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JUL 27 1995

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U.S. DEPARTMENT OF ENERGY (DOE) RESPONSES TO U.S. NUCLEAR REGULATORY COMMISSION (NRC) STAFF COMMENTS ON STUDY PLAN 8.3.1.8.5.1 (CHARACTERIZATION OF VOLCANIC FEATURES) (SCPB: 8.3.1.8.5.1)

References: (1) Ltr, Holonich to Shelor, dtd 5/21/94
(2) Ltr, Brocoum to Holonich, dtd 6/28/95
(3) Ltr, Holonich to Shelor, dtd 3/12/93

The DOE received the NRC staff's seven comments and nine questions on Study Plan 8.3.1.8.5.1 (Characterization of Volcanic Features) (Reference 1). The DOE recently stated its intention to pursue resolution of open items related to Study Plan 8.3.1.8.5.1 (Reference 2). This letter transmits the DOE's responses to the NRC's seven comments and nine questions (enclosure 1) related to this study plan.

The DOE has two general concerns about the nature of many of the comments and questions on Study Plan 8.3.1.8.5.1. First, parts of the Basis sections of several of the open items (e.g., Comments 1, 2, 3, 4, 5, and 6, and Questions 4, 6, and 7) address the subject matter in study plans other than Study Plan 8.3.1.8.5.1. For example, some comments and questions refer to the collection and interpretation of geophysical data. Most geophysical data used in the volcanism program will be synthesized in support of Activity 8.3.1.8.1.1.3 (Presence of Magma Bodies in the Vicinity of the Site). Data collection and synthesis are discussed in Section 3.3.1 of Study Plan 8.3.1.8.1.1 (Probability of Magmatic Disruption of the Repository). This section states that most geophysical data used to support volcanism studies will be generated in three other study plans: (1) Study Plan 8.3.1.15.2.2 (Characterization of

Ambient Thermal Conditions); (2) Study Plan 8.3.1.17.4.1 (Historical and Current Seismicity); and (3) Study Plan 8.3.1.4.2.1 (Characterization of Vertical and Lateral Distribution of Statigraphic Units within the Site Area) Revision 4.

The second concern arises from the observation that several of the comments and questions are based on contractor documents or the scientific literature rather than on specific information in Study Plan 8.3.1.8.5.1. Comments on these documents appear to be beyond the scope of study plan reviews as outlined in the NRC's Study Plan Review Plan (Reference 3). We ask that material neither discussed nor cited in the study plan not be included as part of the study plan review, as it will tend to complicate the resolution of NRC's comments and questions. This study plan explains our program to address the technical issues relevant to the study plan, and it is not intended to present the results of the planned program. For this reason, DOE believes that Comments 3 and 5 and Questions 3 and 6 should be resolved without further evaluation.

However, even though the DOE believes Comments 3 and 5 and Questions 3 and 6 are beyond the scope of the review of Study Plan 8.3.1.8.5.1, brief discussions of the issues raised in these four items have been provided (enclosure 1). The information demonstrates the uncertain relevance of these items and also provides sufficient technical basis to resolve these items. For the remaining open items, the DOE has provided detailed technical information which the DOE regards as sufficient to resolve the comments on Study Plan 8.3.1.8.5.1. The DOE accordingly requests that the NRC provide the DOE with written notification that all of the comments related to Study Plan 8.3.1.8.5.1 have been resolved.

If you have any questions, please contact either me at (702) 794-7971 or Thomas W. Bjerstedt at (702) 794-7590.

Robert W Barton

for Stephan J. Brocoum
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AMSL:TWB-3922

Enclosures:
1. Responses to NRC Comments and Questions on Study Plan 8.3.1.8.5.1
2. List of References Cited
3. Thermoluminescence Dating Analytical Procedure

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Enclosure 1

Responses to Comments

Comment 1: *The aeromagnetic data described in Section 2.11 may not be sufficient to detect and resolve magnetic anomalies associated with small intrusions which are of regulatory concern.*

Recommendation: *Consider conducting more detailed investigations, including ground geophysical surveys, in the area of volcanic centers near Yucca Mountain. In addition, this effort should also involve investigation in appropriate analog areas.*

Response:

The DOE agrees that there are some difficulties with the technical capability to detect and resolve small intrusive bodies. This is particularly the case when the contrast in magnetic properties between the intrusive and country rock is weak. However, the DOE notes that the Basis section addresses a draft contractor document (Crowe and others, 1993) that is not cited in the study plan. Also, the NRC seems to have erroneously ascribed the gathering and interpretation of geomagnetic data to this study plan rather than to Study Plan 8.3.1.8.1.1.

The DOE has had the geophysics program reviewed by Dr. George Thompson (1994, see Enclosure 2) who made the following recommendation:

> "Gravity and Magnetics: The data base is generally excellent, easily available in digital form in USGS files, and well along in interpretation, thanks especially to the recent work of Langenheim. The planned extension over Piute [sic] Ridge will add important constraints. Flexibility to obtain additional details in field measurements and additional physical property measurements is highly desirable."

As a result of Dr. Thompson's report, YMSCO has initiated studies at Paiute Ridge, Scarp Canyon and Nye Canyon. These areas contain well exposed systems of dikes, conduit plugs, and sills emplaced in mostly volcanic country rock. The DOE expects to use the combined information from physical property measurements of rocks and a drape (low-level) aeromagnetic survey of the area to evaluate our capability to detect the magnetic signal of small basaltic intrusions. Modeling of these data will allow the Project to determine the sizes and depths of features that can be detected by these detailed investigations. In addition, the results of ground magnetometer traverses, especially across the dike emplaced along the Solitario Canyon Fault, are being

modeled. These studies are expected to constrain the detection resolution of the technique. If the results are favorable, ground magnetic surveys may be used to detect buried intrusions. Finally, the recent seismic refraction/reflection lines across the site, including Crater Flat, were supplemented with ground-based magnetic readings every 10-20 feet along the seismic lines. These data will soon be available to the volcanism program. The DOE expects that this data will (1) provide information to refine the boundaries of the known buried intrusions in Crater Flat, and (2) help define the limits of detectability of small, buried, basaltic intrusions in material with large component of magnetic material.

In addition, Thompson's comments and suggestions have been incorporated in the description of Activity 8.3.1.8.1.1.3, Magma Bodies. His letter is cited as a reference, and his recommendations have been included in the study plan revision. This revision has completed technical review and is scheduled for transmittal to the NRC in October, 1995.

The DOE believes the above information to be sufficient to resolve Comment 1. We expect to address this technical issue in a future revision of the Mined Geologic Disposal System (MGDS) License Application Annotated Outline.

Comment 2: *The accuracy of thermoluminescence (TL) dates for the youngest soils at Lathrop Wells has not been determined in sufficient detail to resolve the volcanological concerns.*

Recommendation: *This study plan should present the methods that will be used for TL dating. If the referenced procedure is available, submission and subsequent review of this procedure may eliminate some NRC concerns.*

Response:

Thermoluminescence analyses completed prior to 1995 are documented under scientific notebook control (LANL-YMP-QP-03.5, Documenting Scientific Investigations). Copies of these records are stored in the LANL files in Las Vegas. Current thermoluminescence measurements are being done in collaboration with the USGS as described in Study Plan 8.3.1.5.1.4 (Paleoenvironmental History of the Yucca Mountain Region) and are controlled under USGS QA procedures. A copy of the analytical procedure used by the USGS for TL dating has been included for NRC's information (Enclosure 3).

As with Comment 1, the basis for this comment is, in part, derived from a review of Crowe and others (1993), but Crowe and others (1993) is not cited in the study plan. The DOE believes a study plan is not the proper forum to present "complete analytical data, including sampling techniques and glow curves...." Neither is a study plan the proper forum for the interpretation of those data nor for a demonstration of the validity of a particular analytical procedure. DOE is aware of the problems associated with TL dating and will apply appropriate caution to the interpretation of the results.

The DOE believes the submittal of the technical procedure for TL dating, and the above information are sufficient to resolve this comment.

Comment 3: *The basis for the assumption that the young tephra in the quarry south of the main Lathrop Wells cone is contemporaneous with the 20 ka Black Tank cone in the Cima field does not seem warranted.*

Recommendation: *Describe the methodology to determine the age and origin of Lathrop Wells chronostratigraphic unit 1.*

Discussion:

This comment is not based on material presented in the study plan. Rather, Comment 3 questions the results of the chronology studies presented in Crowe and others, 1993, and Wells and others, 1990. Neither of these studies is referenced in the study plan.

The DOE has not compared the "young tephra" (chronostratigraphic unit 4) with the Black Tank cone in the Cima volcanic field. The Basis section description confuses discussions of chronostratigraphic unit 4 with earlier discussions of the Lathrop Wells cone (Wells and others, 1990). In fact, an extremely critical and key inference for the stratigraphic position of the deposits of the youngest event is that the geochemistry of chronostratigraphic unit 4 is distinctly different from the deposits of chronostratigraphic unit 3 (the main cone).

The DOE believes that this item should be considered resolved for purposes of the study plan.

Comment 4: *It is unclear how the volume of eruptive basalts is being calculated.*

Recommendation: *Provide a more complete description of parameters used to calculate eruption volumes and the assumptions used to convert volumes to dense rock equivalents. Describe the method used for compensating for the dispersed ash associated with eruptions.*

Response:

The eruption volumes were calculated by taking areal distributions of map units, and assigning unit thickness using a combination of field measurements and thickness extrapolations from topographic data. The areal assignments incorporated drillhole and aeromagnetic data as well as extrapolations to reconstruct centers that have been modified by erosion. The density correction for dense rock equivalents (DRE) involves correcting the data to magmatic volumes assuming a melt density of 2.8 gm/cm^3 and taking a ratio to field volumes. Because of the unique nature of magma volume estimation the calculations of magma volume estimates have been documented in scientific notebooks. If the NRC wishes to examine documentation in scientific notebooks, the DOE will arrange access to the notebooks. (Note: The method the DOE has used to calculate eruptive volumes and the results of those calculations are described in the Volcanism Status Report (Crowe and others, 1995) beginning on page 7-44. The Volcanism Status Report was provided to the NRC for their information. The DOE does not wish to complicate the resolution of this study plan comment by introducing material that is neither discussed nor cited in the subject study plan.)

The main importance of the volume calculations is in estimating recurrence rates using the volume-predictable method. Because there has been an approximate exponential decline in magma volumes through time (factor of 30), the probabilistic volcanic hazard assessment (PVHA) is relatively insensitive to the magma volume estimates. These volume calculations were completed prior to the approval of a QA program, and the DOE intends to publish revised volume calculations when Activity 8.3.1.8.1.1.1 is funded (currently planned for FY 96).

The DOE notes that parts of the Basis section for this comment refer to documents which are not cited in Study Plan 8.3.1.8.5.1. The materials on which the NRC has commented are neither included, nor cited, in the description of Activity 8.3.1.8.5.1.5, Evolutionary Cycles of Basaltic Volcanic Fields, which is the pertinent section of the study plan. This activity specifies that "...volume...of continental basaltic volcanic fields in the southwestern United States...." is one of the

parameters to be evaluated as part of this activity. Calculation of volume of basalt is addressed in Study Plan 8.3.1.8.1.1, on pages 33 and 34.

In Revision 2 to Study Plan 8.3.1.8.1.1, the DOE stated its intention to develop technical procedures to calculate estimates of magma volumes. Based on the experience of calculating magma volumes and the fact that each calculation is unique, the DOE no longer intends to develop these procedures. This change in the DOE's approach will be described in Revision 3 to Study Plan 8.3.1.8.1.1 which the DOE intends to transmit to the NRC in October 1995.

The DOE believes the information provided above to be sufficient to resolve this comment.

Comment 5: *It is unclear how the model that assumes northwest trending structures provide deep-seated control on magma pathways will be tested.*

Recommendation: *Provide a methodology which will allow the various alternative tectonic models to be tested and evaluated.*

Discussion:

The structural control on basaltic volcanism is discussed in section 2.2 of Study Plan 8.3.1.8.1.1: Study Plan for Probability of Magmatic Disruption of the Repository, not in Study Plan 8.3.1.8.5.1, which is the study plan under consideration in this review. Revision 2 to Study Plan 8.3.1.8.1.1 discusses the DOE's approach to evaluating alternative tectonic models by specifying the following on page 11:

> No attempt will be made to develop a single model or a set of preferred volcanic and tectonic models for this activity. Rather, we will systematically evaluate the structural and tectonic data from the activities listed in Table 1 to attempt to develop a data catalog of permissive models of the structural controls of basaltic volcanic centers.

[Note: Table 1 is entitled Studies and Activities Providing Information for Activity 8.3.1.8.1.1.2: Evaluation of the Structural Controls of Volcanic Activity.]

Revision 3 to Study Plan 8.3.1.8.1.1, scheduled for release in October 1995, contains refinements of the method the DOE proposes to use to ensure that alternative tectonic models are tested and evaluated. More recently, the efforts the DOE has made to carry forward and evaluate multiple alternative tectonic models were described during presentations made on March 9, 1994 at the NWTRB Structural Geology and Geoengineering Panel Meeting, and on May 17, 1995 at Expert Judgment Workshop 3 for the DOE's Probabilistic Volcanic Hazards Assessment.

The DOE has made a judicious effort to ensure that its evaluation of the probability of magmatic disruption of the proposed repository considers viable alternative tectonic models. The DOE's inventory now includes at least thirteen distinct models, and Revision 3 to Study Plan 8.3.1.8.1.1 will provide an explanation of the method the DOE proposes to use to evaluate alternative tectonic models. The combination of documented past efforts to evaluate alternative models plus the explicit description of the method in the Revision 3 of Study Plan 8.3.1.8.1.1 provide ample basis to resolve this comment. If, after review of Revision 3, the item is still of concern, the NRC could visit the issue as a comment on Study Plan 8.3.1.8.1.1. In

the interim, the DOE believes that an adequate basis has been provided to resolve this comment in terms of Study Plan 8.3.1.8.5.1.

Comment 6: *There is no discussion in the study plan of the xenolith content of the Lathrop Wells cinder cone or other cinder comes in the region, or how xenolith abundances will be studied to better characterize volcanism and constrain consequence models.*

Recommendation: *Describe what studies of the abundance, size distribution, morphology, and composition of xenoliths in the Lathrop Wells ejecta will be performed in order to construct models of fragmentation and transport of subsurface material.*

Response:

The DOE considers that the discussion of "xenolith content" in specific volcanic centers: (1) is outside the scope of a study plan and (2) should be included in technical documents reporting the results of the planned work. Also, xenolith studies are not part of Study Plan 8.3.1.8.5.1. Studies to determine the amount of material that could be brought to the surface from repository depth in case of formation of a new volcanic center through the repository are described in Activity 8.3.1.8.1.2.1, Eruptive Effects. The NRC received Study Plan 8.3.1.8.1.2 for review in October 1993, prior to completion of the review of 8.3.1.8.5.1. The DOE is developing responses to the NRC comments on Study Plan 8.3.1.8.1.2 and intends to submit those responses to the NRC in July 1995. Additionally, the DOE is preparing Revision 1 to Study Plan 8.3.1.8.1.2 and intends to submit this revision to the NRC in October, 1995.

The DOE believes the information on xenolith studies described in the Eruptive Effects section of Study Plan 8.3.1.8.1.2 to be sufficient to resolve this comment as it pertains to Study Plan 8.3.1.8.5.1.

Comment 7: *It is unclear how the research discussed in this study plan will resolve alternative petrogenetic models.*

Recommendation: *The study plan should describe the methodology which will be used to differentiate between the various alternative petrogenetic models.*

Response:

The purpose of Activity 8.3.1.8.5.1.5, "Evolutionary Cycles of Basaltic Volcanic Fields" is to use major, trace-element, phenocryst, and isotopic compositions of post-Miocene volcanic rocks of the Yucca Mountain region to infer temporal patterns of mantle melting episodes (e.g., changes in the amount or depth of partial melting) to constrain whether magmatic processes are waxing or waning in the Yucca Mountain region. This information will provide a physical framework for volcanism probability calculations. Geochemical and physical models of magmatic processes developed under this activity will be assessed in light of alternative petrogenetic models published in the geologic literature during the last 10-20 years.

It is beyond the scope of the study plan to provide detailed information on specific methods designated for testing or resolving alternative petrogenetic models. The methods are specific to the data set. However, the suite of major and trace element, and isotopic studies proposed in the study plan is sufficient to allow identification and full consideration of alternative petrogenetic models. Possible sources of confusion in the study plan relevant to the development of this comment could be discussions which described petrologic studies of polycyclic models.

The DOE is unclear about the apparent emphasis on lithospheric to asthenospheric source transitions in relation to petrogenetic trends in the Yucca Mountain Region (e.g., "The Crater Flat system has not reached an asthenospheric stage of magmatism, and therefore, cannot be considered a waning magma system on the basis of regional petrogenetic trends.") The DOE is aware of no studies in the western U.S. that relate waning of volcanism specifically to a change to asthenospheric sources. Instead, the timing of the lithosphere/asthenosphere source transition appears to be controlled by the tectonic history of particular regions (i.e., the extent and timing of lithospheric thinning because of lithospheric extension). Given the unique tectono-magmatic history of the southern Great Basin, it is very possible that magmatism will never reach an asthenospheric stage, but magmatism will surely wane at some point. As petrogenetic studies progress, our conclusions regarding the evolution of the Crater Flat system will be guided primarily by data obtained from the Crater Flat system itself, but tempered by insights gained from consideration of appropriate analog systems.

The NRC continues to express concern over waning volcanic models. Presumably, the basis for the concern is the potential for underestimating the volcanic hazard because of inferences about the level of activity based on a waning model. While the current data indicate that the Crater Flat system is waning, the DOE has used a steady-state model in probability estimates. The "waning versus steady-state" explanation was made repeatedly to the NRC during the Technical Exchange on June 9, 1993. The DOE plans to continue to test alternative geochemical models to ensure that probability models do not underestimate risk. However, the DOE notes that because of the steady-state assumption, a demonstration that the system is waning may not be required to support the DOE's regulatory arguments. The steady-state assumption may provide sufficient conservatism to provide the basis for a demonstration that the potentially adverse condition has been adequately evaluated according to the criteria in 10 CFR 60.122.

The DOE believes the information provided above to be sufficient to resolve this comment.

Question 1: *What methods for the determination of all important rock magnetic properties have been considered?*

Recommendation: *Consider analyzing the samples in a rock magnetics laboratory so that the VRM component can be removed prior to estimation of polarity.*

Response:

The provision for determination of rock magnetic properties in Study Plan 8.3.1.8.5.1 is primarily for cross-checking the results of geochronology studies. The DOE does not intend to undertake detailed paleomagnetic studies except where the studies could prove critical to discrimination of alternative models. For example, detailed paleomagnetic studies have been undertaken for the Lathrop Wells center to attempt to discriminate monogenetic versus polygenetic eruption models (see Section 3.2.2.8 Paleomagnetic Studies [page 36] of Study Plan 8.3.1.8.5.1 for descriptions of paleomagnetic studies and procedures used to test or discriminate field volcanic units.)

The fluxgate magnetometer has been used routinely in field studies to establish polarity of basaltic volcanic rocks. Uncertainty in vertical remnant magnetism (VRM) is accounted for by making multiple polarity measurements and comparing the results with aeromagnetic surveys. Further discrimination of polarity data will be considered only if polarity results conflict with geochronology studies. The paleomagnetic studies are used primarily as a cross-checking tool that does not require ultra-precise measurements. Section 3.2.2.8, Paleomagnetic Studies (p. 36), describes planned remnant magnetism studies and procedures that will be used to test or discriminate field volcanic units. Results of these studies have been described in Champion (1991).

Magnetic modeling studies underway this fiscal year are aimed at determining the depth and width of detectable buried dikes. These studies include determination of rock magnetic properties in the laboratory of John Geissman at the University of New Mexico. The DOE recognizes the value in such studies, and they will be continued as appropriate.

The DOE believes this information to be sufficient to resolve this question.

Question 2: *How were the paleomagnetic directions sampled for the Crater Flat System?*

Recommendation: *The procedure used to determine paleomagnetic polarities (e.g., field flux-gate magnetometer) should be presented and discussed, along with the sampling procedure used (e.g., the number of samples per flow, the location of the sample, the number of sites per unit).*

Response:

Numerous magnetic polarity measurements were made of basalt centers in the Crater Flat area during the early 1980's. These data proved especially timely during the interval of studies when there were limited K-Ar age determinations for the Pliocene and Quaternary basalt of Crater Flat. The measurements predate the implementation of a fully qualified QA program, but nonetheless, the procedures followed and the results were recorded in field notebooks that are on file in Las Vegas.

The measurements were made with a portable fluxgate magnetometer. Generally multiple outcrops were inspected using a combination of the brunton compass and fluxgate magnetometer to identify areas of nondisturbed magnetic properties mostly to avoid effects of lightening strikes and replicate measurements were made at individual sites (5 to 10 polarity measurements per site) to obtain magnetic polarities. In some cases oriented samples were collected and returned to Los Alamos for verification under more controlled conditions. The polarity measurements were used to test, in a general way, the results of K-Ar age determinations, and field observations of the degree of erosional dissection of the volcanic landforms. Further geochronology work using a variety of geochronology methods has shown that the volcanic cycles are of distinctly different ages (3.7, 1.0 and 0.1 Ma) and thus the polarity data are not regarded as critical to verification of the geochronology results. Moreover, it is also clear that the polarity measurements cannot be used to discriminate volcanic centers within individual cycles of activity.

Thus we do not anticipate that the polarity measurements will be significant in any anticipated conclusions that may be presented during licensing activities, should the Yucca Mountain site be considered formally as a repository for disposal of high-level radioactive waste.

While it is true that magnetic polarity data may help distinguish whether rocks were emplaced during a period of normal or reversed magnetic polarity, it is not clear that such fine-scale time differentiation is important to the assessment of volcanic hazards. For example, the 1 Ma Crater Flat basalts were emplaced near the time of a polarity reversal. Therefore, the

presence of a change in polarity does not necessarily exclude buried anomalies from being temporally related. Given the magnitude of the inherent uncertainty in the probability of disruption of the repository because of the number of structural models and modeling techniques employed by both DOE and NRC contractors, the DOE regards the volcanic risk component due to fine-scale time differentiation for the Quaternary Crater Flat system as embedded within the larger uncertainty.

The information requested by the NRC in the Recommendation for this item may be found in contractor's technical procedures, scientific notebooks, and technical publications. All of these items are available for inspection by the NRC. If the NRC wishes to examine documentation in scientific notebooks, the DOE will arrange access to the notebooks. The DOE believes that the information in this response and the scientific notebooks is sufficient to resolve this question.

Question 3: *How are the intrusion geometries associated with the development of the Crater Flat alignment to be characterized?*

Recommendation: *Describe the field investigation program, including geophysics, which will be conducted to better describe the intrusion geometries in the area of Crater Flat. If anomalies can be identified from these geophysical investigations, directional drilling should be considered as a method of sampling these anomalies.*

Discussion:

The determination of intrusion geometries associated with the development of the Crater Flat alignment is outside the scope of Study Plan 8.3.1.8.5.1. Intrusion geometries will be investigated within the context of structural controls on basaltic volcanism, and this activity is included in the scope of Study Plan 8.3.1.8.1.1. Study Plan 8.3.1.8.1.1 establishes (page 21) the linkages for the acquisition of geophysical data to address the volcanism issue. While the question is outside the scope of Study Plan 8.3.1.8.5.1, the DOE is planning investigations in the geophysical program to resolve lingering issues associated with the volcanism program. The results of the geophysical investigation program were reviewed by Dr. George Thompson (1994), and Dr. Thompson's conclusions are being incorporated into the design of the remaining investigations as follows:

1. Electrical methods generally lack sufficient resolution and produce data that are difficult to interpret. Therefore, the DOE has no plans to employ electrical methods for characterization of volcanic features.

2. As described in the response to Comment 1, the DOE has initiated ground-based and drape (low-level) aeromagnetic surveys to evaluate their utilities for the investigation of buried igneous bodies. In addition, gravity and magnetic data were gathered along the recent seismic reflection/refraction lines, including lines that cross possible buried intrusive features in Crater Flat. The DOE will continue to use ground and low-level aeromagnetic surveys, and seismic surveys where these methods can be reasonably expected to help detect buried igneous bodies.

In addition, Thompson's letter is cited as a reference, and his recommendations have been included, in the Revision 3 of Study Plan 8.3.1.8.1.1. This revision has completed technical review and is scheduled for transmittal to the NRC in October, 1995. If these technical issues are of continued concern to the NRC, the DOE suggests the NRC refer to Study Plans 8.3.1.8.1.1, 8.3.1.15.2.2, 8.3.1.17.4.1, and 8.3.1.17.4.3 as appropriate sources for comment.

The DOE is maintaining directional drilling as an option for sampling subsurface anomalies should such anomalies be defined. However, the DOE is not in a position to make a commitment to directional drilling until both a sound technical basis and a unique need to implement such a program have been demonstrated.

The DOE considers that sufficient information on (1) the determination of intrusion geometries and (2) the roles of various geophysical investigations in these determinations have been provided in the appropriate study plans to resolve this question.

Question 4: *How will seismic tomographic data be integrated into volcanological site characterization as the project continues?*

Recommendation: *Specifically address how seismic tomographic data will be incorporated into site characterization of volcanic features.*

Response:

The use of geophysical data are discussed in section 3.3 of Study Plan 8.3.1.8.1.1, and we refer the NRC to that document in order to evaluate the adequacy of the DOE's geophysical program.

The DOE has upgraded the seismic network described in Study Plan 8.3.1.17.4.1. This upgraded instrumentation is expected to produce higher resolution, 3-component seismic data which could be used to support seismic tomographic studies. Additionally, the DOE is considering deployment of a local net of temporary seismic stations in Crater Flat. This net could be used to support tomographic studies. However, the DOE has made no determination that seismic tomographic studies are either necessary or appropriate at this time. Such studies represent options which the DOE may evaluate and could incorporate into the volcanism program if warranted.

The DOE believes the information above and in Study Plan 8.3.1.17.4.1 to be adequate to resolve this question.

Question 5: *If the theory of polycyclic volcanism is correct for the volcanoes in the region of Yucca Mountain, how will it be assured that the age determinations accurately represent the age of the various cones?*

Recommendation: *Present a sampling scheme that will be used to resolve the concerns with age determinations of potential polycyclic feature.*

Response:

Conventional geochronologic techniques have limits in accuracy and precision, especially for young mafic rocks that have low radiogenic yields. However, the DOE has carefully documented both the procedures used and the results of its age determinations. This documentation will allow trained geochronologists to independently assess the significance of the data and the accuracy of the age determinations.

In Study Plan 8.3.1.8.5.1, the DOE specified that a variety "of calibrated-age methods will be used to test the consistency of age determinations" (p. 30). Generally speaking, consistency of quantitative age determinations with qualitative geologic evidence would be considered as evidence that the age determinations are reasonably accurate. The DOE notes that 10 CFR Part 60 does not contain a requirement for absolute assurance. The standard is "reasonable assurance." The DOE considers (1) the combination of consistency of the age determinations with other qualitative geologic evidence and (2) the capability for trained geochronologists to review the data, procedures, and results, and independently evaluate to ensure that the results are sufficiently accurate.

The number of samples collected from each volcanic center and the specific geochronologic techniques employed to determine the age of samples will vary at each eruptive center. Sampling strategy is guided partially by results of other characterization techniques (e.g., geologic mapping, stratigraphic and field studies, geomorphic studies, geochemistry studies). For older volcanic centers with no evidence of a polycyclic history, 2 or 3 reproducible age determinations by the $^{40}Ar/^{39}Ar$ method are sufficient to establish the age of volcanism. Younger centers, or centers with evidence of polycyclic activity, may require a larger number of samples, comparison and interpretation of results from different eruptive units at individual volcanic centers, and use of multiple geochronologic techniques to test for consistency of results. The exact number of samples required and the geochronologic techniques used at a specific center is an iterative process based on ongoing field studies, and the results and reproducibility of completed analyses. Procedures for collecting geochronology samples are documented in LANL-EES-13-DP-606, "Volcanism Field Studies."

The DOE is re-sampling all of the post-Miocene volcanic localities in the Yucca Mountain region, and is employing the $^{40}Ar/^{39}Ar$ technique. In FY 94, samples were obtained at Little Cones, Red Cone, Makani Cone, the Pliocene centers of Crater Flat, and Buckboard Mesa. The DOE intends to complete $^{40}Ar/^{39}Ar$ dating of basalt samples for all post-Miocene volcanic centers by the end of FY 95. $^{40}Ar/^{39}Ar$ dating of sanidine from fused tuff xenoliths will be completed at the Lathrop Wells volcanic center, and the interpretation of the chronology of the Lathrop Wells center will be finalized. Paleomagnetic, geomorphic, and soils analysis will be completed at selected volcanic centers, as required, to resolve important age relationships.

Where possible, the DOE intends to constrain ages of partially to completely reset sanidine crystals in tuff xenoliths. Because of the high-K content of sanidine, this work has already provided useful results for the maximum age of chronostratigraphic units at Lathrop Wells as well as precise ages for Little Cones (Heizler and others, 1994). The NRC should be aware that recent age determinations and future geochronologic work are being done with the best possible techniques and under a fully approved and implemented QA program. Thus, the NRC can expect data from this resampling program to supersede previously collected data.

The $^{40}Ar/^{39}Ar$ technique involves multiple age determinations (usually 10-20) for each sample (5-15 total samples for each volcanic center) in addition to a sampling strategy to measure age differences in possible time-stratigraphic units at each volcanic center. Thus, a firm basis is established whereby absolute age and uncertainty can be adequately addressed. Information on the $^{40}Ar/^{39}Ar$ technique is presented in section 3.2 of Study Plan 8.3.1.8.5.1 (p. 31).

The DOE believes the information in Section 3.2 of the study plan and in this response to be sufficient to resolve this question.

Question 6: *How will geodetic data be incorporated into volcanological site characterization?*

Recommendation: *Describe how measurements of contemporary strain will be factored in development of volcanological models.*

This question is based on a scientific report (Crowe and others, 1993) which is not referenced in Study Plan 8.3.1.8.5.1. Furthermore, Study Plan 8.3.1.8.1.1, not 8.3.1.8.5.1, provides for the incorporation of geophysical data into volcanism site characterization investigations. The measure of contemporary strain will be estimated from strainmeters installed in boreholes (Study Plan 8.3.1.2.3.1) and from geodetic leveling measurements (Study Plan 8.3.1.17.4.10). Results from these studies will be available to the volcanism program.

Although Crowe and others (1993) stated that strain rates are decreasing, this does not imply that there is no present day strain, or that there is no relationship between strain and magmatism. Assuming a cause and effect relationship between the strain and magmatism, the consequences are captured in an examination of the Quaternary geologic record of volcanism in the Yucca Mountain region. The NRC suggests that magmatism may be preferentially located in Crater Flat because of a hypothetical localization of strain. If this were the case, the volcanic hazard to the site would be reduced because future volcanism would be predicted in Crater Flat rather than at the proposed repository site in the range interior of Yucca Mountain. Such a prediction would increase the conservatism of LANL contractor repository disruption estimates which do not take credit for localization of volcanism into structural basins. Even if the NRC does not accept this conclusion, the pertinent technical issue is not strain localization or rate, but rather how to treat apparent clustering of volcanic events, a phenomenon which is readily recognized in the geologic record. The DOE notes that the information necessary to respond to this question is available in the indicated study plans.

The DOE believes that the information provided in this response and in Study Plan 8.3.1.8.1.1 to be adequate to resolve the question.

Question 7: *How will data on degassing and hydrothermal alteration be gathered for incorporation into probability and consequence models?*

Recommendation: *Provide information on the methodology for mapping the zones of alteration around Lathrop Wells and other cinder cones in the Yucca Mountain Region to better understand and constrain the effects of degassing.*

Response:

The DOE does not dispute any of the observations made by the NRC in the Basis section of this question, except to note that the comparison of arc volcanic systems (Cerro Negro, Tolbachik, and Paracutin) to the Yucca Mountain region, DOE believes, is spurious. The topic of degassing and hydrothermal alteration is discussed in Study Plan 8.3.1.8.1.2, not in Study Plan 8.3.1.8.5.1. This topic was also described extensively in the papers by Valentine and others (1992; 1993). The DOE considers that the information in Study Plan 8.3.1.8.1.2 is sufficient to resolve this question. [Note: Revision 1 to Study Plan 8.3.1.8.1.2 is scheduled for transmittal to the NRC by the end of October 1995.]

If, after review of Study Plan 8.3.1.8.1.2, the item is still of concern, the NRC could visit the issue as a comment on Study Plan 8.3.1.8.1.2. In the interim, the DOE believes that the basis to resolve this question in terms of Study Plan 8.3.1.8.5.1 has been provided.

Question 8: *How will the volumetric relationships from the different volcanic systems in western North America be used to develop specific time-dependent volume predictable models for the Crater Flat system?*

Recommendation: *Provide more information regarding the basis for selection of volcanic fields thought to be analogous to those near the Yucca Mountain repository.*

Response:

The establishment of volumetric relationships from different volcanic systems in western North America requires establishing criteria upon which selection of suitable analogs for the Crater Flat volcanoes can be based. In the Basis section for this question, the NRC has noted a potential problem with the acceptance of the Springerville field as an analog for the Crater Flat field. The DOE is concerned about the NRC's willingness to exclude the Springerville field as an analog while apparently accepting (in Question 7) that some arc volcanic systems (Cerro Negro, Tolbachik, and Paracutin) which feature large eruption volumes, shallow magma chambers, possible higher volatile contents, and entirely dissimilar tectonic settings, are analogs to Yucca Mountain.

The basis for selection of analog volcanic fields is provided in Study Plan 8.3.1.8.5.1. Section 3.5 (p. 49) of the study plan indicates that small volume volcanic fields (Death valley, Pancake Range, Lunar Craters) in the region will be examined. In fact preference will be given to small-volume fields in the selection process. Section 3.5 also lists six specific criteria for selecting volcanic fields for study (p. 49):

1. The volcanic fields will be of predominantly basaltic composition.
2. The volcanic fields will be in the Basin and Range geologic province or marginal areas.
3. Preference will be given to volcanic fields of closest proximity to the Yucca Mountain region. The oldest volcanic activity will be less than 10 Ma.
4. Emphasis will be placed on selecting volcanic fields that are the most analogous to the Crater Flat volcanic field (small volume, alkali basalt).
5. Emphasis will be placed on choosing volcanic fields that exhibit evidence of being extinct (no eruptive activity for a significant period of time). This will allow us to evaluate patterns of volcanic activity associated with a waning volcanic field.
6. Preference will be given to volcanic fields that have available geologic data (age control, chemical analysis, geologic mapping) to reduce the study time required for this activity.

Information relevant to the use of volume data to develop time-dependent volume-predictable models is found on page 50 of Study Plan 8.3.1.8.5.1.

> Using the geologic data base for the fields, we will develop a range of models for the evolutionary patterns of volcanic fields. Emphasis will be placed on models that can be tied to mechanisms associated with the initiation and development of episodes of magma generation in the mantle. Predictions from each model will be compared with the geologic data set for the Crater Flat volcanic field to determine how the model could constrain predictions of future volcanic activity.

The intent of this information is to describe the use of a variety of data (expected to include temporal and spatial characteristics, volume and geochemistry) to test for patterns in the evolution of basaltic volcanic fields. If such patterns are present, they may provide insights on future basaltic volcanism in the Yucca Mountain region.

The DOE believes that the information provided above to be sufficient to resolve this question.

Question 9: *How will phenocryst mineralogy be characterized in sparsely phyric rocks?*

Recommendation: *Describe how the phenocryst assemblage will be characterized.*

Response:

The methods and procedures that the DOE uses to describe the petrographic characteristics of samples are generally described on page 46 of Study Plan 8.3.1.8.5.1, Revision 0. Phenocryst mineralogy will be studied using standard petrographic techniques employing petrographic microscopy and electron microprobe with both wavelength dispersive and energy dispersive spectrometers, and with scanning electron microscope and back-scatter imaging capabilities. However, given the considerations outlined below, the DOE believes that the level of detail suggested by the NRC in the Basis for the question for phenocryst investigations is not warranted.

Many variables control the stability and composition of plagioclase, including pressure, temperature, magmatic water concentration, oxygen fugacity, and melt composition. Hence, plagioclase stability and its presence or absence in lavas are of limited value in the evaluation of volcanic hazards. Nelson and Montana (1992) showed that plagioclase in rapidly ascending magma may be quickly resorbed. Conversely, microphenocrysts of plagioclase may grow under reduced pressures during ascent if heat loss is significant. Thus, the presence or absence of plagioclase by itself cannot be considered diagnostic of depth of melting or differentiation. The DOE does not consider it likely that the origin of the depth of Yucca Mountain magmas will be adequately resolved by phenocryst studies.

The DOE assumes that the discussion of amphibole and biotite in the Basis section, is related to determining magmatic water content. Given probability estimates from Study Plan 8.3.1.8.1.1, Study Plan 8.3.1.8.1.2 will determine the range of effects that may reasonably be expected from an intrusion near, below, into, or through the repository. To assure that the study captures the range of effects that could reasonably occur, and at the same time avoid underestimating those effects, certain assumptions will be made. These assumptions include the distribution of magmatic water contents with a component of that distribution well above that required to stabilize amphibole in basalt. Thus, even if no amphibole had ever been encountered in basalts in the Yucca Mountain region, the implied water contents and subsequent impacts of that water would be considered anyway.

The DOE has identified the techniques it intends to use to determine phenocryst mineralogy in sparsely phyric rocks and has explained why the level of detail suggested by the NRC in the

Basis for the question is unnecessary. The DOE believes this information to be sufficient to resolve this question.

Enclosure 2

List of References Cited in the Responses

Champion, D.E., 1991. "Volcanic Episodes Near Yucca Mountain as Determined by Paleomagnetic studies at Lathrop Wells, Crater Flat, and Sleeping Butte, Nevada," *Proceedings High Level Radioactive Waste Management Conference, Las Vegas, Nevada, p.* 61-67.

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Nelson, S.T., and A. Montana, 1992. "Sieve-textured plagioclase in volcanic rocks produced by rapid decompression," American Mineralogist, v. 77, p. 1242-1249.

Thompson, G., 1994. Letter to J. Nesbit, "Geophysics relevant to basaltic magmatism at Yucca Mountain," in Los Alamos National Laboratory, Yucca Mountain Site Characterization Project August/September 1994 Monthly Activity Report, LAES 13-12-94-008, p. 322-328, as attachment to memo from B. Crowe to J. Canepa, "Level 4 Milestone Letter Report (Milestone Number 3245)(SCPB:8.3.1.8.1.1), dated October 4, 1994.

Valentine, G.A., B.M. Crowe, and F.V. Perry, 1992. "Physical processes and effects of magmatism in the Yucca Mountain region," *Proceedings High Level Radioactive Waste Management Conference, Las Vegas, Nevada,* vol. 3, p. 2344-2355.

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ENCLOSURE 2

Wells, S.G., L.D. McFadden, C.E. Renault, and B.M. Crowe, 1990. "Geomorphic Assessment of Late Quaternary Volcanism in the Yucca Mountain Area, Southern Nevada: Implications for the Proposed High-Level Radioactive Waste Repository," Geology, vol. 18, p. 549-553.

Enclosure 3

Contractor's Thermoluminescence (TL) Dating Procedure