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COMPARISON OF YUCCA MOUNTAIN SITE WITH 10CFR960 DISQUALIFYING CONDITIONS

The attached enclosure is a portion of Chapter 2 now being prepared for NNWSI's Environmental Assessment. This enclosure compares the Yucca Mountain site (using only information currently available) with the disqualifying conditions specified in DOE's 10CFR960. This comparison was requested by E. S. Burton of your office and is being provided for your review and comment. We would like to receive your comments by December 2, if possible, because the enclosure will be incorporated into the two draft chapters that are due to Headquarters on December 15.

for Donald L. Vieth, Director
Waste Management Project Office

WMPO:MBB-267

Enclosure:
1. Comparison of Yucca Mtn. with Disqualifying Conditions

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960.4.2.1 Geohydrology

A site shall be disqualified if the expected pre-waste-emplacement groundwater travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment is less than 1,000 years, unless the characteristics and conditions of the geologic setting, such as the capacity for radionuclide retardation and the groundwater flux, would limit potential radionuclide releases to the accessible environment to the extent that the requirements specified in Section 960.4-1 could be met.

Statement of Position

Analyses of currently available field and laboratory data indicate that the expected pre-waste-emplacement groundwater travel time along any path of likely radionuclide travel from the disturbed zone at Yucca Mountain to the accessible environment exceeds 1,000 years. Additionally, analyses which consider the low magnitude of the expected groundwater flux through the unsaturated zone and the evidence for high retardation capacity in the geologic system provide expectation that the total release of radionuclides to the accessible environment in 10,000 years will be less than than specified in Section 960.4.1 (40 CFR Part 191). Therefore, the Yucca Mountain site is not disqualified based on the geohydrology requirements of 960.4.2.1.

Rationale

Water Travel Time

The time required for water to travel from the proposed repository location to the accessible environment depends upon the flow path, the hydrologic conditions, and properties of material through which the water must flow. A detailed description of different strata through which the water must flow to travel from the Yucca Mountain site to the accessible environment is presented in Attachment 1, which also contains the calculations and rationale upon which the estimates of groundwater travel time are based. The discussion contained in this rationale is a summary of that document.

The stratigraphy at Yucca Mountain consists dominantly of ash-flow and bedded tuffs extending to depths greater than 1,830 m. The water table is at 400-500 m below the land surface. The surficial unit consists of alluvium in the washes and the Tiva Canyon welded unit forms much of the caprock at Yucca Mountain.

Porous flow dominates in the alluvium, while flow through the tuffs occurs through both pores and fractures. The next lower unit, the Paintbrush nonwelded unit, is highly porous and vitric; the matrix permeability of this unit is considered moderately high, and porous flow is probably the principal flow mechanism. The last unit occurring entirely above the water table at the site is the Topopah Spring welded unit, the lower part of which contains the proposed repository location. The matrix permeability is very low; however, the rock is pervasively fractured. Flow is thought to occur primarily through the fractures.

Beneath the Topopah Spring welded unit is a sequence of ash-flow and bedded tuff referred to as the Calico Hills nonwelded unit. As a result of the eastward dip of Yucca Mountain and a nearly horizontal potentiometric surface, the unit occurs above the water table except along the eastern side of the site, where it is partially below the water table. The eastern segment is zeolitic and slightly argillic. Water movement is probably primarily by porous flow in the Calico Hills nonwelded unit.

Beneath the Calico Hills nonwelded unit are the older volcanics in the saturated zone. These rocks commonly consist of zeolitic and argillic ash flow tuffs, most of which are nonwelded to moderately welded. This sequence is in part highly transmissive; water movement occurs primarily through the fractures. Approximately 2,500 m southeast of the site, pre-Tertiary carbonate rocks occur at a depth of about 1,250 m; however, beneath the site they are believed to be greater than 3000 m deep.

The proposed repository location is situated above the water table. The amount of infiltration is probably less than 4 mm/year and may be less than 1 mm/year. Infiltration is expected to be episodic but attenuated to a large degree by the nature of the strata.

The travel time calculations include the movement of water through the strata above the water table; this movement is generally downward. Below the water table movement is generally horizontal toward the accessible environment.

Travel time calculations presented here consider only that portion of the flow through the Calico Hills nonwelded unit in the unsaturated zone and from the water table to the accessible environment in the saturated zone. The details of the calculations are covered in Attachment 1. The travel times calculated through the Calico Hills nonwelded unit range from 1,900 to 5,600 years. The component of travel time for the saturated zone is 30 to 700 years. Hence, the total travel time calculated for the site ranges from 1,930-6,300 years; because of conservative assumptions made here, total travel time probably is greater.

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Radionuclide Release

The radionuclide transport for the Yucca Mountain site was analyzed using the geohydrologic model defined in Attachment 1. The details of this analysis are given in Attachment 2. The results of the analysis are summarized in the following statements.

Given the travel times of the radionuclides of Table 2, (Attachment 2), the integrated release at the accessible environment boundary (i.e., 10 km) for the first 10,000 years would be zero, except for ~~technetium and~~ carbon isotopes. ~~Technetium release is not expected to exceed the EPA release limits and~~ carbon isotope inventory in the repository cannot be estimated at the present time and will not be included in the calculation. Therefore, it is reasonable to expect that release limits specified in the December 1982 EPA Standard 40 CFR 191 are satisfied.

XREF to Appendix

The way that water moves within and is controlled by the geologic framework is very important to evaluations of Yucca Mountain as a possible repository for nuclear waste. Therefore, described below are the current conceptual models of the geohydrologic framework.

A. Hydrogeologic Units. Variations in the physical and chemical properties of the rocks in the unsaturated zone do not necessarily correspond to rock-stratigraphic boundaries. Those properties (rather than the mode of origin) control the characteristics of water occurrence and flow in the unsaturated zone and other aspects that are of concern in assessments of HLW isolation capabilities and engineered barrier designs. Therefore, based on these physical and chemical properties, the rocks have been grouped into hydrogeologic units, as described below. A summary of properties of the unsaturated-zone units and their relationship to rock-stratigraphic units is shown in Table 1.

1. Alluvium. Poorly consolidated alluvium underlies the washes that dissect Yucca Mountain and forms the surficial deposit in broad inter-ridge areas and flats near Yucca Mountain. Lithology, sorting, and permeability of the alluvium are highly variable; particles range in size from clay to boulders and in places the unit is moderately indurated by caliche. Compared to the tuff units, however, the permeability of alluvium is generally high.

2. Tiva Canyon welded unit. The Tiva Canyon welded unit corresponds to the densely to moderately welded tuff of the Tiva Canyon Member. This unit forms the "caprock" of much of Yucca Mountain and dips 5 to 8° eastward, resulting in a relatively planar eastward sloping land surface. The matrix of the unit has very low permeability and the unit has high fracture density.

3. Paintbrush nonwelded unit. The Paintbrush nonwelded unit includes the Pah Canyon Member, Yucca Mountain Member, and upper nonwelded part of the Topopah Spring Member. Tuffs of this unit are vitric, nonwelded, highly porous, poorly indurated, and in part, bedded. The unit has very low fracture density. Although specific data are not available, the Paintbrush nonwelded unit probably has moderately high matrix permeability.

4. Topopah Spring welded unit. The Topopah Spring welded unit consists of a thin upper vitrophyre, a thick central zone comprising several densely welded ash flow sheets, and a thin lower vitrophyre. At Yucca Mountain, the unit (1) is densely to moderately welded and devitrified throughout its central part; (2) contains several lithophysal cavity zones that are generally continuous but vary appreciably in thickness and stratigraphic position; and (3) is intensely fractured. The matrix has very low permeability. Based on characteristics of cores, fluid losses during drilling, and the productivity of wells that penetrate it beneath the water table

Table 1. Properties of unsaturated-zone hydrogeologic units at Yucca Mountain.

Rock-Stratigraphic Unit			Hydrogeologic Unit	Thickness (m)[1]	Fracture Density (f/unit m^3)[2]	Permeability[3] Matrix	Permeability[3] Fracture
Alluvium			Alluvium	0-30+	--	Generally High	--
Paintbrush Tuff	Tiva Canyon Member		Tiva Canyon welded unit	69-148	10-20	Very low	High
Paintbrush Tuff	Pah Canyon Member		Paintbrush nonwelded unit	0-200	1	Moderately high	Low?
Paintbrush Tuff	Yucca Mountain Member						
Paintbrush Tuff	Topopah Spring Member	Nonwelded					
Paintbrush Tuff	Topopah Spring Member	Vitrophyre	Topopah Spring welded unit	287-359	8-40	Very low	Very high
Paintbrush Tuff	Topopah Spring Member	Welded					
Paintbrush Tuff	Topopah Spring Member	Vitrophyre					
Paintbrush Tuff	Topopah Spring Member	Nonwelded	Calico Hills nonwelded unit	100-400	2-3	Low-medium	Low-high
Tuffaceous [illegible]s of Calico Hills	Vitric		water table[4]				
Tuffaceous [illegible]s of Calico Hills	Zeolitized		saturated zone				
Crater Flat Tuff	Prow Pass Member	Nonwelded					
Crater Flat Tuff	Prow Pass Member	Welded					

1. Ref. 19
2. Ref. 8
3. Assumed, based on physical characteristics
4. In the southeastern part of Yucca Mountain, the welded part of Prow Pass Member and the Bullfrog Member of the Crater Flat Tuff are in the unsaturated zone. In most of the repository block, however, the water table occurs within the tuffaceous beds of Calico Hills, and for purposes of this report, unsaturated-zone hydrogeologic units are not designated below the nonwelded part of the Prow Pass Member.

elsewhere, this unit is presumed to have a very high fracture permeability. The central and lower part of the Topopah Spring welded unit is the candidate host rock for a Yucca Mountain repository.

5. Calico Hills nonwelded unit. The Calico Hills nonwelded unit includes, in descending order, (1) a nonwelded vitric layer, locally zeolitized, that is the lower most part of the Topopah Spring Member, (2) tuffaceous beds of Calico Hills, the principal component of this hydrogeologic unit; and (3) the nonwelded upper part of the Prow Pass Member of the Crater Flat Tuff, where it is above the water table. The base of the Calico Hills nonwelded unit is determined by the position of the water table. In the eastern and northern parts of Yucca Mountain, the water table is above and near the base of the tuffaceous beds of Calico Hills; in the western and southern parts of Yucca Mountain, the water table is in the Crater Flat Tuff. In the eastern and northern parts, the unit is pervasively zeolitized; in the southwestern part it is vitric. It is presumed, but not confirmed, that zeolitization is associated with a formerly higher water table and that the zeolitic facies advances upward from the base of the tuffaceous beds of Calico Hills from southern to more northeastern positions beneath Yucca Mountain.

Both the vitric and zeolitic facies of the tuffaceous beds of Calico Hills are highly porous; 30% by volume is probably a conservatively low value. Laboratory porosimeter studies from a core sample of this unit show that only a small percentage (about 5 percent) of the pore space is large enough to contribute significantly to flow in saturated conditions (   ). This pore space that contributes to flow is equivalent to an effective porosity of 1.5 percent. However, under unsaturated conditions, the larger pores are probably drained and do not contribute to water flow. The remaining 28.5 percent of porosity that is probably water filled in the unsaturated zone has a very uniform pore-size distribution. About half of these pores are approximately the same size; assuming that these uniform pores are those that contribute to flow in the unsaturated zone, effective porosity would be about 15 percent. Thus a value of 1.5 percent may be assumed as an absolute minimum for unsaturated-zone effective porosity, whereas 15 percent is a more probable value.

Measured values for the saturated hydraulic conductivity of zeolitic samples from two core holes at Yucca Mountain comprise a unimodal distribution with a most frequent value of about 5×10^{-2} m/yr. Values for vitric samples comprise a bimodal distribution with most frequent values of about 1×10^{-4} m/yr and 1×10^{-1} m/yr.

6. Older volcanics. Rocks older than the tuffaceous beds of Calico Hills occur partly above the water table beneath the western half of the disturbed zone and below the water table there and to the east. Nonwelded to moderately welded tuffs predominate over thinner intervals of densely welded ash-flow tuff, bedded ash-fall tuff, and dacitic lava and flow breccia. The rocks are commonly zeolitized and argillized (Ref. 4) where they have been sampled. Hydraulic testing, (Ref. 5) including flow surveys while pumping, has shown the rocks to contain moderately to highly transmissive zones with fracture permeability dominating. Bulk transmissivity is variable from place to place, and flow surveys demonstrate that there is not clear stratigraphic control on the locations of permeable zones. Hydraulic tests show that an average hydraulic conductivity of 1 m/day characterizes this unit where it is highly fractured.

   Although matrix porosities are commonly in the range of 20 to 30 percent for partially to nonwelded tuffs (Ref. 6), effective porosity is most likely determined by the fracture porosity, and is therefore lower. Few field tests have been performed that yield estimates of fracture porosity. A bromide tracer was introduced into UE-25a#1 during the 29-day pumping test of UE-25b#1; estimates of effective porosity based on the resulting breakthrough are on the order of 0.0002 to 0.002 (Waddell, 1984). Calculation of effective aperture from analysis of pumping test data from J-13 (Thordarson, 1984) yield fracture porosities ranging from 0.00001 to 0.005, depending on various assumptions for number of fractures contributing flow and the friction coefficient; the larger number is probably more representative. Thus, effective porosity is probably less than 0.005 and may range over several orders of magnitude.

7. Pre-Tertiary rocks. Carbonate rocks occur beneath the Tertiary volcanic sequence at a depth of about 1250 m in only one drill hole, UE-25p#1, located about 2.5 km east of the proposed repository. These consist of fractured and brecciated dolomites of probable Silurian age. Recent testing shows that they are highly permeable with fracture flow predominating, but values of hydraulic conductivity and effective porosity are not available. Geophysical evidence (Ref. 7) indicates that Paleozoic rocks are either not present beneath Yucca Mountain itself or else occur at great depth ($>$ 3,000 m) beneath the thick section of volcanic rocks.

B. Structural Flowpaths

The area of principal interest, informally termed the "central block," is bounded on the west by a fault, topographically expressed by Solitario Canyon, that significantly offsets the target horizon; on the north by a probable fracture zone topographically expressed by Drillhole Wash; on the east by several small faults; and on the south by an area of closely spaced small faults and fracture zones (Ref. 8). Minor faults of small displacement also occur within the central block; hydraulic characteristics of these faults remain to be determined.

For the purpose of geohydrologic evaluation, it is assumed that fracture and fault zones are preferential pathways for saturated flow in rocks that have insufficient matrix permeability to allow passage of the prevailing flux under the prevailing hydraulic gradient. It is further assumed that the repository would be within only the central block. (Information that is presently available, however, does not preclude expansion beneath Drillhole Wash to the northern block.) No multiple-well test data are available (though tests are planned) to show either the degree of hydraulic continuity and interconnectivity of the fracture and fault zones, or the resultant anisotropy of bulk transmissivity. Hence, the hydraulic conductivity (1 m/day) chosen (A.6 above) for calculation of groundwater velocity in the saturated zone to the accessible enviroment is that determined from tests (Ref. 9) in well J-13 east of the site and in UE-25b#1, a hole that penetrates the fracture zone beneath Drillhole Wash; also conservative is the assumption that this and other potential pathways are hydraulically continuous to the accessible environment along 10 km a straight-line flow path.

C. Recharge

Recharge was estimated by two independent techniques. The first technique is derived from perturbations of the geothermal heat flow by the downward flux of water in the unsaturated zone and in the uppermost saturated zone. Calculations published to date (Ref. 10) indicate a Darcian flux of 1-10 mm/yr. Further analyses that are underway indicate that unsaturated zone flux is probably less than 4 mm/yr and may be less than 1 mm/yr. For example, analysis of data from USW-G1 borehole (Ref. 10) indicates a flux of about 4 mm/yr if only the unsaturated zone is considered and even this amount of flux could be the result of the movement of drilling fluid in the vicinity of the borehole. Based on heat flow data from boreholes UE25-a#4 and UE25-a#5, a large negative (upward) flux was calculated (about -50 mm/yr). A negative flux was also reported (Ref.) for the unsaturated zone using heat-flow data from UE25-a#1 (about -150 mm/yr). These upward fluxes are probably the result of convection cells formed by air movement in the more fractured Topopah Spring welded unit. Although the absolute values of the negative fluxes may not be realistic (the original calculations are for incompressible fluids), the concept of potential upward flux is important.

Low flux is also indicated by preliminary data from the borehole USW UZ-1 (Ref.). Moisture contents measured in the cuttings obtained from the Topopah Spring welded unit are less that 5 percent by weight. Although this value corresponds to . saturation of 80-85 percent, because of the low porosity in these rocks, the high water tensions (greater than 20 bars) measured in the matrix of these cuttings indicate that no significant liquid-phase flow is occurring in the matrix. Preliminary data from the instruments in the UZ-1 borehole indicate high water tensions at depths below 500 feet, thus supporting the validity of the drill cutting data. These results indicate that the fractures are devoid of water, except near the bottom of the borehole, where drilling water was encountered.

The second technique utilizes relationships among recharge, altitude zone, and precipitation that have been developed by the U.S. Geological Survey in water-budget studies in cooperation with the Nevada Department of Conservation and Natural Resources (Ref. 11). For the Yucca Mountain area and altitude zone, the annual precipitation is 150 mm to 200 mm (Ref. 12) and the part of that estimated to recharge the groundwater system is 3 percent (Ref. 13). The resulting value of about 5 mm/yr Darcian flux compares favorably with the upper values estimated by the heat-flow analysis.

Within the local setting, the persistent soil-moisture deficiency indicates that only major runoff-producing precipitation events are likely to produce recharge. This local recharge is probably concentrated areally in the major ephemeral washes that define the boundaries of the central block at Yucca Mountain. The actual recharge in the interchannel and undissected areas overlying the proposed repository is probably less than the 5 mm/yr established above. A value of 4 mm/yr selected for travel-time calculations is believed to be conservative, perhaps highly so.

D. Conceptual Flow Models and Travel Time

1. Unsaturated Zone

Although little is known concerning the manner and rate in which flow occurs in the unsaturated zone at Yucca Mountain, certain assumptions have been made concerning the flow system. Based on these assumptions, three conceptual models have been developed that differ largely due to different assumptions concerning the locus and rate of infiltration.

Three conditions of intensity of flux can be considered: (a) low intensity flux due to relatively uniform distribution of recharge in time and space; (b) moderate intensity of flux, based on relatively nonuniform distribution of recharge in time and concentration beneath washes; and (c) high intensity of flux, due to periodic highly intense and localized recharge events.

Flow in the Paintbrush nonwelded unit and Calico Hills nonwelded unit is thought to be primarily vertically downward by matrix flow. Due to relatively high matrix porosities and permeabilities and low fracture density and permeability, fractures probably do not contribute significantly to flow under partially saturated conditions in these units. At zones of contrast between relatively fine-grained nonwelded units and relatively open fractures of welded units, a strong capillary barrier may retard flow from the matrix into the fractures. Flow will also be hindered from entering the fine-grained matrix of the welded unit because of low matrix permeability. This is the expected condition throughout Yucca Mountain at the contact between the Paintbrush nonwelded unit and the underlying Topopah Spring welded unit. A capillary barrier also exists where a welded unit overlies a nonwelded unit because of the finer pore sizes in the matrix of the welded unit compared to the pores in the matrix of the nonwelded unit. This condition would occur where the Tiva Canyon welded unit overlies the Paintbrush nonwelded unit, and where the Topopah Spring welded unit overlies the Calico Hills nonwelded.

Variability in flux is the primary factor controlling the relative contribution of fracture and matrix flow to total flux through the unsaturated flow system. Flow through major structural features is thought to occur more readily and in greater amounts than flow through the fractured but relatively intact blocks bounded by such features. At relatively low fluxes, water moving in fractures in welded units probably becomes diffused into the matrix, whereas at high fluxes, flow in the fractures is sufficiently rapid to escape diffusion. Varying fluxes and permeability contrasts will lead to lateral flow in both the nonwelded and welded units. In a nonwelded unit, this flow could occur because water does not readily enter the underlying welded unit. In a welded unit, lateral flow through intersecting fractures could occur if flux is greater than can be accepted by the underlying nonwelded unit.

Figure 1 shows the unsaturated zone flow system for a condition in which infiltration is relatively uniformly distributed over Yucca Mountain in time and space. Large volumes of rocks are involved in transporting low flux and most flow is in the matrix. Fracture flow is minimal and short-lived because the water diffuses into the matrix.

Figure 2 is a flow model based on the assumption that nonuniform recharge periodically produces moderately intense flux. Downdip flow occurs in the Tiva Canyon welded unit along the contact with the underlying Paintbrush nonwelded unit. Much of this flow travels in the major structural features directly to the water table; some water diffuses into the matrix of the Paintbrush nonwelded unit and moves downward until sufficient saturation is attained to allow downdip flow. Downdip flow is expected at contacts between units with differing permeabilities; water in fractures in the Topopah Spring welded unit moves by sheet flow and diffuses into the matrix, while some water may move by vapor diffusion and become incorporated into convection cells under the influence of the geothermal gradient. In this model, minimal flow would be expected in the host rock except along the major structural features; this model is supported by the high water contents known to occur in nonwelded units and by the very low water contents that are known to exist in the Topopah Spring welded unit (Ref.).

Figure 3 is a flow model that is based on the assumption that periodic recharge events are sufficiently intense to create saturated conditions in the lower Paintbrush nonwelded unit. This condition would create sufficient head to initiate flow through fractures of the underlying Topopah Spring welded unit and flow rates could be high enough that most water escapes diffusion into the matrix. A large proportion of the water would be diverted into the major structural features. Flow in this model occurs principally through fractures and travel times are short.

Travel time from the disturbed zone to the top of the Calico Hills nonwelded unit is not considered in the analysis. Assume first that the upper range of the bimodally distributed permeability predominates areally in the vitric tuff of the Calico Hills nonwelded unit. Under the unit hydraulic gradient ($i=1$) in the unsaturated tuffs, the maximum flux (q_{max}) that can be transmitted without at least partial rejection is equal to the saturated hydraulic conductivity (k_s):

$$q_{max} = (k_s)\ (i) = 100 \text{ mm/yr}$$

Similarly, for the zeolitic tuff, $q_{max} = 50$ mm/yr. Therefore, both tuff facies can readily transmit the conservatively high recharge flux of 4 mm/yr.

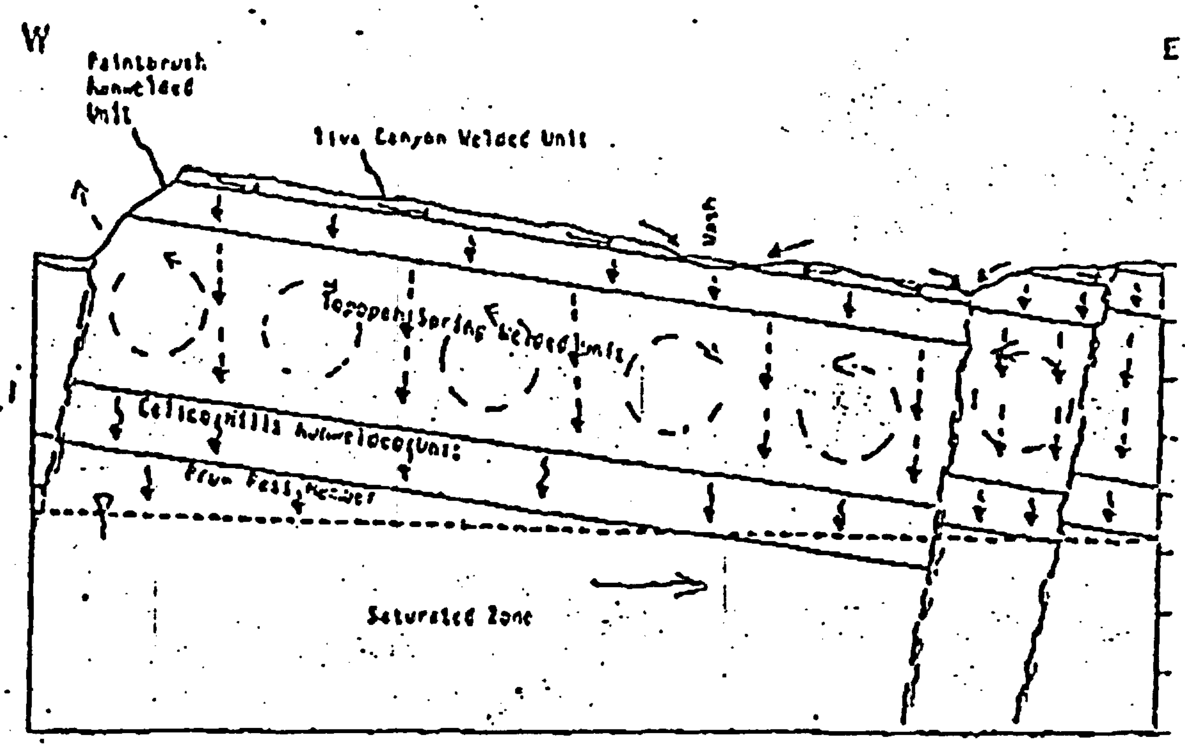

Figure 1. Generalized section across Yucca Mountain showing unsaturated-zone flow system under assumed conditions of uniform distribution of recharge resulting in low flux intensity (Conceptual Model No. 1). Matrix flow dominates in the Topopah Spring welded unit, and convection cells of vapor transport occur.

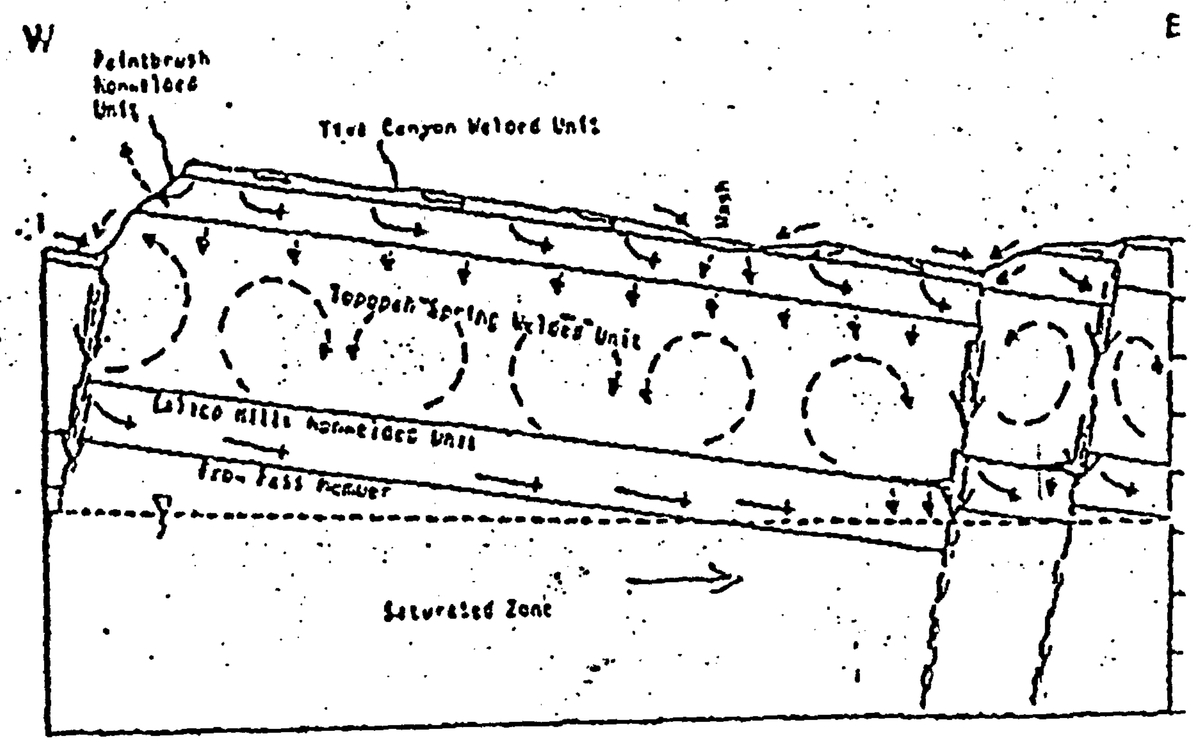

Figure 2. Generalized section across Yucca Mountain showing unsaturated-zone flow system under assumed conditions of nonuniform recharge conditions periodically producing moderately intense flux (Conceptual Model No. 2). Convection cells of vapor transport occur in the Topopah Spring welded unit.

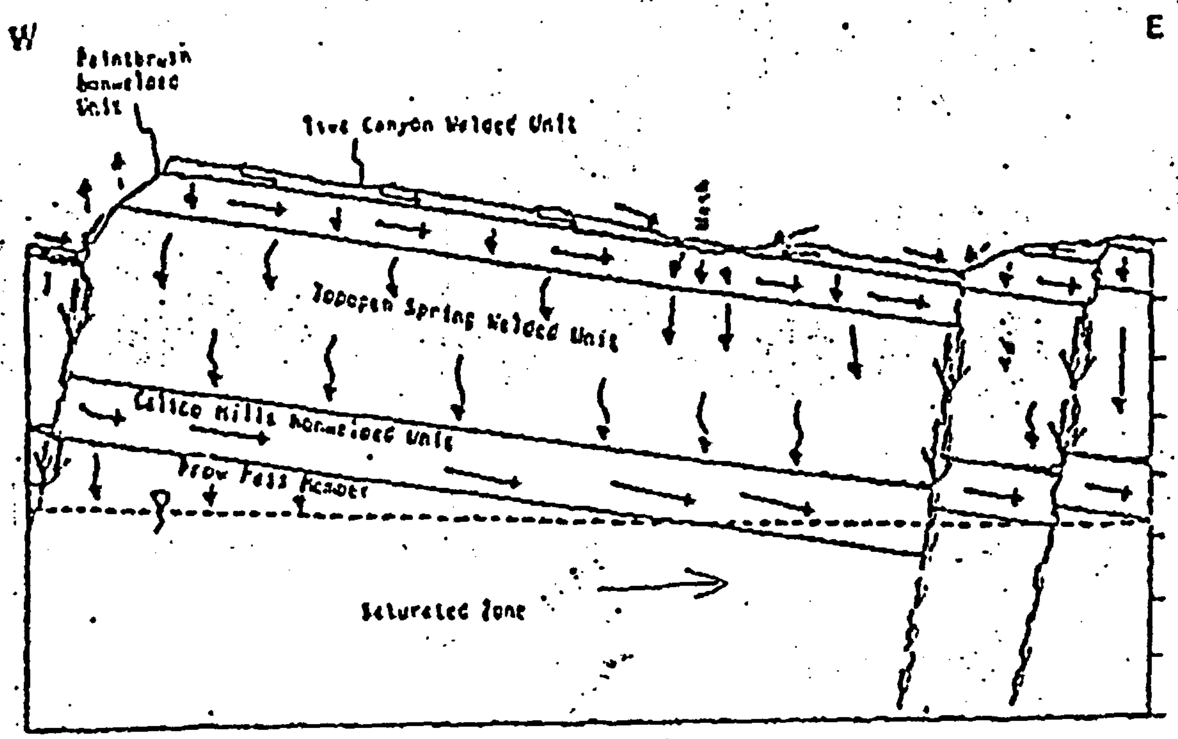

Figure 3. Generalized section across Yucca Mountain showing unsaturated-zone flow system under assumed conditions of periodic intense recharge events (Conceptual Model No. 3). Fracture flow dominates in the Topopah Spring welded unit.

There are not yet sufficient data to estimate the velocity of unsaturated flow through the Calico Hills nonwelded unit by rigorous methods relating the dependency of hydraulic conductivity and effective porosity to ambient moisture content, flux, and pore geometry. However, from the few measurements or estimates that are available a reasonable prediction of probable average velocity can be obtained by the relation,

$$v_s = \frac{\left(\frac{q}{q\ max}\right) k_s}{n} = \frac{q}{n} = \frac{.004\ m/yr}{.15} = 0.0267\ m/yr.$$

The thickness of the Calico Hills nonwelded unit ranges from about 100 m at the southern end of the central block to about 150 meters at the northern end (Refs 2, 3, 4, 14). Dividing this range by the average velocity results in calculated travel times of 3,800 to 5,600 years.

Alternatively, if the lower range of permeability measured in the vitric tuff (1.0×10^{-4} m/yr) is stratigraphically continuous (which is not known to be the case), the recharge could be rejected and diverted eastward and northward to the zeolitic facies. Again, conservatively estimating that all of the recharge might flow through only half of the cross-sectional area, where the Calico Hills nonwelded unit is at least 100 m thick, the calculated travel time is 1,900 years.

2. Saturated Zone

Measurements of hydraulic conductivity, hydraulic potential, temperature and depths of permeable zones in boreholes indicate that flow paths in the older volcanics beneath the water table are tortuous, preferentially following fractures where they are open and favorably oriented. Permeable fractures occur with the greatest frequency in the upper 500 m of the saturated zone. That fracture properties vary in space is indicated by the fact that transmissivity or storage coefficients appear to change during hydraulic testing, as the zone of influence of the test expands from the borehole.

The water table to the north and west of the proposed repository site and beneath the western part of the central block is higher than that farther south and east by several tens of meters. Data are sufficient to indicate, though not yet to demonstrate conclusively, that the Solitario Canyon fault is not a major pathway for southward flow despite its favorable orientation with respect to the regional southward direction of flow.

Beneath the eastern half of the repository and to both the east and south, the water table is nearly flat and is difficult to characterize. Tentative results of an ongoing drilling program suggest that, from the southern end of the disturbed zone, flow is southward but that, from the central and northern parts, flow is generally eastward. The general southward direction of regional flow is well documented (Refs. 12 a, 13, 15) and constrains this eastward flow from the central block of Yucca Mountain. The most probable pathway is eastward or southeastward to a position beneath Fortymile Wash, about 7 km east of Yucca Mountain and then south-southeastward following the trend of the wash. Such a curvilinear path would increase the actual distance of flow to the accessible environment to more than 10 km. For purposes of the calculations that follow, it is conservatively assumed that neither curvilinear nor tortuous flow paths significantly increase the 10-kilometer distance.

Similarly, no credit is taken for transit times beneath the Calico Hills nonwelded unit under the repository, even though most of the flux through this zone will be significantly delayed in this segment of the total pathway. An additional thickness of up to 50m is encountered in the western half of the repository block.

The calculation of flow time to the accessible environment is as follows:

Hydraulic conductivity, k = 1 m/day, or 365 m/yr (See A.6 above), for a unit hydraulic gradient.

Hydraulic gradient, $i = 2.0 \times 10^{-4}$ (Distance-weighted average of gradients between USW-G-4 and Well J-13 and between Well J-13 and Well J-12, based on measured hydraulic heads and distances. The first segment has a gradient of 2.25×10^{-4} over a distance of 7.1 km; the second has a gradient of 1.7×10^{-4} over a distance of 4.7 km).

Effective porosity, n_e = 0.0002 to 0.005 (See A.6 above.)

Average velocity along flow path,

$$v = \frac{(k_s i)}{(n_e)} = \frac{(365)(2.0 \times 10^{-4})}{(0.0002 \text{ or } 0.005)} = 365 \text{ m/yr or } 14.6 \text{ m/yr}$$

Travel time for 10 km,

$$t = \frac{10{,}000}{365 \text{ or } 14.6} = 27 \text{ to } 700 \text{ yrs}$$

These results are very tentative and cannot be verified until additional field tests are conducted to determine effective porosity more precisely.

These results are inconsistent with results of regional investigations. Hydraulic analyses of Pahute Mesa, which is comprised of similar rock types provide a probable velocity on the order of 5 m/yr (Ref. 16). Carbon-14 ages of groundwater in the vicinity of Yucca Mountain are in the range of 10,000 to 13,000 years (Ref. 17). If it is assumed that these water are derived from Pahute Mesa, 65 km to the north, the calculated groundwater velocities are 5 to 7 m/yr. Addition of recharge between the basin extremity and Yucca Mountain would result in lower calculated velocities. Until additional field tests are conducted to determine effective porosities, the inconsistency in velocities and resultant travel times cannot be resolved.

ATTACHMENT 2

Travel Times of Radionuclides Through the Calico Hills

Radionuclide travel times through the Calico Hills are presented in terms of Yucca Mountain travel times, given in Attachment 1. The Calico Hills is 100 m thick with a water velocity of 0.0267 m/yr, and a porosity of .15 is given for the Calico Hills. To calculate radionuclide migration rate, the bulk density for the unit is taken to be 1.6 gm/cc (Ref. 2).

Radionuclide travel time is then given by:

$$\text{Travel Time} = \frac{\text{Distance x Retardation Factor}}{\text{Water Velocity}}$$

For porous flow:

$$\text{Retardation Factor (R)} = 1.0 + \frac{\text{Bulk Density x Sorption Coeff.}}{\text{Porosity}}$$

From these assumptions, $R = 1.0 + \frac{1.6}{.15} K_d$

and $\text{Travel Time (TT)} = \frac{100M \times R}{0.0267 \text{ m/yr}}$

Table 1 gives Calico Hills travel times for various K_d's. Calico Hills travel times for the radionuclides listed by EPA are given in Table 2.

The chemical species having the poorest sorption is TcO_4^-. It should be noted, however, that desorption values appear to be much greater than sorption indicating irreversible retention of Tc. The conservative value chosen provides confidence that Tc release will not exceed EPA release limits at the accessible environment (10 km) boundary.

C-14 could not be evaluated because not enough is known about the chemical form of carbon which would be released from spent fuel. Also, the inventory of C-14 in spent fuel is not well defined. These are not site specific factors. All other elements specified in 40 CFR 191 but not included in Table 2 would have travel times many orders of magnitude greater than 10^4 years.

Given the travel times of the radionuclides in Table 2 plus the travel time in the saturated zone (neglecting retardation in the saturated zone), the integrated release at the accessible environment for the first 10,000 years following emplacement would be zero. Therefore, based on this analysis, the standards of the December 1982 EPA 40 CFR 191 are satisfied.

TABLE 1.

Calico Hills Travel Times for Representative K_d Values

K_d	Retardation Factor	Travel Time
0	1.00	3.7 z 10^3
0.1	2.07	7.7×10^3
0.2	3.14	1.2×10^4
0.5	6.35	1.2×10^4
1	11.70	4.4×10^4
10	108.0	4.0×10^5
100	1071.0	4.0×10^6

TABLE 2.

Calico Hills Travel Times for Elements in EPA Isotope List

Element	K_d for Calico Hills****	Travel Time Through Calico Hills in Years
Am	4600	1.8×10^8
Cs	13000	5.2 z 10^8
Np	11	4.4×10^5
Pu	130	5.2×10^6
Ra*	85000	3.4×10^9 ERROR!
Sr	27000	1.1×10^9
Tc**	0.22	~~8.8×10^3~~ ← 1.25×10^4
Sn***	260	1.0×10^7
C	NA	3.7×10^3***** or greater

* Ba was used as a chemical analogue

** K_ds for T_c have not been measured in air for the Calico Hills. The value in the table is the average of the measured values for the units above and below.

*** Not from Calico Hills but from similar mineralogy (G1-2233)

**** The K_ds are taken from Ref. 2.

***** Travel time for retardation factor = 1.00.

REFERENCES

1. Attachment 1 - this document

2. Schwartz, B. M., 1983, "Bulk Properties of Core Samples From Hole USWGU3," Memo to A. R. Lappin, SAND-9763-830113, Sandia National Laboratories.

3. Daniels, W. R., et al., 1982, "Summary Report on the Geochemistry of Yucca Mountain and Environs," Los Alamos National Laboratory Report LA-9328-MS.

960.4.2.5 Erosion.

The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface.

Statement of Position

The welded tuff section of the Topopah Spring Member has sufficient thickness and depth that all portions of the underground facility will be located, by both design and placement, at least 200 meters below the directly overlying ground surface. Therefore, the Yucca Mountain site is not disqualified based on the Erosion guideline (960.4.2.5).

Rationale

The 200 meter overburden requirement is being utilized as a principal design constraint for locating the underground facilities. Stratigraphic data obtained during preliminary investigations of the Yucca Mountain region has shown that sufficient Topopah Spring welded tuff exists in which to locate the underground facilities of a waste repository at a depth greater than 200 meters.(1) This information was derived from the identification and correlation of geologic units based on data from boreholes and surface mapping.(2,3,4)

As discussed under favorable condition number 1 of 960.4.2.3, Rock Characteristics, emplacement in rock units below the Topopah Spring member has not been shown to be unacceptable. Therefore, location of the underground facility at greater depths is possible should some condition be found that makes emplacement in the Topopah Spring member infeasible or unacceptable.

References

1. Mansure, A. J., Memo of Record detailing the existence of 200 meters overburden for proposed waste emplacement zone, August 1983.

2. Scott, R. B., Spengler, R. W., Diehl, Sharon, Lappin, A. R., and Chornack, M. P., Geologic character of the unsaturated zone in ash-flow tuff at Yucca Mountain, southwestern Nevada, in Role of the unsaturated zone in radioactive and hazardous waste disposal: Ann Arbor, Ann Arbor Science, p. 189-335, 1983.

3. R. W. Spengler, F. M. Byers, Jr., and J. B. Warner, "Stratigraphy and Structure of Volcanic Rocks in Drill Hole USW-G1, Yucca Mountain, Nye County, Nevada," USGS Open-file report 81-1349, 1981.

4. Scott, R. B., and Castellanos, Mayra, Preliminary report on the geologic character of drill holes USW GU-3 and USW G-3: U.S. Geological Survey Open-file Report (in preparation).

960.4.2.6 Dissolution.

The site shall be disqualified if, during the first 10,000 years after closure, active dissolution fronts will cause a hydraulic interconnection of the underground facility to the geohydrologic system of the site such that the requirements specified in Section 960.4.1 cannot be met.

Statement of Position

The minerals which compose the rock in and around the repository are considered insoluble and no significant dissolution is expected to occur even at the elevated temperatures expected in the near field. Consequently, the formation of active dissolution fronts is not a logical expectation for conditions at Yucca Mountain. Therefore, the Yucca Mountain site is not disqualified based on the Dissolution guideline (960.4.2.6).

Rationale

The host rock of Yucca Mountain consists of the moderately-to-densely welded and devitrified portion of the unsaturated Topopah Spring Member. The host rock has been extensively studied by drill hole sampling in and around the exploration block (Bish et al., 1981; Byers and Warren, 1983; Caporuscio et. al., 1982; Carroll et al., 1981; Heiken and Bevier, 1979; Levy, 1984; Maldonado and Koether, 19__; Scott and Castellanos, 1984; Spengler et al., 1979; Sykes et al., 1979; Vaniman et al., 1984). A current summary emphasizes the mineralogic simplicity of the host rock (Bish et al. 1984). At all points within the exploration block, over 95% of the host rock horizon consists of alkali feldspars, quartz, and cristobalite. The reports enumerated above point out that the remainder consists of other silicate minerals and iron-titanium oxide minerals. None of these minerals are prone to aqueous dissolution in any significant quantities. No evidence of Quaternary dissolution fronts or other Quaternary dissolution features has been found.

The least stable mineral present in significant quantities in the host rock and below is volcanic glass. A vitric zone with a thickness of about 100 feet (Ref. 2) is located below the Topopah Spring Member at Yucca Mountain. In Rainier Mesa, which has an upper vitric layer as does Yucca Mountain, the groundwater composition has been shown to be strongly influenced by the dissolution of glass (Ref. 1). The maximum water temperature expected in the vicinity of the waste is about 140°C, based on the calculation of Travis et al. (Ref. 3). The infiltration rate is assumed to be about 8 mm of water per year. This infiltration rate is considered to be conservative and consistent with estimates of 1-10 mm/yr based on measurements of the geothermal gradient in USW-G1 (Ref. 4) and other information (Ref. 5). The solubility of amorphous silica at 140°C is 8×10^{-3} molal (Ref. 6). This corresponds to 480 mg/l of SiO^2. With 8×10^{-4} liters of water per cm^2 per year passing through the repository, 0.38 mg of SiO^2 per year dissolve away, ignoring the possible precipitation of silicate minerals in the cooler underlying rock. The SiO^2 composition of the vitrophyre is 77% (Ref. 7) and the density of the vitric layers is about 2.3 g/cm^3. Thus, 2.2×10^{-4} cm^3 per cm^2 of vitric rock could be dissolved per year. In 10,000 years only 2.2 cm^3 of the $3 \times 10^3 cm^3$ of vitric rock could dissolve per cm^2.

This very conservative estimate shows that potentually a maximum of 0.1% of the vitric rock underlying the repository could be dissolved in 10,000 years. This would not create a preferential flow path from the underground facility to the water table.

References

1. A. F. White, H. C. Claassen, and L. V. Benson, "The Effect of Dissolution of Volcanic Glass on the Water Chemistry in the Tuffaceous Aquifer, Rainier Mesa, Nevada," Geological Survey Water-Supply Paper 1535 - Q, 1980.

2. R. W. Spengler, F. M. Myers, Jr., and J. B. Warner, "Stratigraphy and Structure of Volcanic Rocks in Drill Hole USW-G1, Yucca Mountain, Nye County, Nevada," USGS Open-file Report 81-1349, 1981.

3. B. J. Travis, S. W. Hodson, H. E. Nuttall, T. L. Cook, and R. S. Rundbery, "Preliminary Estimates of Water Flow and Radionuclide Transport in Yucca Mountain," Rough Draft, 1983.

4. J. H. Sass and A. H. Lachenbruch, "Preliminary Interpretation of Thermal Data From the Nevada Test Site," USGS Open-file Report 82-973, 1982.

5. R. K. Blankennagel and J. E. Weir, Jr., "Geohydrology of the Eastern Pahute Mesa, Nevada Test Site, Nye County, Nevada," USGS, Prof. Paper 712-B, 1973.

6. J. V. Walther and H. C. Helgeson, "Calculation of the Thermodynamic Properties of Aqueous Silica and the Solubility of Quartz and its Polymorphs at High Pressures and Temperatures," Amer. Journal of Science 277, 1315, 1977.

7. P. W. Lipman, K. L. Christiansen, and J. T. O'Connor, "A Compositionally Zones Ash-Flow Sheet in Southern Nevada," U.S. Geological Survey Prof. Paper 524-F, 1966.

960.4.2.8.1 Human Resources.

A site shall be disqualified if previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment.

Statement of Position

There have been no commercial exploration mining or extraction activities at the site, hence no pathways have been created between the projected underground facility and the accessible environment. Therefore, the Yucca Mountain site is not disqualified on the basis of the Human Resource guideline (960.4.2.8.1).

Rationale

Thorough examination of the site and the surface above and around the projected underground facility as well as comprehensive searches of literature and mining claim files have disclosed no evidence of ground-disturbing activities. Searches have included:

- o Archaeological field surveys for historic artifacts, prospects, or other indicators of resource extraction activity on the site (Ref. 1),
- o A search of mining literature and claim files for records of past interest in or activity on the site (Ref. 2),
- o Geologic mapping of the site.

References

1. Pippin, L. C., Clerico, R. L., and Reno, R. L., An Archaeological Reconnaissance of the NNWSI Yucca Mountain Project Area, Southern Nye County, Nevada, DRI Social Sciences Center Publication No. 28, December 1982 (Draft).

2. Bell, F. J. and Larson, L. T., Overview of Energy and Mineral Resources for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada, NVO-250 (DE83001418), September 1982.

960.5.2.1 Population Density and Distribution

A site shall be disqualified if:

1. Any surface facility of a repository would be located in a highly populated area; or

2. Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. Census, where a surface facility shall be considered adjacent to such area if that area abuts the restricted area; or

3. The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations) and related guides or, when issued by the NRC, in 10CFR60, Subpart I, "Emergency Planning Criteria."

Statement of Position

Surface facilities associated with the proposed candidate site at Yucca Mountain in Nye County, southern Nevada, would be located in the center of an uninhabited area that has a radius of at least 10 kilometers. No residentially populated area 1 mile by 1 mile could be located within that 10 kilometer radius, although daytime joint use is not currently restricted. Furthermore, there is no evidence that DOE could not prepare an emergency program plan, particularly in light of the fact that such a plan exists for current activity at the Nevada Test Site. Therefore, the Yucca Mountain site is not disqualified by the requirements of the Population Density and Distribution Guideline (960.5.2.1).

Rationale

"Highly populated area" means any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not are specifically excluded from the definition of "place" as used herein.

There are no residential inhabitants within a 10-kilometer radius of the proposed candidate site at Yucca Mountain; all land within this radius is currently federally controlled and not open to settlement. The site is located on the joint boundary of Census Enumeration Districts (EDs) 745 and 746. The two towns in the vicinity of the surface facility location are Amargosa Valley, 22 kilometers south, and Beatty, 30 kilometers west. The combined populations of EDs 745 and 746 in April 1980, according to the 1980 U.S. Census, was 223 persons. Also according to the 1980 Census, Lathrop Wells (recently renamed Armargosa Valley) had a population of 65; Beatty had a population of 900. The NTS and NAFBR surround the proposed candidate site on three sides, covering an area of about 5,500 square miles. About 5,000 individuals work at the NTS and several hundred may intermittently remain

The nearest and largest urban area, Las Vegas and surrounding communities in Clark County, is located about 150 kilometers from Yucca Mountain and has a population of 463,097 (1980 U.S. Census).

The question of the ability of DOE to prepare an Emergency Preparedness Plan in accordance with DOE Order 5500.3 is perhaps best addressed in light of the fact that such a document has already been prepared to cover present activities at the Nevada Test Site. The existing Emergency Preparedness Plan covers accidental release of radionuclides as a function of weapons testing by DOE. This plan addresses gaseous emissions following weapons tests; no problems are anticipated for preparation a plan covering airborne releases following handling accidents or waterborne releases caused by waste canister corrosion in an operational repository.

Reference

U.S. Department of Commerce Bureau of the Census 1982. 1980 Census of Population, General Population Characteristics, Nevada; PC80-1-30, Washington, D.C.

960.5.2.5 Environmental Quality

Any of the following conditions shall disqualify a site:

1. Repository construction, operation, closure, or decommissioning would result in an unacceptable adverse impact on the health or welfare of the public or the quality of the environment, if such impact cannot be mitigated by reasonable measures, taking into account technical, social, economic, and environmental factors.

2. Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System or the National Wild and Scenic Rivers System.

3. The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System, or any comparably significant state protected resource that was dedicated to resource preservation at the time of the enactment of the Act.

Statement of Position

On the basis of preliminary assessments in Chapter 6 of this Environmental Assessment, the construction, operation closure, and decommissioning of a repository located at Yucca Mountain would not result in any unacceptable adverse environmental impacts that threaten the health or welfare of the public or the quality of the environment. Neither the restricted area, nor the supporting facilities for a repository at Yucca Mountain, would be located within or abut the boundaries of a significant, nationally protected natural resource. Nor would the repository and its supporting facilities interfere with the previously-designated use of nearby federally-protected areas.

The presence of the restricted area or the repository support-facilities would not conflict irreconcilably with the previously designated use of a federal or state protected resource that was dedicated to resource preservation at the time of enactment of the Act.

Therefore, the Yucca Mountain Site is not disqualified on the basis of this technical guideline.

Rationale

The adverse environmental impacts that are associated with construction, operation, and/or decommissioning of a repository at Yucca Mountain are described in Chapter 6 of this Assessment. They include (1) destruction of approximately 1,500 acres of desert habitat, (2) fugitive dust emissions, (3) vehicle emissions, and (4) radiological releases during (a) excavation of the repository, (b) normal operation of the repository, and (c) accidents. Contamination of the ground water is not expected to occur because the wastes will be several hundred feet above the ground water table (REF. NEEDED).

Fugitive dust emissions will result from surface preparation, excavation, and manipulation of the spoils piles during construction, operation and backfilling. Dust emissions will also result from the disturbance of approximately 1000 acres during the construction of a railroad line to the repository and disturbance of 150 acres during construction of an access road to the site from U.S. Highway 95. Vehicle emissions will include carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen that will be released from construction equipment and from private vehicles that transport workers to and from the site. Dust and vehicle emissions released to the atmosphere will be greatest during construction, decline during operation and repository loading, increase again during backfilling, and will be least during decommissioning. At the boundary of the controlled area, during construction, the maximum estimated ambient concentrations of carbon monoxide, (hydrocarbons, and oxides of sulfur and nitrogen from vehicle emissions should not exceed air-quality limits specified in 40CFR50. Assuming no dust-suppression measures (and therefore a "worst case" estimate), maximum fugitive dust emissions during construction are not expected to exceed 8 metric tons/day, which would result in an estimated maximum ambient concentration of 28 g/m^3 and a deposition rate of .19 g/m^2/yr needs to be reconciled with wording of 40CFR191) at the nearest point of human habitation, 15 miles from the site. This is below the ambient air quality standards for fugitive dust specified in 40CFR50. Because dust suppression measures are expected to be employed, actual ambient concentrations and deposition rates will be less.

Release of naturally-occurring radon and decay products from the volcanic rocks of the Yucca Mountain site will increase during excavation of the repository and during manipulation of the spoils piles. During construction, the total 70-year whole-body dose to the regional population from these emissions is estimated to be 5 man-rem for the horizontal waste-emplacement option and 12 man-rem for the vertical-emplacement option (Chapter 6). The total natural 70-year whole-body dose to the regional population from naturally-occurring radionuclides is estimated to be 3.6×10^6 man-rem. Estimated routine releases from radon in the surface spoils piles during backfilling are expected to be negligible. On the basis of these estimates, the environmental impact from radiological releases during normal repository construction, operation, closure and decommissioning will not be significant.

The operational accident involving spent fuel and high-level waste having the mot severe radiologic consequences would be a canister dropped down a vertical shaft (DOE, 1980). Radiation released from this accident is assumed to pass through a filter train including two HEPA filters, and then released through a 360-foot stack. Estimates of the total 70-year dose commitment to the regional population from this accident is 2.9×10^{-3} man-rem for spent fuel and 6.1×10^{-5} man-rem for high-level waste. In comparison, the estimated regional 70-year dose commitment from naturally occurring radionuclides is 3.6×10^6 man-rem.

The surface and underground facilities at Yucca Mountain would be located entirely on federal lands administered by the U.S. Department of Energy (the Nevada Test Site), the U.S. Department of Defense (Nellis Air Force Base Bombing and Gunnery Range), and public-domain lands under the jurisdiction of the Bureau of Land Management (DOE, in prep). These facilities would therefore have no impact on federal lands that are protected for environmental reasons.

If a repository is located at Yucca Mountain, a railroad line would be constructed from Yucca Mountain to a point a few miles northeast of Las Vegas (DOE, in prep.). At some localities along this proposed route, the rail line would be within a few miles of the southern boundary of the Desert National Wildlife Range adminsitered by the U.S. Fish and Wildlife Service (Lutsey and Nichols, 1972). Furthermore, part of the Wildlife Range has been proposed for inclusion in the Wilderness Preservation System (REF. NEEDED). The impacts to the animals and to the management of the Desert National Wildlife Range that may result from the construction and operation of the rail line--even assuming that part of the Wildlife Range is ultimately included in the Wilderness Preservation System--are expected to be insignificant, and pose no irreconcilable conflict with current or proposed use of the range area.

The boundary of Death Valley National Monument lies approximately 20 to 25 miles west and southwest of the Yucca Mountain site (Lutsey and Nichols, 1972). The environmental effects on the Monument from constructing and operating a repository at Yucca Mountain include increased use of the Monument by construction workers and employees of the repository. This will result in some degredation of the scenic qualities and attributes of the Monument, but the significance of these impacts is expected to be minor.

The northern part of the controlled area surrounding the repository site would be approximately 5 miles south of the Timber Mountain Caldera National Natural Landmark (REF. NEEDED). This Federally-designated landmark would not be disturbed during construction and operation of the repository. Furthermore, the Landmark is located within the Nellis Air Force Bombing and Gunnery Range and the Nevada Test Site. It presently has, and will continue to have, restricted access.

Devil's Hole National Monument lies about 25 miles south-southeast of the Yucca Mountain Site. This Monumant is protected from intruders by a high chain-link fence topped with barbed wire. The only potential adverse impact to the Monument is related to an increase in ground water consumption by construction workers and repository employees that may live in the area. This potential impact can presumably by mitigated by limiting the number of housing-construction permits in the Ash Meadows area.

The surface and underground facilities at Yucca Mountain would be located entirely on federal lands administered by the U.S. Department of Energy (the Nevada Test Site), and U.S. Department of Defense (Nellis Air Force Base Bombing and Gunnery Range), and public-domain lands under the jurisdiction of the Bureau of Land Management.

Approximately 1,500 acres of land will be cleared during construction and operation of the reopsitory and during construction of the supporting transportation facilities in southern Nevada (see Chapter 6). Surveys to date indicate that no threatened or endangered plant or animal species, or their critical habitats, occur in the Yucca Mountain area.

Two species that are currently under review by the U.S. Fish and Wildlife Service as candidates for inclusion on the Federal list of threatened or endangered species--the Mojave fishhook cactus (Sclerocactus polyancistrus) and the desert tortoise (Gopherus agassizi)--have been found in Yucca Mountain area (REF. NEEDED). On the basis of preliminary analyses in Chapter 6, populations of the cactus are not located in areas where extensive surface disturbance asssociated with the main repository facilities is projected (REF. OR SUBSTANTIATION NEEDED). Also, based on preliminary analyses in Chapter 6, population densities of the desert tortoise are low in the area of Yucca Mountain site (AGAIN REF. OR SUBSTANTIATION IS NEEDED). Mitigation measures during construction and operation of the repository may include physically transporting individuals of these species from areas to be disturbed to remote undisturbed locations; however, the survival of transported individuals is uncertain, and the fact would remain that some habitat for the species would still be removed in the areas to be disturbed. Other more definitely effective mitigation measures, such as avoiding populations of the cactus identified during preconstruction surveys and avoiding areas of known tortoise habitat (if these areas can be identified), will be practiced to the extent that unacceptable tradeoffs in economy and safety do not occur.

The U.S. Fish and Wildlife Service is in the process of designating eleven springs and the spring outflow channels plus immediately adjacent land areas in Ash Meadows as critical habitat for two proposed endangered species of pupfish. Construction and operation of a repository at Yucca Mountain will not directly affect the outflow of these springs. However, a potential indirect adverse impact to these springs may occur as a result of an increase in groundwater consumption by cntraction workers and repository employees that may choose to live in the Ash Meadows area. This potential impact could presumably be mitigated by limiting the number of housing-construction permits in the area.

960.5.2.9 Rock Characteristics

The site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation, or closure are projected to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonable available technology.

Statement of Position

Based upon the applicable laboratory and field data for Yucca Mountain obtained to date, thermomechanical stress calculations, and observations and experience in similar excavations, activities at the NNWSI site associated with repository construction, operation, or closure are not projected to cause significant risk to the health and safety of personnel. The site is therefore not disqualified on the basis of the rock characteristics siting guideline (960.5.2.9).

Rationale

While it is recognized that rock characteristics impact the meeting of dust control standards, the primary emphasis of the disqualification statement is interpreted as being related to assurance that stable openings can be developed in tuff. For a repository, both excavation and thermally induced loadings are considered.

The rationale used in developing the statement of position relies on a definition of the applicable geoengineering data and analyses of the anticipated stability of mined openings in the tuff of the Topopah Spring Member. Both the data and analyses are synopsized below and detailed references are provided.

Data

At present, the data base (Ref. 1 thru 5) of geoengineering properties to be used in technical decisions related to the repository at Yucca Mountain consists of the results of laboratory tests on core samples from Yucca Mountain and Rainier Mesa. Rainier Mesa and Yucca Mountain are both composed of layered volcanic rocks, and measurements on core samples from densely welded tuffs from both sites indicate that matrix mechanical properties are similar. In addition, excavations in G-Tunnel (beneath Rainier Mesa) and planned excavations at Yucca Mountain are similar with regard to overburden loadings, opening dimensions and excavation methods. Because of these similarities, field observations, tests and experience in G-Tunnel can be used to support technical decisions related to safe construction and operation of a repository at Yucca Mountain.

The selection of the Topopah Spring Member as the target horizon was based in large part on the average thermal and mechanical properties defined for each of the four horizons considered using results from approximately 75 thermal conductivity tests, 95 thermal expansion tests, 35 mineralogical-petrological analyses, 60 mechanical tests on jointed rock samples, and 120 unconfined and 50 pressure-dependent mechanical properties tests. The average values for thermal and mechanical properties in the Topopah Spring are given in Table 1.

The in situ stress state impacts excavation stability. Stress measurements at Yucca Mountain have resulted in calculated ratios of vertical stress to minimum horizontal stress up to 3.5 (Ref. 6) with a mean for twelve measurements of 2.1 and a standard deviation of 0.6. This compares to ratios in the tuffs in G-Tunnel in Rainier Mesa of up to 8.4 with a mean of 2.7 and a standard deviation of 1.3 based on 67 measurements (Ref. 7-11). G-Tunnel is in general supported only with roof bolts and wire mesh. In the more than 10 years of operation of the tunnel, the stresses have not resulted in opening stability problems, even when combined with severe ground accelerations from nearby nuclear tests.

Results

In the selection of the Topopah Spring as the target horizon for a repository at Yucca Mountain (Ref. 12), opening stability was evaluated using

- o nonlinear, finite element thermomechanical stress analyses
- o rock mass classification systems
- o linear calculations for mine design/pillar sizing

From these analyses, it is concluded that existing mining technology can be used to develop stable underground openings in a repository in the Topopah Spring Member that will allow repository operations to be carried out safely from construction through decommissioning. Experienced gained in G-Tunnel at Rainier Mesa on the NTS supports this conclusion and further indicates that it should be expected that openings can be stabilized using roof bolts and wire mesh. Mineability assessments (Ref. 12), also supported by G-Tunnel experience, indicate that controlled blasting can be successfully used to excavate the openings in the densely welded tuff.

References

1. Price, R. H., "Analysis of Rock Mechanics Properties of Volcanic Tuff Units from Yucca Mountain, Nevada Test Site," SAND82-1315, Sandia National Laboratories, Albuquerque, New Mexico, in final review.

2. Price, R. H., K. G. Nimick, and J. A. Zirzow, "Uniaxial and Triaxial Compression Test Series on Topopah Spring Tuff," SAND82-1723, Sandia National Laboratories, Albuquerque, New Mexico, 1982.

3. Lappin, A. R., 1980, a. "Thermal Conductivity of Silicic Tuffs: Predictive Formalism and Comparisons with Preliminary Experimental Results," SAND80-0769, Sandia National Laboratories, Albuquerque, New Mexico.

4. Lappin, A. R., 1980, b. "Preliminary Thermal Expansion Screening Data for Tuffs," SAND78-1147, Sandia National Laboratories, Albuquerque, New Mexico.

5. Lappin, A. R., R. G. Van Buskirk, D. O. Enniss, S. W. Butters, F. M. Prater, C. B. Miller, and J. L. Bergosh, "Thermal Conductivity, Bulk Properties, and Thermal Stratigraphy of Silicic Tuffs from the Upper Portion of Hole USW-G1, Yucca Mountain, Nye County, Nevada," SAND81-1873, Sandia National Laboratories, Albuquerque, New Mexico, 1982.

6. Healy, J. H., S. H. Hickman, M. D. Zoback, and W. L. Ellis, "Report on Televiewer Log and Stress Measurements in Core Hole USW G-1, Nevada Test Site, December 13-22, 1981," U.S. Geological Survey Open-file Report 83-XXX (Approved for release), 1983.

7. Tyler, L. D. and W. C. Vollendorf, "Physical Observations and Mapping of Cracks Resulting from Hydraulic Fracturing In Situ Stress Measurements," Soc. Petr. Eng. of AIME, Paper SPE-5542, 16 p., 1975.

8. Warpinski, N. R., R. A. Schmidt, D. A. Northrop and L. D. Tyler, "Hydraulic Fracture Behavior at a Geologic Formation Interface: Pre-Mineback Report," SAND78-1578, Sandia National Laboratories, Albuquerque, New Mexico, 1978.

9. Ellis, W. L., and J. R. Ege, "Determination of In Situ Stress in U12g Tunnel, Rainier Mesa, Nevada Test Site, Nevada," USGS-474-219, U.S. Geological Survey, Denver, Colorado, 1975.

10. Hooker, V. E., J. R. Aggson and D. L. Bickel, "Report on In Situ Determination of Stresses, Rainier Mesa, Nevada Test Site," United States Department of Interior, Bureau of Mines, 1971.

11. Warpinski, N. R., "Results of Perforation Experiments," Memorandum of Record, Sandia National Laboratories, Albuquerque, New Mexico, 1981.

12. Johnstone, J. K., P. F. Gnirk, and R. R. Peters, "Unit Evaluation at Yucca Mountain, Nevada Test Site: Summary Report and Recommendation," SAND83-0372, Sandia National Laboratories, Albuquerque, New Mexico, in final review.

Table 1

Average Thermal and Mechanical Properties of the Topopah Spring Member

(Compiled from References 1-5)

Thermal Conductivity (saturated, W/m°C)	1.8±0.4
Thermal Conductivity (dry, W/m°C)	1.6±0.4
Pre-dehydration linear expansion coefficient (10^{-6}°C^{-1})	10.7±1.7
Transition-dehydration linear expansion coefficient (10^{-6}°C^{-1})	31.8 (to 300°C)
Post-dehydration linear expansion	15.5±3.8 (to 400°C)
Young's Modulus (GPa)	26.7±7.7
Poisson's Ratio	0.14±0.05
Compressive Strength (MPa)	95.9±35.0
Matrix Cohesion (MPa)	28.5
Angle of Internal Friction (degrees)	26.0
Matrix Tensile Strength (MPa)	12.8±3.5
Joint Cohesion (MPa)	1
Coefficient of Friction for Initiation of Sliding on Joints	0.8