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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

AUG 22 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

Dear Mr. Milner:

SUBJECT: NRC STAFF REVIEW OF THE U.S. DEPARTMENT OF ENERGY TOPICAL REPORT ON EXTREME EROSION

On March 9, 1993, the U.S. Department of Energy (DOE) transmitted the topical report entitled "Evaluation of the Potentially Adverse Condition 'Evidence of Extreme Erosion During the Quaternary Period' at Yucca Mountain, Nevada" (hereafter, "Topical Report") to the U.S. Nuclear Regulatory Commission (NRC) staff for review and comment. DOE was subsequently provided with the staff's preliminary review comments (letter from J. Holonich to D. Shelor; dated December 30, 1993). This letter conveys the results of the formal staff review and thus, supersedes the December 1993 preliminary comments. As a result of its review, the NRC staff has determined that the Topical Report does not contain sufficient information to acceptably address the subject of the report at this time, that is, to demonstrate that the potentially adverse condition (PAC) -- evidence of extreme erosion during the Quaternary Period (10 CFR 60.122(c)(16)) -- is absent at the Yucca Mountain site.

In reaching this determination, the NRC staff considered the following: (1) information contained in the Topical Report itself; (2) field data that were discussed during the February 1994 site visit; (3) DOE's response to the staff's December 1993 comments (letter from L. Barrett to B.J. Youngblood dated January 26, 1994); and (4) additional data that were omitted from the original March 1993 Topical Report submittal (letter from D. Shelor to J. Holonich, dated March 31, 1994). The NRC staff's review of the subject report has resulted in the identification of nine comments. These comments will be tracked by the NRC staff as open items similar to those previously raised by the NRC staff in its 1989 Site Characterization Analysis (SCA). The results of the staff review are summarized below and discussed in detail in the enclosure.

## 1. Scope of the Topical Report

The Topical Report does not acceptably address the 10 CFR Part 60 regulatory requirements applicable to the extreme erosion topic at this time. Specifically, this Topical Report has provided information on long-term denudation rates averaged over the Quaternary Period rather than on periods of extreme erosion during the Quaternary. DOE's approach in the Topical Report is to average the effects of geomorphic processes operating on



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hillslopes through at least several, probably many, cycles of hillslope aggradation and degradation. As noted in SCA Comment 43 (p. 4-42):

> "Regional, long-term rates of erosion averaged over time and applied to specific areas do not provide a conservative estimate of potential erosion which could occur over a short time period during a single erosive event. Failure to consider maximum conditions in predicting erosion over the next 10,000 years may result in an underestimation of the effect of potential erosion."

Therefore, as stated in its December 30, 1993, preliminary comments, the NRC staff believes that the Topical Report does not acceptably address the subject such that the staff has no questions or disagreements at this time. The basis for this finding is that DOE's assessment relies on average denudation estimates over long intervals of time (i.e., in excess of 100,000 years) rather than on periods of extreme erosion that have occurred during the Quaternary which, if they recur, could have an adverse effect on repository performance.

**2. Adequacy of the Dating Method not Demonstrated**

DOE's position on the absence of the extreme erosion PAC is based on the varnish cation ratio (VCR) dating technique. Based on its review of the information provided, the staff has concluded that DOE has not provided sufficient justification on the acceptability of using this particular technique. Specifically, the justification in the Topical Report does not resolve the NRC staff concerns that this technique may not provide reasonable assurance about the exposure ages of boulder deposits. These concerns stem from uncertainties with regard to the formation of desert varnish and the time-dependence of changes in the VCR. The staff believes that these uncertainties must be acceptably addressed in the report in order to demonstrate that the VCR dating technique is an acceptable dating method suitable for use in the Yucca Mountain, Nevada site. In addition to the concerns with the Topical Report's failure to demonstrate the acceptability of the VCR dating method, the staff has also identified a lack of justification in the information provided that the technique has been accurately calibrated.

**3. Deficiencies in the Qualification Process**

The qualification process for the VCR dating technique (and, consequently, the data acquired through employment of the technique) has not been demonstrated to be acceptable. The qualification process provides a formal process through which the suitability of a dating technique can be demonstrated to be suitable for its intended use. Two ways to demonstrate this are the use of independent confirmation (through the use of a second dating technique), and peer review.

In its review of the Topical Report, the staff determined that DOE had failed to demonstrate the technical adequacy of the VCR dating technique, primarily due to a lack of calibration. A review of the VCR dating technique by a 1989 Los Alamos National Laboratory Peer-Review Group for DOE made recommendations on how to better calibrate this age-dating technique. The Los Alamos Peer-Review Group noted deficiencies in data calibration and confirmatory benchmarking, and included in its recommendations: (1) the acquisition of

more calibration points; and (2) the use of additional confirmatory dating methods. In its review of the Topical report, the NRC staff was unable to identify any evidence that the Los Alamos Peer-Review Group recommendations had been acknowledged and/or implemented. In addition to the calibration issues raised by the Los Alamos Peer-Review Group, the staff identified concerns regarding the viability of the uranium-trend-method used to calibrate, in part, the VCR dating technique. Given both sets of concerns, the staff has concluded that DOE has not demonstrated the acceptability of its qualification process of the VCR dating technique.

In order to assist the resolution of the issues raised in the staff's review of the Topical Report or to provide further insight into the bases underlying these comments, the staff is prepared to support a technical meeting with DOE to discuss these comments. If you have any questions concerning this review, please contact Michael P. Lee at 301/415-6677.

Sincerely,
/s/
Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery
Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

cc: See Attached List

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Comment 1

By relying on long-term denudation rates to define the absence of the potentially adverse condition, the Topical Report does not address the regulatory requirement for the potentially adverse condition (PAC), set forth in 10 CFR 60.122(c)(16), concerning evidence of extreme erosion during the Quaternary Period.

Basis

- It is essential to determine whether the time periods which are used to calculate the erosion rates during the Quaternary are appropriate for evaluation of possible evidence of extreme erosion. NUREG-0804 (NRC, 1983a, p. 382) defines extreme erosion as the "... occurrence of substantial changes in landforms (as a result of erosion) **over relatively short intervals of time....**" (emphasis added) Hence, estimates of erosion rates based on net erosion over hundreds of thousands or even millions of years may be inappropriate. It is feasible that much of the incision of a surface which is 500,000 year old could have occurred over perhaps 10,000 year or less. If this is the case, the shorter time interval could constitute a period of extreme erosion. However, averaged over a 500,000 year interval, estimated erosion rates would be 50 times less than the actual rates during the erosional episode. It is inappropriate to assume that the mean conditions which have prevailed over the past million years or so (perhaps 12 million year in the case of estimated canyon incision rates) will be replicated over the next 10,000 to 100,000 years. The intent of 10 CFR 60.122(c)(16) must be carefully considered.

- The role of PACs is stated in The Statement of Considerations (NRC, 1983b, p. 28201) where the Commission stated "Thus, its interest in specifying that the geologic setting shall have exhibited "stability" since the start of the Quaternary Period was to assure only that the processes be such as to enable the recent history to be interpreted and to permit near-term geologic changes to be projected over the relevant time period with relatively high confidence. This concept is best applied by identifying, as potentially adverse conditions, those factors which stand in the way of such interpretations and projections."

- The purpose of the extreme erosion PAC is to assure a program of exploration and analysis which will ensure sufficient site characterization information to allow a projection of the erosion rates that could be expected during the period of intended repository performance -- presently 10,000 years.

- The staff sees nothing in the Topical Report which provides information which can be used to project erosion rates over the relevant time frame, the period of intended repository performance, or which addresses directly the question of extreme erosion.

- On pages 2 and 3, DOE agrees with the NRC characterization of "extreme erosion"

as the occurrence of substantial changes in landforms (as a result of erosion) over relatively short intervals of time.

- On page 31, it is stated that "The erosion rates calculated in this study are long term erosion rates that average the effects of processes operating on these hillslopes through at least several, probably many, cycles of hillslope aggradation and degradation." Therefore, while the report agrees with the basic concept behind extreme erosion, the investigations documented in this report are not aimed at gathering the information necessary to resolve the question of extreme erosion.

- From examination of information found in Tables 4 (p. 44) and 5 (p. 48) it is apparent that not only were several cycles of both deposition and erosion used to calculate the values quoted, but that the time periods used are, in some instances, over two orders of magnitude greater than the present regulatory period of performance (i.e., 10,000 years).

- The major portion of the Topical Report deals with dating of hillslope deposits presumed to be geomorphically stable. Estimates of rates of incision of channels adjacent to the stable boulder deposits are provided but there is little discussion of rates of incision along the canyons and washes, or of scarp retreat and other backwearing phenomena that are fundamentally distinct from regional lowering of the land surface. Although the terms **denudation** and **erosion** are often used interchangeably (for example, see Kearey, 1993), for the purposes of this study, they should be clearly defined and differentiated.

- The foregoing observation calls into question the concept underlying the approach to this study. By dating stable geomorphic surfaces, the study is more likely to provide an impression of landscape stability than if its focus was the dating of erosional landforms and events. It would be valuable to estimate the likely range in erosion rates by comparing, for example, 1,000 or 10,000 year of an interpluvial episode (such as the Holocene) with a period of similar length during a pluvial cycle (such as that from about 25 to 15 ka).

**Recommendation**

DOE should use a methodology that provides information on the "extreme erosion rates"; those erosion rates which may have been experienced in the general Yucca Mountain area during relatively short periods of time, on the order of those periods of time equal to the regulatory period of performance (i.e., 10,000 to 100,000 years).

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Nuclear Regulatory Commission, "Disposal of High-Level Radioactive Wastes in Geologic Repositories Technical Criteria [Statement of Considerations in Final Rule], *Federal Register*, vol. 48, no. 120, June 21, 1983b.

**Comment 2**
The rate of canyon cutting (quoted on page 55) appears to underestimate an estimated erosion rate in the Yucca Mountain region.

**Basis**

- The Topical Report indicates that the rate of canyon cutting has been calculated at 0.8 cm/ka or less based on the fact that 60- to 100-meter canyons are cut into 12.7 million year old volcanic tuff.

- If the effect of tectonism is ignored, from the crest of Yucca Mountain to either Jackass Flat or to Crater Flat, over 300 meters of material has been eroded in the last 12.7 million years, not 60 to 100 meters.

- In addition to those formations present on the crest of Yucca Mountain, the Rainier Mesa Member of the Timber Mountain Tuff is found on both sides of Yucca Mountain, and an unknown ash fall/ash-flow unit is present in the subsurface in the area of the proposed repository. This unit is thought to be equivalent to units between the Tiva Canyon Member of the Paintbrush Tuff and the Rainier Mesa Member of the Timber Mountain Tuff. Therefore, the thickness of the Tiva Canyon remaining represents an underestimate of the amount of material which was originally present at Yucca Mountain. A conservative estimate would suggest that the canyon cutting rate quoted in the report could be low by a factor of 3 to 4 or more.

- During the past 12.7 million years, the "erosion potential" of the Yucca Mountain area varied considerably during different climatic regimes -- there were periods of primary erosion and periods of primary deposition. Even if the average rate of canyon cutting for the last 12.7 million years can be calculated, it is unclear how this rate would be related to the rate which could be expected to occur during the period of performance. The rate quoted in the report could underestimate the expected rate of canyon cutting during the period of performance.

**Recommendation**
DOE should provide a methodology for determining of the rate of canyon cutting which is representative of the conditions that have occurred in the Yucca Mountain region during the Quaternary Period.

Comment 3
The hillslope degradation rates, quoted in Table 5 (p. 48), appear to underestimate the rates of erosion which have occurred in the Yucca Mountain region during individual periods of erosion.

Basis

- The purpose of the potentially adverse conditions (PACs -- 10 CFR 60.122(c)) is to identify those characteristics of the site that might have an unfavorable effect on 10 CFR Part 60 performance objectives. The rule requires that these conditions be described and analyzed a particular way (10 CFR 60.21(c)(1)(ii)) in order to demonstrate that the performance objectives will be met (10 CFR 60.122(a)). One of the criteria that must be demonstrated is that "... the effects [of the PAC on the performance objectives] have not been underestimated" (60.122(a)(2)(ii)).

- On page 27, it is stated that during pluvial periods colluvium aggradation occurs on the hillslopes, while during more arid conditions (such as the present) hillslope stripping occurs.

- On page 43, it is suggested that five periods of boulder deposition can be documented to have occurred in the Pleistocene in the Yucca Mountain area.

- On page 46, it is stated that these deposits were "... deposited in and filled topographic lows and hollows, and spilled over into adjacent slopes ...."

- On page 42, it is stated that the cation ratio age is the estimated surface exposure age of the boulder deposit.

- On page 38, it is stated that the oldest deposits were those selected.

- On page 45, it is stated that the process rate equals the magnitude of the process divided by the time the process operated. Therefore, if the magnitude of the process is underestimated or if the time of the process is overestimated the resultant process rate will be an underestimate.

- As it is suggested that several periods of aggradation and intervening degradation are reflected in the erosional record of the Yucca Mountain area, the rates calculated reflect not an erosion rate but a summation of landscape changes by erosion and deposition through the period analyzed.

- From Topical Report Table 5 (p. 48), a comparison of the calculated rates for Boundary Ridge (the youngest deposit sampled) with those rates which include several periods of erosion/degradation strongly suggest that the average rate

quoted is an underestimate since the rate for Boundary Ridge is approximately a factor of three greater than any other deposit.

- If the age quoted in Table 4 (p. 44) represents the surface exposure age of the deposit, this age reflects the time at which the material was deposited, and therefore represents a period of aggradation, not degradation. The period of time between the age cited on Table 4 and the onset of erosion is unknown. As the oldest date for the deposit was purposely selected and analyzed the methodology has served to maximize the possible degree of overestimation. Therefore, based only on age relationships, the rates appear to underestimate the rate of erosion.

- As can be seen from Figure 12 (p. 47), the methodology assumes that the present top of the deposit represents the original land surface. If, as the report states, these deposits were believed to have been deposited in lows, there had to be some topographic "highs" present. The former slope surface had to be at a higher elevation than that shown on this figure. Thus, the process of magnitude calculations appears to have been selected such that the erosion rate has been underestimated.

- If the boulder deposits represent the remains of a semi-uniform mantle of boulders that covered the surface and that the top of the boulder deposit is a good approximation of the former land surface, the process that is being measured is the average rate of degradation of an armored surface -- a surface that was covered with natural riprap. As this does not represent the normal condition for the hillslopes in the Yucca Mountain area, the values reported are not relevant in projecting erosion rates over the period of performance.

**Recommendations**

DOE should provide a methodology for the calculation of erosion rates which does not underestimate the effects.

**Comment 4**
Reliance on the varnish cation ratio (VCR) dating method alone to establish the age of geomorphic surfaces is inadequate for demonstrating the absence of extreme erosion.

**Basis**

- The VCR dating technique has received considerable attention since it was first proposed and developed by Dorn (1983). Despite a considerable amount of work on the physical and chemical properties of desert varnish (Perry and Adams, 1978; Potter and Rossman, 1979; Krumbein and Jens, 1981; Dorn and Oberlander, 1982; Dorn, 1984), the exact reasons for apparent variations in the ratio of potassium and calcium to titanium (K + Ca)/Ti or (KCT) are obscure.

- There are three primary models to account for variations in minor element abundances in rock varnish with time. A widely held model is that relatively mobile K and Ca are preferentially leached from accreting varnish while Ti remains immobile, resulting in lower KCT with time (e.g., Dorn, 1983; Dorn and Krinsley, 1991). However, Reneau *et al.* (1992) concluded that variations in the composition of detrital mineral grains and authigenic mineralization strongly influence the composition of rock varnish, and that these variations in composition invalidate the basic premises of the VCR dating technique. In addition, Reneau and Raymond (1991) and Bierman and Gillespie (1994) have observed that minor element variations in rock varnish were inconsistent with a leaching hypothesis. Instead, they postulated that observed KCT relationships reflect the preferential incorporation of host-rock fragments, which have high KCT ratios, into thin, young varnish deposits. Older, thicker deposits contained relatively fewer host-rock fragments and thus have lower KCT ratios. However, the results of these studies indicate that the amount of substrate incorporation does not vary linearly with time.

- If the host rocks for the dated varnish deposits have similar lithologies (i.e., composition, mineralogy, texture), then KCT ratios may vary uniformly with time for these deposits (i.e., Dorn, 1983). However, if different host lithologies are present, then different KCT ratios could be incorporated into the analyzed varnish deposits. This observation is especially significant for the Yucca Mountain region because different host lithologies are used in both calibration standards and dated samples.

- Basaltic rocks in the Yucca Mountain region have KCT ratios that are between about 10 to 13. These basalts are the primary host for dated varnish deposits at Skull Mountain, Little Skull Mountain, Buckboard Mesa, and Crater Flat. However, talus deposits at Yucca Mountain consist of fragments of welded rhyolitic ignimbrite, which are primarily from the Tiva Canyon member of the Paintbrush Tuff (see Chapter 1.2 ("Site Geology") in DOE, 1988). KCT ratios for Tiva Canyon rhyolite are about 60, but decrease to about 30 for less abundant quartz latite members (Broxton *et al.*, 1989). These ignimbrites also are the dominant lithologies in the alluvial deposits used

to construct part of the cation-ratio calibration curve for Yucca Mountain (Harrington and Whitney, 1987; and Whitney and Harrington, 1993). Thus, two distinct lithologies (basaltic lava and welded rhyolitic ignimbrite) are used to construct the cation-ratio calibration curve for Yucca Mountain.

- If the hypothesis of Reneau and Raymond (1991) and Bierman and Gillespie (1994) is accepted, then a linear relationship may not exist between the 40–255 ka ignimbrite hosts and the 1.1 Ma basaltic hosts on the Yucca Mountain cation-ratio calibration curve. The KCT ratios of these two lithologies could represent two different cation-ratio trends that originate at different initial KCT ratios that reflect the different host lithologies. In addition, measured KCT ratio variations on samples of unknown age may reflect variations in the amount of substrate fragments incorporated into the varnish and not accurately represent the age of the deposit.

- Furthermore, varnish deposition is thought to be controlled by the microtopography of the substrate (Dorn and Oberlander, 1982; Dorn and Krinsley, 1991; Reneau *et al.*, 1992). Local microtopographic lows trap detrital mineral grains more readily and collect water for authigenic mineral formation, resulting in relatively thick varnish layers (e.g., Reneau *et al.*, 1992). Basaltic lavas and rhyolitic ignimbrites have obvious differences in macroscopic and microscopic textural features, including the presences of vesicles, groundmass porosity and permeability, amounts of groundmass glass and crystals, abundances and sizes of primary minerals, and the morphologies and abundances of fissures and joints (e.g., Vaniman *et al.*, 1982; Bish and Chipera, 1989). Each of these textural features could influence the development of rock varnish, and textural differences between the lava and ignimbrite thus could result in variations in rock varnish thickness and composition.

- In addition to the possible effects of substrate, rock varnish on a single surface may be texturally inhomogeneous and include sites where varnish chemistry may have been influenced by cracking, proximity to the soil, organic matter accumulation, biogenic activity, or ponding of water (Dorn, 1989; Krinsley *et al.*, 1990). These disturbed sites are not suitable for cation-ratio dating studies because they may represent cation ratio variations that developed independent of time (e.g., Dorn and Krinsley, 1991).

- Dorn and Krinsley (1991) measured KCT ratios at the Little Cone volcano, which is part of the Quaternary volcanic alignment that includes Black Cone and Red Cone (e.g., Vaniman *et al.*, 1982). KCT ratios for Little Cone layered-texture varnish are $2.7 \pm 0.2$ (1 sigma), which is comparable to reported values of $2.2 \pm 0.3$ and $2.3 \pm 0.1$ for Black Cone and Red Cone, respectively (Harrington and Whitney, 1987). However, porous-texture varnish at Little Cone has a KCT ratio of $1.9 \pm 0.4$. Although the Dorn and Krinsley (1991) values are each within the range of 1 sigma error reported for Black and Red Cones, the Little Cone data suggests that Black and Red Cone KCT ratios could be mixtures of layered-texture and porous-texture

varnish. Similar textural variations likely affect KCT ratios in other deposits. Thus, textural variations in varnish may produce some of the KCT variations attributed solely to age.

**Recommendation**

In the field of Quaternary geochronology, where new techniques are being developed and old techniques are being refined, it is recommended that additional methods to determine the age of exposure of surfaces be used to provide reasonable assurance with regard to the findings of the study on extreme erosion. Before the VCR dating technique can be used to establish ages of geomorphic surfaces, it is recommended that the hypotheses that cation-ratio variations may represent different degrees of substrate contamination, amount or composition of the underlying substrate, composition of deuteric minerals, or textural variations need to be tested.

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**Comment 5**

The calibration curve for the VCR dating method which illustrates the relationship between the KCT of the varnish and the age of the geomorphic surface uses material dated by the uranium-trend (U-trend) method to determine the age of coarse-grained alluvial deposits and the potassium argon (K-Ar) method to determine the age of basalts. Application of U-trend and K-Ar dates to establish the ages of the stable geomorphic surface is uncertain.

**Basis**

- In the Topical Report, three of the five calibration points are dated using U-trend methods. Swadley *et al.* (1984) used these same dates to estimate the ages of Quaternary soils and alluvial deposits in the vicinity of Yucca Mountain. They noted that the dating method was experimental and "that accuracy of the absolute ages derived by this method is not known... (Swadley *et al.*, 1984: p. 6). Geyh and Schleicher (1990: p. 226) also question whether U-trend dates actually represent the age of the deposit. No data have been presented in the Topical Report to demonstrate that the U-trend dates used in the calibration curve either precisely or accurately represent the age of the varnish associated with these deposits. Although Harrington *et al.* (1988; p. 1052) stated that the "analytical uncertainty in the K-Ar and U-series SIC dates is minimal," the Los Alamos peer-review group felt that "additional calibration points should use all suitable methods" (Birkeland *et al.*, 1989: p. 6). The VCR calibration curve used for this study apparently has not been modified or tested in any way since it was originally published by Harrington and Whitney (1987).

- It is not possible to directly correlate the samples dated by the uranium-trend method (Rosholt *et al.*, 1985) with calibration units Q2c, Q2b, and CF, using the limited data presented in the Topical Report or associated publications. Although unpublished U-trend dates by D.R. Muhs are used in Table 1 of Harrington and Whitney (1987), these dates are not presented in the Topical Report and cannot be evaluated for precision or accuracy. Numerous sites for units Q2c, Q2b, and CF are however, presented in Rosholt *et al.* (1985), but there is no discussion of the range in apparent ages of these units in Harrington and Whitney (1987). The $40 \pm 10$ ka "Crater Flat surface" reported in Harrington and Whitney (1987) apparently corresponds to unit Q2a in Rosholt *et al.* (1985), which has an apparent range in age from $30 \pm 10$ to $55 \pm 20$ ka in the Yucca Mountain area. Unit Q2b, which has a reported age of $160 \pm 20$ ka in Harrington and Whitney, ranges in age from $160 \pm 25$ to $200 \pm 80$ ka in Rosholt *et al.* (1985). Unit Q2c, which has a reported age of $255 \pm 15$ ka in Harrington and Whitney, ranges in age from $240 \pm 50$ to $310 \pm 40$ ka for the upper member reported in Rosholt *et al.* (1985). The precision and accuracy of the dates associated with units Q2c, Q2b, and CF is significantly lower than reported in Harrington and Whitney (1987).

- Rosholt *et al.* (1985) report that gravels in the upper member of unit Q2c "locally overlie and contain reworked cinders from the Big Dune basalt center 11 kilometers

northwest of Lathrop Wells," Nevada. Although earlier K-Ar dates for this volcano (Vaniman *et al.*, 1982) are between 200 and 300 ka, these dates are generally regarded as erroneously old (e.g., Crowe *et al.*, 1992). Relatively high-precision Ar-Ar (Turrin *et al.*, 1991) and cosmic-ray exposure dates (e.g., Crowe *et al.*, 1992; Zreda *et al.*, 1993).indicate that the age of the "Big Dune" volcano is likely 100±50 ka. Thus, unit Q2c should be significantly younger than the 255±15 ka age used in the VCR calibration curve for the Topical Report. Likewise, the ages of overlying units Q2b and CF may also be significantly younger than represented by the U-trend dates.

- The ages of Black Cone and Red Cone have been established by use of the K-Ar dating method. This method assumes that the K-Ar system is closed upon the quenching of the extruded magma. In order to use these materials in the KCT ratio versus age of stable surface calibration, it must be assumed that the varnish began to form as soon as the extruded magma was quenched. No information supporting this assumption is provided and the assumption may be incorrect.

**Recommendation**

To use the VCR dating technique to establish the ages of stable geomorphic surfaces, it is recommended that additional methods of dating such as the cosmogenically-produced isotopes $^{3}He$, $^{14}C$, $^{10}Be$, $^{26}Al$, and $^{36}Cl$ (e.g., Nishimiizumi *et al.*, 1991), be used to make the calibration curve more robust.

If uranium-trend dates of alluvial deposits are to be used in the calibration curve, then apparent ambiguities between U-trend dates used in the Topical Report and those in Rosholt *et al.* (1985) must be addressed.

**References**

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Zreda, M.G., Phillips, F.M., Kubik, P.W., Sharma, P., and Elmore, D., "Cosmogenic $^{36}$Cl Dating of a Young Basaltic Eruption Complex, Lathrop Wells, Nevada," *Geology*, 21:57-60 [1993].

**Comment 6**
The development and issuance of a geomorphic map of Yucca Mountain and adjacent areas is an important factor in the determination of the presence, or absence, of extreme erosion. However, no such map, or its equivalent (such as a surficial geology map) has been submitted with the Topical Report.

**Basis**

- It appears that several objectives of site characterization, related to erosion are: (1) to identify the erosional processes that have been operating in the Yucca Mountain area during the Quaternary; (2) to identify the specific locations of past erosion: and (3) to quantify the rates of the different processes and assess their relative importance. It is assumed that this information would be used in the analysis of the potentially adverse condition of extreme erosion. However, the Topical Report does not appear to have met these objectives.

- A geomorphic (surficial deposits) map of Yucca Mountain would allow: (1) determination of the areal distribution of active erosional areas and geomorphically stable areas; and (2) determination of the spatial distribution of the different types of geomorphic processes and associated deposits. It is not evident to the staff that the data supporting the accomplishment of the above objectives have been submitted for staff evaluation.

- Figure 7 (map of surficial deposits around Yucca Mountain) lacks sufficient detail necessary to evaluate the presence, or absence, of extreme erosion. In addition, the figure does not provide sufficient detail to show landforms (both bedrock and surficial deposits) and to allow evaluation of the types of past and present geomorphic processes that are chiefly responsible for their formation.

**Recommendation**
Develop a geomorphic map of the Yucca Mountain area, or alternatively a surficial deposits map, and use the map as one of the elements in determining the presence, or absence, of the extreme erosion potentially adverse condition.

Comment 7

The technical basis for the Forty Mile Wash maximum incision scenario shown in Figure 13 (see p. 53) is not provided in the Topical Report.

Basis

- Figure 13 suggests that a portion of the alluvium occupying the channel of Forty Mile Wash is assumed to have been incised and then essentially refilled **to a depth of 108 meters** within the Holocene (a time period of approximately 10,000 years).

- Figure 13 shows that a stream once occupying ancestral Forty Mile Wash is assumed to have incised the valley fill (Q2c Alluvium) **to a depth of 133 meters** and then nearly refilled the incised channel with alluvium within a period of 120,000 years. Incision (downcutting) is assumed to have occurred within the first 60,000 years.

- Figure 13 shows that the 430 ka terrace (QTa Alluvium) of ancestral Forty Mile Wash was incised and subsequently refilled to a depth **in excess of 133 meters** within a period of 150,000 years. Incision (downcutting) is assumed to have occurred within the first 80,000 years.

- The maximum incision scenario for Forty Mile Wash is considered permissible and is based upon interpretations of geologic field relations and dated terrace surfaces (DOE, 1994, p.3).

- If the maximum incision scenario is permissible, the three examples of incision (erosion) presented above would be considered as evidence of extreme erosion having occurred: (1) during the Quaternary Period; (2) within the conceptual controlled area boundary: and (3) within a time frame representative of the repository period of performance -- 10,000 to 100,000 years (see NRC, 1993, p. 2).

- A single data point (Well J-13; see p. 51) is used as the sole subsurface basis for defining the maximum/minimum incision scenarios shown on Figure 13 (p. 53) and is inadequate, when used alone, for defining the alluvium-bedrock contact underlying Forty Mile Wash in the vicinity of Busted Butte.

- Site characterization investigations, including drillholes and geophysical surveys, have been conducted in Forty Mile Wash (see DOE, 1992; Ponce *et al.*, 1992) and may provide subsurface information amenable for use in support of the subsurface conditions shown on the maximum/minimum incision scenarios (see Figure 13; p. 53).

- The three erosion/deposition cycles cited above suggest the lowering and raising of the local base level through tectonic processes not acknowledged in either the Quaternary tectonic history presented on page 24 or in the SCP (see DOE, 1988, pp.

8.3.1.6-20 and 8.3.1.6-22).

**Recommendations**

Although it is recognized that the incision scenarios presented on Figure 13 represent, in some cases, the "worst-case" situation, the scenarios described should be internally consistent with other sections of the Topical Report and with the SCP (see DOE, 1988, pp. 8.3.1.6-20 and 8.3.1.6-22), unless more recent site characterization studies have demonstrated otherwise.

Provide a geologic history for Forty Mile Wash that is consistent with the Quaternary tectonic record.

**References**

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Barrett, L.H., U.S. Department of Energy/Office of Civilian Radioactive Waste Management, Letter to B.J. Youngblood, U.S. Nuclear Regulatory Commission/Division of High-Level Waste Management [Subject: Response to NRC's letter of December 30, 1993, Regarding the Status of NRC's Review of the Topical Report on Extreme Erosion], January 26, 1994.

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Comment 8
Insufficient evidence has been presented in the Topical Report regarding the extent of the Quaternary Period in order to determine the presence, or absence, of the PAC on evidence of extreme erosion.

Basis

- DOE's regulatory evaluation of the PAC on extreme erosion during the Quaternary Period (10 CFR 60.122(c)(16)) establishes a time period of the most recent 1.6 million years as bounding the Quaternary Period (DOE, 1993, p. viii).

- However, for regulatory purposes, the NRC has taken the position that a time span of 2 million years is the length of the Quaternary Period (see NRC, 1983, p. 373).

- However, the staff will consider other time periods submitted by DOE provided that DOE can demonstrate a sufficient understanding of the recent geologic past such that geologic changes can be projected over the intended period of performance with reasonably high confidence.

- Twelve hillslope boulder deposits, dated by the varnish cation ratio dating (VCR) technique, yield apparent ages ranging from 170 to 1,380 thousand years.

- Although there are major concerns regarding the reliability of the age-dating of the boulder deposits using the VCR technique, if it is assumed that such data are representative, they can perhaps be used to give an indication of the range of ages of such hillslope deposits.

- The Topical Report fails to address the occurrence of significant, relatively instantaneous events (those events having occurred within a time frame equivalent to the period of performance) before, or during the time interval covered by the boulder deposits studied by DOE. Consideration of these events is significant in determining if the adverse condition is present, but undetected.

- The most recent portion of the Quaternary Period -- the past 170 thousand years -- has not been investigated.

- The gaps in the age-dates assigned to the boulder deposits are so large that about one-half of the total time spanned by the DOE investigation is not represented.

Recommendation
DOE should demonstrate that a reasonable portion of the past (i.e., Quaternary Period) has been investigated and adequately evaluated for evidence of extreme erosion. If the geologic record is incomplete or resolution of time intervals not possible, then this must be factored into the consideration that the adverse condition is present, but undetected.

## References

Nuclear Regulatory Commission, "Staff Analysis of Public Comments on Proposed Rule 10 CFR Part 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories," Office of Nuclear Regulatory Research, NUREG-0804, 1983, 563 pp.

Comment 9

There does not appear to have been follow-up, or resolution, to recommendations made in the Peer Review Report on Rock-Varnish Studies Within the Yucca Mountain Project (Birkeland, Oberlander and Hawley, 1989). This apparent deficiency in the qualification process has resulted in the subsequent submittal to the NRC staff of a milestone document, the Topical Report, that places considerable reliance upon a dating method (i.e., the varnish cation ratio (VCR) dating technique) that appears to the staff, based in part on the results of the peer review, to be unsuitable for its intended use.

Basis

- The Peer Review Report (Birkeland, Oberlander and Hawley, 1989) stated the following in the discussion of the VCR calibration curve: "Calibration needs to be a continuing part of the project, especially as more detailed field work or discussions with other workers suggests potentially good [calibration] sites. Additional calibration points should use all suitable dating methods (tephrochronology, magnetostratigraphy, K/Ar, Ar/Ar, U-trend, U-Series, thermoluminescence, etc.), particularly in a collaborative effort with the USGS."

- The VCR calibration curve presented in the Topical Report and by Whitney and Harrington (1993) appears to have no more data than that originally published by Harrington and Whitney in 1987.

- The Peer Review Report (Birkeland, Oberlander, and Hawley, 1989) stated the following in the discussion of the evaluation of thick varnish films: "The consistency of their [Harrington *et al.*] results suggests that the Los Alamos investigators know by experience when the varnish is correctly averaged -- without requiring an obtrusive display of substrate contamination. Nevertheless, we believe that there should be a check on the procedure." Later, in the same report, "We urge expanded use of the electron microprobe to produce varnish transects and chemical averages as a check on SEM results, particularly where thick varnish films may not be fully (or unequivocally) penetrated by the 30 kev electron beam." The Peer Review Report further recommended that the behavior of immobile elements (in addition to $TiO_2$) should be investigated to better define the leaching process that is the basis of cation-ratio dating.

- There is no information in either the Topical Report or in Whitney and Harrington (1993) to indicate that there has been any follow-up, or resolution, of the above Peer Review Report suggestions.

- The NRC (in Subpart G of 10 CFR Part 60, through reference to Appendix B of 10 CFR Part 50), requires documentation of activities affecting quality. The DOE (in DOE/RW-0333P, and its predecessors) requires implementation of a program to meet the NRC requirements. Since the work in question is being done for DOE, Los

Alamos National Laboratory must meet these requirements. The Birkeland, Oberlander, and Hawley (1989) Peer Review Report comes within the scope of these references. Since the peer review process is incomplete without the resolution of comments, either the Topical Report or Whitney and Harrington (1993) should report how the comments in the Birkeland, Oberlander, and Hawley (1989) Peer Review Report were resolved.

**Recommendation**

In its review of the Topical Report, the NRC staff was unable to identify any evidence that the Los Alamos Peer-Review Group recommendations had been acknowledged and/or implemented. Given this concern, and the concerns expressed earlier in Review Comments 4 and 5, the NRC staff believes that the qualification process for the VCR dating technique (and, consequently, the data acquired through employment of the technique) has not been demonstrated to be acceptable. In order to demonstrate the acceptability of the VCR dating technique, DOE should provide documentation to show that it has an acceptable qualification process in place.

References

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