



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

February 29, 1996

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

SUBJECT: ISSUE RESOLUTION STATUS REPORT ON THE POTENTIALLY ADVERSE CONDITION
- EVIDENCE OF EXTREME EROSION DURING THE QUATERNARY PERIOD AT YUCCA
MOUNTAIN

Dear Mr. Milner:

The Nuclear Regulatory Commission's review of the U.S. Department of Energy's (DOE's) topical report (TR) entitled *Evaluation of the Potentially Adverse Condition Evidence of Extreme Erosion During the Quaternary Period at Yucca Mountain, Nevada* is near completion. Consequently, we believe that it is appropriate to report on the status of the review and on the progress made towards resolution on the issue of extreme erosion. As a result of our review, we believe that sufficient information exists in various forms to demonstrate that extreme erosion has not occurred at the proposed high-level radioactive waste repository at Yucca Mountain during the Quaternary Period. Therefore, available information appears to be sufficient to address the potentially adverse condition (PAC) of extreme erosion and, consistent with the agreement on issue resolution, the staff has no further questions at this time on this topic.

As you are aware, our approach to issue resolution allows us to use all available information, not just information provided by DOE. Given this approach, it should be noted that significant parts of the information used in our evaluation were from sources other than the TR. Further, there remain unresolved issues from the TR review relating mainly to the credibility of the varnish cation ratio (VCR) age-dating technique. Therefore, the staff is not prepared at present to say the TR is, in and of itself, suitable to support, in a licensing application, the determination of the absence of the extreme erosion PAC. Consequently, the staff, in lieu of preparing a safety analysis on DOE's TR, is completing this Issue Resolution Status Report documenting the technical basis for its finding that sufficient information exists to demonstrate that the PAC is absent at Yucca Mountain.

The staff determined that the available data are sufficient to adequately address the concerns raised in the 11 open items (see Table 1, Enclosure) identified by the staff during its review of the extreme erosion issue. The sources of information that provided the basis for the staff's conclusions include: (1) DOE's TR and the responses to NRC's comments on the TR; (2) staff observations and assessments of DOE's on-going extreme erosion-related

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activities; (3) staff review and evaluation of non-DOE documents; and (4) presentations made by DOE scientists to the National Research Council's (Council's) panel reviewing DOE's *Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion* (hereafter, TBR). As you are aware, the Council's December 1995 review report of the erosion aspect of DOE's TBR suggested that DOE provide additional information to more fully address the issue. As stated in the report, the Council "suspects that much of the needed work is already under way...or that the needed data are already at hand or available in the literature...". As indicated in this letter, the staff has independently reached the same conclusion and has described in more detail, in the Enclosure, its bases for determining that the extreme erosion issue has been resolved. Tables 3 and 4 (see Enclosure) identify the published and unpublished sources used by the staff in evaluating evidence related to extreme erosion. The NRC staff considers that, at present, in addition to the DOE references, the non-DOE references identified in Table 4 are necessary for resolution of the extreme erosion issue and suggests that DOE needs to consider this additional material for preparing a final analysis to support a license application.

As noted in the Enclosure, all of the open items have been resolved. Also, based on the available information, the staff has collected and/or calculated erosion rates in the vicinity of Yucca Mountain (see Table 2, Enclosure). The staff believes that the rates presented in Table 2 bound the rates that can be expected at the site. However, a key concern the staff has with DOE's determination of erosion rates has been the heavy reliance on the VCR age-dating technique. To date, the viability of this technique is questioned principally because the technique lacks a firm theoretical basis. Consequently, the staff has not relied on the VCR dating technique in its analysis. Rather, the staff relied on other age-dating techniques employed by DOE and others to support judgments about the absence of extreme erosion. In the absence of a credible explanation for the mechanisms affecting the evolution of rock varnish, DOE will need to consider using the same approach when considering the use of VCR dating in any investigation to support a license application.

Finally, in earlier interactions, the staff noted that it was considering issuing a pre-licensing evaluation report (PER) on the topic of extreme erosion. However, the staff, based on its analysis of the open items related to the topic of extreme erosion, now believes that development of a PER is unnecessary because sufficient information and guidance are presented in this Issue Resolution Status Report to assist DOE in developing a license application. The only action the staff will take on this topic in the future is to review in-progress work for consistency with the closure of the open items and the overall conclusion that the PAC does not exist at Yucca Mountain. The NRC will advise DOE of the results of its review of the in-progress work following its completion and submittal to the NRC. Also, one observation resulting from the closure of the open items is that all information necessary to demonstrate the absence of the PAC has not been fully qualified under DOE's Quality Assurance Program. It is anticipated that prior to NRC's receipt of a DOE license application, all data and analyses will be fully qualified.

If you have any questions concerning this letter or its Enclosure, please contact Harold Lefevre of my staff at (301) 415-6678.

Sincerely,

Michael Bell, Branch Chief
Engineering and Geosciences Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

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**STATUS OF OPEN ITEMS
RELATED TO THE POTENTIALLY ADVERSE CONDITION
EXTREME EROSION DURING THE QUATERNARY PERIOD AT YUCCA MOUNTAIN**

Background

During the course of the Nuclear Regulatory Commission staff's review and evaluation of documents submitted by the Department of Energy (1988 and 1993) on the subject of extreme erosion, 11 open items were identified. These include two Site Characterization Analysis (SCA) comments (NRC, 1989) and nine Topical Report (TR) comments (NRC, 1994). The status of these open items is described below and shown in Table 1.

The status is based on: (1) the staff's reviews of the TR (DOE, 1993) and the responses (DOE, 1995a) to NRC's comments on the TR; (2) staff observations and assessments of DOE's on-going extreme erosion-related activities; (3) staff review and evaluation of non-DOE documents; and (4) presentations made by DOE scientists to the National Research Council's (Council's) panel reviewing DOE's *Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion* (hereafter, TBR).

Open Items

SCA Comment 42 *The overall erosion program does not include an evaluation of escarpment retreat.*

In its TR *Evaluation of the Potentially Adverse Condition — Evidence of Extreme Erosion During the Quaternary Period At Yucca Mountain, Nevada* (DOE, 1993), DOE does not directly discuss retreat of the western escarpment of Yucca Mountain. As understood by the staff, DOE is conducting a cosmogenic isotope age-dating study (Gosse, et al., 1995) which includes escarpment retreat rate data. Based on our informal review of the results of preliminary cosmogenic isotope (including ^{10}Be , and ^{14}C) age-dating investigations related to escarpment retreat, the staff believes that the bases for bounding the rate of escarpment retreat are provided.

Based on the above discussion, this open item has been resolved. In-progress work being conducted by DOE will be reviewed by the staff for consistency with the indicated bases for resolution.

SCA Comment 43 *The rationale for numerical goals specified in Tables 8.3.1.17-3a, 8.3.1.17-4a and b, and 8.3.1.17-7 of the SCP (DOE, 1988) is poorly supported, and the use of averaged values or rates for establishing acceptable limits for fault movement, rates of volcanism, and rates of erosion does not provide for conservative assessment of potential hazards.*

In the review and evaluation (NRC, 1995a) of DOE's (1992) response to NRC's SCA Comment 43, the staff resolved the erosion-related aspect of this SCA comment because staff review of the TR (DOE, 1993) has resulted in the identification of open items that better reflect the staff concerns.

Based on the above discussion, this open item has been resolved.

Enclosure

TR Comment 1 *By relying on long-term denudation rates to define the absence of the potentially adverse condition (PAC), the Topical Report does not address the regulatory requirement for the PAC, set forth in 10 CFR 60.122(c)(16), concerning evidence of extreme erosion during the Quaternary Period.*

The NRC concern that repeated short-term events might represent extreme erosion at the Yucca Mountain site, or that events such as the Jake Ridge debris slide (Coe, et al., 1995) might be considered "extreme" has not been adequately addressed in either the TR or in the responses to NRC's comments (DOE, 1995a). Extreme erosion during a few thousand years can occur in an area which has average long-term, low-average erosion rates for a million or more years.

In response to the Council's review of the TBR, DOE conducted a field trip on August 27-29, 1995, and presented new information (NRC, 1995b) on erosion rates in Midway Valley and Fortymile Wash. This new information, along with other non-DOE information, has been evaluated by the NRC staff to determine if any periods of extreme erosion have occurred within a 10,000-year-period similar to the postulated regulatory period of performance (i.e., 10,000 years). As noted in Table 2, none have been identified.

Further, cosmogenic exposure dates on lava flows at the Lathrop Wells volcano provide additional limits on late Quaternary erosion rates. These exposure dates (about 60-90ka) are younger than dates measured using K-Ar and U/Th dating techniques (about 100-130 ka). Crowe, et al. (1995, p. 2-71 through 2-73) show that the young cosmogenic dates can be explained by the lava flows being covered initially with several meters of unconsolidated scoria and ash. Crowe, et al. (1995) calculate that 45 k.y. of burial can account for the anonymously young cosmogenic dates. This represents an erosion rate of only 0.4 m per 10,000 years for a flat-lying, unconsolidated deposit. This erosion rate would be significantly lower for the lithified deposits at Yucca Mountain and does not adversely affect the site's ability to isolate waste.

In the staff's view, this information, coupled with our review of the literature and conservative estimates of canyon downcutting over a 10,000-year-period (see discussion of TR Comment 2), supports the conclusion that even if above-average erosion rates were to occur during the postclosure period, that erosion would not be extreme, and there would be a negligible effect on waste isolation.

Based on the above discussion, this open item has been resolved.

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

DOE (1993) states that erosion in Solitario Canyon and canyons adjacent to Yucca Mountain occurred primarily during a 1.1 Ma period within the mid-Miocene. If correct, a downcutting rate (using the assumption of 80 meters of downcutting [DOE, 1993, p. 55]) of 7.27 cm/ka or 73 cm in 10,000 years may have occurred. This rate provides an upper bound on the rate of erosion adjacent to Yucca Mountain because the rate of tectonic movement in the Miocene was significantly higher than that which has occurred in the Quaternary. If a downcutting rate of 73 cm in 10,000 years were to occur, this would not be considered extreme erosion, and the effect on the site's ability to isolate waste would be negligible.

The preceding discussion, coupled with the staff's conclusion (NRC, 1994, Enclosure, p.4) that DOE's canyon downcutting rate could be low by a factor of 4 and still result in downcutting of only 3 meters in 10,000 years is sufficient to demonstrate that downcutting is not a significant factor. This is because 3 meters of downcutting in 10,000 years would not be extreme and would be insufficient to significantly affect waste isolation.

Based on the above discussion, this open item has been resolved. In-progress work conducted by DOE will be reviewed for consistency with the indicated bases for resolution.

TR 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.*

In addition to DOE's (1995a) responses to NRC's TR comments, the staff has evaluated the available non-DOE-sponsored extreme erosion-related literature including several publications developed under the auspices of the State of Nevada (see Table 4). Based on this evaluation, it appears that the range of degradation rates possible at Yucca Mountain can be bounded (see Table 2). Moreover, as noted in the staff's evaluation of the DOE response to TR Comment 2, conservative estimates of canyon downcutting projected to occur over short intervals yield downcutting rates that would not be considered extreme and would have a negligible effect on the site's ability to isolate waste. Consequently, the staff concludes that although hillslope degradation rates might underestimate rates of erosion occurring in individual, short intervals of the Quaternary Period, the range of possible events having occurred in the Quaternary Period can be bounded, and when projected into the future, do not appear to cause sufficient erosion such that repository performance would be affected.

Based on the above discussion, this open item has been resolved.

TR 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.*

DOE has in-progress work using dating methodologies on surfaces in the Yucca Mountain vicinity including cosmogenic ^{10}Be , ^{14}C , ^3He , and ^{36}Cl and other techniques such as uranium-series disequilibria of pedogenic carbonates, and thermoluminescence of soils. These techniques can serve as multiple sources of data from which erosion rates can be calculated. By using multiple techniques, the uncertainty of assigning an age to a surface may be minimized.

However, the staff recognizes that all dating techniques are uncertain to varying degrees. The weight of each technique in assigning an age to a surface depends on the degree of each technique's uncertainty. A key concern that the staff has with DOE's treatment of extreme erosion has been the heavy reliance on dates produced by the VCR technique. To date, the viability of this technique is questioned because the cation ratio in varnish can be influenced by environmental variables other than time. Thus, rock varnish dating is considered by the geochronological community to be experimental (Peterson, et al., 1995). Consequently, in the absence of a credible explanation for the mechanisms affecting the evolution of rock varnish, the NRC staff has not relied on the VCR dating technique in its analysis. Rather, the staff has relied on and placed greater significance on surface ages

determined by other methods, such as uranium series disequilibrium and cosmogenic dating techniques. In the absence of a credible explanation for the mechanisms affecting the evolution of rock varnish, DOE will need to consider using the same approach when considering the use of VCR dating in any investigation to support a license application.

Based on the above discussion, this open item has been resolved. In-progress work being conducted by DOE will be reviewed by the staff for consistency with the indicated bases for resolution.

TR 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.*

DOE has in-progress work using dating methodologies on surfaces in the Yucca Mountain vicinity including cosmogenic ^{10}Be , ^{14}C , ^3He , and ^{36}Cl , and other techniques such as uranium-series disequilibria of pedogenic carbonates, and thermoluminescence of soils. Those surfaces dated by one or more of the methodologies described above and on which the cation ratio of the rock varnish has been measured could better constrain the calibration curve. However, a key concern that the staff has with DOE's treatment of extreme erosion has been the heavy reliance on and the viability of the VCR technique (see TR Comment 4).

Based on the above discussion, this open item has been resolved. In-progress work being conducted by DOE will be reviewed by the staff for consistency with the indicated bases for resolution.

TR 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.*

DOE (1995c) has provided a recently-compiled surficial deposits map encompassing most of Yucca Mountain and environs to the east including Midway Valley, Yucca Wash, and a portion of Fortymile Wash. Although DOE has complied with NRC's request for a surficial deposits map, DOE indicates that the map cannot be used for licensing purposes. DOE indicates this is because the data provided on the map have not received complete technical and quality checks. Furthermore, the staff concludes that the U.S. Geological Survey (USGS) letter report accompanying an earlier version of the map (DOE, 1995b) must be revised because it contains descriptions of mapped units whose ages have been estimated using the uranium-trend technique--an age-dating method no longer supported by the geochronological community (Paces, et al., 1995). Ages of stratigraphic deposits based upon uranium-series and thermoluminescence dating recently conducted in the Yucca Mountain area would appear to provide the basis for this revision.

Additionally, the four *in-press* USGS preliminary surficial deposits maps (open file reports) by Lundstrom, et al., which provide the bases for some of DOE's (1995c) erosion rates, are yet to be published and confirmed by DOE as acceptable for use in the licensing process. These preliminary surficial deposits maps (USGS Open-File reports 94-341, 95-132, 95-133, and 95-311) have not yet been published but have received approval from the Director of USGS. Further, it is anticipated that, prior to submittal of the License Application, DOE would have conducted all required data and analysis checks.

Based on the above discussion, this open item has been resolved. In-progress work being conducted by DOE will be reviewed by the staff for consistency with the indicated bases for resolution.

TR Comment 7 *The technical basis for the Fortymile Wash maximum incision scenario shown in Figure 13 (see p. 53) is not provided in the Topical Report.*

In response to NRC's TR Comment 7, the maximum incision scenario contained in the TR has been rescinded as "no longer credible" (DOE, 1995a, p. 2-86). DOE's bases for considering this scenario "no longer credible" are twofold: (1) mapping in Fortymile Wash (Lundstrom and Warren, 1994), and (2) mapping in Midway Valley (DOE, 1995b). These documents, according to DOE (1995a, p. 2-84), indicate the presence of two alluvial units which preclude the catastrophic downcutting hypothesized in the maximum incision scenario.

The staff believes that the assessment of the Fortymile Wash incision scenarios (DOE, 1993, Fig. 13) based upon the above two references (Lundstrom and Warren, 1994; DOE, 1995b) coupled with DOE's in-progress work (see TR Comment 6) will provide sufficient information to resolve the noted concern.

Based on the above discussion, this open item has been resolved. In-progress work being conducted by DOE will be reviewed by the staff for consistency with the indicated bases for resolution.

TR 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.*

VCR dating forms the basis for DOE (1993) concluding that sufficient sampling of the Quaternary Period has been made. A key concern that the staff has with DOE's treatment of extreme erosion has been the heavy reliance on dates produced by the VCR technique (see TR Comment 4). However, the staff notes that DOE has, in progress, site characterization investigations that utilize other age-dating methods (DOE, 1995a, p. 2-98; Gosse, et al., 1995; and NRC, 1995b). The NRC staff recognizes that application of multiple techniques for determining the exposure age of surfaces can increase the range of ages observed in the Yucca Mountain vicinity. Each technique has its own time interval over which the technique is appropriately used. Thus, ^{14}C can be used to date features up to tens of thousands of years old, whereas uranium-series disequilibrium is best suited for surfaces in the range of hundreds of thousands of years. By using multiple dating techniques, the NRC staff considers that DOE has applied the appropriate techniques to address the question of extreme erosion in the Quaternary Period.

Based on the above discussion, this open item has been resolved. In-progress work being conducted by DOE will be reviewed by the staff for consistency with the indicated bases for resolution.

TR 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.*

DOE has in-progress work using dating methodologies on surfaces in the Yucca Mountain vicinity including cosmogenic ^{10}Be , ^{14}C , ^3He , and ^{36}Cl , and other techniques such as uranium-series disequilibria of pedogenic carbonates, and thermoluminescence of soils. These techniques can serve as multiple sources of data from which erosion rates can be calculated. By using multiple techniques, the uncertainty of assigning an age to a surface may be minimized. Consequently, the staff has relied on and placed greater significance on surface ages determined by these other methods (see Comment 4).

Based on the above discussion, this open item has been resolved. In-progress work being conducted by DOE will be reviewed by the staff for consistency with the indicated bases for resolution.

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TABLE 1. ITEMS RELATED TO PAC EVIDENCE OF EXTREME EROSION DURING THE QUATERNARY PERIOD

Open Item	Source	Status
SCA Comment 42. The overall erosion program does not include an evaluation of escarpment retreat.	NRC (1989) ¹	Resolved ³
SCA Comment 43. The rationale for numerical goals specified in Tables 8.3.1.17-3a, 8.3.1.17-4a and b, and 8.3.1.17-7 is poorly supported and the use of averaged values or rates for establishing acceptable limits for fault movement, rates of volcanism, and rates of erosion does not provide for conservative assessment of potential hazards.	NRC (1989)	Resolved Previously (NRC, 1995a) ⁴
TR Comment 1. DOE should present evidence of evaluating occurrences of substantial changes in landforms over relatively short intervals of time rather than relying primarily on long-term denudation rates as surrogates of evidence of extreme erosion.	NRC (1994) ²	Resolved
TR Comment 2. DOE rate of canyon cutting appears to underestimate erosion rate in canyons at Yucca Mountain.	NRC (1994)	Resolved ³
TR Comment 3. DOE hillslope degradation rates appear to underestimate rates of erosion which occurred during individual, short intervals of the Quaternary Period.	NRC (1994)	Resolved
TR Comment 4. Reliance on the varnish cation ratio (VCR) age-dating method alone to establish age of geomorphic processes and surfaces is inadequate.	NRC (1994)	Resolved ³
TR Comment 5. Application of uranium-trend and K-Ar dates to establish the ages of stable geomorphic surfaces is uncertain.	NRC (1994)	Resolved ³
TR Comment 6. No geomorphic map has been presented by DOE.	NRC (1994)	Resolved ³
TR Comment 7. Technical basis for Fortymile Wash maximum incision scenario is not provided in the DOE Topical Report (DOE, 1993).	NRC (1994)	Resolved ³
TR Comment 8. Insufficient evidence has been presented in the Topical Report (DOE, 1993) regarding the extent of the Quaternary Period.	NRC (1994)	Resolved ³
TR Comment 9. DOE has not followed up or resolved recommendations made in the Peer Review Report on Rock Varnish Studies Within the Yucca Mountain Project (Birkeland, Oberlander, and Hawley, 1989)	NRC (1994)	Resolved ³

¹Nuclear Regulatory Commission (1989) - *NRC Staff Site Characterization Analysis of the Department of Energy's Site Characterization Plan, Yucca Mountain Site, Nevada. NUREG-1347.* Washington, DC: Division of High-Level Waste Management, Office of Nuclear Material Safety and Safeguards.

²Nuclear Regulatory Commission (1994) - *Letter of August 22, 1994, from J.J. Holonich (NRC) to R.A. Milner (DOE), Subject: NRC Staff Review of the U.S. Department of Energy Topical Report on Extreme Erosion.* Washington, DC: Division of Waste Management, Office of Nuclear Material Safety and Safeguards.

³In-progress work being conducted by DOE will be reviewed for consistency with the indicated bases for resolution.

⁴Nuclear Regulatory Commission (1995a) - *Letter of February 17, 1995, from M.J. Bell (NRC) to R.A. Milner (DOE), Subject: NRC Review of DOE Responses to SCA Comments 42 and 43.* Washington, DC: Division of Waste Management, Office of Nuclear Material Safety and Safeguards.

**TABLE 2. EROSION/DEGRADATION RATE IN YUCCA MOUNTAIN VICINITY PER 10,000 YEARS
(FROM VARIOUS SOURCES)**

Source for New Calculation	Material Eroded/ Where	Depth of Erosion ²	Total years ka	Rate of erosion in 10,000 years Meters
Crowe, et al. (1995)	Scoria/ Lathrop Wells Volcano	2 m	110	.18 ¹
Spaulding (1995)	Alluvial fill/ Upper Fortymile Wash	65 m	100	6.5 ¹
Lundstrom and Warren (1994)	Alluvial fill/ Lower Fortymile Wash	Not given	2,600	.36
Morrison (1995)	Lake bed/ Glacial Lake Tecopa	65 m	155	4.19 ¹
U.S. Department of Energy (DOE) (1995a)	Bedrock/ Solitario Canyon	80 m	1,100 ³	.73 ¹
DOE (1993)	Bedrock/ Tributary canyons to Midway Valley	60-100 m	12,700	.08
DOE (1995a)	Bedrock/ Midway Valley	Not given (est. 5mm/ka)	20	.05
DOE (1993)	Bedrock/ Boundary Ridge	1 m	140	.0571
Peterson, et al. (1995)	Bedrock/ Boundary Ridge	1 m [from DOE (1993)]	80 (based on Black Cone varnishes)	.125 ¹

**TABLE 2. EROSION/DEGRADATION RATE IN YUCCA MOUNTAIN VICINITY PER 10,000 YEARS
(FROM VARIOUS SOURCES)**

Source for New Calculation	Material Eroded/ Where	Depth of Erosion ²	Total years ka	Rate of erosion in 10,000 years Meters
DOE (1993)	Bedrock/ Yucca Mountain (6 sites)	.733 m (Average)	528 (Average)	.019 (Average)
DOE (1993)	Bedrock/ Yucca Mountain Region (12 sites)	.6 m (Average)	749 (Average)	.012 (Average)
DOE (1993)	Bedrock/ Buckboard Mesa	.2	1260	.0016 ¹
Dorn and Krinsley (1994)	Bedrock/ Buckboard Mesa	.2	310 (³⁶ Cl Maximum Limiting Age)	.0065 ¹
Gosse, et al. (1995)	Bedrock/ Buckboard Mesa	.2	600 (¹⁰ Be Maximum Limiting)	.0033 ¹
	Bedrock/ Antler Ridge & Whaleback Ridge	Calculated Maximum Erosion Rate	200 to 1060	.014 ¹
DOE (1993)	Bedrock/ Yucca Mountain YM3	1.1 m	680	.016
Liu and Dorn (In Press)	Bedrock/ Yucca Mountain YM3	1.1 m	70	.157 ¹

¹NRC calculated erosion/degradation rate

²Planned depth from surface to repository horizon is about 200 m

³These 1.1 My occurred during the Mid-Miocene and occurred from 11.6 to 12.7 My ago. The calculated erosion rate is not a Quaternary Period erosion rate but is presented for comparative purposes only.(DOE, 1993)

TABLE 3. DATA WHICH NEED TO BE QUALIFIED AND CERTIFIED AS TECHNICALLY CORRECT

Data Source	Data Need	Qualification Status
DOE (U.S. Department of Energy), 1995d. <i>Preliminary surficial deposits map of the Busted Butte 7.5' Quadrangle and the southern half of the Topopah Spring NW 7.5' Quadrangle, Nye County, Nevada.</i> YMP-95-491.0. Compiled August 7, 1995, by DOE Remote Sensing Laboratory operated by EG&G/EM.	Surficial deposits geology	Part of DOE program which was accomplished by USGS. Although not yet qualified, the data is expected to be qualified routinely and is to be certified as technically correct.
DOE (U.S. Department of Energy). 1995a. <i>Response to NRC Comments On "Evaluation of the Potentially Adverse Condition—Evidence of Extreme Erosion During the Quaternary Period At Yucca Mountain, Nevada."</i> Yucca Mountain Site Characterization Project Report OCRWM. Washington, DC: U.S. Department of Energy.	Erosion rate in bedrock based on alluvial fill in Midway Valley.	Reported in DOE comments to NRC but no data of any kind was presented. Data is expected to routinely be qualified and is to be certified as technically correct.
DOE (U.S. Department of Energy), 1995c. <i>Preliminary surficial deposits map of the southern half of the Topopah Spring NW 7.5' quadrangle and the northern half of the Busted Butte 7.5' Quadrangle, Nye County, Nevada.</i> YMP-95-014.1, Map compiled February 27, 1995, by EG&G/EM Remote Sensing Laboratory. Accompanied by U.S. Geological Survey letter report, letter, Hayes to Brocoum, dated February 27, 1995.	Surficial deposits geology	Part of DOE program which was accomplished by USGS. The letter report should be checked to reflect the results of the new uranium-series, thermoluminescence, and other age-dating techniques which have reduced some previously assigned ages by a factor of four. Although not yet qualified, the data is expected to be qualified routinely and is to be certified as technically correct.
Lundstrom, S.C., J. W. Whitney, J.B. Paces, S.A. Mahan, and K.R. Ludwig. In Press. <i>Preliminary Surficial Deposits Map of the Southern Half of the Busted Butte 7.5 Minute Quadrangle.</i> United States Geological Survey Open-File Report 95-311. Scale 1:12000.	Surficial deposits geology	Part of DOE program which was accomplished by USGS. Data has not been qualified and certified as technically correct by DOE.
Lundstrom, S.C., J.R. Wesling, E.M. Taylor, and J.B. Paces. In press. <i>Preliminary Surficial Deposits Map of Northeast 1/4 of the Busted Butte 7.5-minute Quadrangle.</i> United States Geological Survey Open-File Report 94-341. Scale 1:12000.	Surficial deposits geology	Part of DOE program which was accomplished by USGS. Data has not been qualified and certified as technically correct by DOE.
Lundstrom, S.C., and E.M. Taylor. In press. <i>Preliminary Surficial Deposits Map of the Southern Half of the Topopah Spring NW 7.5-minute Quadrangle.</i> United States Geological Survey Open-File Report 95-132. Scale 1:12000.	Surficial deposits geology	Part of DOE program which was accomplished by USGS. Data has not been qualified and certified as technically correct by DOE.
Lundstrom, S.C., S.A. Mahan, and J.B. Paces. In press. <i>Preliminary Surficial Deposits Map of Northwest 1/4 of the Busted Butte 7.5-minute Quadrangle.</i> United States Geological Survey Open-File Report 95-133. Scale 1:12000.	Surficial deposits geology	Part of DOE program which was accomplished by USGS. Data has not been qualified and certified as technically correct by DOE.
Gosse, J.C., C.D. Harrington, and J.W. Whitney. 1995. Applications of In Situ Cosmogenic Nuclides in the Geologic Site Characterization of Yucca Mountain, Nevada. Abstract, presentation, and paper at Materials Research Society Symposium on the Scientific Basis for Nuclear Waste Management XIX. Boston, Massachusetts.	Cosmogenic age-dating of Buckboard Mesa varnished clasts and bedrock near Yucca Mountain	Research supported by DOE. Data has not been qualified and certified as technically correct by DOE.

TABLE 4. OTHER SOURCES OF DATA USED IN THE ANALYSIS OF EXTREME EROSION AT YUCCA MOUNTAIN

Data Source	Data Used	Status
Dorn, R. and D. Krinsley. 1994. New perspectives on colluvial boulder deposits in the southwestern Great Basin, USA. <i>Physical Geography</i> 15: 62-79.	Age-dates on colluvial boulder deposits at Buckboard Mesa	Research supported by NSF PYI Award and by State of Nevada.
Liu, T. and R. Dorn. In Press. Understanding spatial variability in environmental change in drylands with rock varnish microlaminations. <i>Annals of the Association of American Geographers</i> .	Age-dates on colluvial boulder deposits and on scarp surfaces at Yucca Mountain	Research probably supported by State of Nevada.
Morrison, R.B. 1995. <i>Preliminary Draft "Quaternary and Pliocene Geology of Tecopa Valley, California: A Five-Million-Year Stratigraphic, Tectonic, Climatic, Erosion, Hydrologic, and Hydrogeologic Record."</i> Morrison and Associates Ltd. Golden, Colorado. 49 p.	Age-dates of erosion in Glacial Lake Tecopa sediments	Research probably supported by State of Nevada.
Peterson, Frederick F., J. W. Bell, R. I. Dorn, A. R. Ramelli and T. Ku. 1995. Late Quaternary geomorphology and soils in Crater Flat, Yucca Mountain area, southern Nevada. <i>GSA Bulletin</i> 107: 379-395.	Age-dates of Yucca Mountain boulder stripes and surficial mapping in Crater Flat	Research supported by State of Nevada.
Spaulding, W.G. 1995. <i>Effects of Climate and Hydrologic Changes in the Vicinity of Yucca Mountain Fortymile Canyon Records</i> . Dames and Moore, 4220 S. Maryland Parkway, Suite 108, Las Vegas, Nevada 89119. 4 p.	Age-dates in alluvium in Fortymile Wash	Research supported by State of Nevada.