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February 21, 1991

John W. Bartlett, Director
Office of Civilian Radioactive
Waste Management
U. S. Department of Energy
Washington, DC 20545

Dear Dr. Bartlett:

The State of Nevada has reviewed the DOE Study Plan "Characterization of Volcanic Features" (Study Plan 8.3.1.8.5.1) and its cited references and is providing its comments in this letter and attachment. The State's comments address the adequacy, completeness, and technical accuracy of the Study Plan to meet the purposes of site characterization.

The State's primary concerns regarding the subject Study Plan are summarized as follows:

1. The overall approach as outlined in the Study Plan seems to be directed towards developing a probablistic analysis focused on supporting a preconceived model for volcanic hazards, rather than collecting data necessary for a deterministic evaluation of risk as required by 10 CFR 60.122.

2. The Study Plan assumes that <u>all</u> of the centers of volcanic activity are known and well defined, therefore the DOE proposes to collect only a limited amount of new information. The reference base cited does not support the assumption of complete identification and knowledge of volcanic centers, nor does it represent a complete information base for southern Nevada volcanism.

3. Considerable emphasis is placed on rock-varnish dating of geomorphic surfaces (Appendix A) as a supporting method for establishing the chronology of volcanism in the region. However, the Study Plan fails to acknowledge the current

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debate in the scientific literature on the reliability of rock-varnish dating.

4. The scientific investigation interfaces between site characterization and environmental protection required by the DOE Systems Engineering Management Plan have not been documented in this Study Plan. This concern has been identified to the Department in State comments on other study plans, but has yet to be addressed in a substantive manner.

Study Plan 8.3.1.8.5.1 outlines a very ambitious long term effort for data collection as the first part of a general research program. The proposed study (research) plan appears to be directed primarily towards determining the gross spatial distribution of late Cenozoic volcanics throughout the southern Basin and Range region with the intent of using the serendipitous results in a Bayesian probability analysis. It is not obvious how this approach will effectively reduce the technical uncertainties that exist in the data now available.

Should you have questions, this Office is available to meet with the Department to discuss the State's comments at any time.

Sincerely,

Robert R. Loux
Executive Director

RRL:cs
Attachment

cc: Carl Gertz, YMPO
Joe Youngblood, NRC
Dade Moeller, NRC-ACNW
Don Deere, NWTRB
Dwayne Weigel, GAO
Steve Kraft, EEI

ATTACHMENT

State of Nevada detailed comments on DOE Study Plan 8.3.1.8.5.1 "Characterization of Volcanic Features".

1. Approach and Relationship to Other Study Plans

The overall approach as outlined in the Study Plan seems to be directed almost totally towards developing a probablistic analysis focused on supporting a preconceived model for volcanic hazards developed by DOE contractor(s) in the 1979 to 1984 time frame. There are indications, based on new data and analysis conducted by others since 1984, that there are several viable alternative models for volcanic processes in the Yucca Mountain area which would place a much different perspective on the conclusions that might be reached as to total risk. These alternative models will have to be given serious consideration prior to any decision on licensing due to potential implications on site suitability for the post closure period. A prudent plan would consider these alternative volcanic models at the earliest stages of any site characterization program in order to minimize the costs in dollars and time when such models could lead to adverse repository performance conclusions.

The Study Plan is difficult to objectively evaluate without the availability of the other study plans that are expected to provide significant input (e.g. "Postclosure Tectonics Data Collection", [8.3.1.8.5]; "Postclosure Tectonic Data Collection", [8.3.1.17.4]; "Geologic Framework" [8.3.1.4.2]; and "Regional Hydrologic System" [8.3.1.2.1]). Even more troublesome is the lack of availability of the study plans that will receive input (i.e. "Probability of Magmatic Disruption of the Repository" [8.3.1.8.1.1]; and "Effects of Magmatic Disruption of the Repository" [8.3.1.8.1.2]). In addition, some written plan beyond the generic statements presented in the SCP on how the DOE will subsequently combine the results of these studies and produce Investigation 8.3.1.8.1 ("Volcanic Activity") is essential. Although the schematic of Investigation 8.3.1.8.1 ("Volcanic Activity") (see Figure 8.3.1.8-3, SCP page 8.3.1.8-50) appears to show some graphical logic it is not intuitively obvious how the results of the various studies and activities including the studies outlined in this Study Plan will be effectively amalgamated. The SCP text which accompanies Figure 8.3.1.8-3 is helpful in a generic sense, however it fails to specifically discuss how volcanic risk will be established deterministically as required by 10 CFR 60.122; what the full spectrum of impacts (consequences) might be from renewed volcanism; the level of risk that DOE considers acceptable; and how the volcanic risk will be coupled to other geologic

processes in establishing overall site suitability. This Study Plan appears to provide little information to help answer those questions.

2. Achievement of Study Plan Objective(s)

The proposed study consists of five semi-independent activities (volcanism drill holes; geochronology studies, field geologic studies, geochemistry of eruptive sequences, and evolution of basaltic volcanic fields) that will be initiated simultaneously and conducted in parallel over a three-six year time frame. The overall objective of the study as stated on page 7, 1st paragraph "is to provide the required field, geochronology, and geochemistry data needed to decipher the history of Cenozoic volcanic activity in the Yucca Mountain area." In that regard the proposed studies have the potential for adding useful new information. However, the study appears to be guided more by the sole purpose of developing input to a regional probablistic risk model and thus will probably add little in the way of significant site area deterministic data that can be used to satisfy NRC regulatory requirements. Because most of the proposed activity will be conducted outside of the immediate Yucca Mountain area, the studies appear to fall far short of providing what would be required to make a significant additional contribution to the data base that already exists for deciphering the volcanic activity that could impact the proposed repository site.

According to the schedule outlined in Figure 3 (page 58), all activities will be completed six years after detailed site investigations commence. Based upon past experience with large investigations in complex geologic environments using techniques with questionable reliability and reproducability, complete resolution of all problems outlined in the Study Plan is unlikely in this time period. The following factors may contribute to delays in timely completion of this project:

1. New techniques for dating young volcanic rocks must be developed, calibrated and applied. Such new techniques will also require acceptance by the scientific community if they contribute to the licensing of the repository.

2. Recent disagreements among DOE contractors and with others in the scientific community as to the relative reliability of geomorphic and geochronologic techniques may slow forward progress.

3. Recent disagreements among DOE contractors and with others in the scientific community as to the polycyclic nature of scoria cones may also slow forward progress.

The State realizes that disagreements between investigators are a healthy sign of active scientific research. However, these disagreements can slow or stop research progress.

4. To characterize the evolutionary patterns of volcanic fields in southern Nevada, a considerable amount of field work and sampling is required in areas distant from Yucca Mountain. The acceptance and use of existing data instead of gathering new data can contribute to minimizing this factor.

5. Insufficient scientific resources may slow the completion of activities. It is unclear from the work plan the resources required to accomplish each of the activities.

3. Reasonableness of the Study

It appears that a basic DOE assumption is that the past volcanic hazard assessment described in the SCP (sections 1.3.2.1.2 and 1.5.1) and the publications Crowe and Carr, 1980; Vaniman and Crowe, 1981; Crowe et. al, 1983a: Crowe et. al., 1983b; Crowe, 1986; Crowe et. al., 1986; Crowe et. al. 1989; Crowe and Perry, 1990 forms an acceptable basis for the proposed Study Plan. The Study Plan assumes that all of the centers of volcanic activity are known and well defined. Therefore, the DOE proposes to limit the amount of new information that will be collected on the two dimensional distribution of volcanic rocks and that new information will be sufficient to reliably predict the future four dimensional (spatial-temporal) behavior of the volcanic processes. To our knowledge, the past studies have not been evaluated within the context of the implicit requirements of 10 CFR 60.122 nor has there been any objective scientific consensus developed regarding all of the reasonable volcanic models that need to be considered. Pending such an evaluation and development of some kind of scientific consensus, at least as to what all the viable volcanic models are, it is suggested that the subject Study Plan as written might be premature.

It is not obvious why a North-Northeast (NNE) trend of the volcanic centers Black Cone, Red Cone, Little Cone, subparallel to the Death Valley Pancake Range (DVPR) zone isn't being considered as credible. The arbitrary North-Northwest (NNW) trending Crater Flats Volcanic Zone (CFVZ) that has been drawn between Crater Flats and Sleeping Butte without scientific basis or justification. Given that a NNE trending zone, if it exists, has serious implications on the overall suitability of the Yucca Mountain site, it would seem to be a prudent course of action that the physical presence or absence of such a trend, as implicitly required by NRC

regulations, be established at the earliest possible time. If any evidence for such a trend is found, the Study Plan for volcanic characterization would need substantial revision. If no evidence for such a trend can be found, providing a diligent effort was expended in looking for it, substantial parts of the proposed study would probably be unnecessary.

The proposal as outlined on page 10 to qualify existing data as QA Level I on a case-by-case basis as the program proceeds is unacceptable. If all work to be conducted under the proposed Study Plan ("except where noted") is considered important enough to be conducted under QA Level I requirements, then the data upon which the future results will be built should be qualified before any of the new studies are initiated.

It is stated at the bottom of page 9 and top of page 10 that a two-phased approach will be used in evaluating the volcanic hazards for the Yucca Mountain site without any supporting statement regarding the level of volcanic risk that DOE considers acceptable. If risk is the combined evaluation of the probability and consequences, it is not obvious how any acceptable risk levels can be developed until the design has progressed to the point that there is some reasonable concept of what the consequences might be.

On page 11, volcanism is identified as a potentially adverse condition at the site based on NRC regulation 10 CFR 60.111 (pre-closure). This position seems to be in conflict with the DOE goal, stated on page 7, 1st sentence, that the primary concern is the risk from volcanic activity in the post-closure period (no NRC regulation is cited by DOE).

On page 11, paragraph 1.2, 3rd sentence, reference is made to NRC regulation 10 CFR 60.111, ("Performance of the geologic repository operations area through permanent closure."), as the basis for volcanism being identified as a potentially adverse condition. Reference to 10 CFR 60.111 may be an incorrect citation. Although any sign of volcanic activity in the Yucca Mountain area during the preclosure phase would most certainly create a lot of adverse publicity, such volcanic activity in and of itself is unlikely to create much of an immediate technical problem in recovering any waste that may have been prematurely implaced. 10 CFR 60.122 (c)(3) and (15) provide the regulatory basis for volcanism as a potentially adverse condition.

There is no specific regulatory requirement (or guidance) that calls for a probability study to be prepared. In fact, to the contrary, the NRC regulations require a deterministic basis be established first. NRC regulation 10 CFR 60.122 (a)(2)(i) states that the DOE <u>must</u> demonstrate that the potentially

adverse natural condition has been adequately investigated including the extent to which the condition may be present and still be undetected. The proposed study will provide little new information beyond what is already available that can be used to satisfy this requirement.

Since the EPA standards for radioactive releases (40 CFR 191) have been remanded for revision, the consequences of volcanic activity cannot be reliably established let alone quantified given that there is no repository design. In addition, regardless of the repository design, there is likely to be added concern for the suitability and long term integrity of repository seals. One way that the kinds of data necessary to provide a realistic estimate of the consequences could be obtained is through a detailed deterministic program focused on the immediate site and the surrounding accessible environment area coupled with appropriate field analog studies in nearby tunnels on the NTS and other locations in southern Nevada. Study Plan 8.3.1.8.5.1 doesn't even hint that such an option has been or will be considered.

If the DOE proceeds with this study as expected, the technical procedures that are being proposed for use appear to be state-of-the-art or better. The technical procedures that are proposed for use coupled with adherence to the Quality Assurance program outlined should produce some resultant useable data that is beyond reproach. Regardless of how much data is obtained however, there are a number of obvious issues that are still likely to be unresolved. These are such issues as whether significant results of any kind can be obtained from the proposed site characterization in time to be effectively used in the license application; whether the results that are obtained will have any significant influence on the present DOE perception of the volcanic hazard that exists; and certainly one of the most important, which is what are the real consequences of any renewed volcanic activity. In order to reasonably determine the consequences, the volcanic source term specific to a repository at Yucca Mountain must be clearly and unambiguously defined. Study Plan 8.3.1.8.5.1 does not appear to offer an appropriate plan to resolve these issues.

4. <u>Sequence of Activities</u>

As in any good scientific study, an investigator must develop a set of working hypotheses to be tested before or during the initial stages of a research project. This is especially important when defining a zone of young volcanism and recognizing migration trends of volcanism. The authors of this Study Plan appear to have chosen a single model (Figure 2 on page 9) and are not considering others. It is too early in the study to focus on a single model.

It is important that detailed geologic mapping be completed before sampling for geochemistry, paleomagnetic and age dating activities is done. Mapping provides the geologic framework required to scientifically select sample locations, and to understand the data produced by these activities.

5. Specific Comments on Study Plan Activities

ACTIVITY 8.3.1.8.5.1 Volcanism Drill Holes

This activity will certainly provide useful data for the buried volcanic centers, but one drill hole per anomaly is not sufficient to characterize the volume or shape of the buried center.

The activity will provide information regarding the presently known anomalies. But, it will provide no information on the possible existence of a magma body beneath Crater Flat (as suggested by recent seismic tomography studies).

Conventional K-Ar dating techniques are not necessarily the most appropriate to apply to date basalts. Plagioclase concentrate K-Ar dates or $^{40}AR/^{39}Ar$ dates would be preferable. Two samples for K-Ar dating per drill hole may not be sufficient, especially if multiple flows are encountered.

ACTIVITY 8.3.1.8.5.1.2 Geochronologic Studies

The activity will certainly provide new age dates for volcanic rocks in the vicinity of Yucca Mountain, but may not resolve age discrepancies for individual volcanic centers involving different dating tools. Recently the use of geomorphic parameters to estimate the age of a scoria cone has been questioned by Duane Champion and Brent Turrin of the Geological Survey. The work proposed in the context of this activity must address any discrepancies in the age of a volcanic cone as determined by both geochronologic and geomorphic studies. It is unclear whether the proposed geochronologic techniques will provide the required high precision dates for the young volcanic centers in the time allotted for this activity.

The activity requires the application of several untested and/or controversial age dating tools. It is unclear whether these techniques can be refined, calibrated and applied in the time available. If the technique is used in licensing, it must be shown that the technique has acceptance by the scientific community. It may be more effective to apply more traditional age dating techniques (such as $^{40}Ar/^{39}Ar$ and plagioclase concentrate K-Ar) before trying new tools.

It would be helpful to have a table indicating the volcanic centers that will be dated as part of this activity.

ACTIVITY 8.3.1.8.5.1.3 Field Geologic Studies

First priority in the technical rationale for geologic studies must be geologic mapping, not the collection of samples for geochronology (page 18). It is crucial to establish a geologic framework for a volcanic center BEFORE collecting samples!

It is not clear which volcanic centers will be mapped in detail. For example on Figure 3 (Milestone schedule for characterization of volcanic features) and in the Schedule, the Buckboard Mesa center is scheduled to be mapped in year 5. This task is not mentioned in either the purpose or descriptive sections of the Study Plan. It would be helpful to have a table listing the volcanic centers to be mapped.

Detailed field studies should be extended to include detailed studies of all volcanic features formed in the Yucca Mountain region in the last 6 Ma. These studies are important inputs to understanding the nature and rates of tectonic processes operating within the geologic setting during the Quaternary Period, as required by 10 CFR 60.122 (b)(1).

ACTIVITY 8.3.1.8.5.1.4 Geochemistry of Eruptive Sequences

In terms of understanding the magmatic evolution of each center, well tested techniques will be applied and the proposed objective can be achieved. It should be remembered, however, that many petrogenetic models are not unique, so possibly the best that can be done by modelling is the elimination of unreasonable hypotheses. A unique single model of volcanism at Yucca Mountain may never be achieved.

In terms of chemically characterizing ash in trenches cut in alluvium and relating this ash to a specific volcanic center, it is doubtful that this objective can be achieved unless unaltered vitric ash can be collected.

The Study Plan assumes that eruptions from scoria cones are polycyclic (because of the presence in scoria cone stratigraphy of soil horizons interbedded with scoria), but recent paleomagnetic work by Duane Champion (USGS) suggests that activity from individual centers occurred quickly and that scoria cones are not polycyclic. These problems must be resolved before meaningful petrogenetic models can be produced.

It is unclear how many samples will be collected at each volcanic center. A sufficient number of samples must be

collected from each center to ensure that the data are statistically representative. Also, analysis of altered and/or reworked scoria and ash may result in incorrect interpretations.. A table listing those volcanic centers to be sampled and the number of samples to be collected would be helpful to evaluate the scope of this activity.

ACTIVITY 8.3.1.8.5.1.5 Evolutionary Cycles of Basaltic Volcanic Fields

It is important that analog volcanic fields studied be in the tectonic setting of the Basin and Range. The Springerville Field is located on the Colorado Plateau and therefore, is not a suitable analog to a volcanic field in the vicinity of Yucca Mountain. On the other hand, excellent choices would be the Lunar Crater-Reveille field and the Fortification Hill volcanic field. The selection of the Springerville Field has not been justified in the Study Plan.

This activity needs a discussion of the volcanic fields to be studied to define the evolutionary cycles and the rationale for selection of those fields. The Study Plan suggests only published data will be used with no new data collection or analyses of the selected fields planned. It is questionable whether published data from two or three volcanic fields (including one in the Colorado Plateau) is sufficient to prove with reasonable assurance that chemical and eruptive trends are typical of waning volcanic activity.

6. Specific Comments on Appendix A-Rock-Varnish Dating

Cation-ratio dating using rock varnishes for the purpose of obtaining relative ages of geomorphic surfaces is a relatively exciting new field where techniques and methods are being developed which may prove to be valuable to interpretive research some time in the future. Because this dating approach is still in the developmental stage, controversy among researchers over techniques and methods is found throughout scientific literature. The Yucca Mountain site characterization program must provide analytical efforts that have reasonable confidence levels considerably above that which is currently available for rock varnish dating. It is questionable whether the general scientific community will accept the results of these proposed investigations given the current state of dating techniques and methodologies. Rock varnish appears to be a complex mixture of transition metal oxyhydroxides containing various organics (see Nagy, et. al., 1990, GSA Abstracts No. 09137) and detrital components. The genesis of the material is poorly understood; its behavior in the weathering environment is also poorly understood. To utilize this material and method to develop age data for studies deemed critical for the characterization of Yucca

Mountain appears to be inappropriate because of the uncertainties inherent in the methods and therefore the results.

In a recent publication on rock varnish dating, D. H. Krinsley, R. I. Dorn, and S. W. Anderson (1990) briefly discussed nine general factors that may interfere with rock-varnish dating of geomorphic surfaces. This publication provides a more complete list of pertinent references than offered by Appendix A.

Rock varnish dating is an analytical method which to date has not been refined. In theory, K and Ca trapped in rock varnish should be leached at a constant rate through time. These cations (K and Ca) are then compared to Ti whose mobility should be insignificant. The cation ratio K + Ca/Ti provides therefore an estimated age of surface stability for geomorphic features and surfaces within a particular region. Figure A-1 (Appendix A, page 10) indicates gross regional ratios with age for particular regions. Regionality effects on varnish dating (cation depletion) are presumably a factor of local K and Ca sourcing and regional climatic influences on weathering reactions including local biotic transfer activity. Variations of weathering (leaching) reactions within subregional areas such as Forty Mile Wash, Yucca Mountain, Crater Flat have not been characterized. Changes in climate regime through time, potentially affecting leaching rates over time are not addressed. Curves are presumed to be linear. Section 2.3, Appendix A, pages 6 to 7, provide the rationale behind using rock varnish dating and the laboratory techniques that will be applied. In essence, chemical composition of the varnish will be determined by SEM-EDX. Harrington, et. al., 1989, have indicated their awareness that Ba and Ti peaks overlap with EDX. Thus, the method of analysis does not produce or does not always produce: (K + Ca)/Ti results, but rather produces or sometimes produces: K + Ca/Ti - Ba. The behavior of Ba in leaching systems should be similar to Ca, therefore, there is no surety as to what is being measured and how this affects the theory behind the method. This problem is not addressed in Appendix A. Krinsley, et. al., (page 103, 1990), suggest that WDX analyses are considerably better for deconvoluting Ti and Ba. Yet, there is no mention of utilizing WDX analyses in Appendix A. Electron Microprobe Analyses will apparently be used for mineral composition analyses but apparently not for cation ratio determinations discussed above (Appendix A, section 3.4.7, page 19).

The following are specific page-by-page comments. We are providing these comments only because of the level of emphasis placed on rock-varnish studies in the Study Plan.

Pages 2 to 3.

1. It is doubtful that the stated purpose will be met if rock-varnish studies are not augmented by additional dating techniques that are supported by sound theory and are reproducible by standard practices.

2. The results will have little utility for the Yucca Mountain site characterization process as the technology to utilize cation-ratio dating is at best a poorly understood relative dating method. This method is not regarded by the scientific community as an absolute dating technique.

Pages 4 to 8.

1. The rock varnish dating curve constructed for the Yucca Mountain area requires significantly more data points using standard and acceptable dating tools than has been offered. Sections 2.1 and 2.2 only mention 14-C data collection of the basal layers of rock varnish for volcanism studies. It must be shown that for 14-C dating, rock varnish is a reasonable material. Amino acid work by Nagy, et. al., (1990) suggests that organics are quite mobile in rock varnish.

2. It is not clear why PIXE analyses are proposed in section 2.2 in light of the comments in section 2.3. The problem with Ba and Ti will still be significant.

3. XRD analyses of rock varnish minerals will probably only identify those of greater than 5% and will not assist in identifying glasses.

4. XRF analyses on SEM prepared samples should contain the substrate rock surface. It is unclear as to the purpose of this activity. XRF analyses will not affect elements lighter than 22. Choice of XRF standards for rock varnish may be difficult.

5. SEM analyses of rock-varnish by EDX will not resolve the Ti and Ba peak interference problems. WDX analyses should be used as an appropriate substitute.

6. It is difficult to see how rock varnish dating could be used in the Yucca Mountain site characterization process if the sampling activity to acquire rock varnish clasts is developmental. The high selectivity of samples appears to suggest that data may not be reproducible. As stated above, acceptance of the dating technique is questionable by the scientific community. Acceptance

will be necessary if the results are presented in licensing.

7. It is difficult to see how the rock-varnish dating curve could be established with adequate error bounds without the extensive use of other dating methods which are not discussed in section 2.

Pages 9 to 19.

1. "The processes of rock-varnish formation and accretion on rock surfaces are not yet clearly understood but likely involve both geochemical and biological agents." (page 9, section 3.1, paragraph 1). This statement is probably true. What is also true is cation-ratio dating of rock varnish is not yet clearly understood. On the basis of those statements, we do not understand why the method is being used to characterize a potential high-level nuclear waste repository.

2. Rock varnish dating curves are based upon K-Ar and U-trend dated deposits. No documented case has been made that the number of well dated K-Ar and U-trend deposits that have been used to obtain standard data for rock-varnish calibration is a statistically representative sample. For example, literature containing K-Ar dating of volcanic lava flows and ash in the Yucca Mountain region does not appear to provide an abundance of sound reproducible dates.

3. In section 3.3.2, there appears to be a strong sampling bias for varnish samples which could diminish the potential for reproducible results. It is unclear how such a sampling approach satisfies QA level 1 requirements. A more representative approach would be to collect all variations of varnish and report the range. The thickest, darkest, and most complete coatings are judgmental factors unless some measuring equipment is used in the field to measure thickness, color, and completeness.

4. During sample preparation, clasts are hand washed in deionized water to remove surficial detritus. Is there documentation that the deionized water wash process does not leach K and Ca? Is there a scientifically-accepted and QA approved procedure for washing varnish?

5. In section 3.3.6, the ratio of K + Ca/Ti is calculated for 6 overlapping sites and the lowest five are averaged for the sample. Why are the lowest five averaged? What ranges are found? The calculation of the cation-ratio appears to require statistical manipulation. The

approach suggests that any one analytical point does not provide useable cation-ratio data for that sample because there is a wide range of cation-ratios within any one sample. Therefore, if the range of cation-ratios were plotted, the result would not have dating utility. It is unclear why the Study Plan concludes that the average figures are potentially age related.

Additionally, in section 3.3.6, K + Ca/Ti is not necessarily what is being measured in the laboratory. A full discussion of the Ba problem is appropriate in this section and should be included.

In section 3.3.6, there appears to be a significant number of anomalies: statistical manipulation of data, and a lack of understanding of the actual geochemical, biogeochemical, and sedimentological processes which occur in rock-varnish. It is difficult to justify using this dating technique given those uncertainties.

6. Section 3.0 appears to emphasize the process of characterization of rock varnish (minus some critical laboratory procedures, and with the addition of several questionable procedures) rather than Yucca Mountain site characterization. There are other dating methods available based upon sound theory and scientific acceptance that have potentially more utility than what is attempted here.

Further questions and comments derived from the Appendix A review are as follows:

1. The field methods proposed for sample collection require specific judgement calls on the collection of desert varnished materials. What are the criteria which will be used to make the field judgement decisions? Without such criteria, the data collected may not be representative of the feature analyzed and the data will not be reproducible by independent analyses. Alternative field methods are available to collect representative samples.

2. The proposed laboratory methods for obtaining cation-ratios are technically inappropriate. Other methods are available that would supply more accurate data.

3. It must be demonstrated that regional dating curves apply for the full range of time to all of the site specific geomorphic regimes within the regional area. For example, why would washes such as Forty Mile Wash (and its terraces) have the same weathering cation behavior as rock outcrops on top of Yucca Mountain? An effective demonstration would utilize another dating tool. Further, geomorphic environments on a

local scale should vary their cation weathering profiles with time, especially if that time span is as great as suggested on page 15 (section 3.4.2 Sample collection, 6,000 to 700,000 years old). Theory of varnish genesis and behavior with respect to its chemical composition, digenesis, and organic behavior must be developed prior to use of varnish cation-dating for Yucca Mountain characterization.

4. The relationship between varnished pebbles and the geomorphic surface hosting the varnished material must be known for each type of landform investigated.

5. Some varnish surfaces appear to be unstable as they are themselves weathered. These would presumably yield ages which are erroneous.

6. All varnish layers are not of the same composition or structure. Therefore the chemical composition of various varnish varieties will vary. How does this affect dating?

7. Organic acids produced in the soil and within the varnish would affect varnish stability and chemical composition (especially mobilized cations). Organic composition would be affected by changes in climate and microtopography. Thus, cation leaching in varnishes may vary on the basis of time, locale, and presumably even within a single varnish sample.

9. Fractures (tensile displacement) within varnish are not homogeneous. These fractures can transport leaching liquids differentially. Cation compositions, therefore, could vary within a single sample. Cation stratigraphy from the surface of a varnish to its substrate probably show little if any pattern and therefore from a cation-ratio dating concept are not time stratigraphic.

10. Remobilization of transition-metals within varnish appears active along aqueous transportation paths. What is the fate of K, Ca, and Ba during remobilization digenesis?

11. How do varnish deformation structures affect the chemical composition of the rock/varnish interface?

12. To what extent does rock composition influence varnish chemistry?

13. What is the behavior of Ti relative to Al during chemical weathering in the desert environments? And how do these data support the cation-ratio used?

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