodes, including the timing for their initiation and duration, will result from the climate modeling for Investigation 8.3.1.5.1. An ancillary product of the preparation for modeling will be a correlation of the paleoclimatic history of the southern Great Basin with the paleoenvironmental history of Yucca Mountain (erosional and depositional responses to climate). From the studies for Investigation 8.3.1.6.1 will come a characterization of present and past locations and rates of erosion in the Yucca Mountain region. Fitting the projected future climate sequence with corresponding known erosion rates and past geomorphic responses will allow the quantification of erosion effects at Yucca Mountain over the next 10,000 yr.

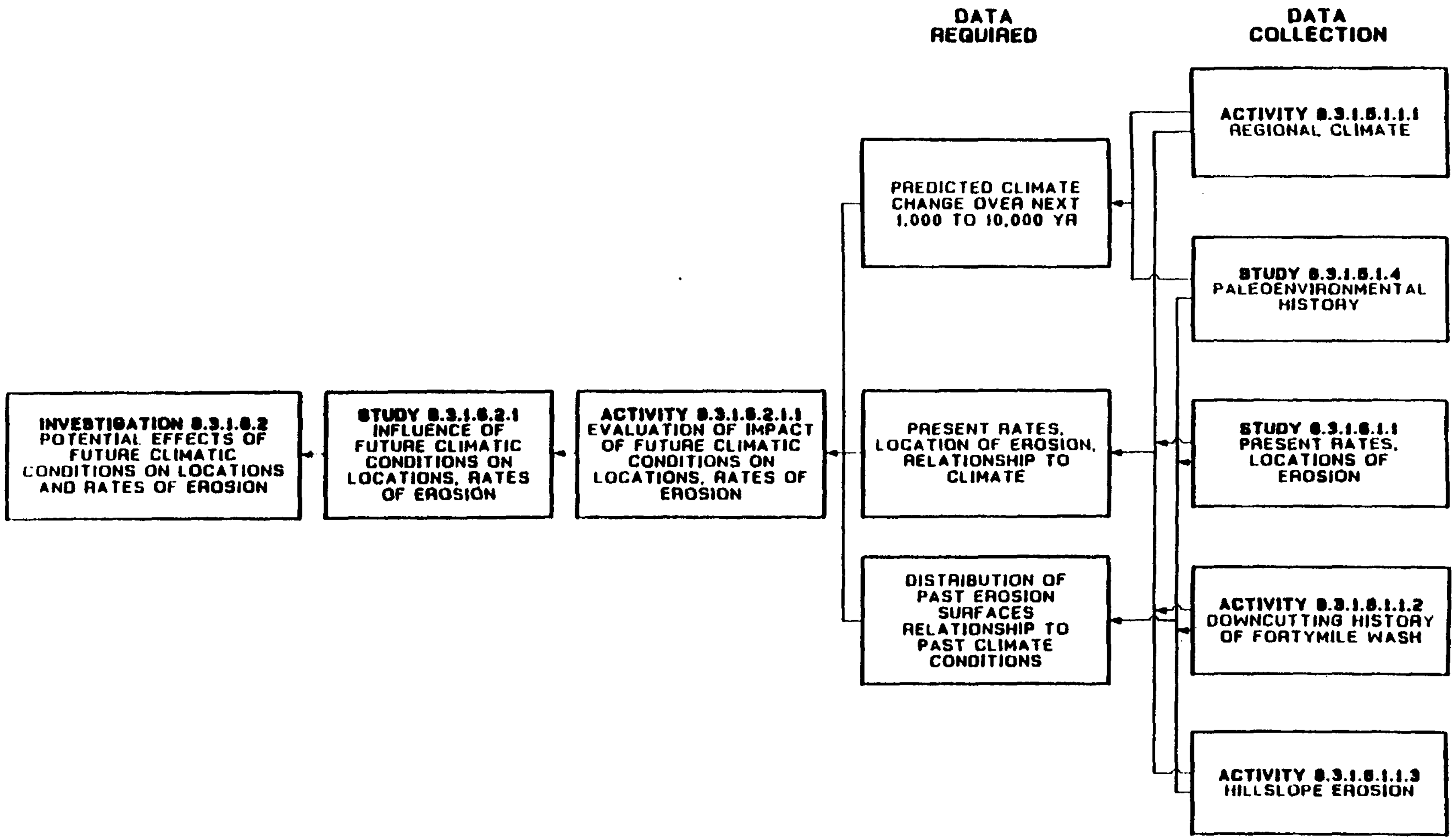

Figure 8.3.1.6-3. Logic diagram for Investigation 8.3.1.6.2.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

Yucca Mountain lies within one of the warmest and driest regions of the United States, with mean annual precipitation averaging about 110 mm per year and relative humidity commonly ranging between 25 and 55 percent. The full-glacial climate in the southern Great Basin is thought to have been semiarid in the basins and lower ranges, although subhumid climates may have existed in the highest mountains. Mean annual temperatures during full glacials were probably about 7 to 10°C colder than at present; annual precipitation was less than 40 percent greater than at present. Glacial processes were probably not active in the Yucca Mountain area during most or all of the Quaternary; lacustrine processes in the Great Basin appear to have been confined to playas, and lacustrine records from the southern Great Basin do not indicate deep lakes or continuous depositions during the late Quaternary.

The semiarid to arid climates of the past and present are responsible for low rates of weathering at Yucca Mountain. Physical weathering appears to be chiefly confined to exposed bedrock hillslopes and piedmont surfaces. Modern surface flow and sediment transport are brief and intermittent.

A future episode of increased precipitation would probably cause an increase in erosion rates. An estimate for (1) the timing, duration, and probability of an expected episode of increased erosion and (2) the expected quantitative effects of the episode at different locations in the Yucca Mountain region (e.g., stream incision versus hillslope erosion) will be made. Anticipated geomorphic responses to possible predicted increases in precipitation at Yucca Mountain will be based on past erosional responses to full pluvial climates during the Quaternary (Study 8.3.1.5.1.4).

One study, consisting of one activity, will be performed in support of this investigation. The study will be a synthesis of the results from activities in support of Investigations 8.3.1.5.1 and 8.3.1.6.1.

8.3.1.6.2.1 Study: Influence of future climatic conditions on locations and rates of erosion

The objectives of this study are to determine the effects of future climatic conditions on the locations and rates of erosion. This synthesis study will use climate and erosion parameters generated by Investigations 8.3.1.5.1 and 8.3.1.6.1 to identify areas and rates of potential stream incision and increased erosion.

8.3.1.6.2.1.1 Activity: Synthesis and data evaluation of impact of future climatic conditions on locations and rates of erosion

Objectives

The objectives of this activity are to integrate Quaternary climate conditions and rates of surface erosion with predicted conditions of future climate, and to estimate significant changes in the character, distribution, and ratio of surface erosion in the Yucca Mountain region over the next 1,000 to 100,000 yr.

YMP/CM-0011, Rev. 1

Parameters

Three sets of parameters will be evaluated in this activity:

1. The predicted climate of the Yucca Mountain region over the next 1,000 to 100,000 yr, including the predicted timing for climatic changes and the nature and duration of predicted climatic episodes.

2. The present locations and rates of surface erosion and their relationship to present climatic conditions.

3. The distribution and characteristics of past erosion and their relationship to past climatic conditions.

Description

One of the expected results of Investigation 8.3.1.5.1 will be the derivation of regional climate history for the Quaternary from paleolimnologic and terrestrial paleoecologic lines of evidence (Studies 8.3.1.5.1.2 and 8.3.1.5.1.3). However, another product of this investigation will be synthesis of the site-specific Quaternary paleoenvironmental history of Yucca Mountain and surroundings, on the basis of local surficial deposits, soils, and past geomorphic processes (Study 8.3.1.5.1.4). The paleoenvironmental evaluation will focus on the geomorphic responses to paleoclimates and climatic changes. The evaluation will also incorporate data on distribution and characteristics of past erosion. A paleoclimate-paleoenvironmental synthesis (Study 8.3.1.5.1.5) will tie the paleoclimate history (especially known episodes of temperature and precipitation extremes) to dated responses in the depositional and geomorphic record that reflect these extremes. A possible example would be correlating an episode of higher precipitation, as evidenced by the palynology of lacustrine sediments, to a period of rising base levels as reflected in a dated period of stream aggradation or reduced incision. Thus, the paleoenvironmental history can serve as the baseline study to examine the relationship between different climatic episodes and the geomorphic responses that controlled erosion during the Quaternary. These responses can then be applied to future predicted climates, from which predicted erosion rates can be calculated.

To determine the effects of future climate on erosion, it will be necessary to integrate the results from Investigation 8.3.1.5.1 (nature and rates of climate change) with those from Investigation 8.3.1.6.1. The first important result of the latter studies will be the correlation of locations (e.g., stream incision) and rates of erosion to present climatic conditions. The second will be the determination of erosion rates and distribution of fluvial and hillslope processes during the Quaternary. By combining Quaternary erosion rates with the correlation between the regional paleoclimatic and local paleoenvironmental histories, together with the predicted future climates, it will be possible to describe expected locations and rates of erosion in response to expected future climatic episodes. If the durations of the future climatic episodes can be reasonably estimated, it will then be possible to quantify the effects of erosion at Yucca Mountain over the next 1,000 to 100,000 yr.

YMP/CM-0011, Rev. 1

8.3.1.6.3 Investigation: Studies to provide the information required to determine the potential effects of future tectonic activity on locations and rates of erosion.

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation. Section 1.3.2 discusses the structures and structural history of Yucca Mountain and the vertical and lateral crustal movement as they relate to tectonic activity. Section 1.1.3 examines the influence of tectonism on geomorphic processes and its effects on average erosion rates in the Yucca Mountain area and discusses significant late Quaternary geomorphic processes in the Yucca Mountain area.

Parameters

Four sets of parameters will be used in the site studies planned to obtain the needed information. This investigation is necessarily a synthesis of the results of studies undertaken to satisfy other investigations. Rates of regional uplift and subsidence, as determined from studies of tectonic geomorphology and the geodetic leveling network, will be supplied from Investigation 8.3.1.8.2. The present and past locations and rates of surface erosion will be determined from the geomorphic map. The effects of future climate on erosion will be obtained from Investigation 8.3.1.6.2.

Other site studies that provide data that support the determination of the parameters needed for this investigation include (1) a synthesis of the paleoenvironmental history of the Yucca Mountain region from Study 8.3.1.5.1.4 and (2) the tectonic model synthesis from Section 8.3.1.17.4.12.

Purpose and objectives of the investigation

Estimates of the potential effects of future tectonic activity on locations and rates of erosion will be derived in this investigation using information from Investigation 8.3.1.8.2, from Investigation 8.3.1.5.1, and from other activities performed within this program. The logic diagram for this investigation is shown in Figure 8.3.1.6-4.

Geomorphic processes in the southern Great Basin and northern Mojave Desert are determined largely by climate, existing topography, and tectonic activity, and by the spatial and temporal relations between these determinants. Late Cenozoic extensional tectonism and a predominantly semiarid-to-arid climate have combined to produce a structurally dominated landscape of high relief with narrow, rugged uplands separated by broad, gently sloping lowland basins. Within this landscape, erosion and erosional processes are concentrated in the high, steep, and relatively moist uplands, whereas deposition and depositional processes are generally concentrated in the low, gently sloping, and relatively arid lowlands. The intervening piedmonts serve primarily as surfaces of transport between the eroding uplands and aggrading basins.

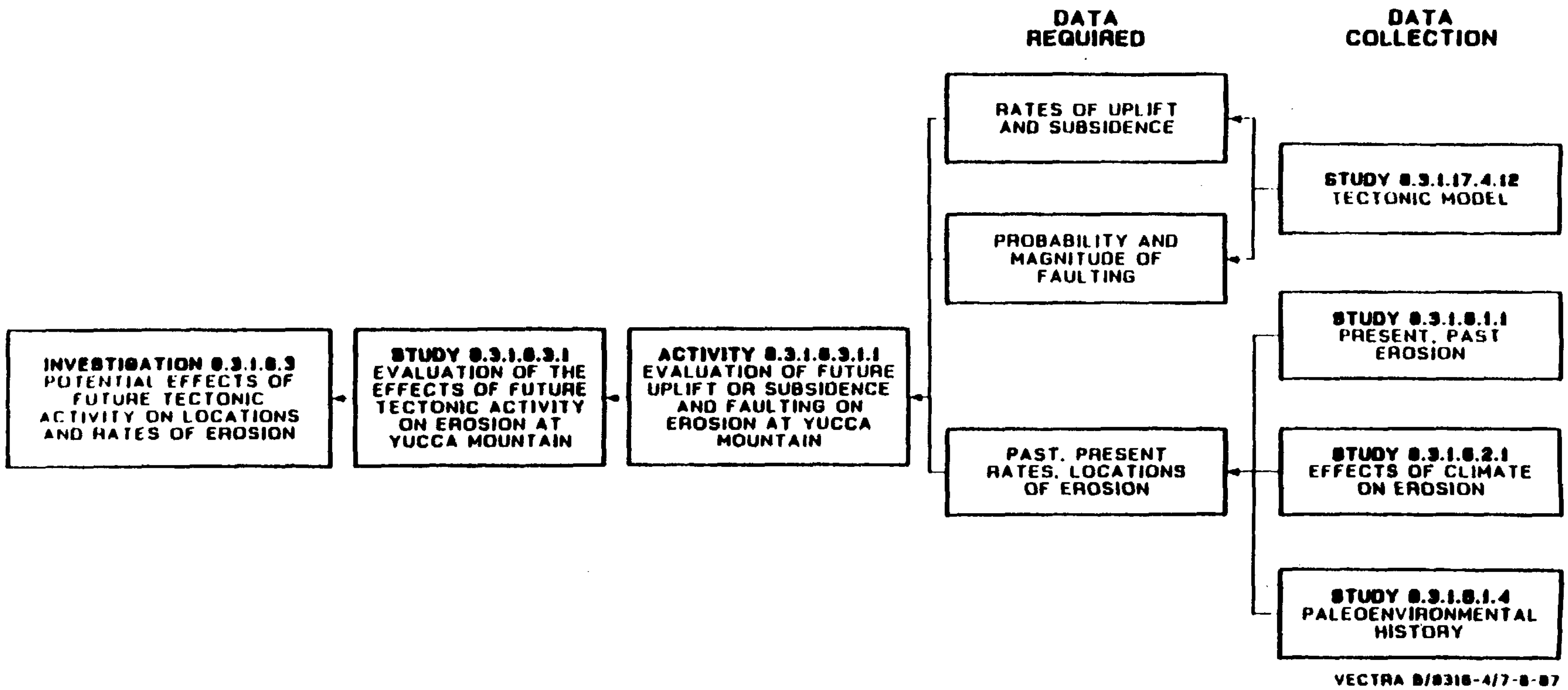

Figure 8.3.1.6-4. Logic diagram for Investigation 8.3.1.6.3.

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

Differential vertical movement induced by regional extensional tectonism has probably been the single most important factor in the development of the landscape of the region surrounding Yucca Mountain. Essentially all landscape elements in the southern Great Basin and northern Mojave Desert are the structurally dominated products of late Cenozoic tectonism. However, with the exception of the southwest Great Basin and its bounding fault zones, tectonism appears to have played a much less significant role in regional landscape evolution during the Quaternary. For example, regional morphometric analyses indicate that large areas of the northern Mojave Desert and southern Great Basin (in particular, the eastern and southern sections of the Goldfield block of the Walker Lane belt as discussed in Chapter 1, Geology) have undergone little, if any, vertical tectonic activity during the Quaternary. Local tectonic stability since latest Miocene time is documented by relations between potassium-argon-dated lava flows and relict and active erosion surfaces near the Cima volcanic field in the northeastern Mojave Desert and in the Pancake and Reveille Ranges of the central Great Basin. In the Yucca Mountain area, average rates of relative vertical tectonic adjustment during the latest Tertiary and Quaternary have been less than 3 cm per 1,000 yr. The impact of extensional tectonism on the late Quaternary landscape of Yucca Mountain has been extremely small, and the impact upon the magnitude and distribution of degradational processes in the area is very local, even in the vicinity of Quaternary faults.

If uplift rates at Yucca Mountain during the postclosure period are negligible, then (using present estimates of erosion rates) the average erosion rate of the mountain would probably be about 1 m over the next 10,000 yr. If the estimated Quaternary rate of uplift is projected over the postclosure period, even with a return to pluvial conditions, it is highly unlikely that the average rate of erosion will increase significantly. These regional erosion and uplift rates need to be verified with the site-specific data from Yucca Mountain.

One study will be undertaken under Investigation 8.3.1.6.3. The study consists of one synthesis activity that will integrate data generated from tectonics investigations and from Investigations 8.3.1.6.1 and 8.3.1.6.2.

8.3.1.6.3.1 Study: Evaluation of the effects of future tectonic activity on erosion at Yucca Mountain

The objective of this study is to identify the potential effects of tectonic activity on erosion at Yucca Mountain during the postclosure period. The study is aimed at (1) defining those components of erosion that are dependent upon tectonic activity, and (2) determining how future tectonic adjustment might influence local incision rates.

 YMP/CM-0011, Rev. 1

8.3.1.6.3.1.1 Activity: Synthesis and data evaluation of the impact of future uplift or subsidence and faulting on erosion at Yucca Mountain and vicinity

Objectives

The objectives of this activity are to estimate (1) the effects of tectonic activity on erosion over the repository postclosure period on the basis of probable future tectonic scenarios for the Yucca Mountain region, (2) the locations and rates of present and past erosion for present climatic conditions, and (3) the effects of future climatic conditions on erosion.

Parameters

Four sets of parameters will be evaluated in this activity:

1. The rates of regional uplift and subsidence, as determined from studies of tectonic geomorphology (Section 8.3.1.17.4.9) and the geodetic leveling network (Section 8.3.1.17.4.10).

2. The tectonic model synthesis, including the probability and expected magnitude of faulting in the Yucca Mountain area during the repository postclosure period from Sections 8.3.1.17.2 and 8.3.1.17.4.

3. Present and past locations and rates of erosion from Investigation 8.3.1.6.1.

4. Estimated effects of future climate on erosion from Investigation 8.3.1.6.2.

Description

This synthesis activity will be aimed at identifying the magnitudes of the components of erosion rate (both local and regional) caused by Quaternary tectonic activity, and assessing the effects of probable future tectonic activity on rates of erosion expected in the Yucca Mountain region over the repository postclosure period. The tectonic data for this synthesis will be derived from Programs 8.3.1.8 and 8.3.1.17. Erosion rate data will come from Study 8.3.1.6.1.1 (distribution and characteristics of present and past erosion), Activity 8.3.1.6.1.1.3 (hillslope erosion), Activity 8.3.1.6.2.1.1 (impact of future climatic conditions on erosion), and Study 8.3.1.5.1.4 (paleoenvironmental history of Yucca Mountain region).

The apportionment of local and regional erosion rates (Quaternary through present) into components attributed to climatic and tectonic causes will be critical to this activity. Although climatic conditions are believed to be the dominant control on erosion rates, proposed studies on past erosion in the Yucca Mountain region and the reconstruction of the paleoenvironmental history will yield a quantification of the tectonic erosional component for the Quaternary. Combining local data with projected regional uplift or subsidence rates, and probable local fault movement, will result in quantitative estimates for the tectonic influences on erosion rates in the postclosure period.

YMP/CM-0011, Rev. 1

8.3.1.6.4 Investigation: Potential effects of erosion on hydrologic, geochemical, and rock characteristics

Because existing data on the effects of erosion on hydrology, geochemistry and rock characteristics satisfy the design and performance requirements, no further studies are planned. Instead, a topical report will be prepared by the Yucca Mountain Project to document the tentative conclusion that erosion will have a negligible effect on the hydrologic, geochemical, and rock characteristics important to waste isolation. The steps to be used in addressing this investigation are shown in Figure 8.3.1.6-5.

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters summarize the information related to this investigation:

SCP section	Subject
1.1.3.2	Average erosion rates in the region surrounding Yucca Mountain
1.1.3.3	Significant late Quaternary geomorphic processes in the Yucca Mountain area
1.8.1.1.2	Discussion of significant results (geomorphology)
1.8.3.1	Information needs bearing on geomorphology
2.1, 2.2, 2.3	Mechanical properties of rock units
2.4, 2.5	Thermal and thermomechanical properties
2.6	Existing stress regime
2.7	Special geoengineering properties
2.8	Excavation characteristics
3.7.1	Areas of recharge and discharge
3.7.2	Regional ground-water flow paths
3.9.3	Conceptual model for ground-water flow system
3.9.4	Calculations of ground-water velocity and travel time
3.10	Summary sections
4.1	Baseline geochemical characteristics at Yucca Mountain

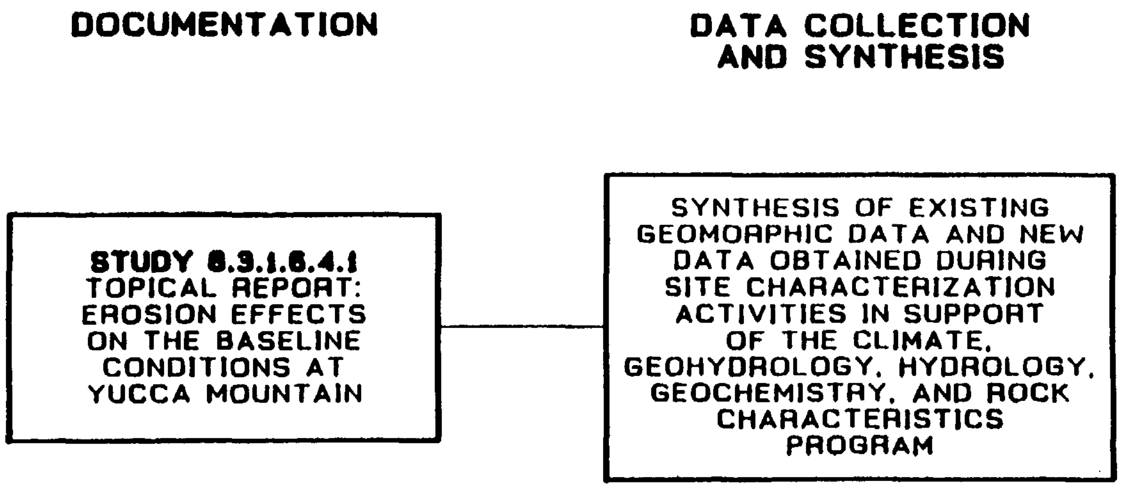

Figure 8.3.1.6-5. Logic diagram for Investigation 8.3.1.6.4.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

Parameters

The parameters for this investigation are

1. The expected effects of erosion on hydrologic, geochemical, and rock characteristics during the 10,000 yr postclosure period.

2. The probability that the repository will be exhumed during the next 10,000 to 100,000 yr.

Purpose and objectives of the investigation

The product of this investigation, a topical report, will address the possibility that erosional processes at Yucca Mountain could adversely affect the potential for radionuclide releases to the accessible environment because of changes in the ground-water system, the geochemical conditions, or the rock characteristics. The likelihood of radionuclide releases because of changes in the hydrologic system is negligible. The probability that erosion will modify the surface-water regime during the postclosure period is extremely small. For erosion-induced changes in hydrologic characteristics to adversely affect waste isolation, a reduction in ground-water travel time resulting from the removal of enough rock above the water table to modify hydraulic gradients and locations of recharge or discharge near Yucca Mountain would be necessary. It is highly unlikely that expected erosion rates (even considering possible changes in climate and tectonism) will be adequate to cause the removal of sufficient overburden material necessary to change the hydrologic conditions.

Erosion-induced changes in geochemical characteristics that might adversely affect waste isolation most likely would be changes in geochemical properties along flow paths to the accessible environment. The effects of erosion on the geochemical properties along flow paths for both ground water and gases will be discussed in the topical report. Erosion is expected to have negligible effects on mechanical, thermal, or thermomechanical properties, on special geoengineering properties, or on excavation characteristics within the controlled area in ways that would affect waste isolation. Erosion may very slightly modify in situ stresses, but the expected amount of erosion within the controlled area and the corresponding change in in situ stress is so small that effects on waste isolation will be negligible.

One study, consisting of a synthesis activity and an analysis activity, will be undertaken in support of this investigation. The objective of the synthesis activity is to integrate the existing erosion data and additional erosion data that will be obtained from Investigations 8.3.1.6.1 through 8.3.1.6.3, with information on the hydrologic, geochemical, and rock characteristics. These data will be used to develop a topical report that will address the expected effects of erosion on conditions at the site needed to address the requirements of 10 CFR Part 60.

 YMP/CM-0011, Rev. 1

The objective of the analysis activity is to apply statistical techniques to information obtained from Investigations 8.3.1.6.1 through 8.3.1.6.3 to determine with a high level of certainty the probability that repository exhumation by erosional processes will not occur over the next 10,000 and 100,000 yr. The results of the statistical analysis will be presented in a topical report.

8.3.1.6.4.1 Study: Development of a topical report to address the effects of erosion on the hydrologic, geochemical, and rock characteristics at Yucca Mountain

Objectives

The objective of this study is to assemble data showing the expected effects of erosion on (1) the hydrologic, geochemical, and rock characteristics of the controlled area and (2) the ability of the mined geologic disposal system to effectively isolate waste over 10,000 and 100,000 yr after disposal.

Parameters

The following parameters will be considered in the topical report:

1. Rates and locations of future erosion.

2. Depth to water table in the controlled area.

3. Geochemical process along flow paths to the accessible environment.

4. Effect of erosion on retardation of radionuclides by all geochemical processes along ground-water flow paths and gaseous flow paths.

5. Effects of erosion on in situ stresses in the controlled area.

Description

Two topical reports will be prepared that will assemble and analyze existing data and data gathered during site characterization. The first report will address the expected magnitude of erosion in the controlled area and the extent to which such erosion would reduce ground-water travel time to the accessible environment. The report will also identify and address the expected effects of erosion on the geochemical characteristics along flow paths and the expected effects of erosion on the in situ stresses in the controlled area.

In the second report, existing information and data obtained during site characterization will be used in performing statistical calculations to determine the probability that erosion of overburden materials will result in repository exhumation during 10,000 and 100,000 yr after closure.

8.3.1.7 Overview of rock dissolution program: Description of rock dissolution required by the performance and design issues

Because the findings made for the Yucca Mountain environmental assessment (DOE, 1986b) are adequate to meet the requirements of Issue 1.8 (Section 8.3.5.17, NRC siting critieria) and 1.9 (Section 8.3.5.18, higher level findings--postclosure system and technical guidelines), no additional studies are specifically planned to resolve this issue. Further work related to chemical and mineralogical changes in the post-emplacement environment is discussed in Section 8.3.4.2.4.1.

8.3.1.7.1 Investigation: Rates of dissolution of crystalline and noncrystalline components in tuff

Technical basis for obtaining the information

Link to technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
4.1.1	Mineralogy and petrology
4.1.1.3.1	Potential host rock
4.1.1.4	Mineral stability
4.1.2	Ground-water chemistry

Parameters

For this investigation, parameters are not applicable.

Purpose and objectives of the investigation

For this investigation, purpose and objectives are not applicable.

Technical rationale for the investigation

This investigation has been satisfied by information presented in the Yucca Mountain environmental assessment (DOE, 1986b). The conclusions in the environmental assessment were as follows:

1. No evidence of Quaternary dissolution fronts or other dissolution features has been found.

2. None of the minerals in the host rock are considered soluble under expected repository conditions.

YMP/CM-0011, Rev.

3. There is no evidence of past or potential future significant dissolution that would provide a hydraulic interconnection between the host rock and any immediately surrounding geohydrologic unit.

4. The minerals that compose the rock in and around Yucca Mountain are considered insoluble, and significant subsurface rock dissolution is not a credible process leading to radionuclide releases greater than those allowable under the requirements of 10 CFR Part 960 and 10 CFR Part 60.

Because the findings made for the EA are adequate to meet the higher level findings of 10 CFR Part 960 and 10 CFR Part 60, no additional studies are specifically planned to address this issue. Studies on mineral stability are described in Section 8.3.1.3 (Geochemistry Program). These studies are being done to assess geochemical retardation along flow paths to support the assessments made in Issue 1.1 (total system performance, Section 8.3.5.13).

YMP/CM-0011, Rev. 1

8.3.1.8 Overview of the postclosure tectonics program: Description of future tectonic processes and events required by the performance and design issues

Summary of performance and design requirements for postclosure tectonics information

The flow of data through the postclosure tectonics program is shown in Figure 8.3.1.8-1. The performance and design requirements that the postclosure tectonics program must address are to supply data on the probability and effects of tectonic "initiating events" that may alter existing conditions at Yucca Mountain and adversely affect repository performance. These requirements for tectonic information can be summarized as follows:

1. Data on the probability and effects of potentially significant tectonic release-scenario classes addressing both anticipated and unanticipated conditions that are needed for performance assessment calculations of radionuclide releases to the accessible environment (Issue 1.1, Section 8.3.5.13, total system performance).

2. Data required to perform the analysis to determine the degree to which each of the favorable and potentially adverse conditions listed in 10 CFR 60.122 contributes to or detracts from isolation (Issue 1.8, Section 8.3.5.17, NRC siting criteria).

3. Data needed to accommodate requirements for knowledge of site-specific tectonic conditions in design concepts for the geometry, layout, and emplacement borehole locations of the underground facility (Issue 1.11, Section 8.3.2.2, configuration of underground facilities (postclosure)).

4. Data required so that the higher level findings of 10 CFR Part 960 can be evaluated (Issue 1.9a, Section 8.3.5.18, higher level findings (postclosure)).

Four investigations in the postclosure tectonics program provide the analysis and assessment of data necessary to meet these requirements (Figure 8.3.1.8-1). These four investigations have been designed to parallel the intermediate performance measures and initiating events defined in Sections 8.3.5.13 and 8.3.2.2. Investigation 8.3.1.8.3 (tectonic effects on hydrology) has been further subdivided into three separate intermediate performance measures because of the number of performance parameters that have been identified by Issue 1.1 in this investigation. The final column of Figure 8.3.1.8-1 identifies the investigations that will provide data required by Investigations 8.3.1.8.1 through 8.3.1.8.4 in order to complete their analysis and assessment for the postclosure tectonics program. These data collection investigations include Investigation 8.3.1.8.5, which will house the data collecting studies and activities specific to the postclosure tectonics program, and investigations from several other programs that provide important data for the analysis and assessment investigations.

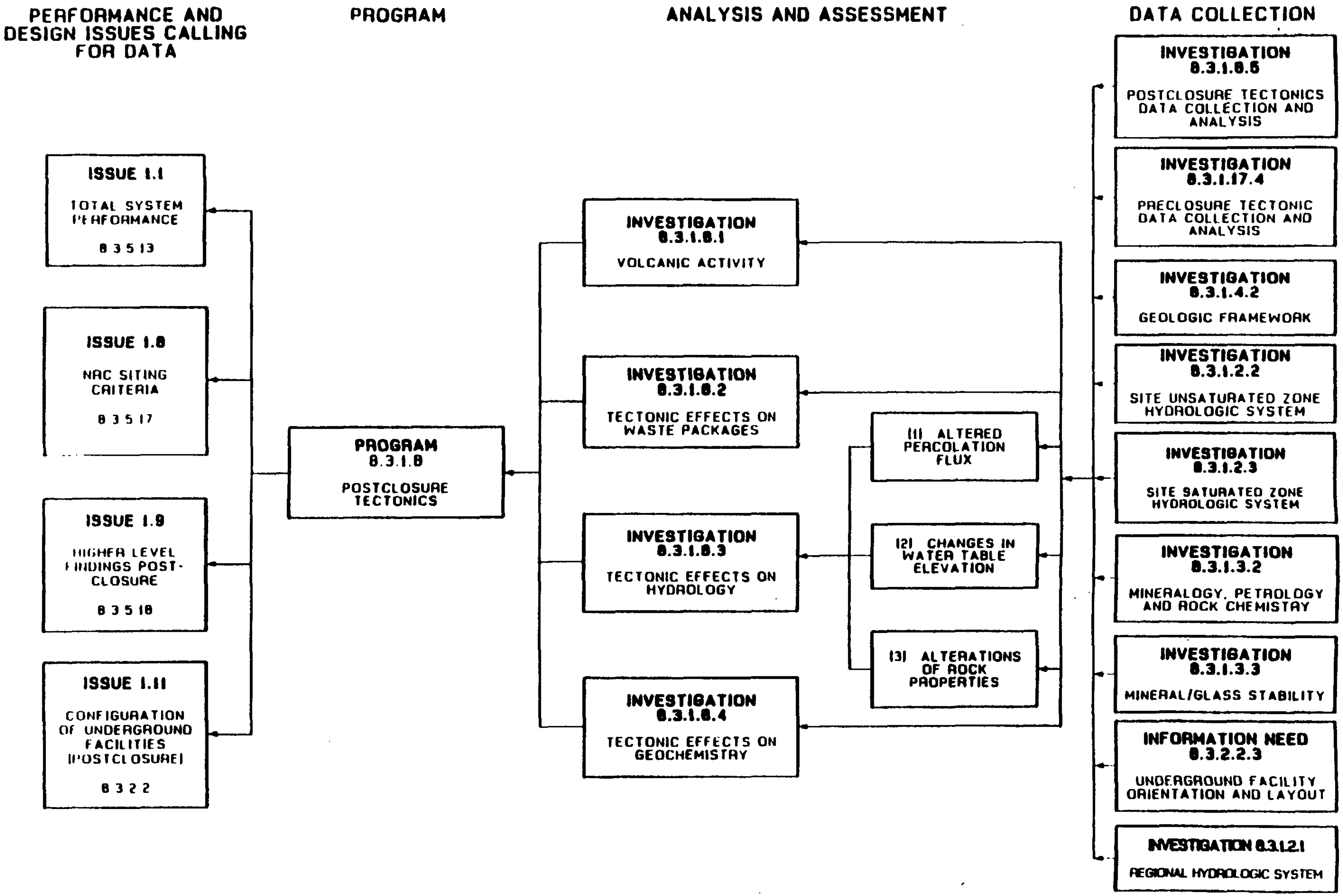

Figure 8.3.1.8-1. Relationships between the postclosure tectonics program, investigations, and performance design issues.

 YMP/CM-0011, Rev. 1

Tables 8.3.1.8-1 through 8.3.1.8-6 list the favorable and potentially adverse conditions on which data are required for the resolution of Issue 1.8 and the performance measures, intermediate performance measures and performance parameters on which data are required by Issue 1.1 and Issue 1.11. Each table is linked to a specific performance or intermediate performance measure identified by Issue 1.1 or 1.11 and a specific post-closure tectonics program investigation. The first column in Part A of the tables identifies the performance or design issue that has requested information from the postclosure tectonics program. The second and third columns identify the potentially adverse and favorable conditions from Issue 1.8 that will be addressed by each initiating event.

The fourth column lists the initiating events identified by Issues 1.1 or 1.11 that are related to the performance measure or intermediate performance measure. Initiating events are tectonic events or processes that, if they should occur during the period of interest, could directly or indirectly lead to releases or adversely affect estimates of release at the accessible environment boundary. An example of an initiating event that could directly lead to releases is the penetration of the repository by a volcanic event. Most initiating events only indirectly affect estimates of release by potentially altering another parameter (such as average percolation flux rates) that, if changed, could adversely affect estimates of releases at the accessible environment boundary.

The fifth and sixth columns identify a performance measure and associated goal. Performance measures are high level measures of total system performance and are described in more detail in Section 8.3.5.13 (Issue 1.1) and Section 8.3.2.2 (Issue 1.11). The seventh and eighth columns describe an intermediate performance measure and associated goal that is related to a significant component of the radionuclide release calculation (e.g., average percolation flux rates) that could be altered by tectonic processes or events. The goal for the intermediate performance measure is not intended to indicate the expected value that will result from the analysis of the tectonics program or the value at which the site would fail to meet the system performance objective. Instead, the goal provides an estimate of when the initiating event may start to become significant in performance calculations and is intended to provide guidance to the tectonics program on the level of accuracy or precision required in the program's analyses. The intermediate performance measures and the scenario classes to which they belong are further described in Section 8.3.5.13 for Issue 1.1 or in Section 8.3.2.2 for Issue 1.11.

The final column in Part A describes the performance parameters that have been related by Issue 1.1 or Issue 1.11 to each initiating event. For each initiating event in the tectonics program there are usually two performance parameters. The first performance parameter provides the probability that the tectonic event described in the initiating event will occur during the period of interest. In many instances, estimating probabilities for a tectonic initiating event over 10,000 yr may be difficult. Evaluation of these probabilities are subject to considerable uncertainty, but these uncertainties are quantifiable using available data and judgment. The second performance parameter provides a description of the effects of the event on the concern described in the intermediate performance measure should such an event actually occur. The specific requirements of 10 CFR Part 960 are not

Table 8.3.1.8-1a. Investigation 8.3.1.8.1 - Studies to provide information required on direct releases resulting from volcanic activity

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Tentative goal	Intermediate performance parameter	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance)	15	1	Volcanic eruption penetrates repository and causes direct releases to the accessible environment.	EPPM*	<<1	Not applicable	Not applicable	Annual probability of volcanic eruption that penetrates the repository
8.3.5.17 (Issue 1.8, NRC siting criteria)								Effects of volcanic eruption penetrating repository, including area of repository disrupted
8.3.5.18 (Issue 1.9, higher level findings-postclosure)								

*EPPM = expected partial performance measure (Section 8.3.5.13).

YMP/CM-0011, Rev. 1

Table 8.3.1.8-1b. Investigation 8.3.1.8.1 - Studies to provide information required on direct releases resulting from volcanic activity (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of volcanic eruption that penetrates the repository	$< 10^{-6}$ per yr	High	Location and timing of volcanic events	See Section 1.3.2.1.2	Moderate	High	8.3.1.8.5	8.3.1.8.5.1.1 - Volcanism drillholes 8.3.1.8.5.1.2 - Geochronology studies 8.3.1.8.5.1.3 - Field geologic studies 8.3.1.8.5.1.4 - Geochemistry of scoria sequences
			Evaluation of structural controls on volcanism	See Section 1.3.2.1	Low	Moderate	8.3.1.8.1	8.3.1.8.1.1.1 - Location and timing of volcanic events
							8.3.1.8.5	8.3.1.8.5.1.3 - Field geologic studies 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields
							8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Presence of magma bodies in the vicinity of the site	See Section 1.3.2.1	Low	Moderate	8.3.1.17.4	8.3.1.17.4.7 - Subsurface geometry of Quaternary faults at Yucca Mountain
							8.3.1.8.5	8.3.1.8.5.2.1 - Evaluation of depth of curie temperature isotherm 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain
							8.3.1.17.4	8.3.1.17.4.1.2 - Monitor current seismicity 8.3.1.17.4.3.1 - Evaluate crustal structure and subsurface expression of Quaternary faults

YMP/CM-0011, Rev. 1

Table 8.3.1.8-1b. Investigation 8.3.1.8.1 - Studies to provide information required on direct releases resulting from volcanic activity (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Effects of volcanic eruption penetrating repository, including area of repository disrupted, and confidence bounds of estimate	Show that < 0.1% of repository area is disrupted with a conditional probability of <0.1 of being exceeded in 10,000 yr, should such an intrusion occur	Moderate	Effects of Strombolian eruptions	< 0.05% of repository area disrupted	Moderate	Moderate	None planned (See Sections 1.3.2.1 and 1.5.1)	
			Effects of hydrovolcanic eruptions	Data not available	Low	Moderate	8.3.1.8.5	8.3.1.8.5.1.3 - Field geologic studies

YMP/CM-0011, Rev. 1

Table 8.3.1.8-2a. Investigation 8.3.1.8.2 - Studies to provide information required on rupture of waste packages due to tectonic events

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Tentative goal	Intermediate performance parameter	Performance parameter
8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.2.2 (Issue 1.11, configuration of underground facilities-postclosure)	15	1	Igneous intrusion penetrating repository resulting in failure of waste packages	Usable area: is usable area adequate for 70,000 MTU of waste?	Probability < 0.1 in 1,000 yr that > 0.5% of waste packages will be ruptured by tectonic processes or events	Not applicable	Probability of igneous intrusion penetrating repository Effects of igneous intrusion penetrating repository
8.3.5.18 (Issue 1.9, higher level findings-postclosure)	11	1	Offset of one or more faults intersect waste packages and cause failure	Usable area: is usable area adequate for 70,000 MTU of waste?	Probability < 0.1 in 1,000 yr that > 0.5% of waste packages will be ruptured by tectonic processes or events	Not applicable	Number of waste packages affected by fault penetrating repository Probability of faulting with displacement over 5 cm in repository
	12 13 14	1	Ground motion causes spalling or failure and closes air gap around waste package	Usable area: is usable area adequate for 70,000 MTU of waste?	Placement of waste packages in zones with rock properties that will not lead to failure during expected ground motions	Not applicable	Expected ground motion at emplacement boreholes in 1,000-yr period
	11	1	Folding or distributed shear causes waste emplacement borehole deformation and results in waste package failure	Usable area: is usable area adequate for 70,000 MTU of waste?	Probability < 0.1 in 1,000 yr that >0.5% of waste packages will be ruptured by tectonic processes or events	Not applicable	Rate of deformation due to folding or distributed shearing in repository horizon

YMP/CM-0011, Rev. 1

Table 8.3.1.8-2b. Investigation 8.3.1.8.2 - Studies to provide information required on rupture of waste packages due to tectonic events (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Probability of igneous intrusion penetrating repository	Annual probability less than 10^{-8}	High	Characterization parameters identical to Investigation 1.19.1	10^{-8} to 10^{-10}	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.14 - Probability calculations and assessment
Effects of igneous intrusion penetrating repository	Less than 0.5% of waste packages disrupted	Low	Number of waste packages disrupted by intrusion	1 to 10	Moderate	Moderate	8.3.1.8.1	8.3.1.8.1.2.1 - Effects of Strombolian eruptions
							8.3.2.2.3	8.3.2.2.3 - Design concepts for the underground facility
Number of waste packages affected by fault penetrating repository	Less than 0.5% of waste packages intersected by a single fault with a 95% level of confidence	High	Width of Quaternary fault zones in and near site in which faulting exceeds 5 cm in a single event	< 5 m	Low	Moderate	8.3.1.17.4	8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
			Orientation of faults in and near the repository block	N.25.W-N.25.E	Moderate	Moderate	8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff
							8.3.1.4	8.3.1.4.2.3.1 - Development of 3-D geologic model of the site area
							8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
			Repository layout of waste packages and fault slip rates	See Section 6.2.6; < 0.01 mm/yr	Moderate	High	8.3.2.2.3	8.3.2.2.3 - Design concepts for the underground facility
							8.3.1.17.4	8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults

YMP/CM-0011, Rev. 1

Table 8.3.1.8-2b. Investigation 8.3.1.8.2 - Studies to provide information required on rupture of waste packages due to tectonic events (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Probability of faulting with displacement over 5 cm in repository	Annual probability less than 10^{-4} of faulting with displacement over 5 cm	Moderate	Characteristics of faults that penetrate the repository with total offset > 10 m				8.3.1.17.4	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff 8.3.1.2.3.1 - Development of 3-D geologic model of the site area
			Density	See Section 1.3.2.2.2	Low	Moderate	8.3.1.4.2	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Age and recurrence of movement on suspected and known Quaternary faults
			Length	< 3000 m	Moderate	High		
			Total Offset	10-50 m	Moderate	High		
			Characteristics of Quaternary faults in and near site with slip rates > 0.001 mm/yr				8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Age and recurrence of movement on suspected and known Quaternary faults
			Location	See Figure 1-36	Moderate	High		8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Slip rate	< 0.01 mm/yr	Moderate	High		
			Length	< 35 km	Low	Moderate		
			Total offset	200-500 m	Low	High		
Expected ground motion at emplacement boreholes in 1,000-yr period	Probability of exceeding ground motion values < 0.1 in 1,000-yr	Moderate	Characterization parameters identical to Investigation 8.3.1.17.3	Expected PGA[a] (10,000 yr return period) 0.5-0.7g	Low-moderate	Moderate	8.3.1.17.3	8.3.1.17.3.5.2 - Characterize ground motion from the controlling seismic events 8.3.1.17.3.6.2 - Evaluate ground motion probabilities
Rate of deformation due to folding or distributed shearing in repository horizon	Waste emplacement boreholes will be subject to < 0.005 shear strain in 1,000 yrs as a result of folding or deformation	Low	Nature and age of folding in the repository horizon	No detectable folding in 10 million yr	Moderate	High	8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff
							8.3.1.4.3	8.3.1.4.2.3.1 - Development of 3-D geologic model of the site area
							8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
							8.3.1.8.2	8.3.1.8.2.1.2 - Calculation of the number of waste packages intersected by a fault

[a]PGA - Peak Ground Acceleration.

YMP/CM-0011, Rev. 1

Table 8.3.1.8-3a. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 1; alteration of average percolation flux) (page 1 of 2)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance) 8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.5.18 (Issue 1.9, higher level findings-postclosure)	3, 15	1, 8(i)	Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	EPPM[a]	<< 1	Radionuclide transport time through UZ[b], given fixed UZ thickness, rock hydrologic properties and geochemical properties	Tectonic processes and events will not adversely alter the average percolation flux at the top of the Topopah Spring welded unit by more than a factor of 2. The probability of exceeding the goal will be <0.1 in 10,000 yr	Annual probability of volcanic events within the controlled area Effects of a volcanic event on topography and flux rates
			Igneous intrusion, such as a sill, that could result in a significant change in average flux	Same as above	Same as above	Same as above	Same as above	Annual probability of significant igneous intrusion in the controlled area Effects of an igneous intrusion on flux rates
	3, 4, 11	1, 8(i)	Offset on fault creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds, thereby significantly changing average flux	Same as above	Same as above	Same as above	Same as above	Probability of offset > 2 m on a fault in the controlled area in 10,000 yr Probability of changing dip by > 2° in 10,000 yr by faulting Effect of faulting flux rates

YMP/CM-0011, Rev. 1

Table 8.3.1.8-3a. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 1; alteration of average percolation flux) (page 2 of 2)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
	3, 4, 11	1, 8(i)	Folding changes dip of tuff beds controlled area thereby significantly changing average flux	EPPM	<< 1	Same as above	Same as above	Probability of changing dip by > 2° in 10,000 yr by folding
	3, 4, 11, 16	1, 8(i)	Uplift or subsidence changes topography or drainage thereby significantly changing average flux	Same as above	Same as above	Same as above	Same as above	Probability of exceeding 30 m elevation change in 10,000 yr

[a]EPPM = expected partial performance measure (see Section 8.3.5.13).
[b]UZ = unsaturated zone.

YMP/CM-0011, Rev. 1

Table 8.3.1.8-3b. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 1; alteration of average percolation flux) (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of volcanic events within the controlled area	< 10^{-5} per yr	High	Probability calculation for volcanic events	10^{-7} to 10^{-9} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.4 - Probability calculations and assessment
Effects of a volcanic event on topography and flux rates	Show topographic changes are not great enough to significantly affect flux	Low	Data on topographic changes caused by an eruption	See Section 1.5.1.2.2	Moderate	Moderate	8.3.1.8.1	8.3.1.8.1.2.1 - Effects of Strombolian eruptions 8.3.1.8.1.2.2 - Effects of hydrovolcanic eruptions
			Hydrologic model of flow in the unsaturated zone	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.2	8.3.1.2.2.8 - Flow in unsaturated, fractured rock 8.3.1.2.2.9 - Site unsaturated zone modeling, synthesis, and integration
Annual probability of significant igneous intrusion in the controlled area	< 10^{-5} per yr	High	Probability calculation for igneous events	10^{-7} to 10^{-9} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.4 - Probability calulations and assessment
Effects of an igneous intrusion on flux rates	Show igneous intrusion will not significantly affect flux because of depth, location, and extent of intrusion	Low	Orientation and dimensions of possible intrusions at the site	= N.30.E; < 4 km x 0.3-4 m	Moderate	Moderate	No new activities planned	None
			Hydrologic model of flow in the unsaturated zone	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.2	8.3.1.2.2.8 - Flow in unsaturated, fractured rock 8.3.1.2.2.9 - Site unsaturated zone modeling, synthesis, and integration
Probability of offset > 2 m on a fault in the controlled area in 10,000 yr	< 10^{-1} per 10,000 yr	Moderate	Vertical slip rate and recurrence interval on Quaternary faults in and near the site	Slip rate < 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.4.3 - Evaluate Stagecoach Road fault zone
							8.3.1.17.4	8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults

YMP/CM-0011, Rev. 1

Table 8.3.1.8-3b. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 1; alteration of average percolation flux) (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Probability of changing dip by >2° in 10,000 yr by faulting	< 10^{-4} per 10,000 yr	Low	Vertical slip rate on Quaternary faults in and near the site and rate of tilting	< 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
							8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff
							8.3.1.4.3	8.3.1.4.2.3.1 - Development of a 3-D geologic model of the site area
Effect of faulting on flux rates	Show faulting will not significantly affect flux because of low slip rate	Moderate	Hydrologic model of flow in the unsaturated zone	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.2	8.3.1.2.2.8 - Flow in unsaturated, fractured rock 8.3.1.2.2.9 - Site unsaturated zone modeling, synthesis, and integration
Probability of changing dip by >2° in 10,000 yr by folding	< 10^{-4} per 10,000 yr	Low	Rate of folding in the unsaturated zone section	No detectable folding in 10 million yr	Moderate	High	8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of the exploratory shaft and drifts
							8.3.1.4.3	8.3.1.4.2.2.4 - Geologic mapping of the exploratory shaft and drifts
Probability of exceeding 30 m elevation change in 10,000 yr	< 10^{-4} per 10,000 yr	Low	Rate of uplift or subsidence at site	< 3 x 10^{-2} mm per yr	Moderate	Moderate	8.3.1.17.4	8.3.1.4.2.3.1 - Development of a 3-D geologic model of the site area
								8.3.1.17.4.9.2 - Evaluate extent of Quaternary uplift and subsidence at and near Yucca Mountain 8.3.1.17.4.1.10 - Geodetic leveling

YMP/CM-0011, Rev. 1

Table 8.3.1.8-4a. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 2; changes in water table elevation) (page 1 of 2)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance) 8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.5.18 (Issue 1.9, higher level findings - postclosure)	5, 15, 22, 23	1, 8(ii)	Igneous intrusion causes barrier to flow or thermal effects that alter water-table level	EPPM[a]	<< 1	Radionuclide transport time through UZ[b], given fixed UZ rock hydrologic and geochemical properties	Water table will not rise to within 100 m of emplaced waste in 10,000 yr	Annual probability of a significant igneous intrusion within 0.5 km of controlled area boundary
							No discharge points created in the controlled area	Barrier-to-flow effects of igneous intrusions on water-table levels
							Perched aquifers will not be created within 100 m of emplaced waste	Thermal effects of igneous intrusions on water-table levels
							The probability of exceeding the goals will be < 0.1 in 10,000 yr	
	4, 5, 11, 22, 23	1, 8(ii)	Episodic changes in strain in the rock mass due to faulting causes changes in water-table level	Same as above	Same as above	Same as above	Same as above	Probability that strain-induced changes increased to potentiometric level to > 850 m mean sea level

YMP/CM-0011, Rev. 1

Table 8.3.1.8-4a. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 2; changes in water table elevation) (page 2 of 2)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
	4, 5, 11, 22, 23	1, 8(ii)	Folding, uplift, or subsidence lowers repository with respect to water table	Same as above	Same as above	Same as above	Same as above	Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr
	4, 5, 11, 22, 23	1, 8(ii)	Offset on fault juxtaposes transmissive and nontransmissive units resulting in either the creation of a perched aquifer or a rise in the water table	Same as above	Same as above	Same as above	Same as above	Probability of total offsets > 2.0 m in 10,000 yr on a fault within controlled area boundary Effects of fault offset on water-table levels

[a]EPPM - expected partial performance measure (see Section 8.3.5.13).
[b]UZ - unsaturated zone.

YMP/CM-0011, Rev. 1

Table 8.3.1.8-4b. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 2; changes in water-table elevation) (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of a significant igneous intrusion within 0.5 km of controlled area boundary	< 10^{-8} per yr	Moderate	Probability calculation for volcanic events	10^{-7} to 10^{-9} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.4 - Probability calculations and assessment
Barrier-to-flow effects of igneous intrusions on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,000 yr	Low	Orientation and dimensions of possible intrusions at the site	Orientation: N.20°-40°E. Length: 400-4000 m	Moderate	Moderate	8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Hydrologic model of saturated zone flow system	See Section 3.9.3.2.2	Moderate	High	8.3.1.2.3	8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models
Thermal effects of igneous intrusions on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,0000 yr	Low	Model thermal effects around a dike	400°C at 2 m distance after 40 days	Moderate	Moderate	8.3.1.8.1	8.3.1.8.1.2.1 - Effects of Strombolian eruptions 8.3.1.8.1.1.3 - Presence of magma bodies in vicinity of site
			Hydrologic model of saturated zone flow system	See Section 3.9.3.2.2	Moderate	High	8.3.1.2.3	8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models
Probability that strain-induced changes increase potentiometric level to > 850 m MSL[a]	< 10^{-8} per yr	Low	Strain rates and strain changes due to faulting	See Section 1.3.2.3	Low	Moderate	8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Hydrologic model of saturated zone flow system	See Section 3.9.3.2.2	Moderate	High	8.3.1.2.3	8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models
Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr	< 10^{-4} per 10,000 yr	Low	Folding, uplift, and subsidence rates in site area	< 3×10^{-2} mm per yr	Moderate	Moderate	8.3.1.17.4	8.3.1.17.4.9.2 - Evaluate extent of Quaternary uplift and subsidence at and near Yucca Mountain 8.3.1.17.4.10 - Geodetic leveling
							8.3.1.4.2	8.3.1.4.2.2.1 - Geologic mapping of zonal features of Paintbrush Tuff 8.3.1.4.2.2.4 - Geologic mapping of exploratory shaft and drifts
							8.3.1.4.3	8.3.1.4.2.3.1 - Development of a 3-D geologic model of the site area

YMP/CM-0011, Rev. 1

Table 8.3.1.8-4b. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 2; changes in water-table elevation) (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Probability of total offsets > 2.0 m in 10,000 yr on a fault within controlled area boundary	< 10^{-1} per 10,000 yr	Low	Slip rates on Quaternary faults in and near site	< 0.01 mm/yr	Moderate	High	8.3.1.17.4	8.3.1.17.4 . . - Evaluate Stagecoach Road fault zone 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
Effects of fault offset on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,000 yr	High	Orientation and length of faulting	N.25°E. - N.25°W. 10-20 km	Moderate	Moderate	8.3.1.17.3	8.3.1.17.3.1 - Relevant earthquake sources
			Hydrologic model of saturated zone flow system	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.3	8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models
			Hydrologic model of unsaturated flow system	See Section 3.9.3.2.1	Moderate	High	8.3.1.2.2	8.3.1.2.2.8 - Flow in unsaturated, fractured rock 8.3.1.2.2.9 - Site unsaturated zone modeling, synthesis, and integration
			Evidence of higher water levels in Quaternary due to faulting	See Section 1.2.2.2.10	Low	Moderate	8.3.1.5.2	8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits

*MSL = mean sea level.

YMP/CM-0011, Rev. 1

Table 8.3.1.8-5a. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 3; alteration of rock properties along significant travel paths)

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance) 8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.5.18 (Issue 1.9, higher level findings-postclosure)	5, 15, 24	1, 8(i)	Igneous intrusion causes changes in hydrologic properties	EPPM[a]	<< 1	Radionuclide transport time through UZ[b], given fixed thickness of UZ	The localized flux along travel paths from the repository to the accessible environment will not be significantly increased for distances that are a signifi- part of the the travel path over 10,000 yr	Annual probability of significant igneous intrusions within 0.5 km of controlled area boundary Effects of igneous intrusions on local fracture permeabilities and effective porosities
	4, 5, 11, 24	1, 8(i)	Episodic offset on faulting causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow, creating barriers to flow, or creating new conduits for drainage	Same as above	Same as above	Same as above	Same as above	Annual probability of faulting events on Quaternary faults within 0.5 km of controlled area boundary Effects of fault motion on local fracture permeabilities and effective porosities
	4, 5, 11, 24	1, 8(i)	Changes in stress or strain in the controlled area resulting from episodic faulting, folding, or uplift causes changes in the hydrologic properties of the rock mass	Same as above	Same as above	Same as above	Same as above	Effects of changes of stress or strain on hydrologic properties of the rock mass

[a]EPPM = expected partial performance measure (Section 8.3.5.13).
[b]UZ = unsaturated zone.

YMP/CM-0011, Rev. 1

Table 8.3.1.8-5b. Investigation 8.3.1.8.3 - Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events (Study 3; alteration of rock properties along significant travel paths)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of significant igneous intrusions within 0.5 km of controlled area boundary	< 10^{-5} per yr	Moderate	Probability calculation for volcanic events	10^{-7} to 10^{-9} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.4 - Probability calculations and assessment
Effects of igneous intrusions on local fracture permeabilities and effective porosities	Show no significant changes in rock hydrologic properties	Low	Evidence of change in rock properties around dikes in the region	No data available	Low	Moderate	8.3.1.8.5	8.3.1.8.5.2.2 - Chemical and physical changes around dikes
Annual probability of faulting events on Quaternary faults within 0.5 km of controlled area boundary	Show < 10^{-4} per yr for each fault	High	Location of Quaternary faults in and near site	See Figure 1-36	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
			Slip rate and recurrence interval for Quaternary faults in and near site	Slip rate < 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
Effects of fault motion on local fracture permeabilities and effective porosities	Show change in fracture permeability is < a factor of 2, and that fracture porosity increases	High	Evidence of episodic rock property changes along faults	See Section 1.3.2.2.2	Low	Moderate	8.3.1.4.2	8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures 8.3.1.4.2.2.4 - Geologic mapping of exploratory shaft and drifts 8.3.1.3.2.1.3 - Fracture mineralogy
Effects of changes of stress or strain on hydrologic properties of the rock mass	Show changes in conductivity and porosity of rock mass are < a factor of 2	Low	Potential stress and strain changes in the rock mass due to faulting or other tectonic processes	See Section 1.3.2.3	Low	Moderate	8.3.1.17.4	8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site
			Hydrologic models of flow in the saturated and unsaturated zone	See Sections 3.9.2.1 and 3.9.3.2.2	Low	Moderate	8.3.1.2.2 8.3.1.2.3	8.3.1.2.2.8 - Flow in unsaturated, fractured rock 8.3.1.2.2.9 - Site unsaturated zone modeling, synthesis, and integration 8.3.1.2.3.3.1 - Conceptualization of saturated zone flow models

YMP/CM-0011, Rev. 1

Table 8.3.1.8-6a. Investigation 8.3.1.8.4 - Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes

SCP section requesting parameter	Potentially adverse condition addressed (10 CFR 60.122(c)) (Section 8.3.5.17)	Favorable condition addressed (10 CFR 60.122(b)) (Section 8.3.5.17)	Initiating event	Performance measure	Goal	Intermediate performance measure	Goal	Performance parameter
8.3.5.13 (Issue 1.1, total system performance) 8.3.5.17 (Issue 1.8, NRC siting criteria) 8.3.5.18 (Issue 1.9, higher level findings-postclosure)	8, 15, 24	1, 3	Igneous intrusion causes changes in rock geochemical properties	EPPM[a]	<< 1	Radionuclide transport time through UZ[b], given fixed thickness of UZ	For radionuclides with travel times less than 10,000 yr, the change in K_ds[c] will not be more than a factor of 2 in 10,000 yr with a high level of confidence	Annual probability of igneous intrusions within 0.5 km of the controlled area boundary Effects of intrusions on local rock geochemical properties
	8, 11, 24	1, 3	Offset on a fault causes changes in movement of ground water that results in mineralogical changes along fault zone	Same as above	Same as above	Same as above	Same as above	Probabilty of movement and location of Quaternary faults in controlled area Degree of mineral changes in fault zone in 10,000 yr
	8, 11, 24	1, 3	Offset on a fault changes travel pathway to one with different geochemical properties	Same as above	Same as above	Same as above	Same as above	Probability of total offsets > 2.0 m in 10,000 yr on a fault within 0.5 km of controlled area boundary Effects of fault offset on travel pathway
	8, 11, 24	1, 3	Tectonic processes cause changes in ground-water table or movement that results in mineral changes in controlled area	Same as above	Same as above	Same as above	Same as above	Degree of mineral change in the controlled are resulting from changes in water-table level or flow paths in 10,000 yr

[a]EPPM - expected partial performance measure (Section 8.3.5.13).
[b]UZ - unsaturated zone.
[c]K_d - distribution coefficient.

YMP/CM-0011, Rev. 1

Table 8.3.1.8-6b. Investigation 8.3.1.8.4 - Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes (page 1 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Annual probability of significant igneous intrusions within 0.5 km of the controlled area boundary	< 10^{-5} per yr	Moderate	Probability calculations for volcanic events	10^{-7} to 10^{-9} per yr	Moderate	High	8.3.1.8.1	8.3.1.8.1.1.4 - Probability calculations and assessment
Effects of intrusions on local rock geochemical properties	Show potential changes in mineralogy will not be extensive	Low	Evidence of change in geochemical properties around dikes in the region	Data not available	Low	Moderate	8.3.1.8.5	8.3.1.8.5.2.2 - Chemical and physical changes around dikes
Probability of movement within 2 km of surface and location of Quaternary faults in controlled area	< 10^{-4} per yr for each fault	Moderate	Location of Quaternary faults in controlled area	See Figure 1-36	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain
			Slip rate and recurrence intervals for Quaternary faults in the controlled area	< 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults
Degree of mineralogic change in fault zone in 10,000 yr	Show adverse changes in mineralogy will not occur	Moderate	Nature and age of mineralogic changes on faults in the controlled area	See Section 1.3.2.3	Low	Moderate	8.3.1.4.2	8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures 8.3.1.4.2.2.4 - Geologic mapping of shafts and drifts 8.3.1.3.2.1.3 - Fracture mineralogy 8.3.1.3.2.2 - History of mineralogic and geochemical alteration of Yucca Mountain
Probability of total offsets > 2.0 m in 10,000 yr on a fault within controlled area boundary	< 10^{-1} per 10,000 yr	Moderate	Slip rates on Quaternary faults in and near site	< 0.01 mm per yr	Moderate	High	8.3.1.17.4	8.3.1.17.4.4.3 - Evaluate Stagecoach Road fault zone 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults

YMP/CM-0011, Rev. 1

Table 8.3.1.8-6b. Investigation 8.3.1.8.4 - Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes (page 2 of 2)

Performance parameter	Tentative parameter goal	Needed confidence	Characterization parameter	Testing basis: Current estimate (range or bound)	Testing basis: Confidence in current estimate	Testing basis: Needed confidence in final values	Investigations supplying data	Key studies or activities supplying data
Effects of fault offset on travel pathway	Show significant changes will not occur	Moderate	Hydrologic models of unsaturated and saturated zone flow	See Sections 3.9.3.2.1 and 3.9.3.2.2	Moderate	High	8.3.1.2.2	8.3.1.2.2.8 - Flow in unsaturated, fractured rock 8.3.1.2.2.9 - Site unsaturated zone modeling, synthesis, and integration
							8.3.1.2.3	8.3.1.8.3.3.1 - Conceptualization of saturated zone flow models
Degree of mineralogic change in the controlled area resulting from changes in water-table level or flow paths in 10,000 yr	Show adverse changes in mineralogy will not occur	Low	Probability and magnitude of hydrologic changes	Data not available	Low	Moderate	8.3.1.8.3	8.3.1.8.3.2.2 - Assessment of the effects of igneous intrusion on water-table elevations 8.3.1.8.3.2.3 - Assessment of the effect of strain changes on water-table elevation 8.3.1.8.3.2.4 - Assessment of the effect of folding, uplift, or subsidence on water-table elevation 8.3.1.8.3.2.6 - Assessment of the effect of faulting on water-table elevation

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

explicitly addressed in the tables because it has been determined that no additional data are needed to make the higher level findings of 10 CFR Part 960 over that required to resolve Issue 1.1 (total system performance, Section 8.3.5.13) and Issue 1.8 (10 CFR Part 60, NRC siting criteria, Section 8.3.5.17). Detailed discussion of the 10 CFR Part 960 higher level findings can be found in Section 8.3.5.18 (higher level findings--postclosure).

Part A of Tables 8.3.1.8-1 through 8.3.1.8-6 basically repeats the information called for in Tables 8.3.5.13-9 through 8.3.5.13-16 in Issue 1.1 and the requirements of Issue 1.11 (Section 8.3.2.2). Part B of the tables indicates the data that will be used and the activities supplying the data necessary in addressing the performance parameters. The first column of Part B repeats the performance parameters from Part A to provide a link between the two parts of the table. The second column provides a tentative parameter goal for the performance parameter. Like the goals for intermediate performance measure, performance parameter goals are intended to provide guidance on the level of accuracy or precision required in addressing the performance parameter rather than indicating anticipated results or levels at which total system performance objectives would not be met. The third column presents a subjective judgment on the needed level of confidence and relative importance of the performance parameters in order to demonstrate that the goals for the performance measure and intermediate performance measure are satisfied. These judgments combine a consideration of the level of detail that can reasonably be achieved in addressing the parameter, the probability of the initiating event having a significant impact on the component of the system performance calculation being considered, and the probability of the initiating event occurring. The information in this column is intended to provide guidance to the data gathering activities on the relative amount of effort that should be expended in addressing each performance parameter.

The fourth column identifies the characterization parameters associated with each performance parameter. A characterization parameter is an item of information necessary to prepare the analysis called for in the performance parameter. Characterization parameters are frequently higher level parameters themselves in that data supplied by other activities must generally be compiled and synthesized to supply the necessary information. The fifth column provides the current estimate of the characterization parameter. These estimates are based on the data presented in Chapter 1, the references supporting Chapter 1, and the technical judgments based on these data. The sixth and seventh columns provide a judgment of the confidence in the current estimate of the characterization parameter and a judgment of the confidence needed at the end of site characterization in the characterization parameter. These two columns are intended to provide guidance to the data collecting activities on the amount of additional effort that is required to complete the program. The final two columns in Part B identify the investigation number, and number and short title of the specific studies or activities that are called upon to supply data to satisfy the characterization parameter.

The approach used in this program to satisfy the data needs listed in the performance parameters is to have one activity associated with each initiating event whose role is to prepare a report that provides an assessment of that event. The assessment will address the performance parameters

YMP/CM-0011, Rev. 1

associated with the initiating event and provide an overview of the probability of significant changes in existing conditions that could affect radionuclide release rates resulting from the tectonic process being considered. The report will provide the basis for deciding how the initiating event will be treated in repository performance assessment calculations. The data presented in Chapters 1 and 4 indicate that several of the initiating events (e.g., those related to uplift, folding, and geochemical changes) can be considered as non-credible in repository release calculations. In these cases, the reports prepared by this program will document this conclusion using existing data or bounding calculations, and little or no additional data will be gathered to directly address these initiating events.

Approach to satisfy performance and design requirements

Both the NRC technical criteria (10 CFR 60.122) and the DOE siting guidelines (10 CFR 960.4-2-7) require that prediction of future tectonic processes and events be determined from projections based on an examination of these processes and events during the Quaternary. The Yucca Mountain Project, therefore, intends to base its analysis of performance measures on a projection of Quaternary rates of tectonic processes on geologic structures at and proximal to the site.

This program also supplies data for the resolution of Issue 1.8 (Section 8.3.5.17): analyses to determine the degree to which each of the favorable and potentially adverse conditions, if present, has been characterized and the extent to which it contributes to or detracts from isolation. Specific guidance on the scopes of these analyses is provided in 10 CFR 60.21(c)(1)(ii)(B): "For the purpose of determining the presence of the potentially adverse conditions, investigations shall extend from the surface to a depth sufficient to determine critical pathways for radionuclide migration from the underground facility to the accessible environment. Potentially adverse conditions shall be investigated outside of the controlled area if they affect isolation within the controlled area."

The data identified in the first four investigations will provide the additional detail necessary to accurately characterize the effects of tectonic processes operating at or near the site and to measure the rates at which they operated during the Quaternary. This information will then be used to provide the projection of future rates necessary to satisfy the performance parameters. Before each data gathering activity begins, the related performance parameters will be evaluated to determine if currently available data are sufficient to satisfy the parameter with the required level of confidence. If the performance parameter has been satisfied, then further studies will not be undertaken (Figure 8.3.1.8-2). If the parameter has not been satisfied, then the feasibility of planned or potential activities will be evaluated to determine if the activities will reasonably increase the level of confidence in the parameters that describe the process or not. If it is not feasible to increase the level of confidence, then no additional studies will be performed and the site performance will be evaluated on the basis of available data. The data gathering activities identified in the analysis and assessment investigations will be undertaken if they are found to provide the additional data or confidence necessary to resolve the performance parameter.

 YMP/CM-0011, Rev. 1

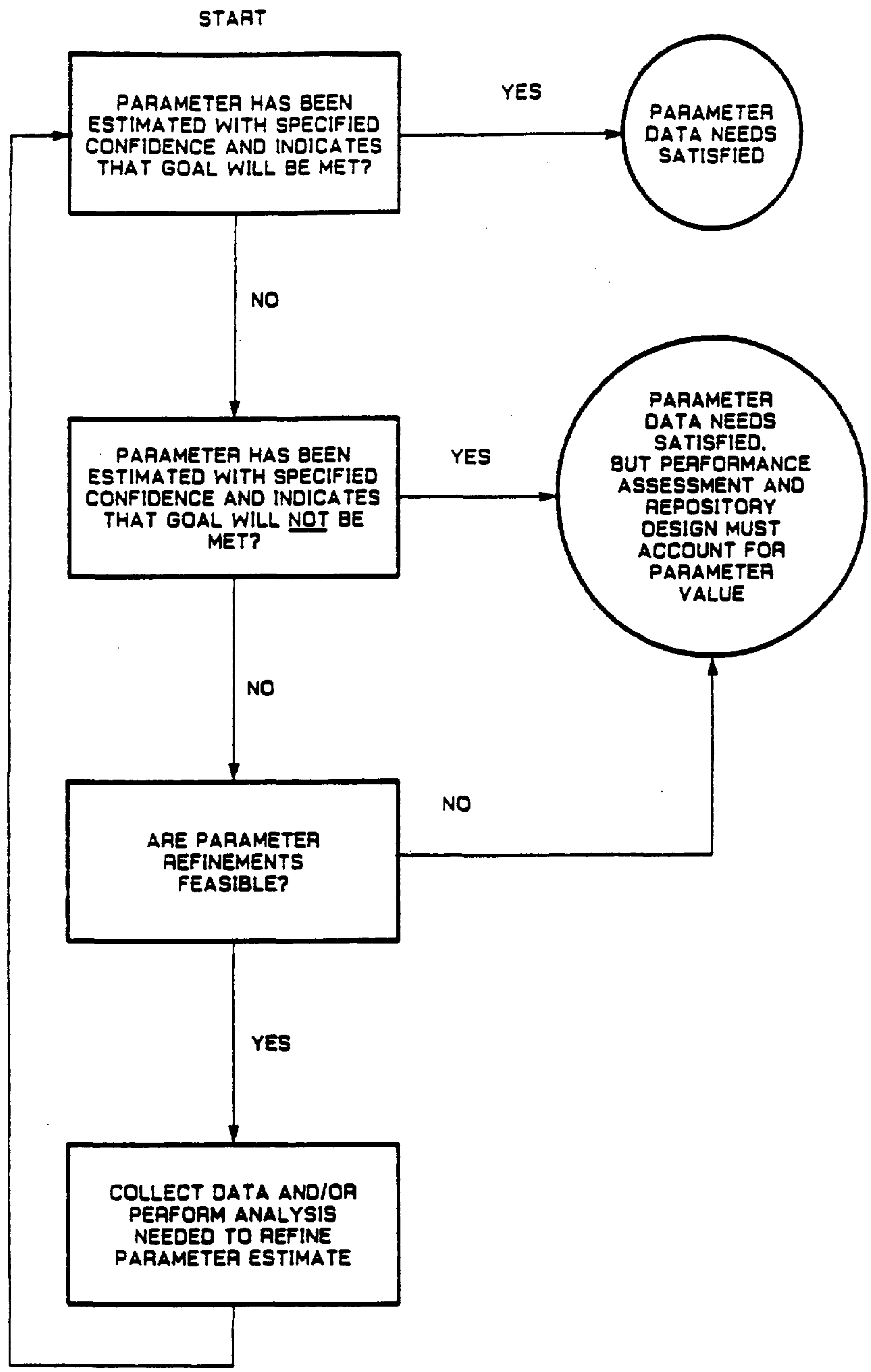

Figure 8.3.1.8-2. Parameter analysis

 YMP/CM-0011, Rev. 1

Various data are used to make the projections of tectonic processes and events into the future, including earthquake observations, fault measurements, geologic mapping, drilling, gravity and magnetic surveys, and other geophysical data. Alternative interpretations of the data will be explored and evaluated with respect to implications for repository performance. These multiple interpretations will be refined to the extent necessary to establish the degree of confidence in the parameter characterization that is specified by the intermediate performance measure goals and performance parameter goals (Tables 8.3.1.8-1 through 8.3.1.8-6).

Five investigations have been identified under the postclosure tectonics program. The first four investigations are related to the six intermediate performance measures in Tables 8.3.1.8-1 through 8.3.1.8-6. The studies and activities connected with these investigations provide the analysis and interpretation necessary to evaluate the site against the performance parameter. These analysis activities also identify the type and level of detail of the data necessary for the resolution of the performance parameter. Because the analysis and interpretation activities for different performance parameters repeatedly call for the same type of data, data gathering activities are grouped separately under a fifth investigation that feeds data as required to the analysis activities associated with the performance and characterization parameters. The interrelationships among the investigations in this program are shown in Figure 8.3.1.8-1. Much of the data required to resolve this issue will be collected by activities associated with other programs. These activities and the data they are required to provide are identified in the investigation descriptions and in their accompanying logic diagrams.

Studies for Investigation 8.3.1.8.1 will provide the analyses to satisfy the performance parameters related to direct releases resulting from volcanic activity. These performance parameters address the initiating event related to the direct intrusion of magma into the repository or potential explosive episodes (hydrovolcanism) that may result from such intrusions which could directly result in releases to the accessible environment. As discussed in Sections 1.3 and 1.5, basaltic volcanism is considered the only credible scenario for igneous intrusion in the controlled area during the postclosure time period. Preliminary calculations of the probability of basaltic volcanism (Section 1.5.1.2.3) indicate that this type of igneous activity may fall into the range of unanticipated events (between 10^{-5} and 10^{-8} annual probability). The performance goal assumes that annual probabilities of occurrence for this type of event are independent of time (Poisson recurrence model) and sets for a goal that this type of event will remain unanticipated with a high level of confidence (10^{-6} annual probability or 99 percent level of confidence that the event will not occur in 10,000 yr). The strategy used in this investigation is to gather more refined data on the age, occurrence, and relation to geologic structure of basaltic volcanism in the site area and to use these data to calculate more detailed probabilistic assessments of the potential for basaltic volcanism intersecting the repository or occurring in the controlled area. The possibility that the occurrence of volcanism is not random over the region, but controlled by geologic structures or other factors will also be considered in the assessment. A second part of the strategy will be an assessment of the effects on a repository of Strombolian or hydrovolcanic eruptions that penetrate the repository.

 YMP/CM-0011, Rev. 1

Investigation 8.3.1.8.2 will provide the analyses to resolve the performance measure related to the failure of waste packages due to tectonic events. Structural deformation resulting from tectonic processes such as faulting (including detachment faulting), uplift, subsidence, or folding could adversely affect the effective lifetime of the waste packages in containing the waste. If deformation was found to be significant enough that the requirements for waste package performance could not be met, the changes required in repository geometry may be such that the repository would no longer be able to accommodate the specified volume of waste (70,000 MTU). The goal (Table 8.3.1.8-2) for the performance measure is derived from the considerations discussed in Section 8.3.4.2. Section 8.3.4.2 sets design goals for rock-induced loads to the waste package. One goal states that less than 0.5% of the waste packages will be breached by anticipated tectonic processes and events that may occur during the first 1,000 yr. This level is designed to be compatible with the overall goal for waste package performance from all modes of failure of less than 5 percent in 300 yr and less than 20 percent in 1,000 yr. (Section 8.3.5.9). The level of confidence for the performance goal was set so that exceedance of the goal would be an unanticipated event.

The first initiating event considered under this intermediate performance measure is the possibility of igneous activity such as the intrusion of a dike or an explosive hydrovolcanic event which could lead to waste package failure (Table 8.3.1.8-2). The number of waste packages affected by a disruptive event such as a hydrovolcanic eruption has not been estimated. The performance parameter goal was set to have the penetration of the repository in 1,000 yr by igneous intrusions be an unanticipated event because waste package disruption scenarios only need to consider anticipated events.

The second initiating event considers the effect of fault displacement on waste package integrity. A value of 5 cm was selected as the performance parameter at which fault displacement becomes significant over a 1,000-yr period because at this value it is estimated that the 7.6-cm air gap around the waste package (Sections 6.2.6.2 and 7.3.1.3) would be partially closed and any additional displacement might result in undesirable reduction of the air gap or possible waste package failure.

The strategy for demonstrating that faulting will not lead to significant waste package failure in 1,000 yr will be to locate and characterize Quaternary faults in and proximal to the controlled area. Because these faults (such as Windy Wash and Paintbrush Canyon (Section 1.3.2.2.2)) have very low slip rates, it is anticipated that the demonstration can be made that the occurrence of 5 cm of displacement in 1,000 yr on even these longer, more significant faults is a very low probability event. The characteristics of the known Quaternary faults in the area will be compared to those of the faults that penetrate the repository block to demonstrate that these smaller faults are much less likely to support a slip rate comparable to the larger faults in the area. A second part of the strategy will be to estimate the number of waste packages a throughgoing fault would intersect in the repository. Using the formula of Link et al. (1982) to estimate the hazard posed by faulting, a randomly oriented fault would intersect about ten waste packages out of an inventory of 18,000 waste packages in a 510 ha repository.

 YMP/CM-0011, Rev. 1

This type of analysis will be used to demonstrate that significant displacement would have to occur on several faults to create failures on more than 0.5 percent of the waste package inventory.

The third initiating event considers the possibility that high rates of folding operating over a 1,000-yr period could result in sufficient waste-emplacement borehole deformation to lead to waste package failure. The performance parameter goal was selected so that, if the goal is met, then bending of waste emplacement boreholes by folding or deformation due to distributed shear of more than 5 cm will not be a credible event (less than 10^{-8} annual probability). The value of 5 cm for the goal for borehole deformation was also selected on the basis of a substantially reduced air gap around the waste package. The strategy for demonstrating compliance with the performance parameter goal will be to demonstrate the absence of significant folding in the repository horizon during the last 10 million yr.

Regional uplift and subsidence are not considered credible processes that could lead to waste package failure. The only conceivable mechanism by which uplift could lead to waste package failure is for extreme uplift rates to occur, which could lead to the exposure of waste packages to erosional processes. This initiating event is considered separately in Investigation 8.3.1.6.3.

Investigation 8.3.1.8.3 addresses the effects tectonic processes may have on hydrologic characteristics in the controlled area. A set of three intermediate performance measures have been identified as the significant hydrologic factors that could be adversely affected by tectonic processes and events. The three intermediate performance measures are alteration of average percolation flux, changes in water-table elevation, and alteration of rock properties along significant potential travel paths (Tables 8.3.1.8-3 to 8.3.1.8-5 and Section 8.3.5.13).

The initiating events identified for the intermediate performance measure that addresses the alteration of average percolation flux are concerned with tectonic processes that could alter flux rates such as (1) the creation of impoundments due to volcanic flows or the formation of fault scarps, (2) the diversion of drainage due to volcanic activity, faulting, uplift, or subsidence, (3) the creation of perched aquifers above the repository due to faulting, (4) the creation of impermeable zones such as the injection of a sill, and (5) a change in dip of the repository rock due to faulting or folding. The basic strategy in addressing this intermediate performance measure will be to measure the Quaternary rate of igneous activity and tectonic deformation due to faulting, folding, uplift, and subsidence in the repository area and demonstrate that these rates are low enough that the performance parameter goal would not be exceeded in a 10,000-yr period.

The intermediate performance measure concerned with changes in water table elevation (Table 8.3.1.8-4) considers the possibility that tectonic events or processes could result in rises in the water table, changes in the potentiometric level of confined aquifers, or the creation of perched aquifers. Such changes could result in the shortening of the ground-water travel pathway in the unsaturated zone and altered radionuclide release rates to the accessible environment. Changes in water-table elevation may also affect hydraulic gradients and the location of discharge points. The distance from the repository horizon to the water table is currently about 250 m. The intermediate performance measure goal was set at a distance of greater than 100 m because it is estimated that the reduction in unsaturated zone release rates would become significant at this point.

The effects of tectonic initiating events considered as possible causes for these changes in the length of the unsaturated zone pathway in Table 8.3.1.8-4 include (1) the creation of barriers to ground-water flow as a result of the formation of igneous dikes, (2) offsets that juxtapose units with differing hydrologic properties due to movement on a fault, (3) the change in elevation of the repository with respect to the water table due to folding or subsidence, and (4) the change in water-table elevation or potentiometric level that might result from strain changes through the faulting cycle.

The intermediate performance measure addressing the alteration of rock properties along significant potential travel paths is concerned with possible changes in rock properties due to tectonic processes that could result in changes in the hydrologic flow properties of the rocks in the controlled area. The effects of initiating events considered are (1) changes in rock properties due to an igneous intrusion, (2) change in rock properties along a fault due to fault movement that results in the creation or destruction of barriers to lateral flow or the creation of conduits of increased vertical flow, and (3) changes in the hydrologic properties of the rock mass due to episodic changes in strain due to faulting or folding (Table 8.3.1.8-5). This intermediate performance measure will also consider the effects that changes in rock properties could have on the movement of gaseous decay products in the unsaturated zone. The strategy for evaluating the magnitude of such changes will be to estimate the rate of tectonic activity in the area and estimate the impact of tectonic processes through hydrologic modeling.

Investigation 8.3.1.8.4 addresses the possibility that geochemical characteristics could be changed in the controlled area as a result of tectonic processes and events. This investigation addresses the concerns of the intermediate performance measure that addresses the possible changes in rock geochemical properties or ground-water chemistry resulting from tectonic processes and events (Table 8.3.1.8-6). The goal for this intermediate performance measure was set so that tectonic processes would not adversely affect the radionuclide release rate due to changes in the distribution coefficient (K_ds) of the rock by more than a factor of 2 in 10,000 yr for those radionuclides with expected travel times of less than 10,000 yr with a high level of confidence. The effects of initiating events that are considered for this intermediate performance measure are (1) alteration of the country rock caused by an igneous intrusion, (2) changes in the mineralogy along a fault zone due to changes in ground water flow paths caused by faulting, (3) changes in travel paths due to faulting, and (4) mineralogic changes caused by fluctuations in water level due to tectonic events. The principal strategy in addressing this intermediate performance measure will be to investigate the nature and extent of mineralogic changes that have occurred in the past around dikes and faults in the area around the site.

YMP/CM-0011, Rev. 1

The studies and activities that provide the data for the analyses of the intermediate performance measures are collected under Investigation 8.3.1.8.5. The data-gathering studies and activities are aggregated separately from the investigations addressing the intermediate performance measures because each of the intermediate performance measures tends to call on the same data to analyze its initiating events. The separation of data-analysis activities from data-gathering activities by placing them in different investigations is believed to improve and clarify the logic flow in the investigations related to the analysis of the intermediate performance measures and to identify more clearly the nature and level of detail of data that must be collected. The activities collected under Investigation 8.3.1.8.5 for this tectonics program are few because most of the data necessary for the resolving of the intermediate performance measures are supplied by activities in other programs. The data that are being supplied by activities in other programs are identified in Tables 8.3.1.8-1 to 8.3.1.8-6 and in the investigation descriptions.

Alternative Conceptual Models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses that are also consistent with available data and which may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) activities or studies designed to discriminate between alternative hypotheses or to reduce uncertainty. Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate. Tables 8.3.1.8-7 and 8.3.1.8-8 summarize the current understanding in the modeling of local and regional tectonics, respectively, that is being performed as part of the preclosure Tectonics Site Program.

To help ensure comprehensiveness of the hypotheses considered in Tables 8.3.1.8-7 and 8.3.1.8-8, hypotheses for postclosure tectonics modeling have been divided into elements or components that describe the physical domain defined by the model, the driving forces/processes that influence the behavior of the model, the boundary conditions that affect the model, the system geometry of the physical components of the model, and a series of elements that describe the system response dynamics of the model in response to its driving forces, boundary conditions and system geometry. These elements are listed in column one.

The second column of the table lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Tables 8.3.1.8-7 and 8.3.1.8-8 provides a judged level of uncertainty designated "high," "moderate," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 1 of 9)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or *performance measure*	Significance of alternative hypothesis: Sensitivity of parameter or *performance measure* to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Physical domain	Area extending 25 km from boundary of controlled area	Low-medium--events or processes outside preferred domain unlikely to affect facility design or waste isolation in the controlled area	Area extending >25 km from boundary of controlled area	Annual probability of volcanic eruption that penetrates the repository	High High	Medium--area of interest is the controlled area, but larger area will need to be considered to calculate probabilities	Medium--need to determine distance that tectonic events could influence performance in controlled area*	8.3.1.8.3.1, 8.3.1.8.3.2, 8.3.1.8.3.3, 8.3.1.8.1.1.4, and 8.3.1.17.3.5.1
				Radionuclide transport time through the unsaturated zone	High	Medium--uncertainties exist about distance at which tectonic events could influence controlled area hydrology	Same as above	Same as above
Driving forces/ processes	Mechanically driven through plate interaction of local and regional structures	Low--geophysical, geochemical, and heat flow data support preferred hypothesis	Thermally driven through mantle convection cell	Thermal effects of igneous intrusions and volcanism on water table levels	Medium	Medium--mantle convection could provide mechanism for producing changes in heat flow	Low--existing data generally sufficient to differentiate	8.3.1.17.4.12.2
			Combination of thermal and mechanical driving forces	Annual probability of volcanic eruption that penetrates the repository	High	Low-probability estimates not greatly dependent on driving forces	Same as above	8.3.1.17.4.12.2
				Radionuclide transport time through unsaturated zone	High	Medium--quantitative link between water table elevation and driving forces not determined	Same as above	8.3.1.17.4.12.2

YMP/CM-0011, Rev. 1

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 2 of 9)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Boundary conditions	Horizontal strains must be consistent with Quaternary Pacific-North American plate movement history and regional controls that affect the distribution of strain in the region surrounding the domain Vertical strains--no boundary conditions specified	Low--no alternatives available	(No alternative but need to reduce uncertainty)	Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	High--local strain rates will affect faulting probabilities and size of events	Medium--strain rates in the local domain will affect faulting rates and probabilities	8.3.1.17.4.12.2
System geometry	Brittle crust--15 km thick, underlain by ductile lithosphere Brittle crust is cut by inactive and active faults of various orientations Ductile crust and underlying mantle are relatively passive elements	Low--geophysical and heat flow data provide some support for preferred hypotheses	Convection cell in mantle introduces heat and strain into brittle crust and results in crustal thinning (Death Valley-Pancake Range zone is incipient rift)	Thermal effects of igneous intrusions and volcanism on water table levels	Medium	Medium--mantle convection could provide mechanism for producing changes in heat flow	Medium--existing data nearly sufficient to differentiate	8.3.1.17.4.12.2 and 8.3.1.17.4.3.1
				Annual probability of volcanic eruption that penetrates the repository	High	Low--probability estimates not greatly dependent on system geometry	Same as above	Same as above

YMP/CM-0011, Rev. 1

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 3 of 9)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
System geometry (continued)				Radionuclide transport time through unsaturated zone	High	Medium--proximity of site to postulated incipient rift could affect rate of fracture dilation and strain causing changes in flux and water table elevation	Same as above	Same as above
SYSTEM RESPONSE/DYNAMICS								
Faulting geometry and mechanisms	No hypothesis selected (one or more alternative hypotheses may apply to domain)	High--no data on subsurface geometry of local faults. No measurements of strike-slip component of movement	Faults in the domain are Planar-rotational faults (north-trending faults in domain are planar normal faults and extend to base of brittle crust. Northeast trending strike-slip faults are shallow features that mark the boundaries of detached blocks.)	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	High--local fault geometries could significantly affect fault slip estimates	High	8.3.1.17.4.7.1, 8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, 8.3.1.17.4.2.2, 8.3.1.17.4.1.2, and 8.3.1.4.2.3.1

YMP/CM-0011, Rev. 1

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 4 of 9)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
			SYSTEM RESPONSE/DYNAMICS (continued)					
Faulting geometry and mechanisms (continued)			Detachment faults (north-trending faults in domain are listric, merging with west-dipping low-angle extensional fault at or below base of Tertiary)	Same as above	Medium to high	Same as above	High	Same as above
			Part of Walker Lane system (faults in domain are part of or related to an en echelon system of NW- and NE-trending, right- and left-lateral fault strands that have a significant strike-slip component of movement. Faults are high angle and extend to base of brittle crust.)	Same as above	Medium to high	Same as above	High	Same as above

YMP/CM-0011, Rev. 1

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 5 of 9)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
			SYSTEM RESPONSE/DYNAMICS					
Faulting geometry and mechanisms (continued)			Related to a strike-slip fault concealed beneath a detached upper fault plate	Same as above	Medium to high	Same as above	High	Same as above
			Normal faults resulting from incipient rifting along the Death Valley-Pancake Range zone due to thermally driven processes	Same as above	Medium to high	Same as above	High	Same as above
Fault activity	Some faults in and near the controlled area have been active in Quaternary time	Low--trenching data show Quaternary activity	None identified	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	High--presence of Quaternary faulting increases design and P.A. concerns related to faulting	None	None
Faulting rates	Slip rates on faults near the controlled area are low (<0.01 mm/yr) with long recurrence intervals (>10,000 yr)	Medium--no direct measurements of strike-slip component	Slip rates are higher because of an unrecognized component of strike-slip faulting	Probability of faulting with displacements over 5 cm in repository and and at location of facilities important to safety	Medium to high	High--slip rates important in estimating probability of various sized faulting events	High	8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, and 8.3.1.17.4.3.2

YMP/CM-0011, Rev. 1

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 6 of 9)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			SYSTEM RESPONSE/DYNAMICS (continued)					
Fault rupture pattern	No hypothesis selected	High--current data insufficient to choose among possible alternatives	Individual faulting events are confined to single fault strands on the north-trending faults around the site	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	High--nature of single event displacements significant in estimating earthquake magnitude and probability of faulting	High	8.3.1.17.4.6.2, 8.3.1.17.4.4, 8.3.1.17.4.5, and 8.3.1.17.4.3.2
			Movement occurs on several parallel north-trending faults during a single faulting event	Same as above	Medium to high	Same as above	High	Same as above
			The north-trending faults are secondary faults or splays off of a larger fault (major strike-slip or detachment feature) and move at the same time movement occurs on the larger fault	Same as above	Medium to high	Same as above	High	Same as above
Type of volcanism	Quaternary volcanic events in area are characterized by Strombolian eruptions with a possible initial phase of hydrovolcanic activity	Low--only type of observed activity in domain during Quaternary	None identified	Effects of volcanic eruption penetrating repository, including area of repository disrupted	Medium	None--no alternative identified	None	None

YMP/CM-0011, Rev. 1

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 7 of 9)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
				SYSTEM RESPONSE/DYNAMICS (continued)				
Controls on volcanism	No hypothesis selected	Medium to high--the probability of volcanism is currently modeled as a Poissonian process. But individual events in the domain appear to be localized along faults or other linear structural features	The occurrence of volcanism is generally randomly distributed in the domain	Annual probability of volcanic eruption that penetrates the repository	High	Medium--if faults control location on a local scale, they could affect probability estimates for site disruption. However, if probability were higher at certain locations (e.g., Lathrop Wells cone), then probabilities at repository may be lowered	Medium	8.3.1.8.1.1.2, 8.3.1.8.5.1.4, 8.3.1.17.4.6.2, 8.3.1.17.4.12.1, 8.3.1.17.4.7.2, and 8.3.1.17.4.7.3
			Structural features, such as faults or fault intersections, may control the location of volcanic vents	Same as above	High	Same as above	Medium	Same as above
			The occurrence of volcanic events is related to the occurrence of faulting events (e.g., presence of ash in fault zones)	Same as above	High	Same as above	Medium	Same as above

YMP/CM-0011, Rev. 1

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 8 of 9)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				SYSTEM RESPONSE/DYNAMICS (continued)				
Rate of volcanism	Rate of volcanism and magma generation has been declining in the domain in Quaternary and late Tertiary time	Medium--better dating of volcanic events needed	The rate of volcanism and magma generation has been constant or increasing during the Quaternary and late Tertiary	Annual probability of volcanic eruption that penetrates the repository	High	High--rate important in calculating probability	High	8.3.1.8.1.1.1 and 8.3.1.8.5.1.2
Effects on ground-water flow	Volcanic or igneous events will not significantly affect unsaturated zone or ground water flow over the next 10,000 yr	Low--feeder dikes too narrow and short lived to alter heat flow. Igneous events large enough to alter heat flow require more than 10,000 yr to develop. Event probability very low	Volcanic and igneous events may produce thermal anomalies or physical barriers that alter ground water flow, moisture flux in the unsaturated zone, and the elevation of the water table	Thermal effects of igneous intrusions and volcanism on water-table elevations	Medium	Medium--if event occurred that had thermal effects great enough to significantly alter water table elevations, then repository performance could be affected	Low--igneous events that could cause significant changes unlikely and take >10,000 years to develop	8.3.1.8.3.2
				Radionuclide transport time through unsaturated zone	High	Same as above	Same as above	8.3.1.8.3.2
	Tectonic events will not cause significant changes in the moisture flux rates through the saturated zone and unsaturated zone during the next 10,000 yr	Medium--amount of future change not considered significant because potential surface and subsurfce changes not great enough to significantly influence flux rates	Episodic faulting, volcanism, or other tectonic events may cause corresponding changes in surface and subsurface features that affect moisture flux rates through the saturated or unsaturated zone and could affect performance	Radionculde transport time through unsaturated zone, given fixed unsaturated zone thickness, rock hydrologic properties and geochemical properties	High	High--basis for calculating release rates could be altered if event probability and ties, amount of flux change were significant	Medium--signficant changes unlikely since surface or subsurface effects due to faulting or volcanism are not likely to be great enough to influence flux rates	8.3.1.8.3.1

Table 8.3.1.8-7. Current representation and alternative hypotheses for the local model for the preclosure tectonics program (page 9 of 9)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	Studies or activities to reduce uncertainty
				SYSTEM RESPONSE/DYNAMICS (continued)				
Effects on ground-water flow *(continued)*	**Tectonic events will not cause significant changes in water table elevation during the next 10,000 yr**	**Medium--more data needed on possible indicators of past fluctuations. More analysis needed on size of possible effects**	**Episodic faulting and strain release or other tectonic events may cause periodic fluctuations in water table elevations that are significant to repository performance**	Radionuclide transport time through unsaturated zone, given fixed unsaturated zone rock hydrologic properties, and geochemical properties	High	High--basis for calculating release rates could be altered if event probability and amount of water table change were significant	High--some interpretations of existing data allow alternative	8.3.1.8.3.2
	Tectonic events will not cause significant changes in rock matrix or fracture hydrologic properties during the next 10,000 yr	**Medium--if fracture dilation and fracture filling with carbonate, silica or manganese oxide are significant and rapid processes, then changes in flux rates and travel times through the unsaturated zone could occur**	Episodic faulting and strain release or other tectonic events may cause changes in the fracture hydrologic properties that are significant to repository performance	Radionuclide transport time through unsaturated zone, given fixed unsaturated zone thickness, flux rates, and geochemical properties	High	High--basis for calculating release rates could be altered if event probability and degree of hydrologic property change were signficant	Medium--data needed on rates of fracture dilation and mineral infilling in fractures	8.3.1.8.3.3
Chemical properties along flow paths	Rock geochemical properties are not affected by tectonic processes during the next 10,000 yr	Low--rate of rock geochemical change too low to produce significant change in 10,000 yr	The hydrologic changes caused by tectonic events may significantly alter rock geochemical properties	Radionuclide transport time through unsaturated zone, given fixed unsaturated zone thickness, rock hydrologic properties, and flux rates	High	Medium--basis for calculating release rates could be altered if event probability and amount of geochemical change were significant. However, geochemistry not a primary barrier	Low--rate of change too low to be significant in 10,000 yr	8.3.1.8.4.1

*Controlled area is the actual area chosen according to the 10 CFR 60.2 definition.

YMP/CM-0011, Rev. 1

Table 8.3.1.8-8. Current representation and alternative hypotheses for the regional model for the postclosure tectonics program (page 1 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
Physical domain	Brittle crust, southern Great Basin	Low--regional processes outside model domain unlikely to affect site design or performance	NA*	NA	NA	NA	Low--processes outside domain unlikely to affect design or performance	8.3.1.17.4.1..2
Driving forces/ processes	Mechanical plate interaction	Low--geophysical, geochemical, and heat flow data support current representation	Mantle convection cell	Thermal effects of igneous intrusions and volcanism on water table levels	Medium	Medium--mantle convection could provide mechanism for producing changes in heat flow	Low--existing data generally sufficient to differentiate	8.3.1.17.4.12.2
				Annual probability of volcanic eruption that penetrates the repository	High	Low--probability estimates not greatly dependent on regional model	Low--existing data generally sufficient to differentiate	8.3.1.17.4.1.2.2
Boundary conditions	Horizontal strains must be consistent with Quaternary Pacific-North American plate movement history Vertical strains-no boundary condition specified	Low--no alternatives available	None identified	Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Low-medium--regional strain rates influence faulting probabilities but local variations more significant	Low-existing data sufficient and increased accuracy probably not reasonably achievable	8.3.1.17.4.12.2
System geometry	Brittle crust--15 km thick, underlain by ductile lithosphere Brittle crust is cut by inactive	Low--geophysical and heat flow data provide support for current representation	Convection cell in mantle introduces heat and strain into brittle crust and results in crustal thinning (Death	Thermal effects of igneous intrusions or volcanism on water table levels	Medium	Medium--mantle convection could provide mechanism for producing changes in heat flow	Medium--existing data nearly sufficient to differentiate	8.3.1.17.4.12.2 and 8.3.1.17.4.1.1

YMP/CM-0011, Rev. 1

Table 8.3.1.8-8. Current representation and alternative hypotheses for the regional model for the postclosure tectonics program (page 2 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
System geometry (continued)	and active faults of various orientations Ductile crust and underlying mantle are relatively passive elements		Valley-Pancake Range zone is incipient rift)	Annual probability of volcanic eruption that penetrates the repository	High	Low--probability estimates not greatly dependent on regional model	Same as above	Same as above
				Radionuclide transport time through unsaturated zone	High	Medium--proximity of Yucca Mountain to postulated incipient rift could affect strain rate and fracture dilation, changing water table elevation and rock hydrologic properties in unsaturated zone	Same as above	Same as above
SYSTEM RESPONSE/DYNAMICS								
Regional faulting mechanisms	None selected	High--data do not support a single hypothesis; geologic and seismic reflection data indicate extensional model with detachments; data from historical earthquakes indicate planar normal faults with a strike-slip component and high-angle, deep-focus strike-slip faults	Regional extension dominates; any strike-slip motion is the result of extensional processes (e.g., detachment faulting with bounding shallow strike-slip faults)	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Medium--regional dynamics affect faulting estimates but local faulting relationships more significant; regional models may allow a variety of local fault geometries	Medium--more important; reduce uncertainties about nature of local faulting for design and performance than to resolve faulting mechanisms throughout the domain	8.3.1.17.4.12.2, 8.3.1.17.4.3.1, and 8.3.1.17.4.3.2

YMP/CM-0011, Rev. 1

Table 8.3.1.8-8. Current representation and alternative hypotheses for the regional model for the postclosure tectonics program (page 3 of 6)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			SYSTEM RESPONSE/DYNAMICS (continued)					
Regional faulting mechanisms (continued)			Strike-slip faulting is a primary feature that controls the Quaternary tectonics of at least part of the domain; a part of Pacific-North American right-lateral transform movement is communicated inland to Death Valley-Furnace Creek faults and Walker Lane. Faulting results from right-lateral movement on en echelon strands of the Walker Lane, and dip-slip movement on north- to northeast trending normal faults connecting these strands.	Same as above	Same as above	Same as above	Same as above	Same as above

YMP/CM-0011, Rev. 1

Table 8.3.1.8-8. Current representation and alternative hypotheses for the regional model for the postclosure tectonics program (page 4 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
			SYSTEM RESPONSE/DYNAMICS (continued)					
Frequency and distribution of events	None selected	High--frequency and distribution of significant events across domain not well known	Volcanism and faulting in the domain are episodic; probability of events may be modeled as Poissonian	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Low-medium--variability of event occurrence probably great enough that Poissonian assumptions are sufficient even if processes are cyclic; cyclic hypotheses most significant if it is assumed site is in quiescent zone	Low-medium--hazard analyses will generally assume site is in active part of a cycle, and use the highest measured rate for a definable part of the Quaternary	8.3.1.17.4.12.2, 8.3.1.17.4.3.2, 8.3.1.8.5.1.5, and 8.3.1.8.5.1.2
			Volcanism and faulting in the domain are cyclic; zones in the domain may be active for a period and then quiescent as activity migrates to another zone	Annual probability of volcanic eruption that penetrates the repository	High	Same as above	Same as above	Same as above
				Radionuclide transport time through unsaturated zone	High	Low-medium--changes in rate of events could cause changes in strain rate and fracture dilation that could change water table elevations and rock hydrologic properties	Same as above	Same as above

YMP/CM-0011, Rev. 1

Table 8.3.1.8-8. Current representation and alternative hypotheses for the regional model for the postclosure tectonics program (page 5 of 6)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
SYSTEM RESPONSE/DYNAMICS (continued)								
Extension rate and distribution	Average east-west extension rate across domain is about 1 cm per yr in the Quaternary, but extension is concentrated in local zones	Medium--degree of localization of extension not well known	Average east-west extension rate across domain is about 1 cm per yr in the Quaternary, and extension is evenly distributed across Great Basin	Probability of faulting with displacement over 5 cm in repository and at location of facilities important to safety	Medium to high	Low-medium--regional strain rates influence faulting probabilities but local variations more significant	Low--existing data on regional rates sufficient and increased accuracy probably not reasonably achievable; local model will assess local rates	8.3.1.17.4.12.2
Nature of volcanism	Volcanic features are fed by thin, short-lived dikes from deep mantle sources in an extensional environment; faults may provide preferred pathways for occurrence	Low-medium--relatively low heat flow, basalt geochemistry, and low-volume, widely distributed nature of volcanism support representation	Incipient rift hypothesis; Quaternary volcanic rocks originate through melting along rift zone coincident with Death Valley-Pancake Range zone	Thermal effects of igneous intrusions and volcanism on water-table levels	Medium	Medium--incipient rift could provide mechanism for producing changes in heat flow	Low--only minor amount of confirmatory data needed	8.3.1.17.4.12.2, 8.3.1.17.4.3.1, 8.3.1.17.4.3.2, 8.3.1.8.1.1.2, 8.3.1.8.1.1.3, and 8.3.1.8.5.1.5
				Annual probability of volcanic eruption that penetrates the repository	High	Low--probability estimates not greatly dependent on regional model	Same as above	Same as above
			Leaky transform hypothesis; Quaternary volcanic rocks leak up along pull-aparts connecting en echelon segments of wrench fault system	Same as above	Same as above	Same as above	Same as above	Same as above

YMP/CM-0011, Rev. 1

Table 8.3.1.8-8. Current representation and alternative hypotheses for the regional model for the postclosure tectonics program (page 6 of 6)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
SYSTEM RESPONSE/DYNAMICS (continued)								
Distribution of volcanism	The Death Valley-Pancake Range volcanic zone is a significant feature controlling the occurrence of volcanism in the domain	Medium--with wide distribution of volcanism in domain, alignments or trends are always subjective	Other volcanic lineaments or patterns can be drawn that connect the volcanic fields of the region (e.g., volcanic lineament pattern of Smith and Luedke, 1984)	Annual probability of volcanic eruption that penetrates the repository	High	Low--probability estimates not greatly dependent on lineament model because area used in calculation is smaller than width of lineament	Low--difficult to reduce uncertainty; result does not control probability calculation	8.3.1.8.5.1.5

*NA = not applicable.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Column six gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of the performance parameters in column five to the selection of hypotheses in columns two and four for that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The final column identifies the characterization studies or activities that will discriminate between alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

Interrelationships of postclosure tectonics investigations

The interrelationship among issues, programs, investigations, favorable conditions, and potentially adverse conditions is shown in Tables 8.3.1.8-1 to 8.3.1.8-6, Figure 8.3.1.8-1, and in the logic diagrams accompanying the investigation descriptions.

The assessment of potential igneous activity in Investigation 8.3.1.8.1 will require an improved data base on the nature and rate of past activity in order to prepare a probabilistic calculation on the possibility of future igneous activity. The assessment will also include a consideration of possible structural controls on igneous activity and an evaluation of the possibility of magma sources underlying the site. A second study will evaluate the disruptive effects of Strombolian and hydrovolcanic eruptions should they occur at the repository.

Investigation 8.3.1.8.2 is composed of one study that will assess the likelihood and effects of each of the four initiating events on waste package integrity. Data for the assessment of waste package rupture due to igneous activity will come from Investigation 8.3.1.8.1. The assessment of waste package rupture due to faulting will use (1) data on the number of waste packages that could be intersected by a throughgoing fault and (2) data on

YMP/CM-0011, Rev. 1

the slip rate, recurrence interval and displacement of individual events, length, sense of movement, and width of zone of Quaternary deformation for the north-trending normal faults found in and near the controlled area from Investigations 8.3.1.17.4 and 8.3.1.4.2.

The performance parameter goals for folding indicate levels of significance that are so high in relation to natural rates that existing data and data from Investigation 8.3.1.4.2 are sufficient to make an assessment. Only minor studies to gather additional data on folding in the region are planned.

Investigation 8.3.1.8.3 will use data on the nature and rates of igneous activity, faulting, folding, uplift, and subsidence collected by the investigations listed in Tables 8.3.1.8-3 to 8.3.1.8-6 to perform an assessment of the amount of change that could be expected over the next 10,000 yr for the three hydrologic concerns discussed in the intermediate performance measures. In each instance, this assessment will have two parts and will be an iterative process. The first part will be an estimation of the probability of occurrence of tectonic processes that could affect hydrologic properties and a characterization of the type of changes that could occur and the volume of rock affected. The second part of the assessment will be hydrologic modeling of potentially significant changes in model parameters due to tectonic processes to determine the expected amount of change in the hydrologic intermediate performance measures. This investigation therefore supplies the interface point needed for the integration of data between the geohydrology and postclosure tectonics program staff.

Investigation 8.3.1.8.4 will provide the analysis necessary to address the intermediate performance measure concerning changes in rock geochemical properties resulting from tectonic processes. The data necessary to perform the analysis will be supplied by activities in Investigations 8.3.1.17.4, 8.3.1.2.2, 8.3.1.2.3, and 8.3.1.4.2 (Table 8.3.1.8-6). The analysis will use data on mineral changes around dikes and faults in the area surrounding the site to project the amount of expected change in the next 10,000 yr. Other studies and activities will evaluate the probability of the initiating events and evaluate the potential mineral changes that could result from the occurrence of those events.

Investigation 8.3.1.8.5 will house the data-gathering studies and activities that are called for by the analysis activities. The studies contained in this investigation are related to the probability and effects of volcanic events and folding in region surrounding the repository. All other required data will be collected by investigations related to other programs.

Schedule information for Site Program 8.3.1.8 (postclosure tectonics) is presented in Section 8.3.1.8.6.

YMP/CM-0011, Rev. 1

8.3.1.8.1 Investigation: Studies to provide information required on direct releases resulting from volcanic activity

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the SCP data chapters and support documents provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.5.1	Volcanism
1.8.1.3.1,	Significant results (structural geology and tectonics), 1.8.1.3.2 discussion of significant results
1.8.1.5.1	Significant results (long-term regional stability)

Parameters

The following performance parameters (Table 8.3.1.8-1 and Section 8.3.5.13) will be measured or calculated as a result of the studies planned to satisfy this investigation:

1. Annual probability of a volcanic eruption that penetrates the repository.

2. Effects of a volcanic eruption penetrating the repository including area of repository disrupted and confidence bounds of estimate.

Purpose and objectives of the investigation

The purpose of this investigation is to provide the data required for an assessment of repository performance with respect to the possibility of direct releases resulting from volcanic events. The two performance parameters for this investigation have been identified by Issue 1.1 (Section 8.3.5.13 and Table 8.3.1.8-1). The evaluation of these two performance parameters is the subject of the two studies in this investigation (Figure 8.3.1.8-3). The two studies in this investigation will also supply the data required by Issue 1.8 (Section 8.3.5.17) to address the favorable and potentially adverse conditions of 10 CFR 60.122 listed in Table 8.3.1.8-1. Investigations 8.3.1.8.2 through 8.3.1.8.4 will also use the results of this investigation in their analyses of other intermediate performance measures.

YMP/CM-0011, Rev. 1

Technical rationale for the investigation

This investigation considers the single initiating event of a volcanic eruption penetrating the repository and resulting in direct releases to the atmosphere or land surface. As discussed in Sections 1.3.2.1 and 1.5.1, basaltic volcanism is considered to be the only credible type of activity to have a possibility of occurrence in the next 10,000 yr. Releases could occur as the result of a dike that feeds a volcanic vent intersecting the repository and entraining some waste. The waste could be ejected in a Strombolian eruption as pyroclasts and incorporated in an ash fall and cinder cone. As an alternative, if the ascending magma intersects a body of ground water, a hydrovolcanic explosion could occur at depths great enough to cause disruption of the repository. This hydrovolcanic type of eruption might result in the ejection of waste fragments as a result of the explosions from a tuff-ring or maar volcano. Hydrovolcanic eruptions may change in time to a Strombolian eruption resulting in the formation of a cinder cone.

Study 8.3.1.8.1.1 correlates to the first performance parameter listed in the previous section. This study will analyze the data collected by the program and estimate the probability of a volcanic event intersecting the repository. The logic flow for the four activities contained in the study is shown in Figure 8.3.1.8-3. The probability calculations will be refined versions of the estimates presented in Section 1.5.1.2 and will assume that the occurrence of basaltic volcanism in the region is independent of time and location (Poisson recurrence model). It is possible that the occurrence of volcanism is not actually a completely random process but that the location of volcanic vents and the probability of their occurrence can be affected by regional structural trends, local structures, and even topography. The influence of regional structural trends was factored into the area ratio (area of repository/area to which volcanic event rate applies) of the probability calculations (Section 1.5.1.2.3). The possibility of local structural controls will be assessed by evaluating the location of late Cenozoic basaltic vents in relation to known structures and aeromagnetic, gravity, and seismic data. The results of these analyses will be incorporated into the final volcanic probability assessment as appropriate. Geophysical evidence will also be evaluated for indications that magma bodies may be present in the vicinity of the site. The evidence for the presence or absence of magma bodies will also be factored into the probabilistic estimates.

Study 8.3.1.8.1.2 correlates with the second performance parameter listed in the previous section and will consider the effects a basaltic eruption could have on repository performance if such an event should occur. Two types of eruptions have been found to be characteristic of past activity in the region: Strombolian and hydrovolcanic (Section 1.3.2.1.2 and 1.5.1.2). Sufficient data have been collected on the effects of Strombolian eruptions for an analysis of repository performance so no additional field data gathering is planned. Additional data are needed on the effects of and controls of hydrovolcanic eruptions. This study will integrate current and newly acquired data into a format that can be used for repository performance assessment.

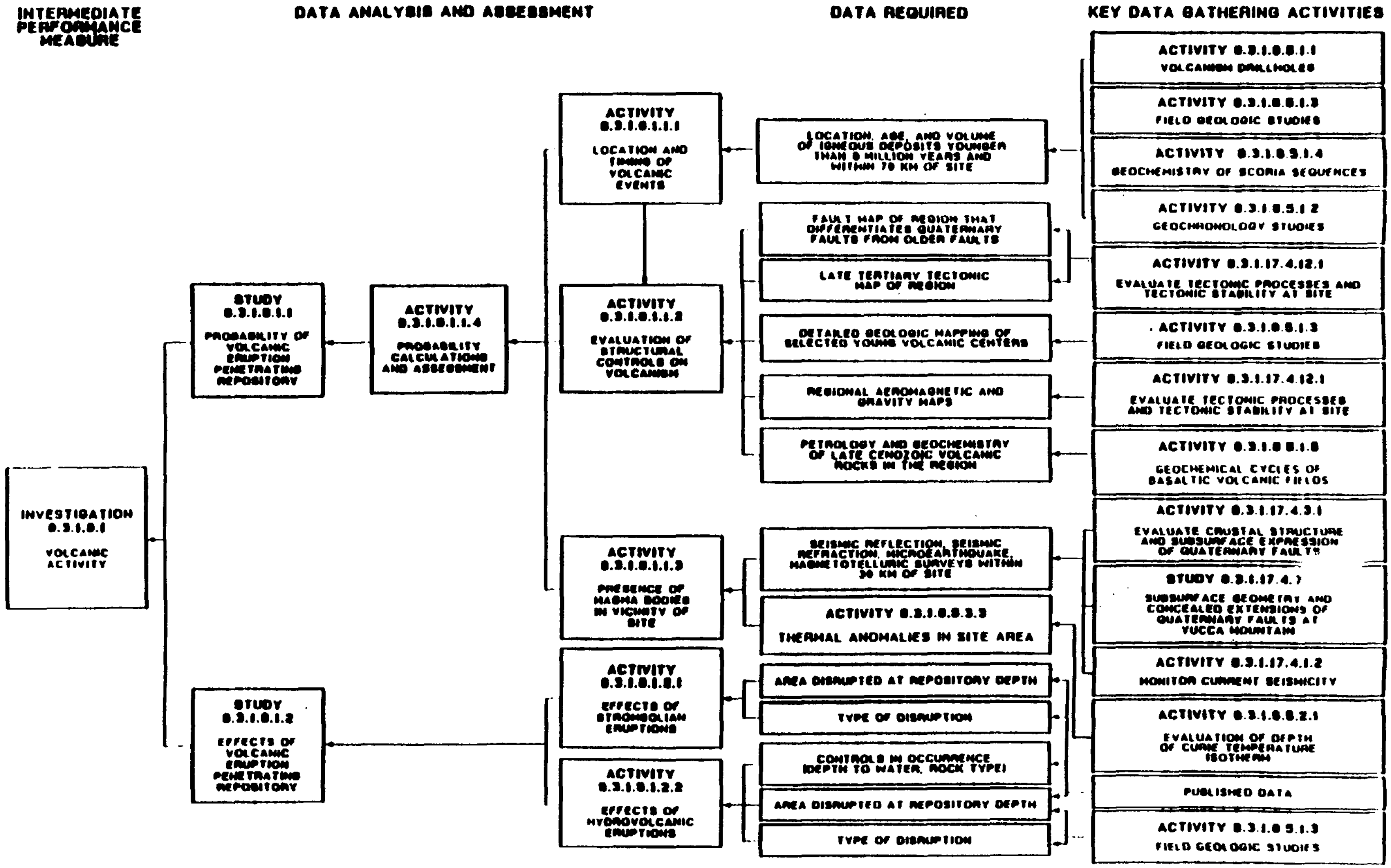

Figure 8.3.1.8-3. Logic diagram for Investigation 8.3.1.8.1 (volcanic activity)

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

8.3.1.8.1.1 Study: Probability of a volcanic eruption penetrating the repository

The purpose of this study is to assess the probability of future volcanic activity with respect to siting of a repository for storage of high-level radioactive waste at Yucca Mountain. The probability assessment will be completed through a combination of studies and the results of these studies will be compared for consistency (Crowe et al., 1983a). The probability that volcanic activity could intersect the repository will be estimated from the analysis of a variety of data on the location and timing of volcanic events during the last 4 to 8 million yr, magma generation rates, structural controls on the location of volcanic activity, and geophysical data on the locations of potential magma bodies that could be the sources for future events.

8.3.1.8.1.1.1 Activity: Location and timing of volcanic events

Objectives

The objective of this activity is to synthesize the data collected by other activities (Figure 8.3.1.8-3) on the dating, location, and volume of late Cenozoic volcanic events in the region surrounding the site. These additional data will be used by Activity 8.3.1.8.1.1.4 to produce revised probability estimates of the disruption of the repository by volcanic events.

Parameters

The parameters for this activity are the location, age, and volume of volcanic deposits within 70km of the site and younger than 8 million yr.

Description

Data from the literature, previously completed studies and the planned studies in Investigation 8.3.1.8.5 will be compiled and synthesized to produce maps showing the age, location of vents, and distribution and volume of lava and pyroclastic deposits erupted from the vents. The resulting maps will be interpreted to determine eruptive patterns of volcanic activity during the last 8 million yr. Magma volumes will be calculated as dense rock equivalents versus time and vent counts will be calculated to provide data for forecasting future rates of volcanic activity for probability calculations (Crowe et al., 1982). The data and analyses produced by this activity will be used to calculate the probability of volcanic eruptions (Activity 8.3.1.8.1.1.4) and in the evaluation of possible structural controls on volcanic activity (Activity 8.3.1.8.1.1.2).

 YMP/CM-0011, Rev. 1

8.3.1.8.1.1.2 Activity: Evaluation of the structural controls of basaltic volcanic activity

Objectives

The time-space distribution of basaltic volcanic activity may not be completely random across the site area. This activity will investigate the time-space patterns of past volcanic activity in the Yucca Mountain region and the possible structural controls of volcanic centers and potential future volcanic centers at and adjacent to Yucca Mountain. Statistical evaluation of geophysical data will be undertaken to assess the significance of possible local and regional structures on the area ratio of the probability calculation.

Parameters

The data gathered from other activities that are needed for this work are

1. A tectonic model for the Yucca Mountain region (including fault map of the region that differentiates Quaternary faults from older faults and a late Cenozoic tectonic map of the region; Activity 8.3.1.17.4.12.2: evaluate tectonic models).

2. Aeromagnetic, gravity and seismic data for the Yucca Mountain region.

3. Field mapping of young volcanic centers (< 4 million yr old) in the Yucca Mountain region (Activity 8.3.1.8.5.1.3: field geologic studies).

4. Geochronology measurements for young volcanic rocks (<4.0 million yr old; Activity 8.3.1.8.5.1.2: geochronology studies).

5. Petrologic cycles of volcanic rocks in the Yucca Mountain area (<8.0 million yr old) and from other basaltic volcanic fields of the southern Great Basin (Activity 8.3.1.8.5.1.5: petrologic cycles of basaltic volcanic fields).

The data to be gathered by this activity are

1. Cluster analysis of aeromagnetic data.

Description

The time-space patterns of basaltic volcanic activity will be examined for the Yucca Mountain region. Crowe et al. (1983b, 1986) divided the basalts of the Yucca Mountain region into three episodes. The time-space patterns of each episode of activity will be examined with an emphasis on the youngest episode (<4 million years old). The objective of this activity will be to determine if there is a random or patterned distribution through space and time of sites of basaltic volcanic activity. Geologic and geophysical

YMP/CM-0011, Rev. 1

evidence concerning the distribution of surface and subsurface volcanic activity will be included in this examination and the results of these studies will be integrated with the tectonic models developed in Investigation 8.3.1.17.4.

Three important lines of evidence will be evaluated for the volcanic/tectonic structural studies. First, plots of magma volume versus time for volcanic activity of the Yucca Mountain area show declining rates of magma production through time. This interpretation must be tested using refined data for the age of volcanic activity from Activity 8.3.1.8.5.1.2 (geochronology studies), and for the volume of volcanic activity from Activity 8.3.1.8.5.1.3 (field geologic studies). Second, geochemistry studies of the Crater Flat area (Vaniman et al., 1982; Crowe et al., 1983b, 1986) show distinct petrologic trends through time. The oldest basalts of the Crater Flat area are hypersthene-normative hawaiite and the youngest basalts are nepheline-normative hawaiite or basanite. These same trends have been observed, but not documented in detail, at other basaltic volcanic fields of the Basin and Range province (Lunar Crater and Cima volcanic fields). Further work is required to determine if the transition to nepheline-normative basalt is indicative of the waning or termination of volcanic activity at a field. Third, the transition from hypersthene- to nepheline-normative basalt in the Crater Flat area is accompanied by a decrease in the volume of eruptive products and an increase in the frequency of eruptions. This observation, if valid, may affect assumptions used for forecasting future rates of volcanic activity. It must be tested by studying time variations in the petrology and volume of basaltic activity at other volcanic fields in the Yucca Mountain vicinity.

The three topics, magma volume/time, petrologic patterns through time, and the decreased volume/increased eruptive frequency through time all are important observations that affect assumptions used for calculating the probability of future volcanic activity at Yucca Mountain. It is important that these concepts be tested at other volcanic fields in the region, particularly fields that have a more voluminous record of eruptive activity, to test the implications of conclusions for the Yucca Mountain area (Activity 8.3.1.8.5.1.5).

The second topic to be examined for this activity is the local structural controls for sites of volcanic activity in the Yucca Mountain area. Cluster analyses routines will be used to assess spatial patterns of aeromagnetic data in the Yucca Mountain area. Identified patterns will be correlated with known structures in the Yucca Mountain area and the location of volcanic centers to identify what structural features control the location of volcanic vents. This information will be used to test for the presence of potential structural features in the Yucca Mountain exploration block that could provide pathways for the localization of future volcanic activity. The results of this analysis will be factored into the volcanic probability calculations (Activity 8.3.1.8.1.1.4).

YMP/CM-0011, Rev. 1

8.3.1.8.1.1.3 Activity: Presence of magma bodies in the vicinity of the site

Objectives

The objective of this activity is to review geophysical and geochemical data collected in the vicinity of the site to assess whether there are any indications of the presence of crustal magma bodies that could be the source of future volcanic activity.

Parameters

The parameters for this activity are seismic refraction, seismic reflection, gravity, magnetics, magnetotelluric, curie temperature isotherm, heat flow, teleseismic P-wave residuals, V_p/V_s variations, and the noble gas isotopic ratios in ground water with an emphasis on the $^3He/^4He$ ratios.

Description

An important part of the assessment of volcanic hazards for the Yucca Mountain site is a determination of whether there are any indications of the presence of magma bodies or indications of the operation of magmatic processes in the crust beneath the Yucca Mountain area. There are two purposes for this activity: (1) to monitor and evaluate results from other activities to ensure that sufficient site characterization data are being obtained to adequately investigate the presence or absence of magma bodies in the Yucca Mountain vicinity and (2) obtain data on the isotopic composition of the noble gases, with an emphasis on the $^3He/^4He$ ratios, in the ground water around Yucca Mountain. These isotopic data can be used to test for the presence of magma bodies beneath the site.

There are two types of potential magma systems that could be present beneath the site. The first is magma, systems associated with silicic volcanic fields such as the Coso, Long Valley, and Valles fields (Reasenberg et al., 1980; Walck, 1988; Lachenbruch et al., 1976, Sass and Morgan, 1988). Magma bodies of this type, if present, are likely to occur at depths of 5 to 15 km. As noted in Chapter 1 (Section 1.5.1.1), an absence of shallow silicic magma bodies beneath the Yucca Mountain area is suggested by the low heat flow and absence of high temperature springs. The second potential occurrence of magma bodies is in association with basaltic magma. Magma bodies of this type have been hypothesized in southern Death Valley, in association with a small volume Quaternary basalt center (de Voogd et al., 1986), in the southern Rio Grande rift near Socorro (Brown et al., 1979; Jiracek et al., 1979; Rinehart et al., 1979) and in Indian Wells Valley south of the Coso region (Walck, 1988). Magma bodies of this type could be present at depths of 10-30 km. The presence of Quaternary basaltic centers in the Yucca Mountain area suggests the possibility that basaltic magma bodies could exist at midcrustral levels beneath the site.

The primary source of data for an evaluation of the presence of magma chambers will be obtained from Study 8.3.1.8.5.2 (characterization of igneous intrusive features) and from Activity 8.3.1.17.4.3.1 (the deep geophysical survey transects across Yucca Mountain). The important activity of Study 8.3.1.8.5.2 is 8.3.1.8.5.2.1 (evaluation of depth of curie temperature

 YMP/CM-0011, Rev. 1

isotherms). This work will compare areas of shallow, higher temperature isotherms with areas of recent volcanism and areas of high heat flow to determine whether the data are consistent with the presence of subsurface magma bodies. Activity 8.3.1.8.5.2.3 (heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies) will provide data to evaluate the magnitude and areal extent of the thermal perturbation due to Quaternary igneous activity. The important techniques from Activity 8.3.1.17.4.3.1 include seismic refraction and reflection profiles, gravity, magnetics, and magnetotelluric surveys closely associated with the profiles. Detection of magma chambers is one of multiple objectives of Activity 8.3.1.17.4.3.1. This activity will monitor the results of Activity 8.3.1.17.4.3.1 to ensure that no changes are made to the geophysics activities that would compromise the ability to detect magma bodies and to recommend any additional geophysical studies that may be needed for the magma body studies. Examples of possible additional data include further work with P-wave residuals and evaluations of three-dimensional variations in V_p/V_s.

Additional studies that are complementary to the geophysical studies will be conducted as part of this task. The $^3He/^4He$ ratios in ground water adjacent to and surrounding Yucca Mountain will be measured to search for evidence of the presence or absence of subsurface magma bodies. The isotopic composition of mantle helium is distinctively different from the radiogenic crustal production composition (Kurz and Jenkins, 1981; Kurz et al., 1983). Because of these differences, the $^3He/^4He$ ratios of helium can be measured in ground water to test for characteristic signatures of helium production reservoirs. These ratios are sensitive to the lithologies containing the ground water, to the age of the ground water and to the tectonic and volcanic processes affecting the region of a ground water system. Torgersen et al. (1987) identified enriched $^3He/^4He$ ratios in ground water of eastern Australia. They suggested that the high ratios could be produced by continued young intrusive activity associated with known lava flow fields, despite the absence of surface volcanic deposits in the vicinity of the He anomaly. Measurement of $^3He/^4He$ ratios in ground water for drillholes at and surrounding Yucca Mountain will allow an evaluation of several possible occurrences of subsurface magma bodies including (1) undetected magma bodies beneath the Yucca Mountain site, (2) undetected magma bodies at depth associated with possible detachment fault systems away from but feeding toward the Yucca Mountain site (Section 1.3.2.2.1), (3) subsurface magma bodies associated with Quaternary sites of basaltic volcanic activity in and surrounding Crater Flat, and (4) subsurface magma bodies associated with the Spotted Range-Mine Mountain structural zone (Section 1.3.2.2.1).

Additional activities in the Site Characterization Plan that will use data from and contribute data to this activity are included under Study 8.3.1.17.4.12 (tectonic models and synthesis). Specifically in Activity 8.3.1.17.4.12.1 (evaluate tectonic processes and tectonic activity stability at the site), the interrelationships between detachment faults and the Death Valley-Pancake Range zone will be evaluated. One potential pathway for rising magma, if it is present beneath the Yucca Mountain region, is along detachment faults. Activity 8.3.1.17.4.12.2 (evaluate tectonic models) will consider two possible models of Quaternary volcanism: (1) association with an incipient rift zone (Death Valley-Pancake Range zone) and (2) a leaky

YMP/CM-0011, Rev. 1

transform model. Both models require a differing geometry of crustal and subcrustal magma feeder systems beneath the Yucca Mountain area and would result in modifications of predictions of the possible locations and geometry of crustal magma bodies.

8.3.1.8.1.1.4 Activity: Probability calculations and assessment

Objectives

The objective of this activity is to revise the estimates of the probability of volcanic disruption of a repository site at Yucca Mountain (Crowe et al., 1982) incorporating newly acquired data on the age, location, and volume of volcanic centers in the Nevada Test Site region and the results from activities investigating the possibility of structural controls of sites of volcanic activity and the presence of magma bodies in the Yucca Mountain area. These data may result in modifications of the area ratio and the rate of volcanic activity used in the probability formula.

Parameters

The parameters for this activity are

1. Maps showing the location and age of volcanic vents within 70 km of the site.
2. Magma generation rates within 70 km of the site.
3. Structural controls on volcanism.
4. Evidence for the presence of magma bodies in the vicinity of the site.

Description

Data from parameters 1 through 4 are used for probability calculations. The probability of disruption of a repository by basaltic magma is formulated as a case of conditional probability

$$Pr = \{E2 \text{ given } E1\} \qquad (8.3.1.8\text{-}1)$$

where Pr is the probability of repository disruption, E1 is the rate of occurrence of volcanic events, and E2 is the probability of intersection of a repository by magma given E1. This probability is expressed as (Crowe et al., 1982)

$$Pr\ [\text{no disruptive event before time } t] = e^{-\lambda t p} \qquad (8.3.1.8\text{-}2)$$

where λ is the rate of volcanic activity and p is the probability that an event is disruptive. The most difficult parameter to estimate for the calculations is λ . The Yucca Mountain Project has defined the parameter λ in two ways using data for the Yucca Mountain region: (1) cone counts through time and (2) calculations of magma volume through time (rate of magma

YMP/CM-0011, Rev. 1

production). Alternative models are possible but are difficult to test with the limited data from the Yucca Mountain region. Much more comprehensive data will be obtained from high cone-density volcanic fields. These data will be used to test existing methods for calculating volcanic rates and developing additional alternative methods. If new methods are developed, they will be tested using the Yucca Mountain data set. Further work will be undertaken to attempt to revise the probability of repository disruption (p). Cluster analysis of the aeromagnetic and gravity data will be used to attempt to correlate spatial trends with sites of surface volcanic activity. If these correlations are successful, the disruption ratio will be revised for the probability calculations. Ongoing work described in Chapter 1 has shown that there has been a progressive southwest migration of sites of basaltic volcanic activity through time. These data lead to the conclusion that the Yucca Mountain region has passed the peak of the most intense volcanic activity. This interpretation will be tested using information on time-space patterns of basaltic volcanism from Activity 8.3.1.8.1.1.1. The results of the revised probability calculation and assessment will be summarized in a report that includes the following:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment on the probability of volcanic events.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.1.2 Study: Effects of a volcanic eruption penetrating the repository

The purpose of this study is to gather data on the effects of a potential volcanic eruption should such an eruption penetrate the site. The data will be used by Issue 1.1 and the other investigations in this program to assess the consequences of such an eruption on repository performance.

8.3.1.8.1.2.1 Activity: Effects of Strombolian eruptions

Objectives

The objective of this activity is to summarize the effects of a Strombolian eruption on a repository. The summary will be available for use in consequence analyses of possible radiological releases.

Parameters

The parameters for this activity are representative eruption parameters for Strombolian eruptions, including area of repository disrupted and confidence bounds of estimate.

 YMP/CM-0011, Rev. 1

Description

The published literature and completed Project reports (e.g., Link et al., 1982) provide sufficient data for the completion of this activity. This activity will compile and summarize those data for use in consequence analyses.

The data used will include the area of the repository that could potentially be disrupted, characteristics and dimensions of intrusions (dikes and sills) associated with an eruption, thickness and extent of flows and ashfalls, temperatures of magma, and duration of eruptions. The data summarized by this activity will also be used in Investigations 8.3.1.8.2, 8.3.1.8.3, and 8.3.1.8.4.

8.3.1.8.1.2.2 Activity: Effects of hydrovolcanic eruptions

Objectives

The objective of this activity is to obtain geologic parameters for the disruption of a repository by magmatic activity accompanied by hydrovolcanic (magma-water) explosions. Critical parameters controlling the hydrovolcanic explosions will be identified and information obtained on these parameters will be used for calculations of the radiological release levels for performance assessment.

Parameters

The parameters for this activity are the representative eruption parameters for hydrovolcanic eruptions including the area of repository disrupted and the confidence bounds of the estimate.

Description

Eruption parameters will be defined for an eruption scenario involving an initial hydrovolcanic eruption changing in time to a Strombolian eruption. Parameters for a Strombolian eruption without a hydrovolcanic component have been completed (Link et al., 1982). There are two important categories of evidence related to the possibility of hydrovolcanic activity at Yucca Mountain: (1) theoretical models of magma/water interaction show that hydrovolcanic explosions are possible in the Yucca Mountain setting and (2) geologic evidence suggests that the likelihood of a hydrovolcanic explosion decreases with increasing depth of the water source (Crowe et al., 1986). Consequence studies of the area of the repository disrupted by a basaltic eruption need to be repeated with a modified eruption scenario that includes hydrovolcanic explosions. Two topics require further studies for these modifications. First, likely scenarios for hydrovolcanic eruptions need to be identified based on information obtained from field studies of basalt centers that exhibited hydrovolcanic activity (Activity 8.3.1.8.5.1.3) and a review of the literature should be conducted. Second, data on key geologic parameters need to be obtained from the scenarios. The data needed will be used to predict (1) whether an ascending magma body will intersect water at a depth to cause an explosive fuel-coolant type reaction between

YMP/CM-0011, Rev. 1

magma and water, and (2) whether that reaction will be of sufficient magnitude to cause an explosive eruption that will disrupt the repository, possibly breach waste canisters, and cause the release of radioactive waste at the surface.

8.3.1.8.2 Investigation: Studies to provide information required on rupture of waste packages due to tectonic events

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.3.2.2	Structural history
1.4.1.5	Seismic hazard within the southern Great Basin
1.5.1	Volcanism
1.5.2	Faulting

Parameters

The following performance parameters will be measured or calculated as a result of the site studies planned as part of this investigation:

1. Probability of igneous intrusion penetrating repository.

2. Effects of igneous intrusion penetrating repository.

3. Effects on waste packages of a fault penetrating the repository.

4. Probability of faulting with displacement over 5 cm in repository.

5. Expected ground motion at emplacement boreholes in 1,000-yr period.

6. Rate of deformation due to folding or distributed faulting in repository horizon.

Purpose and objectives of the investigation

The purpose of this investigation is to provide the data necessary for an analysis and assessment of repository performance with respect to the possibility of tectonic processes and events affecting the lifetime of waste packages. The six performance parameters listed in the previous section have been defined to address the performance measure identified by Issue 1.11 (Section 8.3.2.2). The types of tectonic initiating events that may affect waste package performance and that will be considered in this analysis are

YMP/CM-0011, Rev. 1

listed in Table 8.3.1.8-2. The study and activities in this investigation will take data gathered by field studies in this and other programs and provide an analysis of the probability of the initiating events and their effects on waste package performance for use by Issue 1.11 (Section 8.3.2.2) in assessing layout and design of the underground facilities.

This investigation will also provide data on the nature of tectonic processes operating at the site for use by Issue 1.8 (Section 8.3.5.17, NRC siting criteria) in its analysis of favorable and potentially adverse conditions. The specific conditions addressed by this investigation are listed in Table 8.3.1.8-2.

Parameter 5 indicates the need for data on the ground motion that would be expected during the waste package lifetime. This parameter and its related initiating event respond to the need identified in Issue 1.11 (Section 8.3.2.2, configuration of underground facilities (postclosure)) for such data. Issue 1.11 will use the ground motion data to evaluate the design of emplacement drifts and boreholes in order to assess their postclosure stability.

Technical rationale for the investigation

The flow of data and interconnections between activities is shown on Figure 8.3.1.8-4. The first initiating event considered in this program is the possibility that igneous intrusions penetrating the repository could adversely affect waste package performance. This initiating event is similar to the one considered in Investigation 8.3.1.8.1, but assumes that the basaltic dikes or sills that might penetrate the repository do not feed a volcanic vent and do not directly result in releases at the ground surface. Activity 8.3.1.8.2.1.1 will address this initiating event and satisfy parameters 1 and 2. The assessment of this initiating event will be similar to that in Investigation 8.3.1.8.1 and will use the data analyzed in that investigation to calculate the probability of igneous intrusions penetrating the repository. The number of waste packages that an intrusion might intersect will also be calculated using data on the probable length, width, and orientation of intrusions and current repository design concepts.

The second initiating event considers the possibility that failure of waste packages could occur due to a fault that intersects waste packages and experiences offset that is great enough to cause failure through shearing. Activities 8.3.1.8.2.1.2, 8.3.1.8.2.1.3, and 8.3.1.8.2.1.4 will assess this initiating event and satisfy parameters 3 and 4. This assessment will include calculating (1) the probability that faulting with offset great enough to cause waste package failure would occur in the repository and (2) the number of waste packages that a through going fault might intersect. These activities will organize and assess data collected by Programs 8.3.1.17 and 8.3.1.4 to characterize the nature and Quaternary activity of faults that penetrate the repository and those faults in and near the controlled area. Because of the scarcity of Quaternary deposits on Yucca Mountain, it may not be possible to directly demonstrate the degree of Quaternary activity present on all the faults that potentially penetrate the repository. It is therefore probable that the assessment of the probability and amount of movement on these faults will be characterized by comparison with the known Quaternary faults in the vicinity of the site that have a similar trend and sense of

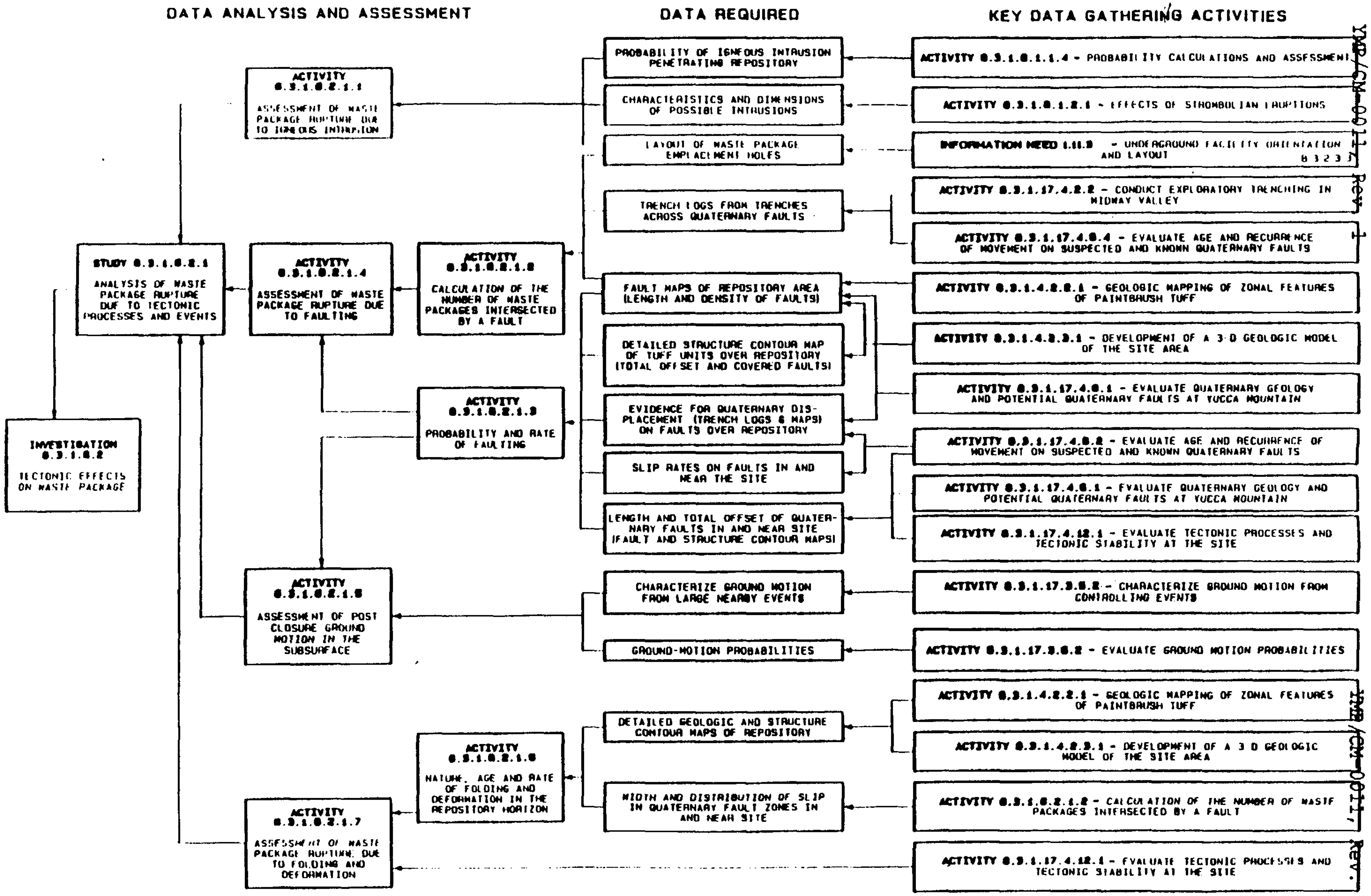

Figure 8.3.1.8-4. Logic diagram for Investigation 8.3.1.8.2 (tectonic effects on waste package).

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

movement. Faults such as the Paintbrush Canyon, Solitario Canyon, and Windy Wash traverse areas are underlain by Quaternary deposits of a variety of ages (Sections 1.2.2.3 and 1.3.2.2.2) that can be used to determine the nature and rate of Quaternary activity. The comparison of the faulting potential of these larger faults with faults penetrating the repository will incorporate a consideration of the differences in length and total displacement between the two classes of faults. When all these data are collected and coordinated, an annual probability of fault displacement exceeding 5 cm will be calculated for faults that may penetrate the repository.

The second part of the assessment will be a calculation of the number of waste packages that a fault might intersect should a faulting event, with sufficient offset to rupture waste packages, occur. Data will be compiled on the length and width of fault zones, and then calculations similar to those in Link et al. (1982) will be carried out using current repository designs to estimate the number of waste packages that might be affected.

The third initiating event considers the possibility that ground motion occurring during the postclosure period could cause spalling or failure in the underground workings that would result in corrosion or mechanical failure of waste packages due to closure of the air gap around them. Activity 8.3.1.8.2.1.5 will partially address this initiating event and address parameter 5 by calculating expected ground motion values in the repository during the lifetime of the waste packages. The performance of underground excavations under these ground motion conditions will be evaluated separately in Issue 1.11 (Section 8.3.2.2). In this investigation, the ground motion estimates for preclosure design in Investigation 8.3.1.17.3 will be reviewed. Appropriate ground motion parameters for the postclosure time period will then be calculated on the basis of this data.

The fourth initiating event considers the possibility that folding, or fault offset distributed across a broad zone of minor shearing, could sufficiently deform the waste-emplacement boreholes through a closure of the air gap surrounding the waste packages such that the waste packages would fail through bending. Activities 8.3.1.8.2.1.6 and 8.3.1.8.2.1.7 will address this initiating event and satisfy parameter 6. These activities will collect data on rates and amount of post-Miocene folding in the repository horizon by reviewing the detailed geologic and structure contour maps of the repository horizon generated by Program 8.3.1.4. Rates of deformation will then be calculated using these data, and a probability of significant waste package failure due to deformation processes calculated.

8.3.1.8.2.1 Study: Analysis of waste package rupture due to tectonic processes and events

The assessment of the probability and effects of all tectonic processes and events that could result in adverse effects on waste package lifetime are aggregated under this study.

 YMP/CM-0011, Rev. 1

8.3.1.8.2.1.1 Activity: Assessment of waste package rupture due to igneous intrusion

Objectives

The objective of this activity is to review and organize supporting field data collected by other activities, and to use this data to calculate the probability of an igneous intrusion penetrating the repository and the number of waste packages that would be affected by such an event.

Parameters

The parameters for this activity are

1. Probability of an igneous intrusion penetrating the repository.
2. Number of waste packages affected by an igneous intrusion.

Description

This activity will use the data and probability calculations in Activity 8.3.1.8.1.1.4 as the basis for estimating the probability that an igneous intrusion may penetrate the repository. The results of Link et al. (1982) will be reviewed and compared with current repository designs and the results of Activity 8.3.1.8.1.2.1 to calculate the number of waste packages that might be intersected by an igneous intrusion. These previous estimates will be revised as necessary to incorporate current data and designs. A report will be prepared that

1. Organizes and summarizes the data on which calculations are based.

2. Presents the theory and calculations used to estimate the probability of igneous intrusion and the number of waste packages affected.

3. Presents a discussion and assessment of the assumptions and uncertainties of the data and the calculations.

8.3.1.8.2.1.2 Activity: Calculation of the number of waste packages intersected by a fault

Objectives

The objective of this activity is to collect and summarize the relevant data from other activities and calculate the number of waste packages that a fault penetrating the repository would intersect.

Parameters

The parameter for this activity is the number of waste packages affected by a fault penetrating the repository.

YMP/CM-0011, Rev. 1

Description

This activity will review data collected by trenching and geologic mapping activities in and around the site by Programs 8.3.1.4 and 8.3.1.17. The data on the length, width, and orientation of known Quaternary fault ruptures will be summarized. Representative values for these fault characteristics will be selected for use in calculations. Current repository designs will be reviewed to collect data on the layout and emplacement mode of waste packages. These data will be used to calculate the number of waste packages that a fault might intersect in the repository. The calculation method will be similar to that used by Link et al. (1982) for volcanic events and will result in a probability distribution of possible effects.

8.3.1.8.2.1.3 Activity: Probability and rate of faulting

Objectives

The objective of this activity is to summarize and evaluate the available data on slip rates and recurrence intervals on faults in and near the controlled area.

Parameters

The parameters for this activity are

1. Evidence of Quaternary activity on faults penetrating the repository.

2. Density, length and total displacement of faults penetrating the repository.

3. Slip rates and recurrence intervals of faults with Quaternary activity in and near the controlled area.

4. Location, length, and total displacement of faults with Quaternary activity in and near the controlled area.

Description

This activity will collect and summarize data on the length, total displacement, and Quaternary activity of faults that are mapped in and near the controlled area and can be projected downward or laterally to intersect the repository. The data will be gathered by several activities in Programs 8.3.1.4 and 8.3.1.17 (Figure 8.3.1.8-4). The data will consist of detailed bedrock geologic maps, structure contour maps, Quaternary deposits maps, remote sensing and geomorphic analyses, and trench logs. The various types of data available will be analyzed and compared with each other to generate a summary of the characteristics of these faults.

 YMP/CM-0011, Rev. 1

Data will also be collected and summarized on the length, total displacement, slip rate, and recurrence interval of Quaternary faults such as the Paintbrush Canyon, Solitario Canyon, and Windy Wash that are in and near the controlled area. These data will come from trenching and mapping studies carried out mainly by Activities 8.3.1.17.4.6.1 and 8.3.1.17.4.6.2. The analyses and data summaries will be used by Activity 8.3.1.8.2.1.4 to assess the probability of significant effects on waste package lifetime due to faulting.

8.3.1.8.2.1.4 Activity: Assessment of waste package rupture due to faulting

Objectives

The objective of this activity is to complete an assessment of the probability of faulting in waste emplacement boreholes and effects of faulting on waste package lifetime.

Parameters

The parameters for this activity are

1. Effects on waste packages of a fault penetrating the repository.

2. Probability of faulting with a displacement over 5 cm in the repository.

Description

This activity will take the data summarized and compiled by Activities 8.3.1.8.2.1.2 and 8.3.1.8.2.1.3 and prepare an assessment of the hazard posed by fault displacement to waste package lifetime. The results of this assessment will be contained in a report that includes the following topics:

1. A summary of data on the characteristics of the faults projected to intersect the repository.

2. A summary of data on the characteristics of the Quaternary faults in and near the controlled area.

3. The calculation of the probability of a cumulative 5-cm displacement occurring in 1,000 yr on a known Quaternary fault in and near the controlled area using slip rates or recurrence intervals and including the type of analysis presented in URS/Blume (1987).

4. A comparison of the characteristics of known Quaternary faults in and near the controlled area with the characteristics of faults projected to intersect the repository and an estimation of the probability of a cumulative 5-cm displacement occurring in 1,000 yr on a fault intersecting the repository.

YMP/CM-0011, Rev. 1

5. An evaluation of the number of faults penetrating the repository on which cumulative displacements greater than 5 cm could occur during a 1,000 yr period and the interrelationship of events on different faults.

6. The calculation of the number of waste packages that a fault penetrating the repository would intersect.

7. An analysis of the assumptions and uncertainties contained in the data and calculations used for the assessment.

8.3.1.8.2.1.5 Activity: Assessment of postclosure ground motion in the subsurface

Objectives

The objective of this activity is to provide an assessment of expected ground motion at the repository horizon in a 1,000-yr period.

Parameters

The parameter for this activity is the expected ground motion at emplacement boreholes in 1,000-yr period.

Description

This activity will supply data that will be used by Issue 1.11 (Section 8.3.2.2) to analyze the postclosure performance of the underground workings under earthquake loading conditions. Data from Studies 8.3.1.17.3.5 and 8.3.1.17.3.6 will be used to characterize ground motions that have a probability of less than 0.1 of being exceeded in the 1,000-yr waste package lifetime. Time histories representative of the estimated ground motions at the repository horizon will be prepared for use in the engineering evaluations. A report will be prepared that

1. Summarizes the data used in the analysis.

2. Discusses the methods used to estimate expected ground motion levels.

3. Analyzes the assumptions and uncertainties in the data and estimation methods.

4. Provides time histories and other data characterizing expected ground motion parameters for use in engineering analysis.

YMP/CM-0011, Rev. 1

8.3.1.8.2.1.6 Activity: Nature, age, and rate of folding and deformation in the repository horizon

Objectives

The objective of this activity is to provide an estimate of the rate of folding or deformation in the repository horizon during Quaternary time.

Parameters

The parameters for this activity are

1. Wavelength and amplitude of folds in the Miocene rocks of the repository horizon.

2. Amount and nature of deformation resulting from faulting in the repository horizon.

Description

This activity will collect and analyze data from Program 8.3.1.4 (rock characteristics) to characterize folding in the repository horizon. The data evaluated will include geologic maps, detailed structure contour maps, and maps of the shafts and drifts. Data on the wavelength and amplitude of any folds found in the area of the repository will be summarized. The site data will also be reviewed for evidence of warping, distributed shear or faulting. Data on the width of Quaternary zones of deformation around faults in the area will also be taken from Activity 8.3.1.8.2.1.2. All the data will be used by Activity 8.3.1.8.2.1.7 in its evaluation of the rate of folding and deformation in the repository and its effect on waste package integrity.

8.3.1.8.2.1.7 Activity: Assessment of waste package rupture due to folding and deformation

Objectives

The objective of this activity is to provide an assessment of the hazard resulting from folding and deformation to waste package integrity.

Parameters

The parameter for this activity is the rate of deformation due to folding or faulting in the repository horizon.

Description

This activity will use the data generated by Activity 8.3.1.8.2.1.6 and data on the rate and changes in deformation in the Neogene from Study 8.3.1.17.4.12 to estimate the rate of folding or deformation in the repository horizon and describe the effects such folding may have on waste package integrity. This activity will result in a report that will include

 YMP/CM-0011, Rev. 1

1. The data used in making the assessment.

2. The methods used to calculate or estimate Quaternary folding rates.

3. Quaternary folding rates and an assessment of the impact on waste package integrity.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.3 Investigation: Studies to provide information required on changes in unsaturated and saturated zone hydrology due to tectonic events

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.3.2.2	Structural history
1.3.2.3	Existing stress regime
1.5.1.2	Basaltic volcanism
1.5.2	Faulting
3.6	Regional hydrogeologic reconnaissance of candidate area and site
3.9	Site hydrogeologic system

Parameters

The following performance parameters will be measured or calculated as a result of the site studies planned as part of this investigation:

1. Annual probability of volcanic events within the controlled area.

2. Effects of a volcanic event on topography and average flux rates.

3. Annual probability of significant igneous intrusion within 0.5 km of the controlled area.

4. Effects of an igneous intrusion on average flux rates.

YMP/CM-0011, Rev. 1

5. Probability of offset more than 2 m on a fault in the controlled area in 10,000 yr.

6. Probability of changing dip by greater than 2 degrees in 10,000 yr by faulting.

7. Effect of faulting on average flux rates.

8. Probability of changing dip by greater than 2 degrees in 10,000 yr by folding.

9. Probability of exceeding 30 m of elevation change in 10,000 yr.

10. Barrier-to-flow effects of igneous intrusions on water-table levels and hydraulic gradients.

11. Thermal effects of igneous intrusions on water-table levels and hydraulic gradients.

12. Probability that strain-induced changes will increase potentiometric level to greater than 850 m mean sea level (MSL).

13. Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr.

14. Probability of total offsets more than 2.0 m in 10,000 yr on a fault within 0.5 km of controlled area boundary.

15. Effects of fault offset on water-table levels and hydraulic gradient.

16. Effects of igneous intrusions on local fracture permeabilities and effective porosities.

17. Annual probability of faulting events on Quaternary faults within 0.5 km of controlled area boundary.

18. Effects of fault motion on local fracture permeabilities and effective porosities.

19. Effects of changes of stress or strain on hydrologic properties of the rock mass.

Purpose and objectives of the investigation

The 19 performance parameters listed above have been identified by Issue 1.1 (Section 8.3.5.13 and Tables 8.3.1.8-3 to 8.3.1.8-5) to address the possibility that tectonic processes and events could produce the following changes in existing hydrologic conditions:

1. Alteration of average percolation flux over the repository.

2. Changes in water table elevation that affect the length of the unsaturated zone travel path or hydraulic gradients.

 YMP/CM-0011, Rev. 1

3. Alteration of rock hydrologic properties along significant travel paths.

The three studies in this investigation will provide assessments of the likelihood and magnitude of these hydrologic changes for use by Issue 1.1 in analyzing total system performance of the repository in limiting radionuclide releases to the accessible environment. Several of the initiating events considered in this investigation probably will have no significant impact on repository performance because of the very low rates at which the related tectonic processes operate at Yucca Mountain (e.g., folding, uplifting, and subsidence). It is anticipated that little or no additional data will be required to complete the assessments of the initiating events related to these tectonic processes. The level of effort for the activities related to these initiating events is therefore anticipated to be low and to consist primarily of organizing and presenting existing data in order to provide the basis for eliminating these initiating events from consideration during performance assessment evaluations. A higher level of effort will be given to those initiating events judged to have a higher probability of affecting repository performance (i.e., faulting and strain effects).

This investigation will also provide data on the nature of tectonic processes operating at the site for use by Issue 1.8 (Section 8.3.5.17, NRC siting criteria) in its analysis of favorable and potentially adverse conditions. The specific conditions addressed by this investigation are listed on Tables 8.3.1.8-3 to 8.3.1.8-5.

Technical rationale for the investigation

The flow of data and interconnections between activities in each study are shown on Figures 8.3.1.8-5 to 8.3.1.8-7. Study 8.3.1.8.3.1 considers the initiating events that may affect the average percolation flux over the repository. The first initiating event considered in this study is the possibility that volcanic events may alter topography as a result of the extrusion of volcanic flows or other effects and create impoundments or diversions of drainage that could adversely affect average percolation flux rates. The second initiating event considers the possibility that an igneous intrusion such as a sill intruded above the repository horizon could divert downward percolating waters to the area above the repository and thereby increase average percolation flux rates. The first two activities in the study address these initiating events and will satisfy parameters 1 to 4. Activity 8.3.1.8.3.1.1 will use data from Activity 8.3.1.8.1.1.4 to calculate the probability of igneous events occurring in the larger area encompassing the controlled area and a buffer zone. Activity 8.3.1.8.3.1.2 will summarize the available data on the size and location of volcanic and igneous features that could occur in the area. This activity will also perform modeling studies to estimate the amount of change in flux rates that could occur as a result of an igneous event. The activity will then use this data and the data from Activity 8.3.1.8.3.1.1 to (1) provide an assessment of the possibility that significant changes could result from these initiating events and (2) prepare a report.

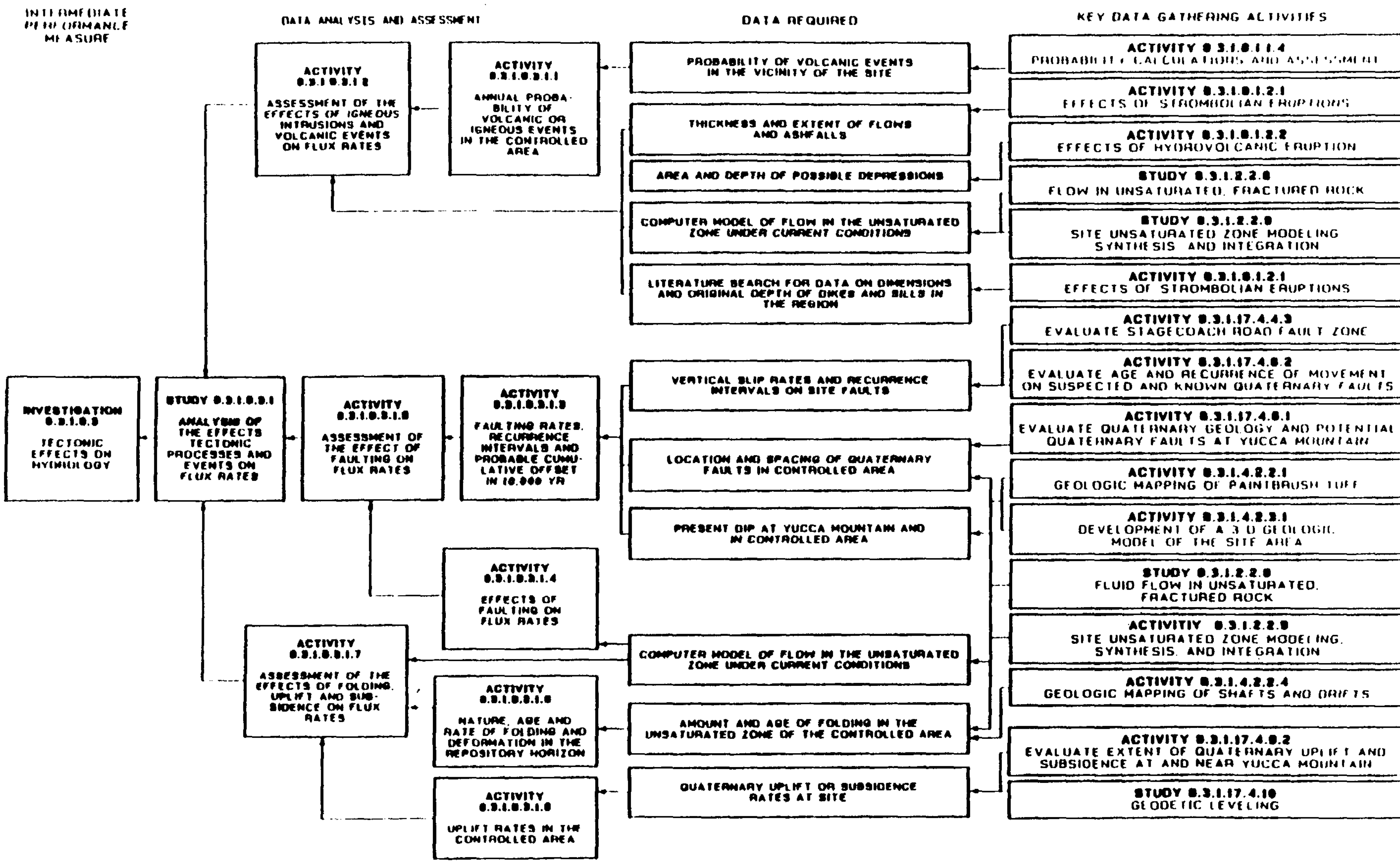

Figure 8.3.1.8-5. Logic diagram for Study 8.3.1.8.3.1 (analysis of the effects of tectonic processes and events on flux rates)

YMP/CM-0011, Rev. 1

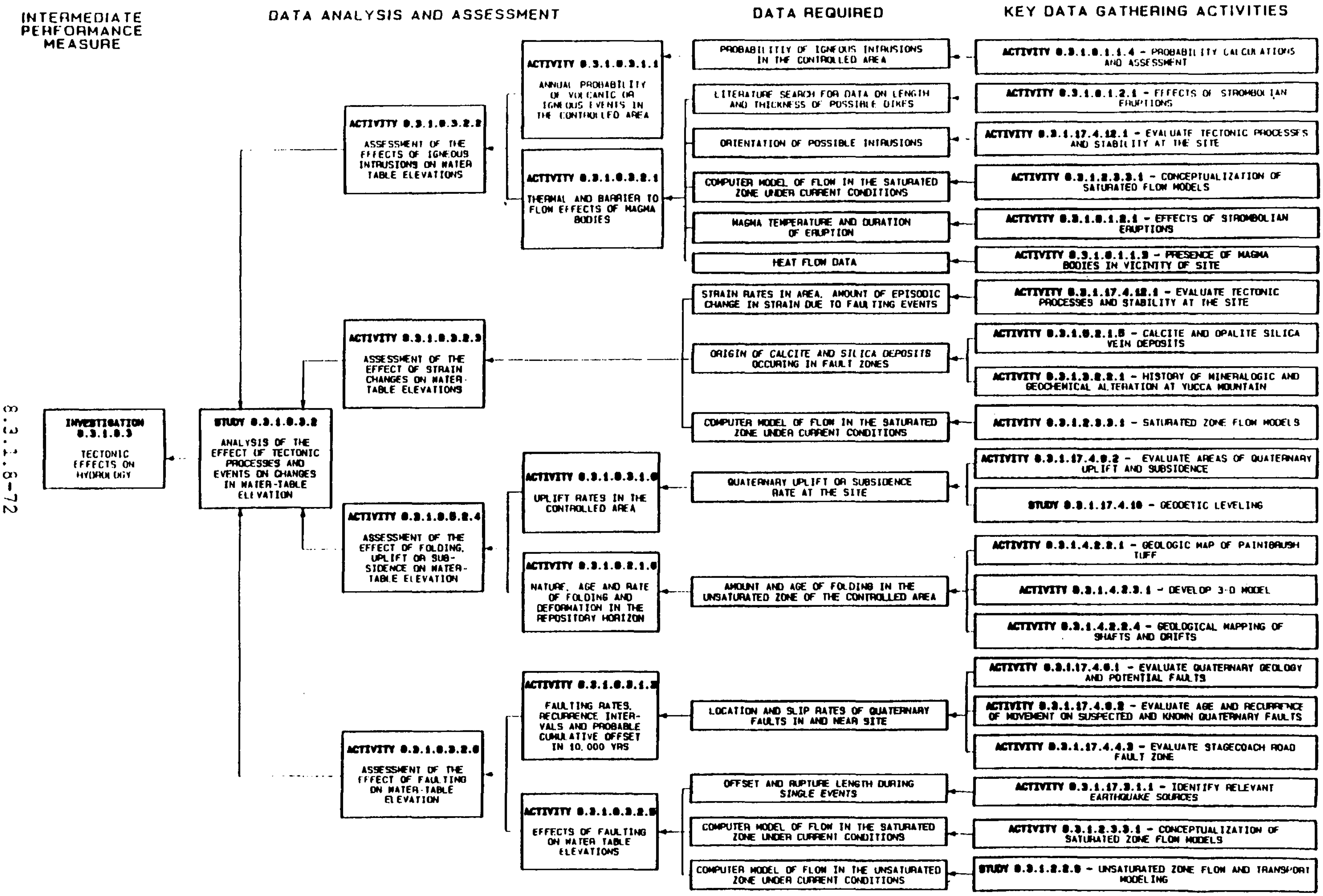

Figure 8.3.1.8-6. Logic diagram for Study 8 3 1 8 3.2 (analysis of effects of tectonic processes and events on changes in water-table elevation).

YMP/CM-0011, Rev. 1

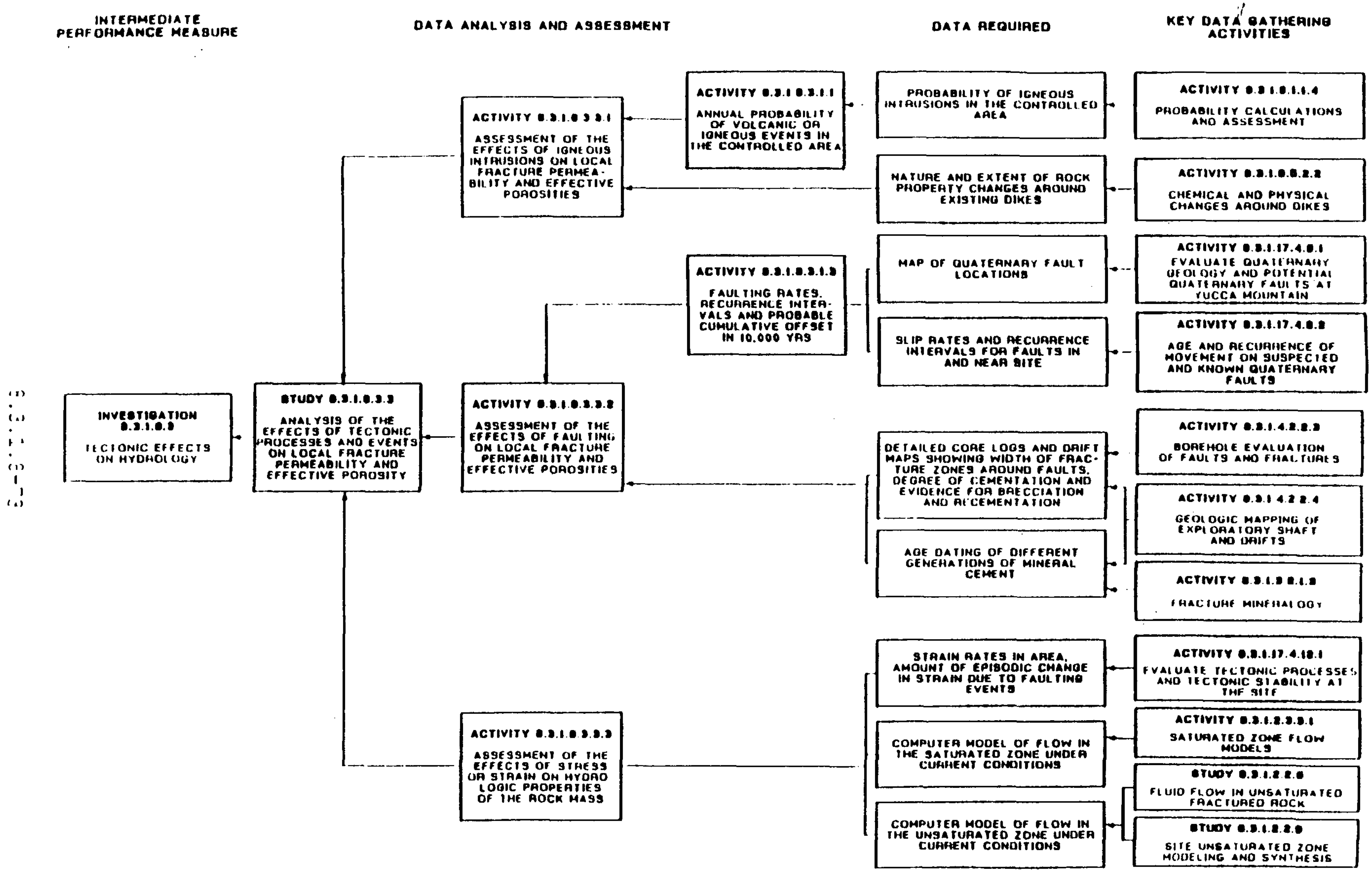

Figure 8.3.1.8-7. Logic diagram for Study 8 3 1 8 3 3 (effects of faulting on local fracture permeability and effective porosity)

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

The third initiating event considered by Study 8.3.1.8.3.1 is the possibility that fault offset could affect average percolation flux rates. Effects to be considered include surface topographic changes such as the creation of a scarp that could create impoundments or divert drainage; and subsurface changes, such as the juxtaposition of units of different hydrologic properties or change in the dip of beds that could create perched aquifers or divert subsurface drainage toward the repository. Activity 8.3.1.8.3.1.3 will collect and summarize field data gathered by other activities and calculate slip rates, recurrence intervals and probable cumulative offset in 10,000 yr for faults in and near the controlled area. Activity 8.3.1.8.3.1.4 will perform hydrologic modeling studies to estimate the effect of faulting on flux rates. Activity 8.3.1.8.3.1.5 will use the data generated by the previous two activities to (1) generate an assessment of the effect of probable fault movement on flux rates that will satisfy parameters 5 to 7 and (2) prepare a report.

The fourth initiating event considers the possibility that folding processes could change the dip of beds in the repository area sufficiently to alter flux rates. This could occur where downward percolating waters are diverted laterally at the contact with a low permeability unit. The laterally moving waters at the contact could be diverted toward the repository by folding, thereby increasing repository flux rates. The fifth initiating event considers the possibility that rapid rates of area-wide uplift or subsidence could alter drainage patterns or gradients sufficiently to affect flux rates. These initiating events and parameters 8 and 9 associated with them will be addressed by Activities 8.3.1.8.3.1.6 and 8.3.1.8.3.1.7. Activity 8.3.1.8.3.1.6 will collect and summarize field data from other activities and calculate uplift and subsidence rates for the area including the site. Activity 8.3.1.8.3.1.7 will use these rates and rates of folding calculated by other activities to estimate the amount of folding uplift and subsidence expected in 10,000 yr. The activity will then (1) perform an assessment of the effect of these changes on average percolation flux rates using hydrologic modeling techniques and (2) summarize the assessment in a report.

Study 8.3.1.8.3.2 will analyze the possibility that tectonic processes and events could cause changes in the elevation of the water table or the potentiometric surface of confined aquifers. Rises in the water table would shorten the length of the unsaturated zone travel path and affect release rates. Such rises could also change the hydraulic gradient, alter the location of discharge points, or create perched aquifers in the area of the site. These effects could affect ground-water travel times or place locally saturated zones in close proximity to the waste. Four initiating events have been identified in connection with this study (Table 8.3.1.8-4).

The first initiating event considers the possibility that igneous intrusions could affect water table elevations by creating barriers to flow such as a dike or creating thermally driven circulation systems that could cause water to rise to repository levels as the result of an intrusion or volcanic event. Activity 8.3.1.8.3.2.1 will collect and summarize data from other activities (Figure 8.3.1.8-6) on the dimensions and orientations of probable intrusions and the thermal effects around such intrusions. Hydrologic models of existing conditions at Yucca Mountain will then be used to estimate the magnitude of the changes that could result from igneous events. Activity 8.3.1.8.3.2.2 will take the results of this activity and combine

 YMP/CM-0011, Rev. 1

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2 of 3

them with data on the probability of such intrusions (Activity 8.3.1.8.3.1.1) to produce an assessment of the effects igneous intrusions would have on water table levels and will satisfy parameters 10 and 11. This activity will also prepare a report summarizing the results of the assessment.

The second initiating event considers the possibility that episodic movement on faults could result in variations in stress and strain levels in the rock mass that produce relatively short-lived fluctuations in water-table or potentiometric levels. If these fluctuations are great enough, these episodic changes could result in the periodic saturation of the repository horizon due to a general rise in the water table or water moving upward along a conduit such as a fault from a confined aquifer. Activity 8.3.1.8.3.2.3 will provide an assessment of the probability and magnitude of these effects and satisfy parameter 12. The activity will collect data on strain rates in the region and calculate the amount and nature of expected changes during a faulting event. Modeling studies will then be performed to analyze the amount of water table fluctuation that could be expected. The assessment will also include a consideration of the field evidence that significant water-table or potentiometric surface fluctuations have occurred in the past near Yucca Mountain and an evaluation of reports of water table occurring in connection with earthquakes at other locations. The activity will also prepare a report summarizing the assessment and the supporting data.

The third initiating event considers the possibility that folding, uplift, or subsidence could significantly change the position of the repository with respect to the water table in 10,000 yr. Activity 8.3.1.8.3.2.4 will review the data collected by other activities on the rates of folding, uplift, and subsidence in the area to provide an assessment of the probability of significant changes of this type and satisfy parameter 13.

The fourth initiating event considers the possibility that offset on faults could be great enough to juxtapose lithologic units of differing hydrologic properties and produce changes in ground-water flow that result in rises in the water table or the creation of perched aquifers. Activity 8.3.1.8.3.2.5 will conduct a hydrologic modeling study to estimate the amount of change in water-table levels that could be expected for a range of displacements. Activity 8.3.1.8.3.2.6 will combine this data with data on the probability of significant offsets (Activity 8.3.1.8.3.1.3) to produce an assessment of the probability of significant changes in water levels in a 10,000-yr period and satisfy parameters 14 and 15. The activity will also produce a report summarizing the data and the results of the assessment.

Study 8.3.1.8.3.3 will consider the possibility that tectonic processes and events could alter the rock properties governing ground-water flow along significant travel paths. The initiating events are related to events or processes that could produce local changes in the saturated fracture permeability or fracture effective porosity. If such changes were to occur, they could result in the formation of barriers to ground-water flow or the creation of conduits to enhanced flow that could adversely affect the containment or transport rate of wastes. Three initiating events have been identified under this study (Table 8.3.1.8-5).

 YMP/CM-0011, Rev. 1

The first initiating event considers the possibility that an igneous intrusion could cause changes in the physical properties of the surrounding rocks. Activity 8.3.1.8.3.3.1 will collect and summarize data from the literature and field data gathering activities on the effects of the intrusion of dikes and sills in tuffs (Figure 8.3.1.8-7). This data will be combined with data on the probability of such intrusions in the controlled area (Activity 8.3.1.8.3.1.1) to produce an assessment that satisfies parameter 16 on the expected changes in local fracture permeability and fracture effective porosity resulting from igneous intrusions. The activity will result in a report summarizing the data and the results of the assessment.

The second initiating event considers the possibility that periodic offset on Quaternary faults in and near the controlled area could cause temporary changes in physical properties along the fault. These changes could result in the fault becoming a barrier to lateral ground-water flow or a conduit to vertical flow until mineralization or other processes return conditions to present values. Activity 8.3.1.8.3.3.2 will collect and summarize data from other activities on the width of fracturing around fault zones and evidence of significant fracturing and recementation along faults. These data will be used to predict the variation in physical properties that can occur along faults through the faulting cycle. This information will then be combined with data on the probability of faulting events in the controlled area (Activity 8.3.1.8.3.1.3) to produce an assessment of the effects of the initiating event and satisfy parameters 17 and 18. The activity will also produce a report summarizing the data and the results of the assessment.

The third initiating event considers the possibility that episodic faulting, folding, uplift, or subsidence could result in cyclic changes in the physical properties of the rock mass because of changes in the stress and strain regime. Activity 8.3.1.8.3.3.3 will address this possibility and satisfy parameter 19 by summarizing data on strain rates in the area and modeling the changes in rock fracture permeability and porosity that could result. The activity will also produce a report summarizing the data and the results of the assessment.

The activities that assess the probability and effects related to any particular initiating event will also consider the possibility that other initiating events, which could also occur as part of the tectonic process being considered, will influence the assessment. For example, the activity that assesses the effects of faulting on flux rates (8.3.1.8.3.1.5) will also consider the results of the activities that assesses the effects of faulting and strain on the hydrologic properties of the rock mass (8.3.1.8.3.3.2 and 8.3.1.8.3.3.3). The probability and effects of different processes (such as changes in thermal flux and strain rates) that might occur at the same time and produce a coupled effect will also be considered. The assessments are intended to provide the probability range and range of effects of coupled processes that can be considered during performance assessment (Issue 1.1). Different activities that consider various aspects of the same process (for example, 8.3.1.8.3.2.3 (effect of strain changes on water table elevation) and 8.3.1.8.3.3.3 (effect of strain changes on hydrologic properties of the rock mass)) will also be closely coordinated so that estimates used about the nature of the process agree.

YMP/CM-0011, Rev. 1

8.3.1.8.3.1 Study: Analysis of the effects of tectonic processes and events on average percolation flux rates over the repository

This study will produce analyses and assessments of the probability and effects of tectonic initiating events that may result in changes in the average percolation flux rate at the top of the Topopah Spring welded unit.

8.3.1.8.3.1.1 Activity: Annual probability of volcanic or igneous events in the controlled area

Objectives

The objective of this activity is to calculate the annual probability of igneous and volcanic events within 0.5 km of the controlled area boundary.

Parameters

The parameters for this activity are

1. Annual probability of volcanic events within the controlled area.

2. Annual probability of significant igneous intrusion within 0.5 km of the controlled area boundary.

Description

This activity will take the data developed in Activity 8.3.1.8.1.1.4 on the probability of volcanic and igneous events penetrating the repository and expand that analysis to calculate probabilities for the area within 0.5 km of the controlled area boundary. Special attention will be paid to the possibility that the influence of structural controls on igneous activity may be different for this larger area than for the repository. The data supplied by this activity will be used by Activity 8.3.1.8.3.1.2 and in other studies in this investigation as part of the assessments of the effects of igneous activity in producing possible changes in hydrologic characteristics.

8.3.1.8.3.1.2 Activity: Assessment of the effects of igneous intrusions and volcanic events on flux rates

Objectives

The objective of this activity is to produce an assessment of the possibility that volcanic or igneous events could cause significant changes in the average percolation flux rate at the top of the Topopah Spring welded unit.

 YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are

1. The effects of a volcanic event on topography and average flux rates.

2. The effects of an igneous intrusion on average flux rates.

Description

This activity will collect and summarize data from the literature and other activities on the thickness and extent of lava flows and ash falls and the dimensions of Strombolian cones or hydrovolcanic maars that are possible in the site area. The data on these features will be reviewed to determine whether the appearance of such features could substantially alter average flux rates through changes in drainage and topography. This activity will also compile data and complete an estimate on the length, depth, and orientation of possible dikes and sills in the area. These data will then be used in computer modeling of the hydrologic flow system to determine the effect of intrusions on flux rates. The results of this analysis will be combined with the probability of such igneous events occurring calculated by Activity 8.3.1.8.3.1.1 into an assessment of the probability of significant changes in flux due to igneous events. The activity will prepare a report that will address the following topics:

1. A summary of the data used in the assessment.

2. A discussion of the methods and models used in the analysis.

3. The results of the assessment.

4. A discussion of the assumptions and uncertainties in the data and the methods of analysis.

8.3.1.8.3.1.3 Activity: Faulting rates, recurrence intervals, and probable cumulative offset in 10,000 yr

Objectives

The objective of this activity is to provide estimates of the slip rates, recurrence intervals, and probable cumulative offset in 10,000 yr on Quaternary faults in and near the controlled area.

Parameters

The parameters for this activity are

1. Location and spacing of Quaternary faults in and near the controlled area.

2. Slip rates on Quaternary faults in and near the controlled area.

YMP/CM-0011, Rev. 1

3. Recurrence intervals on Quaternary faults in and near the controlled area.

4. Present dip of tuff beds at Yucca Mountain in and near the controlled area.

Description

This activity will collect and summarize data from a number of field data gathering activities and synthesize that data to provide estimates of the parameters listed above. The data to be reviewed and summarized include detailed bedrock geologic mapping, mapping of Quaternary deposits and faults, detailed structure contour maps, and logs of trenches across Quaternary faults. Figure 8.3.1.8-5 indicates the key data gathering activities that will be supplying this data. The bedrock and Quaternary geologic maps and the structure contour maps will be used to define the location, length, and orientation of Quaternary faults in the area of the repository. Data on the amount and age of displacement from trench logs, detailed structure contour maps, and detailed geologic maps will be used to calculate slip rates and recurrence intervals. Slip rates for time intervals extending from the present to the Miocene will be calculated in order to determine Quaternary slip rates and to analyze the changes that have occurred in slip rates over the last 15 million yr. The detailed structure contour maps will also be used to determine the range of possible down-dip fault geometries that need to be considered in the depth range that is significant in calculating the effects of faulting on hydrologic properties. These structure contour maps will incorporate data obtained from the geophysical, drilling, and mapping activities. The information generated by this activity will be used by Activity 8.3.1.8.3.1.5 and the other studies in this investigation to satisfy the performance parameters.

8.3.1.8.3.1.4 Activity: Effects of faulting on average flux rates

Objectives

The objective of this activity is to estimate the effects that the creation of scarps, the diversion of drainage, the change in the dip of beds, or the juxtaposition of beds due to fault offset would have on average percolation flux at the top of the Topopah Spring welded unit.

Parameters

The parameters for this activity are models of average flux rate change resulting from a range of faulting conditions.

Description

This activity will generate models that can be used by Activity 8.3.1.8.3.1.5 to analyze the probability of significant changes in average percolation flux rates due to fault activity. These models will be based on the models of present conditions that control flux rates in Studies 8.3.1.2.2.8 and 8.3.1.2.2.9. This activity will consider the perturbations

YMP/CM-0011, Rev. 1

to current conditions resulting from the offset or tilting of beds and changes to topography that a faulting event may cause. Various amounts and locations of offset will be modeled to determine the point at which fault offset could become a significant factor in controlling flux rates.

8.3.1.8.3.1.5 Activity: Assessment of the effects of faulting on flux rates

Objectives

The objective of this activity is to provide an assessment of the probability that average percolation flux rates at the top of the Topopah Spring welded unit at Yucca Mountain would be significantly affected by displacement due to future fault activity.

Parameters

The parameters for this activity are

1. Probability of cumulative offset more than 2 m on faults in the controlled area in 10,000 yr.

2. Probability of changing dip by greater than 2 degrees in 10,000 yr.

3. Effect of faulting on average flux rates.

Description

This activity will use the data and models generated by the two previous activities to prepare an assessment of the probability that faulting will significantly affect flux rates at Yucca Mountain. The data on slip rates and recurrence intervals will be used to calculate the probability that faulting events will occur during a 10,000-yr period. These data will also be used to calculate the amount of expected offset in single events, the cumulative offset in 10,000 yr, and the probability of significantly large cumulative offsets (>2 m) occurring. It was judged that a cumulative 2 m offset might begin to produce significant effects on flux rates due to the creation of surface impoundments, juxtaposition of hydrologic units, creation of perched aquifers, and change in dip. The data on the present dips at the site, location and spacing of Quaternary faults, and slip rates will be analyzed to estimate the amount of change in dip that could result from fault displacement in 10,000 yr and the probability of significant changes (>2) occurring. The models from Activity 8.3.1.8.3.1.4 will then be used to estimate the effects of expected faulting conditions on flux rates. A report that contains the results of the assessment will be prepared that includes the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

YMP/CM-0011, Rev. 1

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.3.1.6 Activity: Uplift rates in the controlled area

Objectives

The objective of this activity is to calculate the rate of uplift or subsidence in and around the controlled area.

Parameters

The parameter for this activity is the uplift or subsidence rates in and around the controlled area.

Description

This activity will compile and summarize data collected by other field data gathering activities that can be used to calculate the rates of uplift and subsidence affecting the controlled area. Data such as geodetic leveling and the geomorphic and geologic indicators of Quaternary uplift and subsidence will be used in the calculation. The rates estimated by this activity will be used by Activity 8.3.1.8.3.1.7 and the other studies in this investigation to assess the effect of uplift and subsidence on hydrologic conditions.

8.3.1.8.3.1.7 Activity: Assessment of the effects of folding, uplift, and subsidence on flux rates

Objectives

The objective of this activity is to assess the probability that folding, uplift, or subsidence will significantly alter average percolation flux rates at the top of the Topopah Spring welded unit over the repository.

Parameters

The parameters for this activity are

1. The probability of dip changing by greater than 2 degrees in 10,000 yr by folding.

2. The probability of exceeding 30 m of altitude change in 10,000 yr.

YMP/CM-0011, Rev. 1

Description

This activity will use the data generated by Activities 8.3.1.8.2.1.6 and 8.3.1.8.3.1.6 to calculate (1) the expected amount of change in dip and altitude in 10,000 yr and (2) the probability that significant changes would occur. If significant changes are considered credible, models based on the present conditions controlling flux rates in Study 8.3.1.2.2.5 will be developed to consider the perturbations to current conditions resulting from the tilting of beds and changes to topography that could occur. A report will be prepared that includes the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.3.2 Study: Analysis of the effect of tectonic processes and events on changes in water-table elevation

This study will produce analyses and assessments of the probability that tectonic initiating events could result in significant changes in the elevation of the water table or potentiometric surface, changes in the hydraulic gradient, the creation of discharge points in the controlled area, or the creation of perched aquifers in the controlled area.

8.3.1.8.3.2.1 Activity: Thermal and barrier-to-flow effects of igneous intrusions on water-table elevation

Objectives

The objective of this activity is to model the effects that dikes or other intrusions would have on water-table elevation due either to the barrier to flow created by intrusion or the thermal pulse produced by the intrusion.

Parameters

The parameters for this activity are models for predicting the effects of igneous intrusions on water-table levels. The data requirements supporting the modeling efforts and the relationship of the requirements to the data gathering activities that will support this activity are shown on Figure 8.3.1.8-6.

 YMP/CM-0011, Rev. 1

Description

This activity will produce models for use in assessing the effects of igneous intrusions on water-table levels. The relationship of this modeling activity to data gathering activities is shown on Figure 8.3.1.8-6. These models will be based on the computer models of present ground-water flow developed in Activity 8.3.1.2.3.3.1. These computer codes will be used directly or modified by the hydrologists from the 8.3.1.2 program who are assigned to this activity. The first part of the modeling activity will consider the perturbations to current conditions resulting from the barriers to flow that intrusive features such as a dike might produce. Dikes of various sizes and orientations will be modeled to estimate the range of effects and determine at what point igneous intrusions would begin to produce significant changes.

The second part of the modeling activity will consider the thermal effects of an intrusion on water levels. As discussed in Sections 1.3.2.1.2 and 1.5.1, basaltic volcanism is considered to be the only credible intrusive scenario during the postclosure period. This type of activity is characterized by the intrusion of dikes from magma bodies with depths of 20 to 30 km. Therefore, the intrusion of a dike is considered to be the only credible process by which changes in the thermal characteristics of the site could occur. Published methods (e.g., Link et al., 1982) will be used to calculate the magnitude and extent of thermal changes around a dike. The results of Activity 8.3.1.8.1.1.3 will also be reviewed to determine if there are any indications of magma bodies in the vicinity of the site with the potential for significant movement in 10,000 yr that could produce significant changes in the thermal gradient. Computer models based on the ground water flow models developed in Activity 8.3.1.2.3.3.1 will then be generated that predict the effects of thermal changes on water levels. These models will be used by Activity 8.3.1.8.3.2.2 in the assessment of the probability that igneous intrusions will cause significant changes in water-table levels.

8.3.1.8.3.2.2 Activity: Assessment of the effects of igneous intrusions on water-table elevations

Objectives

The objective of this activity is to produce an assessment of the probability that igneous intrusions will cause (1) significant changes in the elevation of the water table or potentiometric surface, (2) changes in the hydraulic gradient, (3) the creation of discharge points in the controlled area, or (4) the creation of perched aquifers in the controlled area.

Parameters

The parameters for this activity are

1. Barrier-to-flow effects of igneous intrusions on water-table levels and hydraulic gradients.

 YMP/CM-0011, Rev. 1

2. Thermal effects of igneous intrusions (such as heat from below, point sources, line sources, or spherical sources) on water-table levels and hydraulic gradients.

Description

This activity will use the data in Activity 8.3.1.8.3.1.1 to estimate the probability of an igneous event occurring in or near the controlled area. It will also collect and summarize data from other data gathering activities (Figure 8.3.1.8-6) to estimate the length, thickness, and orientation of possible future intrusions. This data will then be used with models developed in Activity 8.3.1.8.3.2.1 to estimate the effects of expected intrusions. This activity will also review the available literature for evidence of water-table changes during volcanic events in other parts of the world that are analogous to the types of events that might occur in the vicinity of the site. All of this information will then be integrated to produce an assessment of the probability that igneous intrusions will cause significant changes in the elevation of the water table or potentiometric surface, changes in the hydraulic gradient, the creation of discharge points in the controlled area, or the creation of perched aquifers in the controlled area. The results will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.
2. A discussion of the modeling techniques used and their results.
3. The results of the assessment.
4. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.3.2.3 Activity: Assessment of the effect of strain changes on water-table elevation

Objectives

The objective of this activity is to estimate the probability that changes in stress or strain resulting from faulting events could significantly alter water-table levels or potentiometric surfaces in and around the controlled area.

Parameters

The parameter for this activity is the probability that strain-induced changes will increase the water-table level or the level of potentiometric surfaces to more than 850 m mean sea level (MSL).

YMP/CM-0011, Rev. 1

Description

This activity will use the models of present flow in the saturated zone from Activity 8.3.1.2.3.3.1 to develop a model to predict the effects on the level of the water table or potentiometric surfaces in the vicinity of the site of changes in the present level of stress or strain caused by a faulting event. Data on the magnitude of such changes in stress and strain will be estimated using theoretical calculations and data from Activity 8.3.1.17.4.12.1. The model will be used to estimate the effects of anticipated strain changes and to determine the point at which such strain changes could become significant.

This activity will also compile and analyze data on the effects of historic earthquakes on water-table elevations. Earthquakes that have induced water-table fluctuations will be studied to determine the type of material in which changes occurred (rock or alluvium), the amount and duration of changes, and the local geologic and ground-water conditions that may influence whether or not significant changes occur. The results of this analysis will be compared with conditions present at the site to estimate whether any of these occurrences represent analogs of possible future site behavior.

Field evidence from the site will be reviewed to determine if there is any evidence of past water-table fluctuations that may be related to tectonic events. For example, the results of Activity 8.3.1.5.2.1.5 will be reviewed to determine whether or not the calcite-silica deposits that are found along some faults are episodic spring deposits that may be related to fluctuations of the water table or potentiometric surface or whether the deposits are the result of surface pedogenic processes.

The results of these studies will then be incorporated into an assessment evaluating the possibility of significant water-table fluctuations due to strain changes. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.3.2.4 Activity: Assessment of the effect of folding, uplift, or subsidence on water-table elevation

Objectives

The objective of this activity is to provide an assessment of the probability that folding, uplift, or subsidence could change the elevation of the repository with respect to the level of the water table sufficiently to significantly alter the length of the unsaturated zone travel path.

YMP/CM-0011, Rev. 1

Parameters

The parameter for this activity is the probability that the repository will be lowered by 100 m through the action of folding, uplift, or subsidence in 10,000 yr.

Description

This activity will use the data generated by Activities 8.3.1.8.2.1.6 and 8.3.1.8.3.1.6 to calculate the expected amount of change in the elevation of the repository horizon over 10,000 yr caused by folding, uplift, or subsidence. This activity will also assess the probability that changes of a significant nature would occur. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.3.2.5 Activity: Effects of faulting on water-table elevation

Objectives

The objective of this activity is to produce models to analyze the potential for fault offset to change the elevation of the water table or potentiometric surface, change the hydraulic gradient, create discharge points in the controlled area, or create perched aquifers in the controlled area.

Parameters

The parameters for this activity are the models for predicting the effects of faulting on water-table levels.

Description

This activity will use the models of present flow in the saturated zone from Activity 8.3.1.2.3.3.1 and unsaturated zone from Studies 8.3.1.2.2.8 and 8.3.1.2.2.9 to develop a model to predict the effects of a faulting event on the level of the water table or the creation of a perched aquifer. The effects of a variety of fault offsets, orientations, down-dip geometries, and locations will be calculated to estimate the point at which faulting could become significant. The models produced by this activity will be used by Activity 8.3.1.8.3.2.6 in the assessment of the effects of faulting on water-table levels.

 YMP/CM-0011, Rev. 1

8.3.1.8.3.2.6 Activity: Assessment of the effect of faulting on water-table elevation

Objectives

The objective of this activity is to prepare an assessment of the probability that fault offset will result in significant changes in the elevation of the water table or potentiometric surface, changes in the hydraulic gradient, the creation of discharge points in the controlled area, the creation of perched aquifers in the controlled area in 10,000 yr.

Parameters

The parameters for this activity are

1. Probability of cumulative offsets more than 2.0 m in 10,000 yr on faults within 0.5 km of the controlled area boundary.

2. Effects of fault offset on water-table levels and hydraulic gradient.

Description

This activity will use the data on slip rates and recurrence intervals on Quaternary faults in and near the controlled area from Activity 8.3.1.8.3.1.4 to calculate the expected cumulative displacement in 10,000 yr and the probability of significant cumulative offset (>2 m) occurring on any fault. These data and data on the length and location of Quaternary faults will then be used with the models produced in Activity 8.3.1.8.3.2.5 to estimate the changes that would be produced under anticipated and unanticipated conditions.

This activity will also consider the results of Activity 8.3.1.8.3.2.3 on the evidence of possible past changes in water-table levels in the site area and the effects of faulting during historic earthquakes on water-table levels. The above data will then be incorporated into an assessment of the probability of significant cumulative fault offsets occurring in 10,000 yr and the effects of cumulative fault offset on water-table elevation. The assessment will include an analysis of possible changes in the elevation of the water table or potentiometric surface, changes in the hydraulic gradient, the creation of discharge points in the controlled area, the creation of perched aquifers based on the results of the modeling and probability calculations. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. A discussion of the modeling techniques used and their results.

3. The results of the assessment.

4. An analysis of the assumptions and uncertainties in the data and the assessment.

YMP/CM-0011, Rev. 1

8.3.1.8.3.3 Study: Analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity

The activities in this study address tectonic initiating events and processes that could cause local changes in saturated fracture permeability or fracture effective porosity.

8.3.1.8.3.3.1 Activity: Assessment of the effects of igneous intrusions on local fracture permeability and effective porosities

Objectives

The objective of this activity is to assess the possibility that igneous intrusions, such as dikes or sills, could cause changes in the hydrologic flow properties of the surrounding rocks.

Parameters

The parameters for this activity are the effects of igneous intrusions on local fracture permeabilities and effective porosities.

Description

This activity will use the results of Activity 8.3.1.8.3.1.1 on the probability of igneous intrusions in and near the controlled area and Activity 8.3.1.8.5.2.3, which measures the nature and extent of physical changes around intrusions in tuff. These data will be reviewed, summarized, and combined into an assessment of the probability that igneous intrusions could result in significant changes in local saturated fracture permeability and fracture effective porosity. The assessment will also include a consideration of how probable changes in physical properties could affect the movement of gaseous decay products in the unsaturated zone. The assessment will be summarized in a report that includes the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.3.3.2 Activity: Assessment of the effects of faulting on local fracture permeability and effective porosities

Objectives

The objective of this activity is to assess the probability that movement on faults could result in significant local changes in saturated fracture permeability and fracture effective porosity along the fault that could affect the regional ground water flow system.

 YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are

1. The annual probability of faulting events on Quaternary faults within 0.5 km of the controlled area boundary.

2. The effects of fault motion on local fracture permeabilities and effective porosities.

Description

This activity will determine the nature of faulting and calculate the annual probability of faulting in and near the controlled area using the data on slip rates, recurrence intervals, down-dip geometry, and number of faults from Activity 8.3.1.8.3.1.3. Data on the width of fracture zones around faults, evidence of the possible episodic brecciation and recementation of mineral fillings along fault zones, and the age and nature of the mineral fillings will be collected and summarized after reviewing the core logs, the geologic mapping of shaft and drifts, and fracture mineralogy studies collected by other field data gathering activities (Figure 8.3.1.8-7) near Quaternary faults. These data will be analyzed to determine the nature, extent, and duration of changes in physical properties that could occur along faults in the vicinity of the site. An assessment of the probability of significant changes will then be produced by integrating all the above results. The assessment will also include a consideration of how the probable changes in physical properties could affect the movement of gaseous decay products in the unsaturated zone. The assessment will be summarized in a report that includes the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.3.3.3 Activity: Assessment of the effects of stress or strain on hydrologic properties of the rock mass

Objectives

The objective of this activity is to assess the probability that changes in stress or strain conditions around the site caused by a tectonic event could result in significant changes in the saturated fracture permeability and fracture effective porosity of the rock mass.

Parameters

The parameters for this activity are the effects of changes of stress or strain on hydrologic properties of the rock mass.

YMP/CM-0011, Rev. 1

Description

This activity will use theoretical calculations and the data from Activity 8.3.1.17.4.12.1 to estimate the magnitude of stress and strain changes through the faulting cycle for the site area. Modeling studies will then be performed to estimate the effect that these changes might have on hydrologic properties. These results will then be combined with the probability of faulting events in and near the controlled area to calculate the probability that significant changes in the physical properties of the rock mass could occur. The assessment will also include a consideration of how the probable changes in physical properties could affect the movement of gaseous decay products in the unsaturated zone. The assessment will be summarized in a report that includes the following topics:

1. A summary of the data used in the assessment.
2. A summary and discussion of the models used in the assessment and their results.
3. The results of the assessment.
4. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.4 Investigation: Studies to provide information required on changes in rock geochemical properties resulting from tectonic processes

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.3.2.2	Structural history
1.5.1.2	Basaltic volcanism
1.5.2	Faulting
4.1.3.7	Geochemical retardation of the host rock and surrounding units--anticipated conditions
4.1.3.8	Geochemical retardation of the host rock and surrounding units--unanticipated conditions
4.4.2	Potential effects of natural changes

YMP/CM-0011, Rev. 1

Parameters

The following performance parameters will be measured or calculated as a result of the site studies planned as part of this investigation:

1. Effects of igneous intrusions on local distribution coefficients.

2. Degree of mineralogic change in fault zones in 10,000 yr.

3. Effects of fault offset on travel pathway.

4. Degree of mineralogic change in the controlled area resulting from changes in water-table level or flow paths due to tectonic processes in 10,000 yr.

Purpose and objectives of the investigation

The four performance parameters listed in the previous section have been identified by Issue 1.1 (Section 8.3.5.13, total system performance, and Table 8.3.1.8-6) to address the possibility that tectonic processes and events could produce significant changes in the geochemical properties of the rocks of the controlled area that control the rate of radionuclide movement (distribution coefficients (K_ds)). The study and activities in this investigation will address these requirements by providing assessments of the probability that the tectonic initiating events that have been recognized by Issue 1.1 could significantly alter distribution coefficients. These results will be used by Issue 1.1 to analyze total system performance of the repository in limiting radionuclide releases to the accessible environment. The initiating events considered in this investigation probably will have no significant impact on repository performance because of the very low rate at which mineral alteration occurs in the site area (see Section 4.1.1.4). It is anticipated that the data to be gathered in the geochemistry program (Section 8.3.1.3) to address other concerns will provide the data necessary to evaluate the rate of geochemical change. The level of effort for the activities related to these initiating events is therefore anticipated to be low and to consist primarily of organizing and presenting the data collected in other programs to provide the basis for evaluating the credibility of the initiating events in performance assessment activities.

This investigation will also provide data on the nature of tectonic processes operating at the site for use by Issue 1.8 (Section 8.3.5.17, NRC siting criteria) in its analysis of favorable and potentially adverse conditions. The specific conditions addressed by this investigation are listed on Table 8.3.1.8-6.

Technical rationale for the investigation

The flow of data and interconnections between activities in the single study of this investigation are shown on Figure 8.3.1.8-8. The first tectonic initiating event considered in this investigation is the possibility that an igneous intrusion could alter the mineralogy of the surrounding host rocks. Activity 8.3.1.8.4.1.1 will provide an assessment of this initiating event and satisfy parameter 1 by considering (1) the probability of an igneous intrusion occurring in the controlled area and (2) the extent and nature

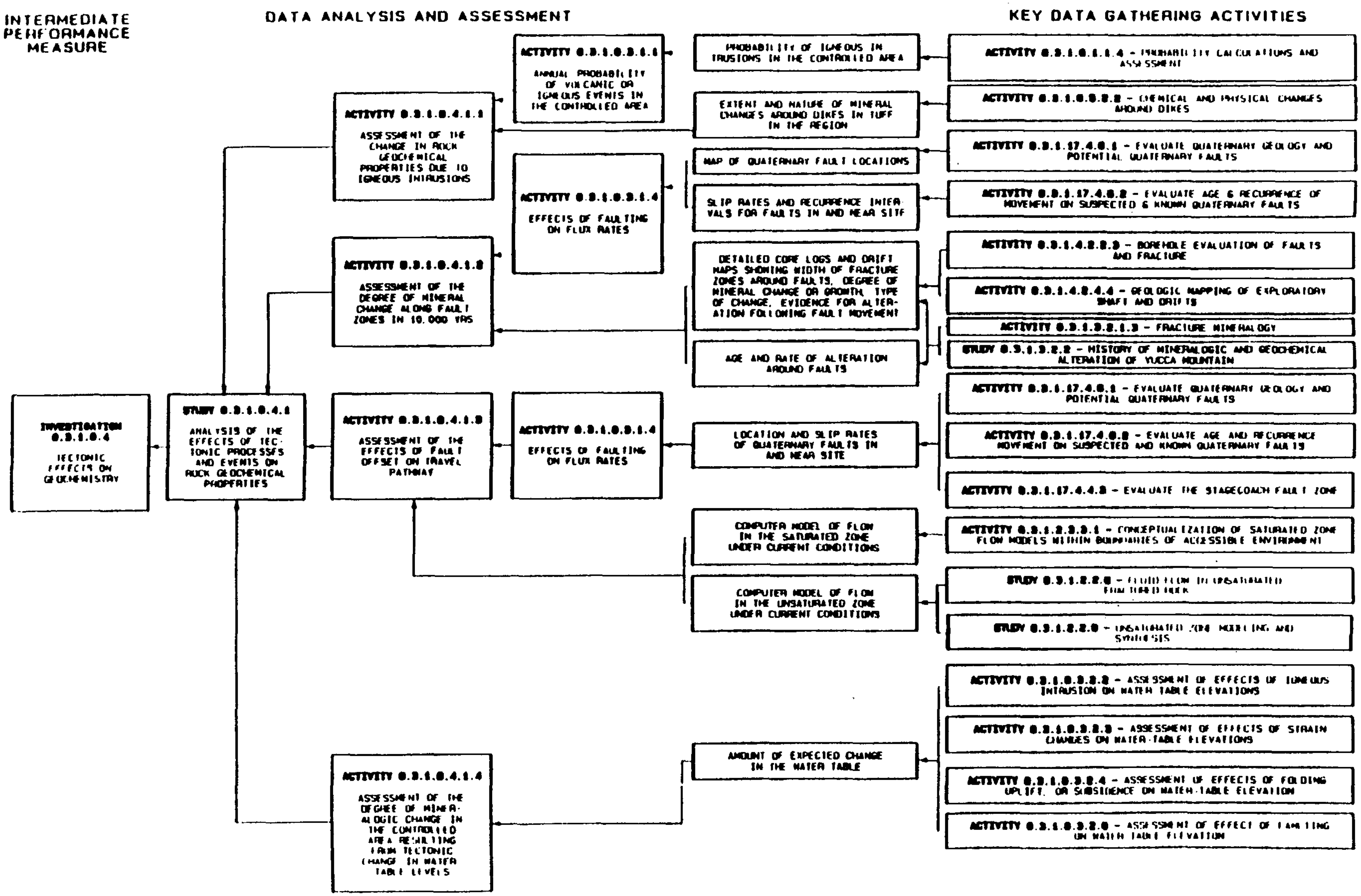

Figure 8.3.1.8-8. Logic diagram for Study 8.3.1.8.4.1 (analysis of the effects of tectonic processes on rock geochemical properties).

YMP/CM-0011, Rev. 1

of mineral changes that have been found to occur around dikes and sills in tuffs during field studies. The activity will combine these data in an assessment of the probability that significant changes would occur.

The second initiating event considers the possibility that offset on a fault could result in significant mineral changes along the fault that could affect local distribution coefficients. Changes in distribution coefficients could result from the growth of mineral fillings in the fault zone itself or from the sealing effect of the mineral fillings that prevent interaction between fluids moving through the fault zone and the surrounding country rock. Activity 8.3.1.8.4.1.2 will provide an assessment of this initiating event and satisfy parameter 2 by analyzing data from core and the mapping of drifts and shafts to review the evidence of significant changes during past faulting events to determine the age, type, and extent of mineral changes that have occurred. The probability and location of faulting events will be determined from mapping and trenching activities that will provide data on slip rates, recurrence intervals, and locations of Quaternary faults. The assessment will integrate these data.

The third initiating event considers the possibility that offset on a fault could significantly affect distribution coefficients by diverting flow to pathways with significantly different mineral properties or water chemistry as a result of the juxtaposition of different lithologic units. Activity 8.3.1.8.4.1.3 will provide an assessment of this initiating event and satisfy parameter 3 by conducting modeling studies to determine the amount of offset necessary to produce significant changes. The results of the modeling activity will be combined with the probability that such offsets could occur using data on slip rates and recurrence intervals of faults in and near the controlled area as part of the assessment. The activity will summarize the results of the assessment in a report.

The fourth initiating event considers the possibility that changes in water-table levels or ground-water movement as a result of tectonic processes could produce significant mineral alteration in the formerly unsaturated rocks. Activity 8.3.1.8.4.1.4 will provide an assessment of this initiating event and partially satisfy parameter 4 by calculating the probability of significant faulting events and the nature of water-table fluctuations that could be expected from such events. Activity 8.3.1.3.7.1.2 will complete the characterization of this parameter by calculating the rate that mineral changes could occur in this environment using data on the history of mineral and geochemical alteration at Yucca Mountain and incorporating the results in the integrated geochemical transport calculations. These data will be combined with the results of Study 8.3.1.8.3.2 on the probability of significant water-level changes occurring as the result of tectonic processes to complete the assessment. The activity will summarize the results of the assessment in a report.

 YMP/CM-0011, Rev. 1

8.3.1.8.4.1 Study: Analysis of the effects of tectonic processes and events on rock geochemical properties

The activities in this study provide assessments of the initiating events related to local changes in distribution coefficients resulting from tectonic processes and events.

8.3.1.8.4.1.1 Activity: Assessment of the change in rock geochemical properties due to igneous intrusions

Objectives

The objective of this activity is to assess the probability that igneous intrusions will cause significant changes in local distribution coefficients in the controlled area in 10,000 yr.

Parameters

The parameters for this activity are the effects of igneous intrusions on local distribution coefficients.

Description

This activity will use the data collected by Activity 8.3.1.8.5.2.2 on the nature and extent of mineral changes occurring around dikes in tuffs to evaluate whether the observed changes would significantly alter distribution coefficients in the controlled area. The results of this evaluation will be combined with the probability of igneous intrusions occurring in the controlled area from Activity 8.3.1.8.3.1.1 to produce the assessment on the probability of significant change. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.4.1.2 Activity: Assessment of the degree of mineral change along fault zones in 10,000 yr

Objectives

The objective of this activity is to assess the probability that local distribution coefficients will be significantly altered along faults in 10,000 yr by displacement events.

 YMP/CM-0011, Rev. 1

Parameters

The parameter for this activity is the degree of mineral change along a fault zone in 10,000 yr.

Description

This activity will review and summarize the data on the nature and extent of mineralization along faults for evidence of brecciation and recementation that would result from periodic fault offset. This data will come from drilling activities that recover core from fault zones and the activities that will conduct geologic mapping of the shafts and drifts of the exploratory shaft facility. Data on the age and mineralogy of these zones will also be used in an assessment of the nature, extent, and rate of possible changes in distribution coefficients. These results will be combined with the probability of faulting events occurring in the controlled area derived from the data on slip rates and recurrence intervals in Activity 8.3.1.8.3.2.3 to complete the assessment of the probability that significant changes will occur. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.

2. The results of the assessment.

3. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.4.1.3 Activity: Assessment of the effects of fault offset on travel pathway

Objectives

The objective of this activity is to assess the possibility that offsets occurring on faults in 10,000 yr in the controlled area will divert radionuclides to travel pathways with significantly different distribution coefficients or water chemistry.

Parameters

The parameters for this activity are the effects of fault offset on travel pathway.

Description

This activity will use models based on the models of flow in the saturated and unsaturated zones under current conditions from Activity 8.3.1.2.3.3.1 and Study 8.3.1.2.2.5 to estimate the amount of offset necessary to produce significant changes in radionuclide travel pathways. To produce the assessment, these results will be combined with the probability of such displacements occurring in the controlled area derived from slip rate

YMP/CM-0011, Rev. 1

and recurrence interval data in Activity 8.3.1.8.3.1.4. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.
2. A discussion of the modeling techniques and their results.
3. The results of the assessment.
4. An analysis of the assumptions and uncertainties in the data and the assessment.

8.3.1.8.4.1.4 Activity: Assessment of the degree of mineral change in the controlled area resulting from tectonically induced change in water-table elevations

Objectives

The objective of this activity is to assess the probability and nature of tectonically induced changes in water-table level that might result in significant mineral changes in the newly saturated or unsaturated rock.

Parameters

The parameter for this activity is the degree of mineral change in the controlled area resulting from changes in water-table level or flow paths caused by tectonic processes in 10,000 yr.

Description

This activity will generate an assessment of the probability that faulting events could significantly alter water levels during the postclosure period and estimate the amount of these water-table fluctuations. The data for this assessment will be provided by Study 8.3.1.8.3.2. The assessment will be used by Activity 8.3.1.3.7.1.2 to complete characterization of the parameter by calculating the degree of mineral change such fluctuation could produce and the effect of these changes on the geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. The results of the assessment will be summarized in a report that will include the following topics:

1. A summary of the data and calculations used in the assessment.
2. The results of the assessment.
3. An analysis of the assumptions and uncertainties in the data and the assessment.

 YMP/CM-0011, Rev. 1

8.3.1.8.5 Investigation: Studies to provide the information required by the analysis and assessment investigations of the tectonics program

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

The following sections of the SCP data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
1.3.2.1	Volcanic history
1.3.2.2	Structural history
1.5.1	Volcanism

Parameters

The following parameters will be measured or calculated during the studies planned to satisfy this investigation:

1. Location, age, and volume of igneous deposits younger than 4 million yr and within 70 km of the site.

2. Detailed maps showing the relation of geologic structures to selected young volcanic centers.

3. Map showing depth to curie isotherm.

4. Chemical and physical changes around dikes in tuff.

5. Petrology and geochemistry of late Cenozoic volcanic rocks in the region.

6. Evaluation of folding in the region and its relation to faulting or detachments.

7. Evaluation of heat-flow data.

Purpose and objectives of the investigation

The studies and activities in this investigation will collect the field data called for by the analysis and assessment activities in Investigations 8.3.1.8.1 through 8.3.1.8.4. Because most of the data required by these analysis and assessment activities are being collected by other programs, the activities in this investigation are limited to a small number providing data to support the analysis of volcanic, igneous intrusion, and folding processes. Figures 8.3.1.8-3 through 8.3.1.8-8 and Tables 8.3.1.8-1 through 8.3.1.8-6 show the relationship of the data gathering activities in this section to the analysis and assessment investigations.

 YMP/CM-0011, Rev. 1

Technical rationale for the investigation

One of the main requirements in the evaluation of the hazard of volcanic or igneous events is the calculation of the probability that such events would actually occur in the repository or the controlled area. Parameter 1 indicates the data required by Activities 8.3.1.8.1.1.1 and 8.3.1.8.1.1.4 to carry out this calculation. Activities 8.3.1.8.5.1.1 through 8.3.1.8.5.1.4 are designed to improve the existing data base on the age, location, and volume of young volcanic and igneous rocks in the region surrounding the site. These activities refine the dating of known occurrences using a variety of techniques, many of which have not previously been employed, and determine by drilling the nature of suspected buried deposits.

Another concern related to the probability of volcanism in the site area is that the location of any intrusion may not be entirely random across the area but controlled by structural features. To address this possibility, parameter 2 has been identified as one of the data requirements of Activity 8.3.1.8.1.1.2. Activity 8.3.1.8.5.1.3 will satisfy the requirement by completing detailed geologic mapping around selected volcanic features to clarify the relationship that might exist between the volcanic features and local structures. Parameter 5 has also been identified as a data requirement of Activity 8.3.1.8.1.1.2; this parameter will be used to address tectonic models for the time-space patterns of igneous events in the Yucca Mountain area and the structural controls for volcanic sites or future volcanic sites at or adjacent to Yucca Mountain. These data will be factored into probability calculations. Activity 8.3.1.8.5.1.5 will evaluate petrologic and volume trends of volcanic fields through time to test for indications of waning volcanism or increases in the rate of eruptive activity associated with decreasing eruption volumes.

For data on thermal anomalies in the area that might be related to magma bodies that could be sources of volcanic or igneous activity, parameters 3 and 7 have been identified as a data requirements of Activity 8.3.1.8.1.1.3. Activities 8.3.1.8.5.2.1 and 8.3.1.8.5.2.3 will satisfy the requirement by generating maps showing the depth to the curie isotherm and heat-flow data in the area surrounding the site.

Parameter 4 has been identified as a data requirement of both Activities 8.3.1.8.3.3.1 and 8.3.1.8.4.1.1 and will provide information on the nature and extent of physical and geochemical changes around dikes and other intrusions. Activity 8.3.1.8.5.2.2 will satisfy this requirement by collecting the required data from field studies of known intrusions in the region around the site and from literature reviews.

Parameter 6 will provide general regional data on the relationship of Neogene folding in the region to faults and detachments. Activity 8.3.1.8.5.3.1 will satisfy this parameter by reviewing the available literature and possible detailed mapping in selected areas.

YMP/CM-0011, Rev. 1

8.3.1.8.5.1 Study: Characterization of volcanic features

The activities under this study will provide refined data on the age, location, and volume of young volcanic rocks in the vicinity of the site. These data will be used to refine the calculations on the probability of igneous or volcanic events occurring in the controlled area and penetrating the repository. Much of the work for this study has been completed and is described in Chapter 1. The focus of this study is to summarize continuing activities that are necessary to complete risk assessment. The major activities include (1) geochronology studies to refine the ages of Quaternary basaltic activity and the youngest silicic volcanic activity in the Yucca Mountain area, (2) refining the area parameter used in probability calculations based on revised procedures to quantify the structural controls of surface volcanic centers, (3) drilling of prominent aeromagnetic anomalies in Crater Flat and the Amargosa Valley that are inferred to represent shallowly buried basaltic volcanic centers, and (4) collecting additional field data on the possibility of structural controls on volcanism in the vicinity of the site.

Other activities in this study will investigate the petrologic and geochemical cycles of volcanic fields in the region. The goals of these activities are to

1. Establish the geochemical sequence through time of the lava flows and scoria deposits at Crater Flat for correlation with basaltic ashes exposed in various trenches excavated in alluvium for the preclosure tectonic program (Study 8.3.1.17.4.6) and test petrologic models of polycyclic volcanism.

2. Examine and document the temporal and spatial geochemical patterns of the late Cenozoic basaltic fields of the southwest Basin and Range province. These patterns will be compared in Activity 8.3.1.8.1.1.2 with patterns established from the Crater Flat data and to test tectonic models for the spatial distribution for volcanic activity at the Crater Flat volcanic field.

These data will be used in Activity 8.3.1.8.1.1.2 to assess the significance of petrologic patterns of the Crater Flat volcanic field and to examine, in conjunction with geophysical data, the possibility that the Death Valley-Pancake Range volcanic zone (DV-PRVZ) represents an incipient rift zone.

8.3.1.8.5.1.1 Activity: Volcanism drillholes

Objectives

The objective of this activity is to investigate the origin of four aeromagnetic anomalies found in Crater Flat and the Amargosa Valley. These anomalies are inferred to represent shallowly buried basaltic or silicic volcanic centers or intrusive bodies. The anomaly sites will be drilled and continuous core recovered from the drillholes. Data from this work will be

 YMP/CM-0011, Rev. 1

used to refine probability calculations, to evaluate the tectonic setting of volcanic centers, and to test concepts of the temporal geochemical patterns of basalts in the NTS region.

Parameters

The data gathered by other activities and needed for this activity are

1. The location and extent of aeromagnetic anomalies.

2. The potassium-argon (K-Ar) and Ar-40/Ar-39 age determinations of volcanic material recovered by the drilling program. This information will be obtained from Activity 8.3.1.8.5.1.2.

The data to be gathered by this activity are

1. Core from drillholes.
2. Stratigraphy and location of core from drillholes.
3. Magnetic polarity measurements of core.
4. Major-element geochemical data of recovered volcanic materials.
5. Trace-element geochemical data of recovered volcanic materials.
6. Sr and Nd isotopic data of recovered volcanic materials.
7. Petrography of recovered volcanic materials.

Description

The inferred, buried volcanic centers may represent volcanic events that have not been documented in the geologic record. These anomalies need to be drilled, dated, and volumes obtained to apply to volcanic rate calculations used for the probability model for the Yucca Mountain area.

Four anomalies have currently been identified from aeromagnetic data for investigation using drillholes (USGS, 1978). One is located in southwest Crater Flat; the remaining three are in the Amargosa Valley (Figure 8.3.1.8-9). The anomaly sites will be drilled and core recovered from volcanic rocks encountered in the hole. Four drillholes are currently planned and each will be drilled to a depth of approximately 330 m.

The anomalies may be buried surface volcanic centers or they could be intrusive bodies. If they are intrusive bodies, there are no established constraints on their age--they could be as young as the younger events in the Yucca Mountain region. The thickness of the recovered volcanic core material and the geometry of aeromagnetic anomalies will be used to estimate volumes of buried volcanic centers. This data will be combined with potassium-argon ages to refine probability calculations and establish a tectonic model of basaltic volcanic activity (Activity 8.3.1.8.1.1.4). K-Ar ages of the core will be combined with major- and trace-element data and isotopic data to test geochemical patterns of basaltic volcanism in the NTS region (Activities 8.3.1.8.5.1.4 and 8.3.1.8.5.1.5).

YMP/CM-0011, Rev. 1

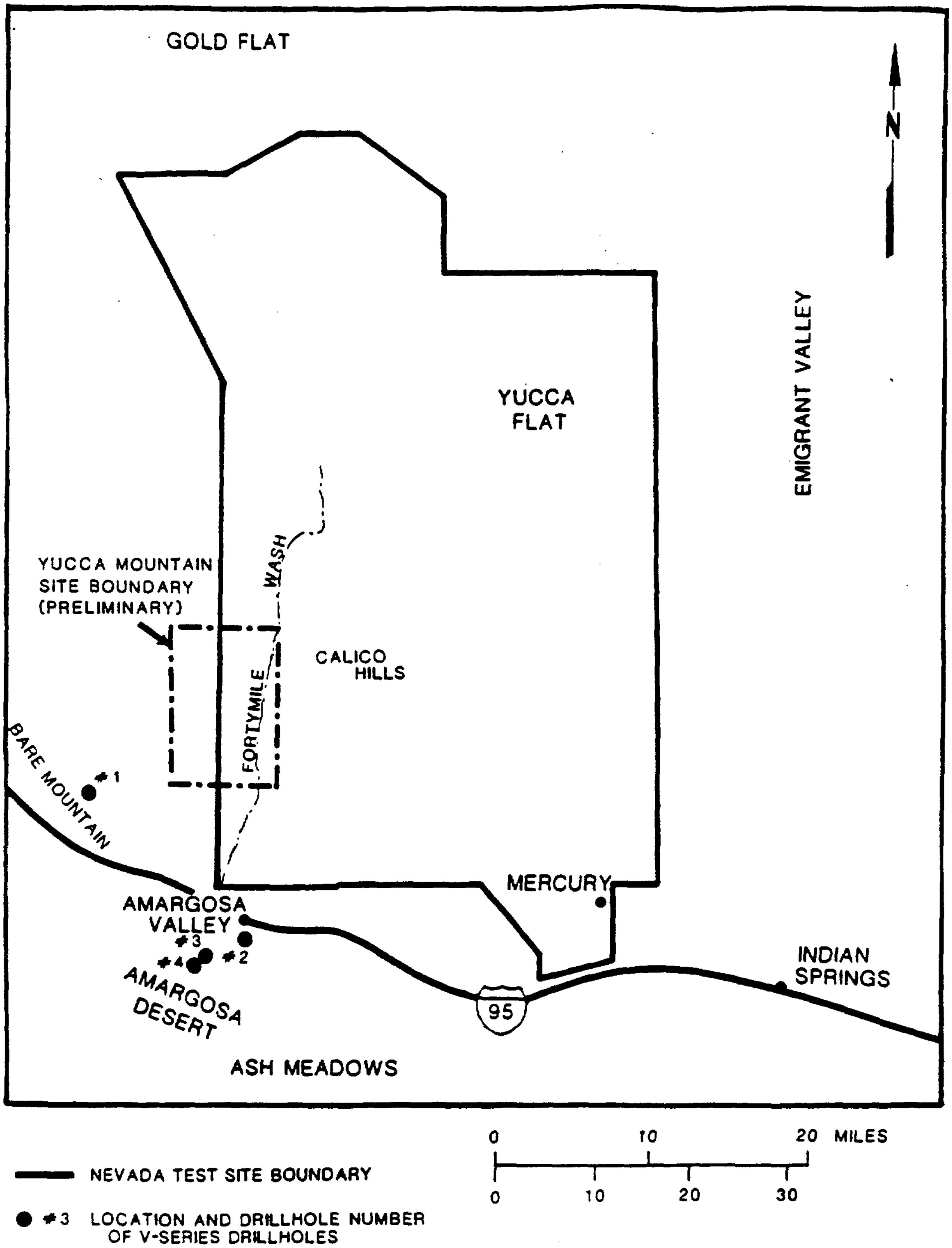

Figure 8.3.1.8-9. Map showing location of volcanism drillholes

 YMP/CM-0011, Rev. 1

8.3.1.8.5.1.2 Activity: Geochronology studies

Objectives

The objective of this activity is to establish the chronology of basaltic volcanism and the youngest silicic volcanic activity in the Yucca Mountain region. These data will be used to revise the rate parameter of the volcanic probability calculations and to determine the age of cessation of silicic volcanic activity. The geochronology studies have been under way for a number of years and the chronology of older basaltic activity (> 8 million yr) has been established. Further studies are required for three topics:

1. The age of Quaternary volcanic events in the Yucca Mountain region.

2. The age of the youngest volcanic event in the Yucca Mountain area.

3. The age of the youngest silicic volcanic activity in the region with emphasis on the Black Mountain caldera or young silicic rocks that may be encountered in shallow volcanic drillholes.

Parameters

The data gathered by other activities and needed for this activity are

1. Geographic location and geologic field relations of volcanic rocks or volcanic features used for age determinations. This information will be obtained from Activity 8.3.1.8.5.1.3.

2. Core from volcanic rocks recovered from the volcanism drillholes. This material will be obtained from Activity 8.3.1.8.5.1.1.

The data to be gathered by this activity are

1. Age determinations of volcanic rocks using the potassium-argon (K-Ar) and Ar-40/Ar-39 methods.

2. Age determinations of silicic volcanic rocks using a single crystal, laser-fusion method for determination of the Ar-40/Ar-39 ages.

3. U-Th disequilibrium measurements of crystals and whole rock for age calibration of basaltic volcanic rocks.

4. Measurement of the cosmogenic He-3 accumulation in basaltic volcanic rocks to obtain the surface exposure age of the rocks.

5. Measurement of the cosmogenic Cl-36 accumulation in basaltic volcanic rocks to obtain the surface exposure age of the rocks.

6. Measurement of cation element ratios in desert varnish developed on basaltic volcanic rocks to calibrate the time of surface exposure of the rocks.

YMP/CM-0011, Rev. 1

7. Carbon-14 dating of desert varnish developed on basaltic volcanic rocks to determine the surface exposure age of the rocks or volcanic features.

8. Measurement of the paleomagnetic pole position of young basaltic volcanic rocks to test age constraints from crystallization and surface exposure age determinations.

9. Measurement of scoria cone and lava flow geomorphic parameters to evaluate the surface exposure age of the volcanic features.

10. Measurement of soil development for evaluation of the age of soils developed on young basaltic rocks or volcanic features.

Description

Potassium-argon (K-Ar) age determinations are needed to establish the chronology of volcanic activity in the Yucca Mountain region. Previous work has established the timing of major episodes of activity in the region (Crowe et al., 1986). The focus of work for probability calculations has been based on patterns of basaltic activity during the last 4.0 million yr (Crowe et al., 1982). The age of basaltic volcanic events during this interval is a key parameter for the probability calculations. It is important, therefore, to obtain high quality age determinations for volcanic events in this age interval. Duplicate ages are needed for the volcanic centers to (1) establish the accuracy and precision of the age determinations and (2) allow statistical analysis of age data.

A second problem is the age of the youngest silicic volcanic center in the Yucca Mountain region, the Black Mountain caldera. Published ages of the Thirsty Canyon Tuff, the major outflow unit of the Black Mountain caldera, are as young as 6.5 million yr (Kistler, 1968). These age determinations were obtained from anorthoclase mineral separates. This mineral tends to lose Ar and therefore the ages are probably minimum ages and do not record the crystallization age of the mineral. Dated basalt flows that overlie individual units of the Thirsty Canyon Tuff range in age from 8.0 to 9.1 million yr and are inconsistent with the anorthoclase ages. This inconsistency needs to be resolved through additional K-Ar dating of the overlying basalt flows and determination of single-crystal Ar-40/Ar-39 ages of minerals in the Thirsty Canyon Tuff.

The final problem that requires refinement of continuing work is an evaluation of the age or ages of the Lathrop Wells volcanic center. This center was considered to be about 200,000 to 300,000 yr old as reported in the environmental assessment for Yucca Mountain (DOE, 1986b). However, new data suggest the lava flows are somewhat younger and the scoria cone is much younger than this reported age (Wells et al., 1988; Crowe et al., 1988; Crowe and Turrin, 1988). A sufficient number of K-Ar dates will be obtained to resolve the age of the lavas through statistical analysis and to address the problem of why there has been such variability in the results of K-Ar age determinations. Dating of the scoria cone is much more difficult. To resolve this problem, a variety of techniques will be used that either provide crystallization ages of the magma that formed the cone or date the

 YMP/CM-0011, Rev. 1

time of surface exposure of the cone. Because these techniques are developmental, multiple results will be obtained from two separate laboratories, and the results will be compared for consistency. Additionally, the measurements of paleomagnetic pole positions, the evaluation of geomorphic parameters of the cone, and the soils chronology provide cross-checking procedures for the data obtained from crystallization ages and surface exposure ages.

8.3.1.8.5.1.3 Activity: Field geologic studies

Objectives

The objective of this activity is to establish the field geologic relations and the eruptive history of basaltic volcanic centers in the Yucca Mountain region. Most of the work is completed, including reconnaissance mapping of older volcanic centers (>6 million yr) and detailed mapping of younger volcanic centers. Two problems remain:

1. Recently acquired geochronology data have shown that some small volume basalt centers may be polycyclic (i.e., formed during multiple cycles of volcanic activity separated by significant intervals of inactivity). Further geologic mapping coupled with geochronology studies are required to investigate how common polycyclic activity is at the young (<4.0 million yr) volcanic centers of the Yucca Mountain region.

2. Field studies are needed to attempt to correlate scoria sequences exposed in alluvial deposits in trenches with the scoria cone deposits in the Crater Flat area.

Parameters

The data gathered by other activities and needed for this activity are

1. The results of geochronology studies from Activity 8.3.1.8.5.1.2.

2. The results of scoria geochemistry studies from Activity 8.3.1.8.5.1.4.

The data to be gathered by this activity are

1. Contact relations and geologic maps of basaltic volcanic centers in the Yucca Mountain region.

2. Eruptive sequences of basaltic volcanic centers in the Yucca Mountain region.

3. Volumes of eruptive deposits of the basaltic centers in the Yucca Mountain region.

4. Tephra sequences and correlations among the scoria deposits of the basaltic volcanic centers of the Yucca Mountain region.

 YMP/CM-0011, Rev. 1

Description

A major assumption over the past several decades in geology is that small volume volcanic centers form during short periods of time (days, months, or at most years). Rock units such as separate lava flows or scoria cone clusters at basaltic volcanic centers are inferred to have formed virtually instantaneously relative to the resolving ability of conventional dating techniques. Recent geologic work using new techniques for dating the time of surface exposure of volcanic features combined with geomorphic analysis of degradation rates of volcanic features, and calibration of the time required for development of soils on young volcanic rocks has shown that some basaltic volcanic centers may be polycyclic. This means that they were formed from multiple pulses of basaltic activity with significant time intervals between events. The time interval between pulses may be sufficiently long to affect the rate parameter of probability calculations. Studies at the Lathrop Wells volcanic center suggest that it was formed by two, possibly three, pulses of basaltic magma over a period of time that may have exceeded 100,000 yr. Further geologic mapping coupled with geochronology studies are needed to evaluate the possibility of multiple eruption cycles at the Quaternary volcanic centers of the Yucca Mountain region. This work will allow refinement of constructed curves of magma volume versus time, which yields the rate of generation of magma, a key parameter for probability calculations. The second problem, correlation of tephra sequences, requires the same information base. Petrologic studies conducted to date assume the composition of lava represents the composition of the entire range of eruptions at small volume basalt centers. If these centers are polycyclic, the magma that formed separate pulses may differ in composition. Geologic mapping is required to identify the separate eruptive units, and these units will be evaluated as potential eruptive sources for tephra deposits that are interbedded with alluvium in the Yucca Mountain region.

8.3.1.8.5.1.4 Activity: Geochemistry of scoria sequences

Objectives

The objective of this activity is to determine the geochemistry of scoria sequences of different ages at the Lathrop Wells center and older centers in the Crater Flat area. These data will be used to test and develop petrologic models of polycyclic volcanism. The models will be used to test geologic assumptions made for (1) the probability calculations and (2) the time-space tectonic model for the distribution of basaltic volcanism developed from Activity 8.3.1.8.1.1.2. In addition, the data on the geochemistry of the scoria sequences will also be used to correlate basaltic ash interbedded in trenches with their correct eruptive source.

Parameters

The data gathered by other activities and needed for this activity are

1. Field relationships of scoria sequences at the Lathrop Wells volcanic center. This information will be obtained from Activity 8.3.1.8.5.1.3.

2. Ages of multiple scoria sequences at the Lathrop Wells center. This information will be obtained from Activity 8.3.1.8.5.1.2.

The data to be gathered by this activity are

1. Major-element data of scoria from Lathrop Wells center, centers of the 1.1 to 1.5 million-year-old event in Crater Flat, and the 0.3 million-year Sleeping Butte basalt centers.

2. Trace-element data of scoria from Lathrop Wells center, centers of the 1.1 to 1.5 million-year-old event in Crater Flat, and the 0.3 million-year Sleeping Butte basalt centers.

3. Mineral chemistry and petrography of scoria from Lathrop Wells center, centers of the 1.1 to 1.5 million-year-old event in Crater Flat, and the 0.3 million-year Sleeping Butte basalt centers.

4. Major- and trace-element chemistry of lava flows at the Lathrop Wells center, the 1.1 to 1.5 million-year cycle in Crater Flat, and the 0.3 million-year Sleeping Butte basalt center. Most of this information has already been obtained (Crowe et al., 1986).

Description

At least two eruptive events, separated by a significant time interval, occurred at the Lathrop Wells center. This indicates that small basaltic centers of this type may be polycyclic. The major-, trace-element, and mineral chemistry of scoria sequences, bombs, and lava flows will be determined and combined with chronologic information (Activity 8.3.1.8.5.1.2) to test petrologic models of polycyclic volcanism. An understanding of the mechanisms of polycyclic volcanism derived from this modeling will provide an important means of assessing the possibility of future eruptions at the Lathrop Wells center. The geochemistry of scoria sequences will be used to correlate eruptive events to basaltic ash deposits exposed in trenches dug for tectonic studies (Study 8.3.1.17.4.6). In addition, the geochemistry of scoria can be used to constrain the existence of discrete eruptive events where field relationships may be ambiguous.

8.3.1.8.5.1.5 Activity: Geochemical cycles of basaltic volcanic fields

Objectives

The objective of this activity is to determine the time-space geochemical variations of the volcanic fields of the southern Great Basin. These patterns will be compared with the documented geochemical patterns for the volcanic fields of the Yucca Mountain area. This information will be used to test a model that associates changes in basalt composition, increases in the eruptive frequency of polycyclic eruptions, and decreases in the volume of eruptive activity with the waning or termination stages of basaltic volcanic fields. This model, if valid, supports the idea that the Yucca

 YMP/CM-0011, Rev. 1

Mountain area has passed the peak of maximum basaltic volcanic activity. Probability calculations, which are based on the peak rate of activity, could therefore be shown to be a worst-case approach to volcanic risk assessment.

Parameters

The data gathered by other activities and needed for this activity are geologic, geochemical, and geochronologic data (geologic maps, geochemical data, and K-Ar ages) for volcanic fields of the southern Great Basin. This information will be obtained from the published literature and from Activities 8.3.1.8.5.1.2, 8.3.1.8.5.1.3, and 8.3.1.8.5.1.4.

The data to be gathered by this activity are geochemical patterns of basaltic volcanism through time for volcanic fields of the southern Great Basin.

Description

Geochemical and geochronological studies of basalt of the Yucca Mountain area have shown that there are distinct variations in these parameters with time. Early eruptions were moderately high volume (> 0.5 km^3) hypersthene hawaiite (3.7 to 1.1 million years). Subsequent eruptions were smaller volume (0.1 km^3) and the rocks are increasingly undersaturated (Vaniman et al., 1982; Crowe et al., 1986). Similar trends have been noted at the Lunar Crater and southern Death Valley volcanic fields (Crowe et al., 1986). These geochemical patterns may be indicative of the terminal stage of basaltic volcanic activity at a volcanic field. If this interpretation is valid, it supports the concepts being developed for the volcanic/tectonic model for the Crater Flat area, including (1) southwesterly migration of basaltic volcanic activity in the Yucca Mountain region and (2) the observed decreased volume of basaltic activity in the Yucca Mountain area. Both concepts support the assumption that the calculated probability bounds for future volcanic activity at Yucca Mountain are worst-case values. If volcanism is waning for this area, rates of magma generation calculated for past volcanic activity should be higher than future rates.

These concepts need to be tested by examining the time-space geochemical trends of other basaltic fields of the southern Great Basin. Emphasis would be placed on examining the geochemical patterns of older fields where there is clear evidence that volcanic activity has ended (no basaltic volcanic activity in Quaternary time). The patterns observed for the Yucca Mountain area need to be corroborated at several volcanic fields to support the volcanic/tectonic model. A second important parameter is the apparent increased frequency of volcanic eruptions associated with the transition to small volume, undersaturated basalt. This parameter needs to be investigated to determine if the trend could result in small-scale fluctuations in rates of volcanic activity. The fluctuations could be significant in forecasting future volcanic activity.

YMP/CM-0011, Rev. 1

8.3.1.8.5.2 Study: Characterization of igneous intrusive features

The activities in this study will gather data concerning the presence of thermal anomalies in the area and data on the geochemical and physical effects of intrusions on the surrounding rock. The evidence for the presence or absence of thermal anomalies will be used as part of the evaluation of the presence of significant magma bodies in the area and their relation to the probability of future volcanic events. The data on the effects of intrusions on surrounding rocks will be used as part of the assessments of the probability of significant changes on local fracture permeabilities and local effective porosities (Study 8.3.1.8.3.3) and local distribution coefficients (Study 8.3.1.8.4.1).

8.3.1.8.5.2.1 Activity: Evaluation of depth of curie temperature isotherm

Objectives

The objective of this activity is to determine the depth of the curie temperature isotherm by analyses of existing magnetic survey data.

Parameters

The long wavelength attributes of magnetic survey data are the parameters for this activity.

Description

The curie temperature isotherm is the deepest level that significant crustal magnetic sources can exist; anomalies from these sources consequently have long wavelengths and very low amplitudes compared with shallower crustal sources. Hence, any method used to study the limiting depth of these sources must be capable of characterizing the long wavelength attributes of a magnetic survey. The Connard-Couch technique (Connard et al., 1983), accomplishes this characterization by dividing the survey area into overlapping rectangular cells, calculating the power spectrum of each cell, and analyzing the shape of the long wavelength part of each spectrum. All of the sources contributing to the spectrum are treated as a statistical set, or ensemble.

This method and its application to a part of the Oregon Cascade Range was described by Connard et al. (1983). Their curie temperature depths agreed approximately with published heat flow measurements, recent structural features, and surface geothermal manifestations. Couch et al. (1985) have summarized their results in the Cascade Range. They now have analyzed magnetic data over the Cascade geologic province from Mount Hood to Lassen Peak, and the agreement between their curie temperature depths and heat flow measurements is quite remarkable.

The proposed method has some limitations. Anomalies due to deep sources are difficult to separate from their dominant shallow counterparts, no matter which method is used, and particularly in Nevada, where the data are of

YMP/CM-0011, Rev. 1

lesser quality and the geologic situation more complex than in the Oregon Cascade Range. Finally, the method estimates the depth to the bottom of magnetic sources, which are assumed to correspond to curie temperatures.

Nevertheless, this technique offers a method for characterizing undulations of the curie temperature isotherm in Nevada, and to compare areas of shallow isotherms with areas of recent volcanism and zones of high heat flow.

8.3.1.8.5.2.2 Activity: Chemical and physical changes around dikes

Objectives

The objective of this activity is to gather data on the nature and extent of chemical and physical changes that may occur in the surrounding tuffs as a result of the intrusion of dikes or sills.

Parameters

The parameters for this activity are

1. The extent and nature of changes to physical properties such as fracturing and effective porosity that could affect ground-water flow in tuffs surrounding a basaltic dike or sill.

2. The extent and nature of changes to geochemical properties that could affect local distribution coefficients (K_ds) in tuffs surrounding a basaltic dike or sill.

Description

As discussed in Sections 1.3.2 and 1.5.1, basaltic volcanism is considered the only credible igneous process that could affect the site. This activity will investigate the possibility that the intrusions related to this type of activity such as dikes or sills could adversely affect the hydrologic or geochemical characteristics of the surrounding rock in a significant manner. The first phase of the activity will be a literature review of the effects of dikes and sills of the type expected in the area on tuffs and other rock types. This will be followed, as necessary, by a field investigation of selected localities in the region where dikes or sills are known to have penetrated rock types similar to those found at the site. The rocks surrounding these intrusions will be examined petrologically to describe the nature of the mineral changes caused by the intrusion and the distance that these changes extend from the intrusion. Changes in fracturing and other physical characteristics that could affect ground-water flow will also be described. These data will be used by Activities 8.3.1.8.3.3.1 and 8.3.1.8.4.1.1 as part of the assessment of the effects of igneous intrusions on hydrologic and geochemical characteristics of the site.

 YMP/CM-0011, Rev. 1

8.3.1.8.5.2.3 Activity: Heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies

This activity will be undertaken in cooperation with Activity 8.3.1.9.2.1.3 (assessment of geothermal resources). Both activities are aimed at characterizing the local geothermal regime as it might relate to repository performance during the postclosure period. Activity 8.3.1.9.2.1.3 will focus on assessing geothermal activity as a potential resource. This activity (8.3.1.8.5.2.3) will evaluate the local ambient heat flow and local heat flow anomalies in relation to Quaternary igneous bodies. Data compilation and evaluation will be carried out jointly through both activities.

Objectives

The objectives of this activity are to

1. Compile available heat flow data at and near Yucca Mountain and identify local heat flow anomalies in conjunction with Activity 8.3.1.9.2.1.3. The quality of these data will be assessed under this activity (8.3.1.8.5.2.3) in conjunction with Activity 8.3.1.9.2.1.3.

2. Compile available calcite and silicate geothermometry data from calcite and silica deposits in soils and core and along faults in the vicinity of Yucca Mountain. These data will be assessed with respect to their utility for measuring thermal and hydrothermal perturbation associated with Quaternary volcanism, such as that at the Lathrop Wells volcanic center. In addition, the utility of such data for calibrating and evaluating theoretical calculations of the thermal and hydrothermal effects of volcanism will be assessed.

3. Assess the potential value of additional heat flow and other geothermometry studies for satisfying project goals. Recommendations will be made as to the objectives, nature and scope of any additional studies that may be needed, including the collection of geothermal data from existing or planned drillholes or specific methods of drill hole construction necessary to collect the highest quality heat flow data.

Parameters

The parameters for this activity are

1. Geothermal profiles of drillholes.
2. Temperature of ground water from springs and wells.
3. Thermal conductivity of core and other samples.
4. Surface temperature.
5. Silica geothermometry of water samples.
6. Calcite geothermometry of calcite-silica deposits.

 YMP/CM-0011, Rev. 1

Description

Local heat flow anomalies could be associated with faults, shallow magma bodies, and/or local areas of anomalous ground-water flow, such as segments of thermally driven ground-water convection cells. Internally consistent heat-flow calculations from drillhole UE-25a#3 in the Calico Hills yield values of as much as 3.08 to 3.34 heat flow units. These data are between two and three times the expected ambient values according to Sass et al. (1980), who suggest that Calico Hills is the focus of an ascending segment of a geothermal convection cell. The ambient thermal regime beneath Yucca Mountain is not known with sufficient confidence that a similar geothermal process can be ruled out there. In this activity, heat-flow calculations will be made for existing and planned drillholes where feasible. The data will be compiled onto maps and compared with other geological, hydrological, and geophysical data. Recommendations for additional heat-flow measurements will be made to evaluate local heat-flow anomalies. Such recommendations could include plans for an additional drillhole specifically constructed to acquire high quality data to evaluate regional ambient heat flow. Additional heat-flow data could also be required to evaluate tectonic or fault models, tectonic history, geothermal resource potential, regional ground-water flow, and/or calculation of ambient heat flow at and near Yucca Mountain. The silica geothermometry method used by Fournier et al. (1979) will be evaluated as to its utility in corroborative heat-flow calculations for Yucca Mountain in conjunction with Activity 8.3.1.9.2.1.3.

An understanding of the present thermal regime also is helpful to evaluate the magnitude and areal extent of the thermal perturbation due to Quaternary igneous activity. Available calcite and silica geothermometry data from calcite and silica deposits along faults and in soils and cores in the vicinity of Yucca Mountain (collected for Activity 8.3.1.5.2.1.5) will be compiled and assessed as to their utility for measuring thermal and hydrothermal perturbation associated with volcanism such as that at the Lathrop Wells volcanic center (part of which may be synchronous with a pluvial maximum). Such data will also be evaluated as a method to confirm calculations of the thermal effects. Plans for additional studies will be made depending on the findings of this activity and program needs.

8.3.1.8.5.3 Study: Investigation of folds in Miocene and younger rocks of region

The objective of this study is to establish the regional pattern and rate of Neogene folding. The parameters to be determined are distribution, amplitude, and age of folds.

8.3.1.8.5.3.1 Activity: Evaluation of folds in Neogene rocks of the region

Objectives

The objective of this activity is to establish the pattern, rate, amplitude, and wavelength of post-middle-Miocene folding in the region.

YMP/CM-0011, Rev. 1

Parameters

The parameters for this activity are the distribution, amplitude, and age of folds.

Description

Neogene strain within the Nevada Test Site (NTS) and vicinity consists of displacements due both to folding and to faulting. To explain the strain in terms of some tectonic model or theory, the contribution from folding as well as faulting must be considered. Preliminary evaluation indicates that where detachment faults are present, the wavelength of folds in upper-plate rocks is substantially less than that in lower-plate rocks. No attempt has as yet been made to rationalize fold patterns or relate them to wrench tectonics, but it is possible that the fold pattern in the area of intersection of the left-lateral fault systems (Mine Mountain and Rock Valley faults) with the right-lateral faults of the Las Vegas Valley shear zone may help show whether these faults are contemporaneous conjugate systems or independent systems of different age.

As a first step, data pertaining to folds from existing detailed geologic maps of the NTS will be abstracted and synthesized. Depending on the results of this effort, it may be necessary to supplement the data base through detailed mapping of folds in selected areas.

Evaluation of the structural attitude of Neogene rocks of the NTS and vicinity will involve synthesis of data pertaining to the structural attitude of the Horse Spring, Pavits Spring, and the younger volcanic, pyroclastic, and volcaniclastic rocks from existing detailed geologic maps.

 YMP/CM-0011, Rev. 1

8.3.1.9 Overview of the human interference program: Description of potential future human activities at or near the site, required by performance and design issues

Summary of performance and design requirements for human interference information

The postclosure human interference test program addresses (1) the likelihood of inadvertent human intrusion into a mined geologic disposal system (MGDS), (2) interference with long-term MGDS performance due to human activities, and (3) the possible consequences of such interference events. The likelihood of these events must be very low, because the potential consequences of events of this nature may pose unacceptable risks to the public health.

The performance and design requirements for the human interference program directly reflect the regulatory requirements of the NRC, the EPA, and the DOE. These requirements, and their relationships to the human activities program can be summarized as follows:

1. Issue 1.1 (total system performance, Section 8.3.5.13) requires information that can help in estimating the probability of human intrusion and interference during the postclosure period. This will be accomplished through the development of release scenarios. The development of these scenarios will focus on relating potential specific human activities to the specific effects on the variables of the system important to waste isolation. Thus, the human interference program will focus on identifying those factors that can affect the probability of future inadvertent human interference (i.e., the presence of potential economic resources at the site, and the long-term survivability of the surface markers), and describing qualitatively and quantitatively the effects of specific human activities.

2. Issue 1.8 (NRC siting criteria, Section 8.3.5.17) addresses NRC regulations 10 CFR 60.21(c)(13), 60.122(a), 60.122(c)(2), and 60.122(c)(17) requiring that resources at the site with current markets be identified, and described in terms of net and gross values. Resources that occur in abundances that may be marketable in the future must also be identified and described in terms of physical factors such as tonnage (or other amount), grade, and quality. The evaluation of resources, including undiscovered resources, shall be conducted for the site in comparison to areas similar to the site that are representative of and are within a similar geologic setting. A complete assessment of the potential consequences of exploration activities (e.g., drilling) or resource extraction that could realistically influence the ability of the MGDS to isolate waste during the postclosure period, is required. This would include identification of human activities such as ground-water withdrawal and fluid waste injection.

3. Issue 1.9 (higher level findings - postclosure system and technical guidelines, Section 8.3.5.18) is the evaluation of the site against the qualifying and disqualifying conditions of the DOE siting

YMP/CM-0011, Rev. 1

guidelines. For the site to be considered for selection as the first repository, it must be demonstrated that the site is located in an area such that natural resources at or near the site are not likely to give rise to interference activities. The presence of natural resources (whether known to be present or inferred to be present) could lead to exploration and exploitation activities by future generations that might affect long-term repository performance. Thus, information regarding the natural resource potential at and in the vicinity of the site will be obtained during the human activities program. The land ownership and mineral rights program (Program 8.3.1.11) addresses postclosure site ownership and control concerns, and discusses the only other qualifying conditions related to human interference.

4. Issue 4.4 (preclosure design and technical feasibility, Section 8.3.2.5) requires site-specific data for the design and placement of the permanent warning system. The warning system, which will consist of surface markers and monuments, will be placed along the boundary of the controlled area following repository closure and decommissioning. (The controlled area is the actual area chosen according to the 10 CFR 60.2 definition of controlled area.) Parameters relative to natural processes like erosion, deposition, ground motion, and burial by volcanic materials are required to identify the most suitable locations for the markers.

Approach to satisfy performance and design requirements

The consideration of inadvertent human intrusion or human interference events is based on several assumptions (10 CFR Part 60; 40 CFR Part 191, Appendix B). These assumptions, reproduced from the regulations, are as follows

> Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that (1) the monuments provided for by this part are sufficiently permanent to serve their intended purpose; (2) the value to future generations of potential resources within the site can be assessed adequately under the applicable provisions of this part; (3) an understanding of the nature of radioactivity, and an appreciation of its hazards, have been retained in some functioning institutions; (4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned; and (5) relevant records are preserved, and remain accessible, for several hundred years after permanent closure (10 CFR 60.2).
>
> The [U.S. Environmental Protection] Agency believes that the most productive consideration of inadvertent [human] intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive controls (although passive institutional controls should not be assumed to completely rule out the possibility

YMP/CM-0011, Rev. 1

> of intrusion). Therefore, inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies. Furthermore, the implementing agencies can assume that passive institutional controls or the intruders own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities. (40 CFR Part 191, Appendix B.)

The approach to assessing future human activities at Yucca Mountain will be consistent with the previously presented assumptions. The program will follow the principle that highly speculative intrusion scenarios will not be included, and that only those factors and potentially adverse human activities that could directly affect waste isolation will be addressed.

Human interference presents special problems because of its dependence upon unpredictable future human activities. This anthropogenic factor makes defining the potential for radionuclide releases resulting from human activities, in quantitative or probabilistic terms, particularly difficult. For this reason, professional judgment may be required (Study 8.3.1.9.3.1) to determine the likelihood of future human intrusion or interference that could result from resource exploration or extraction.

The general approach to obtaining the required parameters from the human interference program is to identify the natural and anthropogenic parameters that are required by the design and performance issues. Table 8.3.1.9-1 lists the performance issue that requests data from this program, along with the performance and characterization parameters required by the issue.

The data requirements of Issue 1.1 primarily involve quantifying, in probabilistic terms, the site-specific factors that could contribute to unanticipated natural phenomena or anthropogenic events at or in the vicinity of Yucca Mountain. Design of the marker system (Issue 4.4) requires site-specific data to ensure strategic placement of the monuments in locations having low risk associated with the consequences of natural phenomena or human activities. Archaeological studies of ancient monuments and structures (Kaplan, 1982; Berry et al., 1984) have been used to address identifiable and potentially disruptive and destructive anthropogenic factors that could affect marker survivability. The remaining parameters, the consequences of natural phenomena, will be obtained through other site activities and evaluated in Study 8.3.1.9.1.1 as listed in Table 8.3.1.9-1.

Current information and new data acquired from site activities will be employed to assess the natural resource potential of Yucca Mountain (Investigation 8.3.1.9.2). These data will be used to describe qualitatively the various categories of potential human interference and intrusion scenarios (Study 8.3.1.9.3.2). For example, the possible presence of four natural resources (i.e., mineral, geothermal, hydrocarbon, and ground-water resources) would require that at least one category of initiating events (exploratory drilling) must be evaluated. After examining the potential for each resource, the probability of occurrence for each type of human intrusion scenario in the exploratory drilling category will be estimated. This will

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 1 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases	8.3.5.13	Exploratory drilling intercepts a waste package and brings up waste with core or cuttings	Presence and readability of C-area[a] markers over 10,000 yr (long-term survivability of markers)	Rates of Erosion Weathering Deposition Igneous activity Seismic activity at marker locations	8.3.1.9.1
			Expected drilling rate (no. of boreholes/km^2/yr) in R-area[b] over the next 10,000 yr	Quantities, tonnages, and grades of known or inferred resources at Yucca Mountain	8.3.1.9.2.1
			Distribution of diameters of exploratory drilling	Types of known or inferred resources at Yucca Mountain	8.3.1.9.2 and 8.3.1.9.3
			Distribution of depths of exploratory drilling	Types of known or inferred resources at Yucca Mountain	8.3.1.9.2 and 8.3.1.9.3
		Extensive groundwater withdrawal occurs near C-area	Expected magnitude of change in water-table level in the C-area due to extensive groundwater withdrawal in next 10,000 yr	Quantity, rates, well locations, and hydrostratigraphic unit sources of groundwater withdrawals	8.3.1.9.2.2 and 8.3.1.16.2.1

YMP/CM-0011, Rev. 1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 2 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)		Expected magnitude in changes in gradient of water table under C-area due to ground-water withdrawal near C-area in next 10,000 yr	Quantity, rates, well locations, and hydrostratigraphic source of ground-water withdrawals	8.3.1.9.2.2 and 8.3.1.16.2.1
			Presence and readability of C-area markers over 10,000 yr	See the activity parameter for the exploratory drillers intercept under the initiating event column of this table	8.3.1.9.1.1
		Extensive surface or subsurface mining occurs near the C-area	Expected magnitude of change in water-table level due to mine-water use or mine dewatering near C-area over next 10,000 yr	Estimated depth of mine, cross-sectional area of mines or shafts	8.3.1.9.3.2

YMP/CM-0011, Rev. 1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 3 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)		Expected magnitude of change in gradient under C-area due to mine-water usage or mine dewatering	Estimated water usage based on quantity of water-available, depth of mine	8.3.1.9.3.2
			Expected magnitude of changes in distribution coefficient (K_ds) of unsaturated zone (UZ) and saturated zone (SZ) due to mining activities near the C-area	No changes expected	8.3.1.9.3.2
			Presence and readability of C-area markers over next 10,000 yr	See the activity parameter for the exploratory drillers intercept under the initiating event column of this table	8.3.1.9.1.1

YMP/CM-0011, Rev. 1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 4 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)	Large-scale surface-water impoundments are constructed near the C-area	Expected magnitude of change in water-table level due to presence of artificial lake near C-area	Area, depth, volume of surface-water impoundment; seepage rates, percolation rates and transmissivity of near-surface and subsurface materials	8.3.1.9.3.2
			Expected magnitude of changes in K_ds for UZ and SZ units due to presence of an artificial lake near C-area	No changes expected	
			Expected magnitude of changes in head gradients of the SZ in C-area due to the presence of an artificial lake near C-area	Area, depth, volume of surface-water impoundments	8.3.1.9.3.2

YMP/CM-0011, Rev. 1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 5 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)		Expected magnitude of flux change due to presence of an artificial lake near the C-area in next 10,000 yr	Area, depth, and volume of surface water impoundment; seepage rates, percolation rates, and transmissivity of near-surface and subsurface materials	8.3.1.9.3.2
			Presence and readability of C-area markers over 10,000 yr	See the activity parameter for the exploratory drilling intercept under the initiating event column of this table	8.3.1.9.1.1
		Extensive irrigation is conducted near the C-area	Expected magnitude of change in altitude of water-table under C-area due to extensive irrigation near C-area over next 10,000 yr	Area of irrigation, crop cultivation, quantity of water used for irrigation based on quantity of water available	8.3.1.9.3.2

YMP/CM-0011, Rev. 1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 6 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
1.1 Total system releases (continued)	8.3.5.13 (continued)		Expected magnitude of flux change due to extensive irrigation near the C-area over next 10,000 yr	Area of irrigation, crop cultivation, quantity of water applied, infiltration, and percolation rate	
			Expected magnitude of change in read gradients below C-area due to extensive irrigation over next 10,000 yr	Quantity of irrigation withdrawals	8.3.1.9.3.2
			Expected magnitude of changes in K_ds of UZ and SZ	No change expected	8.3.1.9.3.2
			Presence and readability of surface markers over 10,000 yr	See the activity parameter for the exploratory drilling intercept under the initiating event column of this table	8.3.1.9.1.1

YMP/CM-0011, Rev. 1

Table 8.3.1.9-1. Initiating events, associated performance parameters, and activity parameters for the human interference program (page 7 of 7)

Issue requesting parameter	SCP section	Initiating event	Performance parameter	Activity parameter	SCP section
4.4 Technical feasibility	8.3.2.5	NA[c]	Surface markers located in geomorphically stable locations	Rates of deposition, igneous activity and seismic activity near C-area boundary	

[a]C-area = controlled area (i.e., the actual area chosen according to the 40 CFR 191.12 definition of controlled area).
[b]R-area = restricted area (i.e., the projection of the primary area and extensions onto the surface).
[c]NA = not applicable).

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

require the use of professional and expert opinion (Study 8.3.1.9.3.1). The probabilities obtained from this exercise will be provided to Issue 1.1 (total system performance, Section 8.3.5.13), and will be used as input parameters in predicting potential radionuclide releases to the accessible environment.

The final information that will be obtained from the human activities program is an evaluation of the potential effects that could result from resource extraction. These data will be gathered under Investigation 8.3.1.9.3. Presently, only the effects of ground-water withdrawal on the hydrologic system will be evaluated because ground water is the only commodity currently identified as a resource. If other potentially marketable resources are identified during site characterization, plans will be developed to examine the effects of their extraction on the hydrologic, geochemical, and rock characteristics.

<u>Interrelationships of human interference investigations</u>

The first investigation (8.3.1.9.1) identified for this program determines all factors, both natural and anthropogenic, that could destroy or degrade the surface markers and monuments. Because the anthropogenic factors have been considered and incorporated into the marker design, only three specific data needs are identified, all of which will be provided from other investigations. The magnitudes and locations of fault rupture and seismically induced ground motion (Investigation 8.3.1.8.2); the rates, magnitudes, and locations of potential igneous activity (Investigation 8.3.1.8.1); and the potential effects of tectonic activity and future climatic conditions on locations and rates of erosion and deposition (Investigations 8.3.1.6.3 and 8.3.1.6.2, respectively) will aid in determining the best locations for the surface markers and monuments.

The second investigation (8.3.1.9.2) requires the identification of all resources at the site with current markets and an estimate of their gross and net value. Resources without current markets, but which are potentially marketable in the future, will be described in terms of such physical factors as tonnage (or other amount), grade, and quality. The evaluation of resources, including undiscovered resources, shall be conducted for the site in comparison to areas of similar size that are representative of and are within the geologic setting. The present assessment of commodities as presented in Chapter 1, Section 1.7 and reviewed in Section 1.8.1.7, classifies most commodities as "occurrences" and some as "undiscovered, speculative resources of subeconomic grade," using the USBM/USGS (1980) classification system. If identified resources and reserves are defined, they will be delineated and quantified (Study 8.3.1.9.2.1) and the impact of their presence will be addressed in Studies 8.3.1.9.3.1 and 8.3.1.9.3.2.

Ground water currently is the only commodity to be classified as a resource in the immediate vicinity of the site. Exploitation of this resource is expected to become economically feasible in the near future (DOI, 1985). Study 8.3.1.9.2.2 will integrate existing scientific and institutional data with information obtained during characterization of the saturated zone (Investigation 8.3.1.2.3) to (1) quantify and qualify the ground-water resources proximal to the site, (2) assess the current and future value of the resource, and (3) project the probable rates and loca-

YMP/CM-0011, Rev. 1

tions of ground-water exploitation in the reasonably foreseeable future. These parameters (Table 8.3.1.9-1) will be considered in calculating the probability for human interference (Study 8.3.1.9.3.1) and in assessing the potential effects of ground-water exploitation on the conditions at the site (Study 8.3.1.9.3.2).

The final investigation (8.3.1.9.3) examines the potential effects of resource extraction on the baseline hydrologic, geochemical, and rock characteristics. The parameters that have been identified are the specific resources determined in Investigation 8.3.1.9.2, the conditions at the site and the extraction methods that would be used for the specific resources under consideration. The parameters obtained for this investigation will be analyzed and evaluated to determine whether the potential effects of resource exploitation can change the characteristics of the site such that repository performance would be affected. Professional judgment will then be used to define the interdependence between natural resources at the site and the potential for human intrusion as a result of exploratory drilling (Study 8.3.1.9.3).

The second part of Investigation 8.3.1.9.3 will focus on the initiating events of the release scenarios (Table 8.3.1.9-1) that relate to human interference, and their potential effects on long-term repository performance. The parameters defined for this investigation are (1) the initiating events identified in Issue 1.1 (total system performance) that may not be considered sufficiently credible to warrant further consideration because of the improbability of their occurrence (e.g., large-scale surface-water impoundment above the repository zone) and (2) those potential consequences of initiating events that are not expected to significantly affect long-term repository performance. These parameters will be evaluated to establish with a high level of confidence whether they are sufficiently credible or significant to warrant further consideration within Issue 1.1.

The information needed from the human interference program for the performance and design issues will be obtained from these three investigations. Table 8.3.1.9-2 lists the studies and activities that will be undertaken to obtain the required performance and design data. Figure 8.3.1.9-1 illustrates the relationships between the three investigations making up the human interference program and other issues that require input from this program.

8.3.1.9.1 Investigation: Studies to provide the information required on natural phenomena and human activities that might degrade surface markers and monuments

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Pursuant to the regulations of the EPA (40 CFR 191.14(c)) and the NRC (10 CFR 60.21(c) and 60.51(a)), a warning system composed of surface markers and monuments will be placed at the site as a means of informing future generations of the risks associated with the repository and its contents.

YMP/CM-0011, Rev. 1

Table 8.3.1.9-2. Studies and activities making up the human interference program

Study	Activity	Description
8.3.1.9.1.1		An evaluation of natural processes that could affect the long-term survivability of the surface marker system at Yucca Mountain
	8.3.1.9.1.1.1	Synthesis of tectonic, seismic, and volcanic hazards data from other site characterization activities
	8.3.1.9.1.1.2	Synthesis--evaluation of the effects of future erosion and deposition on the survivability of the marker system at Yucca Mountain
8.3.1.9.2.1		Natural resource assessment of Yucca Mountain, Nye County, Nevada
	8.3.1.9.2.1.1	Geochemical assessment of Yucca Mountain in relation to the potential for mineralization
	8.3.1.9.2.1.2	Geophysical/geologic appraisal of the site relative to mineral resources
	8.3.1.9.2.1.3	Assessment of the potential for geothermal energy at and in the vicinity of Yucca Mountain, Nevada
	8.3.1.9.2.1.4	Assessment of hydrocarbon resources at and near the site
	8.3.1.9.2.1.5	Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration
8.3.1.9.2.2		Water resource assessment of Yucca Mountain, Nevada
	8.3.1.9.2.2.1	Projected trends in local and regional ground-water development, and estimated withdrawal rates in southern Nevada, proximal to Yucca Mountain

 YMP/CM-0011, Rev. 1

Table 8.3.1.9-2. Studies and activities making up the human interference program (continued)

Study	Activity	Description
8.3.1.9.3.1		Compilation of data needed to support an assessment of the likelihood of inadvertent human intrusion at Yucca Mountain as a result of exploration and/or extraction of natural resources
	8.3.1.9.3.1.1	Compilation of data to support the assessment calculation of the potential for inadvertent human intrusion at Yucca Mountain
8.3.1.9.3.2		An evaluation of the potential effects of exploration for, or extraction of natural resources on the hydrologic characteristics at Yucca Mountain
	8.3.1.9.3.2.1	An analysis of the potential effects of future ground-water withdrawals on the hydrologic system in the vicinity of Yucca Mountain, Nevada
	8.3.1.9.3.2.2	Assessment of initiating events related to human interference that are considered not to be sufficiently credible or significant to warrant further investigation

Human activities and many natural phenomena that could contribute to the degradation, destruction, or disruption of the marker system have been evaluated and presented in Kaplan (1982) and Berry et al. (1984). These factors have been considered and are being used as criteria in the final marker design. There are some site-specific natural processes and their consequences that require further consideration because of their potential to degrade, disrupt, or destroy the marker system. These processes are (1) potentially destructive fault displacement or seismically induced ground motion, (2) potentially destructive volcanic events or volcanic burial due to hydrovolcanic eruptions, and (3) increased erosion or deposition rates resulting from tectonic activity or climatic change. The current knowledge of these processes and their potential consequences as presented in Chapters 1, 3, and 5 of this document is not adequate to thoroughly assess the potential associated risks to the surface markers and monuments.

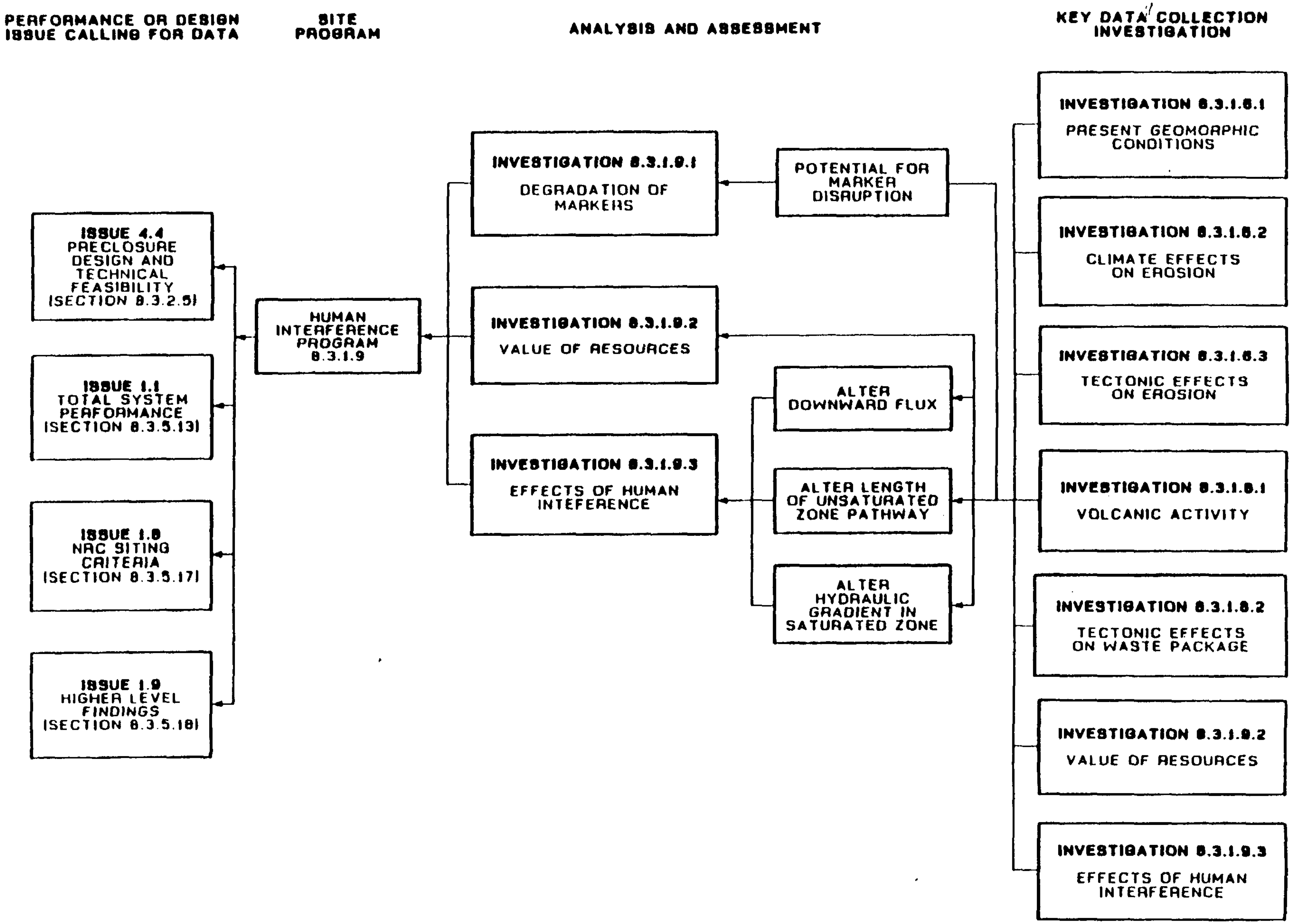

Figure 8.3.1.9-1. General logic diagram for the Human Interference Program.

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

Parameters

Three parameters will be evaluated to resolve this portion of the investigation:

1. Potential fault movement and ground motion at the site from man-made natural seismic events (Investigation 8.3.1.8.2).

2. The rates and magnitudes of potential igneous activity that could affect the site (Investigation 8.3.1.8.1).

3. The potential effects of tectonic activity and future climatic conditions on locations and rates of erosion and deposition (Investigations 8.3.1.6.2, 8.3.1.6.3, and 8.3.1.5.1).

Purpose and objectives of the investigation

The purpose of Investigation 8.3.1.9.1 is to obtain the site-specific information on the occurrence and consequences of natural phenomena needed to satisfy the parameter requests of the performance and design issues. The objective of the investigation is to compile and evaluate these data so that they can provide information directly to the performance and design issues.

The information needed to satisfy Issue 1.1 is an estimate of the long-term survivability of the warning system. Data on the consequences of natural phenomena such as erosion, deposition, volcanic activity, and strong ground motion are needed to assess the possible damage to the warning system that might occur during the 10,000-yr postclosure period. The probability of inadvertent human intrusion and interference will be influenced by the effectiveness of the marker system to warn intruders of the potential hazards of the mined geologic disposal system (MGDS). Thus, bounds on the probability that the markers will be effective over the 10,000-yr postclosure period will provide input to the total system releases calculation.

Similar information is required by Issue 4.4 (preclosure design and technical feasibility) to supplement the general warning system design developed by the Office of Nuclear Waste Isolation (Kaplan, 1982). Geologic information gathered to assess the potential hazards associated with natural phenomena in the vicinity of the controlled area boundary will aid in determining the most suitable locations for the markers.

Investigation 8.3.1.9.1 ensures that the risks associated with natural phenomena are incorporated into the final design of the warning system. Figure 8.3.1.9-2 shows the flow of data for this investigation. By maximizing the effectiveness of the passive institutional controls, the likelihood that future generations will inadvertently affect the performance of the MGDS can be reduced.

Technical rationale for the investigation

Fault movement and ground motion at the site, whether from man-made or natural seismic events, could dislocate and damage large monuments and surface markers. Information regarding fault locations and the magnitudes of

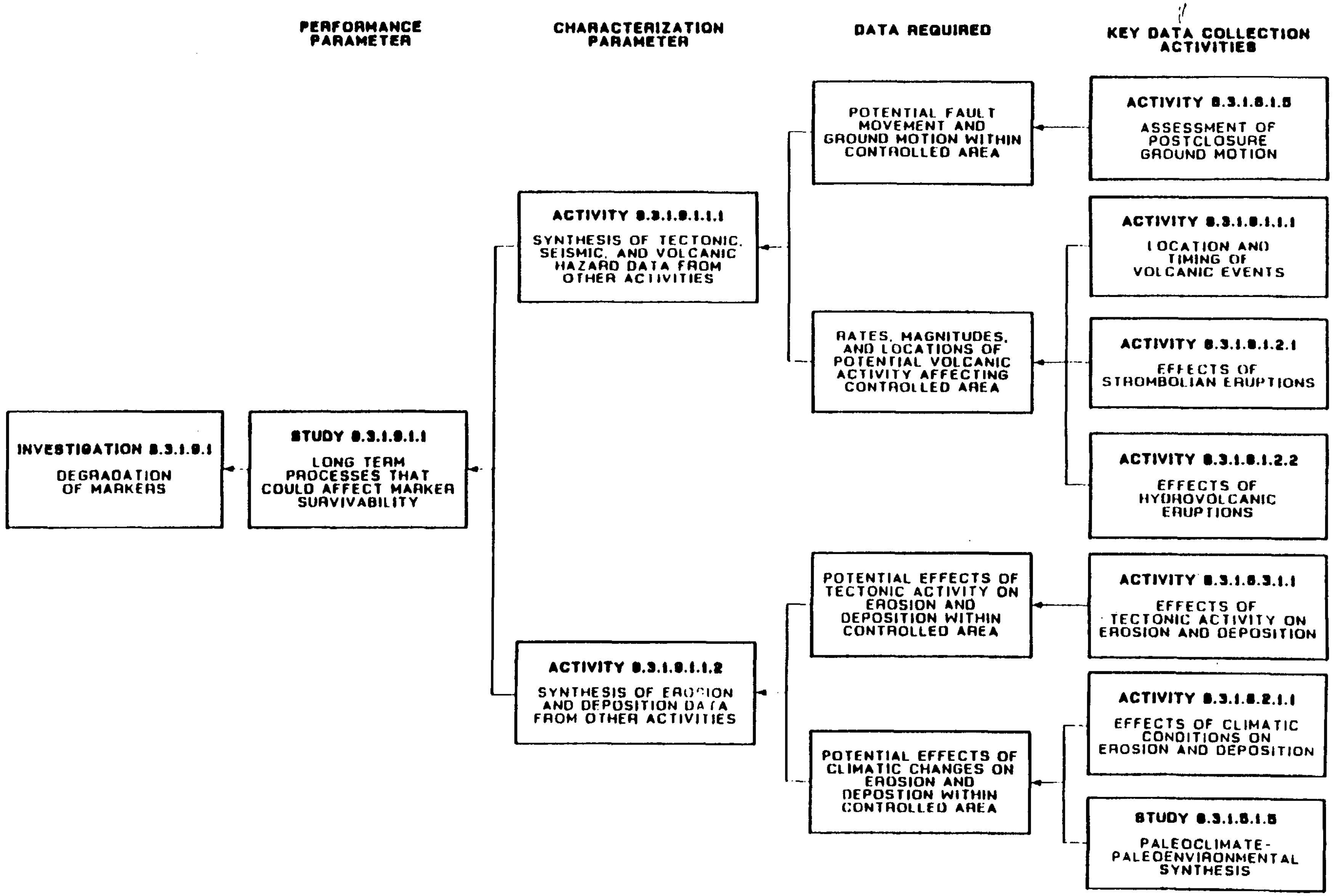

Figure 8.3.1.9-2. Logic diagram for Investigation 8.3.1.9.1.

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

potential ground motions associated with fault rupture will aid in the placement and design of the surface marker system. Strategic placement of the markers will reduce the risk of their degradation or destruction.

Volcanic events could potentially degrade, cover, or destroy surface markers and monuments by dislocation, burial or incorporation into extruded volcanic material. Knowledge of the locations, rates, and magnitudes of potential volcanic events will aid in the placement of the markers and monuments, thereby reducing the associated risks.

Tectonic activity such as uplift or subsidence can increase erosion and deposition rates by changing the local or regional base level. Future climatic changes could potentially affect the locations and rates at which erosion and deposition occur. Erosion along the foundations of the markers could undermine their stability and result in dislocation. Deposition could result in rapid burial of the markers. Information regarding the locations and rates of potential erosion and deposition, which could contribute to marker dislocation or disruption, is needed to determine the most strategic placement of the markers and monuments.

Data that are required to satisfy the design and performance issues will be derived from studies done as part of Investigations 8.3.1.5.1, 8.3.1.6.2, 8.3.1.6.3, 8.3.1.8.1, and 8.3.1.8.2. The results obtained from these studies will be compiled and evaluated to determine the optimum locations for the surface markers.

8.3.1.9.1.1 Study: An evaluation of natural processes that could affect the long-term survivability of the surface marker system at Yucca Mountain

This study provides information on the currently or potentially active natural processes at Yucca Mountain capable of adversely affecting the long-term survivability of the surface marker system. This study will be a synthesis of data obtained from other activities to be undertaken in support of several investigations. The data will then be evaluated to determine the most suitable locations of the monuments for the surface marker system. Input for this study will be provided by Investigations 8.3.1.6.2, 8.3.1.6.3, 8.3.1.8.1, and 8.3.1.8.2. Detailed activity descriptions can be found under the appropriate investigation discussions.

8.3.1.9.1.1.1 Activity: Synthesis of tectonic, seismic, and volcanic hazards data from other site characterization activities

Objectives

The objective of this activity is to identify the potential locations of faulting and volcanic eruption or intrusion that could occur where they could affect the marker system.

 YMP/CM-0011, Rev. 1

Parameters

The parameters required for this activity will be derived from descriptions of the seismic, volcanic, and tectonic processes in the vicinity of the site and their associated physical consequences. These data will be taken from Studies 8.3.1.8.1.2 and 8.3.1.8.2.1.

Description

This activity will integrate all applicable data involving faulting, folding, uplift and subsidence, and volcanism. Each segment of the controlled area boundary will be examined in light of this information to determine the locations that have the lowest associated risk. The range of geologic consequences, as they might adversely affect the long-term survivability of the surface markers and monuments, will be described.

8.3.1.9.1.1.2 Activity: Synthesis: evaluation of the effects of future erosion and deposition on the survivability of the marker system at Yucca Mountain

Objectives

The objective of this activity is to determine the effects of future erosion and deposition on the topographic elements of the controlled area boundary at Yucca Mountain. This information will be evaluated to identify the optimum locations for the markers.

Parameters

The locations of potential future erosion surfaces identified in Activities 8.3.1.6.1.1.1 and 8.3.1.6.2.1.1 will be used as the input parameters for this activity.

Description

This synthesis activity will be aimed at identifying the locations along the controlled area boundary expected to have low rates of erosion and deposition during the postclosure period. Using this information in conjunction with results from volcanic and fault hazard analyses (Investigation 8.3.1.8.1) the tentative marker locations will be chosen.

8.3.1.9.2 Investigation: Studies to provide the information required on present and future value of energy, mineral, land, and ground-water resources

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

YMP/CM-0011, Rev. 1

A preliminary assessment of the natural resource potential at Yucca Mountain (energy, mineral, ground water, and land), based on published literature, was presented in the Yucca Mountain environmental assessment (DOE, 1986b). Sections 1.7 and 1.8.1.7 (summary) of the SCP provide additional information and an evaluation of the mineral and energy resources for the site. Section 3.8 of the SCP contains a preliminary assessment of the ground-water resources in the relevant geohydraulic basins at and in the vicinity of Yucca Mountain. Land resources have been evaluated in Sections 3.4 and 6.2 of the Yucca Mountain environmental assessment (DOE, 1986b).

Parameters

Several groups of parameters must be evaluated to determine all the factors that must be considered when assessing the future value of potential resources at Yucca Mountain. These groups of parameters include the following:

1. The assessment for the occurrences of economically attractive deposits of precious metals, base metals, strategic metals, industrial minerals, or other commodities, and energy resources including hydrocarbon or geothermal resources.

2. The projected value and future development of local ground-water resources.

Purpose and objectives of the investigation

The natural resource potential of a candidate site for an mined geologic disposal system is an important consideration in evaluating the likelihood for inadvertent human intrusion and interference. The presence of natural resources or an environment that is favorable for the occurrence of natural resources could lead to prospecting exploration within or near the controlled area, and possible subsequent resource exploitation. The exploration or extraction of resources could result in direct releases of radionuclides to the accessible environment or could modify the hydrologic, geochemical, and rock characteristics at the site (Investigation 8.3.1.9.3) by possibly shortening travel paths to the accessible environment. Thus, a complete evaluation of the natural resource potential of the Yucca Mountain site is essential in determining the likelihood for inadvertent human intrusion and interference.

Technical rationale for the investigation

The potential occurrence of precious- and base-metal deposits, other metallic or nonmetallic deposits, and ground-water, geothermal, or hydrocarbon resources at Yucca Mountain will play an important role in determining the likelihood for future exploratory drilling within the boundaries of the controlled area. This knowledge will provide the basis for Investigation 8.3.1.9.2 as outlined in Figure 8.3.1.9-3, and additionally will provide input to Investigation 8.3.1.9.3 by identifying those resources that may attract exploration or may potentially be exploited, and thus could affect the long-term waste isolation ability of the Yucca Mountain site. Figure 8.3.1.9-3 shows the flow of data for this investigation.

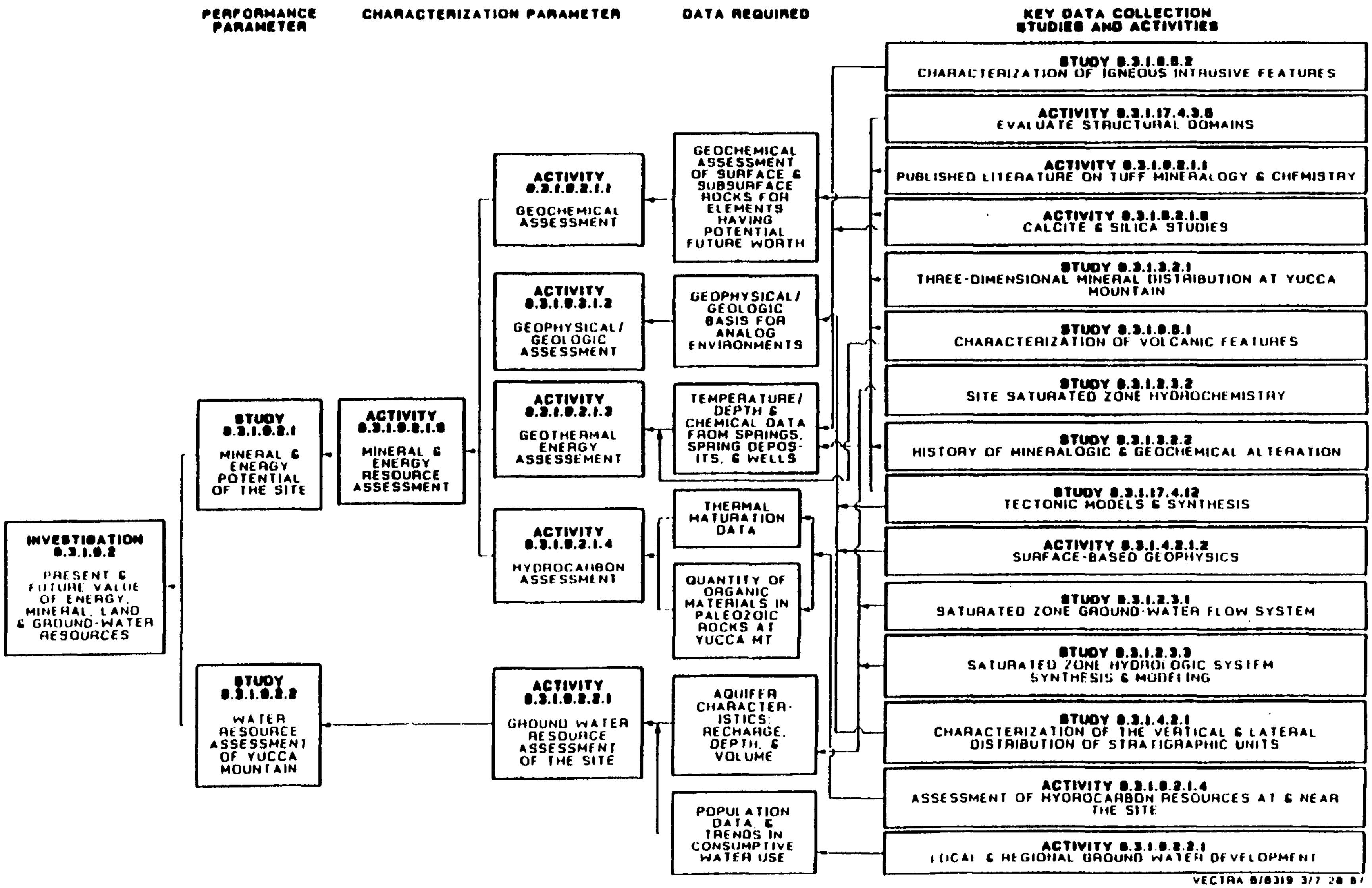

Figure 8.3.1.9-3. Logic diagram for Investigation 8.3.1.9.2.

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

To assess the potential for resource exploration or exploitation over the next 10,000 yr, it will be necessary to identify all resources at or near the site with current markets and provide an estimate of their gross and net values. Resources without current markets, but which could potentially be marketable in the future, will be described in terms of physical factors such as tonnage (or other amount), grade, and quality. The discussion of commodities, as presented in Section 1.7 and reviewed in Section 1.8.1.7, classifies most commodities as "other occurrences" and some as "undiscovered, speculative resources of subeconomic grade," using the USBM/USGS (1980) classification system. It is extremely unlikely that drilling or mining will occur in the area unless commodities that are presently valued or may be valued in the future are found in amounts that greatly exceed the average crustal abundance (Section 1.7). Identified resources and reserves will be delineated and quantified (Study 8.3.1.9.2.1) and the impact of their presence will be addressed in Studies 8.3.1.9.3.1 and 8.3.1.9.3.2.

The relative value of the ground-water resources that are located proximal to the site is known to be low at the present time. The depth to these resources, and the distances over which transport would be required, currently preclude economic exploitation (Sinnock and Fernandez, 1982). Through time, these economic conditions may change, and ground-water development and exploitation may occur as a result. As discussed in the previous section, ground-water development and exploitation proximal to the site could affect the geohydrologic system. Such effects must be evaluated in Investigation 8.3.1.9.3. The projections of the probable future withdrawal rates that will be obtained from activities conducted in support of this investigation will be used as an input parameter for Investigation 8.3.1.9.3.

Sections 3.4 and 6.2 of the environmental assessment for Yucca Mountain (DOE, 1986b) suggest that the use of the land surface as a resource is highly unlikely for the following reasons:

1. The sparse vegetation within the boundaries of the controlled area has historically precluded this land from being used for grazing purposes. Other, better-suited areas are available nearby and throughout southern Nevada that would likely be preferred in the future.

2. Community settlement historically has occurred within valleys where water resources are more accessible. Yucca Mountain and the surrounding controlled area are physiographically poorly suited for community development because of the rough terrain, the absence of surface water, and the great depth to ground water.

3. There is low potential for agricultural development within the boundaries of the controlled area because of the poorly developed soils, the lack of surface water, the depth to ground water, and the variable topographic relief.

The scarcity of vegetation, wildlife, and water has historically precluded using the land within the controlled area for recreational purposes. Thus, based on the historical use of this land, there is little chance that it will ever be considered suitable for recreational use. Information will

YMP/CM-0011, Rev. 1

be used from climate prediction studies (Section 8.3.1.5.1.6) to assess the value of the land within the proposed controlled area. A topical report will be prepared that addresses present and future land use in the Yucca Mountain area. This topical report will be prepared in response to the human interference program, the Yucca Mountain Project environmental program planning efforts, and the environmental impact statement process, as required for the repository construction and operation phases of the Project.

The probability that natural resources occur at the Yucca Mountain site is a required input parameter for evaluating the probability that future exploratory drilling will occur. This probability will be evaluated by an expert panel and incorporated into a subjective probability that describes the likelihood of future exploratory drilling (Study 8.3.1.9.3.1).

Two studies are planned to address Investigation 8.3.1.9.2. The studies consist of activities designed to obtain data from the existing literature and from site characterization. Through these activities, an evaluation will be made of (1) the geochemical characteristics of the site (Activity 8.3.1.9.2.1.1), (2) the geophysical-geologic characteristics of the site (Activity 8.3.1.9.2.1.2), (3) the potential for future occurrences of geothermal resources in the vicinity of Yucca Mountain (Activity 8.3.1.9.2.1.3), (4) the potential for hydrocarbon resources at the site (Activity 8.3.1.9.2.1.4) and water resources (Activity 8.3.1.9.2.2.1) at the site, and (5) a summary assessment of the mineral and energy potential (Activity 8.3.1.9.2.1.5) and water-resource potential (Study 8.3.1.9.2.2) of the site.

Alternative Conceptual Models

As discussed in the Overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed where appropriate to summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated; (2) the uncertainty associated with this current understanding, including alternative hypotheses that are also consistent with available data and which may compose an alternative conceptual model; (3) the significance of alternative hypotheses; and (4) the activities or studies designed to discriminate between alternative hypotheses or to reduce uncertainty. A hypothesis-testing table (8.3.1.9-3) for mineral and energy resources has been constructed since alternative models may be important in evaluating the present and future value of such resources.

Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate.

The hypotheses considered in Table 8.3.1.9-3 have been categorized as elements that pertain to the driving forces processes that are defined by the model. These elements are listed in column one.

Table 8.3.1.9-3. Current representation and alternative hypotheses for mineral and resource models for the human interference program (page 1 of 2)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
DRIVING FORCES/PROCESSES								
Ore-forming processes	Significant ore-forming processes have not occurred; no mineral resources exist at the site	Medium--some mineral resources have yet to be evaluated (e.g., Hg, Ag) or limited information is presently available (e.g., Au). Geochemical evaluation of surface and subsurface will be relied upon heavily for assessment of the present-day value of resources and for a comparison to analogs	Ore-bearing fluids derived from deep sources Ore-bearing fluids derived from lateral flow or surface flux Igneous fractionation processes produce ore or ore-bearing fluids	Types of known or inferred resources at Yucca Mountain	High	Medium--no gross features of mineralization have been observed at the surface or in drillholes, but geochemistry, petrography, etc., are yet to be done; evaluation of faults, rock alterations, etc., need to be assessed. Models for resource emplacement need to be fully evaluated; remotely possible that resources could exist within undrilled parts of domain, west of site	High	8.3.1.9.2.1.1, 8.3.1.9.2.1.2, 8.3.1.9.2.1.5, and drilling of new holes (e.g., USW G-5, USW G-6, and UE25 G-7). (Integrated Drilling Plan)
Hydrocarbon-forming processes	Significant hydrocarbon-forming processes have not occurred; no oil or gas resources exist at the site	Low--no oil or gas has been reported from the many drillholes emplaced in the tuff; potential source rocks have not been identified in the region from outcrop and subsurface information	Potential source rocks exist, thermal maturation history is favorable, and favorable reservior rocks exist	Same as above	Medium--risk for waste isolation is only from the potential for drilling	Low to medium--regional geology (oil and gas occurrences and regional stratigraphy) do not favor resource potential; thermal gradient was too high at the north end of the site; CAI[a] index from Paleozoics south of site is still in thermal range appropriate for gas generation	Medium	8.3.1.9.2.1.4, 8.3.1.9.2.1.2, 8.3.1.9.2.1.5

YMP/CM-0011, Rev. 1

Table 8.3.1.9-3. Current representation and alternative hypotheses for mineral and resource models for the human interference program (page 2 of 2)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DRIVING FORCES/PROCESSES (continued)				
Tectonic/hydrologic processes	A low-temperature (<90°C) geothermal resource is present at the site, as is common to all of Nevada; no higher temperature resources are expected	Low--large thermal systems only can maturate slowly; small dikes, intrusions, or eruptions have limited thermal energy and, thus, would have to intrude the site to have an effect on resource extraction that could affect waste isolation; thermal waters and heat flow at site are low	Geothermal resources as a result of deep basin circulation or hot dry rock Geothermal resources as a result of igneous activity	Same as above	Low	Low--present-day temperatures and heat flow are low; depth to water table limits economic use of resources; 12 km from site a single well has heat flow of 3.1 HFU; rest of region has heat flow near or below Nevada average	Low	8.3.1.9.2.1.3, 8.3.1.9.2.1.2, 8.3.1.9.2.1.5, 8.3.1.8.5.2.3

[a]CAI = color alteration index.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

The second column of the table lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Table 8.3.1.9-3 provides a judged level of uncertainty designated "high," "moderate," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

Column six gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of the performance parameters in column five to the selection of hypotheses in columns two and four for that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The final column identifies the characterization studies or activities that will discriminate between alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

8.3.1.9.2.1 Study: Natural resource assessment of Yucca Mountain, Nye County, Nevada

This study will identify and assess the natural resource potential at the proposed repository site at Yucca Mountain. Mineral and energy resources (including hydrocarbon and geothermal resources) will be included. Water resources will be evaluated under Study 8.3.1.9.2.2. The study includes a geochemical assessment of Yucca Mountain in relation to the potential for mineralization (Activity 8.3.1.9.2.1.1), a geophysical-geologic appraisal of the site relative to mineral resources (Activity 8.3.1.9.2.1.2), an assessment of the potential geothermal energy at and in the vicinity of Yucca

YMP/CM-0011, Rev. 1

Mountain (Activity 8.3.1.9.2.1.3), an assessment of the hydrocarbon resources of the site (Activity 8.3.1.9.2.1.4), and a mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration (Activity 8.3.1.9.2.1.5). The information and data obtained in this study will provide the basis for probabilistic calculations for determining inadvertent human interference and intrusion (Study 8.3.1.9.3.1).

The consideration of the mineral, hydrocarbon, and geothermal resource potential at Yucca Mountain will not necessarily be limited to the silicic volcanic tuffs that host the proposed repository site. Various models of mineral resource genesis characteristic of the region will be considered, as required in 10 CFR Part 60. In addition, general models of resource occurrence available in the literature will also be considered. For example, the assessment of economic potential will include an evaluation of possible mineralization derived from deep or laterally adjacent hydrothermal systems, as well as systems centered in the site area. In addition, the potential for placer and other types of mineralization found in the Tertiary to Quaternary alluvial deposits will be specifically addressed. The evaluation of oil and gas resource potential will consider potential source rocks that may exist, the thermal maturation of the possible source rocks identified, the presence of reservoir rocks, and the potential for structural or stratigraphic traps. Several types of geothermal resources will be evaluated, including thermal water reservoirs resulting from (1) deep basin circulation, (2) hot-dry rock, or (3) igneous activity.

The potential impact on repository performance from exploration or development of a mineral or energy resource is a function of the three-dimensional location of the resource or expected resource, the direction of vadose-zone water movement, and the extent and nature of the specific activities with respect to the planned underground facility. Human actions that could most directly affect isolation involve those activities within the repository block that could (1) directly induce or affect fluid movement in the repository block or (2) disturb the radioactive waste and result in direct releases. Actions that would have a more indirect effect on isolation involve activities outside the repository block that could (1) affect or induce fluid movement or (2) lead to withdrawal of fluids or materials that have since become contaminated with radioactive waste. Activities in both categories include drilling, mining, the creation of surface-water impoundments, or other work performed during exploration for or development of natural resources. The differing nature of the concerns relating to direct and indirect impacts suggests two levels for evaluation of human interference potential: one for evaluating direct isolation concerns and another for evaluating indirect isolation concerns.

As site characterization activities proceed and new information is provided, evaluation boundaries will be more explicitly defined. Specifically, the assumptions used in establishing the present areas of evaluation will be assessed. This includes information concerning the geologic and geomorphic features, the potential flow paths for induced fluids or effects on natural fluid movement, the assumed stability of the present water table, and other parameters.

 YMP/CM-0011, Rev. 1

As a first approximation, the surface boundary for the detailed evaluation of geothermal and oil and gas resources is defined as within 5(?) km of the center of the surface projection of the perimeter drift of the repository. Energy resources outside of this area are considered to have lower significant potential to affect the performance of the site because of the expected nature of the exploration and development activities (i.e., drilling). Because of the greater potential for impacts on waste isolation in the repository block, areas immediately adjacent to the repository block deserve more scrutiny than areas more distant. As site characterization proceeds and new information is provided, the areas of evaluation will be reassessed.

The depth of the zone considered for detailed energy resource characterization may differ from the zone considered for mineral resources due to the differences in exploration and exploitation techniques (e.g., deep drilling and pumping versus shallow drilling and mining activities). Drilling would likely provide a smaller conduit for the transmission of natural fluids and a smaller potential for the introduction of fluids. As resources are located farther away from the repository or at deeper levels in the earth, exploration or extraction activities should have a diminishing potential for interacting with nuclear waste and thus, less potential for an impact on waste isolation. In addition, the assumptions on geologic structures or stratigraphy, geomorphic barriers, vadose-zone flow characteristics, and the stability of the water table that were applied to mineral resources are also generally applicable to energy resources. However, the regional and the pre-Tertiary stratigraphy and structures will be evaluated along with the tuffs and surficial deposits in the regional energy resource assessments.

The regional hydrocarbon and geothermal energy resource assessments must consider source and reservoir rocks at considerable depth below the proposed repository, because these resources are generally accessed by the drilling of deep holes. The potential for these energy resources will be evaluated by considering information obtained in the region, the immediate vicinity, the drillholes in Paleozoic rocks near the site (e.g., drillhole UE-25p#1 and planned drillhole USW G-7). Depth to Paleozoic rock under the site are generally greater than 3 km. Presently, deep drillholes (9,000 to 20,000 ft) that could intersect Paleozoic rocks are not a planned activity because any specific drilling location would be an arbitrary decision for which no reasonable geologic or geophysical information has yet been established.

During the course of site characterization, additional evidence will be gathered and the need for drilling assessed with respect to the evaluation of energy resource potential.

The potential in other pre-Tertiary rocks will be evaluated, but the level of detail planned for the characterization of their resource potential will be a function of their proximity to the site and will be undertaken as a part of the regional assessment planned (see activity descriptions under this study). For example, the regional analog comparison to Yucca Mountain will consider the general region and the various lithologies in the general region.

YMP/CM-0011, Rev. 1

The likelihood and possible effects of various scenarios for human intrusion and interference resulting from resource exploration or exploitation will be evaluated as part of the resource assessment program. If a reasonable scenario is identified, a detailed study of the possible significance and effects of the scenario will be performed in Investigation 8.3.1.9.3. The results will feed the total system performance assessment calculations described in Section 8.3.5.13. As site characterization proceeds and new information is obtained, the previously described approach, the defined, detailed evaluation boundaries, and the associated assumptions will be reevaluated and changed, if necessary.

Mineral and energy resources have been discussed in Sections 1.7 and 1.8.1.7 and will be further assessed in this program. This includes information that will allow the calculation of gross and net values for any identified resources and reserves that have present markets, and the calculation of tonnage, grade, or volume for speculative, undiscovered resources (Section 1.7) that may have value in the future. These data will then be used as input to Issue 1.1.

8.3.1.9.2.1.1 Activity: Geochemical assessment of Yucca Mountain in relation to the potential for mineralization

Objectives

The overall objective of this activity is to conduct a geochemical sampling program to evaluate the potential for precious, base, and strategic metals; energy resources; and industrial mineral resources in the vicinity of Yucca Mountain. Specific objectives include:

1. Selecting a suite of elements for analysis in a geochemical sampling program. The suite will be based upon known commodities that occur in silicic tuffs and/or trace elements indicative of commodities that occur in the tuffs.

2. Developing a field program to include a systematic and biased sampling of surface materials. Using existing core, core obtained during site characterization, and other subsurface samples to evaluate the potential of mineralization at and near the site. This includes evaluation of deposits that occur along faults within breccia zones and deposits that may be hidden by alluvium.

3. Generating a first-order geochemical data base for selected elements obtained from surface and subsurface sampling within the vicinity of Yucca Mountain.

4. Evaluating the data base in conjunction with geological and geophysical data obtained from other site characterization activities to determine if additional data are needed for an evaluation of natural resources.

 YMP/CM-0011, Rev. 1

5. Evaluating the potential for the occurrence of natural resources in the vicinity of Yucca Mountain based on an analysis of the geochemical data. These data will be examined and evaluated statistically from anomaly and residual maps, and by comparison with calculated background levels and average elemental values found in silicic tuffs.

Information obtained from this activity will further address questions concerning the attractiveness of the site relative to the possible presence of resources (Activity 8.3.1.9.2.1.5) and the potential of future drilling or disruption (Study 8.3.1.9.3.1).

Parameters

The following list is considered to be a first approximation of the elements that are currently important commodities in silicic volcanic associations: gold, silver, copper, lead, zinc, tin, mercury, thorium, and uranium. In addition, pathfinder elements may be considered and could include antimony, fluorine, barium, arsenic, and yttrium. The methods employed for the geochemical characterization will be a function of the detection limits required to assess the potential for mineralization; for example, gold will need to be detected to the parts per billion level. Most metals will be evaluated at the ppm level. Existing chemical analyses on the tuffs of Yucca Mountain will also be used in the site geochemical assessment. Information on the occurrence, abundance, and quality of industrial minerals will be collected as sampling is performed. Additional industrial minerals or elements that could be assessed or analyzed, if necessary, will be determined from a literature search and evaluation of the mineralogy and chemistry of tuff.

Description

Geochemical sampling of surface and subsurface materials will be conducted to determine the potential for exploration in the area of the repository. It is anticipated that future exploration for mineral commodities would likely be conducted before activities such as drilling or mining (Section 1.7). On the basis of currently available data and regional comparisons (Sections 1.7 and 1.8.1.7), the mineral-resource potential of the site is considered low. Chemical analyses of surface and subsurface samples could add further confidence to the conclusion that adjacent areas with surface and subsurface anomalies (e.g., Wahmonie, Calico Hills, Bare Mountain) would prove to be more likely locations for future drilling and mining (Section 1.7.1.1). Other geochemical information (e.g., biochemical data and isotopic data) will be evaluated to determine if they would add significantly to the confidence needed to comply with 10 CFR Part 60. Metnods of determining what should be considered anomalous concentrations will also be considered (e.g., Mattson, 1988). A geochemical data base will help to determine if the site is likely to remain unattractive for exploration, even with anticipated changes in exploration methods and concepts.

The approach to the geochemical sampling program and Activity 8.3.1.9.2.1.5 will be based on a review of existing literature of similar geologic environments with known mineral occurrence, data from preliminary geochemical analyses (Section 1.7), the geologic setting of Yucca Mountain

 YMP/CM-0011, Rev. 1

and the nearby mineralized areas (Bare Mountain, Wahmonie, and Calico Hills). A comparison of the suite of elements determined for Yucca Mountain will be compared with proposed ore emplacement models found elsewhere in the literature. The geochemical sampling scheme to be developed will account for subsurface and surface variation in terrain, rock type, or soil type. The elements selected for analysis will be those that represent metallic and nonmetallic commodities known to be associated with silicic volcanic rocks and surficial deposits. Geochemical sampling also will include rocks of various types and rocks exhibiting the effects of alteration or other geological phenomena commonly associated with mineralization. In particular, geological deposits that will be included in this activity include calcite and opaline-silica deposits and breccias located along faults near Yucca Mountain (Vaniman et al., 1988; Section 8.3.1.5). Trench mapping, isotopic work, and age information obtained on these fault deposits will be integrated with the economic and geochemical information obtained under this study. In addition, analog fault-related breccias or hydrothermal breccias known to carry mineralization (Nelson and Giles, 1985; Huben and Nelson, 1988) will be compared with these deposits located near Yucca Mountain. The sampling program will not be restricted to the controlled area. Samples will also be collected and analyzed from northern Yucca Mountain, Calico Hills, and Wahmonie. This will provide a comparative base, along with chemical analyses obtained from the available literature, to compare the site with other areas in Activity 8.3.1.9.2.1.5. Identified industrial minerals or materials will be evaluated from the geochemical suite of samples, from the information obtained from studies on mineralogy and petrology (Section 8.3.1.3.2), and from appropriate data as identified.

The configuration of the surface sampling program, and the number of sample locations, will be based on the geology, known and expected mineral occurrences, topography, and configuration of the perimeter drift and controlled area. A systematic sampling system will be used. Sample spacing within the controlled area is expected to range between 250 and 750 ft. A more closely spaced grid system may be necessary for a second-order geochemical sampling program if anomalies are identified from the first-order program. Soil-survey geochemistry techniques have been widely used and discussed in the literature (e.g., Thomson, 1986; Theobold, 1987). Surface sampling will not be restricted to a grid system. Biased sampling will also be done where rock types and alteration zones or other geological phenomena commonly associated with mineralization are observed. In addition, sediment sampling within selected areas, including drainages, may be necessary at similar spacing (250 and 750 ft).

The subsurface sampling program will be carried out in a similar manner. A representative number of drillhole cores will be selected that cover the controlled area. Spacing of sampling locations of the core is expected to range between 50 and 300 ft. The program is intended to include the deep holes, including UE-25p#1, which intersect the Paleozoic rocks under Yucca Mountain. Biased samples will be taken from rock types and alteration zones commonly associated with mineralization. Additional sampling may be necessary if anomalies are identified.

Sampling intervals at the surface and of drillhole core will vary depending upon the particular element being measured. For instance, gold will require a more closely spaced sampling interval than base metals.

 YMP/CM-0011, Rev. 1

Sampling intervals will be determined after a complete list of elements selected for analysis is finalized and a scoping assessment is made for each element.

Anomaly and residual maps will be prepared for each elemental analysis. Standard statistical analyses will be performed to characterize the background levels and spatial variability for each element, including averages and standard deviations of the results of the analyses. A comparison of background levels found in the silicic tuffs of Yucca Mountain with anomalies identified will be made. In addition, average elemental abundances found in silicic tuffs will be compared with elemental abundances found at Yucca Mountain.

This activity will generate a geochemical data base for two groups of elements. The first group will include those elements with known affinities for silicic volcanic rocks, including elements that are concentrated by primary magmatic processes, secondary weathering, or hydrothermal (mesothermal to epithermal) processes. The precious metals (gold and silver), mercury, and uranium are included in this group. The second group, the so-called pathfinder elements, such as antimony and arsenic, are usually subeconomic. Because of their solubility in alteration processes, however, these elements are useful in defining dispersion halos or detecting emanations from more deeply buried mineral deposits. Elements such as mercury are important as commodity elements (group 1) and are also excellent pathfinder elements (group 2).

Many elements can be excluded from this evaluation based on their known abundances and potential concentration factors in crystal rocks. These include cobalt, chromium, and the platinum group elements, which are known only to be associated with mafic and ultramafic rocks (Stanton, 1972). Additionally, a large body of literature exists relative to the distribution of elements in specific rock types that allow the prediction of which elements could occur in anomalous concentrations by such processes as weathering, hydrothermal activity, or magmatism. Therefore, many additional commodities and elements may be eliminated from further consideration.

Analytical methods to be used may include fire assays, atomic absorption, x-ray diffraction, x-ray fluorescence, neutron activation, or inductively coupled plasma emission spectroscopy. These methods will be evaluated based on their analytical detection limits and the projected number of samples to be analyzed. Further details and additional information will be presented in the study plans for this activity.

8.3.1.9.2.1.2 Activity: Geophysical/geologic appraisal of the site relative to mineral resources

Objectives

This activity will qualitatively evaluate the available geophysical data base as it relates to Study 8.3.1.9.2.1. The existing geophysical data base (Section 1.7.1.1) will be examined to define any geophysical anomalies that may require additional exploration and possibly constrain any known geochemical anomalies (Activity 8.3.1.9.2.1.1). The geophysical data base will also be used as a basis for comparisons to analog environments of known mineralization (Activity 8.3.1.9.2.1.5). Geologic models derived from geophysical data in Section 8.3.1.17 will be evaluated for their impact on mineral resources. Further work may be planned depending on the results of studies described in Section 8.3.1.17.4 and the qualitative evaluation performed in this activity.

Parameters

Existing regional and site-specific reports on geophysical surveys, as well as reports from geophysical work planned in Section 8.3.1.17.3 will be used in this qualitative assessment. Included in this assessment will be a review of the existing aeromagnetic, gravity, and electrical (induced polarization and magnetotelluric) data. Data obtained from the site-specific gravity, ground magnetic, selected geophysical logging, and magnetotelluric surveys (Section 8.3.1.17.4.3) may also be assessed. Possible hydrothermal alteration zones may be identified through the use of remote sensing (thematic myopia) and field mapping (Section 8.3.1.17.4.4). These techniques may provide useful information to the geochemical program (Section 8.3.1.9.2.1.1). Additional parameters maybe defined during this activity.

Description

Interpretations described in the literature and derived from geophysical data may provide additional information to evaluate the geochemical data base (Activity 8.3.1.9.2.1.1) and to aid in determining which types of ore-forming models should be considered. In addition, preliminary geophysical models that have been suggested for Yucca Mountain include the possible presence of detachment faults (Scott, 1986; Scott and Rosenbaum, 1986), and the presence of a metamorphic core complex under Yucca Mountain (Robinson, 1985). These interpretations, if correct, will be assessed relative to their significance to ore-forming processes.

Other geophysical methods (Section 8.3.1.17.4) that are responsive to local, surficial, or shallow variations of the bedrock will be evaluated as potential complements possibly to constrain the site-specific geochemical survey (Activity 8.3.1.9.2.1.1). The information and data evaluated in this activity will provide the geophysical basis for the comparisons to analog environments performed in Activity 8.3.1.9.2.1.5. Further details and additional information will be presented in the study plans for this activity.

8.3.1.9.2.1.3 Activity: Assessment of the potential for geothermal energy at Yucca Mountain, Nevada

This activity will be undertaken in cooperation with Activity 8.3.1.8.5.2.3 (evaluation of regional ambient heat flow and local heat flow anomalies). Both activities are aimed at characterizing the local geothermal regime as it might relate to repository performance during the postclosure period. Activity 8.3.1.8.5.2.3 will focus on geothermal activity and heat flow calculations as they could relate to Quaternary igneous processes or

 YMP/CM-0011, Rev. 1

events. This activity (8.3.1.9.2.1.3) assesses the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems (Section 1.7.1.5.2). Data compilation and evaluation will be done jointly through both activities.

Objectives

The overall objective of this activity is to assess the potential for a geothermal energy resource at Yucca Mountain, Nevada.

The objectives of this activity are to

1. Compile measured geothermal and calculated heat flow data at and in Yucca Mountain and vicinity to quantify vertical and horizontal geothermal gradients. The quality of these data will be assessed under this activity in conjunction and cooperation with Activity 8.3.1.8.5.2.3. Temperature and other data collected under site unsaturated zone hydrology (Section 8.3.1.2.2) and site saturated zone hydrology (Section 8.3.1.2.3) will be assessed here and in cooperation with Activity 8.3.1.8.5.2.3.

2. Compile appropriate chemical and isotopic (oxygen and deuterium) analyses of water samples from springs and wells useful for predicting subsurface temperatures. These data will be useful in comparing subsurface temperatures at the site with measured temperature profiles and heat flow data for the region.

3. Evaluate the existing data on geothermometry and heat flow necessary to adequately characterize the region for its geothermal resource potential.

4. Recommend whether additional studies may be needed, including the collection and integration of additional geothermal data from existing or planned drillholes.

5. Provide the information necessary for the final resource assessment to be performed in Activity 8.3.1.9.2.1.5.

Parameters

The parameters that will be calculated and evaluated for this activity are

1. Temperature gradient and thermal conductivity data from boreholes and similar data from the exploratory shaft facility will be used to calculate heat flow (Sections 8.3.1.8.5.3, 8.3.1.17.4.5, and 8.3.1.8.5.2).

2. Water chemistry and isotopic (oxygen and deuterium) analyses will be used in evaluating geothermometry methods (Study 8.3.1.2.3.2).

YMP/CM-0011, Rev. 1

3. Temperature of ground water from springs and wells, and geological, hydrological, and structural data of the site and surrounding region will be used to assess the geothermal energy potential of Yucca Mountain (Section 8.3.1.2.3.2, 8.3.1.4.2.1, and 8.3.1.8.5.2).

Description

As discussed in Section 1.7.1.5.3, the existing heat flow calculations, temperature data, temperature gradient data, and isotopic analyses (oxygen and deuterium) for Yucca Mountain are consistent with a low-temperature (<90°C) geothermal regime.

Downhole temperature data from Yucca Mountain and temperature data obtained from nearby localities indicate that significant variations occur in temperature gradients for a single hole and between wells. Anomalous heat flow and thermal gradients are observed at localities near the site at drillhole UE-25a#3 (3.08 to 3.34 heat flow units (HFU)) located near Calico Hills, and drillhole UE-20F located at Pahute Mesa (thermal gradient is 37°C/km). These localized anomalies could be associated with several heat-flow models such as water circulation in faults, shallow magma bodies, anomalous ground-water flow, and large variations in stratigraphic thickness (thermal conductivity).

The available data for geothermal assessment have not been compiled or thoroughly evaluated for adequacy or quality. Because data were not collected systematically (in some instances, measurements were taken during or soon after drilling (Sass et al., 1983)), some of the data are of questionable quality. Thus, the available data will be evaluated for their adequacy and quality, and the acquisition of temperature and thermal conductivity data from existing or new drillholes for use in heat flow calculations may be recommended as a result of this activity. A compilation of regional data obtained from the literature will also be assessed so that a comparison can be made with the data from the Yucca Mountain area.

Chemical and isotopic data will be compiled and evaluated for their application to the geothermal assessment of Yucca Mountain (Section 1.7.1.5.2). Data will include chemical analyses of ground-water samples obtained from drillholes (Section 8.3.1.2.3.2), and springs near Yucca Mountain (Section 1.7.1.5.2). These data will be evaluated to determine whether silica geothermometer analyses may be appropriate.

All the data compiled and evaluated will be used in conjunction with geologic, structural, stratigraphic, and hydrologic data to perform the geothermal assessment. This activity will lead into the final energy and resource assessment performed in Activity 8.3.1.9.2.1.5. Further details and updated information will be provided in the study plans for this activity.

 YMP/CM-0011, Rev. 1

8.3.1.9.2.1.4 Activity: Assessment of hydrocarbon resources at and near the site

Objectives

The objectives of this activity are to

1. Determine the potential for the presence or absence of suitable source rocks, reservoir rocks, and traps and seals at and near the site.

2. Determine the potential for occurrence of conventional hydrocarbon resources (crude oil and natural gas) at and near the site. This will include a review and assessment of drillholes emplaced for oil and gas exploration within the geographic area of the site. The radius of this area is expected to be on the order of tens of kilometers, but its size will depend largely on the results of the work described previously.

3. Provide necessary data for the overall mineral and energy resource assessment to be performed in Activity 8.3.1.9.2.1.5.

Parameters

Several investigative efforts and evaluation approaches are intended. First, the presence of organic matter within certain Paleozoic rocks will be ascertained. This will be based upon an examination of samples from drillholes and outcrops in the general area including core material from the one drillhole (UE-25p#1) that penetrated Paleozoic rocks close to the site. Newly obtained core or cuttings from drillholes in areas adjacent to the site will also be studied. An evaluation of the existing petroleum industry exploration drillholes in the vicinity of Yucca Mountain will be made to determine if information relevant to the site can be obtained. Outcrop material from adjacent areas such as Bare Mountain, Calico Hills, and Mine Mountain-Syncline Ridge will also be collected and evaluated.

Second, the thermal maturation of any organic matter found in these samples will be determined. Several techniques, such as kerogen elemental analysis, kerogen coloration (temperature alteration index (TAI)), rock pyrolysis, and vitrinite reflectance, are among those available for determining thermal maturation-source-bed potential. These and possibly other techniques that are based upon organic matter will be compared relative to their applicability, especially with regard to outcrop samples using the most suitable method(s).

Third, parallel consideration of another thermal maturation technique, based upon microfaunal remains (conodonts) and termed the conodont color alteration index (CAI), will be undertaken in conjunction with a literature search intended to focus upon the thermal maturation experienced by the Paleozoic carbonate strata at and near the site. Other techniques will be evaluated (e.g., fluorescence petrography for oil fluid inclusions) to determine if other information could aid in refining the time-temperature history reconstruction estimations. This will allow refinements to be made to the estimate of Lopatin's time-temperature index (Section 1.7.2.2.1) and

YMP/CM-0011, Rev. 1

will expand upon the work of Harris et al. (1980) and M. D. Carr et al. (1986). This will also allow the anticipated integration of the thermal history of adjacent sites (e.g., Bare Mountain) into an understanding of the thermal history of Yucca Mountain.

Other work is intended to review the stratigraphy and geologic structure of the Yucca Mountain site and of areas near the site within the context of available and future drillhole and geophysical data (Section 1.7.1.1; Study 8.3.1.17.4.4). This is intended to identify potential reservoir rocks, traps, and seals that may be present. An allied exercise will be to evaluate comparable petroleum-geology features as they are developed at known hydrocarbon occurrences within the Great Basin of Nevada, and, in particular, the highly productive trend that is present in the Railroad Valley area (e.g., Grant Canyon Field) of northeastern Nye County. The possibility that Mesozoic thrust belts with oil-bearing potential extend to southern Nevada (Scott and Chamberlain, 1987), including the area of Yucca Mountain, will also be addressed. This will provide a basis for assessing the degree to which these factors are relevant to the petroleum potential of the site (Activity 8.3.1.9.2.1.5). New data gathered by several planned geophysical surveys, such as the regional magnetotelluric, deep refraction-seismic, deep and intermediate reflection-seismic, and the ground magnetic surveys planned for fault detection (Table 8.3.1.17-10) will be assessed if applicable for evaluating oil and gas potential. Part of this effort will be conducted under Activity 8.3.1.9.2.1.2, particularly the evaluation of geophysical data, which will include an early assessment regarding the applicability of these data to the interpretation of subsurface geologic structures. Additional parameters may be defined and pursued if these several work efforts, evaluations, and literature investigations fail to provide adequate information on possible source rocks-organic matter, thermal maturation, and the integrated petroleum potential at and near the site. Among these may be a comparative evaluation of both surface hydrocarbon-prospecting techniques and indirect subsurface detection methods such as the analysis of ground water for dissolved hydrocarbon gases.

Description

To date, no hydrocarbons have been discovered at or in the vicinity of the Yucca Mountain site, although relatively few boreholes have been drilled for that purpose. Of the commercially drilled exploration holes located throughout southcentral and southeastern Nevada, none have encountered economic quantities of oil and gas. Significant shows of such hydrocarbons have similarly been lacking.

The thermal history of the general Yucca Mountain area may have been too high over an extended period of geologic time to allow any previously formed hydrocarbons to persist as either oil or gas (Section 1.7.2.2.1). However, data presented by M. D. Carr et al. (1986) suggest that CAI-based temperatures within the Silurian portion of the Paleozoic carbonate sequence as encountered in drillhole UE-25p#1 have been no greater than 180°C, and possibly no less than 140°C (CAI = 3). If these paleogeothermal data represent an accurate reflection of the thermal maturation, these rocks would not be considered overly mature, and thus technically capable of some hydrocarbon potential within the gas range, provided that the several other factors necessary to generate and entrap hydrocarbons were present.

 YMP/CM-0011, Rev. 1

Further refinement of the thermal history will be pursued, along with work designed to evaluate the potential for reservoir rocks, the potential for trap-seals, and the comparison with other producing trends within the Great Basin and Nevada. Analyses of any detected organic matter (as found in drillhole cores and cuttings and samples collected from selected outcrops) will be made based upon an assessment of the most applicable petroleum geochemical methods. Companion work based upon faunal remains and their indications of thermal maturation will also be made. Inclusion of geophysical and drillhole data will also be implemented to evaluate the structural geologic setting as it relates to traps and seals. Further details and additional information will be provided in the study plans for this activity.

8.3.1.9.2.1.5 Activity: Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration

Objectives

The objective of this activity is to integrate the data and information collected from Activities 8.3.1.9.2.1.1 (geochemical assessment), 8.3.1.9.2.1.2 (geophysical/geologic assessment), 8.3.1.9.2.1.3 (geothermal energy assessment), and 8.3.1.9.2.1.4 (hydrocarbon assessment). Integration of these activities and the data acquired from them will allow:

1. The identification of mineral resources with current markets, as well as the calculation of gross and net values for identified resources or reserves.

2. The physical description of mineral resources with potential future markets relative to "tonnage, or other amount, grade, and quality," as described in 10 CFR 60.21(c)(13).

3. The physical description of energy resources using appropriate parameters that describe the extent and magnitude of those resources.

4. The evaluation of the resource potential of any identified or undiscovered mineral and energy resources, based upon a "representative" area of "similar size" and a comparison to the Yucca Mountain site (10 CFR 60.122(c)(17)).

5. An estimation of the potential for undiscovered deposits of those resources described in 10 CFR 60.21(c)(13). This will be accomplished using site-specific data in conjunction with evaluation of models found in the literature of economic mineralization, hydrocarbon generation and entrapping processes, and extraction-conversion methods in geothermal energy utilization.

This activity provides data necessary for the probabilistic calculations for determining future inadvertent human interference or intrusion (Study 8.3.1.9.3.2).

YMP/CM-0011, Rev. 1

Parameters

Existing site-specific data and data collected under Activities 8.3.1.9.2.1.1, 8.3.1.9.2.1.2, 8.3.1.9.2.1.3, and 8.3.1.9.2.1.4 will be used to calculate grades, tonnages, or other amounts. Information obtained from the literature will allow a comparison of analog areas and literature models with the site-specific data obtained for Yucca Mountain under the activities just listed.

Description

Information from Activities 8.3.1.9.2.1.1 and 8.3.1.9.2.1.2 and other site-specific data from the literature will be used to calculate gross and net values of commodities of current commercial value and commodities that may have future commercial value. These site-specific grades, tonnages, or amounts will be compared with the average abundances in crystal rock types to determine if the site has extractable commodities that may be of commercial value, of future commercial value, or anomalous concentrations of a commodity that would attract exploration.

Information from Activities 8.3.1.9.2.1.3 and 8.3.1.9.2.1.4 and other site-specific data from the literature will be used to describe energy resource potential. More detailed assessment of energy resources will be conducted if warranted by data from this activity.

This activity will compare analog environments of known natural resources to the geological conditions present at the site. Information on selected mineral deposit analogs will be obtained from the existing literature and Activities 8.3.1.9.2.1.1 and 8.3.1.9.2.1.2. Ideally, the selected analogs will consist of similar rock types that have originated under similar geologic conditions. For example, analogs will be selected that compare the site to known areas of mineralization such as those found within calderas (Jefferson Caldera, Nevada) and on margins of calderas (Round Mountain and Goldfield, Nevada) or in deposits recently discovered in the vicinity of Yucca Mountain (Bullfrog District and northern Bare Mountain, Nevada). This approach will allow the incorporation of many mineral deposit models, including Round Mountain, Nevada as a lode gold deposit (Tingley and Berger, 1985) or as a high-volume low-grade (bulk-mineable) precious-metal deposit (Bonham, 1988). A large body of literature, including petrologic, petrogenic, structural, geophysical mineralogic, and analytical data of the rocks located at the site, will be evaluated in this comparison. This integrated information will be used to evaluate the site potential for undiscovered deposits and mineral exploration using reasonable inference based on geologic and geophysical evidence as required in 10 CFR Part 60, which states

> For resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality.

The activity will permit a final qualitative assessment of mineral resources at the site in terms of their present value, and the potential for future exploration at the site.

 YMP/CM-0011, Rev. 1

Information on selected geothermal analogs will also be obtained from the existing literature. This information will be compared with existing information on the geothermal resource potential of the site and with new data provided by the results of Activities 8.3.1.9.2.1.1, 8.3.1.9.2.1.2, and 8.3.1.9.2.1.3. Ideally, the selected analogs will consider geothermal resources in similar geologic environments that have originated under comparable geologic conditions. Analogs will be selected to compare the site with known areas of geothermal resources found in association with large-volume silicic caldera systems of similar age, geothermal resources associated with small-volume, intra-plate basaltic volcanism of similar age or similar geologic environments in Nevada with known geothermal resources. The available literature will be used as a source of information on the analogs, including geophysical, geochemical, and geological data. The integrated information will be used to evaluate the potential for undiscovered occurrences at the site using reasonable inferences from geologic and geophysical data. This approach will allow the incorporation of several geothermal resource models such as low-temperature resources, high-temperature fluid dominated resources, dry-steam resources, and hot-dry rock resources. The activity will permit a final qualitative assessment of geothermal resources at the site in terms of (1) the presence or absence of favorable circumstances for occurrence, (2) the present-day value if located, and (3) the potential for future exploration at the site. "For resources without current markets, but which would be marketable given credible projected changes in economic or technological factors, the resources shall be described by physical factors such as tonnage or other amount, grade, and quality" (10 CFR Part 60).

Information on selected hydrocarbon (oil and gas) analogs will be obtained from the existing literature. This information will be compared with the existing information on the hydrocarbon potential of the site and with new data provided by the results of Activities 8.3.1.9.2.1.1, 8.3.1.9.2.1.2, and 8.3.1.9.2.1.3. Ideally, the selected analogs will consider similar age rocks, depositional environments, tectonic regimes, and similar traps and seals that are anticipated in the region. Analogs will be selected to compare the site with known areas of hydrocarbons found associated with Paleozoic carbonate rocks, in similar structurally complex areas such as Grants Canyon, Nevada. The available literature will be used as a source of information on the analogs including geophysical, geochemical, and geological data. This integrated information will be used to evaluate the potential for undiscovered occurrences at the site using reasonable inference based on geologic and geophysical data. This approach will allow the incorporation of several models for source generation, structural and stratigraphic trapping, and reservoir seals. The work will provide a final qualitative assessment of the hydrocarbon resource potential at the site in terms of the presence or absence of favorable circumstances for hydrocarbon generation and entrapment, present-day value if located, and the potential for future exploration at the site.

This activity will also provide synthesized data and evaluations of those data relative to assessing any initiating events under human interference that may be potentially unworthy of further consideration (Activity 8.3.1.9.3.2.2). These data and data evaluations are anticipated to facilitate the requisite probabilistic calculations (Study 8.3.1.9.3.2), but in

YMP/CM-0011, Rev. 1

some instances a less rigorous treatment may be used to dismiss events if they are considered sufficiently noncredible. Further details and additional information will be presented in the study plans for this activity.

8.3.1.9.2.2 Study: Water resource assessment of Yucca Mountain, Nevada

Ground water is expected to be the primary mechanism by which radionuclides might be transported from the repository to the accessible environment. Ground water is the sole source of supply for residents, irrigated agriculture, and industry within the geohydrologic study area. Changes in population, economic and industrial development, and consumptive uses of water will affect ground-water depths and withdrawal rates. Future ground-water withdrawals could affect ground-water flow within the geohydrologic system. This study consists of a single activity that will use available data to estimate the future supply, demand, and value of the ground-water resource in southern Nevada, proximal to Yucca Mountain.

8.3.1.9.2.2.1 Activity: Projected trends in local and regional ground-water development, and estimated withdrawal rates in southern Nevada, proximal to Yucca Mountain

Objectives

The objectives of this activity are to (1) assess the current and projected supply and demand situation for ground water in the geohydrologic study area, and (2) estimate the value of the ground-water resource.

Parameters

Three sets of parameters are required for this activity:

1. The determinants of supply, which include quantities available from alternative sources; the cost of water by alternative source; the physical and chemical characteristics of the ground-water system (e.g., recharge, aquifer depth, volume, and salinity); and the institutional factors relating to water laws and rights (e.g., preferred beneficial uses).

2. The determinants of demand, which include population data (i.e., historical, current, and projected trends); the economic conditions, including industry, employment, and income; the trends in consumptive uses of water (i.e., domestic, commercial, industrial, and agricultural uses); climate; and price.

3. Empirical estimates of the value of water in various uses (i.e., domestic, commercial, industrial, and agricultural).

 YMP/CM-0011, Rev. 1

Description

Current and projected marginal supply curves for water will be estimated. The effects of various current and projected socioeconomic conditions on ground-water development, use, and allocation will be evaluated. Where sufficient price and quantity data are available, water-demand curves can be estimated, from which estimates can be made of the marginal value of the water. For a variety of reasons, market-established prices for water are not generally available. However, there are a number of alternative means of estimating the value of the ground-water resource even in the absence of markets. These include evidence of prices paid for water by a given sector as an indication of the user's willingness to pay (an example of this is the recent purchase of ground water by Nevada Power Company in the Moapa Valley area), shadow prices determined via linear programming, change in net income or value-added approaches, and alternative and opportunity cost.

Because of the degree of uncertainty in forecasting changes in those factors that will determine the future supply and demand situation for ground water, a reasonable range of plausible scenarios will be developed. This information will be used to estimate the current and future value of the ground-water resource in the geohydrologic study area and to project probable withdrawal rates and locations. Estimations will be limited to the foreseeable future (10 CFR 960.4-2-8-1) and be a function of the various supply and demand scenarios.

8.3.1.9.3 Investigation: Studies to provide the information required on potential effects of exploiting natural resources on hydrologic, geochemical, and rock characteristics

Technical basis for obtaining the information

Links to the technical data chapters and applicable support documents

A preliminary evaluation of the resource potential of the Yucca Mountain site is presented in the Yucca Mountain environmental assessment (DOE, 1986b) and in Sections 1.7 and 3.8 of the SCP. Studies will be performed to determine the extent to which the actual or inferred presence of resources at the site might influence the exploration activities of future generations. Additional studies will establish the potential effects of resource exploitation and extraction on the hydrologic, geochemical, and rock characteristics at and in the vicinity of Yucca Mountain.

Ground water currently is the only resource being considered. However, if other economically attractive resources or reserves are identified during the natural resource assessment that is being conducted in support of Investigation 8.3.1.9.2, the potential effects of their exploitation will also be evaluated. These data will be assessed by a panel of experts to determine the probability that human intrusion into, or interference with, a mined geologic disposal system could result from the actual or inferred presence of natural resources.

YMP/CM-0011, Rev. 1

Parameters

The only parameters that have been identified to date are (1) projected rates and the probable locations of future ground-water withdrawals within the geohydrologic study area, (2) the results of the resource assessment (Study 8.3.1.9.2.1), and (3) the probabilities for inadvertent human interference and intrusions.

Additional parameters that will be required if other resources are identified (Investigation 8.3.1.9.2) include the specific types, locations, distributions, and quantities (i.e., grades, tonnages, and volumes) of the materials identified. Necessary information regarding the applicable extraction and exploitation methods will be taken from the literature. Site characterization activities and the existing data base will provide the baseline information relative to the hydrologic, geochemical, and rock characteristics at the site.

Purpose and objectives of the investigation

The purpose of this investigation is to obtain the information that will be used to satisfy the parameter requests made in Issue 1.1 (total system performance). Two types of data are requested in this performance issue: (1) information on the resources presently at the site that would influence the likelihood of exploratory drilling within the controlled area, and (2) the potential effects of resource extraction on the hydrologic, geochemical, and rock characteristics at the site. The first objective of this investigation is to evaluate the data relative to the resource potential at the site, resource extraction, and marker system survivability necessary to determine the probability range for exploratory drilling. The second objective is to assess the potential effects of resource extraction for all commodities known to be present or inferred to be present at the site. Thus, this investigation will compile all the site data generated by the human interference program and pass the required parameters to Issue 1.1 (total system performance, Section 8.3.5.13).

Technical rationale for the investigation

To determine the effects of resource exploitation on the hydrologic, geochemical, and rock characteristics at the Yucca Mountain site, it will be necessary to estimate the quantities, as well as the locations and distributions, of those resources identified in the assessment. These resource parameters, together with their applicable extraction and exploitation methods, will be evaluated to determine qualitatively the effects of exploitation. For instances in which it is possible to model the effects using computer codes, such as with ground-water withdrawals, potential effects will be quantified. The data that will be collected by Studies 8.3.1.9.1.1, 8.3.1.9.2.1, and 8.3.1.9.2.2 will be evaluated to determine the likelihood for human interference and intrusion. Figure 8.3.1.9-4 shows the data flow for this investigation.

Two studies will be undertaken in fulfillment of this investigation. Study 8.3.1.9.3.1 will address factors that directly influence the amount of radionuclide releases that could result from inadvertent human interference and intrusion at the site. The studies to be undertaken to evaluate the

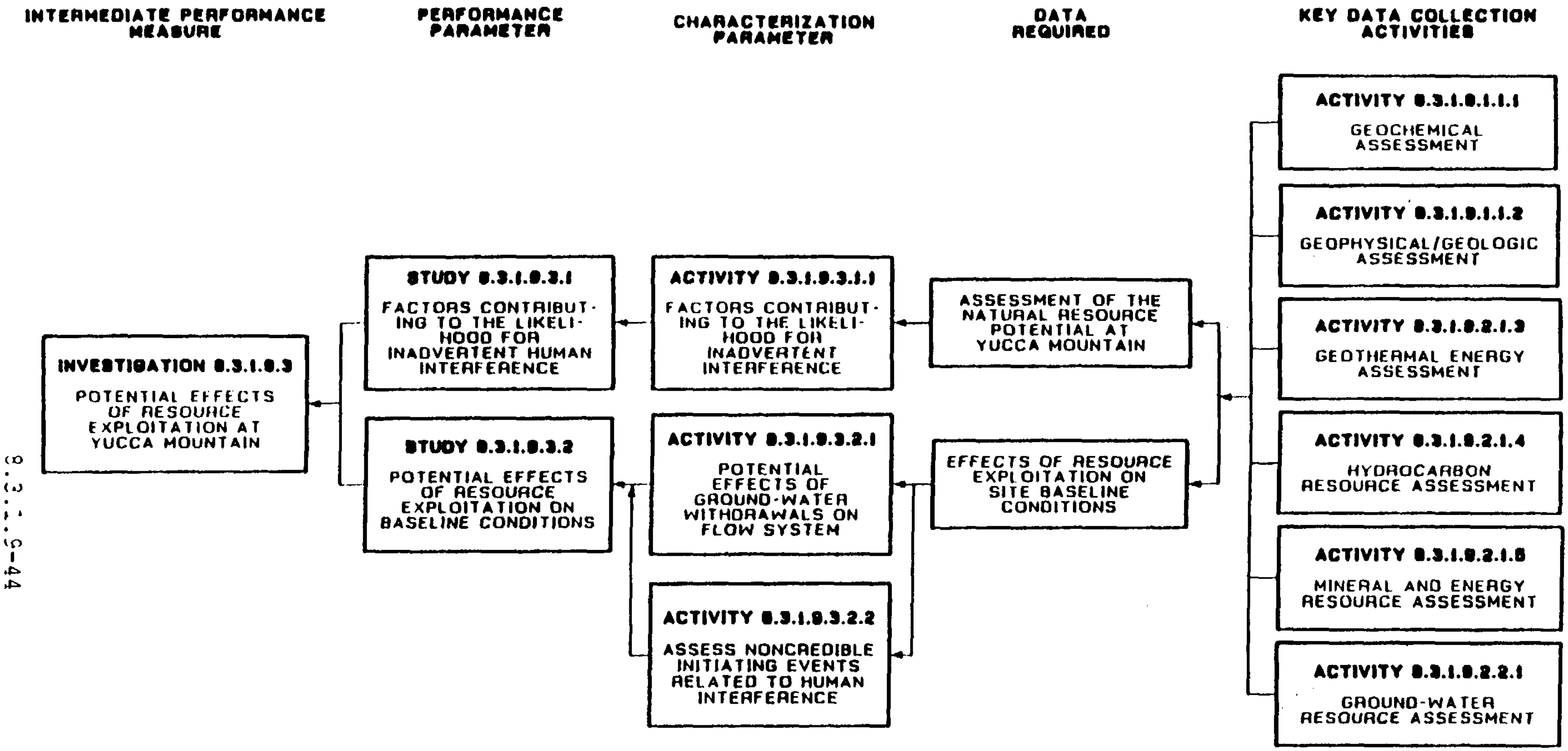

Figure 8.3.1.9-4. Logic diagram for Investigation 8.3.1.9.3.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

potential effects of resource exploitation will be defined in detail when the resource assessment (Study 8.3.1.9.2.1) is completed. On the basis of the data available to date, ground water is the only resource known to be present. Specific plans for evaluating the effects of ground-water withdrawal are presented in the following sections. The second study (8.3.1.9.3.2) will present supporting discussions necessary to demonstrate that certain initiating events identified in the human interference program are not credible and, therefore, not significant.

8.3.1.9.3.1 Study: Evaluation of data needed to support an assessment of the likelihood of future inadvertent human intrusion at Yucca Mountain as a result of exploration and/or extraction of natural resources

In this study, data will be compiled and analyzed for assessing the likelihood of inadvertent human interference in the vicinity of Yucca Mountain. The initiating events for which data will be compiled include exploratory drilling for natural resources and ground-water withdrawal.

8.3.1.9.3.1.1 Activity: Compilation of data to support the assessment calculation of the potential for inadvertent human intrusion at Yucca Mountain

Objectives

The objectives of this activity are to

1. Determine the maximum drilling density and frequency (drillholes per square kilometer per 10,000 yr) that can be reasonably assumed for a repository at Yucca Mountain.

2. Determine the extent to which future ground-water withdrawals will modify the expected ground-water flow paths.

Parameters

The parameters that will be obtained or evaluated by this activity include:

1. Expected drilling density.

2. Distribution and expected depth of drillholes.

3. Expected distribution of drillhole diameters.

4. The probabilities that human interference or intrusion will occur as a result of exploratory drilling or exploitation.

 YMP/CM-0011, Rev. 1

The natural resource assessment parameters for this activity will be input from Study 8.3.1.9.2.1 (assessment of the natural resource potential at Yucca Mountain) and Study 8.3.1.9.2.2 (effects of natural resource exploitation at Yucca Mountain). These data will be used to aid in estimating the likelihood of the initiating events (Table 8.3.1.9-1) for human intrusion and interference at Yucca Mountain during the postclosure period.

Description

This activity will involve compiling data to determine the anticipated maximum drillhole density, borehole diameter, and depths of the drillholes over the next 10,000 yr in the vicinity of Yucca Mountain. The results of the natural resource assessment studies (8.3.1.9.2.1 and 8.3.1.9.2.2) will be used in this activity. In addition, information on state-of-the-art exploration and drilling techniques, as well as information on expected future exploration and drilling equipment trends, will be analyzed in this activity.

8.3.1.9.3.2 Study: An evaluation of the potential effects of exploration for, or extraction of, natural resources on the hydrologic characteristics at Yucca Mountain

This study will assess in qualitative or quantitative terms, the effects of exploiting natural resources known or believed to be present at Yucca Mountain. Consideration of the effects of resource exploitation or extraction are limited to changes in the hydrologic, geochemical, and rock characteristics.

8.3.1.9.3.2.1 Activity: An analysis of the potential effects of future ground-water withdrawals on the hydrologic system in the vicinity of Yucca Mountain, Nevada

Objectives

The objective of this activity is to determine the potential effects of future ground-water withdrawals on the hydrologic system at Yucca Mountain. Effects of the withdrawals will be defined qualitatively and quantitatively.

Parameters

The parameters required for this study are the following:

1. The time-phased estimates of ground-water withdrawals as projected from the activity described in Investigation 8.3.1.9.2.

2. The probable locations of the wells from which projected withdrawals would be made. Locations need only be accurate to within a single hydrographic area (Section 3.8.1). This parameter will also be passed from Investigation 8.3.1.9.2.

 YMP/CM-0011, Rev. 1

3. The appropriate hydrologic parameters (aquifer characteristics) will be obtained from Investigation 8.3.1.2.3.

Description

Various computer models, such as FEMOD (Czarnecki, 1985), will be used to analyze the potential effects of ground-water withdrawal on the local hydrologic system. The input parameters supplied from Investigation 8.3.1.9.2 when used in the computer model will allow simulation of the changes in the geohydrologic system that might occur as a result of withdrawals through break time. The results from the model will provide qualitative and quantitative information on the potential effects of ground-water withdrawals within the geohydrologic system.

8.3.1.9.3.2.2 Activity: Assessment of initiating events related to human interference that are considered not to be sufficiently credible or significant to warrant further investigation

Objectives

The objective of this activity is to demonstrate that those initiating events that have been identified (Table 8.3.1.9-1) for the human interference issue are not considered sufficiently credible or significant to necessitate additional investigation. This will be documented in a topical report.

Parameters

The parameters that will be obtained or calculated by this activity are grouped by initiating events and include the following:

1. Large-scale surface-water impoundment constructed near the controlled area.

   a. Area, depth, and volume of surface impoundment.

   b. Seepage and percolation rates, and transmissivities of near surface and subsurface materials.

2. Extensive irrigation is conducted near the controlled area.

   a. Area of irrigation.
   b. Quantity of water available for irrigation.
   c. Types of crops cultivated.
   d. Infiltration and percolation rates.
   e. Quantity of water applied for irrigation.

All initiating events will require information on the presence and readability of the markers over 10,000 yr.

 YMP/CM-0011, Rev. 1

Description

The results of the natural resource assessment activities along with data from the activities in Section 8.3.1.2 (geohydrology) will provide input to this activity. These data will be used to assess the credibility and significance of the initiating events of potential human interference activities at Yucca Mountain. A special panel of experts from the disciplines of natural resources exploration, geosciences, economics, social sciences, and statistics will be convened to make a qualitative assessment of the noncredible or insignificant initiating events by using their experience and the parameters listed previously. The panel's professional judgment along with previously noted data will be used to prepare topical reports on those noncredible and insignificant initiating events.

 YMP/CM-0011, Rev. 1

8.3.1.10 Overview of population density and distribution program: Description of population density and distribution required by the performance and design issues

This section presents references and information to support resolution of performance and design issues related to preclosure radiological safety. These requirements are derived from 10 CFR Part 20, 10 CFR Part 60, 40 CFR Part 191 and DOE orders. The detailed link to these regulations is presented in the performance and design issues that require data from the population density and distribution program.

Collection of population density and distribution data is not considered a site characterization activity as defined in the Nuclear Waste Policy Act (NWPA, 1983). Therefore, the format and details for data collection will not be presented in this document. Population density and distribution, however, remain important components of the program of preclosure radiological safety for members of the general public, whether through normal operations or as a result of accident conditions (Issues 2.1 and 2.3). The data base established during this program will contribute to Issue 2.5, which addresses higher level findings on the qualifying and disqualifying conditions of the DOE siting guideline on population density and distribution (10 CFR 960.5-2-1).

The distribution of future populations in highly populated areas and in unrestricted areas is currently recognized as a significant factor in defining preclosure radiological safety programs. Preparation of a radiological monitoring plan will help to establish the data base required for resolution of performance and design issues related to radiological safety. This plan, in part, will be the mechanism for implementing the studies necessary for calculating radionuclide doses to members of the general public at varying distances from the potential repository location at Yucca Mountain. The details of the methodology to be used in analyzing the population related information will be discussed in the Radiological Monitoring Plan. The methods and procedures for collection of population data will be part of the Yucca Mountain Project socioeconomic planning process and environmental program planning effort.

 YMP/CM-0011, Rev. 1

8.3.1.11 Overview of land ownership and mineral rights program: Description of status and plans for land ownership and mineral rights required by the performance and design issues

The land ownership and mineral rights program derives from the requirements of 10 CFR Part 960 and 10 CFR Part 60. The provisions of 10 CFR 60.121 require that

> Both the geologic repository operations area and the controlled area shall be located in and on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use.

This provision further requires that (1) such lands shall be held free and clear of all encumbrances, (2) the DOE shall exercise any jurisdiction and control over surface and subsurface estates necessary to prevent adverse human actions that could significantly reduce the repository's ability to achieve isolation, and (3) the DOE shall also have obtained water rights as may be needed to satisfy the requirements of the repository operations area.

The plans and procedures for acquiring land ownership and mineral rights are not considered site characterization activities as defined by the Nuclear Waste Policy Act (NWPA, 1983). Therefore, the standard format and level of detail that is presented for other programs will not be provided in this section. However, the regulatory requirements just listed are an essential component of the repository program in that they provide for a controlled site, which in part addresses preclosure radiological safety aspects of the program. Information about postclosure site ownership and control is presented in Sections 8.3.5.18 (postclosure higher level findings) and 8.3.1.9 (human interference). The performance and design issues concerning radiological dose calculations to the public and workers (Issues 2.1, 2.2, 2.3, and 2.7, Sections 8.3.5.3, 8.3.5.4, 8.3.5.5, and 8.3.2.3, respectively) can be addressed with the knowledge that actions will be taken to withdraw and control the appropriate portion of land in accordance with applicable regulations. In addition, compliance with these requirements will support Issue 2.5 (Section 8.3.5.6), which addresses higher level findings on the qualifying and disqualifying conditions of the site ownership and control guidelines in 10 CFR Part 960. Another aspect of the land ownership program is the process by which the land is acquired and controlled, including rights to subsurface resources. This process is described in the following paragraphs.

The parameters of the controlled area are defined in 40 CFR Part 191 and are based on information about the subsurface. After tentatively identifying the outline of the proposed repository site, the information-gathering elements of the land ownership program will occur in three basic steps. The first step is to define the boundaries of the parcel for which the DOE must obtain control and seek withdrawal. Inherent in this step is applying the information gained during site characterization that would influence the boundaries at the controlled area and accessible environment.

 YMP/CM-0011, Rev. 1

The second step is to ascertain the status of any preexisting outside rights with respect to the land at the site. Prior investigations have identified no such rights (e.g., mineral, grazing, or water rights) at or in the immediate vicinity of Yucca Mountain. However, monitoring of these situations during site characterization will be conducted by the DOE.

The third step involves the actual process by which information will be obtained for purposes of supporting a withdrawal application as set forth in the Federal Land Management Policy Act (FLMPA) and implementing Bureau of Land Management (BLM) regulations.

As established in the environmental assessment for the Yucca Mountain site (DOE, 1986b), the land area of interest to the DOE for the repository operations area and controlled area is entirely on Federal lands controlled by three Federal agencies. These lands include the Nellis Air Force Range (NAFR) controlled by the U.S. Department of the Air Force (DAF), the Nevada Test Site (NTS) controlled by the DOE, and public lands controlled by the U.S. Department of the Interior (DOI), BLM. The Military Lands Withdrawal Act of 1986 (Public Law 99-606; MLWA, 1986), recently enacted by Congress, withdrew the 2.9 million acre NAFR for defense-related use by the DAF. Management of these lands remains the responsibility of the BLM.

The land area of interest to DOE currently under BLM control is in the public domain and has not been segregated from the operation of the public land laws. There exists, therefore, a possibility that control of surface and subsurface rights on the public lands could change as a result of rights granted under FLMPA or applicable mining laws.

The ownership and control status of the land area of interest is important to the DOE for a variety of reasons. These include the length of time required to conduct site characterization activities, the land management plans and agreements, and the public domain status of the BLM controlled lands. The DOE will monitor not only actions taken by the BLM or DAF with regard to the land areas of interest to the DOE but also the current or proposed laws and regulations that may impact land ownership and control, or the rights to access such lands.

If the Yucca Mountain site is recommended and approved for development as a repository following site characterization, it will be necessary, pursuant to 10 CFR 60.121, for the DOE to withdraw the land that would comprise the repository operations area and controlled area and reserve this land for its use. Such a withdrawal action, under current law, must be made pursuant to applicable implementing regulations. To initiate a withdrawal action, FLMPA and the implementing regulations define the data and information required to be provided at the time of application to Congress to support the review of the application. Much of the required data and information will be collected as part of the site characterization activities or other programmatic activities planned by the DOE. The programmatic activities include the repository land withdrawal and control process and the environmental program planning effort for the Yucca Mountain site. To ensure that the data and information relevant and necessary to support a withdrawal action are acquired and documented properly, site characterization activities must be reviewed and withdrawal information and documentation requirements conducted in parallel with the site characterization program. A similar

 YMP/CM-0011, Rev. 1

requirement to recognize and address withdrawal requirements also exists for additional DOE activities directed at assessing the suitability of the Yucca Mountain site under 10 CFR Part 960 and preparing input to the environmental impact statement required by the NWPA (1983) and the National Environmental Policy Act (NEPA, 1969).

 YMP/CM-0011, Rev. 1

8.3.1.12 Overview of the meteorology program: Description of meteorological conditions required by the performance and design issues

Summary of performance and design requirements for meteorological information

The purpose of the meteorological program is to provide data required for resolving of performance and design issues. The types of data requested fall into three categories: (1) data needed in calculating radiological doses resulting from airborne releases from the repository during the preclosure operational period; (2) information required for design of surface facilities; and (3) hydrometeorological measurements for hydrologic and climatic studies. Table 8.3.1.12-1 shows the link between the design and performance parameters (information needed) and the meteorology program parameters that satisfy those needs, respectively.

Approach to satisfy performance and design requirements

The purpose of the meteorology program is to establish (1) regional meteorological conditions (Investigation 8.3.1.12.1), (2) atmospheric and meteorological phenomena at potential locations of surface facilities (Investigation 8.3.1.12.2), (3) locations of population centers relative to wind patterns in the general region of the site (Investigation 8.3.1.12.3), and (4) potential extreme weather phenomena and their recurrence intervals (Investigation 8.3.1.12.4).

The investigations were created so that an understanding of the meteorology of the area, including both average and extreme climatic phenomena, would be gained. Such an understanding will require looking at data from sites throughout the region and relating and comparing these data to site-specific conditions. Parameters that are important in determining the dispersion characteristics and general regional meteorology and, hence, are important to the performance and design issues, are as follows:

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability.
7. Mixing layer depth.
8. Barometric pressure.

These data will provide input to the performance and design issues that assess the preclosure radiological safety aspects of the mined geologic disposal system under normal and accident conditions. These issues are as follows:

Issue	Short title	SCP section
2.1	Public radiological exposures--normal conditions	8.3.5.3
2.2	Worker radiological safety--normal conditions	8.3.5.4

Table 8.3.1.12-1. Performance allocation table for meteorology program

Issue	SCP section	Performance or design parameter	Characterization parameter	Testing basis			SCP study (or activity)[a]
				Current estimate	Current confidence	Needed confidence	
2.1, 2.2, 2.3, 4.2, and 4.4	8.3.5.3, 8.3.5.4, 8.3.5.5, 8.3.2.3, 8.3.2.4, and 8.3.2.5	χ/Q	Wind speed	Figures 5-3 to 5-7	Low	High	8.3.1.12.1.1--Regional meteorological conditions
			Wind direction	Tables 5-6 and 5-7	Low	High	
				Figures 5-3 to 5-7	Low	High	
				Tables 5-6 and 5-7	Low	High	8.3.1.12.2.1.1--Site meteorological monitoring program
			Temperature	Tables 5-2 and 5-3	Low	High	
			Mixing layer depth	Quiring (1968)	Low	High	
			Atmospheric stability	Table 5-11	Low	High	
			Atmospheric moisture	Tables 5-2 and 5-5	Low	High	
			Precipitation (type, amount, intensity)	Tables 5-2 and 5-4	Low	High	
2.2	8.3.5.4	Radon emanation rate from tuff	Temperature	Tables 5-2 and 5-3	Low	High	8.3.1.12.2.1.2--Data summary for input to dose assessments
			Barometric pressure	Table 5-2	Low	High	
2.3 and 4.4	8.3.5.5 and 8.3.2.5	Accident initiating events	Extreme winds and frequency of occurrence	Tables 5-2 and 5-8	Medium	High	8.3.1.12.4.1--Potential extreme weather phenomena and their reoccurrence
			Lightning strikes and frequency	Section 5.1.1.6	Medium	High	
			Precipitation extremes (snow, rain, ice, and amounts and frequency)	Tables 5-2, 5-4, and 5-10	Medium	High	
			Temperature extremes	Tables 5-2, 5-3, and 5-9	Medium	High	

[a]Studies and activities listed apply to all parameters associated with the issue.

YMP/CM-0011, Rev. 1

YMP/CM-0011, Rev. 1

Issue	Short title	SCP section
2.3	Accidental radiological releases	8.3.5.5
2.5	Higher level findings--preclosure radiological safety	8.3.5.6
2.7	Repository design criteria for radiological safety	8.3.2.3

The investigation that deals with population centers relative to wind patterns (Investigation 8.3.1.12.3) will be a part of the radiological assessment because wind is the primary transport mechanism by which airborne radionuclides would reach these population centers. Finally, characterization of potential extreme weather phenomena (e.g., tornadoes, hurricanes, extreme wind speeds, temperature and humidity extremes, precipitation extremes, and obstructions to visibility) will provide input to design criteria issues relative to radiological safety. The extreme weather data will be evaluated in designing physical systems or components of the repository (e.g., wind or snow loading, heating and cooling systems, freeze protection) and must also be factored into the safety analysis in terms of the potential for extreme weather to initiate radiological accidents. Both repository operations and transportation of waste to the site will make use of the extreme weather data, and these data could be important in access route assessments.

Data collected as part of this program will also provide input to investigations associated with the geohydrology program and will be used, for example, in developing storm trajectories through the area. The relationship of the meteorology program to design issues, performance issues, and other programs is shown on the logic diagram for the meteorology program in Figure 8.3.1.12-1. This logic diagram also indicates how the investigations planned to provide the program data are linked to the individual studies and activities.

The environmental assessment (EA) (DOE, 1986b) for the Yucca Mountain Project (formerly called Nevada Nuclear Waste Storage Investigations Project) included meteorological data and analyses from existing meteorological monitoring networks in the vicinity of Yucca Mountain. These data and analyses proved useful for the purposes of the EA in that they provided enough information to support conclusions for the favorable and potentially adverse conditions of 10 CFR Part 960 and, more importantly, to support a preliminary finding on the qualifying condition. Additional data, both regional and site specific, are necessary to support the higher-level findings on the qualifying conditions required at the time of repository site selection (Section 8.3.5.6).

Interrelationships of meteorology investigations

The data and information developed through the meteorology program and associated investigations will have connections with the following issues, programs, investigations, and information needs:

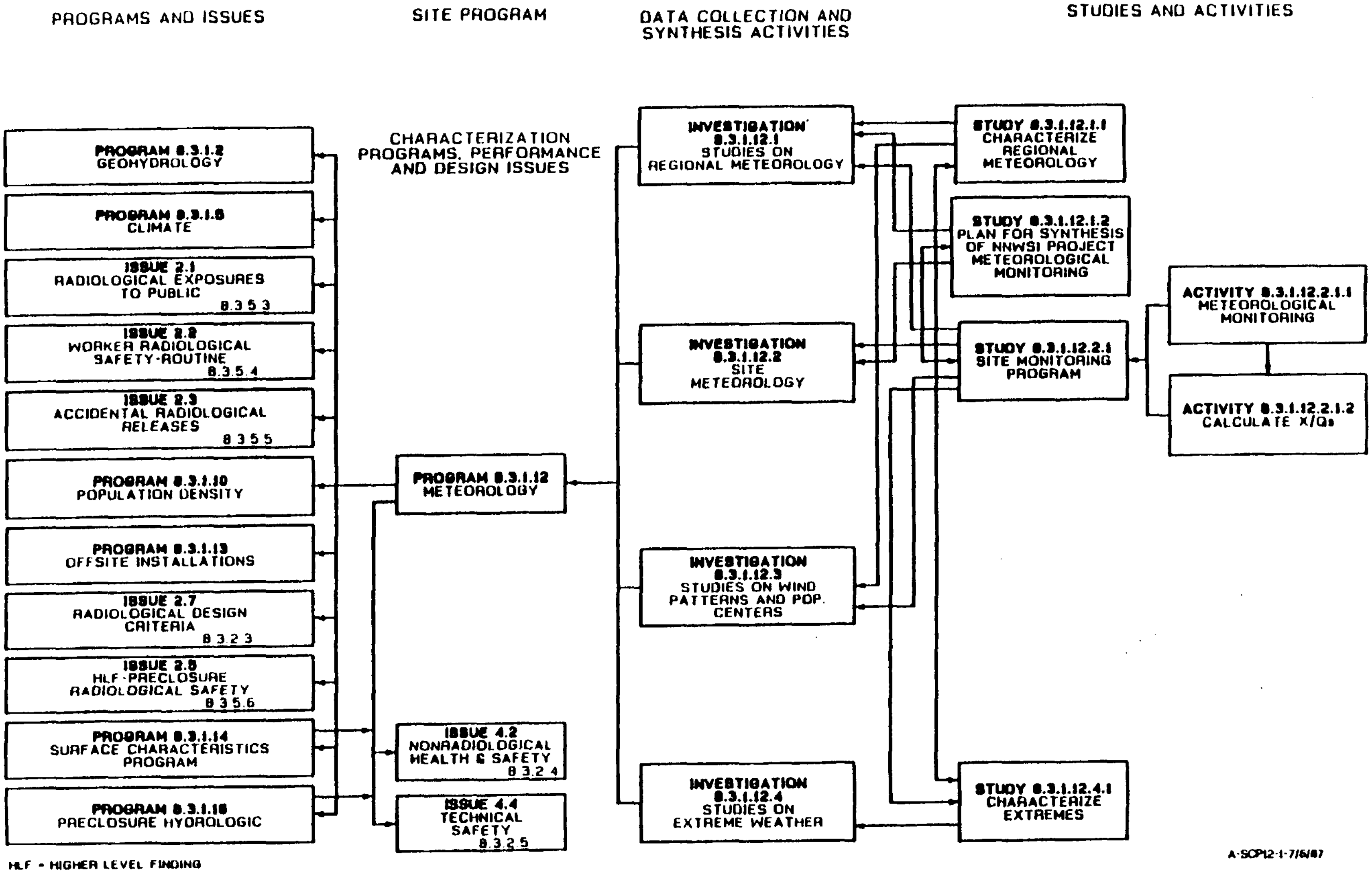

Figure 8.3.1.12-1. General logic diagram for meteorology program.

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

1. Issue 2.1: Preclosure doses to members of the public in highly populated areas and members of the public within any unrestricted area. Information Need 2.1.1--site and design information (Section 8.3.5.3.1)--is linked to the meteorology program.

2. Issue 2.2: Preclosure doses to workers. Information Need 2.2.1--natural radiation environment (Section 8.3.5.4.1)--is linked to the meteorology program.

3. Issue 2.3: Accident-related doses to workers and members of the public. This issue is resolved through Information Needs 2.3.3, worker exposures under accidental conditions (Section 8.3.5.5.3) and 2.3.4, public exposures under accidental conditions (Section 8.3.5.5.3).

4. Issue 2.5: Higher level findings relative to preclosure system and technical guidelines. How the site meets and will continue to meet qualifying conditions of the technical guidelines is related to the meteorology program.

5. Issue 2.7: Design characteristics of the repository in terms of design criteria and performance issues. Information Need 2.7.1--site information for design (Section 8.3.2.3.1)--is linked to the meteorology program.

6. Program 8.3.1.10: Population density and distribution. The importance of meteorological conditions to the population density program is in determining whether winds would transport radiological emissions from the repository toward population centers.

7. Program 8.3.1.13: Offsite installations. The investigation specifically linked with the meteorology program is offsite transportation (8.3.1.13.1).

8. Program 8.3.1.14: Surface characteristics. The applicable investigation under this program is meteorological conditions at surface facility locations.

9. Program 8.3.1.16: Preclosure hydrology. Assessing preclosure hydrologic conditions in the vicinity of Yucca Mountain will rely on the characteristics of precipitation events throughout the region and the wind flow patterns associated with such events.

10. Program 8.3.1.2: Geohydrology. The investigations related to the meteorology program are Investigations 8.3.1.2.1 (description of the regional hydrologic system) and 8.3.1.2.2 (description of the unsaturated zone hydrologic system at the site).

11. Program 8.3.1.5: Climate. The climate program investigations that need meteorological input are those associated with establishing the nature of the existing climate at Yucca Mountain, and how present conditions relate to historical conditions.

YMP/CM-0011, Rev. 1

Summary of studies

The studies planned for the meteorology program fall into two general categories: (1) those studies that are concerned with only site-specific data and (2) those studies that are associated with regional meteorological conditions.

To gain an understanding of the regional meteorological conditions, existing data bases will be evaluated and their applicability to Yucca Mountain determined (Investigation 8.3.1.12.1). These data, in combination with data from the site monitoring program (see following discussion) will then be assimilated into a data set that represents the regional meteorological conditions. This investigation will also coordinate monitoring efforts needed for other issues or programs with the data being obtained through the meteorology program.

A site monitoring program consisting of five towers has been implemented at Yucca Mountain (Investigation 8.3.1.12.2). The locations of these towers are shown in Figure 8.3.1.12-2. Although this network was initially established to support environmental permitting and licensing activities, the parameters being monitored will also be used as input in evaluating preclosure radiological impacts. The data being collected will serve as input to predictive models for dose calculations to ensure that radiological safety is not compromised as a result of the meteorological characteristics of the site.

The studies identified for characterizing wind patterns relative to population centers (Investigation 8.3.1.12.3) will consist of providing data on and analyses of wind parameters that will be used with the population density program identified in Section 8.3.1.10. These results will provide a clear understanding of wind transport patterns relative to population centers and will be used in determining if the patterns would preferentially carry radioactive material released to the air towards these centers.

The existing data bases and technical publications reviewed in characterizing the regional meteorology will also provide data on the extreme weather phenomena that may be experienced at the site. Because extreme weather can affect design and can cause accidents during repository operation and transportation of waste to the site, the occurrence of such phenomena and their recurrence interval must be determined (Investigation 8.3.1.12.4).

8.3.1.12.1 Investigation: Studies to provide data on regional meteorological conditions

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Technical data summaries of regional meteorological conditions are in Chapter 5 of the SCP and in the Yucca Mountain EA (DOE, 1986b). Specifically, Section 5.1 of the SCP includes descriptive text and tables on regional meteorology appropriate to the Yucca Mountain site. Section 3.4.3

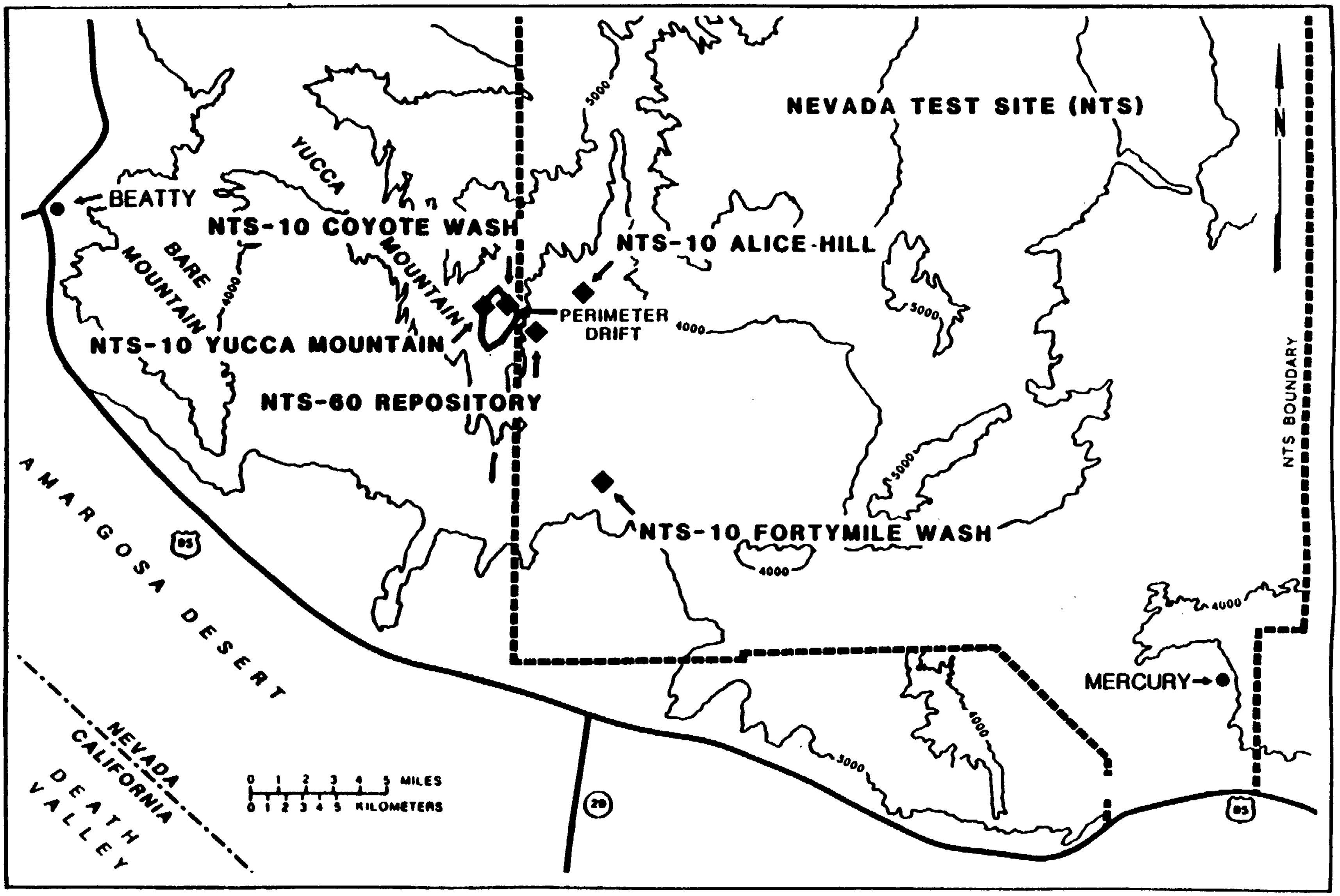

Figure 8.3.1.12-2. Meteorological monitoring sites operated as part of the Yucca Mountain Project.

YMP/CM-0011, Rev. 1

 YMP/CM-0011, Rev. 1

of the EA includes material on regional meteorology and related environmental materials, such as air quality and noise.

Parameters

Existing data bases will be examined to characterize regional conditions in terms of the following meteorological parameters:

1. Wind speed.

2. Wind direction.

3. Ambient temperature.

4. Atmospheric moisture.

5. Precipitation type, amount, frequency of occurrence, and intensity.

6. Atmospheric stability.

7. Mixing layer depth.

8. Barometric pressure.

9. Variability of parameters 1 through 5 at a given site and between sites.

Ideally, each data base examined would contain all of these parameters in a similar format (hourly averages). However, much of the existing data have been collected by private and governmental agencies for varying purposes and are not uniform in content, format, monitoring methodology, or quality. The data identified will, therefore, have to be carefully evaluated to determine their appropriateness to this study. Because some of the data will only be available as summaries of multiyear intervals (e.g., 5- or 10-yr climatological summaries), only general trends and averages for certain regions of the area around Yucca Mountain can be derived.

The data collected at the site (Section 8.3.1.12.2) will supplement the regional meteorology characterization and provide the relationship between the regional data and site-specific data. These data (specifically precipitation amounts used to track storm trajectories) will also serve as input to investigations associated with hydrology.

Purpose and objectives of the investigation

The purpose of this investigation is to provide data on the regional meteorological conditions in the general vicinity of Yucca Mountain, extending to Las Vegas, and to coordinate meteorology program monitoring efforts with other Yucca Mountain Project meteorological monitoring. Some of the data can then be used in calculating radiation doses to the general public and at the nearest major population center that might be caused by the proposed repository under routine and accident scenarios.

YMP/CM-0011, Rev. 1

Technical rationale for the investigation

One of the major concerns in the siting of a geologic repository is to ensure that its design and performance do not result in radiological impacts, due to airborne releases, to workers and the general public that exceed established limits. Because this concern must be satisfied before the construction of the facility, predictive tools are used in estimating the impacts of postulated releases from the repository. These predictive tools are typically dispersion models, which require data on the transport mechanism (in this case the atmosphere). Impacts predicted to occur in the immediate vicinity of the release dictate the use of site-specific meteorological data. This need is covered in Section 8.3.1.12.2. However, the applicable regulations also require that impact determinations be made at distances up to 80 km (50 miles) from the source. Therefore, site-specific data must be used in conjunction with regional data. In addition, impacts at the nearest major population center must be evaluated. For Yucca Mountain, the nearest major center is Las Vegas, Nevada, which is 137 km (85 miles) by air southeast of the site.

Another aspect of the Yucca Mountain site that warrants examination of data from various locations is the terrain. Because the topography of the area is complex, data from any single location may reflect unique terrain influences. These site-specific data will be used in characterizing regional meteorology to show topographic influences on regional windflow and precipitation patterns.

The parameters listed above collectively determine how material emitted from the repository system will be transported downwind. In addition to providing a picture of the overall meteorology of the region, these parameters are required input to dispersion models that will be used in calculating impacts. Atmospheric moisture and precipitation, although not specifically needed in dispersion analyses, are other comparative tools used in determining overall weather patterns for the area. The seasonal variability of the data from any given site and the variability of parameters between sites will aid in constructing the regional meteorology. The operational life of the repository during which postulated releases could be occurring is several years. Therefore, regional data from stations that have operated for long periods of time will help establish a link between present-day meteorological conditions and long-term averages of meteorological parameters.

8.3.1.12.1.1 Study: Characterization of the regional meteorological conditions

Objectives

The objective of this study is to gather and analyze meteorological datafrom various locations to characterize the regional meteorology and assimilate that information into a regional summary report. This will be accomplished by determining if there are meteorological monitoring stations that have been operated in the general vicinity of the site and might be sources of information (in addition to those evaluated in Section 5.1). Comparisons between site and very-near-site data and data from these regional

YMP/CM-0011, Rev. 1

sources will give a more complete picture of the areal variability of conditions around the site than is presently available. This characterization will provide a regional overview of wind flow patterns and other meteorological parameters (related to atmospheric dispersion) associated with those patterns in and around Yucca Mountain.

Parameters

The parameters of interest, although many will not be available at all the monitoring locations identified, are

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability (and method by which it was determined).
7. Mixing layer depth.
8. Barometric pressure.

Description

This study will involve contacting potential sources of meteorological data and determining what data are available in the area of interest. Potential sources of data include the National Weather Service (NWS), State of Nevada agencies (the State), the Environmental Protection Agency (EPA), the Nevada Test Site (NTS), the Nellis Air Force Range (NAFR), Desert Research Institute (DRI), and any other entities, such as private industry, recommended by these initial contacts. The State and the EPA are likely to be useful sources of meteorological data because, in addition to data from stations they operate themselves, these agencies should be able to identify private industry concerns that are collecting or have collected meteorological data to fulfill regulatory requirements. The NTS will be a source of meteorological data because of its proximity to the Yucca Mountain site, and because it has operated a number of meteorological monitoring stations in support of DOE activities. The NWS is always a valuable resource in securing meteorological data, but the density of NWS stations in southwestern Nevada is somewhat low. Organizations like the DRI may be able to identify meteorological data collected in support of research efforts that are not driven by regulations. In addition, periodicals and journals will be reviewed for articles on the meteorology of the area. Obtaining the data on magnetic tape would facilitate analysis and summarization, but much of the data may not be available in that form.

Once the data have been obtained and reviewed in terms of the period of record, the parameters available, the sampling and averaging frequency and the quality, a report on the regional meteorology will be prepared. The report will include a discussion of general wind flow patterns and their seasonality, differences and similarities between sites, general trends of any given parameter, terrain influences, and the relationship between site-specific data (Section 8.3.1.12.2) and regional characteristics.

 YMP/CM-0011, Rev. 1

8.3.1.12.1.2 Study: Plan for synthesis of Yucca Mountain Project meteorological monitoring

Objectives

The objective of this study is to develop a plan that provides for coordination of meteorological monitoring efforts proposed during site characterization by the various Yucca Mountain Project participants.

Parameters

The parameters that will be incorporated into the coordination of Yucca Mountain Project meteorological monitoring are

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability.
7. Mixing layer depth.
8. Barometric pressure.
9. Solar and terrestrial radiation.
10. Chemical and isotopic character of precipitation.

Description

The plan that will be developed under this study will provide coordination between meteorological monitoring efforts initiated through Characterization Programs 8.3.1.12 (meteorology), 8.3.1.5 (climate), 8.3.1.2 (geohydrology), and 8.3.1.16 (preclosure hydrology). The plan will also provide for review of the various monitoring efforts proposed in terms of meteorological adequacy and consistency. The specific studies under these programs that are associated with meteorological monitoring are Study 8.3.1.2.1.1 (characterization of regional meteorology), Study 8.3.1.2.1.3 (characterization of regional ground-water flow), Study 8.3.1.2.2.1 (characterization of unsaturated zone infiltration), Study 8.3.1.5.1.1 (characterization of modern regional climate), and Study 8.3.1.12.2.1 (site meteorological monitoring). The preclosure hydrology program calls for meteorological data from geohydrology program Studies 8.3.1.2.1.1, 8.3.1.2.1.3, and 8.3.1.2.2.1.

Presently no single study encompasses all the meteorological monitoring needed to characterize the site because meteorological data are needed by four different programs for slightly different purposes. For example, the meteorology program needs those parameters that define atmospheric dispersion characteristics, the geohydrology program needs precipitation-related parameters, and the climate program needs meteorological characteristics that relate to regional climate. All the programs, however, need to be coordinated to avoid a duplication of monitoring efforts and to effectively make use of technical experts within each of the programs.

 YMP/CM-0011, Rev. 1

The plan will present a description of all the programs that call for meteorological data, a more complete explanation of why each program needs the data, the parameters that will be measured for the program, and any links between the monitoring efforts. An evaluation of each of the monitoring programs will also be conducted to ensure that adequate data are being collected to satisfy the identified needs. The plan will also include the developing of most of an integrated network of meteorological stations that will incorporate the needs of all the programs. All these efforts will be coordinated among the programs and will use the collective experience and discipline-specific needs of the participants involved. Some of the monitoring programs involved are ongoing or will be expanded as site characterization proceeds.

8.3.1.12.2 Investigation: Studies to provide data on atmospheric and meteorological phenomena at potential locations of surface facilities

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

None of the technical data chapters provides an in-depth description of the site meteorological monitoring program. Section 5.1 of the SCP contains a brief summary of the program, and a detailed description can be found in the Meteorological Monitoring Plan (SAIC, 1985).

Parameters

The following meteorological parameters are being monitored at the Yucca Mountain site:

1. Wind speed.

2. Wind direction.

3. Ambient temperature.

4. Atmospheric moisture.

5. Precipitation type, amount, frequency of occurrence, and intensity.

6. Atmospheric stability (calculated from either wind speed and standard deviation of wind direction or wind speed and net (solar and terrestrial) radiation).

7. Barometric pressure.

Each of these parameters is measured or calculated from measured values as required by applicable EPA monitoring guidelines (40 CFR Part 58) and NRC Regulatory Guide 1.23 (NRC, 1980) and summarized as an hourly average in monthly and quarterly data reports.

YMP/CM-0011, Rev. 1

Purpose and objectives of the investigation

The purpose of this investigation is to collect site-specific meteorological data that can be used in calculating doses to workers, including workers in restricted areas, and the general public under routine and accident scenarios.

Technical rationale for the investigation

One of the primary mandates of the Nuclear Waste Policy Act and associated siting guidelines is to ensure that releases from the repository system do not result in exposures to workers or the public in excess of applicable standards. Compliance with this requirement must be demonstrated before construction of the facility and is generally accomplished through dispersion modeling as explained in Section 8.3.1.12.2.1.2. Although the information summarized for Section 8.3.1.12.1 (regional meteorological conditions) will provide a thorough understanding of the general wind flow patterns, atmospheric dispersion characteristics, temperature, and precipitation throughout the region, site-specific data from the proposed facility locations is needed to fully assess the potential impacts of releases. This is especially true for Yucca Mountain because the terrain in the immediate vicinity is quite complex, which results in micro-meteorological differences within relatively short distances. Regional conditions are, therefore, not sufficient in determining very-near-site meteorology.

To ensure that the meteorology specific to Yucca Mountain was completely evaluated, a monitoring network of five towers was installed and began operation in December 1985. The locations of these towers within the study area is shown in Figure 8.3.1.12-1. Site-specific dispersion parameters, which will be used to calculate concentrations and subsequent doses, are required to satisfy this investigation.

The rationale for the meteorological monitoring program that has been implemented at Yucca Mountain, and the requirements for accuracy, calibration, auditing, reporting, and operating such a program were derived from a variety of rules, regulations, and guidelines. These governing documents are discussed in the following paragraphs.

Both the EPA and the NRC have promulgated regulations or guidelines outlining the meteorological data required to conduct certain environmental analyses, but none are specific to deep geologic repositories. The NRC regulations (10 CFR Part 60) under which a construction authorization and license for the repository would be issued have been approved, but they do not outline the scope and nature of the environmental analyses required to support those decisions. In lieu of specific guidelines concerning meteorological monitoring requirements, the Yucca Mountain monitoring program has been based on an understanding of the types of information (data and analyses) required by the NRC for licensing other nuclear facilities (e.g., reactors, reprocessing plants, spent fuel storage facilities). The primary NRC regulatory guideline that deals specifically with meteorological monitoring programs (NRC, 1980) is not repository specific but is, nonetheless, useful in helping to define the scope of the Yucca Mountain monitoring program. Sections C.2 (Siting of Meteorological Instruments), C.3 (Data Recorders), C.4 (System Accuracy), C.5 (Instrument Maintenance, Servicing

Schedules, and Data Availability), and C.6 (Data Reduction and Compilation) of Regulatory Guide 1.23 (NRC, 1980) were evaluated for guidance in developing the monitoring network. To ensure that the monitoring programs implemented at Yucca Mountain would provide meteorological data acceptable for use in nonradiological regulatory permitting requirements, the program was also designed to comply with the EPA monitoring requirements for the Prevention of Significant Deterioration (40 CFR Part 58). The data these agencies require are to be used in addressing two aspects of repository development: (1) the potential for degrading the air quality in the vicinity of the repository by construction and excavation activities and (2) the role site-specific meteorological conditions would have in effectively dispersing routine operational and accidental releases from the repository.

The specific NRC regulatory guides reviewed to ensure responsiveness to evaluating expected and potential atmospheric releases are Regulatory Guides 4.17 (Standard Format and Content of Site Characterization Reports for High-Level-Waste Geologic Repositories), 4.18 (Standard Format and Content of Environmental Reports for Near-Surface Disposal of Radioactive Waste), 4.2 (Preparation of Environmental Reports for Nuclear Power Stations, Revision 2), 1.70 (Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants, LWR Edition, Revision 3), and 3.8 (Preparation of Environmental Reports for Uranium Mills).

8.3.1.12.2.1 Study: Meteorological data collection at the Yucca Mountain site

The purpose of conducting meteorological monitoring at Yucca Mountain is to provide data that can be used in resolving design and performance issues associated with preclosure radiological safety. This study consists of two activities, one that deals strictly with collecting the meteorological data and the other dealing with processing the data into dispersion-specific parameters.

8.3.1.12.2.1.1 Activity: Site meteorological monitoring program

Objectives

The objective of the site monitoring program is to collect meteorological data at potential locations of surface facilities and at a sufficient number of additional locations deemed necessary to characterize the wind flow patterns in the vicinity of Yucca Mountain.

These data must be suitable for use in dispersion models that will be used in assessing radiological impacts resulting from repository operations. Discussion on the use and applicability of the output of these dispersion models is presented under Information Need 2.7.1 (Section 8.3.2.3.1). Another objective of the site monitoring program, although not related to resolution of this information need, is to provide data that are suitable for permitting and licensing activities for both site characterization and repository development.

YMP/CM-0011, Rev. 1

Parameters

The following meteorological parameters are measured or calculated from measured values and summarized as hourly averages as required by EPA monitoring guidelines (40 CFR Part 58) and NRC Regulatory Guide 1.23 (NRC, 1980) at the five Yucca Mountain site locations discussed in the following description section:

1. Wind speed.
2. Wind direction.
3. Ambient temperature.
4. Atmospheric moisture.
5. Precipitation type, amount, frequency of occurrence, and intensity.
6. Atmospheric stability.
7. Barometric pressure.

Description

A detailed description of the site-monitoring activities can be found in the Meteorological Monitoring Plan (SAIC, 1985) and is summarized below. All activities are conducted in accordance with the Project Quality Assurance Program Plan (SAIC, 1986a).

Five sites in the vicinity of Yucca Mountain were chosen as monitoring locations. These sites are shown in Figure 8.3.1.12-2 and are further identified in Table 8.3.1.12-2.

The main meteorological tower (NTS-60 Repository) is located at an elevation of 1,143 m (3,751 ft) above mean sea level (MSL) near the proposed repository surface facility location. This area is bounded on the west by Yucca Mountain with peak elevation nearly 1,523 m (5,000 ft) above MSL and partially blocked from Jackass Flats to the east by three intermediate buttes with elevations of up to approximately 1,220 m (4,000 ft) above MSL. Data collected at this location will be used in assessing impacts associated with repository operations if the project proceeds to permitting activities.

The other four towers will be used to collect data on overall meteorological conditions in the area so that the site-specific data from the repository site can be interpreted more realistically. Data from these four remote sites will be particularly useful in characterizing terrain-induced perturbations that may significantly influence dispersion and transport of emissions.

The first of these remote locations is along the north-south trending ridge of Yucca Mountain approximately 3.9 km west-northwest of the main site at an elevation of 1,478 m (4,849 ft) above MSL, the highest elevation of any of the towers. This tower, NTS-10 Yucca Mountain, is 10 m high, and there are virtually no obstructions in any direction. Data from this site should be indicative of synoptic-scale weather conditions some of the time. Comparison of this data with the data from NTS-60 Repository during such times could provide insight into the relationship between synoptic-scale conditions and those that can be expected to occur at the surface facilities.

YMP/CM-0011, Rev. 1

Table 8.3.1.12-2. Meteorological monitoring sites operated by the Yucca Mountain Project

Site	UTM[a] Coordinates Zone 11 (m)	Nevada System (ft)	Latitude-longitude	Elevation (above MSL)[b]
NTS-60 Repository	550,776E 4,077,427N	569,127E 761,795N	3650'33" 11625'49"	3,751 ft 1,143 m
NTS-10 Yucca Mountain	547,660E 4,078,781N	558,862E 766,434N	3651'20" 11628'19"	4,849 ft 1,478 m
NTS-10 Coyote Wash	548,884E 4,078,689N	562,876E 766,195N	3651'17" 11627'05"	4,193 ft 1,278 m
NTS-10 Alice Hill	553,122E 4,079,787N	576,810E 769,661N	3651'51" 11624'14"	4,047 ft 1,234 m
NTS-10 Forty-mile Wash	554,396E 4,068,691N	580,882E 733,230N	3645'51" 11623'27"	3,124 ft 952 m

[a]UTM = Universal Transverse Mercator.
[b]MSL = mean sea level.

A second 10-m tower is located at the proposed site of the exploratory shaft, which is 2.7 km (1.7 miles) west-northwest of the main site at an elevation of 1,278 m (4,193 ft) above MSL. This tower is referred to as NTS-10 Coyote Wash and is located in one of the many drainages along the eastern side of Yucca Mountain. Data from this tower will be used primarily to assess impacts from exploratory shaft operations, but will also be used in the overall site evaluation.

A third 10-m tower is located at Alice Hill, one of the buttes separating the project area from Jackass Flats. This site is 3.0 km (1.9 miles) northeast of the main site at an elevation of 1,234 m (4,047 ft) above MSL and is referred to as NTS-10 Alice Hill. This tower is located such that data from NTS-10 Yucca Mountain, NTS-10 Coyote Wash, and NTS-10 Alice Hill will provide a cross-section of the atmosphere in the lee of Yucca Mountain. In addition, because NTS-10 Coyote Wash and NTS-10 Alice Hill are at approximately the same elevation, comparisons with the main site can be used to evaluate the characteristics of the drainage flow that may form between the ridges.

The final 10-m tower is placed at the edge of Fortymile Wash, 9.2 km (5.7 miles) southwest of the main tower, at an elevation of 952 m (3,124 ft) above MSL. This wash is the major surface-water drainage for the area, and

 YMP/CM-0011, Rev. 1

it is expected to influence significantly the air drainage during times when rapid nocturnal surface cooling causes air near the surface to subside. Data from NTS-10 Fortymile Wash will indicate how far down-valley repository emissions would be transported under these drainage conditions.

All monitoring equipment and stations have been designed and sited to ensure that all probes and samplers meet or exceed applicable EPA and NRC requirements and guidelines.

The meteorological sensors on the proposed 10-m towers are mounted at the top of the tower, precluding tower-induced turbulence interference. For the 60-m tower, wind speed and direction sensors will project approximately 1.8 m (5.9 ft) from the tower in the direction of the prevailing wind to minimize tower-induced turbulence effects.

The four 10-m towers are instrumented identically to measure wind speed, wind direction, sigma theta (standard deviation of horizontal wind direction) for determination of atmospheric stability, relative humidity, and temperature at the 10-m level. The 60-m meteorological tower is instrumented to measure or calculate wind speed, wind direction, and sigma theta at the 10- and 60-m levels; sigma phi (standard deviation of vertical wind direction), temperature, and relative humidity at the 10-m level; temperature difference between the 10- and 60-m levels; net radiation (solar and terrestrial) at the 3-m level; and precipitation at essentially ground level a short distance from the base of the tower. The sensors at the 10-m level satisfy the requirement of applicable monitoring guidelines for monitoring meteorological parameters at the standard exposure heights over level, open terrain. The NTS-10 Coyote Wash and NTS-10 Fortymile Wash 10-m towers will be located so as to characterize particular drainage and terrain-induced flow patterns to help define site-specific conditions. The sensors at the 60-m level will provide an indication of larger-scale wind flow patterns. Other details of the monitoring program, such as temperature sensor ventilation and shielding, net radiometer (solar and terrestrial) exposure, and precipitation gauge heating (for water equivalent measurements of snow) are all designed to be in full compliance with acceptable meteorological practice and applicable EPA and NRC regulations and guidelines.

Instrument specifications and station design. Meteorological parameters at all four remote sites will be monitored using continuous analyzers to provide hourly average wind speed, wind direction, sigma theta, relative humidity, and temperature. Power will be supplied by batteries that are trickle-charged by solar cells. Continuous recording of the data on strip charts is not feasible at these sites because of the lack of available commercial electrical power. With this exception, the meteorological equipment and methodologies will be in accord with referenced EPA and NRC rules, regulations, and guidelines.

All meteorological parameters at the main site will also be monitored using continuous analyzers. The continuously recorded meteorological parameters will be reduced and averaged (scalar and/or vector, if appropriate) to produce the following meteorological data base:

1. Hourly average wind speed (10- and 60-m levels).

 YMP/CM-0011, Rev. 1

2. Hourly average wind direction (10- and 60-m levels).

3. Hourly average standard deviation of horizontal wind direction (10- and 60-m levels).

4. Hourly average atmospheric stability based on Pasquill Stability Category using continuous sigma theta monitoring (with differential temperature, sigma phi, and net radiation data as backup).

5. Hourly average surface temperature at standard height for climatic comparisons and plume rise calculations.

6. Hourly average differential temperature measurements between the 10- and 60-m tower levels.

7. Hourly average dewpoint temperature.

8. Hourly average barometric pressure.

9. Hourly precipitation amounts for climatic comparisons.

Except as noted above, meteorological analyzers, equipment, and methodologies will be in accord with applicable EPA and NRC rules, regulations, and guidelines, and will be purchased, installed, and monitored in compliance with Yucca Mountain Project quality assurance requirements.

Instrument specifications will meet or exceed those given in applicable EPA and NRC rules, regulations, and guidelines. Where agency specifications differ, the more stringent specification has been used in designing the monitoring program. The specifications are as follows:

1. Wind direction: ±3° of true azimuth (including sensor orientation error) with a starting threshold of less than 0.45 m/s (1 mph).

2. Wind speed: ±0.22 m/s (0.5 mph) for speeds above the starting threshold of 0.45 m/s (1 mph) but less than 11.1 m/s (25 mph), and ±5 percent of true speed, not to exceed 2.5 m/s (5.6 mph), at speeds greater than 11.1 m/s (25 mph).

3. Sigma theta: wind vane damping ratio of between 0.4 and 0.6 (inclusive) with a 15° deflection and delay distance not to exceed 2 m.

4. Temperature: ±0.5°C (0.9°F).

5. Temperature difference (between levels): ±0.003°C (0.005°F) per meter.

6. Radiation (solar and terrestrial): ±5 percent.

7. Precipitation: resolution of 0.25 mm (0.01 in.) with recorded accuracy of ±10 percent of total accumulated catch.

8. Time: within 5 minutes of actual time for all recording devices.

 YMP/CM-0011, Rev. 1

These specifications apply to digital systems; analog backup systems can deviate by up to 1.5 times these values. There is no prescribed specification for barometric pressure sensors.

Data reporting. The meteorological and quality control data collected during the monitoring program will be summarized in three types of reports: monthly reports at the end of each monitoring month that will be for internal data verification only, quarterly reports prepared after each monitoring quarter, and annual reports summarizing each baseline monitoring year.

The quarterly reports will contain a quality-assured (i.e., in accordance with written, approved procedures and instructions) listing of the meteorological data collected at each site during the previous quarter by month. A discussion of the data recovery rates and significant project activities will also be included in these reports. The monthly reports will serve to track the technical aspect of the monitoring program.

The content and basic format for the monthly, quarterly, and annual data reports will be in a format and scope consistent with reporting requirements for the EPA, NRC, and the State of Nevada, and shall be in accordance with supplemental written and approved instructions. All reports will provide an indication of progress to date, a review of all site activities during the period of record, problems encountered and their resolution, percentage data recovery rates, calibration-audit reports, and other pertinent information.

The quarterly reports will also contain a summary description of the site equipment and operating methodologies and a hard copy of the hourly data listing for each parameter monitored as a second volume. A wind rose for each site showing the percent frequency distribution of wind speed and direction will also be included in each report. In addition, the quarterly reports will include a description of quality assurance and of quality control activities for the quarter.

The annual report will contain discussions and data similar to the monthly and quarterly reports but summarized for the entire monitoring year. In addition, meteorological summaries such as wind direction and speed persistence, diurnal variations, seasonal variations, and meteorological influences will be presented and discussed. Also the annual report will present a chronology of data recovery detailing the annual data recovery rates by parameter. The joint frequency of wind speed, wind direction, and atmospheric stability will be presented and discussed in terms of persistence and frequency of occurrence. These data will be in a form suitable for use in air quality modeling analyses and for modeling potential radiological impacts.

 YMP/CM-0011, Rev. 1

8.3.1.12.2.1.2 Activity: Data summary for input to dose assessments

Objectives

The objective of this activity is to process the meteorological data collected as a result of Activity 8.3.1.12.2.1.1 into a format and content that will be useful in assessing radiological impacts, as required by the design and performance issues.

Parameters

The parameters listed in Activity 8.3.1.12.2.1.1 (from one or more sites) will be used in combination with an estimate of the mixing layer depth to calculate a concentration parameter: χ/Q. This parameter is calculated using dispersion models, and represents the concentration χ over the emission rate Q. χ/Qs will be calculated for several locations at various distances from the surface facilities. Calculating χ/Qs as opposed to concentrations allows the source term Q to be varied without rerunning the model, as needed for determining doses under accident versus routine emission scenarios.

Description

The concentration (χ/Q) values will be calculated using a dispersion model that is capable of simulating the meteorological and topographical influences on material emitted to the atmosphere as it is transported and dispersed downwind. A variety of models have been developed for this purpose, but most are appropriate only for use in flat or gently rolling terrain. The topography of the Yucca Mountain site, however, warrants the use of a model that can simulate complex terrain effects. Both the EPA and the NRC have issued documents that provide guidance on the selection and use of the various models that have been developed. This guidance will help ensure that the appropriate model is used.

The NRC has issued at least four regulatory guides that either reference, provide examples of, or suggest the use of models to determine χ/Q values, but none of them were developed specifically for geologic repositories. However, some of the information in these guidelines will be applicable to a repository. These guides are (1) Regulatory Guide 1.109--Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I (NRC, 1977a); (2) Regulatory Guide 1.111--Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors (NRC, 1977c); (3) Regulatory Guide 1.145--Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants (NRC, 1982a); and (4) Regulatory Guide 3.8--Preparation of Environmental Reports for Uranium Mills (NRC, 1982b). These documents will be reviewed to ensure that the dispersion analysis done for Yucca Mountain is comprehensive enough to satisfy typical NRC requirements.

The guidance for the EPA is contained within the guideline on air quality models (EPA, 1986). The EPA has also developed and provides a magnetic tape containing a variety of the approved and most frequently used models. Although the EPA models are aimed at assessing nonradiological impacts, χ/Q values can be calculated using these models as well.

 YMP/CM-0011, Rev. 1

The χ/Q values will be calculated at discrete locations, but the receptor grid is arbitrary in that no specific sites have been selected for evaluation. Instead, a radial receptor grid will be used and χ/Q values at distances of 4, 8, 16, 24, 32, 40, 48, 56, 64, 72, and 80 km from an assumed source will be calculated in each of the 16 cardinal directions for a total of 176 receptors.

To ensure responsiveness to the design and performance issues, χ/Qs representing routine and accident release scenarios must be developed. Routine releases will be evaluated by calculating an annual average χ/Q value at each of the receptors. Because the accident scenarios must be evaluated under meteorologically worst-case conditions (in terms of dispersion), one-hour χ/Q values also will be required.

Other data needed as input to a dispersion model are one year of hourly sequential meteorological data (wind speed, wind direction, temperature, mixing height, and Pasquill stability class), receptor terrain heights and their Universal Transverse Mercator (UTM) coordinates, and source characteristics (UTM coordinates, stack height, stack diameter, exit gas velocity, exit gas temperature, and building-stack configuration). Once all these data have been put in the format required by the model, the model is run. Although the basic equations used in calculating an χ/Q value are not exceptionally complex, the large number of calculations required for a year of hourly meteorological data dictates the use of a computer.

A report presenting the χ/Q values and the information used in calculating those values will be prepared at annual intervals for up to 5 yr.

8.3.1.12.3 Investigation: Studies to provide data on the location of population centers relative to wind patterns in the general region of the site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The only data contained within the SCP relative to this investigation is in Section 5.1 (recent climate and meteorology). The preliminary finding relative to the qualifying condition associated with this investigation is contained in Chapter 6 of the Yucca Mountain environmental assessment (DOE, 1986b).

Parameters

The following summaries will be calculated using data from the site monitoring program (Activity 8.3.1.12.2.1.1) or from data gathered as a result of Investigation 8.3.1.12.1, regional meteorological conditions:

1. Frequency distribution of wind speed and direction.

2. Persistence of wind speed and direction.

YMP/CM-0011, Rev. 1

3. Diurnal wind speed and direction.

4. Atmospheric dispersion associated with these summaries in parameters 1, 2, and 3 (if appropriate).

Purpose and objectives of the investigation

The purpose of this investigation, similar to Investigation 8.3.1.12.1, is to provide data on wind flow patterns in the general region of Yucca Mountain. These data will then be used in estimating doses to the public and in doing so ensure that wind flow patterns would not preferentially transport material towards population centers.

Technical rationale for the investigation

The qualifying condition for meteorology (10 CFR 960.5-2-3) requires an evaluation of the potential for preferential transport of radioactive emissions toward population centers in the vicinity of the site. Although a preliminary assessment was conducted for the Yucca Mountain environmental assessment (EA) (DOE, 1986b) using existing regional data, site-specific meteorological data are needed to supplement the conclusions reached in the EA.

The population density and distribution data will be collected as part of the population density program (Section 8.3.1.10). The meteorological data gathered and summarized as part of Investigations 8.3.1.12.1 and 8.3.1.12.2 should provide sufficient data in combination with the population data for satisfying this investigation. Assimilation of the population and meteorological data into dose calculations will make use of the data generated in Activity 8.3.1.12.2.1.2 and will be completed as part of Information Need 2.5.2 (Section 8.3.5.6.2) and Issues 2.1 (Section 8.3.5.3) and 2.3 (Section 8.3.5.5).

8.3.1.12.4 Investigation: Studies to provide data on potential extreme weather phenomena and their recurrence intervals

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

Section 5.1 (recent climate and meteorology) provides a technical summary of existing data relevant to this investigation.

Parameters

The following parameters will be evaluated using existing historical data bases and technical publications:

1. Frequency of severe storms (tornadoes, hurricanes, etc.).

2. Magnitude and frequency of extreme wind speeds.

 YMP/CM-0011, Rev. 1

3. Extremes of temperature and humidity.

4. Precipitation extremes (including hail and snow) and their recurrence intervals.

5. Frequency and intensity of fog.

Purpose and objectives of investigation

The purpose of this investigation is to assimilate data that can be used in evaluating the impact of extreme weather phenomena on surface facilities.

Technical rationale for the investigation

Extreme weather phenomena cannot be resolved from short-term, site-specific monitoring programs. Long-term meteorological and climatological data records must be used to provide a sufficient data base upon which to develop statistical predictions of extreme events along with their recurrence intervals.

The identification of extreme conditions is necessary to provide design information for the repository surface facilities. All structures must be designed for the meteorological conditions that may be experienced over the life of the facilities. Example of how meteorological data will influence design are as follows:

1. Temperature and humidity extremes will affect the design of heating and cooling systems.

2. Precipitation extremes will provide data for the design of containment basins, diversion channels, and culverts.

3. Snow and hail data will provide input to the design of roof loadings and external facilities.

4. Extreme wind speed estimates will provide critical design criteria for surface facility structures.

5. The frequency and intensity of fog, dust storms, and other severe storms will be used to design lighting and emergency facilities and will be factored into the accident analyses relative to the repository.

8.3.1.12.4.1 Study: Characterize the potential extreme weather phenomena and their recurrence intervals

Objectives

The objective of this study will be to evaluate the existing historical meteorological and climatological records, technical publications, and other relevant information to quantify the extreme weather phenomena that may be expected at the Yucca Mountain site and determine their recurrence interval.

YMP/CM-0011, Rev. 1

Parameters

1. Frequency of severe storms.
2. Magnitude and frequency of extreme wind speeds.
3. Extremes of temperature and humidity.
4. Precipitation extremes.
5. Frequency and intensity of fog.

Description

Existing data bases and technical publications will be reviewed to characterize the extreme weather phenomena that may be experienced at the site. Where necessary, calculations (e.g., statistical extrapolations) may be made to interpolate existing data to develop site-specific estimates. The data from the site-monitoring program will also be compared with the extreme data.