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STUDY PLAN FOR PROBABILITY OF A VOLCANIC ERUPTION PENETRATING THE REPOSITORY

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PROBABILITY OF A VOLCANIC ERUPTION PENETRATING THE REPOSITORY

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ABSTRACT

The purpose of this study is to assess the probability of future volcanic activity with respect to siting a repository for disposal of high-level radioactive waste at Yucca Mountain. The probability assessment will be completed through a combination of studies, and the results of these studies will be compared for consistency. The probability that volcanic activity will intersect the repository will be estimated from the analysis of a variety of data on the location and timing of volcanic events during the last 4 to 8 million years, magma generation rates, structural controls on the location of volcanic activity, and geophysical data on the locations of potential magma bodies that could be the sources for future events.

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1.0 PURPOSE AND OBJECTIVES OF STUDY

1.1 Purpose

The Yucca Mountain Project (YMP) is conducting volcanism studies to evaluate the hazards of future volcanism with respect to disposal of high-level radioactive waste at the potential repository site at Yucca Mountain [Site Characterization Plan (SCP) (DOE, 1988), Section 8.3.1.8.1.1]. There are two aspects to investigations of the future hazards of volcanism: (1) the hazards of silicic volcanism and (2) the hazards of basaltic volcanism. The hazards of silicic volcanism, based on current data from site characterization, are considered to be negligible for the postclosure period of a repository (SCP Section 1.5.1.1; Crowe et al., 1983a). The hazards of future basaltic volcanism are more difficult to define. The Yucca Mountain site is located in a diffuse zone of basaltic activity named the Death Valley/Pancake Range volcanic zone (SCP Section 1.3.2.1.2; Crowe et al., 1986). This zone has been active from about 6.5 million years ago through the Holocene. Four Quaternary volcanic centers (approximate age of 1.2 million years) are located in Crater Flat, directly west and southwest of the exploration block of Yucca Mountain. Two Quaternary basaltic volcanic centers are located southwest of the Black Mountain Caldera, approximately 40 km northwest of Yucca Mountain. The youngest volcanic center in the region, the Lathrop Wells volcanic center, is located at the south end of Yucca Mountain, 20 km from the exploration block.

Two approaches have been used to evaluate the hazards of future basaltic volcanism for the Yucca Mountain site (Crowe et al., 1983a; Crowe, 1986). First, standard geologic studies that combine field mapping, geochronology, paleomagnetic determinations, geochemistry and petrology, and geophysical data have been used to decipher the geologic history of basaltic volcanism in the Yucca Mountain region. Second, data from these studies have been used for risk assessment, where risk assessment is defined as the product of the probability and consequences of future basaltic volcanism disrupting the Yucca Mountain site. The results of past volcanic hazard assessment using these two approaches have been described in SCP Sections 1.3.2.1.2 and 1.5.1 and in separate publications (Crowe and Carr, 1980; Vaniman and Crowe, 1981; Crowe et al., 1983a and 1983b; Crowe, 1986).

The purpose of this study (8.3.1.8.1.1) is to refine activities that have already been completed for determining volcanic probability. These refinements will be based on development of new methodologies to evaluate the structural controls of volcanism and to quantify magma production rates. The study will also use refined information on volcanic activity from other site characterization activities. This study plan includes the following activities.

- Location and timing of volcanic events. This work will involve collation of data from Study 8.3.1.8.5.1, Characterization of Volcanic Features, for use in published calculations of the probability of volcanic disruption of the Yucca Mountain site.

- Evaluation of the structural controls of basaltic volcanic activity. This work will involve examination of the time/space patterns of the locations of volcanic centers in the Yucca Mountain region. It will focus on two study areas: (1) identification of structural features that are associated with volcanic sites and the time/space variations of these associations and (2) how these structural associations could be factored into revised calculations of the probability of volcanic disruption of the Yucca Mountain site.

- Presence of magma bodies in the vicinity of the site. This work will involve collation of geophysical data, and noble gas isotopic data will be obtained for ground water to permit evaluation of whether there are any indications of the presence of magma bodies or indications of the operation of magmatic processes in the crust beneath Yucca Mountain.

- Probability calculations and assessment. This work will involve revision of the calculation of the probability of future volcanic disruption of the Yucca Mountain site. It will incorporate data from the activities of this study and Study 8.3.1.8.5.1, Characterization of Volcanic Features, to ensure that the assumptions used for probability calculations are based on complete geologic information. The methodology of calculating the magma production rate and disruption probability will be tested and revised using the most current information from site characterization studies.

1.2 Use of Results

This study will provide information in response to information needs that will contribute to the resolution of the following issues:

- Issue 1.1, which is related to the performance of the mined geologic disposal system,

- Issue 1.8, which is related to the identification of favorable and potentially adverse conditions, as required by 10 CFR 60.122 (NRC, 1986), and

- Issue 1.9, which is related to the qualifying conditions of the postclosure system guidelines and the disqualifying and qualifying conditions of the technical guidelines of tectonics given in 10 CFR 960 (DOE, 1986).

The main information needs to which this study plan responds are Information Need 1.1.1, Site Information Needed to Calculate Releases to the Accessible Environment, and Information Need 1.1.2, Set of Potentially Significant Release Scenario Classes That Address All Events and Processes That May Affect the Geologic Repository.

2.0 RATIONALE

The following sections of this study plan describe the approach, types of measurements to be made, rationale for choosing the types of measurements to be made, and the constraints for each activity. The discussions are separated into the individual activities, which include (1) location and timing of volcanic events, (2) evaluation of the structural controls of basaltic volcanic activity, (3) presence of magma bodies in the vicinity of the site, and (4) probability calculations and assessment.

2.1 Activity 8.3.1.8.1.1.1, Location and Timing of Volcanic Events

2.1.1 Approach

The purpose of Activity 8.3.1.8.1.1.1, Location and Timing of Volcanic Events, is to synthesize data obtained by other activities for use in revising the calculations of the probability of volcanic disruption of the Yucca Mountain site. The primary data for the task include the geographic location of basaltic volcanic centers less than 4 million years old in the Yucca Mountain region, the geochronology data for these centers, and the volume (dense rock equivalents) of eruptive units at the volcanic centers. The only data to be gathered for this activity are calculations of magma volumes using information from Activity 8.3.1.8.5.1.3, Field Geologic Studies. The primary objective of the task will be to synthesize the data on geologic maps and in accompanying reports so that the information base used to refine probability calculations will be carefully documented and available in a single reference.

2.1.2 Types of Measurements to Be Made

The data for this activity will be obtained from Activity 8.3.1.8.5.1.1, Volcanism Drillholes; Activity 8.3.1.8.5.1.2, Geochronology Studies; and Activity 8.3.1.8.5.1.3, Field Geologic Studies. The only measurements will involve compilation of geologic maps for the volcanic centers and calculation of magma volumes (dense rock equivalents) of eruptive units from studied volcanic centers shown on those maps. These volume calculations will be based on digitizing the maps produced for the activity to obtain unit areas and will use unit thicknesses determined by Activity 8.3.1.8.5.1.3.

2.1.3 Rationale for Choosing Types of Measurements to Be Made

Map compilation is the standard method for presenting field geologic information. We will compile maps to provide a data base for determining the area and volumes of volcanic units. The map digitization procedure allows precise measurements of the area of volcanic units.

2.1.4 Constraints for the Location and Timing of Volcanic Events

Information on the location of volcanic centers will be used for Activity 8.3.1.8.1.1.2, Evaluation of the Structural Controls of Basaltic Volcanic Activity. The volume data will be used for Activity 8.3.1.8.1.1.4, Probability Calculations and Assessment. It is very important to provide unbiased approaches to obtaining the volume data and to define the uncertainty of the data because the data are a key parameter for calculating density-corrected magma eruption rates.

2.2 Activity 8.3.1.8.1.1.2, Evaluation of the Structural Controls of Basaltic Volcanic Activity

2.2.1 Approach

The purpose of this task is to evaluate the time/space patterns of the distribution of basaltic volcanic centers in the Yucca Mountain region and to assess possible structural controls on the locations of the centers. This information will be used in conjunction with tectonic studies to evaluate the patterns and tectonic controls of past volcanism in an attempt to predict tectonic controls of future volcanic activity. This part of the activity follows an empirical ("deterministic") approach to the prediction of sites of future volcanic activity.

Crowe and Carr (1980) recognized three tectonic settings for occurrence of Pliocene and Pleistocene basalts in the southern Great Basin: (1) small northeast-trending rift zones or areas of relatively young basin/range extension, (2) ring fracture zones in calderas, and (3) the intersections of zones of left-slip faulting with northwest-trending right-slip zones of the Walker Lane structural system. Tectonic and geophysical data from Investigation 8.3.1.17.4, Preclosure Tectonics Data Collection and Analysis, and Investigation 8.3.1.8.5, Studies to Provide the Information Required by the Analysis and Assessment Investigations of the Tectonics Program, will be used to evaluate the tectonic/volcanic setting of the Yucca Mountain area with respect to basaltic volcanism. Information from the deep geophysical surveys on the crustal structure of Crater Flat and Yucca Mountain will be used. The Quaternary faulting studies will be evaluated to determine whether volcanic sites are influenced by the distribution of Quaternary faults. The detachment fault studies will be evaluated to assess whether these inferred fault systems could provide controlling pathways for the ascent of basaltic magma. Conclusions from the paleostress studies will be evaluated to determine how the past and present stress fields affect the distribution of basaltic volcanic centers. Finally, tectonic framework models will be evaluated for application to studies of the structural controls of basaltic volcanism.

The second aspect of this activity is an evaluation of whether it is possible to refine previous approaches to factoring the structural controls of volcanic activity into the probability formulation. Crowe et al. (1982) enhanced the consideration of structural controls in the formulation of the disruption parameter in the probability formula. They developed a numerical method for determining the minimum-area circle and minimum-area ellipse that enclose the Yucca Mountain exploration block and the volcanic centers used to calculate a volcanic rate. These areas depend on the spatial distribution of the volcanic centers and therefore partly factor the structural controls of volcanism into the probability formulation. We will attempt to refine the probability calculation using two techniques. First, we will increase the scale at which structural features are incorporated in the disruption ratio term of the probability formula. Geophysical and geologic data (aeromagnetism, gravity, topography, fault distribution, and distribution of volcanic centers) will be digitized by computer and evaluated in n-dimensional space. Cluster analysis will be used to search for patterns in the data that exhibit covariance with the time/space distribution of basaltic volcanic centers.

Second, we will evaluate the geographic dispersion of Quaternary sites of surface activity. We will determine the significance and degree of data correlations. If significant data correlations are recognized, we will attempt to weight the correlations, and this weighting will be factored into the disruption ratio of the probability calculations.

2.2.2 Types of Measurements to Be Made

This activity synthesizes information from other activities. The only unique measurements are cluster analyses to derive spatial patterns of geophysical and geologic data and the derivation of weighting factors for correlations between sites of volcanism and geologic and geophysical data. The data for location of volcanic centers will be obtained from Activity 8.3.1.8.1.1.1.

2.2.3 Rationale for Choosing Types of Measurements to Be Made

Cluster analysis is a multivariate procedure for detecting natural groupings in data where neither the identity nor the number of subgroups is known. It provides an unbiased approach to identifying spatial patterns in geophysical and geologic data. Cluster analysis was chosen over discriminant analysis because the latter procedure requires information on the identity and number of subgroups in the data set.

2.2.4 Constraints for the Evaluation of the Structural Controls of Basaltic Volcanic Activity

We are following two differing approaches in an attempt to understand the possible structural controls of the location of future basaltic volcanic centers. The first follows a predictive approach that uses judgment in evaluating the association between tectonic setting and sites of volcanic activity. The constraints for this work are two related questions. (1) Are tectonic features present in the Yucca Mountain region that may control the location of future volcanic activity? (2) If such features are present, how do they affect the Yucca Mountain site? The constraint on the probabilistic approach to structural controls of volcanism is whether a methodology can be developed with a reasonable degree of confidence to further refine mathematically the relationship between structural features and the location of past and future sites of basaltic volcanic activity.

2.3 Activity 8.3.1.8.1.1.3, Presence of Magma Bodies in the Vicinity of the Site

2.3.1 Approach

The objective of this activity is to review geophysical data collected in the vicinity of the site to assess whether there are any indications of the presence of crustal magma bodies that could be the source of future volcanic activity. This activity would ensure that sufficient geophysical data have been obtained from other activities to adequately answer the question of whether magma bodies are present. A second objective of this activity is to obtain information on the presence or absence of magma bodies through measurement of the isotopic ratios of noble gases in ground water beneath and around the Yucca Mountain site. This activity does not provide information directly to Activity 8.3.1.8.1.1.4, Probability Calculations and Assessment. However, evidence of magma chambers beneath Yucca Mountain would require a reassessment of the processes controlling the distribution of volcanic activity, which directly affects the assumptions required for a probabilistic approach to volcanic risk assessment.

2.3.2 Types of Measurements to Be Made

The only measurements to be made are analyses of the isotopic ratios of the noble gases (helium, argon, and neon) in ground water beneath and around Yucca Mountain.

2.3.3 Rationale for Choosing Types of Measurements to Be Made

Monitoring $^3He/^4He$ ratios in water is an important new technique that can be used to test for evidence of undetected subsurface volcanic intrusions. Torgersen et al. (1987) identified enriched $^3He/^4He$ ratios in ground water of eastern Australia. They suggested that the high ratios could be produced by continued young intrusive activity associated with known volcanic fields.

2.3.4 Constraints for the Presence of Magma Bodies in the Vicinity of the Site

There are two primary constraints for this activity. (1) Are the proposed geophysical and geologic studies for the Yucca Mountain site sufficient to evaluate the presence or absence of magma bodies in the subsurface in the vicinity of the site? (2) Can the $^3He/^4He$ ratios in ground water be uniquely associated with the presence or absence of buried intrusions? High $^3He/^4He$ ratios can be produced by mantle degassing in tectonically active zones that allow upward migration of helium. The presence of a relatively shallow and hot upper mantle beneath the southern Great Basin and the presence of Quaternary faults and major structural zones in the vicinity of the Yucca Mountain site (Mine Mountain/Spotted Range structural zone) could make helium isotopic data difficult to interpret. However, high ratios associated with a magma chamber may be uniquely identified by the geometry of the helium anomaly (the helium anomaly should be a point source directly above the body and should widen and spread downgradient), by comparison of helium data with similar ground water data for neon and argon, and by comparison of any potential noble gas anomalies with geophysical data.

2.4 Activity 8.3.1.8.1.1.4, Probability Calculations and Assessment

2.4.1 Approach

Crowe and Carr (1980) have completed a preliminary assessment of the risk of volcanism for the Yucca Mountain site. They calculated an annual probability of disruption of a 10-km^2 repository site at Yucca Mountain to be 10^{-8}/yr for a 25-km-radius circle centered at Yucca Mountain and 10^{-9}/yr for a 50-km-radius circle. These determinations were based on preliminary geochronology data, and no attempt was made to factor the structural controls of locations of basaltic volcanism into the calculations. Crowe et al. (1982) revised these calculations and more rigorously formulated the mathematical model for the probability of disruption of the Yucca Mountain site. The probability of volcanic disruption was formulated as a case of conditional probability:

$$\mathrm{Pr} = (\mathrm{E2\ given\ E1}) \ , \qquad (1)$$

where Pr is the probability of repository disruption, E1 is the rate of occurrence of volcanic events, and E2 is the probability of intersection of a repository by magma given E1. This probability is expressed as (Crowe et al., 1982)

$$\mathrm{Pr\ (no\ disruptive\ event\ before\ time\ t)} = e^{-ltp} \ , \qquad (2)$$

where l is the rate of volcanic activity and p is the probability that an event is disruptive. Crowe et al. (1982) developed a new procedure for calculating volcanic rates. They plotted magma volume (dense rock equivalent) versus time for the basaltic volcanic cycles of Crater Flat, the basalt of Buckboard Mesa, and the basalt of Sleeping Butte. These volcanic units show a linear decrease in magma volume with time. Regression analysis, in which magma volume is treated as the dependent variable, gives a coefficient of determination of 0.8 and a magma eruption rate of 210 m^3/yr. This magma eruption rate can be used to calculate a time for the next volcanic event by using representative magma volumes for eruption events and subtracting the time since the last eruption. Crowe et al. (1982) also used more refined geochronology data for the basaltic rocks of the Yucca Mountain region. They assembled a matrix of probability values using differing volcanic rates and disruption ratios, and the range of matrix values was used to provide probability bounds. The conditional probability of disruption of the Yucca Mountain site by future basaltic volcanism was calculated to be bounded by the range of 10^{-8} to 10^{-10}/yr (Crowe et al., 1982).

Several new developments have occurred since the 1982 publication of the disruption probability bounds. First, as summarized in Study 8.3.1.8.5.1, Characterization of Volcanic Features, the chronology of the youngest volcanic event, the Lathrop Wells volcanic center, has been revised. The youngest event at the center is inferred to be the formation of the main scoria cone. That event may be as young as 20,000 yr old or younger. Second, reexamination of the potassium/argon age determinations for the lava flows of the Lathrop Wells volcanic center has shown that these age determinations do not adequately document the age of these units. Further work is under way to determine the age of these lavas. Third, examination of the radiogenic argon contents of the potassium/argon age determinations for the basalt centers of Sleeping Butte show that they vary widely (0.0 to 6.8%). This variation may be indicative of the same types of problems we have experienced with dating the Lathrop Wells volcanic center and suggests that further analytical and interpretative work is necessary. Fourth, the possibility of polygenetic volcanism at all the volcanic centers needs to be evaluated. If the age span between units is sufficiently long, age differences could affect the probability calculations. Finally, the choice of volcanic units for magma eruption rate calculations is critical to constraining a proper volcanic rate. The time/volume data for the original calculations were extended to volcanic units as old as 3.7 million years because there are no identified basaltic volcanic centers in the Yucca Mountain region between 3.7 and 6.5 million years old. This gap provides a natural break in the geologic history, which is a logical limit for bounding the maximum age of the units used in probability calculations. Additionally, all of the 3.7-million-year-old or younger volcanic centers, with one exception, occur in the southwest part of the Yucca Mountain region, which is a reflection of a progressive southwest migration of sites of basaltic volcanic activity in the Yucca Mountain region through time (Crowe et al., 1983a). The one exception to this pattern is the basalt of Buckboard Mesa. The basalt of Buckboard Mesa occurs in the moat zone of the Timber Mountain Caldera, not in the southwest part of the Yucca Mountain region. For this reason, it may be logical to exclude the basalt of Buckboard Mesa from magma volume calculations.

This task will re-evaluate the assumptions and data used for the probability calculations. Based on these re-evaluations, the probability of volcanic disruption of the Yucca Mountain site will be refined for site characterization studies.

2.4.2 Types of Measurements to Be Made

No measurements will be made for this activity. All information for the revised probability calculations will come from other activities.

2.4.3 Constraints for the Probability Calculations and Assessment

There is a continuing controversy over the use of probabilistic studies in geosciences (Crowe, 1986). Questions have been raised as to whether geologic processes are truly random and suitable for probabilistic analysis. Geologic studies on a global scale have shown that volcanism is commonly nonrandom in both space and time. The calculations may be insensitive to short-term variations (nonrandom) in rates of volcanism, and these variations could be on the time scale of the period required for isolating radioactive waste. The accuracy of the probability calculations is limited by the small number of data points for rate calculations, the accuracy of geochronology techniques, and the potential variability in the disruption ratio from currently unknown controls of tectonic features on localization of sites of volcanism. Because of these data uncertainties, the probability bounds are presented as a range that spans three orders of magnitude, and the data assumptions are biased toward the worst case to provide conservative estimates (Crowe et al., 1982).

3.0 DESCRIPTION OF TESTS AND ANALYSES

3.1 Activity 8.3.1.8.1.1.1, Location and Timing of Volcanic Events

3.1.1 Technical Approach to Activities

The technical approach used for this activity is to compile geologic maps that synthesize information gathered from Activity 8.3.1.8.5.1.2, Geochronology Studies, and Activity 8.3.1.8.5.1.3, Field Geologic Studies.

3.1.2 Test Methods

The geologic maps from this activity will be digitized by computer, and the areas of volcanic units will be calculated. This information will be combined with unit thicknesses obtained from Activity 8.3.1.8.5.1.3, Field Geologic Studies, to calculate magma volumes. These magma volumes will be assembled by eruptive units and will be converted to dense rock equivalents. A detailed technical procedure (DP), Procedure for Calculating Density-Corrected Magma Volumes for Volcanic Units (a nonstandard procedure) is to be prepared. All work performed for this activity that is not governed by a DP will be conducted in accordance with Procedure for Documenting Scientific Investigations, TWS-QAS-QP-03.5.

3.1.3 Required Accuracy and Precision

The accuracy and precision of magma volume determinations are not normally evaluated for geologic studies. The required accuracy of the determinations is controlled by the use of the data in the probability calculations. Volume data are used with geochronology data to derive magma eruption rates. We will attempt to establish the sensitivity of the calculated values of magma eruption rates to the time/volume data points. Previous calculations (Crowe et al., 1988) show that the magma rates can vary by 50 to 75% without drastically changing the probability bounds; therefore, an accuracy of 20 to 30% should be adequate for determinations of magma volume. Two major limitations affect these calculations. First, the scoria fall deposits associated with Quaternary volcanic centers have been removed by erosion. Second, some of the volcanic deposits of the Quaternary centers are eroded and buried by alluvial deposits. Both factors tend to result in minimum calculated values for magma volumes. We will use conservatism in our calculations to bias the volume calculations toward maximum volumes. Additionally, the following techniques are available to provide improved accuracy for volume determinations.

- The volume of scoria fall sheets can be approximated by studying the scoria fall/scoria cone ratios of well-characterized historic eruptions (Crowe et al., 1983b).

- The distribution of volcanic units covered by alluvial deposits can be estimated using high-quality aeromagnetic data (Crowe et al., 1986).

- The degree of erosional modification of volcanic landforms can be studied to estimate volumes of missing volcanic deposits.

- Systematic variations in thickness-versus-source relations can be established for some volcanic deposits (for example, exponential fits of thickness versus distance from source). These relations may be used to evaluate volume determinations.

We will attempt to evaluate the precision and accuracy of volume estimates for these basalts by having the area and thickness calculated independently by at least three workers who are involved in the mapping of the deposits.

3.1.4 Equipment Needed

The equipment needed for this activity includes

- Leitz optical stereographic viewer for compiling geologic information from aerial photographs to topographic base maps and
- digitizing tablet and graphical software.

All equipment is currently available. It may be necessary to refine the software for the digitizing procedures.

3.1.5 Data Reduction and Analysis

Digitized data from the geologic maps will be analyzed to determine the distribution areas of volcanic units on the geologic maps. The unit thicknesses will be obtained from Activity 8.3.1.8.5.1.3, Field Geologic Studies. We will evaluate and document a variety of techniques for extrapolating between points of measured unit thickness.

3.1.6 Representativeness of the Tests and Limitations and Uncertainties

Field geologic mapping is the accepted technique for evaluating the volume of volcanic deposits. The suitability of these measurements will be limited by the quality of the geologic maps of volcanic units from Activity 8.3.1.8.5.1.3, Field Geologic Studies, and by the degree of preservation of the volcanic deposits. In general, the younger the deposits the better the degree of preservation and the better the estimation of magma volumes.

3.2 Activity 8.3.1.8.1.1.2, Evaluation of the Structural Controls of Basaltic Volcanic Activity

3.2.1 Technical Approach to Activities

Two approaches may be used to evaluate the structural controls of basaltic volcanic activity. First, the structural and tectonic framework of the area will be examined to determine the association between the structural features of the Yucca Mountain region and the geographic location of centers of basaltic rocks. If an association is established, this association will be assessed with respect to predicting the location and structural setting of potential future volcanic activity. Second, further work will be completed to determine whether it is possible to more rigorously factor the structural controls of volcanism into the probability formulation.

3.2.2 Test Methods

The examination of potential associations between structural features and sites of volcanic activity will be based on information provided by other activities. We will examine the geologic structures and their tectonic associations in the Yucca Mountain area, which have been identified from geophysical studies, from studies of Quaternary faulting, from seismicity studies, from studies of the stress regimes at Yucca Mountain, and from studies of the importance of detachment faulting in the region. A major thrust of the work will be to integrate tectonic models of the Yucca Mountain area with the time/space patterns of the distribution of basaltic volcanism.

The geographic dispersion of the location of Quaternary volcanic centers will be evaluated to determine the probability of a new volcanic event penetrating the repository. Cluster analysis will be used to examine, in n-dimensional space, the relationships between geophysics, geology and topography, and the location of volcanic centers.

These analyses will be performed in accordance with the following DPs, which are to be prepared:

- Procedure for Cluster Analysis of Volcanic and Geophysical Data for Determining the Structural Controls of Volcanism (nonstandard procedure) and
- Procedure for Evaluating the Geographic Dispersion of Surface Sites of Basaltic Volcanic Activity (nonstandard procedure).

All work performed for this activity that is not governed by a DP will be performed in accordance with Procedure for Documenting Scientific Investigations, TWS-QAS-QP-03.5.

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3.2.3 Required Accuracy and Precision

The primary concern in applying multivariate statistical techniques such as cluster analysis to geological problems is that the data results be meaningful geologically; that is, results from the cluster analysis routines and conclusions developed from these results should be examined for consistency with the best available understanding of the geologic and tectonic setting of the site. Cluster analysis routines will be computed using a variety of agglomerative clustering routines, and differing criteria for combining clusters will be examined. The results of each of these different routines will be examined for consistency with the geologic data base for the site.

3.2.4 Equipment Needed

The cluster analysis routines will be computed on a Motorola 68030 microprocessor-based SUN work station. This equipment is currently available.

3.2.5 Data Reduction and Analysis

Geophysical data will be obtained as binary files on digital equipment using VAX-compatible magnetic tape from the U. S. Geological Survey (USGS). Topographic and geologic information will be obtained by digitizing published geologic maps and topographic quadrangles of the USGS. Cluster analysis routines will be used from commercially available statistical programs [SPSS (1985) and SYSTAT (1985)]. Some customization of cluster analysis codes may be needed to adapt them to the unique requirements of the geologic and geophysical data set.

3.2.6 Representativeness of the Tests and Limitations and Uncertainties

The determination of correlations between volcanic sites and geologic data will be based on standard techniques for evaluating geologic data. The application of cluster analysis results to probability calculations is an untested approach. The work may or may not lead to statistically valid methods for modifying the disruption parameter and for factoring the structural controls of volcanism into probability formulations.

3.3 Activity 8.3.1.8.1.1.3, Presence of Magma Bodies in the Vicinity of the Site

3.3.1 Technical Approach to Activities

The two approaches to this activity are designed to investigate the possible presence of magma bodies in the crust beneath Yucca Mountain. These approaches include (1) evaluation of geophysical data obtained from other activities for evidence of magma in the crust and (2) measurement of the isotopic abundance of the noble gases in ground water collected from and surrounding the Yucca Mountain site.

3.3.2 Test Methods

The isotopic composition of helium, neon, and argon will be determined for the ground waters sampled in flowing wells in exploratory drillholes in the Yucca Mountain region. The sampling procedures will be adapted from those used by Torgersen and Clarke (1987). Sample vessels will be inserted in aquifer zones beneath and surrounding Yucca Mountain. The vessels will be flushed with ground water before being sealed to ensure that no residual air bubbles remain. The collection temperature of noble gases will be well below the boiling point. No sampling problems are expected with exsolution of a gas phase while the sample is brought to the surface. Analysis for helium, neon, and argon will be performed using a static noble gas mass spectrometer.

Two procedures are to be prepared for this activity:

- Procedure for Sampling Ground Water of the Yucca Mountain Region for Determination of Noble Gas Isotopic Rating (standard procedure) and

- Procedure for Isotopic Analysis of the Noble Gases in Ground Water by Gas Source Spectrometry (nonstandard procedure).

All work performed for this activity that is not governed by a DP will be performed in accordance with Procedure for Documenting Scientific Investigations, TWS-QAS-QP-03.5.

3.3.3 Required Accuracy and Precision

The isotopic ratios of helium, neon, and argon should have an analytical error of about 1%. The atmospheric composition of noble gases will be used as a standard to establish the accuracy of the isotopic measurements.

3.3.4 Equipment Needed

The analytical equipment for the isotopic analysis of the noble gases is available at Los Alamos National Laboratory (LANL). This equipment includes

- static noble gas mass spectrometer, model MinnMass, Serial #5, with associated gas-handling equipment;

- cryogenically cooled charcoal finger;

- inlet system for purification and degassing of water samples; and
- miscellaneous gas-handling systems for preparing gas pipettes for introduction of the collected and standard gas samples.

3.3.5 Data Reduction and Analysis

The isotopic ratios of helium, argon, and neon will be examined to identify the source of noble gases in the ground water of the Yucca Mountain region. Multiple sources of the noble gases are expected and include degassing of the mantle, degassing of young intrusives, production from crustal components, and the atmosphere. The atmospheric component can be produced by sample contamination or by the introduction of air into ground water by a variety of processes. The former component will be minimized by careful sampling, which may include use of a unique downhole fluid/gas sampler developed at LANL. The air component from natural processes can be identified by application of two-component, bivariate plots of ^{40}Ar versus ^{4}He normalized to ^{36}Ar (Kennedy et al., 1985). Kurtz and Jenkins (1981) and Kurtz et al. (1983) have observed that the isotopic composition of the helium produced in the mantle is distinctly different from that of the radiogenic helium produced in the crust. Torgersen and Clarke (1987) have identified unique $^{3}He/^{4}He$ ratios for the ground waters of the Great Artesian Basin of Australia that correspond to in situ production of helium and the crustal degassing helium flux. Torgersen et al. (1987) also identified enriched $^{3}He/^{4}He$ ratios in the Australian ground waters, which, they suggested, are uniquely associated with degassing of young and previously undetected intrusives.

Our intention for these studies is to focus investigations on the source of high $^{3}He/^{4}He$ ratios in ground water in the Yucca Mountain region over the range $0.7 < R/Ra < 5.0$, where R is the measured ratio of $^{3}He/^{4}He$, and Ra is the atmospheric ratio of $^{3}He/^{4}He$. We will attempt to determine whether the elevated $^{3}He/^{4}He$ ratios are associated with regional tectonic features that allow large-scale vertical transport of mantle gases or with the possible presence of undetected basaltic intrusives.

3.3.6 Representativeness of the Tests and Limitations and Uncertainties

The primary source of uncertainty in noble gas studies is whether anomalies in isotopic ratios can be uniquely associated with the differing sources of the gases. The Yucca Mountain region is located in a complex tectonic province with a past history of extensional faulting, right- and left-slip faulting associated with the Walker Lane structural system, and Pliocene and Quaternary volcanism. Considerable effort will be needed to discriminate between tectonic and volcanic processes through studies of the isotopic systematics of the noble gases.

3.4 Activity 8.3.1.8.1.1.4, Probability Calculations and Assessment

3.4.1 Technical Approach to Activities

This activity will consist of revising the calculations of the probability of volcanic disruption of a repository site at Yucca Mountain using new information obtained from other activities. The major sources of information will be the activities of Study 8.3.1.8.5.1, Characterization of Volcanic Features, as well as activities from this study.

3.4.2 Test Methods

The important parameters that will be refined to revise the data for calculating the probability of volcanic disruption include (1) the chronology of volcanic activity in the Yucca Mountain region, including the age of volcanic centers and the ages of separate volcanic events at individual volcanic centers, (2) the volume of volcanic centers and the volume of separate volcanic events at individual volcanic centers, (3) the location of volcanic events, and (4) the time/space association of volcanic and tectonic features in the Yucca Mountain area.

The eruption rate of basaltic volcanism (the recurrence rate of volcanic events) is a critical parameter for the Yucca Mountain region. This parameter was determined through an evaluation of three approaches (Crowe et al., 1982).

- Evaluation of time trends of volcanic activity. Previously obtained data indicate no distinct patterns or periodicity in Quaternary basaltic activity; therefore, these data were considered insufficient to analyze for interval patterns (Crowe et al., 1982, p. 178). We will re-examine these data for significant patterns in time distribution of volcanic events. New information for this re-evaluation will include the revised chronology of Quaternary volcanic activity and possible episodes of polygenetic eruptions at individual centers.

- Counts of Quaternary volcanic events through time. We will re-evaluate the results of counts of Quaternary volcanic events using the revised chronology of Quaternary volcanic activity and the possibility of previously unrecognized episodes of volcanic activity at individual centers.

- Evaluations of variations in erupted magma volumes through time. We will re-examine the data used to establish a highly correlated regression fit model that yielded the integrated magma eruption rate for the Yucca Mountain area during the last 3.7 million years. This relationship will be re-evaluated using several new approaches. First, the revised chronology of eruptive events as determined from Activity 8.3.1.8.5.1.2, Geochronology Studies, will be examined to test the previously calculated magma eruption rate. Second, if some or all of the Quaternary volcanic centers in the Yucca Mountain area are polygenetic, the chronology of individual polygenetic events will be examined to test previously calculated magma eruption rates. Third, if exploratory drilling confirms the inferred presence of buried basalt centers or volcanic intrusions, data from the volcanism drillholes will be incorporated in the calculation for magma volume versus time. Fourth, we will evaluate the application of the concept of volcanic rate bounds (Crowe et al., 1988) for calculating the magma eruption rates in the Yucca Mountain area. Data from well-studied Hawaiian volcanic fields provide evidence that the long-term behavior of volcanic centers can be quantified through careful studies of the relationship between magma eruption volumes and time. Shaw (1987) has shown that eruption rates at Kilauea and Mauna Loa volcanoes vary between 0.01 and 0.1 km^3/yr. Brief episodes of eruptive activity, including the recent eruptions of the Pu'u O'o vent on the east rift of Kilauea volcano, approach but never exceed the magma production rate, which suggests that a bounding magma eruption rate is established for the long-term behavior of the Hawaiian volcanic fields. This bounding eruption rate provides the basis for predicting long-scale eruptive activity. Shaw (1987) further notes that there is a self-similarity in the relationship between eruption rates in time that applies to the behavior of individual vents, to volcanic centers, to island growth, and to the long-term development of the Hawaiian/Emperor volcanic chain.

These Hawaiian eruption data suggest a possible new method for forecasting the volume/time eruptive behavior of volcanic centers. This method may also have the potential for use in forecasting the behavior of volcanic fields. If sufficient data on the volume and chronology of volcanic events for a volcanic field can be obtained, it may be possible to establish the long-term bound that defines the magma eruption rate. This rate bound could be used to predict the volume/time characteristics of future eruptions. The establishment of rate-bound behavior for a volcanic field can be tested through detailed studies of the youngest volcanic events using the concept of self-similarity.

This study will determine whether a volume/time relationship can be used to numerically bound the magma eruption rate of the basaltic volcanic rocks in the Yucca Mountain region. We will perform several tasks to make this determination.

- The volume/time relationships of the Lathrop Wells volcanic center will be evaluated to derive a volume/time slope (rate bound).
- To test for consistency, this rate bound will be compared with volume/time data from all Quaternary volcanic centers in the Yucca Mountain region.
- Data will be added from the 3.7-million-year-old volcanic event and from the results of exploratory drilling to determine whether these volcanic events are consistent with established rate bounds.
- We will use information from the Cima and Lunar Crater volcanic fields from Study 8.3.1.8.5.1, Characterization of Volcanic Features, to test whether these fields show a rate-bound, volume/time behavior. These fields have over 100 Quaternary volcanic centers and will provide a much more comprehensive data base than currently exists to test the application of the rate-bound concept for the volcanic fields of the southern Great Basin.

Once a magma eruption rate has been established, it can be used to calculate the time to the next volcanic eruption using the equation

$$Tp = (Vm/Em) - Te, \tag{3}$$

where Tp is the predicted time of the next eruption, Vm is a representative eruption volume for a volcanic event, Em is the magma production rate (calculated from the magma eruption rate), and Te is the time since the last eruption. The two most sensitive parameters are Te and Vm. Te will be established from the geochronology studies of the Lathrop Wells volcanic center and is estimated to be about 20,000 yr. Vm has been approximated from the calculated magma volumes of Quaternary basalt centers in the Yucca Mountain region (Crowe et al., 1982 and 1983b). The smallest volume of an individual basalt center in the Yucca Mountain region is about 6×10^6 m^3. The smallest volume of an eruptive event from a single vent was produced by the smaller of the two Little Cones scoria cones—a volume of about 6×10^5 m^3. Assuming a magma production rate of 210 m^3/yr and a time of the last eruption of 20,000 yr, the magma production time for the smallest volcanic center is about 29,000 yr and about 2,900 yr for the volcanic event having the smallest volume. Because Vm is such a sensitive parameter for the probability calculations, we will calculate magma volumes for each of the approximately 200 Quaternary centers of the Cima and Lunar Crater volcanic fields. This number of centers will provide sufficient samples to base the selection of Vm on population statistics for Quaternary volcanic centers.

A nonstandard procedure, Procedure for the Determination of Magma Eruption Rates Based on Analyses of Magma Volume Versus Time, is to be prepared. All work performed for this activity that is not governed by a DP will be performed in accordance with Procedure for Documenting Scientific Investigations, TWS-QAS-QP-03.5.

3.4.3 Required Accuracy and Precision

No measurements will be made for this activity. Information from Study 8.3.1.8.5.1, Characterization of Volcanic Features, will be used for the chronology and volume of volcanic eruptions. The accuracy and precision of those measurements are discussed in that study plan.

3.4.4 Equipment Needed

The equipment needed for this activity includes AST/386 and AST/286 microcomputers with numeric coprocessors, which will be used to store, reduce, and manipulate the parameters and values of the probability calculations.

3.4.5 Data Reduction and Analysis

Data reduction will involve calculation of a probability matrix using the techniques described by Crowe et al. (1982) and Crowe (1986). We will assemble probability values into a matrix, using a range of rate and area ratio determinations based on the differing assumptions used to calculate the parameters. The probability bound will be established for the largest and smallest value in the probability matrix. This matrix will be assembled on a computer spreadsheet using the commercial program, QUATTRO, Version 1.0 (Borland International, 1987).

3.4.6 Representativeness of the Tests and Limitations and Uncertainties

As discussed in Section 2.4.3, the use of probability calculations to define the hazards of future volcanism is controversial. However, several aspects of the history of basaltic volcanism in the Yucca Mountain region provide support for a probabilistic approach. First, there has been either consistency or decline in the rates of basaltic volcanism for the past 8.5 million years. Second, all basalt centers formed during the past 8.5 million years are small-volume Strombolian centers. Third, the petrology of the erupted basalts is broadly similar throughout this period, which suggests similar conditions of magma genesis. This consistency in rates, eruptive behavior, and petrology for an extended period of geologic time (8.5 million years) provides the basis for forecasting rates of future volcanism for the required 10,000-yr containment period of a repository for high-level radioactive waste.

The major uncertainties in probability calculations are determining the volcanic rate and factoring the structural controls of volcanism into the probability formulation. In both cases, we are conducting revised studies to directly determine and reduce the uncertainty of these parameters.

4.0 APPLICATION OF RESULTS

Activity 8.3.1.8.1.1.1, Location and Timing of Volcanic Events, involves collating all the information for Activity 8.3.1.8.1.1.4, Probability Calculations and Assessment. Activity 8.3.1.8.1.1.2, Evaluation of the Structural Controls of Basaltic Volcanic Activity, will interrelate strongly with the tectonics studies (Investigation 8.3.1.8.5, Preclosure Tectonics Data Collection and Analysis, and Investigation 8.3.1.17.4, Studies to Provide the Information Required by the Analysis and Assessment Investigations of the Tectonics Program) and will use information from a number of activities conducted under those studies. The more significant activities that will provide information for Activity 8.3.1.8.1.1.2 include Activity 8.3.1.17.4.3.1, Conduct and Evaluate Deep Geophysical Surveys in an East-West Transect Crossing Furnace Creek Fault Zone, Yucca Mountain, and Walker Lane; Activity 8.3.1.17.4.3.2, Evaluate Quaternary Faults Within 100 km of Yucca Mountain; Activity 8.3.1.17.4.3.5, Evaluate Structural Domains and Characterize the Yucca Mountain Region with Respect to Regional Patterns of Faults and Fractures; Study 8.3.1.17.4.4, Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones; Activity 8.3.1.17.4.5.3, Evaluate the Potential Relationship of Megabreccia Within and South of Crater Flat to Detachment Faulting; Activity 8.3.1.17.4.5.5, Evaluate the Age of Detachment Faults Using Radiometric Ages; Activity 8.3.1.17.4.7.3, Detailed Aeromagnetic Survey of the Site Area; Activity 8.3.1.17.4.8.3, Evaluate Published and Unpublished Data on Paleostress Orientation at and Proximal to the Site and Assess the Relevance of These Data to Quaternary Tectonics; Activity 8.3.1.17.4.12.1, Evaluate Tectonic Processes and Tectonic Stability at the Site; and Activity 8.3.1.17.4.12.2, Evaluate Tectonic Models.

The Presence of Magma Bodies in the Vicinity of the Site, Activity 8.3.1.8.1.1.2, will require information from and provide information to Activity 8.3.1.8.5.2.1, Evaluation of Depth of Curie Temperature Isotherms; Activity 8.3.1.8.5.2.3, Heat Flow at Yucca Mountain and Evaluation of Regional Ambient Heat Flow and Local Heat Flow Anomalies; and Activity 8.3.1.17.4.3.1, Conduct and Evaluate Deep Geophysical Surveys in an East-West Transect Crossing the Furnace Creek Fault Zone, Yucca Mountain, and Walker Lane. The probability calculations and assessment will provide information for Activity 8.3.1.17.4.12.3, Evaluate Tectonic Disruption Sequences; Performance Assessment Activity 1.1.2.1 (SCP Section 8.3.5.13.2.1), Preliminary Identification of Potentially Significant Release Scenario Classes; and Performance Assessment Activity 1.1.2.2 (SCP Section 8.3.5.13.2.2), Final Selection of Significant Release Scenario Classes to Be Used in Licensing Assessments.

5.0 MILESTONES AND SCHEDULE

The milestones for this study are listed in Table 1. A diagram of the schedule is shown in Figure 1.

TABLE 1

MILESTONES FOR PROBABILITY OF A VOLCANIC ERUPTION PENETRATING THE REPOSITORY

Milestone	Description
Location and Timing of Volcanic Events	
New	Compilation of geologic maps for Quaternary volcanic centers of the Yucca Mountain region.
Evaluations of the Structural Controls of Basaltic Volcanic Activity	
New	Evaluation of geophysical data for the structural controls of the location of basaltic volcanic centers.
New	Report on empirical evaluation of the structural controls of future sites of basaltic volcanic activity.
New	Assessment of the feasibility of cluster analysis evaluation for revising the disruption parameter of probability calculations.
Presence of Magma Bodies in the Vicinity of the Site	
New	Compilation and evaluation of geophysical and geologic information on the possible presence of magma bodies beneath the Yucca Mountain site.
New	Development of the methodology and assessment of the measurement of the isotopic composition of the noble gases for detection of buried intrusions.
New	Report on the evaluation of buried intrusions beneath Yucca Mountain based on measurement of noble gas isotopic signatures in ground water.
Probability Calculations and Assessment	
New	Time/volume and eruptive center population parameters for the Cima volcanic field.
New	Time/volume and eruptive center populations parameters for the Lunar Crater volcanic field.
R478	Revised probability calculations.

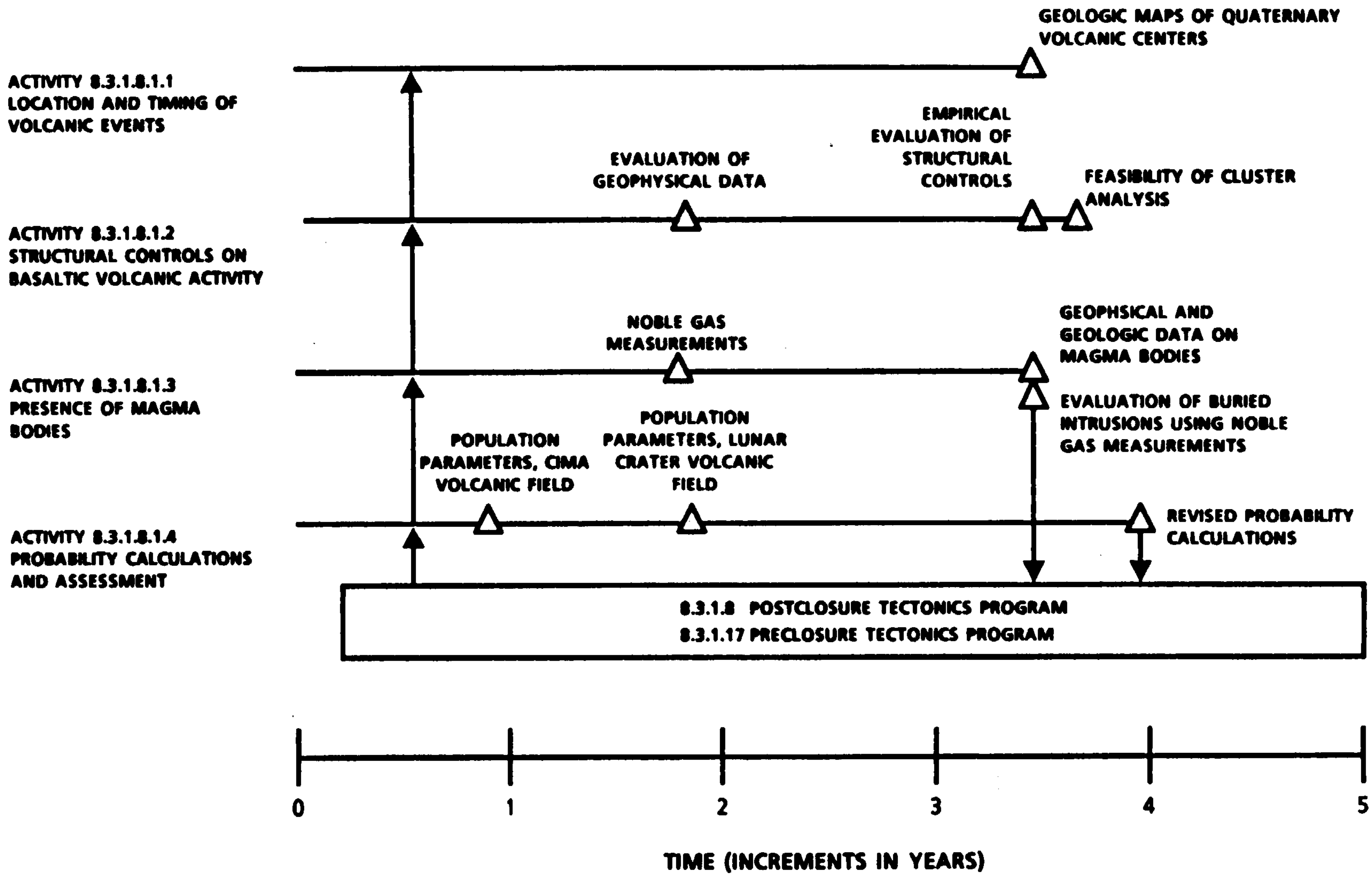

Figure 1. Milestones and Schedule for Probability of a Volcanic Eruption Penetrating the Repository

6.0 REFERENCES

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APPENDIX A

QUALITY ASSURANCE SUPPORT DOCUMENTATION

DRAFT

TABLE A-1

APPLICABLE NQA-1 CRITERIA FOR STUDY 8.3.1.8.1.1
AND HOW THEY WILL BE SATISFIED
(continued)

NQA-1 Criterion	Documents Addressing These Requirements		Anticipated Date of Issue
	TWS-QAS-QP-03.10	Software Documentation and Review	4/30/89
	TWS-QAS-QP-03.11	Software Configuration Management	4/30/89
	TWS-QAS-QP-03.12	Scientific and Engineering Software	4/30/89
	TWS-QAS-QP-03.13	Auxiliary, Commercial and Utility Software	4/30/89
4. Procurement Document Control	TWS-QAS-QP-04.1	Procurement	12/14/88
	TWS-QAS-QP-04.2	Acceptance of Procured Services	1/31/89
	TWS-QAS-QP-04.3	Qualification of Suppliers	1/31/89
5. Instructions, Procedures, and Drawings	TWS-QAS-QP-05.1	Preparation of QPs	12/14/88
	TWS-QAS-QP-05.2	Preparation of DPs	12/14/88
6. Document Control	TWS-QAS-QP-06.1	Controlled Document Distribution	1/31/89
7. Control of Purchased Material, Equipment, and Services	Applicable parts of this criterion are covered in Item 4 (see above).		
8. Identification and Control of Materials, Parts and Samples	TWS-QAS-QP-08.1	Control of Samples	4/30/89
	TWS-QAS-QP-08.2	Control of Data	4/30/89
9. Control of Special Processes	This criterion has been determined to be inapplicable to the scope of work of the LANL YMP.		
10. Inspection	This criterion has been determined to be inapplicable to the scope of work of the LANL YMP.		
11. Test Control	This criterion has been determined to be inapplicable to the scope of work of the LANL YMP.		
12. Control of Measuring and Test Equipment	The control of instrument calibration and data collection is described in the technical procedures referenced in Section 3 of this plan. The following QPs also apply:		

TABLE A-1

APPLICABLE NQA-1 CRITERIA FOR STUDY 8.3.1.8.1.1
AND HOW THEY WILL BE SATISFIED
(concluded)

NQA-1 Criterion	Documents Addressing These Requirements		Anticipated Date of Issue
	TWS-QAS-QP-12.1	Measuring and Test Equipment	4/30/89
	TWS-QAS-QP-12.2	Control of User Calibrated Equipment	4/30/89
13. Handling, Storage and Shipping	TWS-QAS-QP-13.1	Handling, Shipping, and Storage	4/30/89
14. Inspection, Test and Operating Status	This criterion has been determined to be inapplicable to the scope of work of the LANL YMP.		
15. Nonconforming Materials, Parts or Components	TWS-QAS-QP-15.1	Nonconformances	12/14/88
16. Corrective Action	TWS-QAS-QP-16.1	Corrective Action Control	1/31/89
	TWS-QAS-QP-16.2	Trending	4/30/89
17. Quality Assurance Records	TWS-QAS-QP-17.1	Resident File	12/14/88
	TWS-QAS-QP-17.2	Records Processing Center	12/14/88
18. Audits	TWS-QAS-QP-18.1	Audits	1/31/89
	TWS-QAS-QP-18.2	Surveys	4/30/89
	TWS-QAS-QP-18.3	Auditor/Lead Auditor Cerification	1/31/89

QUALITY LEVEL ASSIGNMENT CRITERIA SHEET (QLACS)

SIP No. 2.3.2-TV

Rev. 0

Activity Tectonics and Volcanism

Task: Volcanism

PI: B. Crowe

QA Criterion	Applies	Does not Apply	Comments
1. QA Organization	x		
2. QA Program	x		
3. Design and Scientific Investigation Control	x		Only scientific investigation requirements apply
4. Procurement Document Control	x		
5. Instructions, Procedures, and Drawings	x		
6. Document Control	x		
7. Control of Purchased Material, Equipment, and Services	x		
8. ID and Control of Materials, Parts, Components & Samples	x		

QA Criterion	Applies	Does not Apply	Comments
9. Control of Processes		x	Activities performed under this WBS are not considered to be special processes as per definition in Appendix A SOP-02-01
10. Inspection	x		Applicable for surveillance requirements only
11. Test and Experiment/ Research Control	x		
12. Control of Measuring and Test Equipment	x		
13. Handling, Shipping, and Storage	x		
14. Inspection, Test, and Operating Status		x	No hardware generated in this task
15. Control of Nonconformances	x		
16. Corrective Action	x		
17. QA Records	x		
18 QA Audits	x		