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Study Plan Number 8.3.1.8.2.1

Study Plan Title ANALYSIS OF WASTE PACKAGE RUPTURE DUE TO TECTONIC PROCESSES & EVENTS

Revision Number 0

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STUDY PLAN FOR THE ANALYSIS OF WASTE PACKAGE RUPTURE DUE TO TECTONIC PROCESSES AND EVENTS

Site Characterization Plan
Study 8.3.1.8.2.1

ABSTRACT

This study analyzes the tectonic processes and events that may have an impact on the design and performance of waste packages and the engineered barrier system during the postclosure time period. The tectonic processes considered in this study are igneous intrusion, faulting, ground motion, folding, and deformation caused by minor slip on closely spaced planes. This study will analyze and integrate the data collected by several other studies to provide estimates of the probability and magnitude of tectonic processes and events that could affect waste packages, and an analysis of the nature of credible tectonic processes and events relative to waste package performance. The analyses generated by this study will be used in the design of the underground repository and engineered barrier system, and to assess the performance of the waste packages during the postclosure time period.

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STUDY PLAN FOR ANALYSIS OF WASTE PACKAGE RUPTURE DUE TO TECTONIC PROCESSES AND EVENTS

1.0 INTRODUCTION

1.1 Contents of the Study Plan

This study plan describes the scope and methodology for seven activities to be performed on the Project as part of the Postclosure Tectonics Program of the Project Site Characterization Plan (SCP). They are designed to develop an understanding of the tectonic processes and events that could result in failure of the waste packages.

The seven study plan activities are:

Activity 8.3.1.8.2.1.1: Assessment of waste package rupture due to igneous intrusion

Activity 8.3.1.8.2.1.2: Calculation of the number of waste packages intersected by a fault

Activity 8.3.1.8.2.1.3: Probability and rate of faulting

Activity 8.3.1.8.2.1.4: Assessment of waste package rupture due to faulting

Activity 8.3.1.8.2.1.5: Assessment of postclosure ground motion in the subsurface

Activity 8.3.1.8.2.1.6: Nature, age, and rate of folding and deformation in the repository horizon

Activity 8.3.1.8.2.1.7: Assessment of waste package rupture due to folding and deformation

The number designations (e.g., 8.3.1.8.2.1) used throughout this plan follow the numbering system used in the SCP and serve as references to specific sections of it.

The objectives of the study and the regulatory rationale and justification for the proposed work are presented in Section 1, "Introduction."

The technical rationale and justification for the study are presented in Section 2. In this section the proposed approach to the study, study plan alternatives, and study plan constraints are discussed, along with a rationale and justification for each of the study plan activities. Data requirements are identified for these activities.

Descriptions of the plans for each activity are presented in Section 3. The descriptions include the proposed technical approach for each activity, proposed test methods and analyses, key parameters, and performance goals. Alternative test and analysis methods are summarized, and cross references/interfaces are indicated for quality assurance (QA) grading and technical procedures. The SCP (DOE, 1988) describes the technical rationale of the overall site characterization program and provides a general description of the activities described in detail in Section 3 of this study plan.

Application of the results of the study is summarized in Section 4, study and activity schedules and milestones are presented in Section 5, and a study plan reference list is presented in Section 6. Supporting QA documents are contained in Appendix A.

1.2 Purpose of the Study Plan

Studies are to be conducted as part of the Yucca Mountain Project to provide geologic and other scientific information to evaluate the suitability of the Yucca Mountain, Nevada, site for development as a high-level nuclear waste repository and the ability of the mined geologic disposal system (MGDS) to isolate the waste in compliance with regulatory requirements. In particular, the Project is designed to acquire information for the U. S. Department of Energy (DOE) to demonstrate in an Environmental Impact Statement and license application that the MGDS will meet the requirements of federal regulations 10 CFR Part 60 and 40 CFR Part 191.

This study plan is part of a hierarchy of documents that define the DOE's plans for site characterization and provide a basis for making management decisions on the conduct of the site characterization program. The baseline for the site characterization is Site Characterization Program Baseline (SCPB) (DOE, 1991). Study plans are prepared to satisfy U.S. Nuclear Regulatory Commission (NRC) requests for more detailed descriptions of the studies described in the SCP and SCPB and to provide an additional basis for the review of planned work by the NRC and other agencies.

1.3 Objective of the Study

The objective of the study is to provide the data necessary for an analysis and assessment of repository performance with respect to the possibility of tectonic processes and events adversely affecting the lifetime of waste packages by rupturing or unacceptable deformation.

The study will utilize data gathered by studies in this and other programs for the required analyses and assessments. The general information required to accomplish the objectives of this study is identified in SCP Section 8.3.1.8.2.1 and summarized in Section 3 of this study plan. The study activities will synthesize and compile these data into a form such that the necessary assessments can be performed. These assessments will be made in order to evaluate the following performance parameters:

- o Probability of igneous intrusion penetrating the repository.

- Effects of igneous intrusion penetrating the repository.

- Effects of faulting and number of waste packages affected by a fault penetrating the repository.

- Probability of faulting in a 1,000 year time period with displacement over 5 cm in the repository.

- Expected ground motion at emplacement boreholes in a 1,000-year period.

- Rate of deformation due to folding or distributed shearing in the repository horizon.

For each of the activities, separate reports will be prepared at the conclusion of the work that will contain

- Summaries of the data from which calculations and evaluations were made.

- The assumptions, theories, methods, and calculations used in data reduction and analysis.

- Discussion and assessment of the assumptions and uncertainties inherent in the data and their reduction.

- Conclusions on the performance parameters listed above.

1.4 Regulatory Rationale and Justification

The overall regulatory-technical relations between the SCP design and performance informational needs and the data collected in this study are described in the postclosure tectonics program (SCP Section 8.3.1.8) and the issue resolution strategies (SCP Section 8.3.5).

The main regulatory requirements that this study is intended to aid in addressing are 10 CFR 60.113(a)(1)(i) and 10 CFR 60.113(a)(1)(ii)(A & B), which state that:

> The engineered barrier system shall be designed so that assuming anticipated processes and events: (A) Containment of HLW will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay; and (B) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times...(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that: (A) Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 60.113(b) provided, that such period shall not be less than 300 years nor more

than 1,000 years after permanent closure of the geologic repository; and (B) The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure...

The goal of the activities in this study is to provide information on those tectonic processes and events that should be considered "anticipated" and to provide information on the nature and probability of any anticipated tectonic process or event for use in waste package design and performance assessments. The study will also provide information that can be used in the design of the Engineered Barrier System to mitigate the effects of anticipated processes and events.

Initiating Events. The SCP (SCP Table 8.3.1.8-2a) identified four tectonic initiating events (or processes) that could lead to waste package failure if they were to occur during the period when the waste packages must provide substantially complete containment. These initiating events are

- Igneous intrusion penetrating the repository.
- Offset on one or more faults penetrating the repository.
- Ground motion at the repository horizon.
- Folding or distributed shear in the repository horizon.

The activities in this study are designed to evaluate the likelihood of these initiating events during the first 300 to 1,000 years of the postclosure period and the nature of these initiating events if they should occur. The need to consider these initiating events is derived from the potentially adverse conditions listed in 10 CFR 60.122(c)(11), (12), (13), (14), and (15). For the initiating events considered in this study, the possibility of integrated or coupled processes that might interact must also be considered.

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 the occurrence of extreme rates of uplift, which could lead to the exposure of waste packages through erosional processes. This process is considered separately in Investigation 8.3.1.6.3.

2.0 RATIONALE FOR THE STUDY

This section provides an overview and justification of the study.

2.1 Rationale for the Proposed Study

This study relies on data and information collected by other investigations in order to carry out the planned analyses. Therefore, integration and scheduling with other studies is critical to the successful completion of this investigation. It is recognized that the data gathering studies may not always be able to provide the information anticipated in the preparation of the plan for this study. Should the form or content of data available to this study be such that the approaches described in this plan can not be implemented, a review will be made of the data and alternative approaches that are available and a revision to the study plan will be prepared.

2.1.1 Approach

The overall approach of the postclosure tectonics program is to first consider the elements of the repository system that could be affected by tectonic processes and events (e.g., the waste package). These elements become the subject of individual studies in the program. After potentially affected repository elements are identified, the tectonic processes that could affect those elements are identified (e.g., faulting, folding, ground motion, igneous intrusion). Specific activities or groups of activities are then constructed to evaluate the probability and magnitude of the tectonic process or events occurring within distances that could adversely affect the repository element and the effects of the tectonic process or event on the repository element should the process or event occur. The approach used in assessing postclosure tectonic hazards to the engineered barrier system relies heavily on a probabilistic approach in assessing the likelihood of the hazard occurring. A probabilistic approach is the preferred approach for these types of studies because it allows the evaluation of events that do not have well-defined source structures (e.g., fault movement on an undetected fault), addresses uncertainties in the data, integrates expert opinion, identifies significant input parameters and areas requiring additional work, assesses the impact of new data and theories, and aids in decision making.

The activities are focused on specific performance concerns by postulating specific initiating events that could lead to unacceptable performance of a repository element or the repository system. The initiating events are then evaluated to design an approach that can be used in the activity to evaluate the tectonic process or event and determine the type of data required to complete the analysis and assessment.

The overall approach in the SCP is to define issues related to the determination of site suitability and then to identify Performance Measures and Performance Parameters that provide guidance on the nature and precision of data required to complete an assessment. Study Plan 8.3.1.8.2.1 proposes analyses required to resolve the performance measure related to the failure of waste packages due to tectonic events or processes in the postclosure period. Structural deformation resulting from tectonic processes such as faulting, uplift, subsidence, or folding could adversely affect the effective lifetime of the waste packages in containing the waste. If areas of anticipated potential deformation are found to be large enough that the requirements for waste package performance can not be met, the ensuing required changes in repository geometry or design may be such that the repository could no longer accommodate the specified volume of waste (70,000 metric tons of uranium) (Issue 1.11, SCP Table 8.3.2.2-1).

The goal for the performance measure is derived from considerations discussed in Section 8.3.4.2 of the SCP. This section establishes design goals for rock-induced loads to the waste package, one of which states that less than 0.5 percent of the waste package will be breached by anticipated tectonic processes and events that may occur during the first 1,000 years (SCP Table 8.3.4.2-3). This level is designed to be compatible with the general performance measure for waste package performance which measures the fraction of containers that have failed. The performance goal for all modes of container failure is divided into two time intervals. The goal for the first 300 years after repository closure is that less than 0.05 percent per year of the total population of emplaced containers will fail. The goal for the interval from 300 to 1,000 years after repository closure is that less than 0.1 percent per year of the total population of emplaced containers will fail (SCP page 8.3.5.9-35).

Six performance parameters have been defined in SCP Table 8.3.1.8-2a to address the performance measures on usable area (SCP Table 8.3.2.2-1) and containment by the waste package (SCP Table 8.3.5.9-1). These performance parameters are listed in Section 1.3 of the this Study Plan.

The types of tectonic initiating events that may affect waste package performance, and hence will be considered, are summarized below. The study will take data gathered by studies in this and other programs and provide an analysis of the probability of the initiating events and the nature of such events relative to waste package performance concerns for use in Issue 1.4 (SCP Section 8.3.5.9) to identify hazards to be considered in assessing waste package performance, and in Issue 1.11 (SCP Section 8.3.2.2) in assessing layout and design of the underground facilities.

The study will also provide information on the nature of tectonic processes operating at the site for use by Issue 1.8 (SCP Section 8.3.5.17, NRC siting criteria) and Issue 1.9 (SCP Section 8.3.5.18, Information for higher level findings--postclosure).

2.2 Rationale and Justification for the Study Plan Activities

2.2.1 Activity 8.3.1.8.2.1.1--Igneous Intrusion

The first initiating event considered in this program is the possibility that igneous intrusions penetrating the repository could adversely affect waste package performance. This 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. The assessment of this initiating event will be similar to that in Investigation 8.3.1.8.1. The performance parameter goal for the probability of an igneous intrusion penetrating the repository was selected to be low enough (annual probability less than 10^{-5}) that such a penetration of the repository in 1,000 years would be a low probability event.

The approach used Activity 8.3.1.8.2.1.1 is to investigate both the probability of an igneous intrusion penetrating the repository and the resulting effects of an igneous intrusion on the repository and number of waste packages that could be affected (performance parameters 1 and 2, SCP Section 8.3.1.8.2). Evaluation of these parameters was considered to be necessary during site characterization in order to address concerns of 10 CFR 60.122 (c) (15) with respect to waste package performance since Quaternary igneous activity is known to have occurred in the region although not in the controlled area. Alternatives to the above approach would include considering the probability of an intrusion to be one (a deterministic approach) for the purposes of waste package performance assessment and thereby eliminate the need for site characterization studies in this area. Such an alternate approach was not considered to be supportable at this time because it is judged to be preferable to have a numerical definition of the risk when making decisions regarding events that potentially have an extremely low probability of occurrence. A more detailed discussion of the reasons for preferring a probabilistic approach to the risk assessment of igneous intrusions is contained in Section 2.4.1 of Study Plan 8.3.1.8.1.1.

Another alternative approach would be to use different probabilities for parameter goals in the study. Changing the parameter goals would have little effect on the outcome of the study because the goals are only intended to provide guidance on the general level of accuracy to be used in calculating the values for the parameters. Therefore, changes in the goals would only have an effect if the changes were very large relative to the current goal.

2.2.2 Activities 8.3.1.8.2.1.2, 8.3.1.8.2.1.3, and 8.3.1.8.2.1.4--Faulting

These three activities are described together because they are interrelated.

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 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 performance parameters 3 and 4 (SCP Section, 8.3.1.8.2). The assessment will include calculating (1) the probability that undetected faults exist at the location of waste emplacement and that faulting with offset great enough to cause waste package failure would occur on those faults, and (2) the number of waste packages that a through-going fault might intersect. A value of 5 cm was selected as the performance parameter at which fault displacement becomes significant over a 1,000 year-period, since at this value it is anticipated that the 7.6 cm air gap around the waste package would be partially closed and any additional displacement might result in an undesirable reduction of the air gap or possible waste package failure.

The basic approach that will be used in the analysis will be to use a probabilistic assessment to estimate the likelihood that fault offset will occur at waste emplacement locations. Because it is planned to avoid known faults with a potential for movement in the selection emplacement, a probabilistic approach appears to be the only method available to evaluate the hazard of movement on undetected or new faults. The need for the evaluation and the significance of the evaluation will depend on the results of the geologic mapping of the exploratory drifts in the repository block. If faults can be demonstrated to be absent in waste emplacement areas at the repository level with an extremely high degree of confidence, then concerns related to faulting may not be considered to be significant in the evaluation of engineered barrier system performance.

2.2.3 Activity 8.3.1.8.2.5 -- Ground Motion

The third initiating event considers the possibility that earthquake-induced ground motion occurring during the postclosure period could cause spalling or failure in the underground workings that could result in corrosion or mechanical failure of waste packages due to closure of the air gap around them or movement of the waste package in the emplacement borehole. The objective of Activity 8.3.1.8.2.1.5 is to address this initiating event by estimating expected ground motion values at emplacement boreholes in a 1,000-year period, and thus satisfy performance parameter 5 (SCP Section 8.3.1.8.2).

This activity will use an updated version of the fault-specific seismic hazard model developed for Sandia National Laboratories (SAND86-7013) (URS/John A. Blume & Associates, 1987). This model produces probabilistic assessments for peak ground motion for the proposed facility. This model is preferred because it incorporates both regional and near-site faults, uses the limited deformation rate data to constrain seismic activity to the near-site faults, and uses historic seismicity to constrain seismicity not assigned to specific faults (background seismicity).

An alternative to the probabilistic approach would be to use a deterministic approach that uses a specific event occurring on a specific fault as the basis for design. This approach was not believed to be suitable for this analysis because of the need to consider the effects of multiple events occurring during the 1,000 yr containment period. Critical facilities that use a deterministic approach in design are usually constructed under the assumption that, if the structure is exposed to a damaging event, repairs are presumed to be rendered prior to the occurrence of the next event. However, consideration of performance periods of 1,000 years and greater may entail engineering designs that incorporate consideration of more than one strong motion design events over that performance period. Unlike most engineered structures, it is assumed that there will be no opportunity to repair damage to waste canisters in the event of damaging motions in the postclosure phase. The need to consider the range of events that might affect the engineered barriers during the postclosure period indicates that a probabilistic approach is preferred in determining a design basis.

2.2.4 Activities 8.3.1.8.2.1.6 and 8.3.1.8.2.1.7 -- Folding

Activity 8.3.1.8.2.1.7 addresses the possibility that folding or distributed shear could cause waste emplacement borehole deformation, resulting in waste package failure. This tectonic phenomenon is the fourth initiating event considered in this study. Activities 8.3.1.8.2.1.6 and 8.3.1.8.2.1.7 address this initiating event and satisfy performance parameter 6 (SCP Section

8.3.1.8.2). The performance parameter goal was selected so that, if the goal is met, deformation of waste emplacement boreholes by folding or tectonic deformation due to distributed shear of more than 5 cm will not be a credible event (i.e., 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 approach taken in these activities is to conduct a limited review and synthesis of existing and site characterization data to produce an analysis that will support a DOE position on the concerns expressed in 10 CFR 60.122(c)(11 related to structural deformation and folding. Because it is judged to be highly unlikely that deformation rates will be significant in terms of engineered barrier performance, a very simple analysis based on calculated regional and local deformation rates is planned. Deformation rates will be calculated using geologic maps, detailed structure contour maps compiled from subsurface drilling and logging, and maps of the exploratory shafts and drifts.

2.3 Types of Measurements to be Made

2.3.1 Activity 8.3.1.8.2.1.1 -- Igneous Intrusion

No measurements will be made for Activity 8.3.1.8.2.1.1; the information required for this activity will be obtained from Activity 8.3.1.8.1.1.1, Location and Timing of Volcanic Events; Activity 8.3.1.8.1.1.2, Evaluation of the Structural Controls of Basaltic Volcanic Activity; Activity 8.3.1.8.1.1.4, Probability Calculations and Assessment; and Activity 8.3.1.8.1.2.1, Effects of Strombolian Eruptions. Data on the layout of waste package emplacement holes will come from Information Need 1.11.3, Underground Facility Orientation and Layout (SCP Section 8.3.2.3.3). The results of Link et al. (1982) will be reviewed in the light of new data and compared with current repository designs.

With this input on the probability of future igneous activity, the characteristics and dimensions of possible intrusions, and the underground facility layout, it will be possible to calculate a probability for igneous intrusions penetrating the selected repository location. 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.

2.3.2 Activities 8.3.1.8.2.1.2, 8.3.1.8.2.1.3, and 8.3.1.8.2.1.4 -- Faulting

No measurements will be made for Activities 8.3.1.8.2.1.2, 8.3.1.8.2.1.3, and 8.3.1.8.2.1.4, since all the information for the assessments will come from other activities. As indicated is Section 3.2, the data required for Activity 8.3.1.8.2.1.2 will be supplied from several activities in Programs 8.3.1.17 and 8.3.1.4, as well as from Information Need 1.11.3 (Underground Facility Orientation and Layout). Information for Activity 8.3.1.8.2.1.3 will come from essentially the same sources. Activities 8.3.1.8.2.1.2 and 8.3.1.8.2.1.3 will provide the main information required for Activity 8.3.1.8.2.1.4.

2.3.3 Activity 8.3.1.8.2.1.5 -- Ground Motion

No measurements will be made for Activity 8.3.1.8.2.1.5, since the work involved will synthesize and compile data collected by other activities. Input data will be obtained mainly from Studies 8.3.1.17.3.5 and 8.3.1.17.3.6.

2.3.4 Activities 8.3.1.8.2.1.6 and 8.3.1.8.2.1.7 -- Folding

No measurements will be made for Activities 8.3.1.8.2.1.6 and 8.3.1.8.2.1.7, since all the information for the assessments will come from other activities. Input data required for these activities will be obtained from Activity 8.3.1.4.2.2.1, Geologic Mapping of Zonal Features of Paintbrush Tuff (the proposed repository horizon); Activity 8.3.1.4.2.3.1, Development of a Three-Dimensional Geologic Model of the Site Area; Activity 8.3.1.17.4.12.1, Evaluate Tectonic Processes and Tectonic Stability at the Site; Activity 8.3.1.8.5.3.1, Evaluation of Folds in Neogene Rocks of the Region; and Activity 8.3.1.8.2.1.2, Calculation of the Number of Waste Packages Intersected by a Fault. Assessment of data from these activities will establish the wave length and amplitude of folds in the Miocene rocks of the repository horizon and the amount and nature of deformation resulting from faulting in the repository horizon.

2.3.5 Rationale for Choosing the Types of Measurements to be Made

No new measurements are required for these activities.

2.4 Constraints

Impacts on Site. The activities will be using data gathered from other activities in this or other investigations and therefore will not directly impact the site or its environment.

Simulation of Repository Conditions (Verisimilitude). Wherever possible, the analyses and assessments of this study will be based on data describing the tectonic processes operating at or near the site during the Quaternary Period. Extrapolation of the Quaternary behavior of the site is considered the best method to estimate site behavior during the postclosure time period.

Required Accuracy and Precision. No test instrumentation will be used during the conduct of this study.

Limitations of Analytical Methods. There is controversy over some applications of probabilistic study approaches in the geosciences (Crowe et al., 1986). Care needs to be taken in the probabilistic analysis to recognize the limitations imposed by projecting from a small sample size when considering infrequent events and the possibility that event occurrence is not completely random through time. The probabilistic analyses can also be sensitive to the accuracy and completeness of the input data. For example, events may have occurred but evidence of the events may not be preserved in the geologic record or multiple events may have occurred but are misinterpreted as representing one event.

There are various ways to help account for some of the data uncertainties. These include presenting the probability bounds as a range or biasing the data assumptions towards the worst case as suggested by Crowe et al., 1982. However, to properly represent geologic hazards and their uncertainties, all sources of variability should be categorized and properly treated. To these ends, development of a suitably robust model must take into account the following items:

1. Alternative hypotheses for the geologic process or phenomenon (e.g., episodic or Poissonian events versus cyclic events and processes).

2. Uncertainty or statistical (or modeling) variability that expresses the lack of knowledge (imprecision) about the true state of nature and natural processes. This uncertainty is reducible in principle by the collection of additional data and/or the development of more refined theories or explanations.

Multiple interpretations are a consequence of modeling uncertainties. It is proposed that in order to logically organize and display the multiple hypotheses, assumptions, and parameter values and all their possible combinations, a logic tree approach should be used. Logic trees are a convenient means to express alternative interpretations and their probabilities. Thus, it should be possible to assess alternative hypotheses and scenarios already indicated in the SCP (SCP Table 8.3.1.8-8), as well as those postulated by other views, such as those expressed recently by Linehan (1989) on volcanic hazards.

Statistical Stability of Data. Most of the activities in this study will rely on a probabilistic approach to assessing the tectonic hazard they are evaluating. It will be important that all of these evaluations explicitly consider the stability and reasonableness of the conclusions reached by the assessment when a range of geologically reasonable input values is used or possible alternative models for event occurrence are considered.

Scale and Applicability. The geologic data required by the activities in this study will describe features at the same scale as the tectonic processes and events being considered as possible disruptive scenarios for the waste package environment. Therefore, scaling effects are not considered a serious source of uncertainty.

Interrelationships with Other Studies. No tests are planned as part of this study that would involve interference with tests planned as part of other studies.

Time Constraints (time required for study). Time constraints are discussed in Section 5.2.

3.0 DESCRIPTION OF STUDY PLAN

3.1 Activity 8.3.1.8.2.1.1 -- Igneous Intrusion

This activity considers a minor extension of the concerns addressed in Investigation 8.3.1.8.1. Investigation 8.3.1.8.1 is primarily concerned with evaluating the possibility that a volcanic event could intersect the repository and directly result in releases to the accessible environment by entraining waste in the magma and ejecting it from a vent during either a Strombolian or hydrovolcanic eruption. This activity considers the possibility that an igneous intrusion, such as a basaltic dike, could intersect the repository and result in the movement of magma through the repository drifts or magma intrusion into the waste-emplacement boreholes without causing immediate releases to the accessible environment. This activity is concerned with providing Issue 1.4 (Waste Package Performance Objective for Containment) with an evaluation of the likelihood of such events occurring and the hazards posed by such events that could be significant to waste package performance. This activity, therefore, contributes to the evaluation of the performance goal of rupturing less than 0.5 percent of the waste package inventory because of tectonic processes and events (see SCP Section 8.3.4.2).

Technical Approach to the Activity. This activity will consist of review and organization of data collected by other studies as a continuing part of the determination of the hazard posed by potential igneous activity penetrating the repository. The principal source of information for the activity will be the preceding related Studies 8.3.1.8.1.1, Probability of a Volcanic Eruption Penetrating the Repository, and 8.3.1.8.1.2, Effects of a Volcanic Eruption Penetrating the Repository. The activity will involve calculation of the probability of an igneous intrusion penetrating the repository that does not result in direct releases to the environment and the estimation of the number of waste packages that could be affected by such an event and the nature of these effects.

The probability of an igneous intrusion penetrating the repository, Pr_i, can be expressed by a conditional probability

$$Pr_i = [E2 \text{ given } E1],$$

where E1 is the probability of an igneous event occurring in the region of Yucca Mountain during the time period of concern for waste performance and E2 is the probability the intrusion penetrates the repository workings.

As a starting point for the analysis, this activity will assume that the probability of an igneous intrusion occurring is the same as the probability of a volcanic event in an area surrounding the repository. This appears to be a reasonable assumption because of the relatively shallow depth of the repository. Igneous dikes that reach upward to a level that could penetrate the repository would probably be expressed as a surface eruption somewhere along their length, although possibly not over the repository itself. One part of this activity will be to review the available data on the behavior of shallow intrusions to evaluate this assumption.

The probability of an intrusion occurring will be derived from the probabilistic volcanic hazard analysis performed in Study 8.3.1.8.1.1 (See Study Plan 8.3.1.8.1.1 for a discussion of how these probabilistic analyses will be performed). The recurrence rate of future volcanic events in the Yucca Mountain region will be calculated as the annual probability of a volcanic event. As noted in Study Plan 8.3.1.8.1.1, the variety of techniques that will be used to estimate this parameter will likely result in a range of probabilities or a probability distribution.

The second parameter in the probability assessment is the probability that a dike related to an intrusive event in the region penetrates the repository. In Study Plan 8.3.1.8.1.1, this is called the disruption parameter. This activity will review the disruption parameter(s) used in Study Plan 8.3.1.8.1.1 and may either adopt that parameter directly or modify the parameter to suit the purposes of this activity. The value of the parameter is a function of the size of the waste emplacement area, the area affected by dikes associated with a particular intrusive event, preferred orientations of dikes or other structural controls, and the size of the region considered in the calculation of parameter E1.

The second part of the analysis is the assessment of the effects of an intrusion on engineered barrier systems should an intrusion occur. This assessment will consider both the mechanical and thermal effects of an intrusion. Mechanical effects include the effects of magma movement on a waste package if a dike intersects an emplacement borehole and the effects of magma movement in repository drifts on the engineered barrier system. Information that will be provided to the engineered barrier performance assessment task includes magma velocities in a dike, probable dike dimensions, magma viscosity and density, and information on the probable nature of magma movement in a repository drift. The analysis will include a consideration of the effects of backfilling or not backfilling the drifts on the nature of an intrusive event. This part of the analysis will consist of compiling information from Studies 8.3.1.8.1.1 and 8.3.1.8.2.1 and a review of pertinent literature.

Thermal effects resulting from an intrusion into the repository could also affect engineered barrier system performance. This activity will provide data on the anticipated temperatures of intrusions and thermal properties of basalt. This information will be derived from a literature review.

<u>Data Input Requirements for the Analysis</u>. The important parameters that will be required to assess the probability of this initiating event include:

1. Probabilistic volcanic hazards analysis (from Activity 8.3.1.8.1.1.4).

2. Characteristics and dimensions of possible intrusions (from Activity 8.3.1.8.1.2.1).

3. Information on emplacement borehole orientation (horizontal or vertical), and the spacing and layout of emplacement boreholes in the repository. These data will come from Information Need 1.11.3 (SCP Section 8.3.2.2.3).

<u>Expected Output and Accuracy of the Analysis</u>. This activity will review the igneous event probability estimates supplied by Information Item 1 on the above list with respect to the scenarios to be considered. It is anticipated

that these estimates can be used without significant modification to supply the needed information on event probabilities. Previous studies of volcanic hazard indicate that rates of volcanic activity in the Nevada Test Site region are about 10^{-6} events per year and that the probability of disruption of the Yucca Mountain site by basaltic volcanism is bounded by the range of 10^{-8} to 10^{-10} per year (Crowe, 1986). It is expected that similar values will be produced by this activity.

The major part of the evaluation in this activity will be a consideration of the nature of various igneous scenarios in a repository setting. For the igneous intrusion scenario, Information Item 2 will supply information on the characteristics of possible intrusions, such as dike length, dike width, flow volumes, flow temperatures, duration, and the likely behavior of an intrusion intersecting an underground opening (e.g., nature and extent of flow through open drifts). These data will be used in conjunction with repository design data from Information Item 3 to estimate the area of the repository and the number of waste packages that could be affected by such an intrusive event. The final step of the evaluation will consider the nature of the mechanical and thermal effects that the movement of magma would have on waste packages in the affected area. Previous estimates by Link et al. (1982) indicate that a randomly oriented dike might intersect about 8-9 waste emplacement boreholes. Link et al. (1982) also provide preliminary information on the mechanical and thermal effects an intrusion might have on the waste package. It is expected that the results of this activity will produce results that are similar to those of this previous study.

This activity will provide data and coordination on the use and interpretation of results to the following performance assessment issues and activities:

1. Issue 1.4, Waste Package Performance Objective for Containment; Activity 1.4.4.1, Estimate of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation of Container Failure Rate as a Function of Time.

2. Issue 1.8, NRC Siting Criteria; 10 CFR 60.122(c)(15), Potentially Adverse Effects of Igneous Activity.

3. Issue 1.9, Higher Level Findings; 10 CFR 960.4-2-7(c)(1), Potentially Adverse Effects of Igneous Activity.

The accuracy of the analysis will be affected by the uncertainties inherent in a projection of the probability and location of future volcanic events. Activity 8.3.1.8.1.1.4 will supply this information and will also attempt to quantify the level of confidence associated with the estimates. The estimates of the characteristics of igneous intrusions will be based on observed characteristics of past events in the Basin and Range province and at other localities in the world. For the purposes of the estimate, bounding values will be selected from the range represented by the data for use in calculations. The estimates of the effects of an intrusion on an underground excavation or waste packages will be subject to the greatest uncertainty because of the absence of previous experience on which to base them.

<u>Representativeness and Effect of Alternate Conceptual Models</u>. The

representativeness of the probability estimate for the occurrence of igneous events will depend on the proper incorporation of tectonic model elements into the analysis. The tectonic model elements that affect this estimate are the same as those that affect Investigation 8.3.1.8.1. The model elements that have the greatest impact on the estimates from Activity 8.3.1.8.1.1.4 to be used in this activity are those related to the structural controls on volcanism and the rate of volcanism. The need to determine whether the location of volcanic and igneous events is controlled by structural features or is essentially random in the area will control how the probability estimate is calculated and how representative the estimate is of the occurrence of these events. Structural control of igneous intrusions could also indicate that igneous events and faulting events coincide in time and space. Such an alternative would require consideration of the effects of a coupled process of faulting and igneous intrusion. The need to better date volcanic events in the area and determine the number of events at a given locality will also affect how representative the probability estimate is of the occurrence of events in the area of the site.

3.2 Activities 8.3.1.8.2.1.2, 8.3.1.8.2.1.3, and 8.3.1.8.2.1.4 -- Faulting

These three activities are described together because they are interrelated. They will investigate the possibility that failure of waste packages could be caused by a fault intersecting the waste packages experiencing sufficient offset (greater than 5 cm) to result in unacceptable deformation or rupture of waste packages. In addition to determining the rate and probability of faulting that could penetrate the repository, the number of waste packages that could be intersected by a fault will be estimated.

Technical Approach to the Activities. The strategy identified in the SCP for demonstrating that faulting will not lead to significant waste package failure in 1,000 years is to locate and characterize Quaternary faults in and proximal to the repository waste emplacement areas. Faults that may penetrate the repository horizon will be characterized to determine their surface location, dip, projected location at the repository level, length, width of disturbed zone, evidence of Quaternary activity, and amount of displacement in the Tiva Canyon Member and during the Quaternary. The nature of faulting in the repository horizon will also be characterized, using the drifts in the Exploratory Studies Facility. It is planned to use this information to avoid zones of recognizable significant offset, breccia zones, and gouge zones for reasons related to both potential fault offset and long-term borehole stability.

However, for several reasons, it may not be possible to identify and avoid all potentially significant faults in the repository level during the repository development process. First, there may be difficulties in accurately projecting faults from the surface to the repository horizon. Second, there may be difficulties in detecting fault offset in a single, homogenous lithologic zone in the Topopah Spring Member if faulting is not distinguished by gouge or breccia zones. Third, it may be difficult to determine whether Quaternary offset has occurred on all faults penetrating the repository because of the scarcity of Quaternary deposits on Yucca Mountain. Fourth, there will be a high degree of uncertainty in predicting where new faults might occur in the future. To account for these uncertainties, the activities will estimate the annual probability and effects of fault displacement exceeding 5 cm for undetected or new faults that may penetrate the repository. The probability estimates will be based on the behavior of known Quaternary faults in the vicinity of the proposed repository.

The conditional probability that movement with offset greater that 5 cm would occur on an existing but undetected fault of total displacement (x) in the repository can be expressed as

$$P_{fu>5} = [E1 \text{ given } E2]$$

where E1 is the annual probability of a fault with total displacement (x) of the Tertiary volcanic sequence having a displacement event of greater than 5 cm and E2 is the probability of failing to detect a fault with total displacement (x) in the repository. The result can be illustrated as the probability of movement on an undetected fault as a function of total (vertical) displacement on the fault.

A preliminary estimate of the E1 term has been conducted by URS/John A. Blume & Associates (1987) for faults with varying length in the Yucca Mountain area. This study was a probabilistic hazard analysis and based estimates of earthquake and faulting occurrence on a hypothetical correlation between slip rate and fault length. This study estimated the annual rate of exceedance for peak surface rupture displacements of 5 cm as ranging from 1×10^{-4} for 33 km long faults to 6×10^{-6} for 6 km long faults. One of the assumptions underlying this approach is that the faults were independent of one another as far as their probability of fault movement was concerned. While this assumption might be true for the major block bounding faults in the Yucca Mountain area, movement on the smaller faults within a block (where the repository would be located) may be controlled by the occurrence of events on the block bounding faults (i.e., the faults are secondary or branch faults).

To address this concern, the E1 term can be considered a conditional probability in itself resulting from the probability of greater than 5 cm of offset occurring on a fault given an event occurs and the probability of an event occurring. The probability of an movement occurring on a fault in the block may then be best represented as the product of the probability of movement on the block bounding fault and the probability that a block bounding event causes movement on the fault in the block (i.e., all faults in the block do not move each time a block-bounding fault moves). The probability of movement exceeding 5 cm on a fault of given total displacement (x) can be estimated by constructing a probability density function for average displacement per event constrained by the frequency of events (calculated above) and slip rate on the fault. The slip rate for a fault of given total displacement can be determined directly from field data or estimated by using faults with known slip rates in the area and using the ratio of total displacement between the two faults to adjust the slip rate.

The E1 term will be determined from data compiled in Activity 8.3.1.8.2.1.3 from results of field studies carried out in other investigations. Data will be compiled on the total vertical displacement of faults with Quaternary activity in the Yucca Mountain area, Quaternary net-slip rates on these faults (i.e., slip rates accounting for both the normal and strike-slip components of movement), the range of displacements occurring in single events, and recurrence intervals between events.

The preparation of a plot showing the probability of failing to detect faults against total displacement on the fault in the repository drifts (the E2 term) will be made using judgments based on data collected by Activity 8.3.1.8.2.1.3 from field geologic mapping studies in the Exploratory Studies Facility (ESF). Data to be evaluated by Activity 8.3.1.8.2.1.4 include the presence or absence of distinctive marker horizons or contacts in the drift walls at the repository level, the thickness of lithologically distinctive horizons at the level of the repository drifts, and the nature of known fault zones at the repository level (the presence or absence of distinctive gouge or breccia zones).

If distinctive, sharply defined contacts are found to be present in the drift walls, then it be possible to detect faults with very small vertical displacements in the Topopah Springs Member. If this is the case and it can be shown that only faults with relatively significant total vertical displacements have a significant probability of producing offsets that could affect waste package integrity, then the issue will be resolved and further analysis will not be necessary. If it is determined that there is a significant probability of offset occurring on undetected faults, then the analysis will continue to determine the number of waste packages that could be affected by faulting during the performance period. This will be in the form of a probability density function.

The probability of fault rupture under a structure at Yucca Mountain has been considered previously by Subramanian et al. (1989) in relation to the waste handling buildings at the surface facility. The analysis for this study will be most similar to the random self-similarity model in that study except that total displacements are substituted by slip rates and an additional factor must be added to account for having a large number point locations (waste packages) distributed over an area rather than a single structure. The data needed to complete the calculation of the number of waste packages that would be affected by faulting during the performance period is the density of faulting in the repository block and the number of emplacement boreholes a fault crossing the repository block would intersect.

Fault density (expressed as the cumulative number of faults per unit area with total displacement greater than a given value) will be calculated from the results of surface and subsurface mapping carried out in other investigations in Activity 8.3.1.8.2.1.3. Densities for smaller displacement faults in the area will probably be based on an extrapolation of data for the larger displacement faults because the data will be more complete for these faults. A preliminary plot of fault density in the region is given in Subramanian et al. (1989).

The number of waste packages that a fault might intersect will be calculated by Activity 8.3.1.8.2.1.2 from data on fault characteristics and the distribution of waste packages in the repository. Field studies carried out in other investigations will provide data on fault orientation, width of fault zones, and the length of potential ruptures. This data will come from surface geologic mapping studies, fault trenching studies, and underground geologic mapping in the ESF. Current plans of the repository design will provide data on the number of waste packages, their location and spacing, and emplacement mode (horizontal or vertical emplacement). The above information will be used to construct a probability density function of the number of waste packages intersected by a through going fault. A simplified calculation of this parameter has been carried out previously by Link et al. (1982) for the similar problem of a dike intersecting the repository. They assumed a random dike orientation and a uniform spacing of waste packages over the repository area. Using an expected dike length intersecting the repository of about 600 m and their assumptions about repository area and the number of waste packages, they calculated that the average number of waste packages intersected would be about 8-9.

The probability of faulting in the repository in the above calculations has been based on the assumption that all faulting occurs on previously existing faults. There is a probability that a totally new fault could form in the repository during the performance period. The occurrence of new faults is generally not considered in engineering evaluations of faulting because of the observation that most faulting occurs on pre-existing faults and the low probability of new faulting occurring during the life of an engineered structure. For completeness, the possibility of new faults occurring in the repository will also be addressed. This assessment will consist primarily of a review of the history of faulting in the area based on the results of surface geologic mapping and trenching studies. The review will look at the evidence that faulting recurs on existing faults in the area (a progressive increase in offset or tilting of strata with age by faults) and any evidence that new faults are forming (Quaternary faulting rates that are not consistent with the total Tertiary offset based on a comparison with other faults with a long history of movement). If there appears to be a significant rate of new fault generation in the area, the pattern and location of potential new faulting can be estimated using theoretical studies such as Cole et al. (1984) and Lade et al. (1984) and empirical data on the distribution and displacement of secondary faulting away from the main fault such as Bonilla (1970).

<u>Data Input Requirements for the Analysis</u>. The following data will be gathered by other studies and used to perform the analysis and assessments of the activities in this study:

1. Detailed geologic map(s) of the contacts between mappable zones in the Tiva Canyon and Topopah Spring members covering the repository area (from Activity 8.3.1.4.2.2.1). This map will show the surface geology of the area above the repository and identify and describe mappable faults there. Areas of bedrock outcrop from which geologic interpretation has been extrapolated will be distinguished from areas in which bedrock is not exposed at the surface.

2. Detailed structure contour and isopach maps on various stratigraphic horizons present at the surface or in the subsurface in the repository area (from Activity 8.3.1.4.2.3.1). These maps will integrate the precise information on the elevation and thickness of stratigraphic units obtained from boreholes and the detailed geologic mapping of the area with data on subsurface structure obtained from geophysical surveys. The maps will be used to identify areas of anomalously steep gradients where faulting may be present and to calculate the amount of displacement across mapped faults on the contoured horizons.

3. Detailed geologic maps of the exploratory ramps, shafts and drifts (from Activity 8.3.1.4.2.2.4). These maps will show the nature of faulting at the repository level (e.g., drifts to the Ghost Dance fault and Drill Hole Wash structures) and any stratigraphic features present

in the repository horizon that can be used to detect faulting.

4. Quaternary fault map of Yucca Mountain (from Activity 8.3.1.17.4.6.1). This map will identify and locate known faults with Quaternary displacement that could intersect the repository.

5. Data on known Quaternary faults in and near the repository showing the width of Quaternary faulting at the surface, Quaternary slip rates, the recurrence interval between faulting events, and the amount of displacement during individual faulting events (from the trenching studies in Activity 8.3.1.17.4.6.2).

6. Data on the spacing, displacement history, and surface width of Quaternary faults between the larger block-bounding faults, such as the Solitario Canyon, Bow Ridge, and Paintbrush Canyon faults (from Activity 8.3.1.17.4.2.2). This information will come from the long trench planned to extend across Midway Valley from the Bow Ridge fault to the Paintbrush Canyon fault.

7. Data on the length, nature, and interconnections/interrelationships of Quaternary faults in the site area and surrounding region. These data will come from the regional (1:100,000 scale) fault maps and tectonic analyses generated by Activities 8.3.1.17.4.12.1, 8.3.1.17.4.12.2, and 8.3.1.17.4.3.2.

8. Information on emplacement borehole orientation (horizontal or vertical), and the spacing, layout, and dimensions of emplacement boreholes in the repository. These data will come from Information Need 1.11.3 (SCP Section 8.3.2.2.3).

Expected Output and Accuracy of the Analysis. A major part of the assessment will be an estimate of the probability of fault displacement exceeding 5 cm occurring in the repository on undetected faults with varying total displacements in the Tertiary volcanic sequence. Although Quaternary faulting is known to have occurred on the larger block-bounding faults (such as the Solitario Canyon and Paintbrush Canyon faults (Swadley et al., 1984; Whitney et al., 1986)), the existence of Quaternary displacement, and the amount of any Quaternary displacement that may have occurred, has not been determined for the smaller faults (e.g., imbricate fault zones of Scott and Bonk (1984)) inferred to occur within a fault-bounded block. Since it may be difficult to determine the Quaternary activity of faults in the repository block because of the absence of Quaternary cover, we anticipate that the potential for Quaternary movement on these faults will be estimated by analogy with other areas where Quaternary deposits exist. The most likely area to provide this data is Midway Valley.

Midway Valley is thought to be a good model because the block between the Bow Ridge and Paintbrush Canyon faults underlying the valley is hypothesized to contain numerous small bedrock faults (see unmapped and inferred faults on cross section B-B′ of Scott and Bonk (1984)), and suitably aged Quaternary deposits are found across the width of valley. It is possible that the trenching studies in Midway Valley will show Quaternary faulting is primarily confined to the major block-bounding faults. If it is determined that fault movement is possible on smaller faults within a block, it is expected that the probability of exceeding 5 cm of displacement will be extremely low because the faults in the repository block are probably secondary (e.g., Ghost Dance fault) or tertiary (e.g., imbricate fault zone) relative to the major block-bounding faults. Therefore, we expect that slip rates will be proportionately lower on these faults relative to the block-bounding faults. If, for example, the Paintbrush Canyon fault has total vertical displacement of about 300 m and a Quaternary slip rate of about 0.01 mm/yr then a fault with 3 m of total displacement with the same displacement history would be expected to have a slip rate approximately 100 times smaller or about 0.0001 mm/yr. The probability of an event occurring that exceed 5 cm of displacement would also be expected to be correspondingly smaller. It is also expected that the geologic conditions exposed in the wall of the repository drifts will allow detection of faults with total displacements of substantially less than 1 m.

The probabilistic estimates of faulting and the potential for intersecting waste packages will include explicit considerations of the uncertainty in the analysis. These considerations will include both the potential uncertainty related to the data used in the analysis and the uncertainty resulting from the choice of the probabilistic model used to evaluate the potential hazard. It will need to be recognized that several simplifying assumptions will be used in the analysis. For example, the parameter for fault density will assume that fault density is uniform throughout the repository. In actuality, current models of faulting in the repository area (e.g., Scott, 1990), suggest that fault density should vary across the block with the highest density in the eastern portion of the block.

The scope of the three activities in this section will also include coordination with other studies in the use of the results of this analysis. An interactive exchange is required with the staff working on the detailed designs of the waste package and waste emplacement boreholes in order to provide information that is useful for assessing the impact of tectonic processes on the waste package. Planned coordination and integration efforts include:

1. Providing data as needed to Information Need 1.11.3 for use in the establishment of criteria to avoid significant faults in the selection of waste-emplacement borehole locations (Product 1.11.3-5 in SCP Section 8.3.2.2.3).

2. Coordinate on the probability of faulting in the repository and effects of faulting on waste package performance with Issue 1.4, Waste Package performance Objective for Containment; Activity 1.4.4.1, Estimate of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation of Container Failure Rate as a Function of Time: Issue 1.8, NRC Siting Criteria; 10 CFR 60.122(c)(11), Potentially Adverse Effects of Faulting); and Issue 1.9, Higher Level Findings; 10 CFR 960.4-2-7(c)(1), Potentially Adverse Effects of Faulting.

3. Coordinate with Information Need 1.11.3, Repository Layout, and Issue 1.10, Postclosure Waste Package Characteristics, on any repository layout, waste-emplacement borehole, or waste package design changes that may be required or desired to minimize the effects of faulting on waste package performance.

Representativeness and Effect of Alternate Conceptual Models. The analyses are intended to be as representative of actual repository conditions as possible, because detailed geologic data on the Quaternary behavior of faults in and near the repository form the basis of the analysis. Because of the site-specific nature of the repository-fault-rupture hazard, only elements of the local tectonic model(s) affect the evaluation of this hazard (see SCP Table 8.3.1.8-7). The model elements that most directly affect the analyses are

1. Faulting Geometry and Mechanisms. The alternative hypotheses available for this model element indicate that different slip directions are possible for faults that might intersect the repository. The current uncertainty in this model element indicates that the data-gathering activities feeding this study must evaluate the magnitude and rate of fault slip in both the strike-slip and dip-slip directions. The determination of slip rate and amount offset during individual events will affect the criteria for determining faults to be avoided during the selection of waste-emplacement borehole locations and the probabilistic evaluation of the nature of undetected faulting. Various alternative hypotheses (e.g., detachment fault model) also indicate that the dip on individual faults may change with depth. These alternatives are not expected to greatly change the existing uncertainty in projecting faults from the surface to the repository horizon because of the relatively shallow depth of the repository horizon.

2. Fault Activity and Faulting Rates. Current information and tectonic models indicate there may be faults that penetrate the repository, and some of these faults may have had Quaternary activity. Faulting rates are currently believed to be low, with long recurrence intervals between events in the repository area. Some alternatives suggest that higher rates are possible because of unrecognized components of strike-slip faulting. Consideration of these alternatives would again require that the data-gathering activities feeding this study evaluate the magnitude and rate of fault slip in both the strike-slip and dip-slip directions.

3. Fault Rupture Pattern. The alternatives for this model element indicate that fault ruptures during a single event may occur on a single fault strand or on several parallel strands. Such alternatives would affect the nature of the evaluation of the number of waste packages that could be affected by faulting during the postclosure time period due to the presence of undetected faults. The current uncertainty in this model element indicates that the data-gathering activities feeding data to this study about the occurrence of past events on faults in the repository area will have to evaluate whether events on different faults appear to coincide in time. The probabilistic estimate of the number of waste packages that could be affected by faulting during the postclosure time period due to the presence of undetected faults will have to include a consideration of the fault rupture alternatives.

In addition to the data-gathering activities that provide input directly into this study, Study 8.3.1.17.4.12 will provide information on currently viable tectonic model elements that could affect postclosure faulting concerns in the repository by integrating all geologic, geophysical, and seismologic data and testing a wide range of tectonic model hypotheses.

3.3 Activity 8.3.1.8.2.1.5 - Ground Motion

This activity will assess the possibility of earthquake ground motion during the 300- to 1,000-year period of substantially complete containment. The activity may also assess ground motion probabilities over longer time periods (e.g., 10,000 years), if such information is needed for performance assessments.

The basic elements of the engineered barrier system (according to the current reference design) are the waste emplacement borehole, the air gap around the waste canister, and the waste canister itself. The occurrence of one or more ground-motion events during the postclosure phase, depending on the level of ground motion and timing, may be an important consideration for waste canister design because of: (1) direct mechanical effects caused by movement of canister within the waste emplacement hole and subsequent puncture or rupture of the canister, especially at times of increased corrosion; and/or (2) stress-induced rock spall within the waste emplacement hole that can reduce or eliminate air space surrounding the waste package, resulting in canister puncture or permanent waste canister-repository wall contact, potentially amplifying corrosion rates. Thus, there may be a requirement for a design that could accommodate small lateral movements within the emplacement hole or a requirement for increased material strength so that canister-wall contact can be accommodated. Repeated events need consideration because repeated or long-term wall contact from an earlier event may result in slight canister damage and increased corrosion at contact points or damage locations. The canister would then be more susceptible to further damage and corrosion due to shaking and additional repeated wall contact during subsequent events, potentially reducing canister performance.

This activity will provide information on the nature of ground motions expected to occur during the period of waste package performance to the repository and waste package design activities for use in developing criteria for selecting suitable waste emplacement borehole locations and in developing designs for the engineered barrier system. This activity, therefore, contributes to the performance goal of placing waste packages in zones with rock properties that will not lead to failure during expected ground motion.

Technical Approach to the Activity. This activity will estimate ground motions that might be felt at the repository using the probabilistic model that will be developed for the preclosure ground motion assessment. When considering the 1,000- or 10,000-year periods covered by the assessment, it is possible that the repository will be subjected to a number of ground motion events of varying magnitude from both local and regional sources. The cumulative effect of a number of events producing moderate ground motion at the repository may be more significant to long-term waste package performance than the effects of a single large event, because (unlike an engineered facility such as a nuclear power plant) there will be no provision for repairs at the repository after an event occurs.

In addition, the different design purpose of the ground motion evaluation for the postclosure period, in comparison to an engineered facility such as a nuclear power plant, must be considered. For a nuclear power plant, a single large event is hypothesized in order to design for the ability to safely shut down the reactor in response to the occurrence of an earthquake. The concern is not with the continued functionality of the facility or with the ability of the facility to withstand subsequent events that could occur if very long time periods are considered. In the case of the postclosure period for a repository, the concern is in evaluating the range of events that are reasonably likely to occur over a long time period in order to assess the performance of a system that may not have active human monitors or operators. Because of these differences, a deterministic methodology using a single postulated design earthquake on a single source structure is considered inappropriate for the concerns addressed in this activity. A probabilistic model will allow consideration of the full range of events and seismic sources that could contribute to the ground motion hazard affecting the repository during the first 1,000 years of the postclosure time period. A probabilistic model will also allow an explicit consideration of the uncertainties present in this type of analysis.

As an alternative, it possible that the probabilistic analysis will conclude that the probability of multiple events with ground motions that are significant to design and performance is extremely low, because of the low rate of seismic activity in the area. If this proves to be the case, then a deterministic approach may be adopted for design and performance assessment purposes. It will also be important for this activity to closely coordinate its technical approach with the repository design activities to assure that the products are relevant to repository conditions and design needs. For example, if the strength properties of the host rock vary across the repository, then it may be appropriate to consider a suite of multiple hypothetical ground motion occurrences for design. On the other hand, if the ground motions necessary to induce spalling in an emplacement borehole are high (e.g., greater than 1 g), then it may be more appropriate to consider a single event and deterministic-type approach.

It is planned that the assessment will be based on the occurrence of ground motion as a result of fault movement. However, other types of ground motion, such as volcanic (harmonic) tremor due to eruptions or (non-eruptive) intrusive activity, could occur. Although volcanic tremor is typically only about M_L 3, it can be sustained for long periods of time and may introduce fatigue effects to the waste package or borehole wall. If the probability of volcanic or igneous activity is found to be sufficiently high that these types of events should be considered, then a separate analysis will be prepared for these types of occurrences.

A preliminary evaluation of ground motion probabilities during has the postclosure period has been completed by Lee et al. (1991). This study used the fault-specific seismic hazard model developed for Sandia National Laboratories (URS/John A. Blume & Associates, 1987), because it contains probabilistic assessments for peak ground motion for the proposed surface facility and peak fault rupture along several potentially active faults. It also incorporates both regional and near-site faults, uses the limited deformation rate data to constrain seismic activity to the near-site faults, and uses historic seismicity to constrain seismicity not assigned to specific faults (background seismicity).

The Lee et al. (1991) study was limited because the URS/John A. Blume & Associates (1987) hazard evaluation was done for the central surface facilities area. Because the repository area is more than two kilometers from the surface facility and approximately 300 meters deep, it is expected that ground motion could vary considerably from that expected at the surface facilities. For the purposes of the Lee et al. (1991) study, it was assumed that ground motion predictions of URS/John A. Blume & Associates (1987) are representative of the repository block and no account was taken for reduction in subsurface ground motions, nor an increased distance (4 versus 2 km) from the Paintbrush Canyon fault.

The hazard model used by Lee et al. (1991) assumed a Poisson distribution of earthquake occurrence. This simplified model lended itself to estimation of frequencies of occurrence of exceedance of specific levels of ground acceleration. The Poisson distribution for this application is given by:

$$P(n) = \frac{\exp(-\lambda * T) * (\lambda * T)^n}{n!}$$

where λ is the annual rate of exceedance, T is the period in years, and n is the frequency of occurrence, and P is the probability of occurrence.

This activity will basically update the results of the Lee et al. (1991) study by incorporating the more refined probabilistic seismic hazard models that will be produced as a result of site characterization studies and using predictions of ground motions that are based on the actual repository depth and location. The engineering parameters that are of interest in evaluating waste package performance for the postclosure period will be provided as a result of coordination with the design and performance assessment activities listed below to determine whether parameters such as peak motion values for acceleration or velocity, a spectrum of peak values, or time histories and corresponding response spectra are most useful for design and performance assessment purposes.

Data Input Requirements for the Analysis. The following data will be gathered by other studies and used to perform the analysis and assessments of the activities in this study:

1. Probabilistic seismic hazards analyses of the region within a radius of about 100 km from the site (from Study 8.3.1.17.3.6). These analyses will determine average rates for earthquake recurrence as a function of magnitude for the southern Great Basin and apportion those rates onto active faults and subregional seismic source zones. The data requirements for this study will include the software packages selected by Study 8.3.1.17.3.6 for computing probabilistic seismic hazard estimates. This analysis will also incorporate the selected attenuation models for predicting expected values and variances of required ground motion parameters as a function of distance and source size.

2. Site effects from ground motion recordings at the proposed repository horizon (from Activity 8.3.1.17.3.4.1). This analysis will compare the spectral amplitudes of subsurface motions with the corresponding surface motions and with the area averages for surface motions at rock stations. Activity 8.3.1.17.3.4.1 will use previously recorded relevant Nevada Test Site data and instrumental recordings from two or

more surface sites on Yucca Mountain and several sites in the exploratory shafts and drifts to quantify spectral reductions in motion with depth as a function of frequency.

3. A model of site effects using the wave properties (shear- and compressional-wave velocities, material damping, and densities) of the local stratigraphic column (from Activity 8.3.1.17.3.4.2). This analysis will supply a calibrated, theoretical site-effects model for use in extrapolating observed data to locations and depths where ground-motion predictions are needed but where instrumental recordings are not available.

Expected Output and Accuracy of the Analysis. The results of the Lee et al. (1991) study indicate that a peak ground motion of 0.6g represents an approximately 10% chance of exceedance in a 1,000 year period, this probability of exceedance corresponds to the preliminary waste canister design basis. For the same design acceleration and a 10,000 year period, there is nearly an equal expected probability of occurrence of two or more events (0.283) as for one event (0.366).

The Lee et al. (1991) study indicates that the most probable number of episodes of peak ground acceleration exceeding 0.4g in any 1,000 year period is one. The study also indicates that the most probable number of events producing 0.4g or greater motions in the repository block in any 10,000 year period is 4 or 5. The cumulative probability of the number of events exceeding 0.4g that could occur in 10,000 years is still significant (0.131) for even 8 or more events occurring. If 0.1g is the onset of rocking motion of the waste canister, it may represent the onset of motion at which waste canister damage could occur. The Lee et al. (1991) study found that the most probable number of occurrences of 0.1g and greater ranges from about 8 to 12 occurrences in 1,000 years. It is expected that results of this activity will produce similar results.

If the probabilities of having significant ground motion events remain low and the analyses by the performance assessment and design tasks indicate that only relatively high ground motions are of concern, then a single design event based on a maximum acceleration arrived through a deterministic approach may be judged to be the most defensible approach for license application purposes.

The probabilistic model will allow an explicit consideration of uncertainty in the estimation of the number of events that may occur. In using the output of the model, design values will be selected in a conservative manner to meet the general parameter goal of presenting an overall model of seismicity for the 1,000-year period in which the ground motions values have a probability of less than 0.1 of being exceeded.

This activity will supply the results of the analysis on the number of events and corresponding strong-motion estimates to the repository and waste package design and performance assessment activities listed below. The design activities will use the ground motion estimates in conjunction with data on repository horizon rock properties and state of stress in finalizing underground designs and/or applying any appropriate mitigating measures. The design activities will also have the primary responsibility for supplying information on waste package and repository performance during anticipated ground motion events to the performance assessment activities. In addition to supplying information, this activity will also be responsible for providing necessary coordination and integration with other activities in the use the data being supplied. Activities that will use data generated by this activity and with which coordination will have to occur include:

1. Information Need 1.11.3. Provide and coordinate data for use in the establishment of criteria to avoid unfavorable areas in the selection of waste-emplacement borehole locations and provide data relevant to concerns related to the decision on vertical or horizontal emplacement (Products 1.11.3-5 and 1.11.3-3 in SCP Section 8.3.2.2.3).

2. Issue 1.4, Waste Package Performance Objective for Containment; Activity 1.4.4.1, Estimate of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation of Container Failure Rate as a Function of Time: Issue 1.8, NRC Siting Criteria; 10 CFR 60.122(c)(12), (13), (14), Potentially Adverse Effects of Earthquakes: and Issue 1.9, Higher Level Findings; 10 CFR 960.4-2-7(c)(2), (3), (4), Potentially Adverse Effects of Earthquakes. Provide and coordinate data on the probability of earthquakes in the geologic setting during the first 1,000 years of repository performance and the effects of ground motion on waste package performance.

3. Information Need 1.11.3, Repository layout; and Issue 1.10, Postclosure Waste Package Characteristics. Provide and coordinate data on any repository layout, waste-emplacement borehole, or waste package design changes that may be required or desired to minimize the effects of ground motion on waste package performance.

Representativeness and Effect of Alternate Conceptual Models. The probabilistic models planned for use in this activity are considered to be the most representative technique available for realistically describing the range of ground motion events that are reasonably likely to occur in the first 1,000 years of repository performance. The probabilistic models will be based on site-specific data concerning the magnitude, frequency, and location of earthquakes in the region as derived from historical seismicity and geological evidence. Other approaches, such as deterministic methods for estimating a design event, are not as suitable for estimating the range of events that are likely to occur on a variety of regional and local sources over long time periods.

The effects of alternate conceptual tectonic models on the consideration of postclosure ground motion hazard are basically the same as those for the preclosure ground-motion hazard evaluation (Investigation 8.3.1.17.3). Because earthquakes that might be significant to the ground motion hazard analysis could occur throughout the region, both the local and regional models are important in the analysis (see SCP Tables 8.3.1.17-7 and 8.3.1.17-8). The model elements that most directly affect the analyses are

1. Faulting Geometry and Mechanisms. The alternative hypotheses available for this model element indicate that different slip directions are possible for faults that might be earthquake sources. The current uncertainty in this model element indicates that the data-gathering activities to be used in constructing the probabilistic

seismic hazard analysis must evaluate the magnitude and rate of fault slip in both the strike-slip and dip-slip directions. The determinations of slip rate and amount offset during individual events will affect the model input parameters relating to the frequency and magnitude of events attributed to specific sources. Various alternative hypotheses (e.g., detachment fault model) also indicate that individual faults mapped on the surface may be connected to a large master fault at depth. These alternative models may affect model input parameters relating to the frequency and magnitude of events. Consideration of these alternative hypotheses will require that the data-gathering activities supplying information to be used in constructing the probabilistic model acquire data on the geometry and possible interconnections of faults at depth.

2. Faulting Rates. Faulting rates are currently believed to be low, with long recurrence intervals between events in the repository area. Some alternatives suggest that higher rates are possible because of unrecognized components of strike-slip faulting. Consideration of these alternatives will also require that the data-gathering activities supplying information used to construct the probabilistic model should evaluate the magnitude and rate of fault slip in both the strike-slip and dip-slip directions.

3. Fault Rupture Pattern. The alternatives for this model element indicate that fault ruptures during a single event may occur on a single fault strand or on several parallel strands. The existence of these alternatives would affect the evaluation of the frequency and magnitude of events used in the probabilistic model. The current uncertainty in this model element indicates that the data-gathering activities used to supply data on the occurrence of past events on faults in the region should evaluate whether events on different faults appear to coincide in time.

4. Pattern of Seismicity and Length of Performance Period. The occurrence of multiple seismic events during the 1,000 to 10,000 year interval could significantly affect these controlled release rates if waste packages that are weakened by corrosion resulting from earlier seismic events or other processes suffer increased failure rates as a result of the cumulative shaking effects of subsequent multiple events. The significance of multiple events could also be increased if the events are not uniformly spaced in time, but occur as relatively closely spaced clusters of events during the earlier and/or later parts of the performance period where the cumulative damage from clusters of events may affect long-term performance. It has also been suggested (Nuclear Waste Technical Review Board, 1990) that engineered barrier system designs be considered that would provide substantially complete containment for the full 10,000 year period as an additional barrier to releases. Consideration of multiple seismic events may be a significant factor if these suggestions are implemented.

In addition to the data-gathering activities that provide input directly into the formulation of the probabilistic seismic hazard analysis (Study 8.3.1.17.3.6), Study 8.3.1.17.4.12 will provide information on currently viable tectonic model elements that could affect postclosure faulting concerns in the repository by integrating all geologic, geophysical, and seismologic data and testing a wide range of tectonic model hypotheses.

3.4 Activities 8.3.1.8.2.1.6 and 8.3.1.8.2.1.7 - Folding

These two activities are described together because they are interrelated. These activities will assess the possibility that high rates of folding or deformation operating over the 300- to 1,000-year period when the waste packages must provide substantially complete containment could result in sufficient waste-emplacement borehole deformation to lead to waste package failure. Folding or deformation caused by minor slip occurring on a series of closely spaced planes could close the air gap around a waste package and damage the waste package through the mechanical effects of continued deformation. Closure of the air gap around the waste package could also lead to increased corrosion of the waste package at the points of contact between the waste-emplacement borehole wall and the waste package. These activities will provide an assessment of the possibility that folding and deformation could generally affect repository and waste package performance. These activities, therefore, contribute to the evaluation of the performance goal of rupturing less than 0.5 percent of the waste package inventory because of tectonic processes and events (see SCP Section 8.3.4.2).

Technical Approach to the Activities. The technical approach to these activities involves integration, study, and assessment of geologic data obtained from various investigations to assess the nature and rate of folding in the repository and any resulting hazards. Deformation zones that may penetrate the repository horizon will be characterized to determine their surface location, dip, projected location at the repository level, length, width of disturbed zone, evidence of Quaternary activity, and amount of deformation in the Tiva Canyon Member and during the Quaternary. The nature of deformation zones in the repository horizon will also be characterized using the drifts in the Exploratory Studies Facility. The nature and rate of folding in the repository will be evaluated using conventional surface geologic mapping, structure contour and isopach maps, and mapping of the drifts in the Exploratory Studies Facility. Activity 8.3.1.8.2.1.6 will integrate and summarize the information collected by several data-gathering activities in order to provide an assessment of the nature, age, and rate of folding or deformation that is reasonably likely to affect the repository horizon. Activity 8.3.1.8.2.1.7 will use this information to produce an assessment of the effects of folding and deformation on waste package performance.

Data Input Requirements for the Analysis. The following data will be gathered by other studies and used to perform the analysis and assessments of the activities in this study:

1. Detailed geologic map(s) of the contacts between mappable zones in the Tiva Canyon and Topopah Spring members covering the repository area (from Activity 8.3.1.4.2.2.1). This map will show the surface geology of the area above the repository and identify and describe the locations of possible deformation zones (areas of anomalously steep dips or closely spaced fractures) and folds. The amplitude and

wavelength of any folds that are identified will be described. Areas of bedrock outcrop from which geologic interpretation has been extrapolated will be distinguished from areas in which bedrock is not exposed at the surface.

2. Detailed structure contour and isopach maps on various stratigraphic horizons present at the surface or in the subsurface in the repository area (from Activity 8.3.1.4.2.3.1). These maps will integrate the precise information obtained from boreholes on the elevation and thickness of stratigraphic units and the detailed geologic mapping of the area. The maps will be used to identify areas of anomalously steep gradients where deformation zones may be present, estimate the amount of deformation that has occurred across such zones, and estimate the amplitude and wavelength of larger folds that may be present.

3. Detailed geologic maps of the exploratory shafts and drifts (from Activity 8.3.1.4.2.2.4). These maps will show the nature of folding and deformation zones at the repository level (e.g., the drifts to the Drill Hole Wash structures may supply information on the characteristics of deformation zones). The drift mapping will also identify any stratigraphic features present in the repository horizon that can be used as datums to detect and evaluate folding and deformation.

4. Data on known Quaternary faults in and near the repository showing the width of deformation zones and folding associated with Quaternary faults at the surface, as well as Quaternary deformation rates associated with faults (from the mapping studies in Activity 8.3.1.17.4.6.1 and the trenching studies in Activity 8.3.1.17.4.6.2).

5. A synthesis of all regional and local data that evaluate the tectonic processes affecting the site and its tectonic stability (from Activity 8.3.1.17.4.12.1).

6. Data on the pattern, rate, amplitude, and wavelength of post-middle-Miocene folding in the region (from Activity 8.3.1.8.5.3.1).

7. Information on emplacement borehole orientation (horizontal or vertical), and the spacing, layout, and dimensions of emplacement boreholes in the repository. These data will come from Information Need 1.11.3 (SCP Section 8.3.2.2.3).

Expected Output and Accuracy of the Analysis. All the information items will be used to generate an assessment on the anticipated nature of folding and deformation that can be used to determine whether this is a credible scenario for waste package failure at the Yucca Mountain site and what the rates of failure attributable to this scenario might be. Because the rate of folding or deformation would have to be extremely high to affect waste package integrity in 1,000 years, it is anticipated that bounding calculations may be sufficient to demonstrate that any credible rate of folding or deformation would be below the level necessary to produce significant effects.

These activities will provide assessments to the repository and waste package

Quality Assurance grading process which will be completed in accordance with applicable procedures prior to the start of work. The analyses in this study will not require the preparation of specific procedures. General Project-level procedures that do or may apply to the activities in this study are listed in the Tables 3-1 and 3-2.

Table 3-1. Yucca Mountain Project Quality Management Procedures (QMPs)

QMP No.	QMP Title	Status
QMP-06-04	Project Office Document Development, Review, Approval, and Revision Process	Completed
QMP-17-01	Records Management: Record Source Implementation	Completed

Table 3-2. Yucca Mountain Project Administrative Procedures (APs)

AP No.	AP Title	Status
AP-5.1Q	Control and Transfer of Technical Data on the Yucca Mountain Project	Completed
AP-5.2Q	Technical Information Flow To and From the Yucca Mountain Project Technical Data Base	Completed
AP-5.3Q	Information Flow into the Project Reference Information Base	Completed
AP-5.19Q	Interface Control	Completed
AP-5.28Q	Quality Assurance Grading	Completed
AP-5.32Q	Test Planning and Implementation Requirements	Completed

design and performance assessment activities listed below. An interactive exchange is required with the staff working on the detailed designs of the waste package and waste emplacement boreholes in order to provide information that is useful for assessing the significance of folding or deformation processes on the waste package. Coordination and integration activities will include the following issues and information needs:

1. Information Need 1.11.3. Provide data for use in the selection of waste-emplacement borehole locations (Product 1.11.3-5 in SCP Section 8.3.2.2.3).

2. Issue 1.4, Waste Package Performance Objective for Containment; Activity 1.4.4.1, Estimate of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation of Container Failure Rate as a Function of Time; Issue 1.8, NRC Siting Criteria; 10 CFR 60.122(c)(11), Potentially Adverse Effects of Folding and Deformation: and Issue 1.9, Higher Level Findings; 10 CFR 960.4-2-7(c)(1), Potentially Adverse Effects of Folding and Deformation. Provide assessments on the nature and rate of folding and deformation in the repository and effects of folding and deformation on waste package performance.

3. Information Need 1.11.3, Repository layout; and Issue 1.10, Postclosure Waste Package Characteristics. Provide data and coordinate on any repository layout, waste-emplacement borehole, or waste package design changes that may be required or desired to minimize the effects of waste-emplacement borehole deformation on waste package performance.

Representativeness and Effect of Alternate Conceptual Models. The assessments will be based on detailed geologic data obtained from the site and are expected to be representative of the characteristics of folding and deformation in the site area. Detailed information on the Quaternary rates of these processes may be difficult to obtain. As a result, folding and deformation rates may have to be estimated based the on amount of deformation found in the Miocene tuffs. It is anticipated that the degree of folding in the Miocene rocks will be minor enough that conservative assumptions (e.g., all observed folding in the Miocene rocks occurred during the Quaternary Period) can be used to calculate representative upper bounds.

The concerns addressed by these activities are not particularly sensitive to the various tectonic models listed in SCP Tables 8.3.1.8-7 and 8.3.1.8-8, because any of the deformation geometries and mechanisms listed could result in local folding or zones of distributed shear. The results of Study 8.3.1.17.4.12 will provide the necessary evaluation of the effects of viable alternate models on local deformation rates and styles.

3.5 Applicable Procedures

All the activities in this study provide analyses that will be used for repository performance assessment or repository design. The nature of applicable Quality Assurance controls (Appendix A) will be determined in the

3.6 Reports

The results and conclusions of each of the activities or groups of activities described in sections 3.1 to 3.4 will be summarized in a report. Depending on the schedule and requirements of the activities receiving information from this study, the number of reports produced may be increased or decreased by consolidating the results of several activities into one report or by presenting the result of one activity in a series of progress reports. A summary report presenting the results of all study plan activities may also be prepared, if necessary. Each of the reports will contain the following information:

1. A listing of the data used in making the assessment, the sources of the data, and a discussion of the limitations or uncertainties inherent in the data.

2. The methods used to make calculations or estimates for the assessment, including descriptions of computer software used and the methods for validating and verifying calculations.

3. An analysis of the assumptions and uncertainties in the assessment.

4. A clear description of the performance and characterization parameters to be provided by the activity.

The reports summarizing the results of the activities will be used as sources in the preparation of the Safety Analysis Report and a series of Position Papers. The following is a preliminary list of Position Papers that may use the results of this study:

1. Identification and Mitigation of Unfavorable Conditions Noted During Repository Construction.

2. Performance Assessment of Overall System.

3. Performance Assessment of Barriers.

4. Criteria for Design of Engineered Barriers.

5. Design Bases for Shafts, Ramps, and Underground Facility.

6. Waste Package Design Bases.

7. Identification of Anticipated and Unanticipated Processes and Events.

8. Identification of Potentially Significant Scenarios.

9. Fluid, Chemical, Stress, and Radiation Conditions Affecting the Waste Package.

10. Potentially Significant Scenarios for Disturbed Conditions for the EBS.

11. Potentially Adverse Conditions -- Structural Deformation During the Quaternary Period.

12. Potentially Adverse Conditions -- Earthquakes that Could Affect the Site Significantly.

13. Potentially Adverse Conditions -- Indication that the Frequency or Magnitude of Earthquakes may Increase.

14. Potentially Adverse Conditions -- More Frequent Occurrence of Earthquakes at the Site than in the Region.

15. Potentially Adverse Conditions -- Evidence of Igneous Activity Since the start of the Quaternary Period.

4.0 APPLICATION OF RESULTS

The results of this study will be used for the support of performance assessment and design studies. Performance assessment studies will use this study as a source of information on the probability and effects of tectonic processes and events on waste package performance.

4.1 Resolution of Design and Performance Issues

The performance assessment analyses that will use the information produced by this study are:

1. Issue 1.4, Waste package performance objective for containment; Activity 1.4.4.1, Estimate of the rates and mechanisms of container degradation in the repository environment for anticipated and unanticipated processes and events, and calculation of container failure rate as a function of time.

2. Issue 1.8, NRC Siting Criteria; 10 CFR 60.122(c)(11), (12), (13), (14), and (15), potentially adverse effects of earthquakes, active folding, faulting, and igneous activity.

3. Issue 1.9, Higher Level Findings; 10 CFR 960.4-2-7(c)(1), (2), (3), and (4), potentially adverse effects of earthquakes, active folding, faulting, and igneous activity.

This study will also provide information that will be used in the preparation of designs for the repository drifts, waste-emplacement boreholes, and waste packages to address tectonic hazards related to earthquake ground motion, faulting, and deformation resulting from distributed shear. Design studies that will use this data are Information Need 1.11.3 (Products 1.11.3-5 and 1.11.3-3 in SCP Section 8.3.2.2.3) and Issue 1.10, Postclosure Waste Package Characteristics.

4.2 Interfaces with Other Site Characterization Studies

This study plan affects the planning of other site characterization studies by making specific requests for information products from certain site characterization activities involved in field data collection. The nature of these requests and the activities needed to provide them are described in Sections 3.1 through 3.4.

Some of the information collected for this study and the results of the analyses performed will also be used as input into the analyses performed in Investigation 8.3.1.8.3 (Tectonic Effects on Hydrology) and Investigation 8.3.1.8.4 (Tectonic Effects on Geochemistry).

5.0 SCHEDULES AND MILESTONES

5.1 Duration and Relationships of Study Plan Activities

The duration and relationships of the four major groups of activities described in Sections 3.1 to 3.4 are given in Figure 5-1 and Table 5-1. Each of these four groups is relatively independent of the others, although some of them rely on the same information items to be supplied by data-gathering activities in other studies.

5.2 Scheduling Relative to Other Studies

The four analyses in this study depend on the receipt of data from activities in other studies to complete their assessments. Therefore, the schedule for the completion of this study is constrained by the schedule of other studies providing data. Figure 5-1 shows the current scheduled dates when the major data-gathering activities that constrain this study are planned to have their data available for analysis. The schedules shown on the figure have been revised and updated from the schedules shown in Section 8.5 of the SCP. The reports, design activities, and performance assessment activities that will use the reports generated by this study are listed in Sections 3.6 and 4.1.

During the period when data are being gathered by other activities, the activities in this study will be involved in the development and testing of analysis techniques and in monitoring the progress of the data-gathering activities. Close coordination between the data-gathering and analysis activities is important to assure that the needed information is obtained. The activities in this study will monitor progress in the data gathering to determine if information of the proper type and accuracy is obtained. Preliminary data will be evaluated and preliminary analyses completed. If it is found that the data being obtained are not sufficient to complete the analyses with the desired level of confidence, the activities in this study will request information of greater accuracy or different type. The nature of the data being collected will also influence the methods used to complete the analyses and assessments. The results of preliminary analyses will be reviewed to determine if changes in approach are required. The monitoring of data as it is collected and the completion of preliminary analyses should allow the final analyses and reports to be completed soon after the data-gathering activities are finished.

5.3 Schedule

The milestones indicating the scheduled completion dates of the four major tasks in this study are shown in Table 5-1. The completion dates for these milestones have been revised and do not correspond exactly to the dates given in the SCP schedule (SCP Figure 8.3.1.8-10 and SCP Table 8.3.1.8-9).

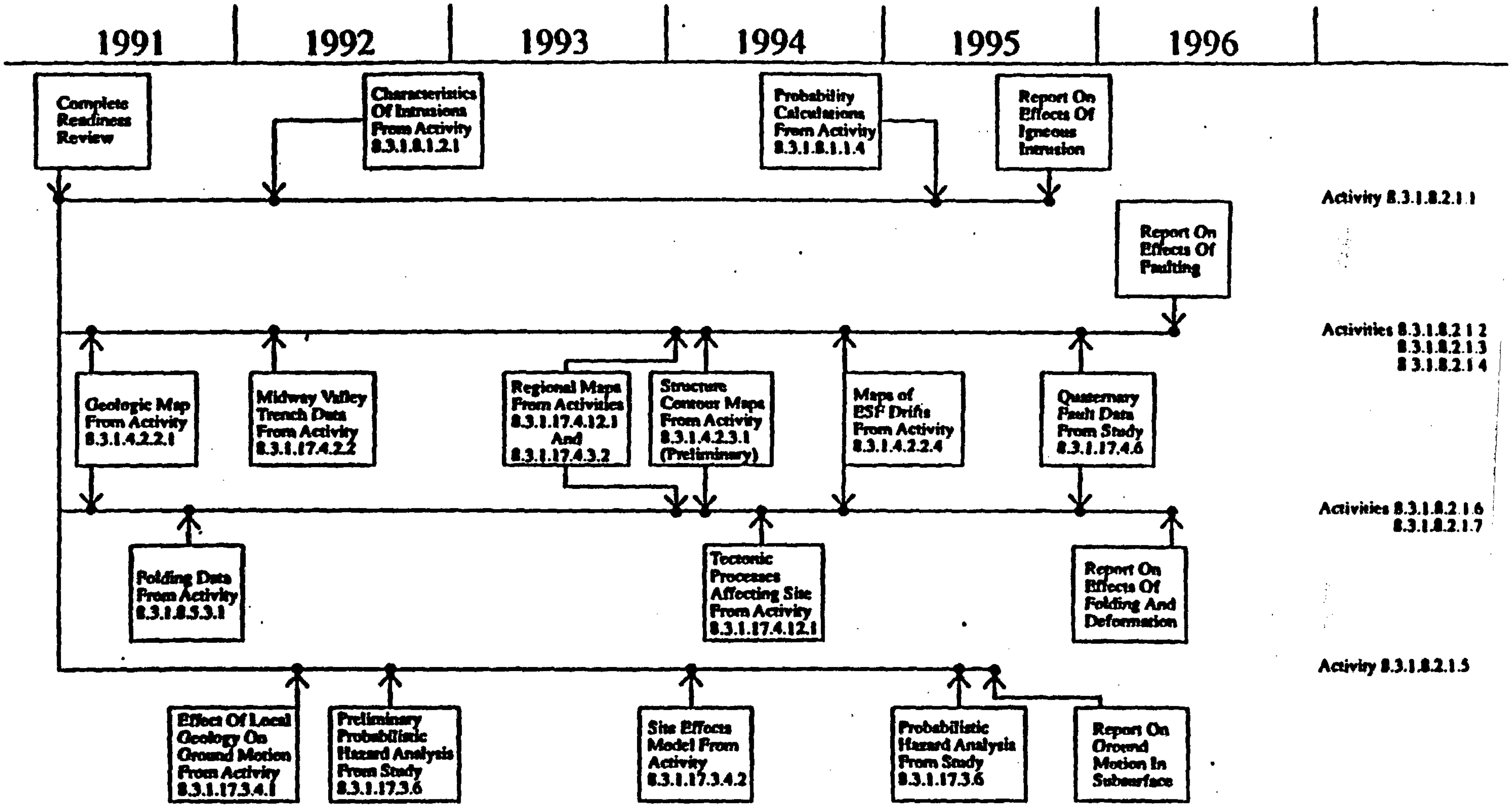

FIGURE 5-1. Schedule Showing Planned Completion Dates of Constraining Data Gathering Activities.

Table 5-1. Summary Of Study Plan Milestones And Schedule

Milestone	Scheduled Completion Date (Months after start of study)
Conduct readiness review and prepare/approve Test Planning Package	3
Complete calculations of the number of waste packages intersected by a fault	18
Draft report available to the DOE[a] on vibratory ground motion that could affect waste package performance	51
Draft report available to the DOE on the assessment of waste package rupture due to igneous intrusion	55
Draft report available to the DOE on the assessment of waste package rupture due to faulting	62
Draft report available to the DOE on the assessment of waste package rupture due to folding and deformation	62

[a] DOE = U. S. Department of Energy

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APPENDIX A
QUALITY ASSURANCE REQUIREMENTS

This Study Plan was prepared in accordance with Yucca Mountain Site Characterization Project Procedure, AP-1.10Q, "Preparation, Review, and Approval of SCP Study Plans," Rev. 3, 03/26/91, and supersedes DOE Letter DCD-282, 10/24/88. QA grading for this study will be determined in accordance with currently applicable procedures (i.e., AP-5.28Q and AP-6.17Q) prior to the start of the work.

Table A-1. Summary of Documents and Procedures That Will Address Each of the 18 Nuclear QA Criteria (Page 1 of 3)

NQA-1 Criterion	Documents/Procedures Addressing Criterion
1. "Organization"	Project Office organizational responsibilities and interfaces are described in the Project Office QAPP (N-QA-045, 10.88) and Quality Management Procedure (QMP) QMP-01-01 (N-QA-015, 12/87 and N-QA-016, 7/87.
2. "QA Program"	A summary description of the Project Office QA program (QAP) is in Section 8.6 of the SCP. The Project Office QAPP and the SAIC/T&MSS QAPP have been consolidated into one QAPP (WMPO/88-1, Rev. 1, 4/89). The QAP is described in detail in Section II of the QAPP.
	QMP-02-01, Rev. 1, 9/88. Qualification, Proficiency, and Training.
3. "Design and Scientific Investigation Control"	As per Section III of the Project Office QAPP, this study plan is a scientific investigation. The following procedures apply:
	QMP-03-01, Rev. 1, 1/89. Peer Reviews.
	QMP-03-02, In preparation. Scientific Investigation Control.
	QMP-03-03, In preparation. Use of Software.
	QMP-03-05, In preparation. Verification and Validation of Software.
	QMP-03-07, In preparation. Software Approval.
4. "Procurement Document Control"	Section IV of the Project Office QAPP and QMP-04-01, Rev. 0, 4/88.

Table A-1. Summary of Documents and Procedures That Will Address Each of the 18 Nuclear QA Criteria (page 2 of 3)

NQA-1 Criterion	Documents/Procedures Addressing Criterion
5. "Instructions, Procedures, and Drawings"	The activities in this study are performed according to the procedures described in Section 3 of this study plan. QMP-05-02, Rev. 0, 5/27/88. Preparation and Control of BTPs.
6. "Document Control"	QMP-06-02, Rev. 1, 12/1/88. Document Control. QMP-06-03, Rev. 1, 2/22/88. Document Review/Acceptance/Approval.
7. "Control of Purchased Material, Equipment, and Services"	Section VII of the Project Office QAPP and QMP-07-03, Rev. 0, 4/11/88.
8. "Identification and Control of Items, Samples, and Data"	Section VIII of the Project Office QAPP, Part C, 4/20/89.
9. "Control of Special Processes"	Not applicable
10. "Inspection"	Not applicable
11. "Test Control"	Not applicable
12. "Control of Measuring and Test Equipment"	Not applicable
13. "Handling, Storage, and Shipping"	Not applicable
14. "Inspection, Test, and Operating Status"	Not applicable
15. "Control of Nonconforming Items"	Section XV of the Project Office QAPP and QMP-15-01, Rev. 1, 5/27/88. Nonconformances

Table A-1. Summary of Documents and Procedures That Will Address Each of the 18 Nuclear QA Criteria (page 3 of 3)

NQA-1 Criterion	Documents/Procedures Addressing Criterion
16. "Corrective Action"	Section XVI of the Project Office QAPP. QMP-06-01, Rev. 0, 12/10/84. Corrective Action. QMP-06-03, Rev. 1, 6/5/89. Standard Deficiency Reporting.
17. "Quality Assurance Records"	Section XVII of the Project Office QAPP and QMP-17-01, Rev. 0, 1/11/89. Record Source and Record User Responsibilities.
18. "Audits"	Section XVIII of the Project Office QAPP. QMP-18-01, Rev. 3, 10/3/88. Audit System. QMP-18-02, Rev. 1, 5/27/88. Surveillance.