DRAFT

Nevada Nuclear Waste Storage Investigations Project

NWPA

ENVIRONMENTAL ASSESSMENT

June 1, 1984

NNWSI PROJECT

Waste Management Project Office

United States Department of Energy

Nevada Operations Office, Las Vegas, Nevada

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Nevada Operations Office
P. O. Box 14100
Las Vegas, NV 89114-4100

TO WHOM IT MAY CONCERN:

JUNE 1, 1984, WORKING DRAFT OF THE NNWSI ENVIRONMENTAL ASSESSMENT

The Nuclear Waste Policy Act of 1982 (PL 97-425) requires that any candidate site nominated by the Secretary, U.S. Department of Energy, for site characterization be accompanied by an environmental assessment, and that such environmental assessment be made available to the public. The U.S. Department of Energy is in the process of preparing an environmental assessment to accompany the nomination of the Yucca Mountain candidate site, located approximately 95 miles northwest of the City of Las Vegas, for site characterization.

This document is a working draft of Chapters 2-6 of the Environmental Assessment called for in the Nuclear Waste Policy Act, and is based upon information, data and analyses currently available. As a working document prepared on a program in progress, it may be modified to reflect new data, analyses, and other information obtained through public and institutional review prior to release in final form. Also, as a working document it may contain errors and omissions, and some results may be based on incomplete analyses or on data which has not been subjected to peer review.

This draft environmental assessment is provided by the U.S. Department of Energy in the spirit of cooperation and is intended to assist the states and other interested parties in familiarizing themselves with project status and to allow public and institutional participation in the nomination process though review and comment. This process will help develop a more complete environmental assessment which considers not only the technical issues, but, in addition, the non-technical issues of public concern.

This draft document was prepared by the U.S. Department of Energy with the participation of Sandia National Laboratories (SNL), Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), U.S. Geological Survey (USGS), and Science Applications, Incorporated (SAI). It has been reviewed in draft form by responsible individuals from each of these participating organizations and has been found suitable for its intended purpose.

Mitchell P. Kunich for

Donald L. Vieth, Director
Waste Managment Project Office

WMPO:MBB-878

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Chapter 2

YUCCA MOUNTAIN SELECTION PROCESS

The Nevada Nuclear Waste Storage Investigations (NNWSI) Project was established in 1977 by the Department of Energy's Nevada Operations Office (DOE/NV) to evaluate the Nevada Test Site (NTS) and contiguous area for sites suitable for a repository for high-level radioactive waste and spent nuclear fuel. Preliminary investigations and site-screening activities identified the Yucca Mountain area in southern Nye County, Nevada, as the most suitable for extensive site-characterization activities. The Yucca Mountain site is about 150 km (95 mi) northwest of Las Vegas, Nevada, and on and adjacent to the southwest corner of the NTS (Figure 2-1). The site is on Federal land under the control of three separate agencies. Most of the site is part of the Nellis Air Force Range (NAFR); a smaller portion is part of the NTS and managed by the Department of Energy (DOE). The final portion is managed by the Bureau of Land Management (BLM).

This chapter outlines the general process by which Yucca Mountain was identified as a potentially acceptable site. Section 2.1 describes generally the regional setting of the site to place in context the general types of alternatives from which Yucca Mountain was selected. To determine whether a site is adequate, the DOE Siting Guidelines (10 CFR 960) were developed incorporating regulatory standards promulgated by the Environmental Protection Agency (EPA) (40 CFR 191) and the Nuclear Regulatory Commission (NRC) (10 CFR 60). The implementation part of the siting guidelines, 10 CFR 960.3-2 (DOE, 1983), states that a potentially acceptable site is one that has first been identified through a site-screening process as potentially suitable for a repository. The screening process by which Yucca Mountain was identified is described in Section 2.2. This discussion is followed by Section 2.3, which evaluates the Yucca Mountain site with respect to the disqualifying conditions for post-closure and preclosure time periods, listed in 10 CFR 960.4 and 960.5 (DOE, 1983), respectively. As called for in 10 CFR 960.3-2 (DOE, 1983), evaluation against the disqualifying conditions is a required step in the nomination process and must be applied to all potentially acceptable sites.

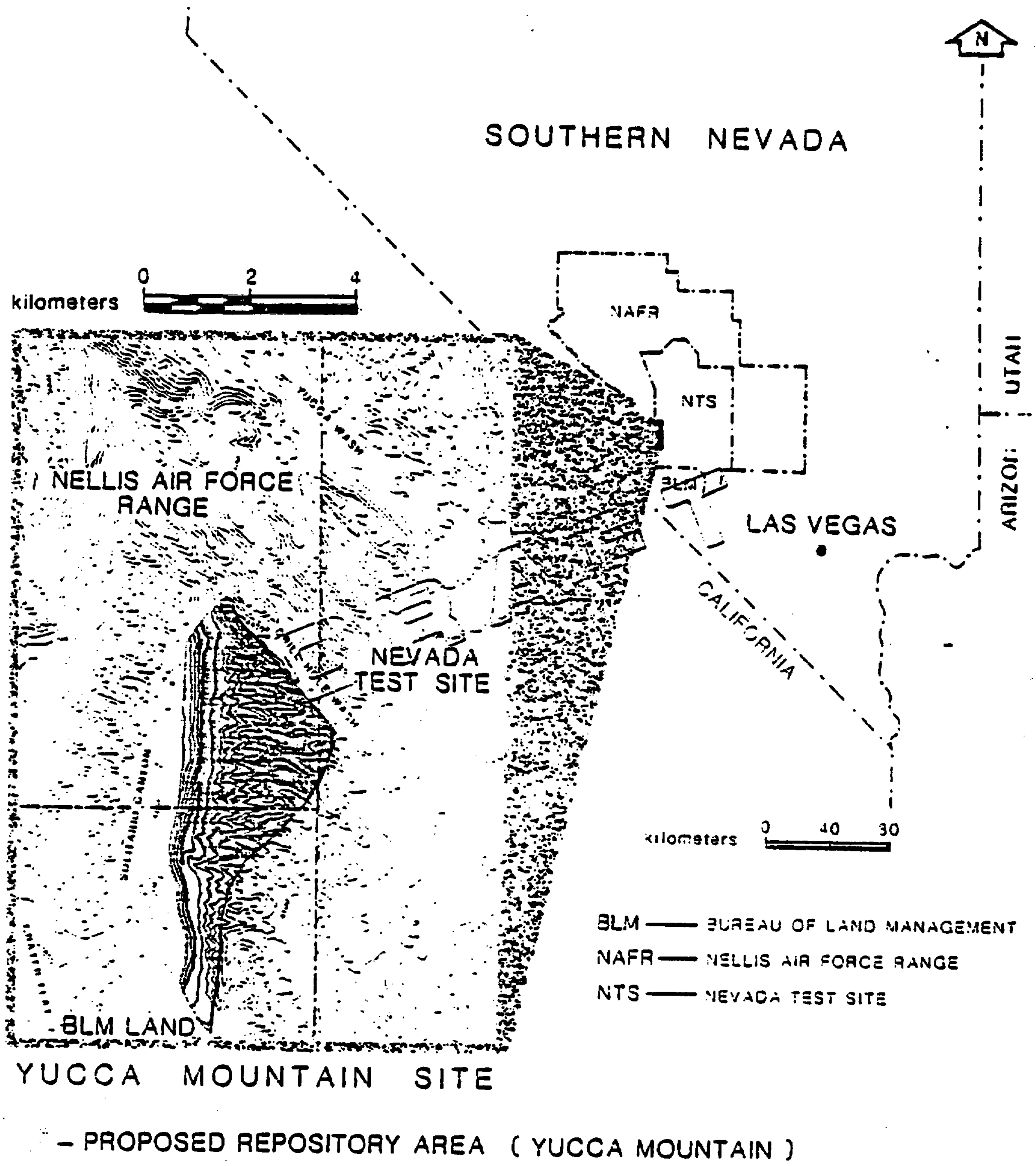


Figure 2-1. Location of proposed repository site at Yucca Mountain in southern Nevada.

6-1-84 Draft
22-May-84/2

2.1 REGIONAL SETTING OF YUCCA MOUNTAIN

The Yucca Mountain site is located within a broad desert region known as the Great Basin. The Great Basin is characterized by generally linear mountain ranges and intervening valleys. No streams or rivers flow out of the region. Primarily because of the scarcity of water, few people live in this vast desert. The few communities that exist are generally located around mining districts, water sources, or tourist attractions. Agricultural production is very limited because of the severe aridity and low nutrient value of the rocky desert soils. A few areas of irrigated cropland occur where ground water is shallow enough to be tapped by wells and where soils are suitable for tillage. As a result of the sparse population, paved roads are also widely spaced, commonly more than 80 km (50 mi) apart.

The basins and intervening mountain ranges of the region strongly influence the climate, vegetation, and surface drainage of local areas. Most precipitation falls on the cooler mountain terrain, whereas the basins are relatively warmer and dryer. As a result, the higher ranges generally support coniferous forests while the basins and lower ranges, such as Yucca Mountain (Figure 2-2), are covered with sparse, desert vegetation. The large number of basins and ranges of various elevations result in several ecological communities within the region.

The mountain ranges are formed by fault blocks that rise above the intervening basins. Based on exposed rock in the ranges, the rocks can be divided into four major groups. The oldest is a billion or more years old and is made up of hard crystalline material, such as gneiss and granite. These rocks are part of the crystalline shield of the North American continent. Stratigraphically above the shield rocks is the second major group of rocks, a thick sedimentary sequence predominantly composed of carbonates, quartzite, shale, and argillite. These rocks were deposited in a large trough-like basin, called the Cordilleran Geosyncline, that existed along the western edge of the continent between about 800 million and 250 million years ago.

Figure 2. View of Yucca Mountain looking southeast. (Photo courtesy of Pan American, Inc.)

From about 250 to 100 million years ago, these sedimentary rocks were strongly squeezed, folded, and faulted creating large mountain ranges that rose out of the shallow seas where the rocks were deposited. During this time, granitic masses were intruded deep within the buried roots of local parts of these ancient mountains. Small outcrops of granite in the northern part of the NTS attest to this episode of granite formation.

From about 100 million to 40 million years ago, the mountain building waned and the ancient ranges were eroded to a gentle rolling plain. Beginning about 40 million years ago, a third major group of rocks was deposited on this plain when volcanic activity spread thick piles of tuffaceous volcanic material over portions of the area. This volcanism lasted from about 40 million to 10 million years ago, and produced the layers of tuff that now form Yucca Mountain. The mountain actually formed during the last 10 to 15 million years of this 30 million year period.

Faulting that produced the current basins and ranges took place at the same general time as the volcanism. In the last 10 million years, tectonic activity has waned (Stewart, 1978) and the basins have been filled with alluvium derived from erosion of the surrounding ranges. Minor volcanism and faulting continued during basin filling, most recently producing thin, locally restricted sheets of basaltic flow material that dot the surface in Crater Flat, just west of the Yucca Mountain site.

Three regional cross sections, shown on Figure 2-3, portray the complexity resulting from the geological history described above. The geological evolution involving deposition, folding, faulting, intrusion of granite masses, and eruption of volcanic material produced a complicated geologic pattern in the rocks of this area.

The hydrology of the southern Great Basin is characterized by a deep water table and closed ground-water basins. Ground-water basins do not necessarily correspond with topographic basins. At some places in the southern Great

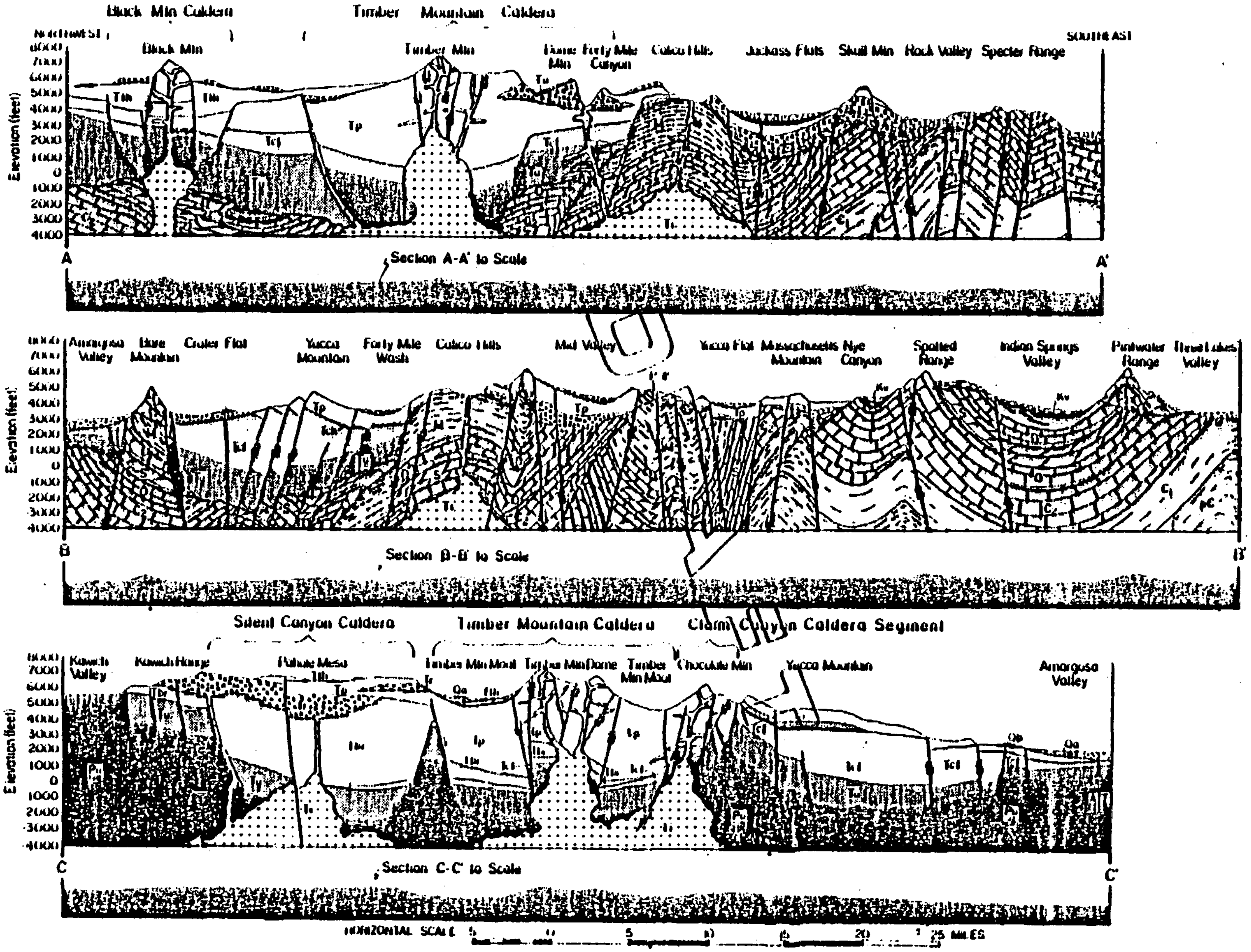
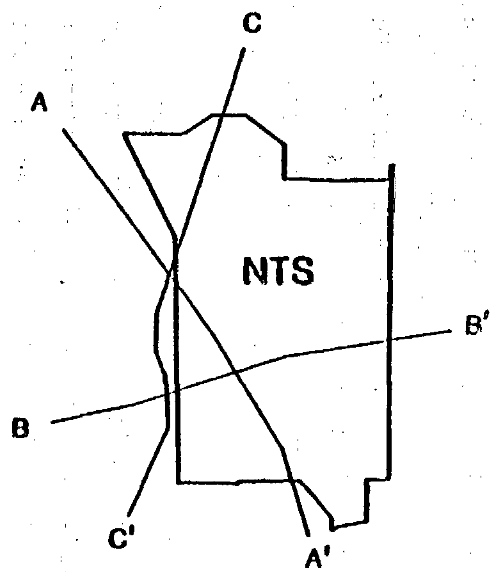


Figure 2-3a. Schematic cross section of southwestern Nevada porti ing the geological complexity surr...nding Yucca Mountain and showing the style of lting and caldera complexes. Se ure 2-3b for location ross sections and d.

TERTIARY AND QUATERNARY ROCKS	PRECAMBRIAN AND PALEOZOIC ROCKS	STRUCTURES
Q — TERTIARY AND QUATERNARY ALLUVIUM	P-P — PERMIAN-PENNSYLVANIAN CARBONATES	TERTIARY BASIN AND RANGE FAULTS
Tb — TERTIARY AND QUATERNARY BASALTS AND BASIC LAVAS	M — MISSISSIPPIAN CLASTICS	T A — STRIKE SLIP FAULTS
Tth — TERTIARY THIRSTY CANYON TUFF	D — DEVONIAN CARBONATES	MESOZOIC THRUST FAULTS
Tp — TERTIARY PAINTBRUSH AND TIMBER MOUNTAIN TUFFS	S — SILURIAN CARBONATES	
Tr — TERTIARY RHYOLITES	O — ORDOVICIAN CARBONATES	
Tch — TERTIARY CALICO HILLS VOLCANICS	C2 — CAMBRIAN CARBONATES	
Tbr — TERTIARY BELTED RANGE TUFF	C1 — CAMBRIAN QUARTZITES	
Tcf — TERTIARY CRATER FLAT TUFF	pC — PRECAMBRIAN QUARTZITES	
Tps — TERTIARY ROCKS OF PAVITS SPRING	Pz — PALEOZOIC (UNDIVIDED)	
Tt — MID-TERTIARY VOLCANICS (UNDIVIDED)		
Ti — TERTIARY INTRUSIVES		
Kv — OLDER VOLCANICS		



LOCATION INDEX FOR SECTION LINES

Figure 2-3b. Legend for Figure 2-3a showing location of cross sections.

Basin, including parts of Yucca Mountain, ground water is more than 500 m (1600 ft) deep. Recharge occurs by slow percolation of surface water through the rocks overlying the water table. Most, if not all, of this recharge is restricted to higher elevations of the ranges where precipitation is greatest. At lower elevations, including Yucca Mountain, most, if not all, precipitation evaporates before it is able to seep deeply into the rocks.

Generally, ground water in the southern Great Basin flows through major aquifers, which are deep beneath the surface of the ranges and most valleys. Winograd and Thordarson (1975) recognized six major aquifers in southern Nevada that transmit water and four major aquitards that retard the flow of water and act as barriers to ground-water movement (Figure 2-4). The lower and upper carbonate aquifers of the sedimentary sequences and the welded-tuff and lava-flow aquifers of the volcanic sequence transmit water primarily through fractures. Because the fractures are related to both the brittleness of the rock and the location of major structural features, local and regional flow is determined largely by the complex stratigraphic and structural conditions outlined above. The bedded-tuff and valley-fill aquifers, in contrast, store and transmit water chiefly through interstitial pores.

Yucca Mountain lies in the Death Valley ground-water system, which is composed of several more or less distinct basins and subbasins (Figure 2-5). It is in the Alkali Flat-Furnace Creek Ranch ground-water basin at a position midway between the Ash Meadows and Oasis Valley subbasins, as shown in Figure 2-5 (Waddell, 1982). The Alkali Flat-Furnace Creek basin discharges at seeps in Alkali Flat, and springs in Death Valley. Regional flow east of the site is through the Ash Meadows subbasin and occurs principally in the lower carbonate aquifer (Figure 2-6). This subbasin partially discharges at the 30 or so springs in Ash Meadows where the lower clastic aquitard apparently is raised along a fault and blocks the flow through the aquifer, forcing water to rise to the surface. Some of the water may seep through the aquitard, eventually discharging at Death Valley. West of the site, local flow from recharge at Timber Mountain and Pahute Mesa occurs through the tuff aquifer and discharges at springs in Oasis Valley, just north of Beatty. This small flow system forms the Oasis Valley subbasin.

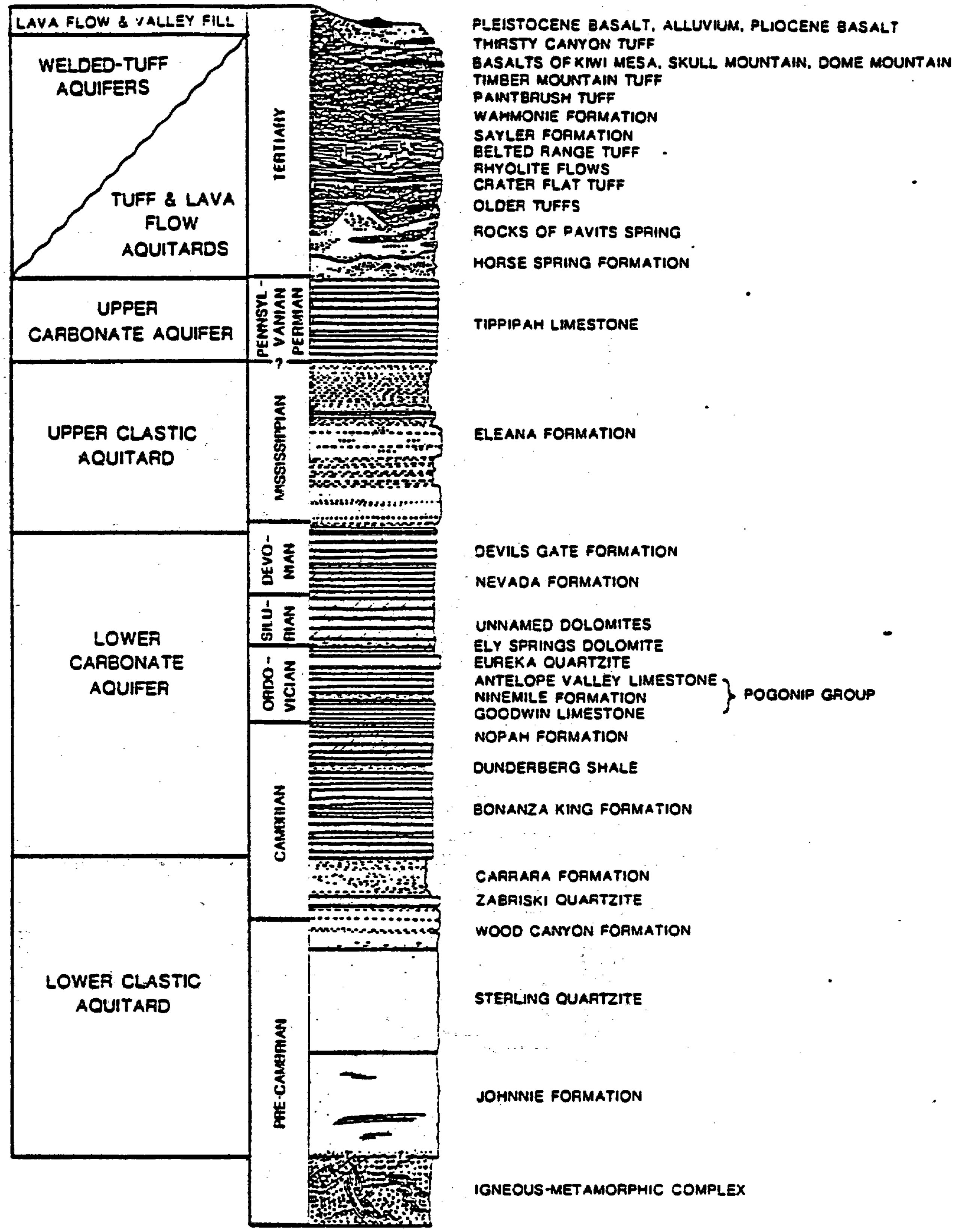
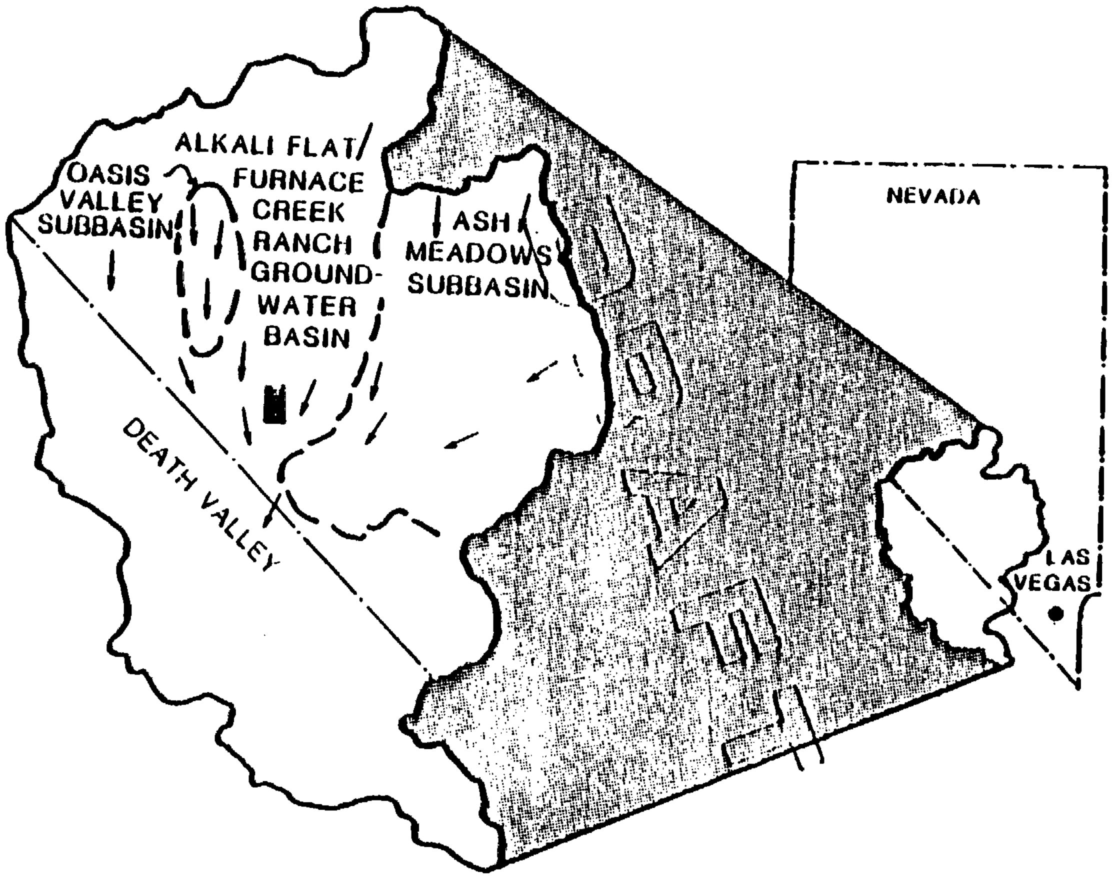


Figure 2-4. General relationships among hydrogeologic units and geologic formations in the southern Great Basin.



- YUCCA MOUNTAIN SITE

→ INDICATES DIRECTION OF REGIONAL GROUND-WATER MOVEMENT

Figure 2-5. Location of Yucca Mountain site with respect to the basins and subbasins of the Death Valley ground water system.

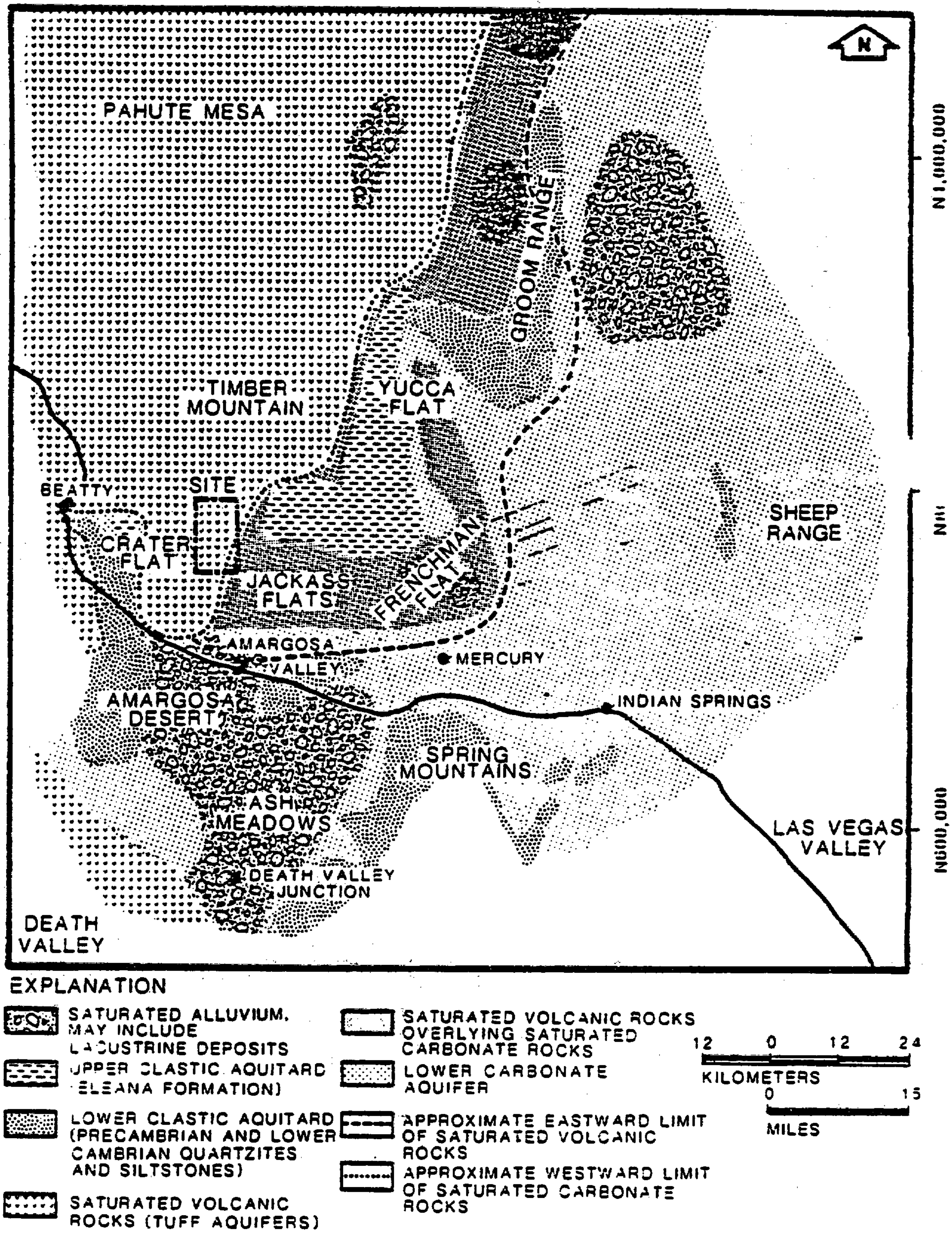


Figure 2-6. General distribution of the major aquifers and aquitards in the southern Great Basin near Yucca Mountain.

In summary, the southern Great Basin is generally characterized by sparse vegetation, low precipitation, few population centers, varied geology, and a hydrology system that includes closed surface and ground-water basins and a thick unsaturated zone with little water movement. This section provides only the most general perspective on the overall setting from which Yucca Mountain was chosen from among other alternatives as discussed in the following section (Section 2.2). The detailed description of Yucca Mountain and the surrounding region is provided in Chapter 3.

2.2 IDENTIFICATION OF YUCCA MOUNTAIN AS A POTENTIALLY ACCEPTABLE SITE

This section briefly summarizes the five step process by which Yucca Mountain and the Topopah Spring host rock were selected by the NNWSI Project for detailed study. The five steps, discussed in turn in the following subsections, are: (1) selection of the NTS (Section 2.2.1), (2) restriction of exploration to an area in and around the southwest NTS (Section 2.2.2), (3) selection of Yucca Mountain as the primary location for exploration (Section 2.2.3), (4) systematic reconsideration of potential locations in the southwest NTS (Section 2.2.4), and (5) selection of the target host rock for the repository (Section 2.2.5).

All steps in the selection process were completed before the Nuclear Waste Policy Act of 1982 (NWPA) was signed into law in January 1983. Accordingly, the selection of Yucca Mountain as a potentially acceptable site was not based on 10 CFR 960. Nonetheless, the systematic screening studies of steps 4 and 5 used objectives very similar to those listed in 10 CFR 960. The identification of Yucca Mountain as a potentially acceptable site was consistent with the siting criteria of NWTS-33(2) and is not inconsistent with 10 CFR 960.

2.2.1 Selection of NTS as an area of investigation

The National Waste Terminal Storage Program (NWTS) was established in 1976. During the early NWTS investigations, the prime geologic material of interest for a repository host rock was salt. Additional geologic host materials, including crystalline (granite, gneiss) and argillaceous rocks (shale, clay) were also considered. The initial approach to site screening was based on the occurrence of particular rock types and came to be known as the host rock approach (DOE, 1982). In 1977, the program was expanded to consider prior land use as an alternate basis for initial screening. This prior land use approach considered the advantages of locating a repository on land already withdrawn and committed to long-term institutional control. Because the NTS was already dedicated to nuclear operations, it was a logical area for investigation for potential repository sites and formal consideration of the NTS for a repository location began at that time. The prior land use at the

NTS establishes a firm reason for concluding that the government will continue to provide strict institutional control over future access to the site.

At the same time the NTS was being considered on the basis of prior land use, the U.S. Geological Survey (USGS) proposed that the NTS also be considered for a number of geotechnical reasons. These geotechnical reasons were later augmented by other considerations. The following lists both geotechnical and other considerations:

- Southern Nevada is characterized by closed hydrologic basins. This means that ground water does not discharge into rivers that flow to major bodies of surface water. It also means that the discharge points for the water can be clearly identified.

- The water table is at great depth [up to 600 m (2000 ft) below the surface]. This provides the opportunity to build a repository in the unsaturated zone where the rock containing a repository would not generally release water to drill holes or tunnels. This lack of water would minimize: (1) corrosion of the waste container, (2) leaching of the waste form, and (3) transport of radionuclides from the repository.

- Long flow paths are present between potential repository locations and ground-water discharge points. Radionuclides would have to travel great distances before they could affect man and his surface environment.

- Many of the geologic materials occurring on the NTS are highly sorptive. Radionuclides could be chemically or physically absorbed by rock and significantly slowed in their movement, making it extremely difficult for them to move in solution.

- The NTS is located in an arid region [less than about 150-200 mm/yr (6-8 in/yr) of rainfall]. With the very low rate of recharge, the amount of moving ground water is also low, especially in the unsaturated zone.

By May 1977, the NWTS Program included evaluations of both the land-use and geological attributes of the NTS, and the NNWSI Project was organized to consider the general suitability of the NTS for a repository and to identify locations, if any, on the NTS and in adjacent areas that might be suitable for a repository. Figure 2-7 illustrates the various sites throughout the NTS initially considered by the NNWSI Project.

2.2.2 Restriction of exploration to the southwestern part of the NTS and adjacent areas

The primary function of the NTS is to provide a testing ground for nuclear weapons. Figure 2-7 shows the past or current, and the proposed general areas dedicated to weapons testing. When the NWTS Program expanded its repository exploration activities to include the NTS, a question arose concerning the compatibility of a repository with nuclear weapons testing. A task group was established to evaluate the conditions under which the weapons testing could fully function despite the presence of a nearby repository. In August of 1978, the Acting Assistant Secretary for Defense Programs of the Department of Energy formalized the task group's finding that locating a repository in certain areas of the NTS might hamper weapons testing. It was also suggested that the southwestern portion of the NTS and adjacent offsite locations were acceptable for further investigation as potential waste repository sites.

In 1977, the geologic medium of prime interest at NTS was argillite. Argillite is present in the Eleana Formation underlying a topographic feature named Syncline Ridge located along the west side of Yucca Flat (Figure 2-7). Geologic investigations there, including exploratory drilling, revealed a complex geologic structure in the center of the area being considered (Hoover and Morrison, 1980; Ponce and Hanna, 1982). It was decided in July of 1978 that the geological complexity of Syncline Ridge would make characterization difficult, possibly so difficult that it could not be understood to the degree necessary to license a repository. At about the same time, the decision by the Assistant Secretary for Defense Programs defined the Syncline Ridge area as unacceptable for a repository because of weapons testing. At this juncture, the program refocused on the area in and around the southwestern corner of the

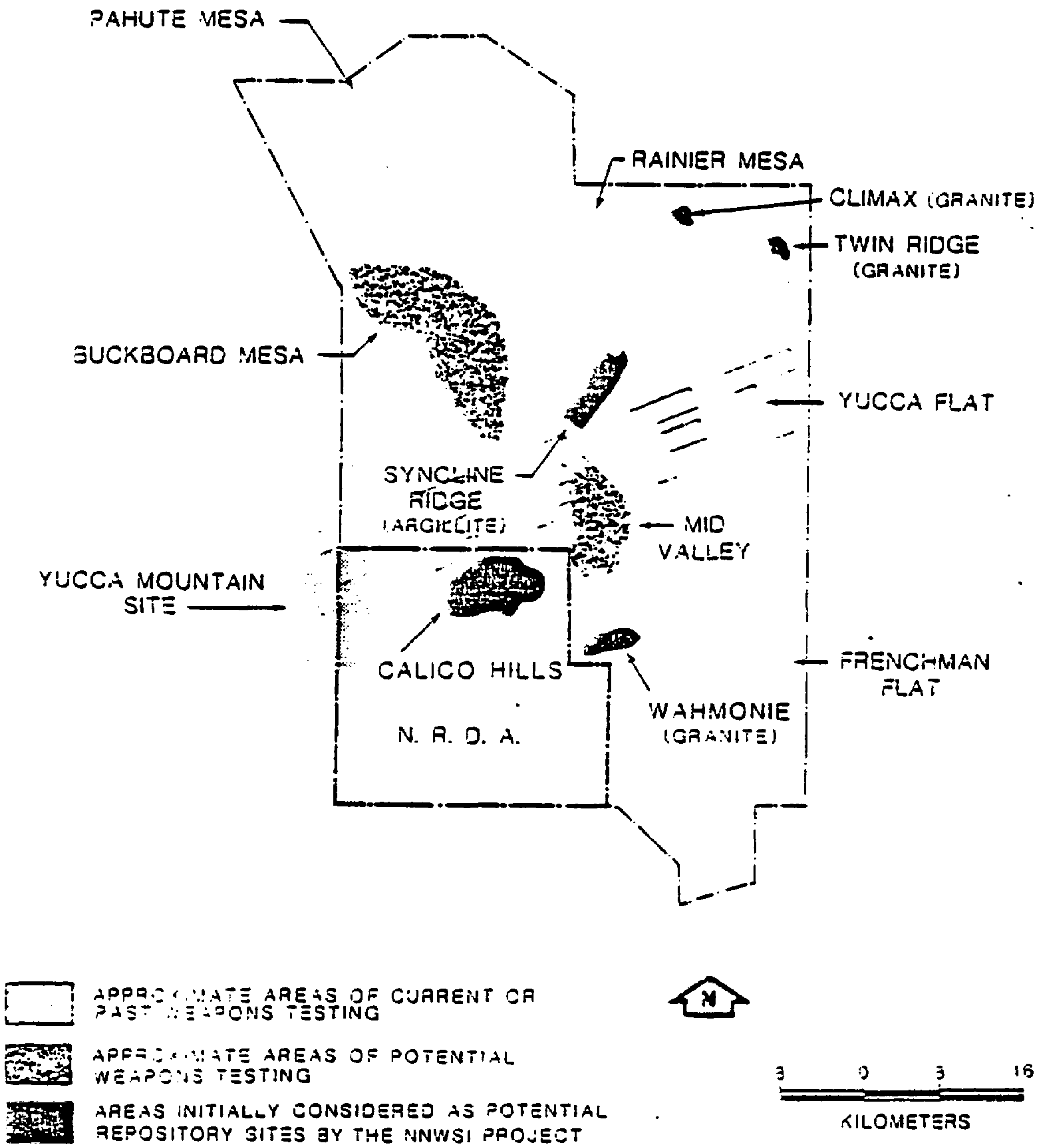


Figure 2-7. Past, current, or potential future weapons testing areas on the Nevada Test Site and areas initially considered for repository siting.

NTS. The portion of the redefined exploratory area that occurred on the NTS was subsequently named the Nevada Research and Development Area (NRDA) (Figure 2-7). The area being evaluated included some BLM land west and south of the NRDA and a portion of the Nellis Air Force Range west of the NRDA.

2.2.3 Selection of Yucca Mountain as the primary location for exploration

In August of 1978, a preliminary list of potential sites in and near the southwestern part of the NTS was compiled. The areas initially considered included Calico Hills, Skull Mountain, Wahmonie, Yucca Mountain, and Jackass Flats. Of these five areas, Calico Hills, Yucca Mountain, and Wahmonie were considered the most attractive locations for conducting preliminary borings and geophysical testing (Figure 2-7).

The Calico Hills location was of particular interest because an aeromagnetic survey showed that granite might occur approximately 500 m (1600 ft) below the surface. The first exploratory hole by the NNWSI Project in the southwest NTS was started in 1978 to explore for granite beneath the Calico Hills. At a depth of 900 m (3000 ft), drilling was discontinued without reaching granite (Maldonado et al., 1979). A high content of magnetite was discovered in a thick section of Eleana Argillite that had contributed to the aeromagnetic anomaly. The argillite was encountered throughout most of the drilling depth. Reevaluation of the geophysical data indicated that the granite is probably 1500 to 1600 m (5000 to 5300 ft) deep (Snyder and Oliver, 1981). Other geophysical surveys indicated the thick section of argillite at Calico Hills and the adjacent reaches of Upper Topopah Wash probably is very complex structurally, similar to the situation at Syncline Ridge (Hoover et al., 1982). Because the granite was considered too deep and the argillite appeared too complex, further consideration of the Calico Hills was suspended in the spring of 1979.

Concurrent with drilling at Calico Hills, geophysical studies conducted at Wahmonie indicated that the granite, which occurs at the surface, would be only marginally large enough for a repository at the depth needed. These studies, plus surface mapping, also suggested that any granite within reasonable depths was probably altered by hydrothermal solutions (Smith et al., 1981; Hoover et al., 1982). Additionally, local surface deposits from a previous warm spring and the presence of faults indicated a potential for upward seepage of ground water, possibly from great depths. For these reasons, Wahmonie was eliminated from consideration in the spring of 1979.

In the summer and fall of 1978, the first exploratory hole was drilled at Yucca Mountain. This hole was drilled more than 600 m (2000 ft) and confirmed the presence of thick, highly sorptive tuff (Spengler et al., 1979). Preliminary surface mapping indicated the existence of generally undisturbed structural blocks possibly large enough for a repository. Because tuff previously had not been considered as a potential host rock for a repository, a presentation was made to the National Academy of Sciences (NAS) Committee for Radioactive Waste Management in September of 1978 to solicit its views on the potential advantages and disadvantages of tuff as a repository host rock. The concept of investigating tuff as a potential host rock was supported.

After comparing the results of preliminary exploration at Calico Hills, Wahmonie, and Yucca Mountain, the U.S. Geological Survey recommended, and the DOE concurred in April 1979, that attention be focused on Yucca Mountain. Immediately thereafter, three technical peer review meetings were held by the NNWSI Project:

1. Media (host rock) investigations - April 25-26, 1979.

2. Geologic and hydrologic investigations - May 22-24, 1979.

3. Tectonic, seismic, and volcanic investigations - July 24-25, 1979.

Reviewers representing several fields of expertise were invited to attend. Nationally known experts, as well as prominent experts from Nevada, participated in the review process. Before each meeting, the reviewers were provided with background information on specific NNWSI Project activities and overall goals. At the meetings, NNWSI Project participants made detailed presentations and answered questions posed by the reviewers. After each meeting, the review panel summarized its overall assessments and recommendations. The general consensus of the reviewers supported DOE's decision to concentrate exploration efforts on the tuffs of Yucca Mountain (DOE/NVO), 1980).

2.2.4 Confirmation of site selection by a formal system study

The foregoing process of selecting Yucca Mountain for early exploration was informal. A more thorough, formal analysis was begun in 1980 to evaluate whether Yucca Mountain was indeed appropriate for further exploration. This analysis was conducted in a manner compatible with the area-to-location phase of site screening described in the National Siting Plan (DOE, 1982), which was used by DOE before the NWPA and ensuing siting guidelines (10 CFR 960) were adopted.

Five publications document the NNWSI screening activity. Each provides details about a separate element of the activity. "A Method for Screening the Nevada Test Site and Contiguous Areas for Nuclear Waste Repository Locations" was published first to generally describe the screening method, and to document the proposed method before its application (Sinnock et al., 1981). "Summary and Conclusions of the NNWSI Area-to-Location Screening Activity" (Sinnock and Fernandez, 1982) presents a summary description of the parameters used in the screening calculations and provides a detailed discussion of screening results. Three documents (Sinnock and Fernandez, 1984; Sinnock et al., 1984; Sharp, 1984) provide detailed background material about, respectively, the performance objectives, physical attributes and associated quantitative criteria, and computer programs for rating alternative locations.

Many assumptions were quantified during the screening study, and the validity of the results and conclusions clearly depends on the reasonableness of these assumptions. The information in the referenced screening reports allows each assumption or set of assumptions to be traced to its effects on the results and conclusions. The remainder of this section contains an overview of the data and analyses contained in these reports.

The formal screening analysis (Sinnock and Fernandez, 1982) was applied to an area on and near the southwestern portion of NTS (Figure 2-8). The analysis consisted of four basic elements:

1. Weighted performance objectives that identified ideal, or at least desired, site conditions to be sought.

2. Physical attributes of the screening area that distinguished the physical conditions of alternative locations and host rocks.

3. Favorability estimates that rated, on a relative scale of zero to ten, how well the physical conditions represented by each attribute satisfied each of the relevant performance objectives.

4. Mathematical equations that calculated summary rating scores for alternative locations and host rocks based on how well the combined favorabilities of the attributes satisfied the performance objectives.

The performance objectives were organized in a three-tiered hierarchical tree (Table 2-1) which allowed site-specific objectives of the lowest level of the tree to be clearly tied to the broad goals of waste management (DOE, 1980) represented by the uppermost level of the tree (Sinnock and Fernandez, 1984). Each objective was correlated with existing criteria of the DOE and NRC to ensure that no relevant siting factors were overlooked (Table 2-2). A weight, or percentage describing relative importance, was assigned to each objective at each level of the tree to account for priorities within each level (see Figure 2-9a and b). The weights were obtained from a poll of experts familiar with nuclear waste management issues (Sinnock and Fernandez, 1984).

Each of the 31 attributes represented some physical condition that both (a) varied throughout the screening area and (b) might influence repository behavior (Sinnock et al., 1984). As Table 2-3 indicates, the attributes fall into two general categories, geographical (attributes 1-23) and host rock (attributes 24-31). A map of the screening area was prepared for each

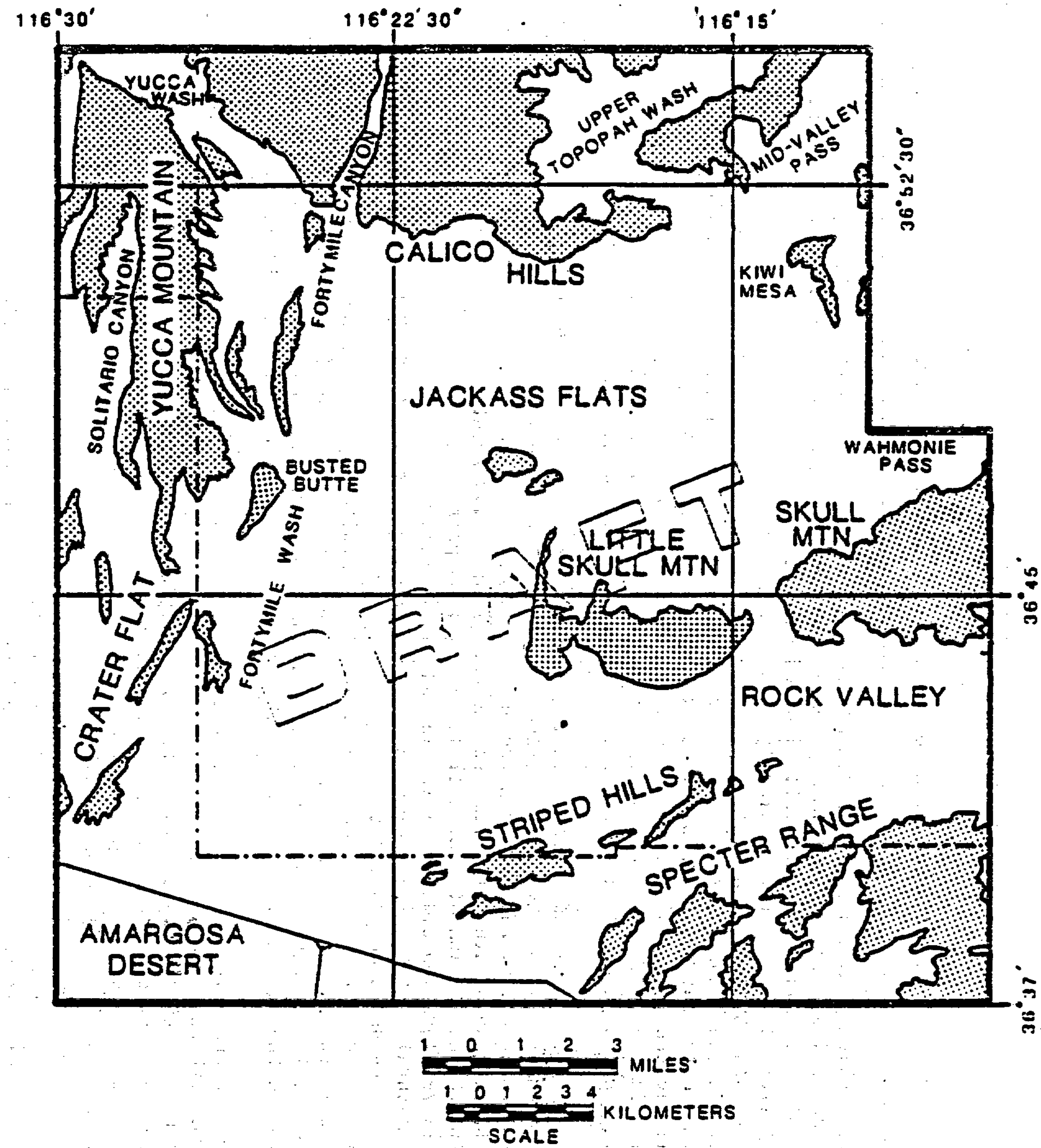


Figure 2-8. Map of the area on and adjacent to the Nevada Test Site within which screening was conducted. Figures 2-11 and 2-12 show results of screening analyses displayed on this base map.

Table 2-1. Three-tiered hierarchical arrangement of objectives used in site screening by the NNWSI Project

---

1.0 Identify locations which permit adequate radionuclide containment in a sealed repository
- 1.1 Screen for natural systems with maximum potential to resist waste package disruption processes
  - 1.1.1 Minimize potential for chemically induced release
  - 1.1.2 Minimize potential for mechanically induced release
- 1.2 Screen for natural systems with minimum potential for waste package disruption events
  - 1.2.1 Minimize the potential for seismic hazards to containment in a sealed repository
  - 1.2.2 Minimize the potential for erosional disruption of waste packages
  - 1.2.3 Minimize the potential for volcanic disruption of waste packages
  - 1.2.4 Minimize the potential for inadvertent human intrusion of a sealed repository
  - 1.2.5 Minimize the potential for events that might disrupt containment

2.0 Identify locations which permit adequate isolation of radioactive waste from the biosphere
- 2.1 Screen for natural systems which will retard migration of radionuclides
  - 2.1.1 Maximize extent of relatively homogeneous host rock
  - 2.1.2 Maximize ground-water flow time to the accessible environment
  - 2.1.3 Maximize retardation of radionuclides along flow paths
  - 2.1.4 Maximize migration times of volatile radionuclides
- 2.2 Screen for natural systems with minimum potential for adverse changes to existing radionuclide migration and retardation processes
  - 2.2.1 Minimize the potential for adverse impacts on isolation due to tectonic changes
  - 2.2.2 Minimize the potential for adverse impacts on isolation due to climatic changes
  - 2.2.3 Minimize the potential for adverse impacts on isolation due to geomorphic changes
  - 2.2.4 Minimize the potential for adverse impacts on isolation due to human activities

3.0 Identify locations where safe repository construction, operation, and decommissioning can be effectively implemented with respect to cost
- 3.1 Screen for locations compatible with surface facility construction and safe operation
  - 3.1.1 Minimize seismic hazards to surface facilities
  - 3.1.2 Minimize surface monitoring system cost
  - 3.1.3 Minimize adverse foundation conditions
  - 3.1.4 Minimize wind loading on surface structures
  - 3.1.5 Minimize flooding hazards to surface facilities
  - 3.1.6 Assure availability of resources to construct and operate the repository

Table 2-1 (continued).

- 3.2 Screen for locations suitable for subsurface facility construction and safe operation
  - 3.2.1 Minimize seismic hazards to subsurface facilities
  - 3.2.2 Minimize flooding hazards to subsurface facilities
  - 3.2.3 Minimize adverse mining conditions
  - 3.2.4 Optimize the geometry (thickness and lateral extent) of the host rock
  - 3.2.5 Optimize host rock homogeneity
  - 3.2.6 Maximize compatibility of a host rock with standardized waste package
- 3.3 Screen for locations with characteristics compatible with safe transport of radioactive wastes to a repository
  - 3.3.1 Minimize adverse terrain along potential waste transport routes
  - 3.3.2 Optimize distance from existing transportation corridors

4.0 Identify locations for which environmental impacts can be mitigated to the extent reasonably achievable
- 4.1 Minimize or avoid adverse impacts on or from sensitive biotic systems
- 4.2 Minimize impact on abiotic systems
  - 4.2.1 Minimize impacts on surface geology
  - 4.2.2 Minimize impacts on water quality and availability
  - 4.2.3 Minimize impacts on air quality
- 4.3 Minimize adverse impacts on the existing socioeconomic status of individuals in the affected area
  - 4.3.1 Minimize adverse impacts on local economies
  - 4.3.2 Minimize the adverse impacts on life style
  - 4.3.3 Minimize conflicts with private land use
- 4.4 Reduce impacts on institutional issues
  - 4.4.1 Cooperate with State and local officials
  - 4.4.2 Carefully implement Federal regulations
- 4.5 Minimize adverse impacts on significant historic and prehistoric cultural resources

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Table 2-2. Objectives used for site screening by the NNWSI Project and the DOE and NRC criteria existing at the time of screening

NNWSI screening objectives		Comparable national criteria	
Number and title	NWTS 33(1) (DOE, 1981a)	NWTS 33(2) (DOE, 1981b)	10 CFR 50 (July 1981 proposed rule) (NRC, 1981)
1.0 CONTAINMENT	3.1.2, 3.2.2(1), 4.2	3.2(par. 1), 3.4(par. 1), 3.3(par. 1)	60.111(b)(2)(i), 60.111(b)(2)(ii)(A), 60.111(b)(3)(i)
1.1 Processes		3.4(2)	
1.1.1 Chemical Release		3.3(1), 3.4(2), 3.2(1), 3.2(4)	50.123(b)(5), 60.123(b)(13-14)
1.1.2 Mechanical Release		3.4(2)	60.123(b)(15), 50.123(k)(1)
1.2 Events		3.5(par. 1), 3.5(1)	60.123(a)(7), 50.123(b)(6;7,10)
1.2.1 Seismic		3.5(2), 3.5(5)	50.112(a), 50.123(a)(5), 60.123(b)(9)
1.2.2 Erosion		3.5(4)	50.112(b), 60.122(i), 60.123(b)(4)
1.2.3 Volcanic		3.5(3)	60.112(a), 50.123(b)(11)
1.2.4 Human Intrusion	3.2.2(3), 3.3.2(4)	3.6(par. 1), 3.6(2)	60.123(b)(1-3)
1.2.5 Miscellaneous	2.3		50.112(j)
2.0 ISOLATION	2.1, 3.1.2, 3.2.2(2), 4.2	3.4(par. 1), 3.1(par. 1), 3.2(par. 1), 3.3(par. 1)	60.111(b)(1), 60.111(b)(3)(ii)
2.1 Nuclide Migration			
2.1.1 Groundwater Flow Time		3.2(1), 3.2(2)	50.112(c), 50.122(c), 50.122(f)(1-4)
2.1.2 Nuclide Retardation		3.3(1)	50.112(d), 50.122(g)(1-3), 50.122(h), 60.123(b)(13-15)
2.1.3 Host Rock Homogeneity			
2.1.4 Volatile Migration			
2.2 Changes to Existing Systems		3.5(par. 1), 3.5(1)	50.123(a)(7), 60.123(b)(7,12)
2.2.1 Tectonic		3.5(2-5)	50.112(a), 50.122(a,b), 50.123(a)(5), 50.123(b)(6,3,10,11)
2.2.2 Climatic		3.2(1)	50.112(b) 50.123(a)(8)
2.2.3 Geomorphic		3.1(1), 3.5(4)	50.112(b), 50.122(e,i), 50.123(b)(4)
2.2.4 Human Activities	3.3.2(4)	3.5(par. 1), 3.5(2)	60.123(a)(3), 60.123(b)(1-3), 50.123(a)
2.2.5 Miscellaneous		3.4(1)	50.122(j)
3.0 CONSTRUCTION	3.1.1, 3.3.1, 4.1		50.111(a)(1,2), 50.130(b)(1), 50.130(b)(2)(ii), 50.131(e)
3.1 Surface Facilities	3.2.1	3.7(par. 1)	50.123(a)(6), 50.131(a), 50.131(c)(1)
3.1.1 Seismic Hazards		3.5(5)	60.123(a)(4), 50.123(b)(9,10)
3.1.2 Monitoring and Characterization Costs	3.3.2(3)	3.7(2)	50.130(9), 50.131(c)(2)
3.1.3 Foundation Conditions		3.7(2)	
3.1.4 Wind Loads		3.7(3)	
3.1.5 Flooding		3.7(1)	50.123(a)(1)
3.1.5 Net Resource Availability	2.6	3.7(4), 3.10(2)	
3.2 Subsurface Facilities	3.1.2, 3.3.2(2)	3.4(3)	60.123(b)(16), 50.130(10), 50.132(a)(1,4), 59.133(b)(4,5)
3.2.1 Seismic Hazard		3.5(5)	50.123(a)(4), 50.123(b)(9,10)
3.2.2 Flooding		3.2(3)	50.122(f)(3), 50.132(a)(2), 50.132(i)(1), 50.132(g)(1,5)
3.2.3 Mining Conditions		3.4(3)	50.123(b)(15,17), 60.132(a)(2), 50.132(e)(1,3), 50.132(f)
3.2.4 Host rock Geometry		3.1(par. 1), 3.1(2)	50.122(i), 50.132(a)(3)
3.2.5 Host rock Homogeneity		3.4(3)	
3.2.6 Waste Package Compatibility	3.4.1, 3.4.2, 3.3.2(1,2)		60.132(a)(1,3), 60.132(i)(2), 60.135(a)(1,2), 60.135(c)(3)
3.3 Transportation			
3.3.1 Terrain		3.8(2)	
3.3.2 Distance		3.7(2)	
4.0 ENVIRONMENT	4.3	3.3(par. 1), 3.9.1, 3.3(2)	50.130(b)(2)(i)
4.1 Sensitive Biotic Systems			
4.2 Abiotic Systems			
4.2.1 Geologic Quality		3.9(1)	
4.2.2 Water Quality		3.9(1)	
4.2.3 Air Quality		3.9(1)	
4.3 Socioeconomics		3.8(par. 1), 3.10(par. 1)	
4.3.1 Local Economies		3.10(1)	
4.3.2 Life Styles			
4.3.3 Private Land Use		3.6(2)	50.121(a)
4.4 Institutional Issues	2.2	3.3(2)	50.121(b)
4.4.1 State Issues		3.5(2), 3.9(2)	
4.4.2 Federal Regulation	4.1.1, 4.1.2	3.9(2)	
4.5 Historic & Prehistoric Res.		3.3(1)	

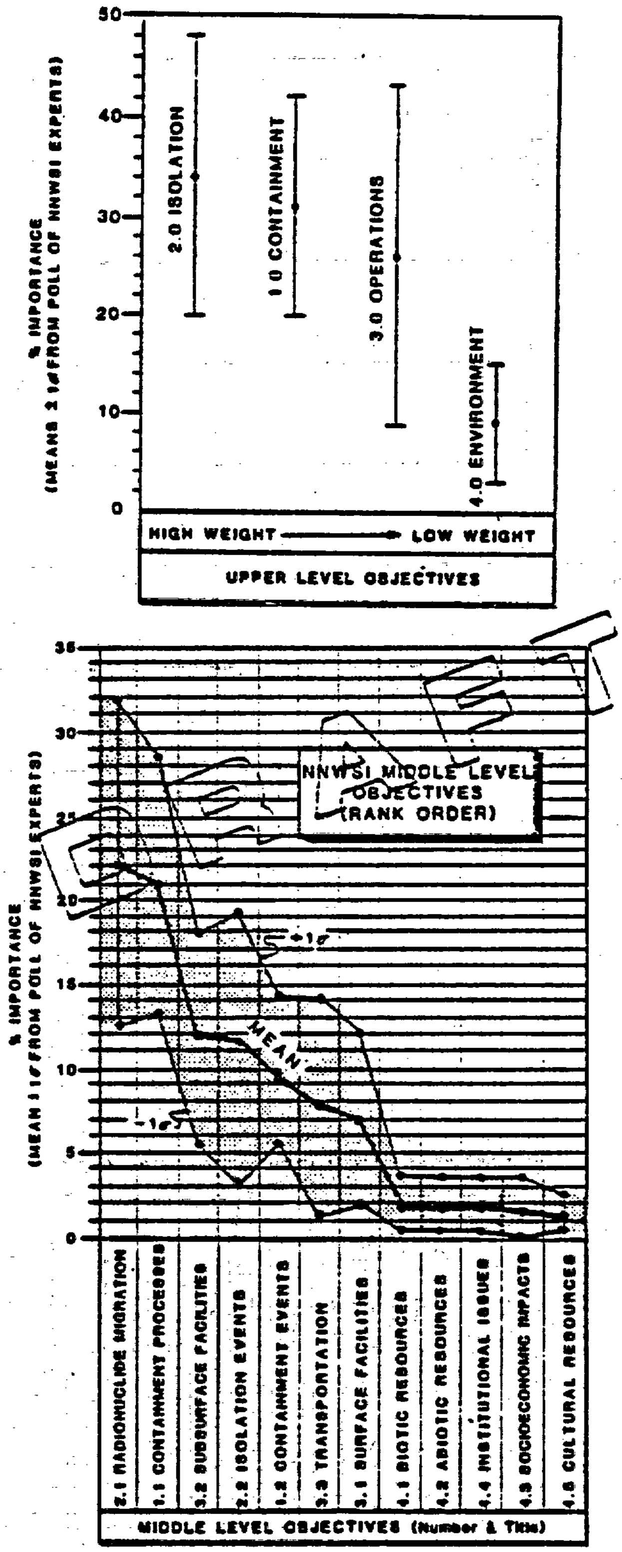


Figure 2-9a. Upper (upper diagram) and middle level (lower diagram) site screening objectives of the NNWSI Project ranked by weight for each level of the objectives tree. Weights and standard deviations (shading, brackets) were obtained from a poll of NNWSI Project participants (from Sinnock and Fernandez, 1984).

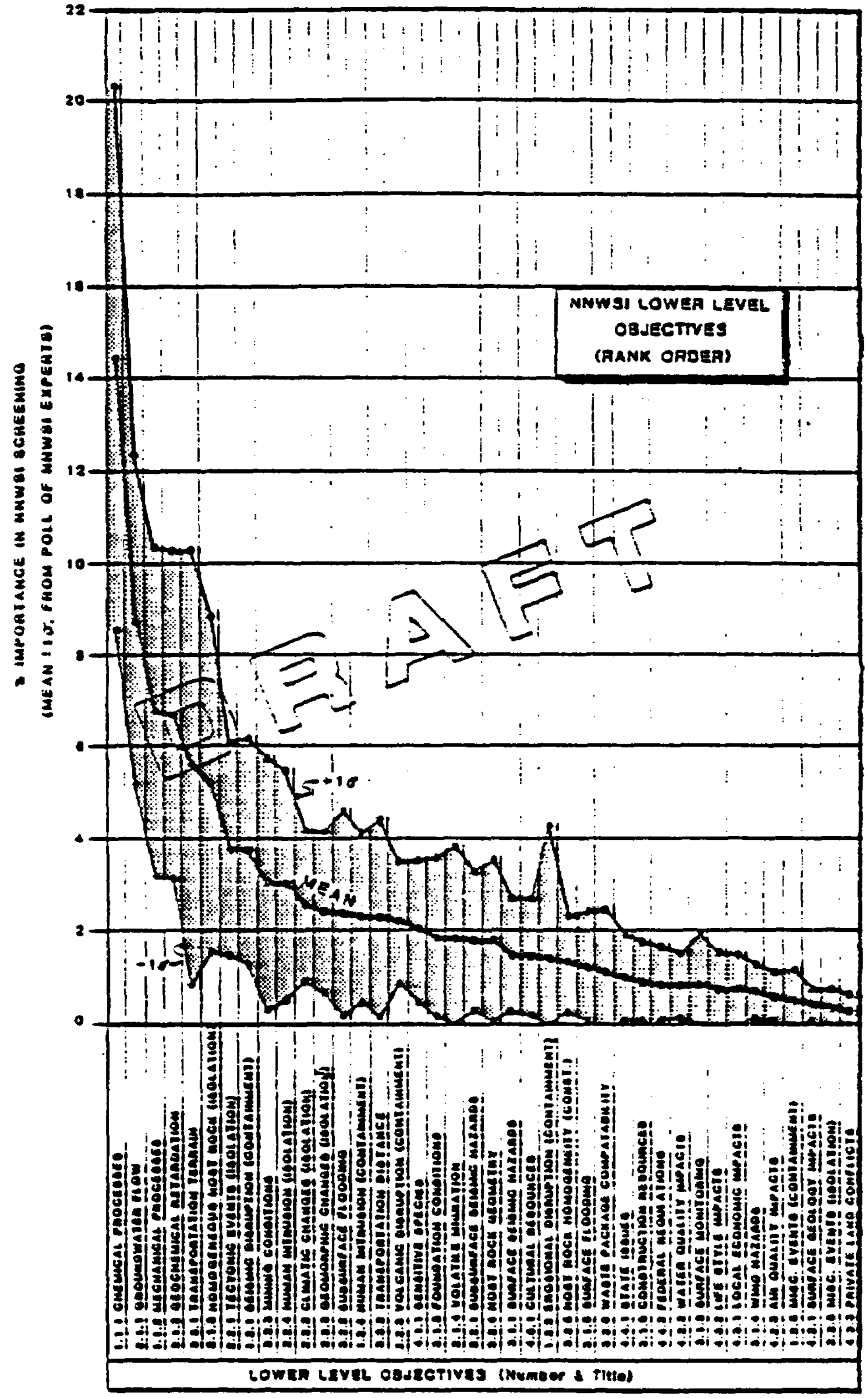


Figure 2-9b. Lower level site screening objectives of the NNWSI Project ranked by weight for each level of the objectives tree. Weights and standard deviations (shading, brackets) were obtained from a poll of NNWSI Project participants (from Sinnock and Fernandez, 1984).

Table 2-3. Physical attributes used to discriminate among alternative locations of the screening area

No.	Attribute	Discriminating conditions
		GEOGRAPHICAL ATTRIBUTES
1	Volcanic potential	Relative potential for basaltic eruptions
2	Fault density	Relative density of faults and fractures
3	Fault trend	Relative potential for fault movement
4	Age of faulting	Fault ages
5	Natural seismic potential	Expected ground acceleration (g)
6	Weapons seismic potential	Expected ground acceleration (g)
7	Bed attitude	Amount of rock dip (degrees)
8	Erosion potential	Projected erosional intensity
9	Flood potential	Flood hazards
10	Terrain ruggedness	Slope steepness (%)
11	Resource potential	Potential for undiscovered metal ores
12	Ground water resources	Potential for development of potential ground water supplies
13	Ground water flux	Saturated ground water flux (m^3/s)
14	Ground water flow direction	Upgradient distance from potential production areas
15	Thickness of unsaturated zone	Depth to water table
16	Sensitive floral species	Potential for the occurence of sensitive species
17	Sensitive faunal species	Likely species habitats
18	Revegetation potential	Vegetation assemblages
19	Known cultural resources	Types and sites of cultural resources
20	Potential cultural resources	Potential density of undiscovered cultural resources
21	Air pollution potential	Air quality zones
22	Permitting difficulties	Land ownership and control
23	Private land use	Private and nonprivate land
		HOST ROCK ATTRIBUTES
24	Thermal conductivity	Thermal conductivity (W/m-°K)
25	Compressive strength (containment)	Unconfined compressive strength (psi)
26	Compressive strength (construction)	Unconfined compressive strength (psi)
27	Expansion or contraction	Expansion or contraction behavior upon heating
28	Mineral stability	Mineral stability upon heating
29	Stratigraphic setting	Stratigraphically weighted sorption potential
30	Hydraulic retardation	Potential for radionuclide diffusion into the rock matrix
31	Hydraulic transmissivity	Hydraulic transmissivity (m^2/s)

geographical attribute showing the distribution of physical conditions represented by that attribute. A value for appropriate rock properties was assigned to each candidate rock type for each host-rock attribute.

Favorability estimates for the various physical conditions represented by each of the attributes were compiled as graphs (Figure 2-10). These graphs constituted quantitative screening criteria by which the relevant physical attributes of the screening area were compared with the objectives. The attributes used to evaluate locations with respect to each of the lower level objectives were also weighted to allow the relative importance of various types of physical conditions to be distinguished (Table 2-4).

The objectives, attributes, favorability graphs, weights, and a base map of the screening area were digitized on an APPLICON graphics system. Computer software was developed to calculate the relative favorability for each of 1514 half-mile centered grid cells of the base map and for each of nine candidate rock types (Sharp, 1984). The calculations multiplied the favorability value of each attribute for each grid cell or host rock, as appropriate, by the weight of the attribute (Table 2-4 entries represent weights assigned to each attribute). The resulting numbers were then multiplied by the weights of the appropriate lower-level objectives (Table 2-5) and added together for a total rating score for each of the 1514 grid cells and for each rock type. Finally, the total scores were scaled to a maximum of 100,000.

Results of the calculations were displayed as maps showing ratings of all 1514 grid cells (Figure 2-11, top) and as lists showing host-rock ratings for both saturated and unsaturated conditions (Figure 2-11, lower left) (Sinnock and Fernandez, 1982). Grid cell ratings shown on the maps were grouped into high, intermediate, and low favorability categories. These categories correspond, respectively, to scores of greater than one standard deviation above the average, within one standard deviation of the average, and greater than one standard deviation below the average (Figure 2-11). The histogram in the lower-right corner of Figure 2-11 shows the range of scores from which the average and standard deviation were calculated. Figure 2-11 shows ratings obtained independently for grid cells (top) and host rocks (lower left) when

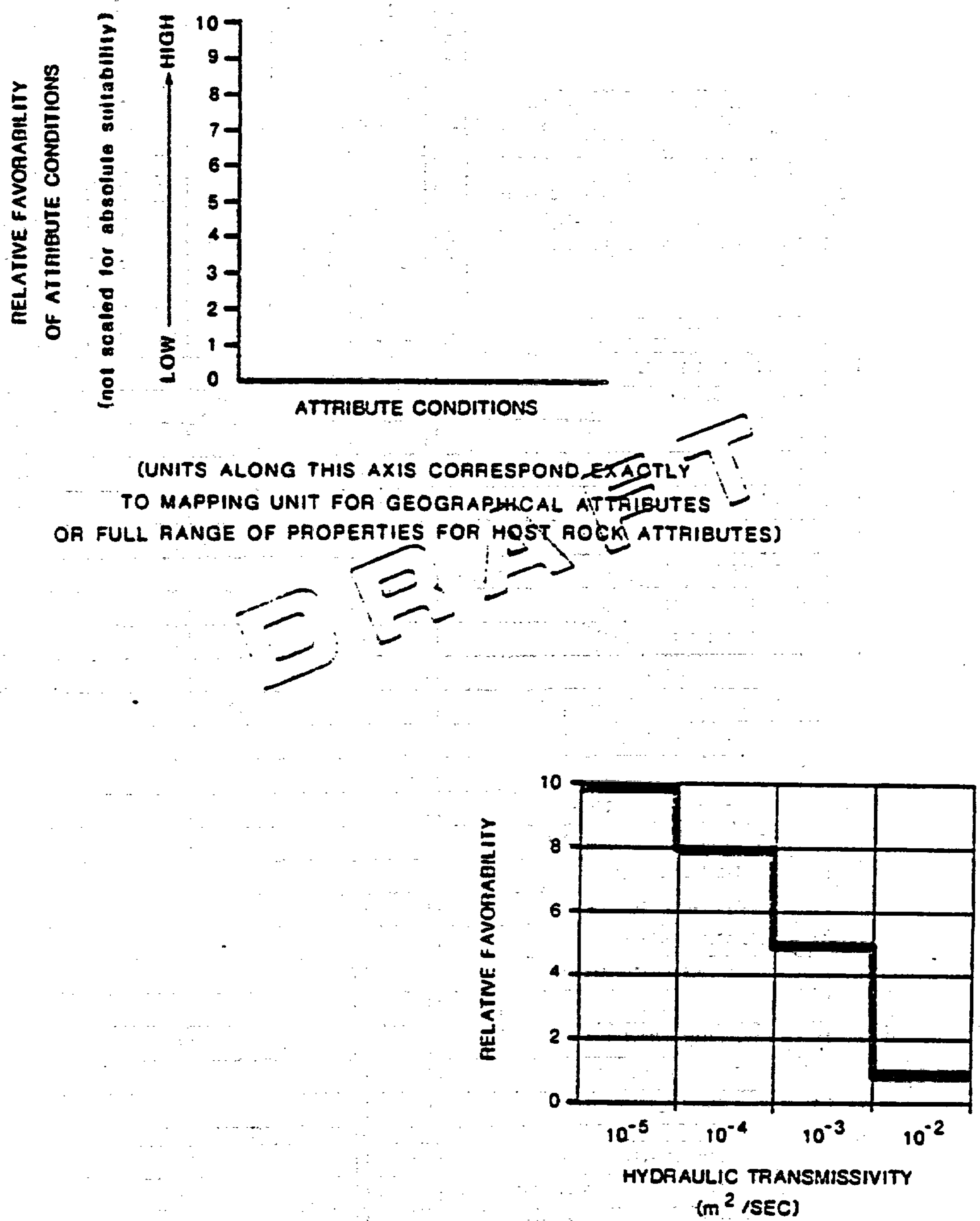


Figure 2-10. General form (upper left) of favorability estimates used to link the attributes to objectives. A specific example for attribute 31, hydraulic transmissivity, is shown on the lower right.

Table 2-4. Attibute-level III objective matrix with weights assigned to attributes

WEIGHTS ASSIGNED TO EACH GEOGRAPHICAL AND HOST ROCK ATTRIBUTE FOR EVALUATING SITE CONDITIONS WITH RESPECT TO EACH LOWER LEVEL OBJECTIVE. THREE-TIERED HIERARCHY IS GIVEN IN TABLE 2-1; PERCENT IMPORTANCE FOR UPPER (I), MIDDLE (II), AND LOWER (III) LEVEL OBJECTIVES ON FIGURES 2-9a AND 2-9b; DISCRIMINATING CONDITIONS FOR GEOGRAPHICAL AND HOST ROCK ATTRIBUTES IN TABLE 2-3; AND WEIGHTS ASSIGNED TO LOWER LEVEL (III) OBJECTIVES GIVEN IN TABLE 2-5.

	LEVEL 1	1.0 PROVIDE CONTAINMENT (31%)							2.0 PROVIDE ISOLATION (34%)								
	LEVEL 2	1.1 DISRUPTIVE PROCESSES (68%)		1.2 DISRUPTIVE EVENTS (32%)					2.1 RADIONUCLIDE MIGRATION (65%)				2.2 DISRUPTIVE EVENTS (35%)				
	LEVEL 3 / ATTRIBUTES	1.1.1 CHEMICAL	1.1.2 MECHANICAL	1.2.1 SEISMIC	1.2.2 EROSIONAL	1.2.3 VOLCANIC	1.2.4 HUMAN INTRUSION	1.2.5 MISCELLANEOUS	2.1.1 GROUNDWATER FLOW	2.1.2 NUCLIDE RETARD.	2.1.3 HOST ROCK THICK	2.1.4 VOLATILE MIGRATION	2.2.1 TECTONIC	2.2.2 CLIMATIC	2.2.3 GEOMORPHIC	2.2.4 HUMAN INDUCED	2.2.5 MISC. & COMPLEXITY
GEOGRAPHICAL	1 VOLCANIC POTENTIAL			5		100							40				
	2 FAULT DENSITY	5							5			10					50
	3 FAULT TREND			5									10				
	4 AGE OF FAULTING			30									10				
	5 NATURAL SEISMIC POTENTIAL			60									40				
	6 WEAPONS SEISMIC POTENTIAL							100								10	
	7 BED ATTITUDE (ROCK [illegible])																30
	8 EROSION POTENTIAL				100										30		
	9 FLOOD POTENTIAL														10		
	10 TERRAIN RUGGEDNESS														10		20
	11 BASE & PRECIOUS METAL RESOURCE POT						50									45	
	12 GROUNDWATER RESOURCE POTENTIAL						50									45	
	13 GROUNDWATER FLUX	5							10	10							
	14 GROUNDWATER FLOW DIRECTION								30								
	15 THICKNESS OF UNSATURATED ZONE								5					100			
	16 SENSITIVE FLORAL SPECIES																
	17 SENSITIVE FAUNAL SPECIES																
	18 REVEGETATION POTENTIAL																
	19 KNOWN CULTURAL RESOURCES																
	20 POTENTIAL CULTURAL RESOURCES																
	21 AIR POLLUTION POTENTIAL																
	22 PERMITTING DIFFICULTIES																
	23 PRIVATE LAND USE																
HOST ROCK	24 THERMAL CONDUCTIVITY	20	30														
	25 COMPRESSIVE STRENGTH (CONTAINMENT)		40								20						
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)																
	27 EXPANSION-CONTRACTION		20														
	28 MINERAL STABILITY	10	10							10		5					
	29 STRATIGRAPHIC SETTING									70	80	30					
	30 HYDRAULIC RETARDATION								10	10		15					
	31 HYDRAULIC TRANSMISSIVITY	60							40			40					

Table 2-4 (Con't)

WEIGHTS ASSIGNED TO EACH GEOGRAPHICAL AND HOST ROCK ATTRIBUTE FOR EVALUATING SITE CONDITIONS WITH RESPECT TO EACH LOWER LEVEL OBJECTIVE. THREE-TIERED HIERARCHY IS GIVEN IN TABLE 2-1; PERCENT IMPORTANCE FOR UPPER (I), MIDDLE (II), AND LOWER (III) LEVEL OBJECTIVES ON FIGURES 2-9a AND 2-9b; DISCRIMINATING CONDITIONS FOR GEOGRAPHICAL AND HOST ROCK ATTRIBUTES IN TABLE 2-3; AND WEIGHTS ASSIGNED TO LOWER LEVEL (III) OBJECTIVES GIVEN IN TABLE 2-5.

	LEVEL 1	3.3 PROVIDE SAFE, COST EFFECTIVE CONSTRUCTION & OPERATIONS (26%)													
	LEVEL 2	3.1 SURFACE FACILITIES (27%)						3.2 SUBSURFACE FACILITIES (43%)						3.3 TRANSPORTATION SYS. (30%)	
	LEVEL 3	3.1.1 SEISMICITY	3.1.2 MONITORING ROADS	3.1.3 FOUNDATION COND.	3.1.4 WIND LOADS	3.1.5 FLOODING	3.1.6 AVAIL. NAT. RES.	3.2.1 SEISMICITY	3.2.2 FLOODING	3.2.3 MINING COND.	3.2.4 HOST ROCK GEOM.	3.2.5 HOST ROCK HOMOG.	3.2.6 WASTE PKG. ACCEPT	3.3.1 TERRAIN	3.3.2 EXISTING COMMUNI
	ATTRIBUTES														
GEOGRAPHICAL	1 VOLCANIC POTENTIAL														
	2 FAULT DENSITY							10	10	20		50			
	3 FAULT TREND														
	4 AGE OF FAULTING														
	5 NATURAL SEISMIC POTENTIAL	90						85							
	6 WEAPONS SEISMIC POTENTIAL	10						5							
	7 BED ATTITUDE (ROCK DIP)										100	40			
	8 EROSION POTENTIAL			10											
	9 FLOOD POTENTIAL			20		100			5					30	
	10 TERRAIN RUGGEDNESS		70	70										70	
	11 BASE & PRECIOUS METAL RESOURCE POT											10			
	12 GROUNDWATER RESOURCE POTENTIAL														
	13 GROUNDWATER FLUX								15						
	14 GROUNDWATER FLOW DIRECTION							10	10						
	15 THICKNESS OF UNSATURATED ZONE														
	16 SENSITIVE FLORAL SPECIES		3												
	17 SENSITIVE FAUNAL SPECIES		7												
	18 REVEGETATION POTENTIAL														
	19 KNOWN CULTURAL RESOURCES		5												
	20 POTENTIAL CULTURAL RESOURCES		15												
	21 AIR POLLUTION POTENTIAL														
	22 PERMITTING DIFFICULTIES														
	23 PRIVATE LAND USE														
HOST ROCK	24 THERMAL CONDUCTIVITY									10			20		
	25 COMPRESSIVE STRENGTH (CONTAINMENT)														
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)									40					
	27 EXPANSION-CONTRACTION												40		
	28 MINERAL STABILITY									10			40		
	29 STRATIGRAPHIC SETTING														
	30 HYDRAULIC RETARDATION														
	31 HYDRAULIC TRANSMISSIVITY								60	10					

Table 2-4 (Con't)

WEIGHTS ASSIGNED TO EACH GEOGRAPHICAL AND HOST ROCK ATTRIBUTE FOR EVALUATING SITE CONDITIONS WITH RESPECT TO EACH LOWER LEVEL OBJECTIVE. THREE-TIERED HIERARCHY IS GIVEN IN TABLE 2-1; PERCENT IMPORTANCE FOR UPPER (I), MIDDLE (II), AND LOWER (III) LEVEL OBJECTIVES ON FIGURES 2-9a AND 2-9b; DISCRIMINATING CONDITIONS FOR GEOGRAPHICAL AND HOST ROCK ATTRIBUTES IN TABLE 2-3; AND WEIGHTS ASSIGNED TO LOWER LEVEL (III) OBJECTIVES GIVEN IN TABLE 2-5.

	LEVEL 1	4.0 PROVIDE ACCEPTABLE ENVIRONMENTAL IMPACTS (3%)									
	LEVEL 2	4.1 BIOTIC SYS. (22%)	4.2 ABIOTIC SYS. (21%)			4.3 SOCIO-ECONOMIC IMPACTS (20%)			4.4 INSTITUTIONAL IMPACTS (21%)		4.5 CULT. RES. (16%)
	LEVEL 3	4.1.1 SENSITIVE SYS.	4.2.1 SURFACE GEOLOGY	4.2.2 WATER QUALITY	4.2.3 AIR QUALITY	4.3.1 LOCAL ECONOMIES	4.3.2 LIFE STYLES	4.3.3 LAND USE	4.4.1 STATE ISSUES	4.4.2 FEDERAL REGS.	4.5.1 ARCH. & HIST. SITES
	ATTRIBUTES										
GEOGRAPHICAL	1 VOLCANIC POTENTIAL										
	2 FAULT DENSITY										
	3 FAULT TREND										
	4 AGE OF FAULTING										
	5 NATURAL SEISMIC POTENTIAL										
	6 WEAPONS SEISMIC POTENTIAL										
	7 BED ATTITUDE (ROCK-3D)										
	8 EROSION POTENTIAL										
	9 FLOOD POTENTIAL		50								
	10 TERRAIN RUGGEDNESS		50								
	11 BASE & PRECIOUS METAL RESOURCE POT										
	12 GROUNDWATER RESOURCE POTENTIAL			100							
	13 GROUNDWATER FLUX										
	14 GROUNDWATER FLOW DIRECTION										
	15 THICKNESS OF UNSATURATED ZONE										
	16 SENSITIVE FLORAL SPECIES	40									
	17 SENSITIVE FAUNAL SPECIES	50									
	18 REVEGETATION POTENTIAL	10									
	19 KNOWN CULTURAL RESOURCES										30
	20 POTENTIAL CULTURAL RESOURCES										[illegible]
	21 AIR POLLUTION POTENTIAL				100						
	22 PERMITTING DIFFICULTIES									100	
	23 PRIVATE LAND USE							100			
HOST ROCK	24 THERMAL CONDUCTIVITY										
	25 COMPRESSIVE STRENGTH (CONTAINMENT)										
	26 COMPRESSIVE STRENGTH (CONSTRUCTION)										
	27 EXPANSION-CONTRACTION										
	28 MINERAL STABILITY										
	29 STRATIGRAPHIC SETTING										
	30 HYDRAULIC RETARDATION										
	31 HYDRAULIC TRANSMISSIVITY										

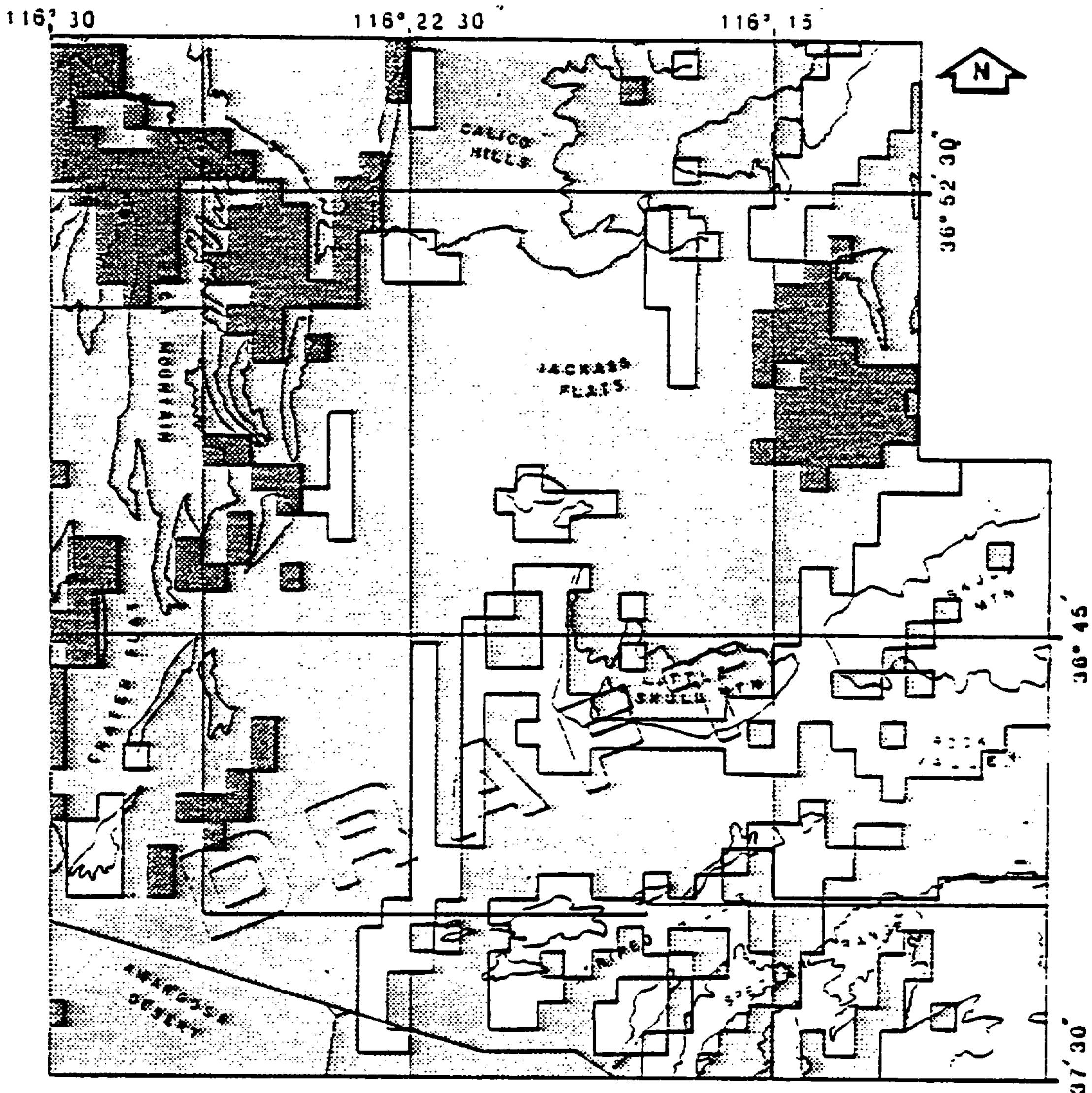
Table 2-5. Weights assigned to lower-level objectives[a] for calculating rating scores for each of the 1514 grid cells and for each rock type

Objective[b]	Weight (%)[c]
1.1.1 Chemical	68
1.1.2 Mechanical	32
1.2.1 Seismic	37
1.2.2 Erosional	14
1.2.3 Volcanic	21
1.2.4 Human intrusion	23
1.2.5 Miscellaneous	5
2.1.1 Ground-water flow	39
2.1.2 Nuclide retardation	30
2.1.3 Host rock thickness	23
2.1.4 Volatile migration	8
2.2.1 Tectonic	31
2.2.2 Climatic	21
2.2.3 Geomorphic	20
2.2.4 Human induced	5
2.2.5 Miscellaneous and complexity	8
3.1.1 Seismicity	21
3.1.2 Monitoring requirements	12
3.1.3 Foundation conditions	26
3.1.4 Wind loads	10
3.1.5 Flooding	18
3.1.6 Available natural resources	13
3.2.1 Seismicity	15
3.2.2 Flooding	21
3.2.3 Mining conditions	27
3.2.4 Host rock geometry	15
3.2.5 Host rock homogeneity	12
3.2.6 Waste package acceptance	10
3.3.1 Terrain	71
3.3.2 Existing corridor	29
4.1.1 Sensitive systems	10
4.2.1 Surface geology	22
4.2.2 Water quality	46
4.2.3 Air quality	32
4.3.1 Local economies	41
4.3.2 Life styles	42
4.3.3 Land use	17
4.4.1 State issues	53
4.4.2 Federal regulations	47
4.4.3 Archeological and historical sites	100

[a] See Figures 2-10 a and b for depiction of weights and standard deviations.

[b] Only general designations; see Table 2-1 for complete statement of objectives.

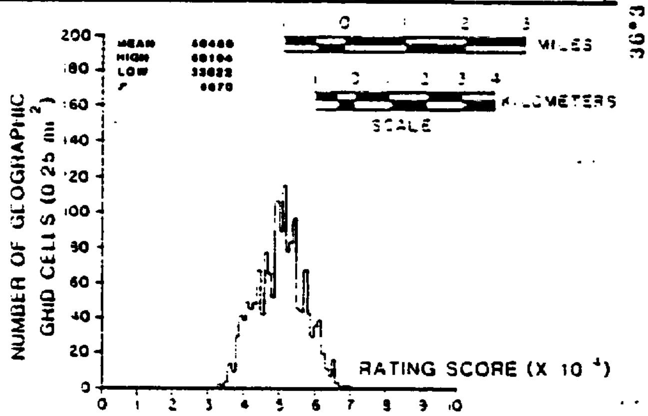
[c] Weights for each group of lower-level objectives sum to 100%.



HOST ROCK RATINGS

AGE	ROCK TYPE	SATURATED RATING	SATURATED RANK	UNSATURATED RATING	UNSATURATED RANK
YOUNGER	Alluvium	46000	7	43000	8
	Basalt	49000	6	48000	7
	Non-welded Paintbrush Tuff	55000	5	42000	9
	Topopah Spring Tuff	41000	8	58000	5
	Calico Hills Tuff	75000	3	62000	3
	Crater Flat Tuff	67000	4	60000	4
	Granite	78000	2	63000	2
	Argillite	82000	1	72000	1
OLDER	Carbonate	39000	9	55000	6

NOTE: Host rock ratings based solely on host rock attributes (numbers 24-31 for saturated list; for unsaturated list numbers 24-30 only). Ratings do not account for site dependent rock conditions such as in-situ stress, in-situ temperature, depth, local structures and others. Unsaturated ratings omit hydraulic transmissivity, attribute #31



LEGEND FOR LOCATION RATINGS (BASED ON ATTRIBUTES 1-23 ONLY)

<45,000 (LOW FAVORABILITY)

45,000-60,000 (MEDIUM FAVORABILITY)

>60,000 (HIGH FAVORABILITY)

Figure 2-11. Example of results of screening analyses. Ratings of the 1514 grid cells that make up the base map are grouped into three categories (see legend). Typical histogram of rating scores used to place individual grid cells into high, medium, and low categories is shown at lower right.

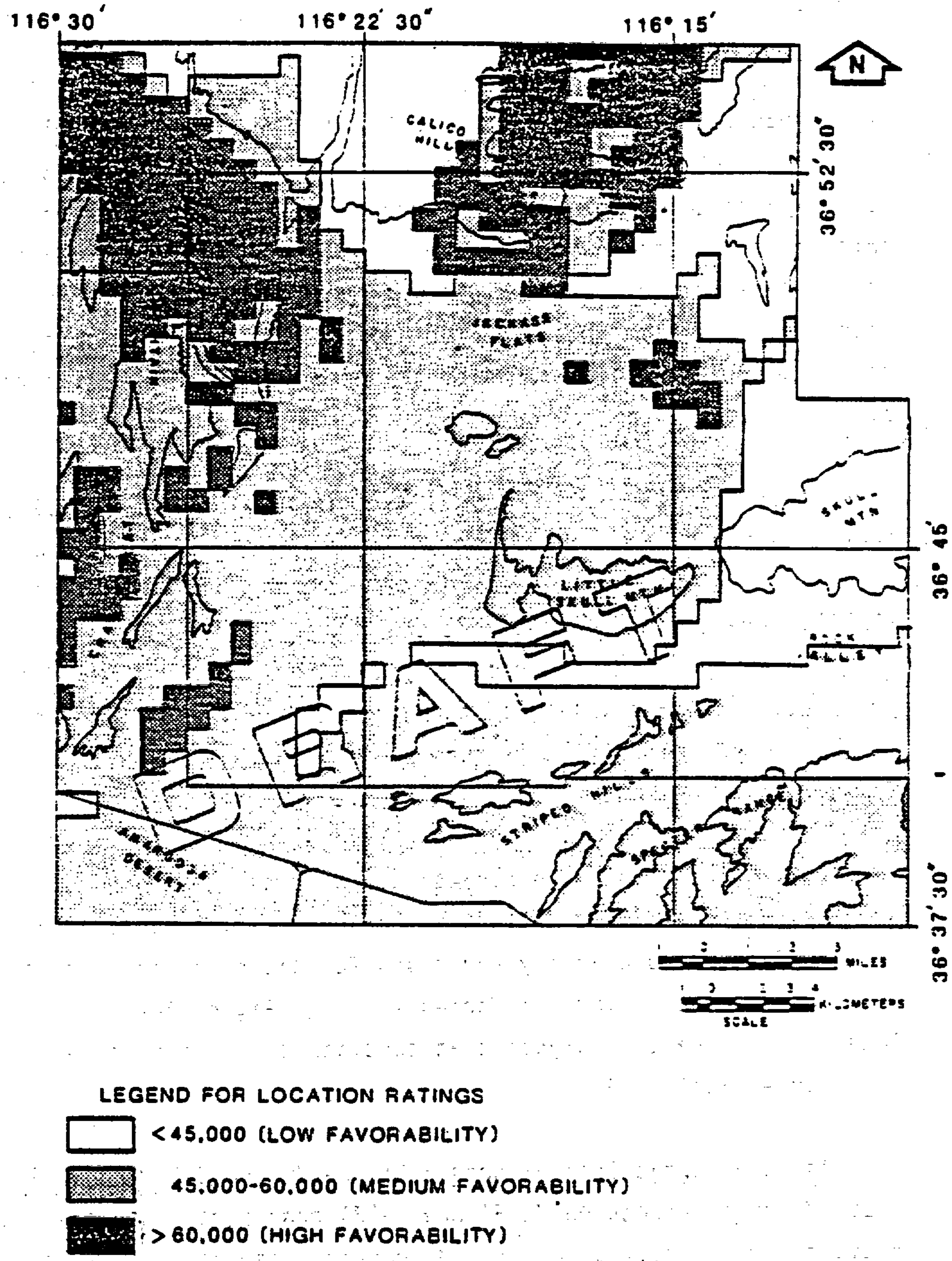


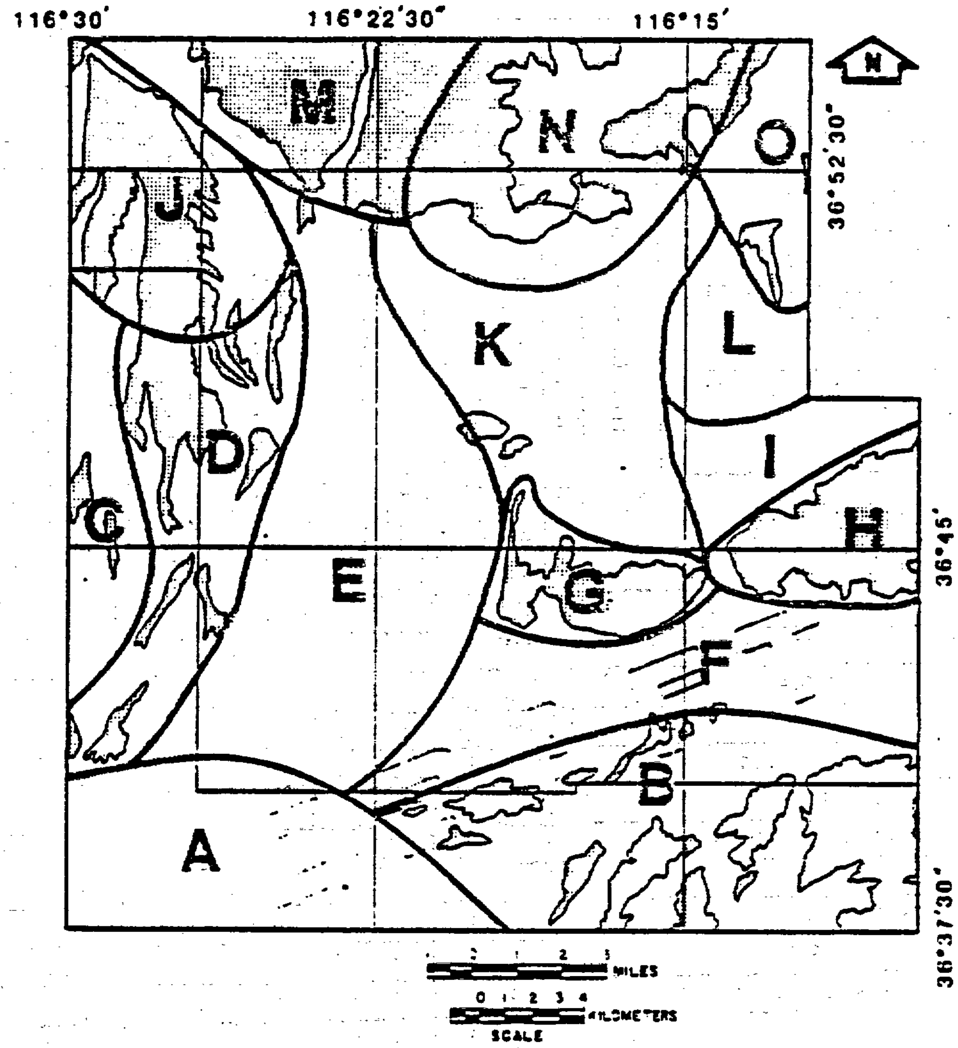
Figure 2-12. Screening analysis results with value of most highly rated host rock added to the grid cell ratings from Figure 2-11, and the total scores were rescaled to a total score of 100,000.

all objectives and associated attributes were used to calculate the scores. Figure 2-12 shows the ratings obtained by adding the score of the highest rated rock type occurring beneath the surface at each grid cell to the scores of the grid cells represented on the map of Figure 2-11. Some localities within the screening area are not underlain by any of the nine rock types evaluated, therefore they had a score of zero added to the corresponding grid cells. Accordingly, the total scores of these grid cells were relatively low as shown by the histogram at the bottom of Figure 2-11.

Figures 2-11 and 2-12 show the results of only two of 19 separate analyses that were performed. The other 17 were based on selected subsets of related objectives or attributes. These analyses, discussed by Sinnock and Fernandez (1982), were used to investigate the factors contributing most to the scores of alternative locations and rock types. Based on groupings of similarly rated grid cells for most or all of the separate analyses, 15 relatively distinct locations were identified (Figure 2-13). In this manner, alternative locations for a repository were established by the analyses.

The 15 locations were ranked according to the number of analyses for which all or most of the grid cells within each location rated high, medium, or low (Figure 2-14). To quantify the basis for the rankings, the weights associated with each of the rating categories shown on Figure 2-14 were summed for each location for the 12 analyses that considered different combinations of objectives (Table 2-6).

As is apparent from Figures 2-11, 2-12, and 2-14 and Table 2-6, northern Yucca Mountain (location J, Figure 2-13) ranked highest, primarily due to high ratings for objectives concerning long-term isolation qualities. Potential drawbacks at northern Yucca Mountain are suggested by relatively low ratings for near-term objectives, including low-cost construction of surface facilities and environmental impacts of construction and operations (Figure 2-14). Three rock types at this location rated highly enough to consider them for use as potential repository host rock. These rock types are the saturated and unsaturated Calico Hills unit, the unsaturated Topopah Spring Member, and the saturated Crater Flat Tuff (Figure 2-11, lower left).



ALTERNATIVE LOCATIONS

- A AMARGOSA DESERT
- B STRIPED HILLS-SPECTER RANGE
- C EASTERN CRATER FLAT
- D CENTRAL-SOUTHERN YUCCA MOUNTAIN
- E WESTERN JACKASS FLATS
- F ROCK VALLEY
- G LITTLE SKULL MOUNTAIN
- H SKULL MOUNTAIN
- I EASTERN JACKASS FLATS
- J NORTHERN YUCCA MOUNTAIN
- K CENTRAL JACKASS FLATS
- L NORTHEASTERN JACKASS FLATS
- M YUCCA WASH-FORTYMILE CANYON
- N CALICO HILLS-UPPER TOPOPAH WASH
- O KIWI MESA-MID VALLEY PASS

Figure 2-13. Approximate boundaries of 15 alternative locations identified from groupings of similarly rated grid cells for 25 separate analyses. The location identified as northern Yucca Mountain (location J) is larger than but encompasses the current target site.

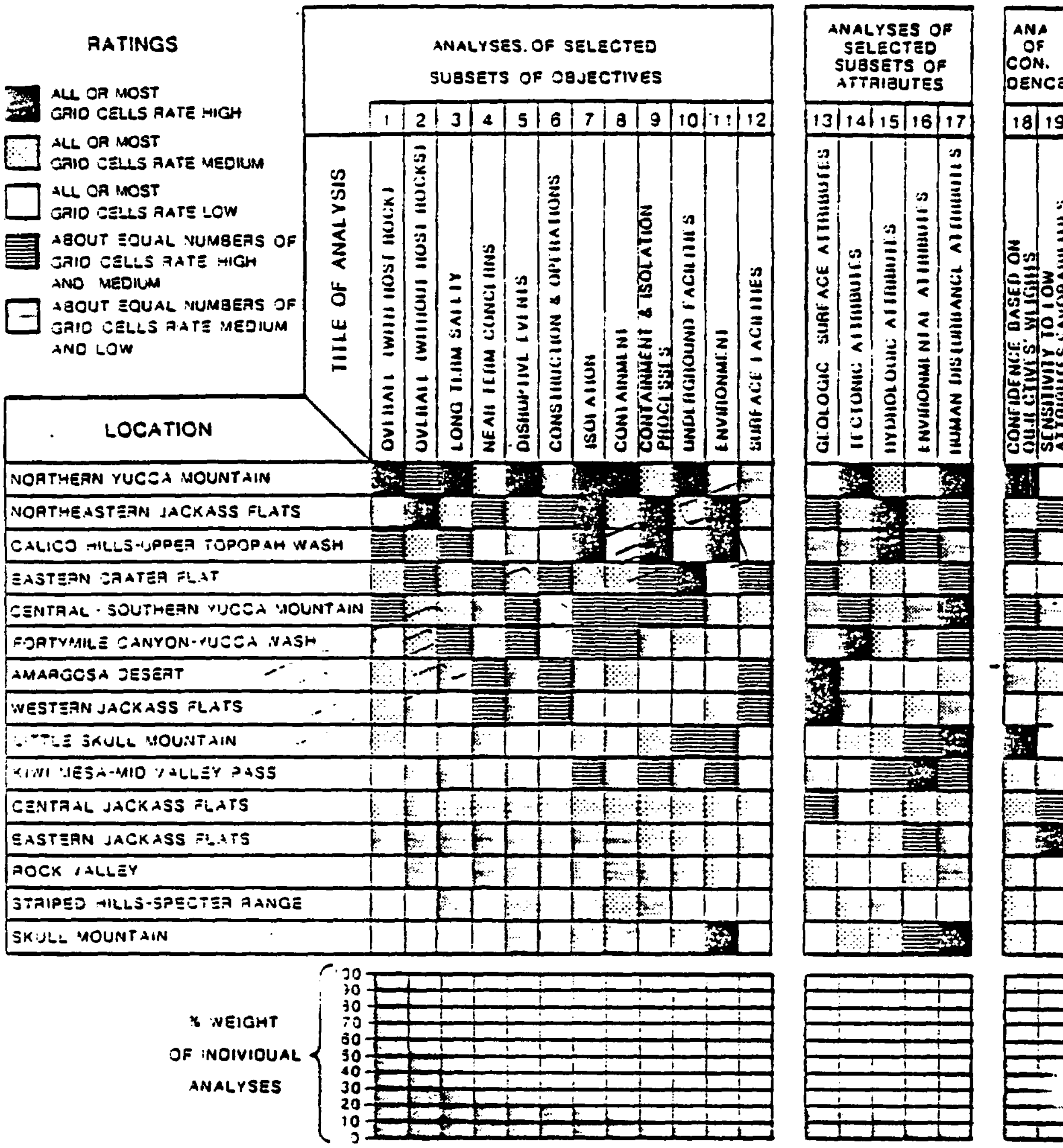


Figure 2-14. Ranking of locations (highest to lowest from top to bottom) based on ratings of all or most grid cells. Separate analyses of (a) objectives (columns 1-12), (b) attributes (columns 13-17), and (c) confidence in the ratings (columns 18-19). For each column, percent weights associated with individual analyses were obtained by polling experts, and are shown in histograms at bottom.

Table 2-6. Ranking of alternative locations (highest to lowest from top to bottom) based on the number and weights of rating categories for the 12 analyses of related objectives shown on the first 12 columns of Figure 2-14.

	Rating category from Figure 2-14									
	High		High and medium		Medium		Medium and low		Low	
Location	No.	Weight	No.	Weight	No.	Weight	No.	Weight	No.	Weight
Northern Yucca Mountain	6	178.79	1	52.42	2	30.59	3	29.41	0	-0-
Northeastern Jackass Flats	4	82.56	2	41.51	5	73.48	1	93.66	0	-0-
Calico Hills-Upper Tonopah Wash	3	30.14	2	122.06	1	52.43	3	39.88	3	46.91
Eastern Crater Flat	3	6.56	5	105.91	3	172.24	0	-0-	1	6.51
Central-Southern Yucca Mountain	0	-0-	6	156.97	3	86.22	2	30.52	1	17.50
Fortymile Canyon-Yucca Wash	0	-0-	4	78.58	2	58.97	4	112.15	2	41.51
Amargosa Desert	0	-0-	3	48.91	3	157.38	4	73.83	2	13.09
Western Jackass Flats	0	-0-	3	46.91	2	100.17	2	74.25	5	69.88
Little Skull Mountain	0	-0-	2	13.06	3	117.29	3	63.71	4	97.15
Kiwi Mesa-Mid Valley Pass	0	-0-	3	30.14	0	-0-	5	120.50	4	140.57
Central Jackass Flats	0	-0-	0	-0-	10	216.96	2	74.25	0	-0-
Eastern Jackass Flats	0	-0-	0	-0-	3	19.64	9	271.57	0	-0-
Rock Valley	0	-0-	9	-0-	1	6.51	9	162.64	2	122.06
Striped Hills-Specter Range	0	-0-	0	-0-	2	33.13	3	52.03	7	206.05
Skull Mountain	1	6.51	0	-0-	2	29.60	2	33.13	7	227.97

Two other locations, northeastern Jackass Flats and Calico Hills-Upper Topopah Wash (locations L and N, respectively, Figure 2-13), also rated generally high. High ratings at northeastern Jackass Flats are primarily due to favorable environmental, surface terrain, and hydrologic attributes. However, this location is not underlain by any of the host rocks evaluated and it had relatively low ratings when host-rock attributes were considered (Figure 2-12). Less favorable tectonic attributes also detracted somewhat from its ratings.

The third location, Calico Hills-Upper Topopah Wash, in contrast to northeastern Jackass Flats, rated low for geographical attributes, and high only when host-rock attributes were considered. Argillite and perhaps granite occur beneath Calico Hills and Upper Topopah Wash, though the granite may be too deep for repository use. Argillite was the first and granite the second rated rock types, for both saturated and unsaturated conditions, and they strongly contributed to the high ratings at this location (compare maps from Figures 2-11 and 2-12). Hydrologic attributes at Calico Hills-Upper Topopah Wash also rated very high, whereas tectonic, surface terrain, and human disturbance attributes generally rated low.

The other 12 locations rated significantly lower than those discussed above.

Yucca Mountain emerged from the formal screening, in agreement with the less formal siting activities described in Section 2.2.3, as the location on or near the NTS that offers the greatest potential for site qualification. The screening systematically compared only the relative merits of alternative locations considered in the study. More site-specific data are needed to allow quantitative predictions of expected short- and long-term environmental and health impacts of repository development. Site characterization is expected to provide the information necessary to confirm the suitability of Yucca Mountain, currently inferred from the site exploration and screening just described.

2.2.5 Selection of the target repository host rock

Complementing the screening for locations described in Section 2.2.4, a separate screening activity was conducted in 1982 and early 1983 to look in greater detail at the relative merits of alternative rock types at various depths beneath Yucca Mountain. By the end of 1981, four rock units had been identified, in part based on the location screening, as primary candidates for a repository. Two units are in the unsaturated zone: the Topopah Spring Member of the Paintbrush Tuff and the tuffaceous beds of Calico Hills. The two other units, the Bullfrog and Tram Members of the Crater Flat Tuff, are located below the water table (Figure 2-15). The objective of the formal evaluation of these four units was to rank them using existing data and analytical methods, supplemented by engineering and scientific judgment. In July 1982, in the midst of the study, planning for an Exploratory Shaft required that a target horizon be chosen. Based on information available at that time, the Topopah Spring Member was designated as the design reference unit. The final evaluation of the four rock units (Johnstone et al., 1984), completed seven months later, supported this preliminary decision.

Several physical properties of the various rock units were used to compare excavation stability, mineability, thermal loading limits, far-field thermomechanical behavior, and ground-water travel time.

The rankings are summarized in Table 2-7. Mineability considered specifically the anticipated ease and cost of the mining process. The Calico Hills unit was a clear choice with respect to this factor because continuous mining machines could be used rather than the more time consuming and expensive drilling and blasting techniques required for the welded units. Even so, the main result from the mineability comparison was that no units were eliminated; all units can be mined successfully with conventional techniques.

Gross thermal loading did not discriminate much among the four units. Loading densities required to keep the floor temperature of emplacement drifts within design limits varied only from 54 to 57 kW/acre. Considering the

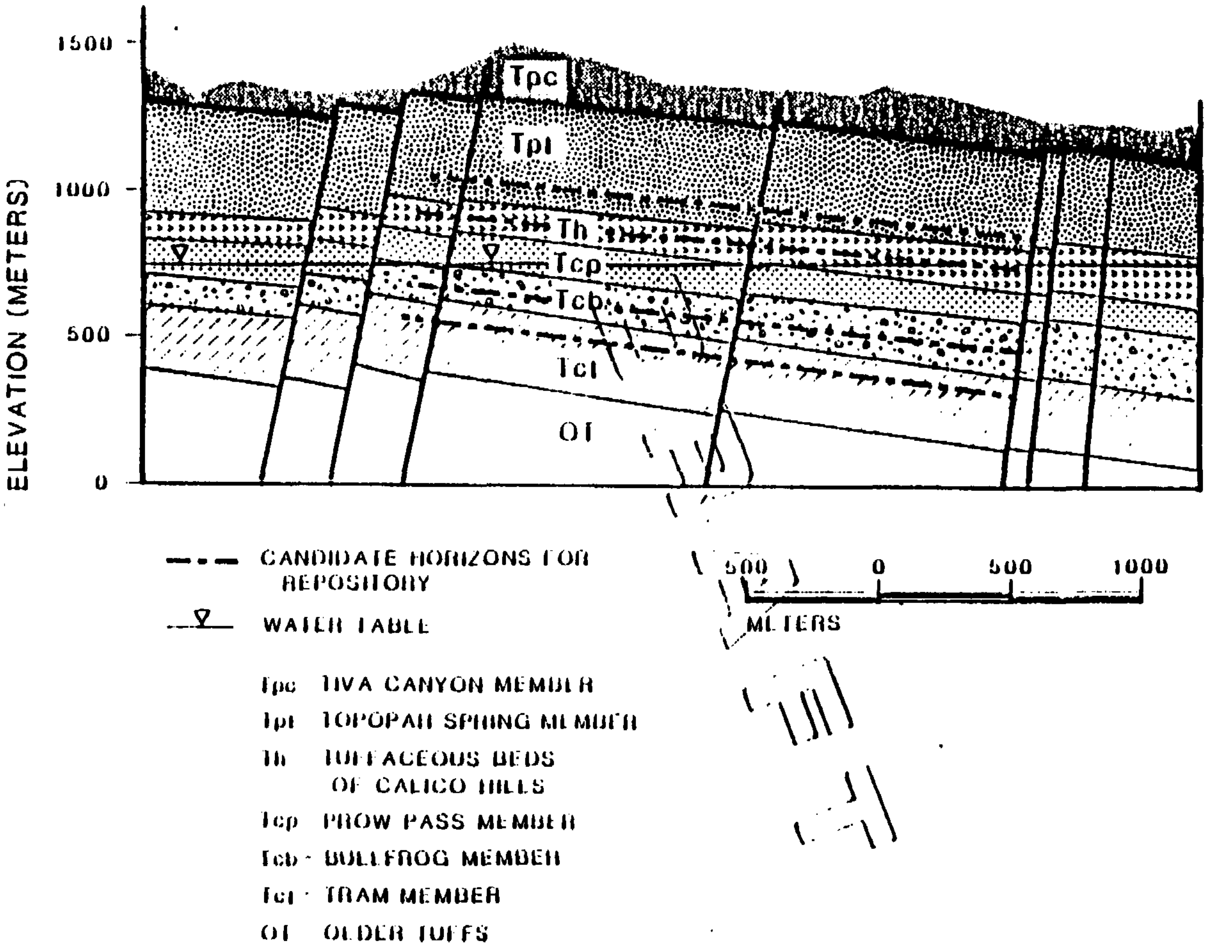


Figure 2-15. General stratigraphy of Yucca Mountain showing the general depth of four candidate repository horizons considered in the unit evaluation study.

Table 2-7. Ranking of four rock units identified as primary candidates for a potential repository host rock (Johnstone and Peters, 1984)(4 is lowest rank; 1 is highest rank)

Comparison factors	Relative rank[a]			
	Topopah Spring	Calico Hills	Bullfrog	Tram
Excavation stability				
calculated near-field thermomechanical response	1	4	2	3
rock matrix properties	1	4	4	4
Norges Geotekniske Institute Classification[b]	1	4	4	4
Council for Scientific and Industrial Research Classification[c]	1	1	2	2
Mineability	2	1	3	4
Gross thermal loading	1	4	2	3
Far-field thermomechanical response	1	2	3	4
Ground-water travel time to the water table	1	2	4	3

[a] Lowest number is highest rank.

[b] Barton, 1976.

[c] Bieniawski, 1976.

variability of thermal properties within each rock unit, the four units are nearly identical with respect to temperature effects due to emplacement of heat generating wastes.

Calculations of far-field, thermal effects also did not discriminate significantly among the units. All units were predicted to affect the far field in virtually the same way. None of the thermal calculations suggested any failure mode for repository performance due to the temperature changes expected in any of the units. Although the differences among them were very slight, the rock units were still ranked on these two thermal factors (see Table 2-7).

The stability of mined tunnels in each unit was evaluated by three different approaches. Near-field computer calculations indicated clear superiority of the three welded units. A subranking among these three units showed that the Topopah Spring Member would be the most stable. An evaluation of rock matrix properties provided a more traditional approach to comparing anticipated stability among the four units. This method also showed that the Topopah Spring Member was clearly more stable than the other three units. Two published techniques for classifying the suitability of rock masses for mining, the Norges Geotekniske Institute (NGI) method and the Council for Scientific and Industrial Research (CSIR) method (Barton, 1976; Bieniawski, 1976), were also used to evaluate mine stability. Based on the NGI system, the Topopah Spring Member was clearly superior to the other three units. Distinctions based on the CSIR system were less dramatic, but this method also ranked this unit first. However, none of the units was classified as unsuitable or unusually dangerous with respect to mine stability.

Vertical ground-water travel times from the candidate repository horizons within each rock unit to the water table were estimated. Ground-water travel time estimates for each rock unit assumed porous flow and did not include the effects of heat. Considerable uncertainty existed in the estimates for each of the candidate rock units. Travel times from the repository horizon to the water table were estimated to be thousands of years. For rock units in the saturated zone, extreme variability in the assumed hydraulic parameters yielded travel time estimates that varied by as much as up to six orders of magnitude.

Travel times in the unsaturated units were longer than in the saturated. Because it is an unsaturated unit, and because it is farther from the water table than the Calico Hills unit (see Figure 2-15), the Topopah Spring Member ranked highest.

Based on the unit evaluation studies, the first choice for the target horizon was the Topopah Spring Member of the Paintbrush Tuff. The second choice was the Calico Hills. The third and fourth choices were the Bullfrog and the Tram Members, respectively. The exact depth and position of a repository in the Topopah Spring Member will be determined during site characterization, based on rock properties that affect predicted performance, mine design, and economic tradeoffs between the costs of facility construction and operations. Nothing in the study suggested that any of the rock units considered would be unsuitable for a repository.

2.3 EVALUATION OF THE YUCCA MOUNTAIN SITE AGAINST THE DISQUALIFYING CONDITIONS OF 10 CFR 960 (DOE, 1983)

The process for the selection of the first site for a nuclear waste repository was established by the Nuclear Waste Policy Act of 1982 and the implementation section of the 10 CFR 960.3. This process requires that the DOE identify within 90 days of enactment of the NWPA, "potentially acceptable sites" and, in the same time period, notify the host states and affected Indian tribes of such identified sites. A notification that Yucca Mountain is a potentially acceptable site was sent in February 1983 to the State of Nevada (Hodel, 1983). The process by which Yucca Mountain was identified as a potentially acceptable site is outlined in the previous section.

From all potentially acceptable sites in the U.S. identified under the NWPA process, the DOE is required to nominate at least five as suitable for site characterization. The purpose of this Environmental Assessment (EA) is, in large part, to provide the information necessary to accompany the nomination of Yucca Mountain for site characterization. The first step in the nomination process, as required in 10 CFR 960.3-2-2-1, is to evaluate each potentially acceptable site against the disqualifying conditions listed in the technical guidelines of 10 CFR 960.4-2 and 10 CFR 960.5-2. This step is to ensure early in the process that any site considered for nomination is not disqualified on the basis of available evidence. Table 2-8 summarizes the evaluation of Yucca Mountain with respect to the disqualifying conditions. Because no disqualifying conditions are judged to exist at Yucca Mountain based on available information, DOE has carried out the remaining steps listed in 10 CFR 960.3-2-2-4 needed to support nomination of the Yucca Mountain site as suitable for characterization. As applicable to Yucca Mountain, which is the only identified potentially acceptable site in its geohydrologic region, these other steps (and the supporting sections of this EA) are:

1. Evaluation of the site against the technical guidelines that do not require site characterization for their application (Section 6.2).

Table 2-8. Summary of evaluations of the Yucca Mountain site against the disqualifying conditions

Disqualifying condition	Conclusion	Reference	Synopsis
• 10 CFR 960.4-2-1(d): GEOHYDROLOGY - less than 1000 yr ground-water travel time	Not disqualified	6.3.1.1	Most likely flow time to the accessible environment is more than 20,000 yr
• 10 CFR 960.4-2-5(d): EROSION - any portion of underground facility less than 200 meters deep	Not disqualified	6.3.1.5	Most of underground facility would be more 300 m deep; shallowest parts more than 225 m deep
• 10 CFR 960.4-2-6(d): DISSOLUTION - dissolution during first 10,000 yr causing hydraulic pathway with releases greater than allowed by system guideline	Not disqualified	6.3.1.6	Tuff not considered to be a soluble rock; disqualifier is more appropriate for evaporites
• 10 CFR 960.4-2-8/1(d): NATURAL RESOURCES - previous mineral exploration creating significant pathways between repository and accessible environment	Not disqualified	6.3.1.8	No at-depth exploration identified at Yucca Mountain.
• 10 CFR 960.5-2-1(d): POPULATION DEN. & DIST. - any surface facility in a highly populated area - any surface facility adjacent to a 1 mi x 1 mi area with 1000 people - inability to develop an emergency preparedness plann	Not disqualified	6.2.1.2	Yucca Mountain is located in least densely populated portion of contiguous U.S.
• 10 CFR 960.5-2-5(d): ENVIRONMENTAL QUAL. - unacceptable impacts - repository or support facility in National Park, National Wildlife Refuge, or National Wild and Scenic River System - irreconcilable conflict with previously designated land use	Not disqualified	6.2.1.6	No unacceptable adverse impacts have been identified and the repository would not conflict with any other land use.
• 10 CFR 960.5-2-9(d): ROCK CHARACTERISTICS - significant risk to health and safety of operating personnel	Not disqualified	6.3.3.2	No rock characteristics that could lead to significant health or safety risks have been identified

2. Evaluation of the site against the technical guidelines that do require data from site characterization (Section 6.3).

3. Evaluation of the effects of site characterization activities on public health and safety and on the environment (Chapter 4).

4. Assessment of the regional and local impacts of locating a repository at Yucca Mountain (Chapter 5).

5. Comparative evaluation of Yucca Mountain and all other sites proposed for nomination for site characterization (Chapter 7).

Summaries of the findings for each of the disqualifying conditions are presented in the remainder of this section. Details of the evaluation of Yucca Mountain against the disqualifying conditions are presented in Sections 6.2 and 6.3 of Chapter 6 along with similarly detailed evaluations against other system and technical guidelines. Table 2-8 refers to the subsections in Chapter 6 where details are available to support the conclusions presented.

Geohydrology (10CFR960.4-2-1(d); Section 6.3.1.1)

Disqualifying Condition: A site shall be disqualified if the expected pre-waste-emplacement ground-water 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 ground-water 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.

Analysis of field and laboratory data indicates that the expected pre-waste-emplacement ground-water travel time along all paths of likely and significant radionuclide travel from the disturbed zone at Yucca Mountain to the accessible environment exceeds 1000 years. The flow paths of interest at Yucca Mountain include segments in both the unsaturated and saturated zone.

Flux through the potential host rock is determined by the volume and rate of infiltration and the hydraulic properties of rocks in the unsaturated zone. Upon reaching the water table beneath Yucca Mountain, this water joins other groundwater in transit from sources of recharge north and northwest of Yucca Mountain, and moves generally horizontally to the accessible environment. Uncertainties in the estimate of travel time at Yucca Mountain include the lack of definition of the extent, and therefore the outer boundary, of the repository disturbed zone; and differing permeabilities along potential travel paths.

Erosion (10 CFR 960.4-2-5(d); Section 6.3.1.5)

Disqualifying Condition: 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.

The welded tuff of the Topopah Spring Member of the Paintbrush Formation is the potential repository host rock at Yucca Mountain. It has sufficient thickness and depth that all portions of the underground facility will be located at least 200 m (650 ft) below the directly overlying ground surface. On the basis of existing information, approximately 75 percent of the waste could be buried more than 300 m (1000 ft) deep.

Dissolution (10 CFR 960.4-2-6(d); Section 6.3.1.6)

Disqualifying Condition: The site shall be disqualified if, during the first 10,000 years after closure, active dissolution fronts will cause an 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.

The minerals which compose the rock in and around the Yucca Mountain site are considered insoluble and no dissolution is expected to occur even at the elevated temperatures anticipated near the waste canisters. Consequently, the formation of active dissolution fronts is not a logical expectation for conditions at Yucca Mountain.

The host rock for the proposed repository horizon at Yucca Mountain consists of the moderately to densely welded and devitrified portion of the unsaturated Topopah Spring tuff. About 95 percent of the host rock consists of alkali feldspars, quartz, and cristobalite, which are minerals that are not prone to dissolution. Below the proposed repository horizon some parts of the Topopah Spring tuff consist of as much as 77 percent volcanic glass (the most soluble phase present), but calculations show that no more than 0.3 cm (0.1 in.) of the 30 m (98 ft) of vitric rock could be dissolved in 10,000 years. This is such a small volume that no significant change in the geohydrologic system could reasonably be expected.

Human Interference: Natural Resources (10 CFR 960.4-2-8-1(d); Section 6.3.1.8)

Disqualifying Condition: 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.

Thorough examination of the Yucca Mountain 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 previous exploration, mining, or extraction activities for resources of commercial importance. The site is within an area of Federally controlled lands, most of which were restricted in the early 1950s to prevent public access, and thereby excluded from exploration and development. The U. S. Geological Survey has also mapped the entire area by physical inspection of the ground surface, and it is extremely unlikely that unknown excavations exist at the site. Consequently, no significant pathways have been created between the projected underground facility and the accessible environment.

Population Density and Distribution (10 CFR 960.5-2-1(d); Section 6.2.1.2)

Disqualifying Conditions:

(1) Any surface facility of a repository would be located in a highly populated area.

(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.

(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, 10 CFR 60, Subpart I. "Emergency Planning Criteria."

The nearest highly populated area to Yucca Mountain with population densities of 1000 or more per square mile is Las Vegas which is about 150 km (95 mi) away. Consequently, surface facilities at Yucca Mountain would not be located within a highly populated area. In addition, an existing Emergency Preparedness Plan covers accidental release of radionuclides as a result of weapons testing at the Nevada Test Site (DOE, 1983). No problems are anticipated for preparation of a plan covering airborne or waterborne releases from an operating repository at Yucca Mountain.

Environmental Quality (10 CFR 960.5-2-5(b); Section 6.2.1.6)

Disqualifying Conditions:

(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.

If a repository were to be located at Yucca Mountain on the basis of existing information, its construction, operation, closure, or decommissioning is not expected to 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 the boundaries of or irreconcilably conflict with the previously designated use 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 dedicated to resource preservation.

Environmental impacts associated with construction, operation, and/or decommissioning of a repository at Yucca Mountain include (1) disruption of approximately 600 ha (1500 acres) of desert habitat, (2) fugitive dust emissions, (3) vehicle emissions, (4) natural radiological releases from excavation of volcanic rock for the repository, and (5) operation of the repository, including operational accidents. The repository will be designed and operated in compliance with all applicable state and Federal health, safety and environmental protection regulations.

Rock Characteristics (10 CFR 960.5-2-9(b); Section 6.3.3.2)

Disqualifying Condition: 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 reasonably available technology.

Based upon currently available laboratory and field data for Yucca Mountain and observations and experience in similar excavations at similar depths, activities associated with construction, operation, and closure are not projected to cause significant risk to the health and safety of personnel. Opening stability has been evaluated using thermomechanical stress analyses, rock mass classification and linear calculations for mine design/pillar sizing. These calculations show that existing mining technology is sufficient to construct and maintain underground openings in the Topopah Spring Member that will allow repository operations to be carried out safely from construction through decommissioning.

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Chapter 3

YUCCA MOUNTAIN AND THE EXISTING ENVIRONMENT

This chapter describes the existing environment of Yucca Mountain and surrounding region and includes those areas that may be affected by proposed site characterization activities (Chapter 4) and possible future development as a repository (Chapter 5). Yucca Mountain was selected by the Department of Energy (DOE) as a potentially acceptable site for a mined geologic repository (Hodel, 1983). The area identified as the Yucca Mountain site is shown on Figure 3-1 and in other figures in Chapter 3. The site is on limited-access Federal land, and is controlled by the U.S. Air Force, the Bureau of Land Management (BLM), and the DOE.

3.1 THE SITE

This section describes the location, present use, geology, hydrology, environmental setting, transportation, and socioeconomic characteristics of the Yucca Mountain site and surrounding region. The environmental setting sections include land use, terrestrial and aquatic ecosystems, air quality, weather conditions, noise, aesthetic resources, archaeology, and cultural and historic resources. Discussions presented in each section have been developed from existing information in accordance with the Nuclear Waste Policy Act of 1982 (NWPA).

3.1.1 Location, general appearance and terrain, and present use

The Yucca Mountain site, shown on Figure 3-1, is located on and immediately adjacent to the southwest portion of the Department of Energy's Nevada Test Site (NTS). The NTS is located in Nye County, Nevada, about 105 km (65 mi) northwest of Las Vegas.

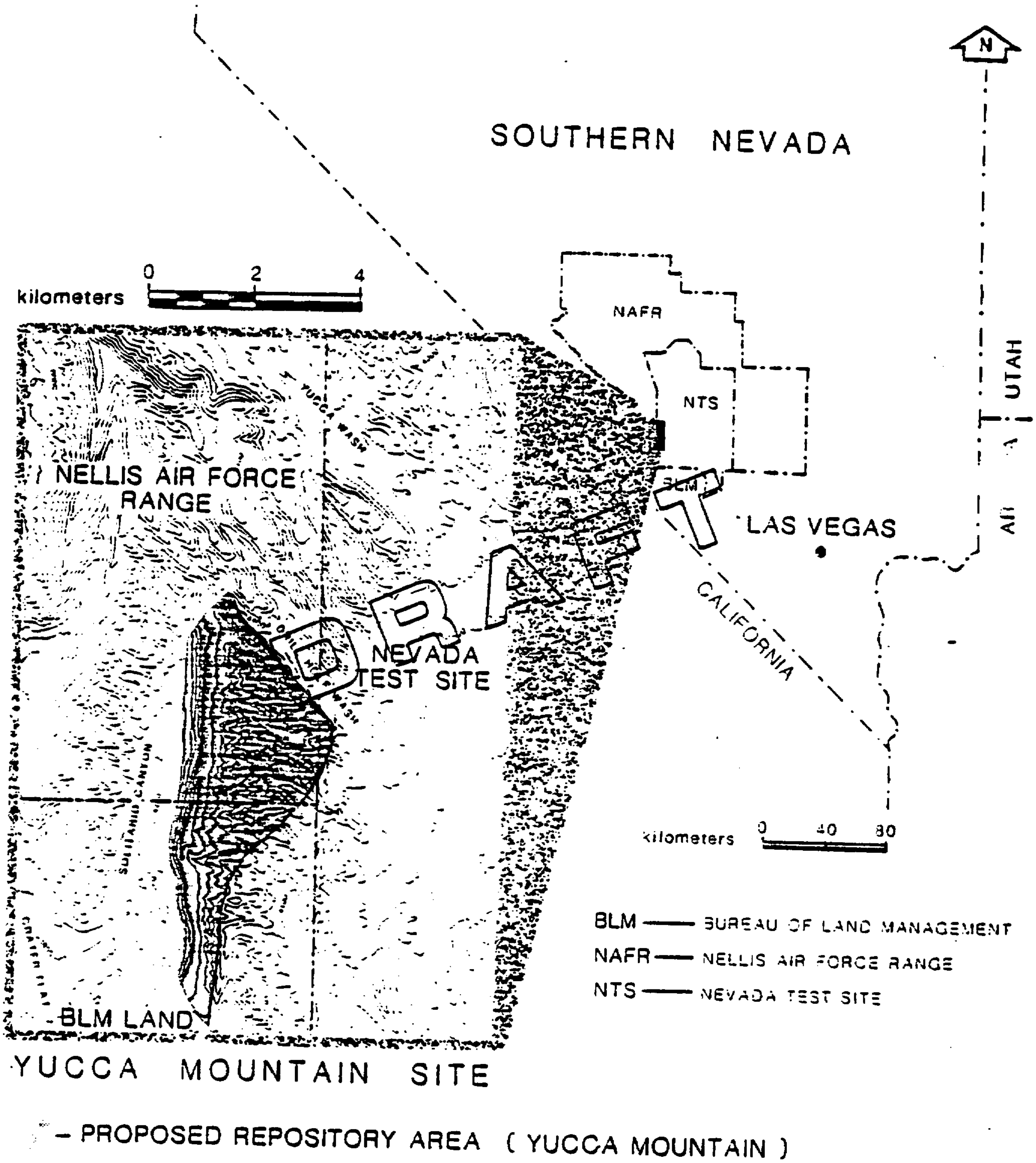


Figure 3-1. Location of proposed repository site at Yucca Mountain in southern Nevada.

The Yucca Mountain site lies within the physiographic Basin and Range Province, that is a broad region of generally linear mountain ranges and intervening valleys. The site lies in the southern part of the Great Basin, a subdivision of the Basin and Range Province with internal surface drainage. Figure 3-2 shows the physiographic features in the site area. The elevation of northern Yucca Mountain is approximately 1500 m (5000 ft), which is more than 370 m (1200 ft) above the western edge of Jackass Flats to the east and more than 300 m (1000 ft) higher than the eastern edge of Crater Flat.

Yucca Mountain is a prominent group of north-trending, fault-block ridges that extend southward from Beatty Wash on the northwest to U.S. 95 in the Amargosa Valley. Topography at the site is controlled by high-angle normal faults and eastward tilted volcanic rocks. Slopes are locally steep (15° to 30°) on the west-facing side of Yucca Mountain and along some of the valleys that cut into the more gently sloping (5° to 10°) east side of Yucca Mountain. The valley floors are covered by alluvium. Sandy fans extend down from the lower slopes of the ridges. Fortymile Wash is cut from 13 to 26 m (40 to 85 ft) into the surface of Jackass Flats. North of Yucca Wash is the high, rugged volcanic terrain of Pinnacles Ridge. To the west of Yucca Mountain, along the west side of Crater Flat, steep alluvial fans extend from deep valleys that have been cut into Bare Mountain. Basalt cones and small lava flows are present on the surface of the southern half of Crater Flat.

The Yucca Mountain site is located exclusively within lands controlled by the Federal government. The land parcel under consideration, which includes both the proposed geologic repository, the repository surface operations area, and all of the proposed controlled area, is divided as follows: (1) the U.S. Department of Energy controls the eastern portion through the withdrawn land of the Nevada Test Site (2) the U.S. Air Force controls the northwestern portion through the land-use permit for the Nellis Air Force Range (NAFR); and (3) the Bureau of Land Management holds the southwestern portion in public trust. There are no competing land-use activities at the site. The U.S. Air Force portion of the site is used exclusively for overflight and contains no facilities. The BLM administered portion of the land has no grazing permits or mineral claims and is not used for recreational purposes (Bell and Larson, 1982).

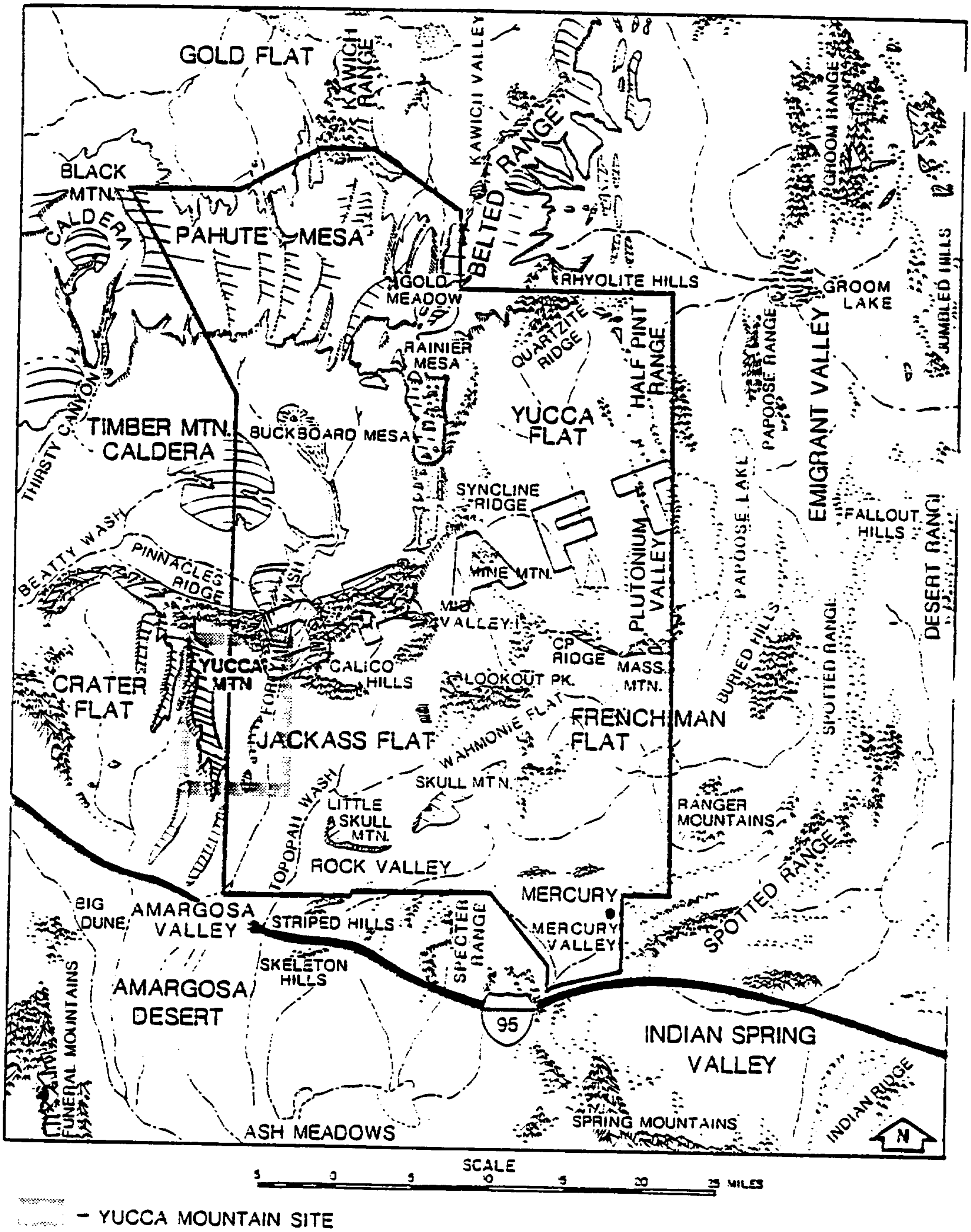


Figure 3-2. Physiographic features of Yucca Mountain and surrounding region. (Source: Sinnock, 1982)

These lands are currently free and clear of encumbrances, such as rights arising under general mining laws, easements for rights-of-way, and other rights arising under lease, right of entry, deed, patent, mortgage, appropriation, prescription, or other such potential encumbrances (Bell and Larson, 1982).

3.1.2 Geology

This section describes the stratigraphy, structure, seismicity, and mineral-resource potential of the Yucca Mountain site and nearby areas. Unless otherwise referenced, the general descriptions of stratigraphy and structure are from Lipman et al. (1966), several articles in Hoover (1968), Byers et al. (1976), Christiansen et al. (1977), Stewart (1980), Sinnock (1982), and Maldonado and Koether (1983). Readers requiring additional information on the geologic development of southern Nevada are referred to the reports listed above and to the many references contained therein. For more detailed descriptions of the tectonics, rock characteristics, and geochemistry of the Yucca Mountain area, readers are referred to corresponding discussions of the technical siting guidelines in Chapter 6.

An understanding of the geology of the Nevada Test Site and surrounding areas has been developed through several decades of surface, subsurface, and geophysical investigations in support of the weapons-testing program. Included in these studies are geologic maps of the Yucca Mountain area that were published in the mid-1960s (Lipman and McKay, 1965; Christiansen and Lipman, 1965.) As described in Chapter 2, detailed geologic investigations of Yucca Mountain as a potential site for nuclear wastes began in 1978 when the first exploratory hole was drilled. Since that time, geologic studies at Yucca Mountain have centered on stratigraphy, structure, geochemistry, mechanical properties, volcanic history, and seismicity. Many of these studies are still in preliminary stages.

3.1.2.1 Stratigraphy and volcanic history of the Yucca Mountain area

The regional stratigraphic setting of Yucca Mountain is characterized by the four major rock groups discussed in Chapter 2. The first and oldest of these groups, the Precambrian crystalline rocks, are not exposed in the vicinity of Yucca Mountain but may occur at great depths beneath portions of the site. The second group, Upper Precambrian and Paleozoic sedimentary rocks, is present at the surface about 15 km (10 mi) east of Yucca Mountain at Calico Hills where it is composed of Devonian and Mississippian argillite and carbonates. This group is also observed 30-40 km (19-25 mi) southeast of Yucca Mountain in the Specter Range and Skeleton Hills where predominately Cambrian and Ordovician carbonates and some quartzite are exposed. Carbonates and quartzite of similar age are also present in the Bare Mountains about 20 km (12 mi) west of Yucca Mountain. Silurian carbonates have been encountered at a depth of 1250 m (4100 ft) about 2.5 km (1.5 mi) east of the Yucca Mountain area. Both east and west of the drill hole, geophysical evidence suggests that the Paleozoic crystalline rocks occur at depths as great as 3000 m (10,000 ft) beneath the surface.

The third major group, Tertiary volcanic rocks, occurs at Yucca Mountain and comprises at least the upper 2000 m (6500 ft) of the total stratigraphic section. They are composed chiefly of rhyolitic ash-flow tuffs, with smaller amounts of dacitic lava flows and flow breccias, and minor amounts of tuffaceous sedimentary rocks and air-fall tuffs.

These rocks form the southern end of the southern Nevada volcanic field, a large plateau segmented by contemporaneous faults and built chiefly of rhyolitic ash flows and related volcanic material. The ash flows that formed this plateau were erupted between about 6 and 16 million years ago from a complex of overlapping nearly circular volcanic depressions called calderas (Figure 3-3). Collectively, the calderas comprise an area of about 1800 km^2 (700 mi^2). Outcrops throughout the region indicate that the volcanic rocks extruded from this caldera complex once covered an area of more than 6500 km^2 (2500 mi^2).

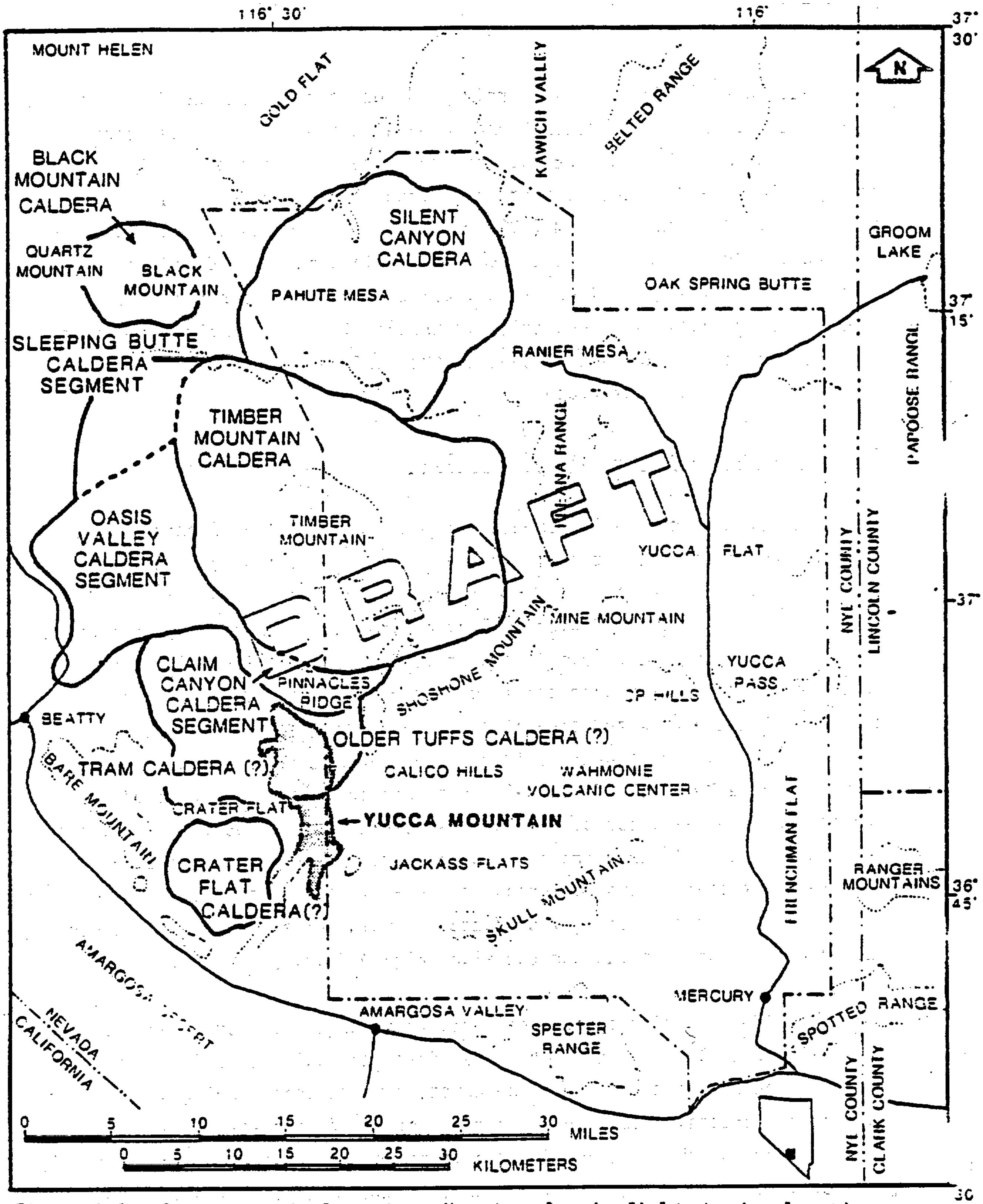


Figure 3-3. Southern end of southern Nevada volcanic field showing location of calderas in the vicinity of Yucca Mountain. (Source: Maldonado and Koether, 1983)

Quaternary (and uppermost Tertiary) deposits comprise the fourth group. These are represented at Yucca Mountain by alluvium and unsorted debris-flow deposits in channels that are cut into the uppermost layers of volcanic rocks and by alluvial-fan deposits that form aprons along the east and west sides of the mountain. Thick alluvium (>200 m or 650 ft) blankets the volcanic rocks beneath Crater Flat to the west and Jackass Flats to the east of Yucca Mountain. Aeolian (windblown) sands, caliche, and soil zones also occur in these thicker Quaternary sections. In Crater Flat, basalt flows and cinder cones of Quaternary age are present at the surface, and flows occur also within the alluvium in the subsurface.

Caldera evolution and genesis of ash flows

The voluminous ash-flow sheets which comprise the major thicknesses of volcanic rocks at Yucca Mountain originated from eruptions during development of calderas. To place the volcanic rock descriptions and terminology in a historical perspective, a brief summary of the evolution of a typical caldera is provided in this section. According to Smith and Bailey (1968), development of a typical caldera is characterized by seven general stages. Some stages overlap, some are repeated several times, and not all take place at every caldera. The Timber Mountain caldera, the source for the youngest volcanic rocks at Yucca Mountain (Table 3-1) went through all seven stages of evolution (Christiansen et al., 1977). Although volcanic activity at Timber Mountain ceased about 11 million years ago, the caldera is still a well-preserved topographic feature. Its evolution is probably similar to the evolution of the older calderas in the vicinity of Yucca Mountain which produced the older volcanic rocks present beneath the site (Figure 3-3).

The life span of a typical caldera, from stage 1 through stage 7, is generally about 1.5 to 2 million years (Smith and Bailey, 1968). During stage 1, magma is intruded into the crust, causing broad doming of the land surface and crustal extension. Minor eruptions of rhyolitic lavas occurr along fissures through the dome and along a major zone of ring fractures, probably tens of kilometers in diameter. Stage 2 is characterized by massive eruptions in rapid succession through the ring fractures, producing massive ash flows which spread over thousands of square kilometers. The volume of material

Table 3-1. Generalized volcanic stratigraphy for Yucca Mountain showing probable source calderas and ages when caldera was active

Age (m.y.)[a]	Volcanic center	Formation	Unit	Range in thickness[b] (meters)[c]
11.3	Timber Mountain Caldera	Timber Mountain Tuff	Rainier Mesa Member	
12	Claim Canyon	Paintbrush Tuff	Tiva Canyon Member	0 - 69
			Yucca Mountain Member	0 - 36[d]
			Bedded Tuff	0 - 44
			Pah Canyon Member	11 - 83[d]
13			Topopah Spr. Member	287 - 356
13.4	Northwest part of the Calico Hills[f]		Tuffaceous beds of Calico Hills	95 - 306[e]
13.5	Crater Flat Caldera	Crater Flat Tuff	Prow Pass Member	127 - 176[e]
			Bullfrog Member	99 - 161[d]
	Tram Caldera[f]		Tram Member	154 - 328
	Northern Yucca Mountain area		Dacitic Lava and Flow Breccia	0 - 112[g]
ND[h]	Northeastern Crater Flat[f]			
ND	[f]		Tuff of Lithic Ridge	42 - 311[e]
	Northern Yucca Mountain area		Rhyolitic, Quartz Latitic and Dacitic Lava and Flow Breccia	9 - 323
ND	Northeastern Crater Flat[f]			
	Northeastern Yucca Mountain (?)		Older Ash-Flow and Bedded Tuffs	

a m.y. = millions of years.
b Thicknesses based on four drill holes at Yucca Mountain, as reported in Maldonado and Keother (1983).
c 1 m = 3.28 ft.
d Includes overlying and underlying bedded tuffs.
e Includes overlying bedded tuffs.
f Volcanic center uncertain
g Includes underlying bedded tuffs.
h ND = no age determination available.

erupted from a single caldera is commonly many hundreds of cubic kilometers. Some of the ash flows produced during stage 2 from calderas in southwestern Nevada are among the most voluminous and widely distributed in the world. Stage 3 generally occurs at the same time as stage 2. As the magma producing the ash flows rises to the surface, the source chamber is drained. The top of the volcano then collapses into the drained magma chamber along the ring fractures, forming a circular depression known as a caldera. Vertical displacement along the ring fractures during the collapse of the caldera commonly amounts to many thousands of feet. During stage 4 minor volcanism occurs within the caldera, the unstable outer walls of the caldera undergo landsliding, and small lakes commonly form on the caldera floor. Stage 5 is characterized by rhyolitic volcanism and renewed doming within the central part of the caldera. The resurgent dome is broken by a complex system of faults as the surface extends. During stage 6, rhyolitic lava flows and ash-flow tuffs erupt along the ring fractures. These late-stage volcanic rocks often are interlayered within and near the caldera with debris flows, gravels, bedded tuffs, and sediments derived from the erupted material. The final stage of caldera evolution (stage 7) is hydrothermal alteration and fumarolic activity. Much of the alteration apparently occurs along fractures.

The ash flows of stage 2 described above generally originate from massive gas-charged explosive eruptions. The explosions are caused by rapid expansion of the ascending rhyolitic lava into clouds of ash-sized particles consisting of hot, molten glass shards and crystals. As the incandescent clouds of gas and superheated ash collapse back to the earth's surface, they flow rapidly down the volcanic slopes and spread across the surrounding terrain. After coming to rest, the still-hot glass shards and crystals begin to settle, become compacted, and weld together under their own weight, forming the rock type known as densely welded tuff. Commonly the glassy shards develop crystals of feldspar and quartz minerals when hot vapors seep through the semimolten mass during the cooling period. This crystallization process is called vapor-phase devitrification. If devitrification does not occur, the rocks remain glassy and are referred to as vitric tuffs.

Single ash flows sometimes cool completely before being covered by another hot flow, thereby forming a single cooling unit characterized by densely welded, fractured, central parts surrounded above and below by less-welded parts. Complete cooling of earlier ash flows may not occur if several eruptions are closely spaced, forming volcanic sequences called compound cooling units. A glassy unit called a vitrophyre often occurs at the base or top of an ash flow, where rapid cooling was caused by contact with the earth or the atmosphere. Lithophysal cavities, formed as gas pockets in the viscous flows commonly occur in the central parts of thick, densely welded zones. The lithophysae may be circular, elliptical, or flattened, depending on the amount of viscous flow and compaction that occurred after they formed. The interior, densely welded parts of the ash flows generally contain closely spaced vertical fractures that developed as the rock cracked during cooling. Fractures with other orientations are developed during sluggish movement of the partially consolidated ash flow or from later tectonic stresses.

Air-fall tuffs commonly occur in association with ash-flow tuffs. They originate from erupted ash that cools in the atmosphere before it settles on the land surface downwind from the source. These lower-volume and lower-temperature ash falls form rock types known as bedded tuffs, which are nonwelded, porous, and visibly stratified.

The following sections briefly describe the major Tertiary stratigraphic ash-flow and related units at Yucca Mountain. The general units and calderas are shown on Table 3-1. Rock types and thicknesses described below are based on the results of exploratory drill holes at Yucca Mountain reported by Maldonado and Koether (1983). General descriptions are from the publications listed at the beginning of this section and from Guzowski et al. (1983).

<u>Timber Mountain Tuff</u>

The Timber Mountain Tuff is the youngest volcanic unit exposed at Yucca Mountain. It is commonly divided into the Ammonia Tanks Member and the underlying Rainier Mesa Member. Only the Rainier Mesa Member is preserved at Yucca Mountain (Lipman and McKay, 1965). It is an ash-flow unit that was erupted 11.3 million years ago from the Timber Mountain caldera (Figure 3-3).

At Yucca Mountain, it occurs only in low-lying fault blocks (Section 3.1.2.2), indicating the fault blocks had formed by the time the Rainier Mesa Member was erupted. This unit is a moderately welded, devitrified tuff that grades downward into a nonwelded vitric tuff at the base.

Paintbrush Tuff

The Paintbrush Tuff at Yucca Mountain consists of four members with thin bedded reworked or air-fall tuffs between them. From youngest to oldest, the units are the Tiva Canyon Member, the Yucca Mountain Member, the Pah Canyon Member, and the Topopah Spring Member (Table 3-1). These units were erupted between about 12 and 13.2 million years ago from the Claim Canyon caldera and perhaps, in part, from the Oasis Valley caldera (Figure 3-3).

The Tiva Canyon Member forms the caprock at Yucca Mountain and ranges in thickness from zero where it has been eroded away in channels and washes to greater than 50 m (160 ft) on the ridge crests. It has a moderately to densely welded devitrified central portion, underlain by a less densely welded vitric zone. It is a compound cooling unit, compositionally zoned from rhyolite in the lower and middle parts to quartz latite near the top. Large xenoliths (fragments of preexisting rocks incorporated in the rising lava) occur at several places within the unit. Flattened lithophysae are common in the middle and upper parts. Bedded air fall tuff and tuffaceous sediments a few meters thick occur at the base of the member. The total volume of the Tiva Canyon Member is 1000 km^3 (240 mi^3), indicating the massive eruption required to produce it.

The Yucca Mountain Member ranges in thickness from zero to 36 m (118 ft) and had an estimated original volume of only 17 km^3 (4.1 mi^3). It is a simple cooling unit with nonwelded to partly welded zones at the base, top, and distal portions. North of the site (drill hole USW G-2) the interior is moderately to densely welded with a lithophysal core. Compositionally, the unit is a rhyolite with little variation from top to bottom.

Bedded tuff and nonwelded ash flow tuffs occur locally between the Yucca Mountain Member and the underlying Pah Canyon Member. These tuffs range in thickness from zero to 44 m (144 ft). The matrix is mostly vitric and contains abundant xenoliths of volcanic rocks.

The Pah Canyon Member at Yucca Mountain ranges in thickness from 11-83 m (36-272 ft). It is a simple ash-flow cooling unit with nonwelded to partly welded zones at the base and top, and an interior zone of moderate to dense welding north of the site. It is generally vitric, and tuffaceous sediments and air-fall tuff occur at the base.

The Topopah Spring Member, the next lower unit is the target host rock. It is a compound cooling unit composed of as many as four separate ash flow sheets, and varies in composition from low-silica rhyolite near the top to high silica rhyolite near the base. At least 275 km^3 (66 mi^3) of ash flow material were spread over an area of about 1800 km^2 (700 mi^2) during eruption of the Topopah Spring Member. At Yucca Mountain, it is about 350 m (1150 ft) thick, but it thins abruptly to the south and is absent near the southwest corner of the Nevada Test Site. It also appears to thin to the north where it is only about 290 m (950 ft) thick (drill hole USW G-2).

At the site, the Topopah Spring Member is characterized by four distinct zones, from top to bottom: a nonwelded to densely welded, generally vitric tuff; a moderately to densely welded, devitrified tuff that comprises most of the total thicknesses of the member; a basal vitrophyre; and a vitric tuff grading downward from welded to nonwelded. The thick welded devitrified zone, second from the top, is the target host rock for the repository. It contains abundant lithophysae in several intervals but they are most common in its upper and central portions. In the lower part of the densely welded interval, lithophysae are less abundant, and most attention has been directed to this zone for consideration as a host rock for nuclear waste. The rock is densely fractured, and is almost exclusively composed of quartz and feldspar.

Tuffaceous Beds of Calico Hills

The tuffaceous beds of Calico Hills is an informal name for tuffaceous rocks that may have originated from a currently obscured volcano near the north end of Calico Hills, east of Yucca Mountain (Figure 3-3). The unit ranges in thickness from 90-150 m (300-500 ft) at the site though it thickens to nearly 306 m (1000 ft) to the north (drill hole USW G-2). It is composed chiefly of nonwelded ash-flow tuffs, numerous thin tuffaceous sedimentary beds, and minor air-fall tuffs. The rocks in the northern and eastern part of the site are typically zeolitized, having undergone a low-temperature, low-pressure alteration to zeolite minerals which strongly retard the movement of radionuclides. The rocks in the southern and western part of the site (drill holes USW G-3 and H-5) are vitric and not zeolitized.

Crater Flat Tuff

Beneath the Calico Hills unit is the Crater Flat Tuff which consists of three members; the Prow Pass Member at the top, the Bullfrog Member in the middle, and the Tram unit at the base. The Prow Pass Member is 127-175 m (417-574 ft) thick at Yucca Mountain. The Prow Pass Member contains six partly zeolitized, partly devitrified ash-flow tuffs that probably cooled as a compound unit (drill hole USW G-1). Most of the unit is partially to moderately welded; however, bedded, reworked, and densely welded materials occur in the central part of the unit, and zeolitized air-fall tuffs occur at the base. Mudstone fragments, derived perhaps from the Eleana Formation of Devonian-Mississippian age, are abundant in the Prow Pass Member. The Bullfrog Member ranges in thickness from 99-161 m (325-530 ft) and consists predominantly of partially to moderately welded ash-flow tuffs with isolated, thin, densely welded layers. The Tram unit is 154-327 m (507-1073 ft) thick and consists of at least four slightly to densely welded ash-flow tuffs, some of which are zeolitized and devitrified. Reworked bedded tuffs also occur in the Tram unit.

Older Tuffs

For this document, all rocks below the Crater Flat Tuff are referred to as older tuffs. No formal stratigraphic units are recognized in the older volcanic rocks. Most of these units have been observed only in drill holes at Yucca Mountain. They generally consist of moderately to densely welded ash-flows; interspersed with rhyolitic lava flows, breccia flows, and nonwelded air-fall tuffs and bedded, reworked tuffs. The total thickness of the older tuffs is unknown. Four drill holes (USW G-1, USW G-2, USW G-3, and H-1) have penetrated more than 1800 m (6000 ft) without reaching the base of the volcanic rocks.

3.1.2.2 Structure

The structural development of southern Nevada and southeast California has been long and complex, as briefly discussed in Chapter 2. Crustal extension and associated volcanism, Basin and Range style faulting, and alluvial filling of intermontane valleys during Cenozoic time has obscured the relationship of older, regional structural features. In Mesozoic time (65-150 million years ago), the Precambrian and Paleozoic sedimentary rocks of Southern Nevada were strongly compressed. The folds and thrust faults formed during this interval indicate that compression was directed generally from west to east, and that the age of deformation decreases to the east. The patterns of exposed pre-Tertiary rocks suggest that several thrust-fault systems and several broad, associated folds trend north to northeast through the area east of Yucca Mountain. The tectonic forces that created these ancient structures have long since been inactive (see detailed discussion in the Tectonics Technical Guideline, Section 6.3.1.7). This factor, in combination with the absence of rocks deformed by these forces at the site, constrains the discussion of pertinent structures to those produced by Tertiary extensional tectonics. The Tertiary structures are, however, complex and result from a long and complicated history. Nevertheless, field work conducted during the past few decades and recent studies at Yucca Mountain by the NNWSI Project have established a basic understanding of the structural and tectonic framework of this region.

The site lies in the southern Great Basin. Although topographic expressions of the Basin and Range style structures seem to indicate a relatively simple system of uplifted and downdropped crustal blocks, the deep structural configuration of some parts of the Basin and Range is complex (Anderson et al., 1983; Allmendinger et al., 1983). Many investigators link the origin of Basin and Range type structures to right-lateral faulting along the western edge of North America during Cenozoic time (Christiansen and McKee, 1978; Atwater, 1979; Hamilton and Myers, 1966.) According to this view, western North America lies within a broad belt of right-lateral movement caused by differential motion between the North American and Pacific crustal plates. Some of the right-lateral movement occurs presently along the San Andreas fault and similarily oriented faults in California (Figure 3-4). This type of motion may have occurred earlier in southern Nevada and eastern California along the Walker Lane, Death Valley, Furnace Creek and Las Vegas Valley shear zones. This motion may have been related to extensional processes that fragmented the crust into the basins and ranges oriented along trends oblique to the right-lateral fault zones. Relatively high seismic activity also continues today along the right-lateral Death Valley and Owens Valley shear zones northwest and southwest of Yucca Mountain, suggesting that these shear zones might still be active.

Cumulative displacement across the entire zone of inferred right-lateral faulting in the western Great Basin, including fault-slip and large scale bending, may be in excess of 150 km (90 mi) (Albers, 1967.) This estimate includes the bending of structural features to a northeasterly trend due to drag folding along the Walker Lane (Albers, 1967) and the Las Vegas Valley shear zone (Longwell, 1960). Maximum displacement along individual fault zones, however, is generally thought to be less than 48 km (30 mi). Several investigators suggest the right-lateral fault zones became active about 25 million years ago, (Carr, 1974; Atwater, 1970) although others believe they were active for a much longer time (Albers, 1967).

Most displacement along the Las Vegas Valley shear zone southeast of Yucca Mountain has apparently occurred during the past 17 million years. Fleck (1970) and Carr (1974) reason that motion along this zone ceased about 10 million years ago. Although the Las Vegas Valley shear zone seems to have been inactive for millions of years, seismic activity and surface displacements have occurred during this century within the Walker Lane (Figure 3-4.) Moreover, some surface displacements at Pahute Mesa and Yucca Flat north of Yucca Mountain, and along a trend between the Las Vegas Valley shear zone and the Walker Lane have been triggered by nuclear explosions (Hamilton et al., 1969.)

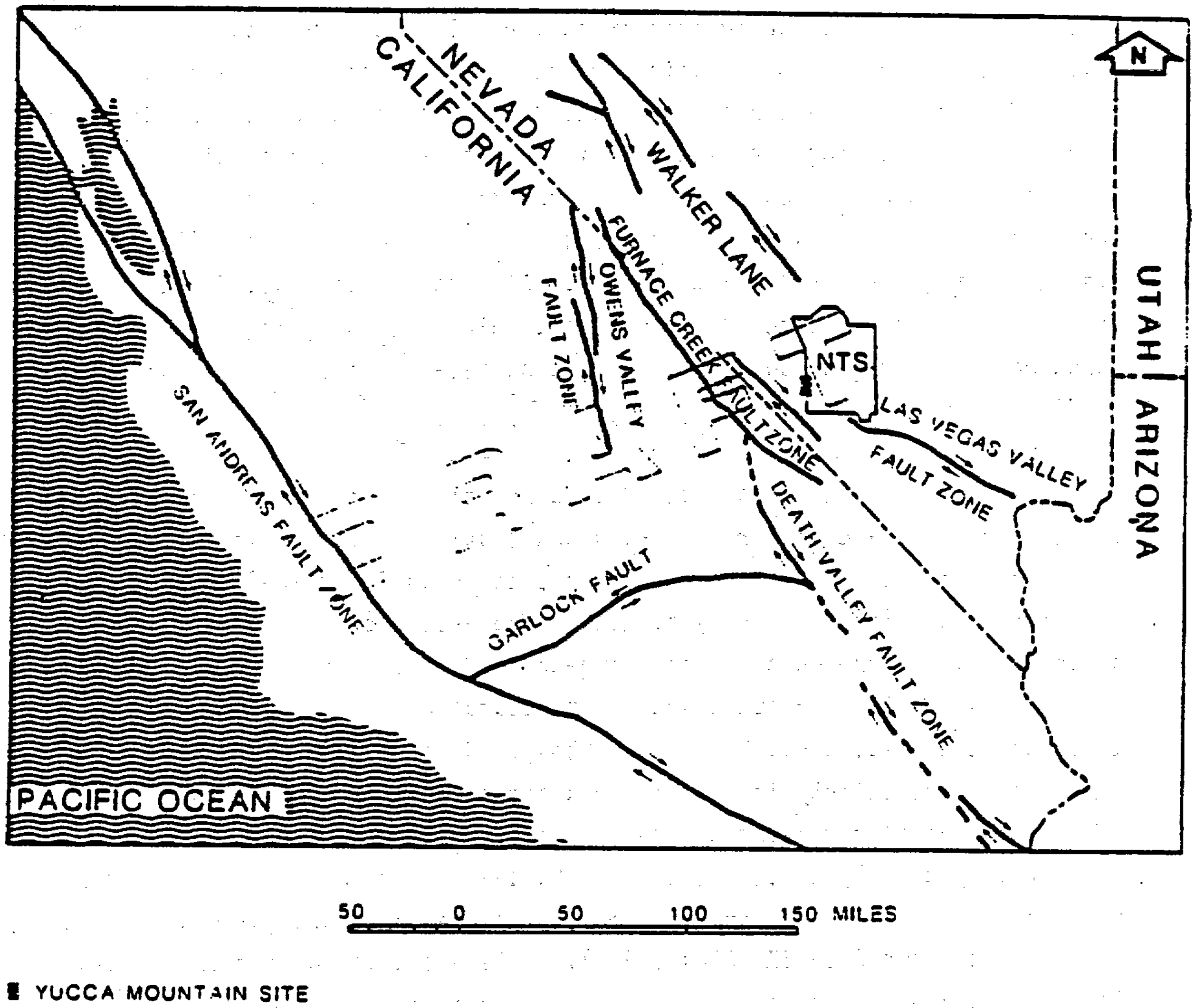
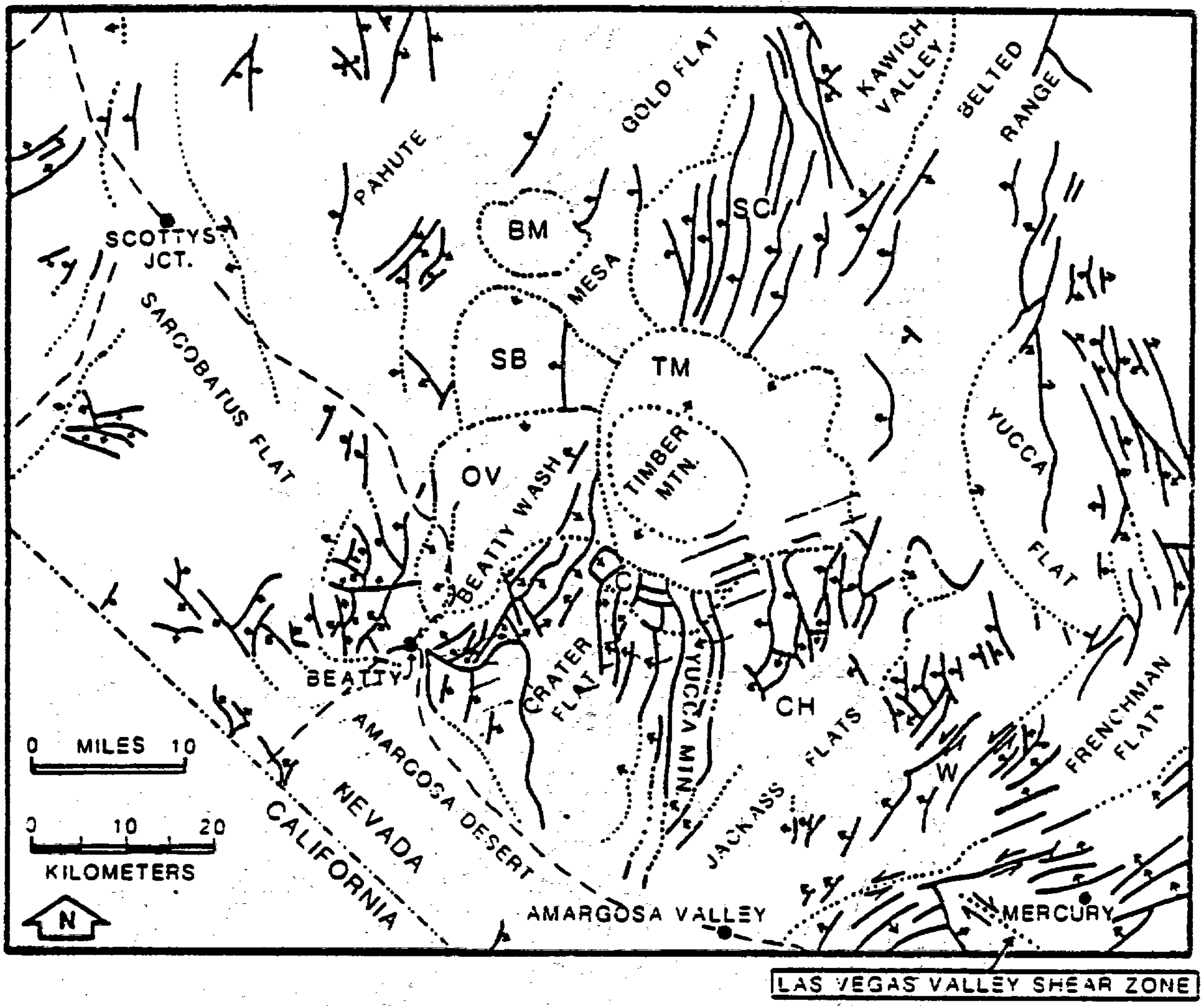


Figure 3-4. Major strike-slip fault zones in Nevada and California. (Source: Sinnock, 1982)

Therefore, some residual structural deformation may still be occurring along this zone, although apparently at very low levels.

The caldera complex in southwestern Nevada (described in Section 3.1.2.1) lies along a northwest trend connecting the Walker Lane and the Las Vegas Valley shear zone. Some investigators believe that the caldera complex at Timber Mountain is preferentially located where this northwest-trending zone of right-lateral faulting intersects Basin and Range faults extending southward from the Belted or Kawich Ranges, or where the northwest trending zone intersects the southwest-trending fault zones with components of left-lateral displacement (Carr, 1974) (Figure 3-5). Although no distinct faults can be traced between the two zones, structural, volcanic, and topographic features throughout this region suggest a connection between them (Christiansen et al., 1977).

Structural features at Yucca Mountain include local faults related to caldera collapse and longer Basin and Range style faults. The faults are shown on Figure 3-6 and on a structural cross section on Figure 3-7. The stratigraphic units are gently tilted to the east and are offset by several north-trending high-angle faults, down-dropped chiefly to the west, which created several large north-trending structural blocks (Maldonado and Koether, 1983; Scott et al., 1983; Lipman and McKay, 1965.) Other fault systems trend northwest, particularly in the northern and southeastern parts of Yucca Mountain. Detailed mapping of the southern part of the site has revealed an area of very closely spaced, small faults that trend northeast. The preferred repository area is within the informally designated central block, which dips eastward at about 5 to 8° (Figure 3-8). This block is bounded on the west by a large fault zone along Solitario Canyon. Vertical displacement along the Solitario fault diminishes from about 200 m (700 ft) at the southern end of the central block to about 20 m (70 ft) at the northwest corner. To the east, the central block is bounded by several smaller, closely spaced faults. The northern edge is defined by Drill Hole Wash, an informally named canyon that occurs along a zone of inferred faulting or dense fracturing, though vertical offsets are not observed. The southern boundary is less well defined, but it is generally placed where the east- and west-bounding fault zones converge. One moderately sized fault, informally designated the Ghost Dance Fault, occurs



CALDERAS

TM - TIMBER MOUNTAIN BM - BLACK MOUNTAIN C - CLAIM CANYON
OV - OASIS VALLEY CH - CALICO HILLS DOME W - WAHMONIE-SALYER CENTERS
SB - SLEEPING BUTTE SC - SILENT CANYON

FAULTS.DOTTED WHERE CONCEALED. ARROWS INDICATE DIRECTION OF DIP

APPROXIMATE LOCATION OF MAIN ROADS

ILLUSTRATES SENSE OF DISPLACEMENT

ONLY CENOZOIC FAULTS SHOWN

Figure 3-5. Generalized map of Yucca Mountain and vicinity showing calderas and late Cenozoic normal faults. (Source: Christiansen et al., 1977)

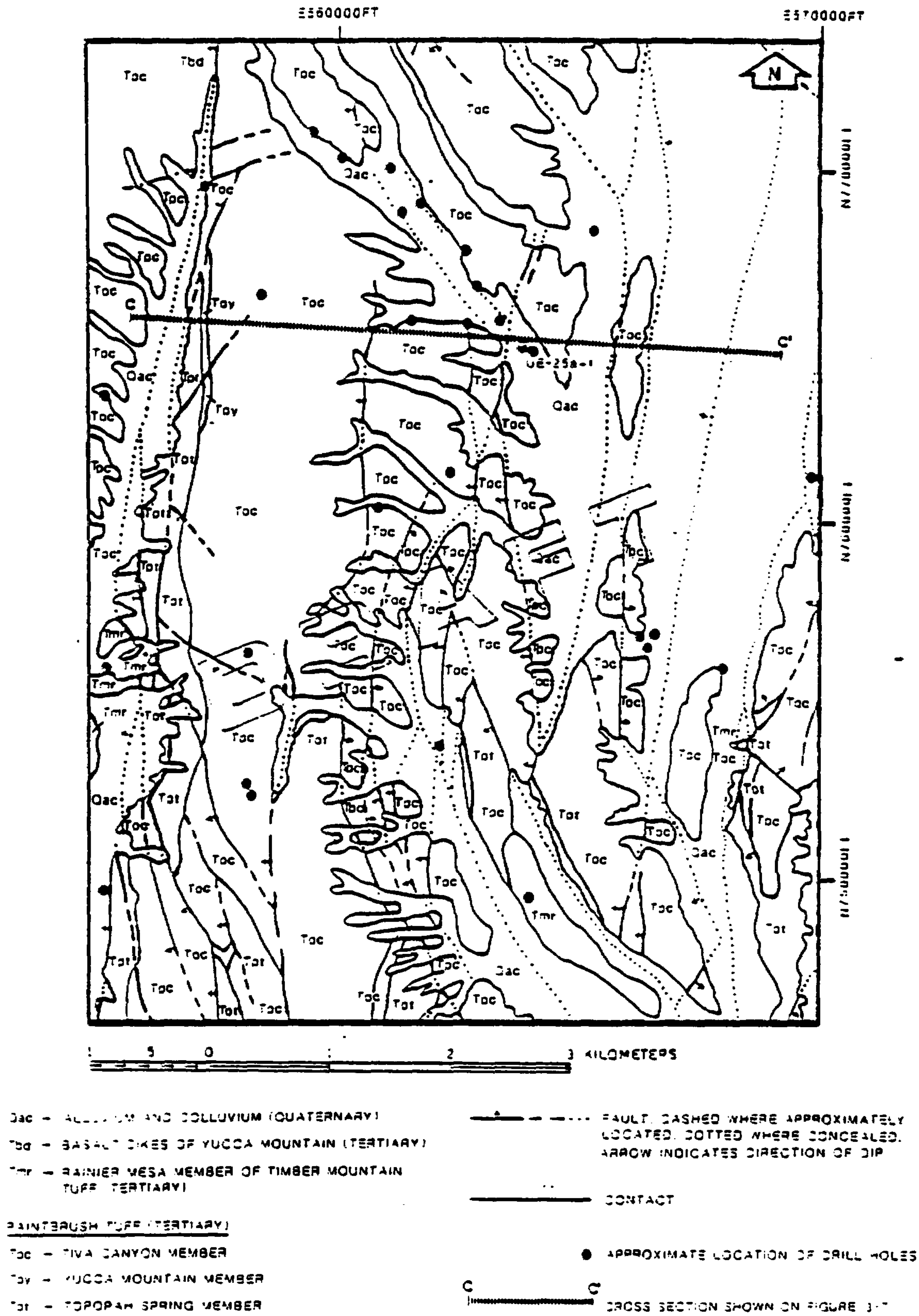


Figure 3-6. Geologic map of Yucca Mountain site showing approximate location of drill holes. Cross section C-C' is shown on Figure 3-7. (Source: Maldonado and Koether, 1983)

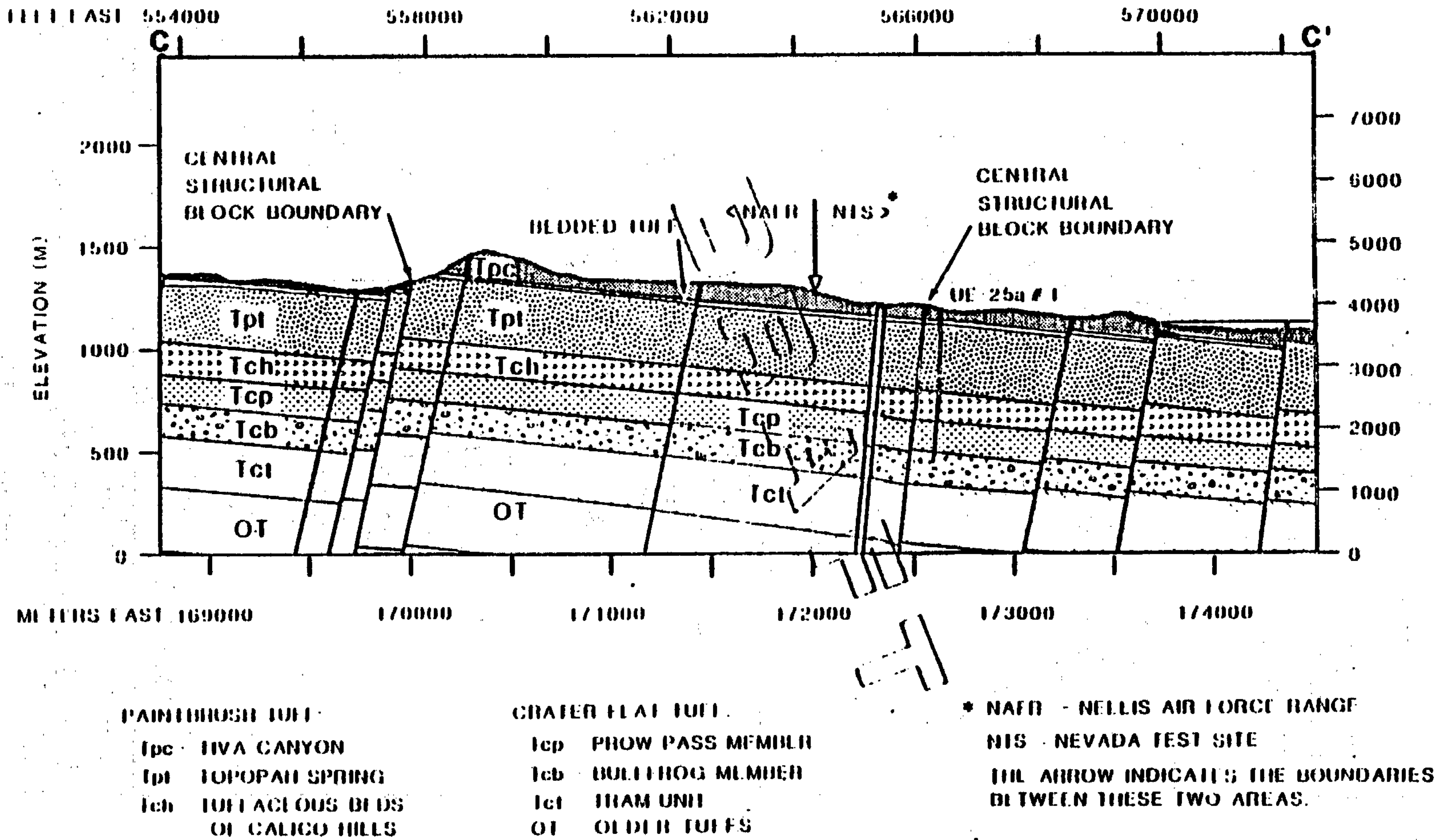


Figure 3-7. Schematic computer-generated cross section of the Yucca Mountain site showing central structural block boundaries and stratigraphy.

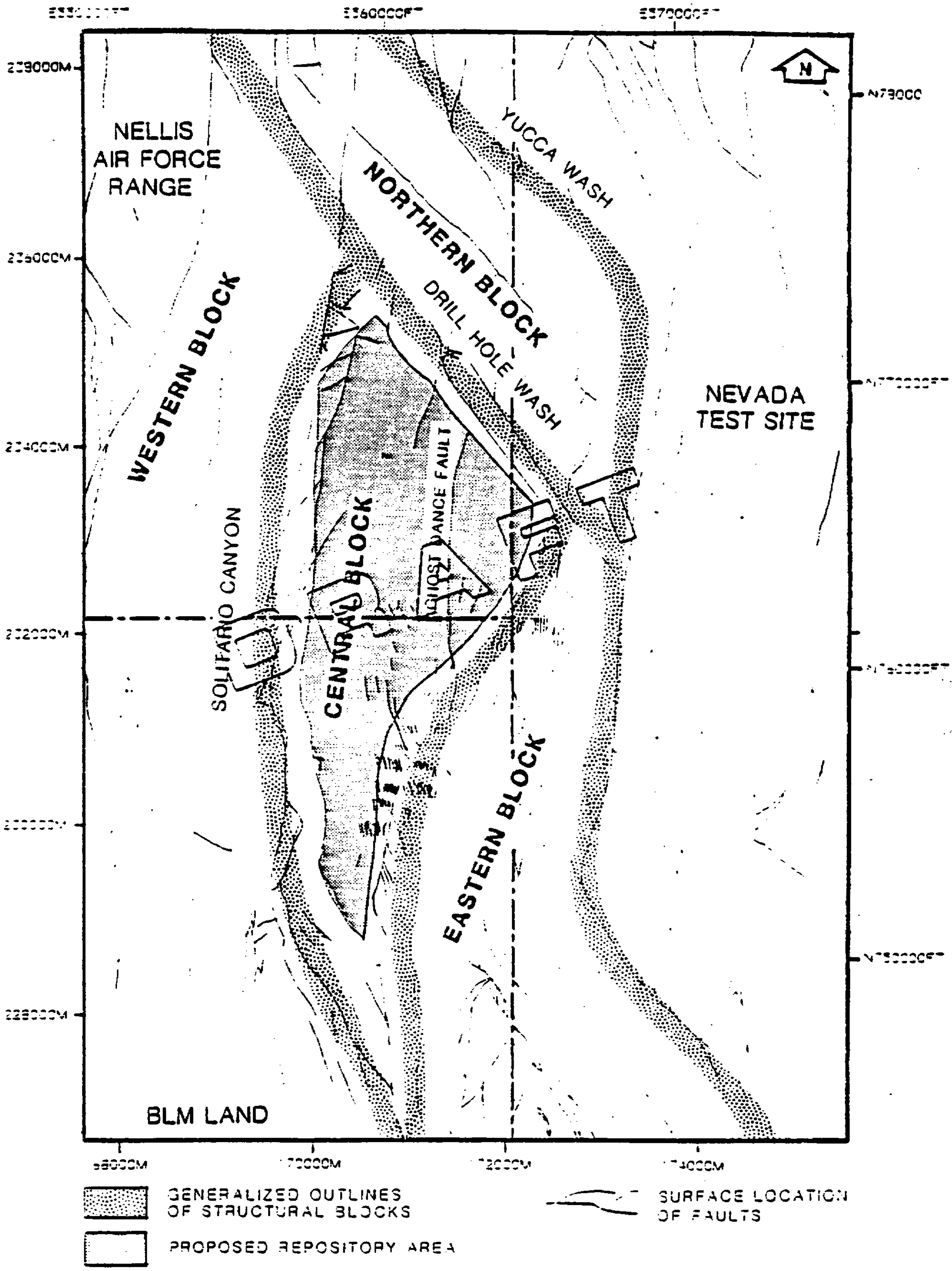


Figure 3-8. Generalized outlines of structural blocks showing location of the central block which is the proposed repository area. (Source: Sinnock, 1982)

within the central block. This fault has a maximum of about 15 m (50 ft) of vertical offset near its midpoint. Offsets diminish to near zero within a few hundred meters in both directions from the midpoint.

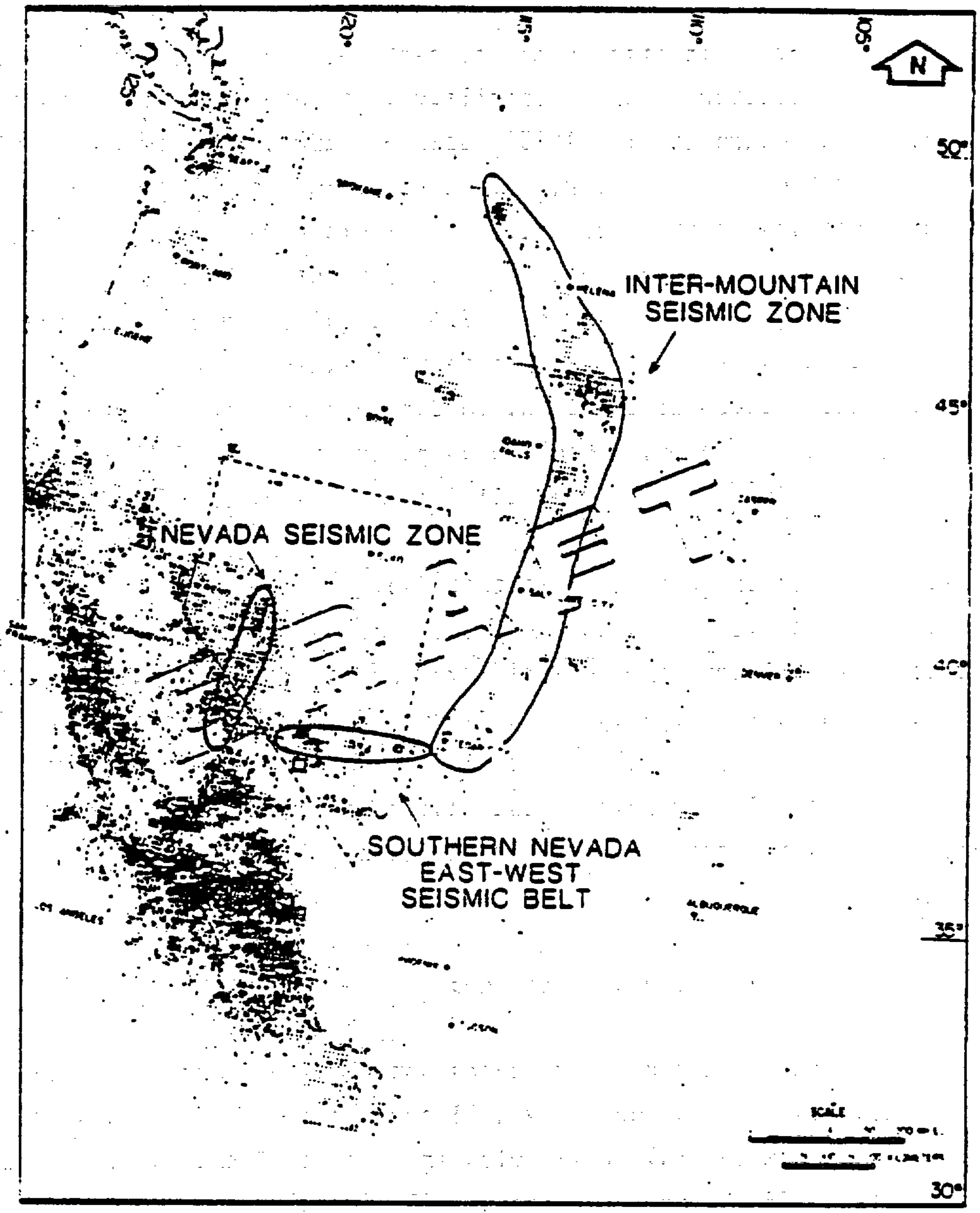
Drill-hole data indicate that some minor high-angle faults may have lateral as well as vertical components of displacement, particularly along northwest-trending faults north of the central block (Maldonado and Koether, 1983.) Displacements along individual faults within the central block are generally less than a few meters, whereas faults that separate major structural blocks may have a hundred or more meters of offset. The density of fractures is generally proportional to the degree of welding of the stratigraphic units and is probably somewhat uniform for each stratigraphic unit within each structural block. Near the major faults and in some local areas of abundant, small-offset faults, fracture density probably increases.

The age of the large block-forming faults at Yucca Mountain can be bounded between about 12 and 11.3 million years (Lipman and McKay, 1965; Marvin et al., 1970). The Tiva Canyon Member, which forms the surface rock throughout most of the site, is about 12 million years old and is displaced by the large block-forming faults in the area. Surface offsets of the Tiva Canyon Member north of the central block indicate movement along the faults occurred after this unit was deposited. At several locations around Yucca Mountain, the younger Timber Mountain tuff, which is about 11.3 million years old and is essentially unbroken by faults, occurs within the present valleys which are formed by the range-bounding faults that offset the Tiva Canyon Member. Thus, much of the displacement along the major block-forming faults had occurred by about 11 million years ago. Since then, faulting has apparently waned. Displacement of Quaternary alluvium within about 10-20 km (5-10 mi) of the site is limited to a few, very small, degraded scarps less than a meter or so in height. Dating of materials gathered from trenches dug across these low fault scarps has produced no unequivocal evidence that movement has occurred in the last 35,000 years (Swadley et al., 1984). Carr (1982) suggests that local Quaternary faulting along the east side of Crater Flat was related to, and synchronous with, nearby eruptions of small basaltic lava flows dated as about 1 million years old.

3.1.2.3 Seismicity

Yucca Mountain lies in an area of relatively low historic seismicity, just south of the southern Nevada East-West Seismic Belt (Smith, 1978) (Figure 3-9). This belt connects the north-trending Nevada Seismic Zone, about 160 km (100 mi) west of Yucca Mountain, with the north-trending Intermountain Seismic Zone about 240 km (150 mi) to the east (Figure 3-9). Much remains to be learned about regional or local seismic cycles or the relation between seismicity and fault age in the Basin and Range province (Thenhaus and Wentworth, 1982). As pointed out by Smith (1978), the pattern of historic earthquakes in the western United States is marked by relatively brief episodes of intense activity in areas that may have been inactive for tens, hundreds, and perhaps thousands of years. Geologic field evidence suggests that Yucca Mountain has been relatively stable for the past several million years. However, until there is a better understanding of seismic cycles, and of why seismically stable and unstable areas exist within the same structural province, earthquakes near Yucca Mountain should be considered possible.

During the past several decades, only two natural earthquakes greater than Richter magnitude M 4 have been recorded within about 30 km (20 mi) of Yucca Mountain. These earthquakes were east of the site near Frenchman Flat where the possible left-lateral shear zones of the Rock Valley and Mine Mountain Faults occur. The largest earthquakes recorded within the southern Nevada East-West Seismic belt were about M 6 (Smith, 1978). Correlations of fault length with earthquake intensity (Algermissen and Perkins, 1976) in conjunction with the lengths of known faults within a few tens of kilometers from Yucca Mountain (at Bare Mountain, Mine Mountain, Beatty, and Rock Valley), suggest that earthquakes approaching a maximum of M 7 could occur near Yucca Mountain. Farther away, within the California segment of the Nevada Seismic Zone, earthquakes of M 8+ have occurred. The largest earthquakes recorded in the Intermountain Seismic Zone have been about M 7, although studies of fault length suggest a potential for earthquakes up to M 8. Deterministic modeling by Rogers et al. (1977), gives an estimated maximum ground acceleration at Yucca Mountain of about 0.4g from an M 7 earthquake along the projected trend of the Mine Mountain Fault in Jackass Flats or along the Bare Mountain fault, 15 km (10 mi) west of the site.



= YUCCA MOUNTAIN SITE

Figure 3-9. Historical seismicity in the western United States showing the Nevada seismic zone, the inter-mountain seismic zone, and the southern Nevada east-west seismic belt. (Source: Smith, 1978)

The age of fault displacements, particularly for older faults, may not be a reliable indicator of the possibility of future seismic events (Ryall, 1980; Smith, 1978; Rogers et al., 1983) because recurrence intervals could be hundreds of thousands of years. Some seismologists suggest that zones of low seismic activity in the Great Basin may indicate a buildup of unreleased strain, thereby dictating caution in concluding that large earthquakes are unlikely (Ryall, 1980). Rogers (1977) recognized this factor and applied probabilistic assessments to estimate the likely recurrence period of the maximum acceleration at any point in the southern Great Basin. He concluded that accelerations of 0.7g could have return periods of 15,000 years or more; i.e., 10^{-4} to 10^{-5} yearly probabilities of occurrence.

Studies in progress suggest that fault orientation, with respect to current stress fields, is an important consideration in determining the potential for future seismic activity (Rogers et al., 1983; Carr, 1984). Initial results indicate that faults near Yucca Mountain trending from north to northeast are approximately perpendicular to the direction of minimum horizontal stress. As a result, these faults are potentially more susceptible to renewed dip-slip normal movement than faults with other trends (Healy et al., 1983).

3.1.2.4 Energy and mineral resources

The energy- and mineral-resource potential of Yucca Mountain and surrounding areas, has been evaluated by Bell and Larson (1982). This study, as well as analyses from several drill holes in support of the NNWSI project (Maldonado and Koether, 1983; Spengler et al., 1981; Spengler and Chornack, 1984), indicates that the overall potential for exploration or development of mineral or energy resources at Yucca Mountain is low.

<u>Energy resources</u>

There is no evidence to indicate that Yucca Mountain contains any hydrocarbon, uranium, or geothermal resources (Bell and Larson, 1982). None of the drill holes at or near Yucca Mountain have shown evidence of hydrocarbons. The only potential energy resource near Yucca Mountain is low- to moderate-temperature springs more than 30 km (20 mi) from the site (Garside and Schilling, 1979; Trexler et al., 1979). However, there are no warm springs at Yucca Mountain. The geothermal gradient measured in several drill holes at Yucca Mountain (Sass and Lackenbruch, 1982) also indicates that no high-temperature waters could be present at depths that are economically attractive. The geothermal gradient is about 2°C/100m (1.1°F/100 ft) in the unsaturated zone, and about 2.9°C/100m (1.61°F/100 ft) in the saturated zone. This gradient is equal to, or less than the gradient over one-half the continental United States, and thus presents no unique or unusual attraction for future exploration.

Minor amounts of uranium have been reported west of the site at Bare Mountain, but no uranium mines or prospects have been developed. Under current economic conditions, uranium resources identified in the Bare Mountain area are not attractive targets for uranium development (Bell and Larson, 1982). The volcanic rocks from the Silent Canyon caldera north of the site are petrologically similar to the rocks from the McDermitt caldera in northern Nevada which contain minor amounts of uranium (Bell and Larson, 1982), but no prospects or claims have been developed.

Metals

Table 3-2 identifies the status, number, and types of mining operations for base and precious metals in the Yucca Mountain area, and Figure 3-10 shows the location of these deposits. Historically, Nevada's metallic industry centered around the mining of precious metals in the Comstock district in west-central Nevada and in the Tonopah and Goldfield districts more than 150 km (90 mi) northwest of the site. Although there are numerous small mining districts throughout the southern Great Basin, the only active silver and gold mine in the region is the Stirling (Panama) mine near Bare Mountain. Bell and Larson (1982) estimate gold reserves at the Sterling mine to be 930 kg (2000 lb). The total value of gold produced from the mine since early 1980 is estimated to be no more than $1.8 million; the mine is profitable but small compared to industry standards.

Table 3-2. Mining operations in the vicinity of the Yucca Mountain site (Bell and Larson, 1982)

Location	Number and status of operations	Type of operations
Bare Mountain (gold, silver, mercury, tungsten, lead)	4 active 10 inactive 10 unknown status	Prospect pits, open pits, placer, underground tunnels, and shafts
Mine Mountain (silver, lead, mercury	None active 3 inactive	Underground tunnels and shafts
Wahmonie (gold, silver, copper)	None active	Prospect pits, underground shaft
Lee (gold, copper, tungsten)	None active 1 inactive	Prospect pits, shallow diggings, underground shafts
Yucca Flat (Climax) (gold, silver, lead)	None active 1 inactive	Shallow surface diggings, underground shafts
Amargosa Desert (tungsten, iron)	None active 1 inactive	Prospect pits

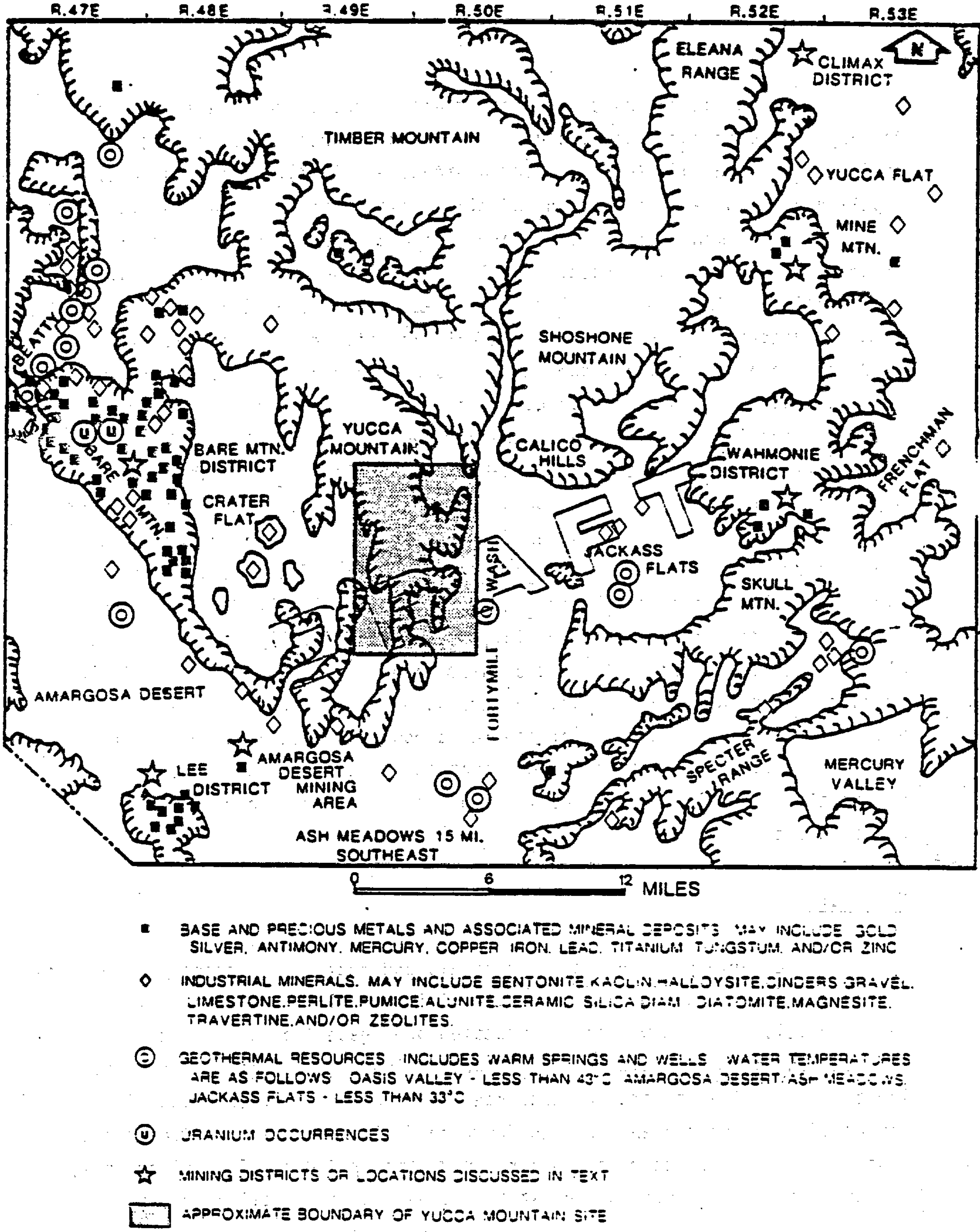


Figure 3-10. Location of metal deposits, industrial minerals, thermal waters, and mining districts in the vicinity of Yucca Mountain. (Source: Bell and Larson, 1982; Trexler et al., 1979)

A mine located northwest of Yucca Mountain has produced a small amount of mercury from cinnabar distributed in seams and spheres in silicified and opalized rhyolite tuff (Cornwall and Kleinhampel, 1961). Base and precious metals have also been prospected and mined east of the site in the Mine Mountain and Wahmonie districts. Information on the mining history in these districts, however, is limited. The land around these districts was withdrawn from public domain more than 30 years ago as part of the Nevada Test Site. The Wahmonie district apparently produced gold and silver sometime between 1905 and 1910 and again in 1928, but the amount was not recorded. Geophysical surveys suggest that the Wahmonie district may contain some precious metal deposits, but the potential amounts remain undetermined (Hoover et al., 1982). The Calico Hills area northwest of the Wahmonie district has been the location of substantial prospecting, but no production has been recorded. Trace amounts of silver and gold occur in the lower Tram Member at about the 1070 m (3515 ft) depth in drill hole USW G1 (Spengler et al., 1981). The concentrations are 0.5 ppm (0.016 oz/ton) gold, and 20 ppm (0.64 oz/ton) silver, and are not high enough to be considered of commercial interest, especially at this depth. Although mercury, lead, zinc, and uranium have been identified along fault and fracture zones in volcanic rocks in Nevada, no occurrences of these metals have been reported along fractures of the Yucca Mountain site. Based on this preliminary site information, Yucca Mountain is not considered to have any potential for development of metal resources under forseeable economic conditions and extraction techniques.

Nonmetals

A large variety of industrial minerals and rocks are present in the Yucca Mountain area, including clays, ceramic silica, zeolites, alunite, fluorite, sand, gravel, and lightweight construction aggregate (volcanic cinders, perlite, and pumice). Clay resources are dominantly kaolinite, montmorillonite, and halloysite and are extracted from shallow surface pits. A small amount of silica has been produced from the Silicon Mine in the Bare Mountain district. Zeolites occur at the site at depths of 400 m (1300 ft) or more, but there is no evidence to suggest that they are of a quality or extent to make them commercially attractive. Fluorite occurs widely in the Bare Mountain district, 15 km (10 mi) east of the site, but no fluorite has been found at Yucca Mountain.

Sand and gravel deposits are ubiquitous in the Yucca Mountain area. These deposits are extracted from shallow, surface pits and are used chiefly for road construction. Volcanic cinder, perlite, and pumice occur in Crater Flat. These materials are mined from surface pits and used for lightweight aggregate, concrete blocks, road base, and decorator stone. Other than sand and gravel, none of these surface resources occurs at Yucca Mountain.

3.1.3 Hydrologic conditions

This section describes the hydrology of Yucca Mountain and nearby areas. Topics discussed include surface water, ground water, and present and future water use. Much of the descriptive information in this section is summarized from Winograd and Thordarson (1975), and from the descriptions in the Post-Closure Technical Guideline for geohydrology in Section 6.3.1.1.

Numerous investigations of the geohydrology of Yucca Mountain and nearby areas have been conducted since 1978 (see Relevant Data (II) of Section 6.3.1.1 for list of studies). These studies have resulted in a general understanding of the geohydrology of the site. Detailed studies of water movement, including flow through the unsaturated zone, are in progress or are planned.

3.1.3.1 Surface Water

No perennial or intermittent streams occur at or near Yucca Mountain. The only reliable sources of surface water are the springs in Oasis Valley, the Amargosa Desert, and Death Valley. Because of the extreme aridity of this region, where annual precipitation averages about one-third of potential evapotranspiration, most of the spring discharge travels only a short distance before evaporating or infiltrating back into the ground.

Rapid runoff during heavy precipitation fills the normally dry washes for brief periods of time. Local flooding can occur where the water exceeds the capacity of the channels. The potential for flooding at Yucca Mountain, and its potential effects on a repository, are described in Chapter 6. In contrast to the washes, the terminal playas may contain standing water for days or weeks after severe storms. Runoff from precipitation at Yucca Mountain drains into Fortymile Canyon on the east and Crater Flat on the west, and both areas drain into the normally dry Amargosa River (Figure 3-11). If runoff is very significant, water in the Amargosa River flows into the playa in southern Death Valley.

3.1.3.2 Ground water

Yucca Mountain lies within the Death Valley ground-water system, a large and diverse area in southern Nevada and adjacent parts of California composed of many mountain ranges and topographic basins that are hydraulically connected at depth. In general, ground water within the Death Valley system travels toward Death Valley, although much of it discharges before reaching Death Valley. Ground water in the Death Valley system does not enter neighboring ground-water systems.

There are several subdivisions of the Death Valley ground-water system called ground-water basins and subbasins. Information now available indicates that ground water moving beneath Yucca Mountain discharges in Alkali Flat and perhaps in Death Valley, but not in Ash Meadows or Oasis Valley. Yucca Mountain is in the Alkali Flat-Furnace Creek Ranch ground-water basin at a position midway between the Ash Meadows and Oasis Valley subbasins (Waddell, 1982), as shown in Figure 2-5.

Geologic formations in Southern Nevada have been grouped into broad hydrogeologic units by Winograd and Thordarson (1975). Several of the units transmit water in sufficient quantities to supply water needs (aquifers), whereas other units have relatively low permeabilities that tend to retard the flow of ground water (aquitards.) The geologic and hydrologic properties of the aquifers vary widely. Some of the hydrogeologic characteristics of the Tertiary volcanic rocks at Yucca Mountain are shown on Table 3-3. The lower and upper carbonate aquifers and the welded-tuff aquifers store and transmit water chiefly along fractures, although part of the welded-tuff aquifer is

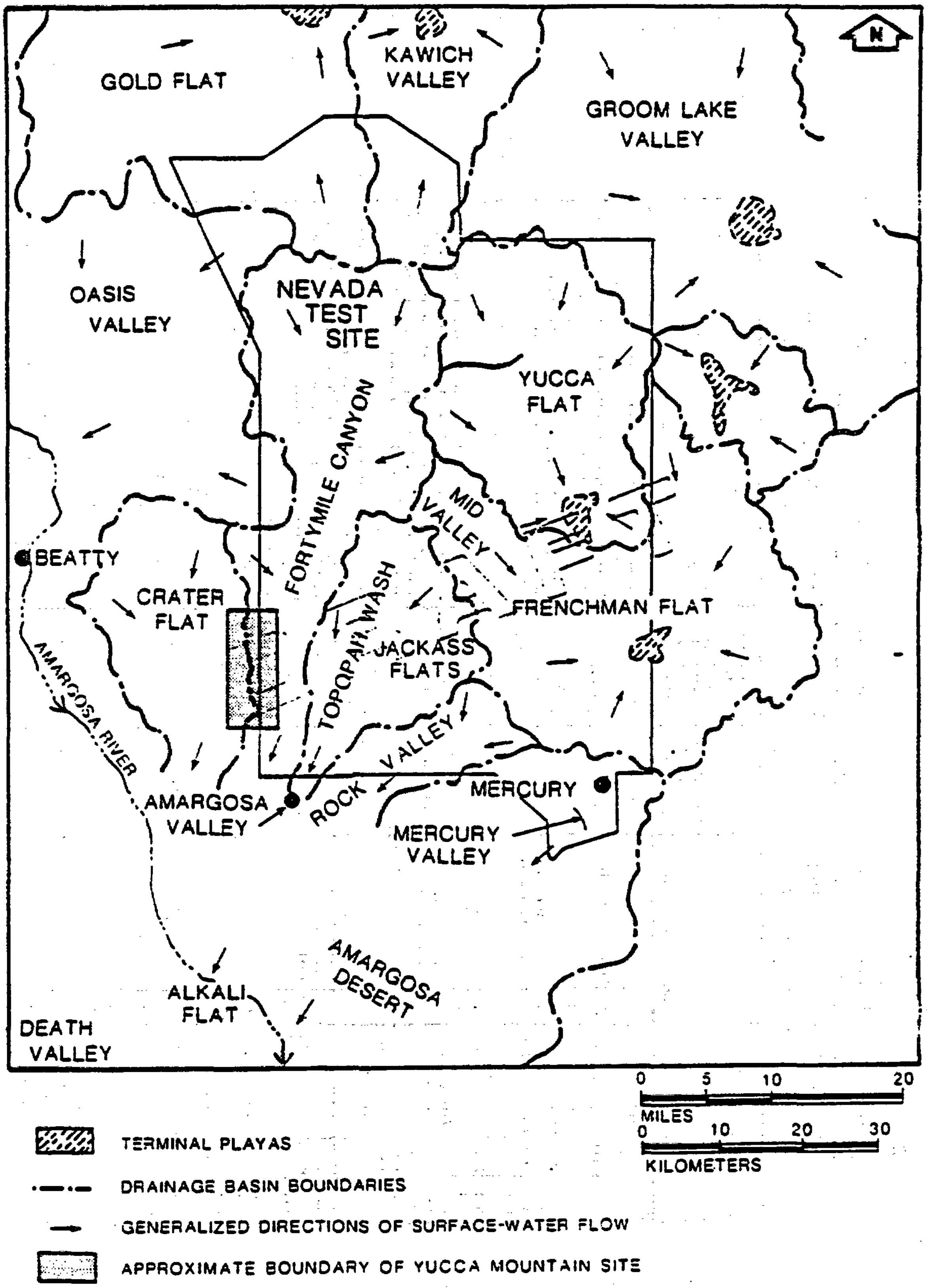


Figure 3-11. Drainage basins in the Yucca Mountain area showing direction of flow of surface water. (Source: ERDA, 1977)

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Table 3-3. Dual classification of Tertiary volcanic rocks at Yucca Mountain, stratigraphic units reflecting origin and hydrogeologic units reflecting hydrologic characteristics and properties (Winograd and Thordarson, 1975)

STRATIGRAPHIC UNIT			ZONE	HYDROGEOLOGIC UNIT	APPROXIMATE THICKNESS (METERS)	SATURATED MATRIX HYDRAULIC CONDUCTIVITY (MONTAZER AND WILSON, 1984)	COMMENTS
Alluvium			Unsaturated Zone	Alluvium	0-30+	Generally high	Underlies washes; thin layer on flats.
Paintbrush Tuff	Tiva Canyon Member		Unsaturated Zone	Tiva Canyon welded unit	70-150	1 mm/yr	Caprock that dips 5-8° eastward at Yucca Mountain. High fracture density.
Paintbrush Tuff	Pah Canyon Member		Unsaturated Zone	Paintbrush nonwelded unit	0-200	10,000 mm/yr	Vitric, nonwelded, porous, poorly indurated, bedded in part. Low fracture density.
Paintbrush Tuff	Yucca Mtn. Member		Unsaturated Zone	Paintbrush nonwelded unit		33,000 mm/yr	
Paintbrush Tuff	Topopah Spring Member	Nonwelded	Unsaturated Zone	Paintbrush nonwelded unit			
Paintbrush Tuff	Topopah Spring Member	Vitrophyre Welded	Unsaturated Zone	Topopah Spring welded unit	290-360	1 mm/yr	Densely to moderately welded; several lithophysal (cavity) zones; intensely fractured. Central and lower part is candidate host rock for repository. Bulk hydraulic conductivity in saturated zone east of the site (at well J-13) about 1.0 m/day.
Paintbrush Tuff	Topopah Spring Member	Nonwelded	Unsaturated Zone	Calico Hills nonwelded unit	100-400	Vitric: 2600 mm/yr	Beneath Yucca Mountain, base of unit for unsaturated zone determined by water table. Unit is vitric in southwest Yucca Mountain, zeolitized in east and north. Includes bedded units. Bulk hydraulic conductivity in saturated zone from pumping tests about 0.2 m/day.
Tuffaceous Beds of Calico Hills		Vitric / Zeolitized	Unsaturated Zone	Calico Hills nonwelded unit		Zeolitic: 1 mm/yr	
Crater Flat Tuff	Prow Pass Member	Nonwelded	Unsaturated Zone	Calico Hills nonwelded unit			
Crater Flat Tuff	Prow Pass Member	Welded			100-200	28 mm/yr	
Crater Flat Tuff	Bullfrog Member				120-170	62 mm/yr	
Crater Flat Tuff	Tram Member		Saturated Zone		170-350	51 mm/yr	
Lava			Saturated Zone		0-250	Very low	Occurs in northwest part of repository block.
Lithic Ridge Tuff			Saturated Zone		80-190	Very low	
Older Volcanics			Saturated Zone			Very low	In USW H-1 hydraulic head about 50 m higher than water table.
Pre-Tertiary Rocks			Saturated Zone			Unknown	Occurs 2.5 km east of proposed repository at depth of 1250 m in UE-25p#1, where hydraulic head is about 20 m higher than water table. Bulk hydraulic conductivity high, probably due to high fracture density.

above the water table at Yucca Mountain. In contrast, the valley-fill aquifers store and transmit water chiefly through interstitial openings. The lower carbonate and valley-fill aquifers are the chief sources of ground water in the eastern part of the Nevada Test Site.

Ground-water movement

The unsaturated zone within the boundary of the central block at Yucca Mountain is about 500-750 m (1600-2500 ft) thick, but thins to as little as 200 m (600 ft) within 10 km (6 mi). Within the block, the water table slopes to the southeast, from an altitude of 800 m (2600 ft) to as low as 730 m (2400 ft) above sea level (see Figure 6.3.1.1-1) for a water table contour map). The water table is 200-400 m (600-1300 ft) below the horizon recommended for the repository (see Section 6.3.1.1 for detailed discussion of Yucca Mountain hydrology).

A small part of the precipitation that falls on Yucca Mountain could infiltrate vertically through the unsaturated zone where it eventually enters the underlying tuff aquifer, the principal source of recharge for which is probably Pahute Mesa to the north and northwest of Yucca Mountain (see Figure 3-2). The ground water then moves horizontally toward Alkali Flat and Death Valley. The paragraphs below characterize the most important aspects of ground water movement in the vicinity of Yucca Mountain as they are currently understood.

Of the 150-200 mm (5.9-7.8 in.) per year of precipitation in the area, most of the water is returned to the atmosphere by evaporation and plant transpiration, and probably less than 1 mm/yr percolates downward to the water table (Montazar and Wilson, 1984). Ground-water travel time from land surface to the level of the repository has not been estimated, but travel time from below the repository level to the base of the host rock (Topopah Spring welded unit) is calculated to be 5000 years or more. Travel from the base of the host rock to the water table is believed to be 25,000 years or more. Water entering the saturated zone at the water table flows mainly through fractures in the welded tuffs. Travel time in the saturated zone to a distance 10 km (6 mi) away is estimated to be 500-1200 years (see Section 6.3.1.1).

From Yucca Mountain, ground-water travel in the saturated zone is to the south-southeast through tuff, and possibly through alluvium. Depth to the carbonate aquifer beneath the repository block has not been determined, but it is probably much greater than the 1250 m (4100 ft) observed in drill hole UE-25p#1 located 2.5 km (1.5 mi) east of the block. At drill hole UE-25p#1, the hydraulic head in the carbonate rocks is higher than in the overlying tuffaceous rocks. Because water cannot move in the direction of higher hydraulic head, it is believed that ground water in the Yucca Mountain area does not enter the carbonate aquifer.

Deep, regional movement of ground water, south and east of Yucca Mountain occurs chiefly through the lower carbonate aquifer. This aquifer is composed of highly fractured and locally brecciated middle Cambrian to late Devonian limestone and dolomites that are highly transmissive (Winograd and Thordarson, 1975). Because of complex geologic structure, flow paths in the lower carbonate aquifers are complex and are poorly defined. In places the ground-water flow is diverted laterally or vertically because of fault displacements that have juxtaposed the lower carbonate aquifer against less permeable rocks. Where the flow is blocked, such as at Ash Meadows in the southern Amargosa Desert, the water table may intersect the land surface causing springs.

Ground-water quality

Schoff and Moore (1964) recognized three types of ground water at the Nevada Test Site and vicinity: (a) sodium and potassium bicarbonate, which generally occurs in tuff aquifers and valley-fill aquifers that are composed chiefly of tuff detritus; (b) calcium and magnesium bicarbonate, which generally occurs in the carbonate aquifers and the valley-fill aquifers that are composed chiefly of carbonate detritus; and (c) mixed, which is defined as having chemical characteristics of both preceding types.

All of the three types of ground water occur in the Ash Meadows basin which included the proposed repository site when it was defined by Winograd and Thordarson (1975). Recent information (Waddell, 1982) places Yucca Mountain in the Alkali Flat-Furnace Creek Ranch basin of the Death Valley ground-water system. See Figure 2-5 for positions of ground-water basins. Winograd and Thordarson (1975) report and summarize total dissolved solids from many analyses of these three types of waters; the values range from 91 to 1071 mg/l, with mean values ranging from 217 to 580 mg/l.

3.1.3.3 Present and projected water use in the area

Water in southern Nevada (excluding the Las Vegas area) is used chiefly for irrigation, and to a lesser extent for livestock, municipal needs, and domestic supplies. Almost all the required water is pumped from the ground, although some springs supply water to establishments in Death Valley and other areas that lie south of Yucca Mountain (Pitstrang and Kunkel, 1964; Hunt et al., 1965; Thordarson and Robinson, 1971; Waddell et al., 1984). In addition, springs in Oasis Valley near Beatty, Nevada, about 30 km (20 miles) northwest of Yucca Mountain are a significant source of water for public and domestic needs and for irrigation (Thordarson and Robinson, 1971; White, 1979). Table 3-4 summarizes the amounts of water used annually by towns and communities in the vicinity of Yucca Mountain.

The principal users of ground water in this area are in the Amargosa Desert south of the town of Amargosa Valley. According to McNealy and Woerner (1974), 800 ha (2000 acres) of land were being irrigated in the Amargosa Desert in 1969. From 1967 to 1970 an extensive well field was developed for irrigation in the Ash Meadows area along the east side of the Amargosa Desert. In a study by the U.S. Geological Survey at the request of member organizations of the Desert Pupfish Task Force,* Dudley and Larson (1976) concluded that withdrawals of ground water from parts of this well field caused a 0.8 m (2.5-ft) reduction in the altitude of the pool in nearby Devils Hole, thereby threatening the survival of the Devils Hole pupfish (Cyprindon diabolis). Subsequent law suits and a final ruling by the U.S. Supreme Court in 1976 [Cappaert 426 U.S. 128 (1976) v. U.S.] ordered a restriction in pumping from specific wells in the Devils Hole area.

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* Includes representatives of the National Park Service, the Bureau of Reclamation, the Bureau of Land Management, the Bureau of Sport Fisheries and Wildlife, and the Geological Survey.

Table 3-4. Current (1980) water supply in nonmetropolitan areas of Clark and Nye Counties

Community	Estimated population	Water sources[a]	Estimated water use[b,c] acre-ft/yr	mgd
Ash Meadows and Amargosa Farms	2235	ND[d]	1687	1.506
Beatty	900	Two municipal wells supplying 250 customers; third well is source of water for industry	686	0.612
Crystal	42[e]	Domestic wells 160 feet deep	33	0.029
Indian Springs	912	Municipal well capable of supplying 0.8 mgd to 53 customers, plus approximately 80 domestic wells with unknown capacity	686	0.612
Indian Springs Air Force Base	500	Two wells supplying 0.2 mgd potable water	326	0.291
Johnnie	2[f]	ND	0.12	<0.001
Amargosa Valley	65	Domestic wells 320 feet deep	44	0.039
Mercury	300	Three municipal wells coupled with a distribution system	237	0.212
Nevada Test Site	ND	Six wells supplying 1.2 mgd	1344	1.200
Pahrump	1358	Domestic wells 70 feet deep	1006	0.898
Rhyolite	4[g]	Served by pipeline from water tank at new Beatty well. Other family uses bottled water.	2.4	0.002

[a] French et al. (1982), cited by McBrien and Jones, 1983.

[b] McBrien and Jones, 1983. Original data source unknown.

[c] 1 acre-ft = 1234 m^3; mgd = million gal/day.

[d] ND = no data.

[e] 20 families.

[f] 1 family.

[g] 2 families.

Water for the small communities near the site is supplied from wells. Wells also supply domestic drinking water to most residents of farms, ranches, and single-family dwellings outside of these communities. Table 3-5 summarizes the municipal and domestic water supply and waste-water treatment systems in the vicinity of Yucca Mountain.

The mining industry in southern Nevada uses a small amount of water for processing. Water for this purpose is supplied from nearby shallow wells or is trucked in from nearby towns. Many of the mines currently recycle process water, which reduces their consumptive water demand.

The major agricultural areas in the vicinity of the site are in Amargosa and Pahrump Valleys. Irrigation is required to grow crops in these areas, and wells are the major source of the water. The amount of water used in the Amargosa Valley is not known, but individual family wells are limited to 2500 m^3 (2 acre-ft) per year. Pahrump Valley uses about 58,000,000 m^3 (47,000 acre-ft) per year. In 1970, because of a declining water table, the State Engineer stopped granting ground-water permits for irrigation in the Pahrump Artesian Basin. Permits for other uses are being considered on a case-by-case basis. The only projections for future ground-water use in this area are for the planned communities in Pahrump Valley.

3.1.4 Environmental setting

This section contains a detailed description of existing land use, ecosystems, air quality, noise, aesthetics, archaeological resources, and the radiological background of Yucca Mountain and the surrounding region. The data provides a baseline for assessing potential impacts during site characterization (see Chapter 4) and during construction, operation, and decommissioning if Yucca Mountain is selected for a repository (see Chapters 5 and 6).

Table 3-5. Municipal and domestic supply and waste-water treatment systems in the vicinity of Yucca Mountain

Community	Estimated population	Source of supply	Waste water disposal	Planned water supply and waste-water disposal improvements	Potential development in area requiring additional water supplies and waste-treatment facilities
Indian Springs, Nevada	912	Municipal well capable of supplying 0.8 mgd[a] to 53 customers in additional approximately 80 domestic wells whose quantity is unknown.	Waste water from sewers discharged to evaporation ponds presently covering X acres.	An additional municipal water supply well.	State correctional facility south of community.
Beatty, Nevada	900	Two municipal wells supplying 250 customers; third well is source of water for industry.	Waste water from sewers discharged to evaporation ponds.	New well believed to be in regional regional carbonate aquifer.	Expansion of mine operation in local area.
Indian Springs Air Force Base, Nevada	500	Two wells supplying 0.2 mgd potable water for base.	Imhoff tank to separate solid wastes; solids pumped to sludge pits.	No improvements planned.	No plans for expansion or closure of base.
Pahrump, Nevada	1358	Most residents obtain water from domestic wells 70 feet deep.	Septic tanks.	Expansion of service outside Calvada development.	Development of 100,000 lots in Pahrump Valley.
Ash Meadows, Nevada	2235	NA[b]	NA	Expansion of service outside Calvada development.	
Town of Amargosa Valley, Nevada	65	Residents obtain water from domestic wells 320 feet deep.	Septic tanks.	NA	No development is planned although employment levels at NTS can have definite effect.

[a] mgd = million gallons per day.

[b] NA not available.

3.1.4.1 Land use

Land use in the Yucca Mountain area includes Federal use, agriculture, mining, recreation, and private and commercial development. These uses are discussed below. Land-use patterns in southwestern Nevada are shown in Figure 3-12.

Federal use

As discussed in Section 3.1.1, the Yucca Mountain site is on limited-access Federal land that is controlled by three Federal agencies. As shown on Figure 3-12, the Nellis Air Force Range includes 10,670 km^2 (4120 mi^2) controlled by the U.S. Air Force, the Nevada Test Site includes 3500 km^2 (1350 mi^2) controlled by the DOE, and many thousands of square kilometers are controlled by the BLM and the U.S. Forest Service. The Nellis Air Force Range is used for military weapons testing and personnel training. The portion of the range in the immediate vicinity of Yucca Mountain is reserved for occassional overflights and provides air access to the bombing and gunnery areas located further north and west of the site. Land use at the Nevada Test Site supports nuclear weapons research and development. The site is dedicated to underground nuclear testing, development and testing of nuclear explosives for peaceful applications, and testing of weapon effects. The BLM and the U.S. Forest Service apply a multiple use concept in administering the public domain lands and forests. These lands are currently used for recreation, grazing, forest management, and wildlife management.

Agriculture

A limited amount of agriculture is supported in the Beatty/Oasis Valley, the Amargosa Valley, Ash Meadows, and the Pahrump Valley. None of these areas is considered to contain prime agricultural land. A portion of the extensive Federal lands in southern Nye County is used for cattle grazing; and, as such, it constitutes the major agricultural resource near the site (Collins et al., 1982).

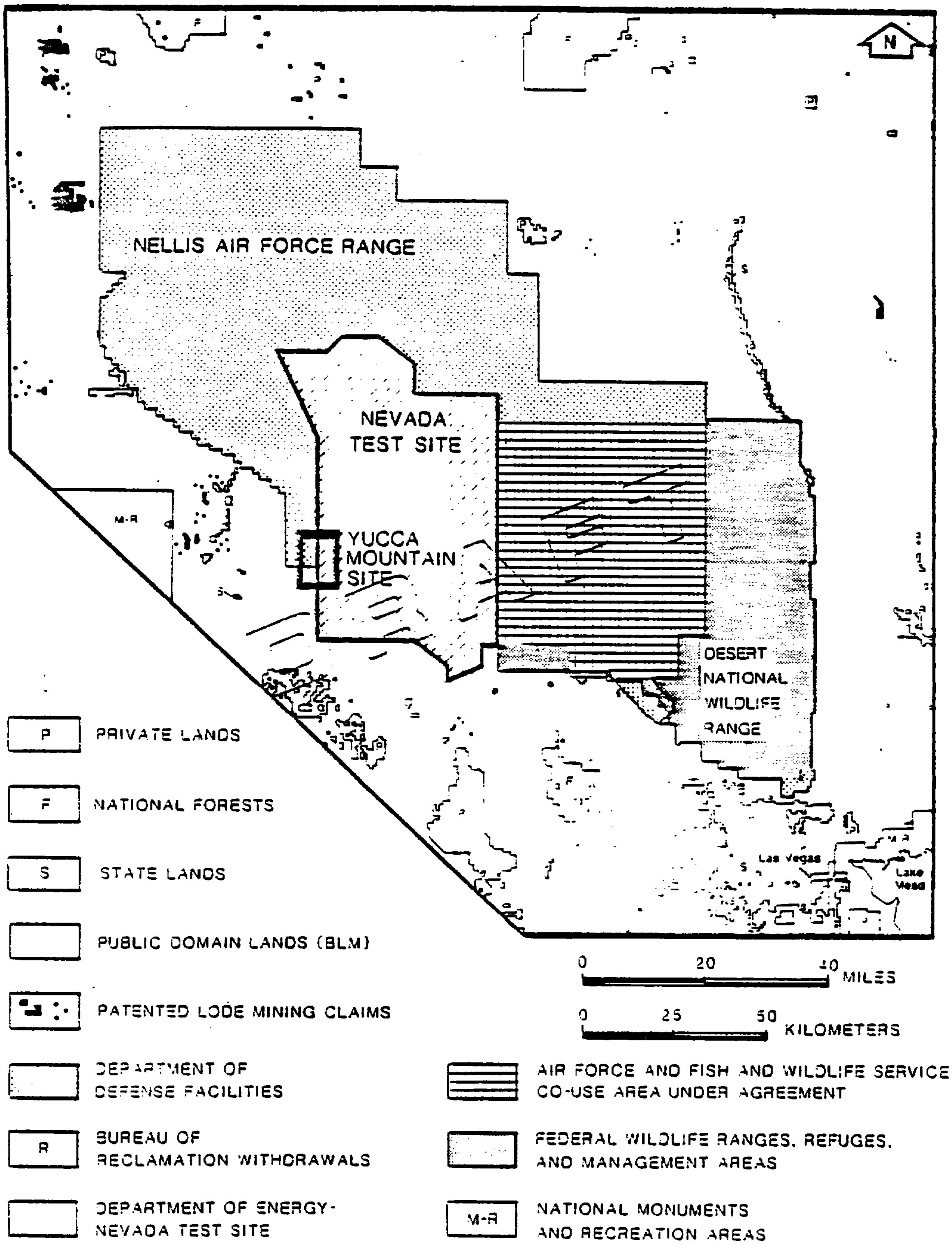

Figure 3-12. Land use in southern Nevada. (Source: State of Nevada, Nevada Bureau of Mines and Geology, 1972)

Grazing land. The Bureau of Land Management controls large parcels of range land south and west of the site, portions of which are leased for cattle grazing. Five leases exist near the site (Figure 3-13). With two exceptions, no grazing leases have been issued for lands lying north or east of Highway 95 from Las Vegas to Tonopah. There is no grazing on the Yucca Mountain site.

Cropland. Blocks of private land in Amargosa Valley, Beatty, Oasis Valley, Ash Meadows, and Pahrump Valley contain the only farming and ranching operations in the region. The Amargosa and Pahrump valleys contain the only extensive cultivation. An informal poll conducted by the Department of Agriculture's County Cooperative Extension agent in Pahrump indicates that farms located south of Beatty had a total of 3850 ha (9500 acres) under irrigation in July 1981 as follows: 2430 ha (6000 acres) alfalfa, 810 ha (2000 acres) irrigated pasture, 325 ha (800 acres) cotton, 130 ha (320 acres) small grains, 97 ha (240 acres) Sudan grass, 25 ha (60 acres) turf, 25 ha (60 acres) orchard, and 8 ha (20 acres) melons (Collins et al., 1982).

Mining

There are 17 active mines and mills in southern Nevada. Most of the mining operations employ less than 10 workers per mine, although a few operations employ as many as 250 workers. The mineral resources in the area near Yucca Mountain are described in Section 3.1.2.4.

Recreation

Recreational land uses are abundant in southern Nevada. In general, the camping and fishing sites in the northern part of the region are used during spring, summer, and fall, and those in the south are utilized throughout the year. The Desert National Wildlife Range, a joint-use area with the U.S. Air Force and the U. S. Fish and Wildlife Service, also provides some recreational opportunities.

The Mojave Desert in California, which includes Death Valley National Monument, extends along the southwestern border of Nevada about 56 km (35 mi) from Mercury. The National Park Service estimates that the population within

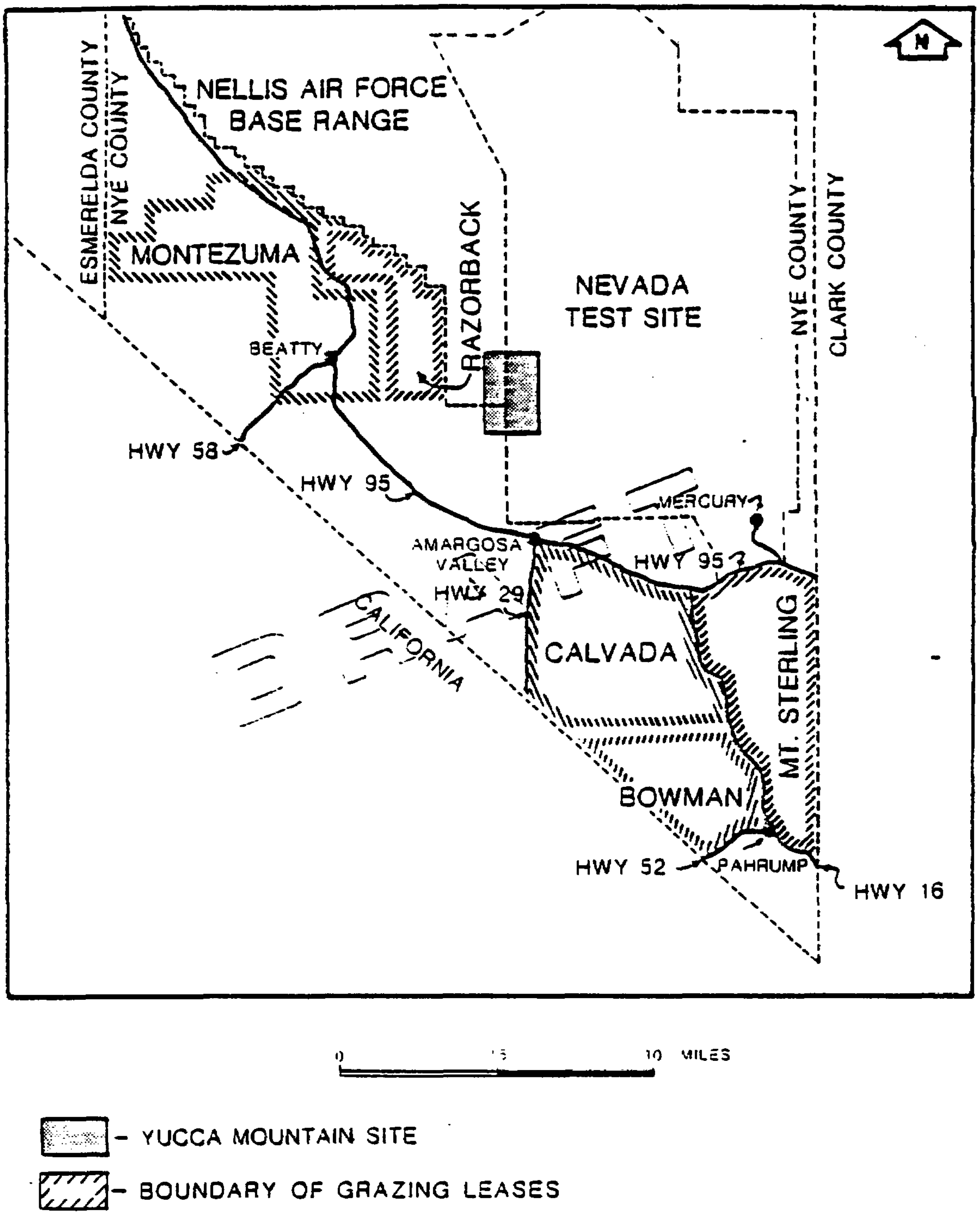

Figure 3-13. BLM grazing leases near the Yucca Mountain site. (Source: Collins et al., 1982)

the Monument boundaries ranges from a minimum of 900 permanent residents during the summer months; to as many as 35,000 tourists per day during the major holiday periods in the winter months; and to a maximum of 80,000 during Death Valley Days in November. The Spring Mountains 80 km (50 mi) to the southeast are also a major recreation area.

Private and commercial development

Most private and commercial development is concentrated in the Las Vegas metropolitan area (Figure 3-12). Private lands are scarce in the area immediately surrounding the site and are located within the following towns and valleys:

1. Amargosa Valley - 600 ha (1500 acres).

2. Beatty - limited acreage along Highways 95 and 58.

3. Indian Springs - limited acreage along Highway 95.

4. Town of Amargosa Valley - limited acreage at intersection of Highways 95 and 29.

5. Pahrump Valley - small planned community development.

6. Ash Meadows - planned subdivisions totalling approximately 100 ha (260 acres).

7. Oasis Valley - unknown acreage.

Future subdivisions are planned in Ash Meadows and Pahrump Valley. In Ash Meadows, Johnnie Townsite is planned to be about 65 ha (160 acres), and Forty Bar Estates is planned to be about 40 ha (100 acres). The largest subdivision in Pahrump Valley is planned to be located near the center of the valley around the old Pahrump Ranch (O'Farrell et al., 1981). Other parcels of former farm-lands in the valley have been purchased for future subdivision.

3.1.4.2 Terrestrial and aquatic ecosystems

An extensive literature review was performed in 1981 to determine the current state of knowledge about the ecological characteristics of the NNWSI Project study area (Collins et al., 1982). Based upon the review findings, a field study was initiated in 1982 to gather site-specific information of the ecological characteristics of the Yucca Mountain area (O'Farrell and Collins, 1983). The findings of these studies are summarized in the following sections.

Terrestrial vegetation

The southwestern Nevada Test Site encompasses three floristic zones: (1) the Mojave Desert, which is a warm dry desert occurring below an elevation of 1200 m (4000 ft); (2) the Great Basin Desert, which is a relatively cooler and wetter desert occurs at elevations above 1500 m (5000 ft); and (3) the transition zone, often called the Transition Desert, which extends in a broad east-west corridor between the Mojave and Great Basin deserts at elevations of between 1200 and 1500 m (4000 and 5000 ft). Literature reviews indicated that the following five major vegetation associations would occur in the southwest portion of the Nevada Test Site within the three floristic regions: Larrea-Ambrosia (creosote bush-bursage), Larrea-Lycium-Grayia (creosote bush-boxthorn-hopsage), Coleogyne (blackbrush), Artemisia (sagebrush), and Artemisia-pinyon-juniper.

During the 1982 site-specific investigation, six, rather than five, vegetation associations were observed and their characteristics and distribution were described (Figure 3-14). Five of the associations were named for the species of woody perennials that were dominant, based upon either numbers of individuals or percentage of cover. The sixth association included vegetation reclaiming an old burn. These six associations are described below. Detailed lists of the species composition can be found in O'Farrell and Collins (1983).

Larrea-Ambrosia. An association dominated by Larrea tridentata and Ambrosia dumosa exists on the bajada (an area of coalescing alluvial fans) on the southeastern side of the study area (Figure 3-14). The association comprises 7.3 percent, or 4 km^2 (1.5 mi^2), of the project area and generally

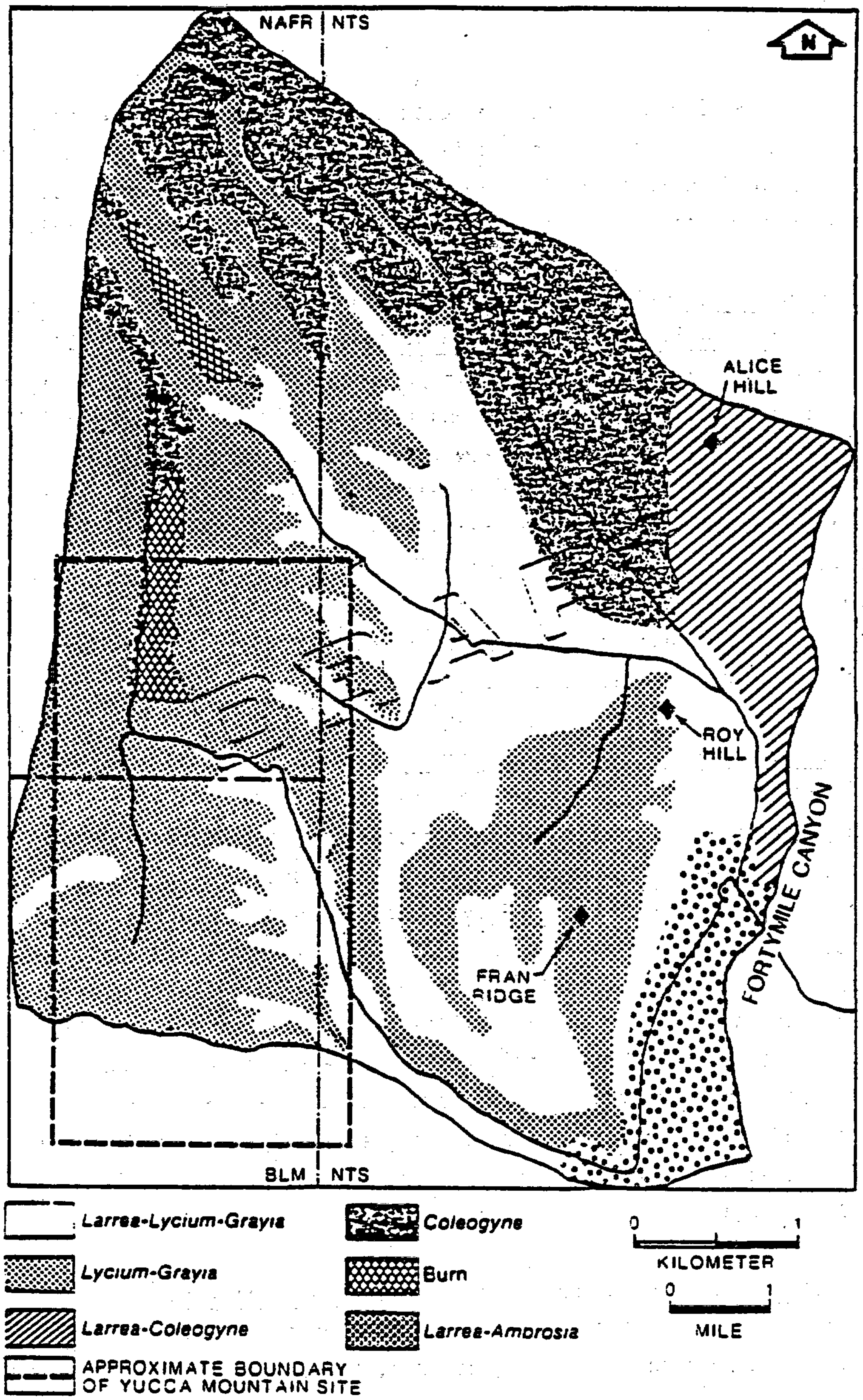

Figure 3-14. Vegetation associations of the Yucca Mountain area. (Source: O'Farrell and Collins, 1983)

occurs below 1000 m (3400 ft) in loose soils either with or without pavements of small rocks. Larrea-Ambrosia is at its upper elevational limit and contains elements of Transition Desert vegetation. Shrub cover averages 18.3 percent, and average perennial plant biomass is 12,465 kg/km^2 (1397 lb/acre).

Larrea-Lycium-Grayia. The association dominated by Larrea tridentata, Lycium andersonii, and Grayia spinosa, covers 34.5 percent, or 18 km^2 (7.1 mi^2), of the project area. It predominates on the eastern bajadas of central Yucca Mountain at elevations ranging from 1000 to 1300 m (3400 to 4300 ft). Relief is generally low to moderate, and soils are rocky with an imperfectly developed surface pavement. Larrea is absent on upper bajadas and at the bases of high hills or mountains where slopes begin to steepen sharply, but it is present along drainages in mountainous areas. Shrub cover averages 22.0 percent, and average biomass is 17,230 kg/km^2 (1931 lb/acre). The Larrea-Lycium-Grayia vegetation association is characterized by a relatively large number of winter annual species.

Lycium-Grayia. The Lycium-Grayia vegetation association, which occupies 26.2 percent or 14 km^2 (5.4 mi^2) of the project area, is a fairly complex, highly variable association which contains many subassociations and locally dominant species. The ubiquitous presence of both Grayia and Lycium, however, is a unifying factor. Lycium-Grayia occurs above the Larrea dominated associations on upper bajadas and slopes of all grades and exposures and seems to prefer rocky soils. It is the dominant vegetation on slopes and ridge tops throughout the southern and central sections of Yucca Mountain (Figure 3-14). This association is similar to Larrea-Lycium-Grayia vegetation, contains most of the same species not commonly found with Larrea, and occurs primarily near the top of Yucca Mountain and on the highest hills. Shrub cover averages 34.7 percent and average biomass of perennial plants is 29,770 kg/km^2 (3337 lb/acre).

Coleogyne. Vegetation in which Coleogyne ramosissima predominates occurs in two distinct locations: (1) on the tops of the larger, flatter ridges of the northern portion of the project area, including the northern portion of

Yucca Mountain, and (2) on the bajada south of Pinnacles Ridge and east of Prow Pass in the upper Yucca Wash drainage. Coleogyne vegetation exists over 21.4 percent, or 11 km^2 (4.4 mi^2), of the project area. This association is an indicator of and is restricted to the Transition Desert. Coleogyne favors sites with moderate- to low-slope angles and does not occur on steep, rocky, or boulder-strewn slopes. Coleogyne is absent where relatively level ridge tops give way to steep, rocky slopes. Desert pavements are often well developed on bajadas where Coleogyne occurs. Shrub cover varies from 45 to 51 percent, and perennial biomass averages 31,700 kg/km^2 (3554 lb/acre). The density of annual plants seems to be lower than in any other association surveyed. Coleogyne tends to form near monocultures having few associated species. Bromus rubens, an introduced winter annual grass, does not occur in the thick stands that usually characterize Coleogyne in other parts of the Nevada Test Site.

Coleogyne-Larrea. A distinct area on the bajada near Fortymile Canyon (Figure 3-14) supports an association dominated by both Larrea tridentata and Coleogyne ramosissima. Coleogyne-Larrea vegetation comprises 8.8 percent, or 4.7 km^2 (1.8 mi^2), of the project area. This association probably best represents the ecotone between Mojave and Transition Desert vegetation. It more closely resembles Coleogyne association both because of the paucity of associated shrub and annual species and because of the well-developed desert pavement soils. Shrub cover is 26.0 percent, and perennial biomass averages 26,750 kg/km^2 (2998 lb/acre).

Grassland-Burn Site. A large portion of the ridge top of central Yucca Mountain was burned either shortly before or in 1978. This burn, which extended for 2.3 km (1.4 mi) and occupied 77 ha (190 acres), is old enough that a community of perennial and annual grasses, with only scattered shrubs, has had time to develop. Composition of the original vegetation was difficult to determine because dense Coleogyne existed at the northern boundary of the burn, but at the southern boundary a diverse Grayia-Lycium community with only scattered Coleogyne predominated. Because Coleogyne has higher susceptibility to fire, it most likely predominated throughout most of the site prior to the burn.

A more recent burn covering 15 ha (38 acres) occured on the northwest ridge. The former vegetation was certainly Coleogyne since this association occurs at the edges and in scattered unburned patches throughout the burn. Charred shrub stumps are still standing and there is some sprouting from stumps. The vegetation consists mainly of herbaceous species, primarily grasses. These two burns comprise 1.8 percent of the project area.

Terrestrial wildlife

Mammals. Forty-six mammal species occur within the study area; rodents account for nearly half of this number. Two rodent families are most abundant: (1) the Heteromyidae, which includes kangaroo rats and pocket mice; and (2) the Cricetidae, or New World, mice. Activity patterns, food habits, population dynamics, life spans, and home ranges are well documented for the small mammals of the area (Jorgensen and Hayward, 1965).

The 1981 literature survey shows that rodent diversity is greatest in Transitional desert vegetation where species characteristic of the two deserts overlap. The precise composition and abundance of rodent populations in a given habitat are difficult to predict, primarily because many rodent species occur over a wide range of habitats but are abundant in only a few.

During the June and July 1982 site-specific investigations, rodents were trapped using live traps. The results of these surveys are shown in O'Farrell and Collins, 1983.

Comparatively little is known about populations of medium to large mammals. Black-tailed jackrabbits, Nuttall's cottontails, and desert cottontails are the most conspicuous and wide ranging of the larger mammals. The coyote is the most widely distributed and the most numerous carnivore, but the kit fox, badger, bobcat, and long-tailed weasel are also common. Mule deer live primarily at higher elevations and are the most abundant large mammal. Feral horses are most commonly sighted in the northern portions of the Nevada Test Site. Burros have been sighted near Cane, Topopah, and Captain Jack Springs, but sightings are rare (O'Farrell and Emery, 1976).

Evidence of mule deer was observed at all elevations and in all vegetation associations sampled. However, there were concentrations of sign both in sheltered upper canyons on the eastern slope of Yucca Mountain and along some ridge lines that may represent access routes. Scats were fresh and in various states of decomposition and had been deposited by both adults and fawns. Skeletal material of adults and a fawn were also observed. Sightings and fresh signs of deer decreased in late spring.

Although it is sometimes difficult to distinguish between horses and burros on the basis of tracks and scats alone, it was determined that only burros were present on Yucca Mountain. Burro tracks and scats of various ages were observed throughout the project area except in the lower elevations of the Larrea-Ambrosia vegetation association. Yucca Mountain ridge and the valley along the southern boundary of the project area contained significant concentrations of fresh sign. However, the highest concentrations were observed in Solitario Canyon, which is also called Hinge Fault Valley in several publications, where a herd of about 20 burros was observed. No evidence of bighorn sheep was found in the area.

Birds. The literature describes the avifauna on the Nevada Test Site (Hayward et al., 1963). Sixty-six species of birds are recorded as either seasonal or permanent residents in the area. Many other species visit the area briefly during spring and fall migration. There are 27 permanent breeding residents, most of whom inhabit sagebrush-pinyon-juniper vegetation, and a number of more widely distributed spring and summer residents. The Nevada Test Site is a winter feeding ground for large flocks of migrating passerine birds (sparrows and finches). Several species remain as winter residents because disturbed areas have an abundance of tumbleweed seed, which is an important winter food source. Migratory waterfowl and shore birds frequent the temporary lakes formed by precipitation runoff in Yucca and Frenchman playas.

During the 1982 site-specific investigations (O'Farrell and Collins, 1983), a total of 35 species of birds were recorded. Black-throated sparrows (Amphispiza bilineata) were observed most frequently. Rock wrens (Salpinctus obsoletus) were also observed at all elevations, especially in rocky habitats and along washes. Mourning doves (Zenaida macroura) arrived during the first week in May and bred at the site. Common ravens (Corvus corax) were also conspicuous residents, although they were not present in large flocks.

Six species of raptorial birds were observed, but sightings were infrequent. A red-tailed hawk (Buteo jamaicensis) was nesting in the project area. No waterfowl or suitable habitats for waterfowl were found.

Reptiles. The reptilian fauna of the study area includes one species of tortoise, 14 species of lizards, and 17 species of snakes. Mojave Desert vegetation supports the greatest numbers of reptiles. The most abundant and widespread lizards are: side-blotched lizards (Uta stansburiana), western whiptails (Cnemidophorus tigris), desert horned lizards (Phrynosoma platyrhinos), and desert spiny lizards (Sceloporus magister). The desert tortoise is discussed below as a special interest species.

Special interest species

No plant or animal on the Nevada Test Site is currently listed, nor is one an official candidate for listing, under the Endangered Species Act of 1973. The Mojave fishhook cactus and desert tortoise, both of which are under consideration for Federal protection as threatened species, occur in the study area.

The Mojave fishhook cactus, Sclerocactus polyancistrus, on the rocky ridges of Yucca Mountain (Figure 3-15), was more abundant than expected based upon published information. Its areal distribution included the top of Yucca Mountain and the entire western slope to the western boundary of the project area (Figure 3-15). Twenty-two live and a number of dead Sclerocactus individuals were recorded during 40 km (25 mi) of surveys in Solitario Canyon. Most were found in the middle and southern portions of the Canyon. All of the

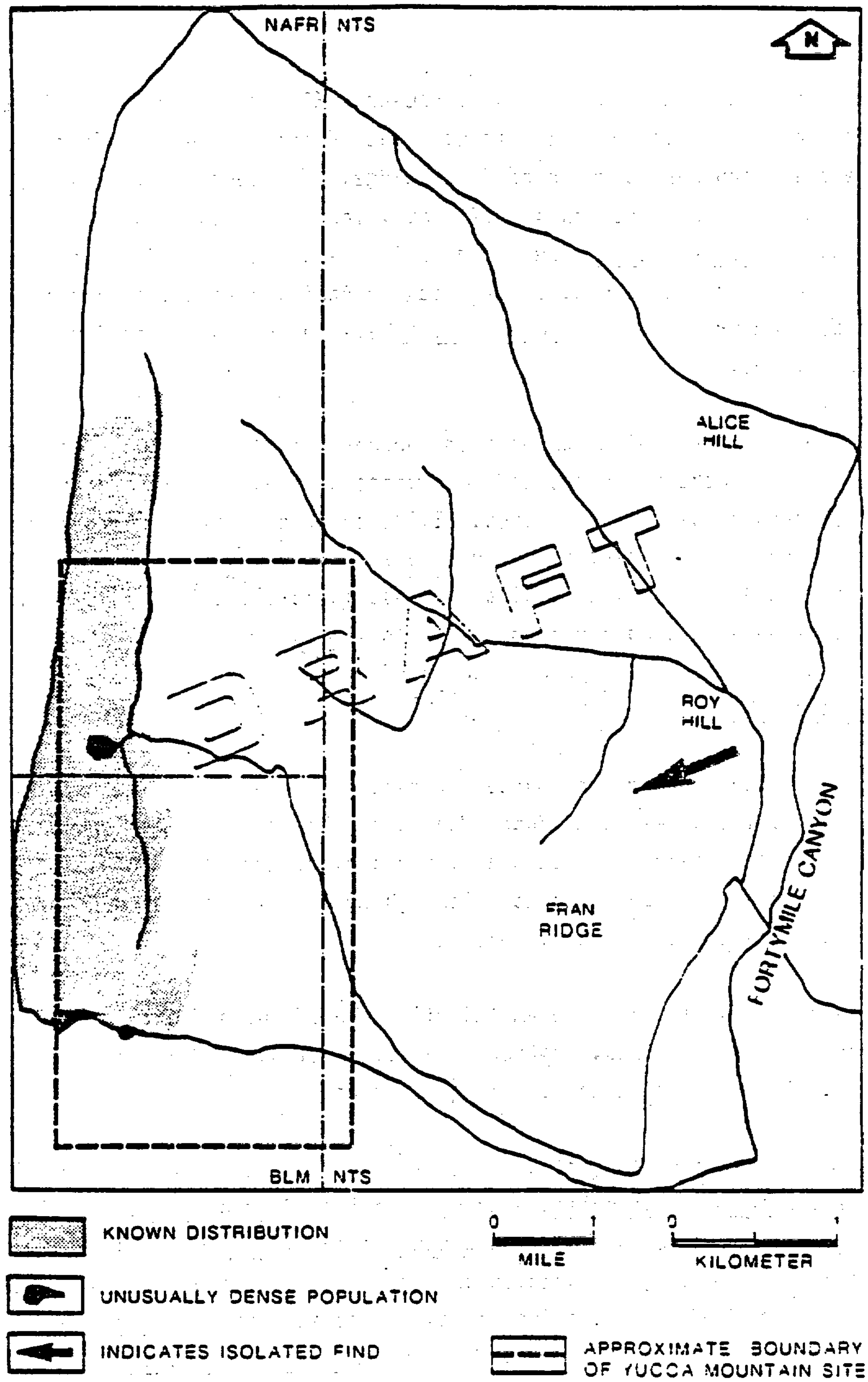

Figure 3-15. Distribution of Mojave fishhook cactus on Yucca Mountain. (Source: O'Farrell and Collins, 1983)

dead cacti had succumbed to natural causes. Eleven were recorded in 20 km (13 mi) of transects on Yucca Ridge; eight of the eleven were found together on the extreme southern portion of Yucca Ridge. The density of Sclerocactus observed on Yucca Ridge was significantly lower than the density in Solitario Canyon. No Sclerocactus were found during 34 km (21 mi) of ridge surveys conducted on the eastern slope of Yucca Mountain; however, an archaeologist reported the presence of a Sclerocactus between Fran Hill and Roy Hill (Figure 3-15).

The desert tortoise ranges from northern Sinaloa, Mexico, into Arizona, California, southern Nevada, and southwestern Utah. Yucca Mountain is close to the northern range of the species. Evidence of the desert tortoise was observed throughout the project area to elevations of 1600 m (5240 ft) (Figure 3-16); however, densities were estimated to be low (less than 20 per square mile) when compared to other parts of its range.

Aquatic ecosystems

No permanent or major sources of seasonal free water, and hence no riparian habitats, exist on Yucca Mountain. The larger washes and drainages within the area tend to contain a distinct flora consisting of species found only in washes and species that, although present in the surrounding vegetation, are most common in washes.

Ash Meadows is about 40 km (25 mi) south of Yucca Mountain and contains approximately 30 springs. Relict populations of pupfish and many unusual endemic plants exist in these spring habitats.

Species of concern include three endangered species of fish: Devil's Hole Pupfish, Cyprinodon diabolis; Amargosa Pupfish, Cyprinodon nevadensis pectoralis; and Pahrump killifish Empetrichthys latos (Collins et al., 1982). Two additional endangered species and their critical habitats were recently listed by the USFWS (1983): Ash Meadows Amargosa pupfish, Cyprinodon nevadensis mionectes; and Ash Meadows speckled dace, Rhinichthys osculus nevadensis). Nine plant species, which are under review for protection, are also found in the Ash Meadows area (Collins et al., 1982). Recently, The Nature Conservancy

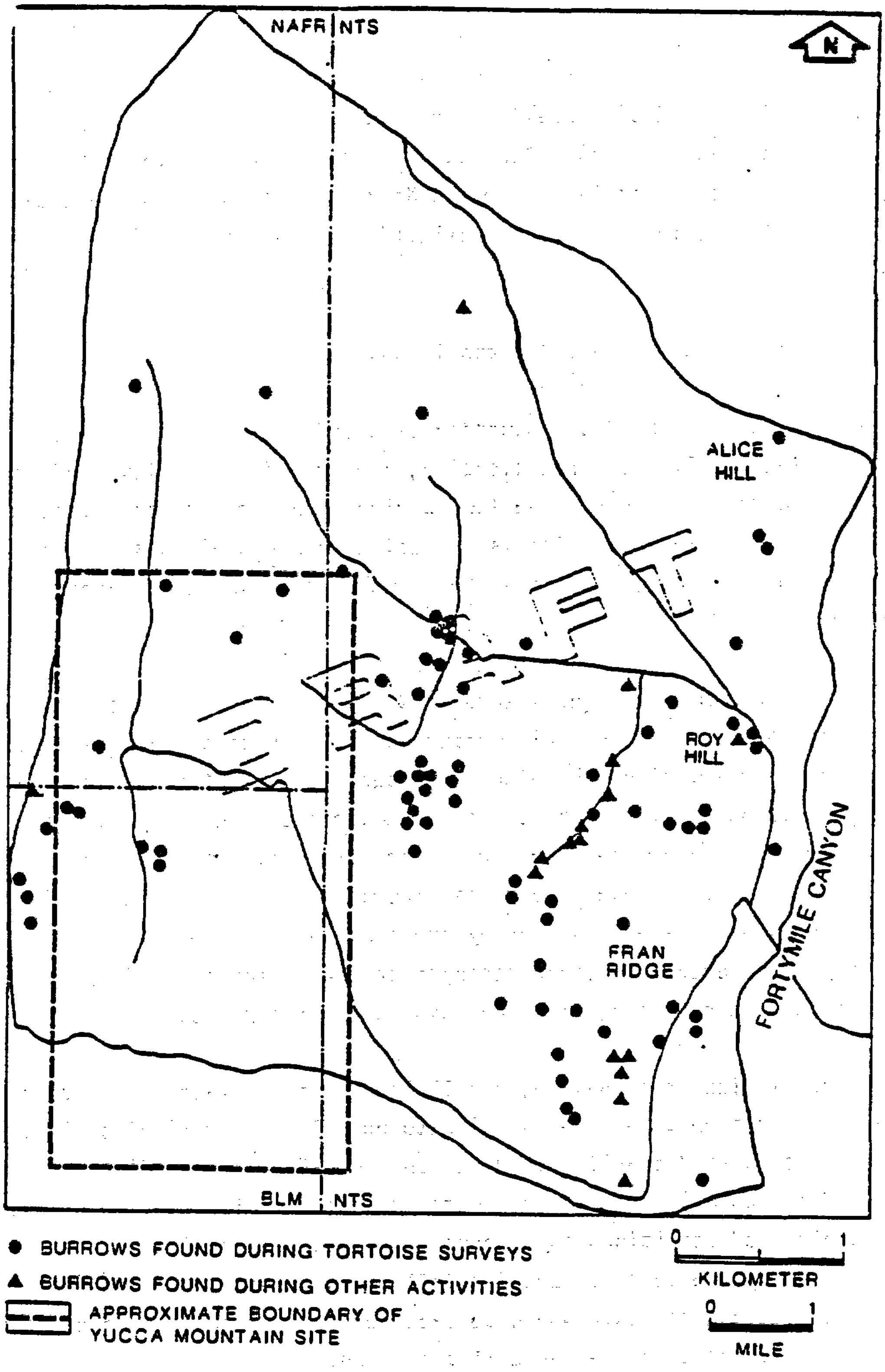

Figure 3-16. Distribution of desert tortise burrows on Yucca Mountain. (Source: O'Farrell and Collins, 1983)

purchased 5121 ha (12,654 acres) of private land in the vicinity of Devils Hole (the Ash Meadows area). Current plans call for the U.S. Fish and Wildlife Service to purchase this land from The Nature Conservancy and to establish the area as a unit within the National Wildlife Refuge System (USFWS, 1984; Sada, 1984).

3.1.4.3 Air quality and weather conditions

The climate of the Yucca Mountain site and the surrounding area has high solar insolation, limited precipitation, low relative humidity, and large diurnal temperature ranges. The lowest elevations are characterized by hot summers and mild winters, which is typical of other Great Basin desert areas. As elevation increases, precipitation amounts increase and temperatures decrease.

Daily minimum temperatures sometimes deviate from this pattern, because minimum temperatures occasionally occur at low elevations in closed geologic basins during calm, cloudless nights. Under these conditions, the ground surface cools quickly, thereby cooling the air near the surface. This cooler, denser air then drains down the terrain to form pools of cold air in closed topographic basins. These conditions generally dissipate quickly after sunrise when the ground surface is heated by the sun. Aside from these locally induced conditions, the overall weather patterns of the region are primarily influenced by continental air masses, which contain only limited amounts of moisture.

Meteorological data have been collected on the Nevada Test Site since 1956 at various locations. A ten-year climatological summary (1962 to 1971) for the weather station at Yucca Flat is given on Table 3-6. Yucca Flat is approximately 40 km (25 mi) northeast of Yucca Mountain. This summary is considered to be typical of conditions throughout the area, but local conditions may differ slightly due to site-specific influences. Because of elevation differences, Yucca Mountain would be expected to have greater precipitation and lower temperatures than the Yucca Flat station.

Temperature is probably one of the most variable meteorological parameters of the Yucca Mountain area on both a daily and an annual basis. The hottest

Table 3-6. Climatological summary for Yucca Flat, 1962-1971.

Month	Temp. (°F)[a] Avg. daily maximum	Avg. daily minimum	Avg. monthly	Extremes highest	Year	Lowest	Year	Degree days (base 65°) heating	Cooling	Precip. (inches)[b] average	Greatest monthly	Year	Least monthly	Year	Greatest daily	Year	Snow average	Snow greatest monthly	Year	Snow greatest daily	Year
JAN	52.1	20.8	36.5	73	1971	-2	1970	877	0	.53	4.02	1969	T	1971#	1.25	1969	0.9	4.3	1962	4.3	1962
FEB	56.7	25.8	41.3	77	1963	5	1971#	662	0	.84	3.55	1969	T	1967#	1.16	1969	1.9	17.4	1969	6.2	1969
MAR	60.9	27.7	44.3	87	1966	9	1969	634	0	.29	.60	1969	.02	1966	.38	1969	2.0	7.5	1969	4.5	1969
APR	67.8	34.4	51.1	89	1962	13	1966	411	1	.45	2.57	1965	T	1962	1.00	1965	0.7	3.0	1964	3.0	1964
MAY	78.9	43.5	61.2	97	1967	25	1967	147	38	.24	1.62	1971	T	1970#	.86	1971	0	T	1964	T	1964
JUN	87.6	49.9	68.8	107	1970	29	1971#	35	154	.21	1.13	1969	T	1971	.45	1969	0	0		0	
JUL	96.1	57.0	76.6	107	1967	40	1964#	0	366	.52	1.34	1968	0	1963	.77	1969	0	0		0	
AUG	95.0	58.1	76.6	107	1970	39	1968	1	368	.34	1.04	1965	0	1962	.35	1970#	0	0		0	
SEP	86.4	46.7	66.5	105	1971	25	1971	51	103	.60	2.38	1969	0	1968#	2.13	1969	0	0		0	
OCT	76.1	36.9	56.5	94	1964#	12	1971	266	9	.15	.45	1969	0	1967#	.47	1969	0	T	1971	T	1971
NOV	61.8	27.6	44.7	82	1962	13	1966	602	0	.71	3.02	1965	0	1962	1.10	1970	0.5	4.8	1964	2.3	1964
DEC	50.7	19.9	35.3	70	1964	-14	1967	914	0	.79	2.66	1965	T	1969#	1.31	1965	2.3	9.5	1971	7.4	1971
ANN	72.5	37.4	54.9	107	AUG 1970#	-14	DEC 1967	4600	1039	5.73	4.02	JAN 1969	0	SEP 1968#	2.13	SEP 1969	8.1	17.4	FEB 1969	7.4	DEC 1971

Month	Relative humidity (%) hour (Pacific Standard Time) 04	10	16	22	Wind[c,d] (speeds in mph) average speed	Peak speed	Year	Resultant dir/spd 23-02 PST	11-14 PST	Station pressure (inches) averages	Highest	Lowest	Average sky cover sunrise to sunset[e]	Sunrise to sunset: clear	Partly cloudy	Cloudy	Precip. .01 inch or more	.10 inch or more	.50 inch or more	1.00 inch or more	1.0 inch or more of snow	Thunderstorms	Max. 90°F or more	Max. 32°F or less	Min. 32°F or less	Min. 0°F or less
JAN	67	49	35	60	6.6	58	1965	235/03	335/21	26.10	26.54	25.42	4.9	13	8	10	2	1	*	*	*	*	0	1	27	*
FEB	67	45	32	56	6.9	52	1967	275/41	110/27	26.05	26.42	25.56	5.0	11	8	9	3	2	*	*	1	0	0	*	25	0
MAR	58	31	23	44	8.4	55	1971	240/11	086/45	25.99	26.43	25.40	4.8	12	9	10	3	1	0	0	1	1	0	0	24	0
APR	52	27	21	38	9.1	60#	1970#	250/22	098/51	25.96	26.39	25.50	4.5	13	9	8	3	1	*	*	*	1	0	0	17	0
MAY	46	22	17	31	8.3	60#	1967	260/15	179/72	25.94	26.39	25.47	4.3	14	11	6	2	1	*	0	0	1	4	0	7	0
JUN	39	19	14	26	7.9	60#	1967	272/15	105/07	25.92	26.20	25.56	3.0	19	7	4	2	1	0	0	0	2	14	0	*	
JUL	40	20	15	28	7.5	55	1971	278/1[illegible]	145/21	26.00	26.19	25.68	3.0	19	9	3	3	2	*	0	0	4	29	0	0	0
AUG	44	23	16	30	6.7	60#	1968	222/15	112/01	26.00	26.22	25.71	3.0	20	8	3	3	1	0	0	0	4	27	0	0	0
SEP	43	21	17	32	7.0	52	1970	208/13	163/64	26.00	26.36	25.56	2.1	22	6	2	2	1	1	*	0	2	11	0	1	0
OCT	46	24	19	36	6.8	60	1971	286/13	130/37	26.06	26.40	25.52	2.9	20	7	4	1	1	0	0	0	*	2	0	9	0
NOV	61	39	31	52	6.1	51	1970	234/42	152/01	26.08	26.50	25.64	4.8	13	7	10	3	2	*	*	*	*	0	0	23	0
DEC	68	50	41	64	6.6	63	1970	208/19	059/10	26.07	26.59	25.49	4.6	14	8	9	3	1	1	*	1	*	0	1	23	1
ANN	53	31	23	41	7.4	60#	APR 1970#	—	—	26.01	26.59	25.42	3.9	190	97	78	30	14	3	1	3	14	87	2	152	1

[a] # = most recent of multiple occurrences

[b] T = trace, an amount too small to measure

[c] * = one or more occurrences during the period of record but average less than 0.5 day

[d] Average and peak speed are for the period starting with December 1964. The direction of the resultant wind are from a summary covering the period December 1964 through May 1969.

[e] Sky cover is expressed in the range from 0 for no clouds to 10 when the sky is completely covered with clouds. Clear, partly cloudy and cloudy are defined as average daytime cloudiness of 0-3, 4-7 and 8-10 tenths, re[illegible]tively.

Source: Air Resources Laborato[illegible] Vegas, NV (Bowen and [illegible], 1981) months are generally July and August, which have average monthly temperatures for the ten-year record at Yucca Flat of 24.8°C (76.6°F), and average daily maximums of 35.6°C (96.1°F) and 35.0°C (95.0°F), respectively. Average daily temperature ranges for these months are nearly 22°C (40°F). The highest temperature recorded at Yucca Flat is 42°C (107°F), and has occurred in June, July, and August. Conversely, December is usually the coldest month of the year with a monthly average temperature of 1.8°C (35.3°F) and an average daily minimum temperature of -6.7°C (19.9°F). The extreme low temperature recorded in December was -25°C (-14°F). Minimum temperatures at the site can be affected by the drainage flows described previously, and may differ from the temperatures recorded at Yucca Flat.

Precipitation in the region is sparse; it averages only about 145 mm (5.7 in.) annually at Yucca Flat. This sparse precipitation is due to the land based air masses that influence the region's weather and the blocking effect of the Sierra Nevada Mountains. Pacific air masses that could bring moisture to the region generally drop most of their moisture on the western slopes of the Sierra Nevadas and leave little precipitation to fall on the east side. Precipitation that does reach the area is concentrated in the winter months, but thunderstorms at other times of the year can also be significant sources of moisture for the area. Thunderstorms occur 16 percent of the days in July and August, but only 5 percent of the days annually. The greatest monthly precipitation for Yucca Flat is 102 mm (4.02 in.), and the greatest daily amount is 54 mm (2.13 in.). With an average of only 145 mm (5.7 in.) of precipitation annually, these maximums represent significant storm events. The statistical maximum 24-hour precipitation for 10-year and 100-year storm events for Yucca Flat is 38 mm and 57 mm (1.50 in. and 2.25 in.), respectively (DOC/NOAA, 1963).

High winds in the area are usually associated with the passage of winter storm fronts, but they can also accompany thunderstorms. Wind speeds in excess of 100 km/hr (60 mph), with gusts of up to 163 km/hr (101 mph) have been recorded on several occasions (Quiring, 1968). Such velocities are not common, however, as is evidenced by the Yucca Flat annual average wind speed of 12 km/hr (7.4 mph). Monthly average wind speeds do not deviate significantly from this value, with a high of 15 km/hr (9.1 mph) in March and a low of 10 km/hr (6.1 mph) in November.

Other than temperature extremes, severe weather in the area includes thunderstorms, tornados, hail, lightning, and sandstorms. Severe thunderstorms create a potential for flash flooding, but they generally do not last longer than an hour (Bowen and Egami, 1981). Tornados have been observed within 80 km (50 mi) of Yucca Flat, but are considered rare (DOC/NOAA 1981).

Air quality

Site-specific air quality data are not available for the study area. Data from similar desert locations, however, suggest that air quality at the site is probably very good. Elevated levels of either ozone or total suspended particulates may occasionally occur due to either pollutants that are transported into the area, or to local sources of fugitive particulates (Bowen and Egami, 1981). Ambient concentrations of other criteria pollutants (sulfur dioxide, nitrogen oxides, and carbon monoxide) are probably low because there are no significant sources of these pollutants nearby. The nearest significant source of pollutants is the Las Vegas area, which is at least 105 km (65 mi) away, and is not expected to measurably affect the air quality in the Yucca Mountain area.

3.1.4.4 Noise

Although baseline noise levels have not been measured in the Yucca Mountain area, they can be estimated. There are two types of noise-producing areas in the study area: 1) uninhabited desert, and 2) small rural communities. In the uninhabited desert, the major sources of noise are natural physical phenomena such as wind, and rain, the activities of wildlife, and an occasional airplane. Annually, wind is the predominant noise. Between 1962 and 1971, the Air Resources Laboratory recorded an average annual wind speed of over 3 m/s or 7 mph at Yucca Flat (Table 3-6). This area would thus be considered windy. Desert noise levels as a function of wind have been estimated at an upper limit of 22 dBA for a still desert and 38 dBA for a windy desert (Brattson and Bordello, 1983). For Yucca Mountain, 30 dBA is probably a reasonable estimate; it corresponds with noise levels presented in the environmental impact statement prepared for the MX Missile System for areas similar to Yucca Mountain (Henningson, Durham, and Richardson, Inc., 1981).

Annual rural community noise levels have been estimated by the EPA at 50 dBA (EPA, 1974). This level would be characteristic of annual noise expected for Indian Springs, Mercury, or the town of Amargosa Valley.

3.1.4.5 Aesthetic resources

Yucca Mountain is in the southern part of the Great Basin and is characterized by dissected ranges that rise abruptly from moderate slopes of alluvial piedmonts. The terrain is rugged, arid, and has scant vegetation.

The project area is not visible from major population centers, public recreation areas, or public highways.

3.1.4.6 Archaeological, cultural, and historical resources

A cultural resource overview and an intensive reconnaissance of the Yucca Mountain area was conducted in 1982-83. Resources that may be affected by repository activities have been identified and clearly marked. Limited test excavations on a sample of the identified sites were also conducted (Pippin et al., 1983).

An archaeological site is identified as any location of past human activity evidenced by the presence of material items manufactured or altered by man (stone tools, pottery), architectural structures (walls, windbreaks), or functionally specific facilities (hearths, pits, and cairns). Thus, a location which contains anything from a single pottery shard to a large campsite would be recorded as an archaeological site.

A total of 178 prehistoric aboriginal sites were identified, which represented use of the Yucca Mountain area by small and highly mobile groups or bands of aboriginal "hunter-gatherers." The sites consisted of two basic types; campsites, and extractive locations. Campsites are temporary locations where groups varying in size from single-family units to small bands of 20 to 30 individuals lived for days or months utilizing nearby resources. Such campsites, 21 of which were identified on Yucca Mountain, are recognized by the presence of artifacts, structures, and facilities related to food preparation and consumption, shelter, and other maintenance activities such as the manufacture or repair of clothing and tools.

One hundred forty-one of the prehistoric sites are extractive locations. These are the remains of more limited, task-specific activities associated with hunting, gathering, and processing of wild plants, and procurement of other raw materials used in manufacturing tools and clothing. The survey identified several kinds of extractive locations which are summarized in Table 3-7. In addition, 16 sites were identified but not classified. Some of the major archeological sites in the area are shown in Figure 3-17.

According to Pippin et al. (1983), the cultural resources of Yucca Mountain can be categorized according to four general adaptive strategies. The earliest strategy was reflected by a linear pattern of archeological sites along major ephemeral drainages. Although the terrace edges of these drainages continued to be occupied by later populations, there appears to have been a shift in settlement patterns away from these linear sources of water that began about 7000 years ago. During that time, temporary camps became established in the uplands of Yucca Mountain. About 1500 years ago, there appeared to be another shift in adaptation. Unlike earlier periods, the availability of plant resources seemed to have a major influence on site locations. Finally, a historic adaptation in the area was indicated by numerous cairns, several isolated tin cans, and a prospector's camp.

Although Nevada has been occupied since early times, it was the last state entered by white explorers during historical times. The first recorded entry of Euro-American travelers into the Nevada Test Site was that of a group of emigrants to California in 1849 (Worman, 1969). This group had broken away from a party led by Captain Jefferson Hunt after hearing rumors of a shorter route to California than that afforded by the Old Spanish Trail. While Hunt headed southward over known territory, the splinter party plunged off into the unknown. A second split was made north of Indian Springs where a group of

Table 3-7. Prehistoric archaeological sites in the Yucca Mountain area (Pippin et al., 1982)

Site type	Activities represented	Typical features, artifacts, location	Number
Temporary camps	Food Preparation and consumption; shelter; maintenance activities	Evidence of fire (hearths, pits, etc.), rock alignments (windbreaks, shelters), stone tools, bone, vessels, grinding implements, etc.; location variable	21
Tinajas (cisterns)	Water collection	Bedrock basins with rock covers to retard evaporation; often near other extractive locations or camps	19
Knapping stations	Stone tool manufacturing	Stone tools and waste material; locations quite variable	16
Quarries	Collection of tool-stone	Large amounts of waste, parent material, stone tools, located on or near sources of material, some very extensive	12
Milling stations	Processing of plant resources (seeds)	Grinding implements (manos); stone tools, locations vary but common in rock shelters	27
Caches	Storage of tools, raw materials	Rock alignments, piles; concentrations of raw materials, tools; common in small rock shelters	3
Isolated artifacts	Hunting and/or collecting activities	Isolated stone tools and waste, variable locations	64
Sites of unknown function	Diffuse concentrations of stone tools and waste; isolated artifacts with a suspected subsurface component. Variable locations but ioslates common in small rock shelters		16
Total			178

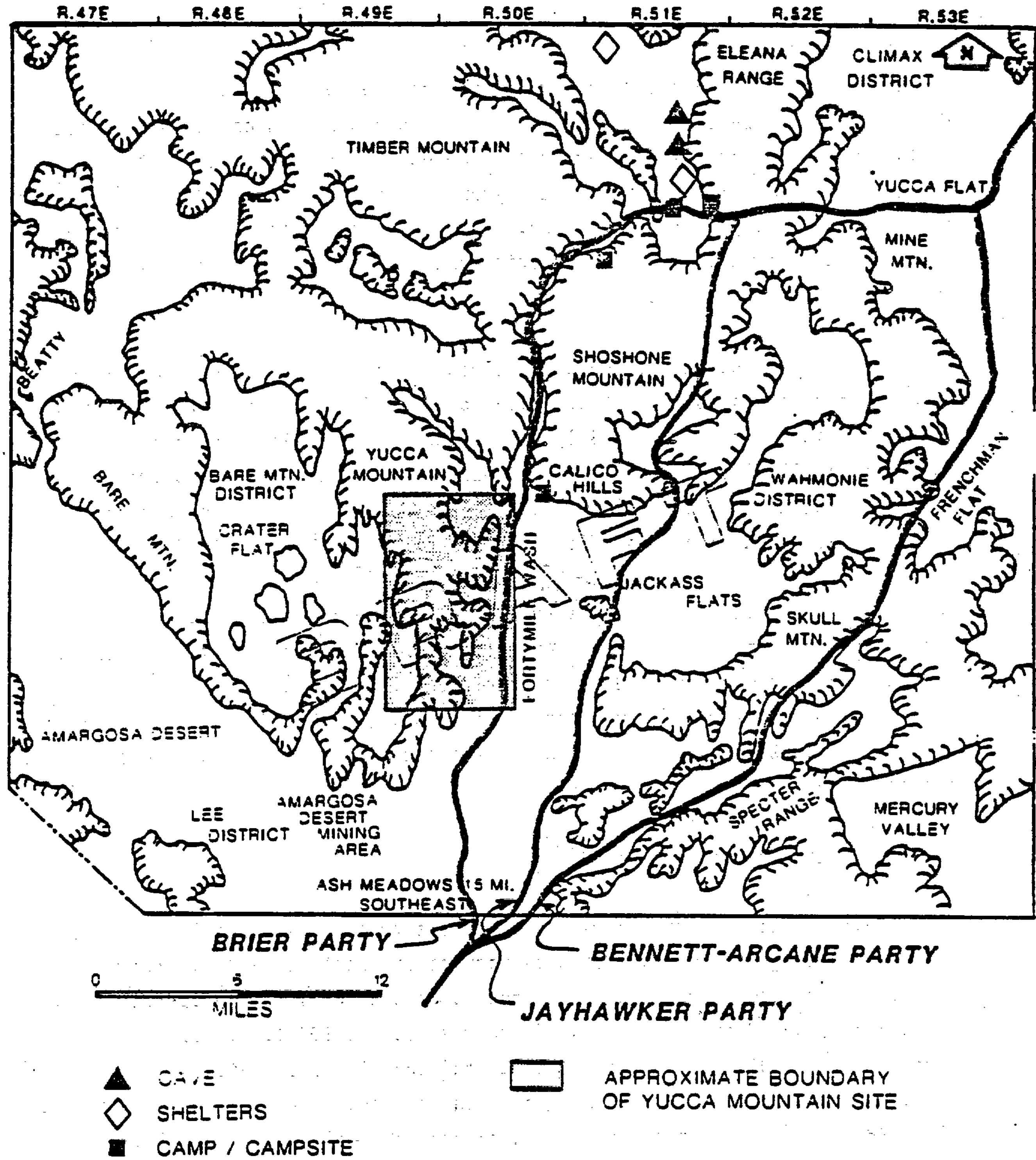

Figure 3-17. Location of major archaeological sites and historic trails near Yucca Mountain. (Adapted from Worman, 1969)

wagons, known as the Bennett-Arcane Party, decided to take a southerly route. The remaining wagons, the Jayhawkers, followed a westward course to Tippipah Spring where another split occurred and the Jayhawkers went south between Skull Mountain and Fortymile Canyon. The Jayhawkers crossed Topopah Wash and entered the Amargosa Valley east of the Wash. The other group, the Briers, entered Fortymile Canyon west of Tippipah Spring and went on to Amargosa Valley. These trails are shown in Figure 3-17.

Later movements into the area involved prospectors, ranchers, wild-horse hunters, and the establishment of relay stations for stage and freight lines. Operating mines were the Horn Silver Mine and the short-lived town of Wahmonie (3 months in 1928) about 6.5 km (4 mi) west of Cane Springs, the Climax Tungsten Mine at the north end of Yucca Flat, a cinnabar mine and retort on Mine Mountain, and galena deposits at the Groom Mine (Worman, 1969).

Other historic resources located in the region include ghost towns, mining camps, Mormon settlements, and ranches located in southern Nevada. A Department of Energy study revealed 145 historic and 5 prehistoric sites located within a 140-km (87-mi) radius, but not inclusive, of the Nevada Test Site (URS/Blume, 1982). The most common sites identified were mining operations and ranches.

3.1.4.7 Radiological background

Environmental background radiation levels from all sources in the general area surrounding the Nevada Test Site vary considerably depending mainly on elevation and natural radioactivity content of the soil. A typical value for the southwestern United States is 130 mrem/yr (ERDA, 1977). In 1982, the environmental radiation dose rate at 32 monitored locations within a 300 km radius, ranged from 42 to 139 mrem/yr, with an average of 88 mrem/yr (Black et al., 1983). It has been observed that exposures (whole-body radiation) measured at offsite stations nearest to the Nevada Test Site are decreasing with time (ERDA, 1977). This decrease is believed to result from radioactive decay of fallout deposited mainly during periods of atmospheric testing.

Radiation levels within the NTS boundary increased from 1951 to the mid-1960's as a result of atmospheric weapons testing and other experiments. Radiation levels at specific locations within the NTS vary considerably depending on the history of the location, and may approach very localized levels as high as 5 mrem/hr. Most of the radioactivity created at the Nevada Test Site by underground tests remains in or near the respective underground cavity locations. Measures of radioactivity in the principal Nevada Test Site water system during the 1982 measuring period showed only background tritium and other radionuclides except for wells that enter the test cavity (Black et al., 1983). Some radioactivity remains on the surface from pre-1962 atmospheric testing of weapons, nuclear cratering explosions, nuclear propulsion systems tests, and radioactive wastes generated by other NTS activities (ERDA 1977). The locations of these wastes on the Nevada Test Site are shown in Figure 3-18 (ERDA, 1977). Almost all of the sites shown are located in the northeastern quadrant of the Nevada Test Site, relatively far removed from the potential repository site at Yucca Mountain.

Monitoring program

The Department of Energy is responsible for providing radiological safety services on the Nevada Test Site and maintaining an environmental surveillance program designed to control, minimize, and document exposures to the Nevada Test Site working population. Air and potable water samples are collected at specific areas where personnel spend significant amounts of time. Additional air-sampling stations are located at sites throughout the Nevada Test Site in support of the testing program and the radioactive waste management program. Water from supply wells, open reservoirs, natural springs, contaminated ponds, and sewage ponds is also sampled and analyzed to evaluate the possibility of any movement of radioactive contaminants in the Nevada Test Site water system. Thermoluminescent dosimeters (TLDs) are used to measure the ambient Nevada Test Site external gamma radiation levels.

The Environmental Protection Agency, through its Environmental Monitoring Systems Laboratory in Las Vegas, has performed radiological monitoring in the Nevada Test Site off-site area. Since 1958, continuous monitoring has been performed to determine the levels of radiation and radioactivity present.

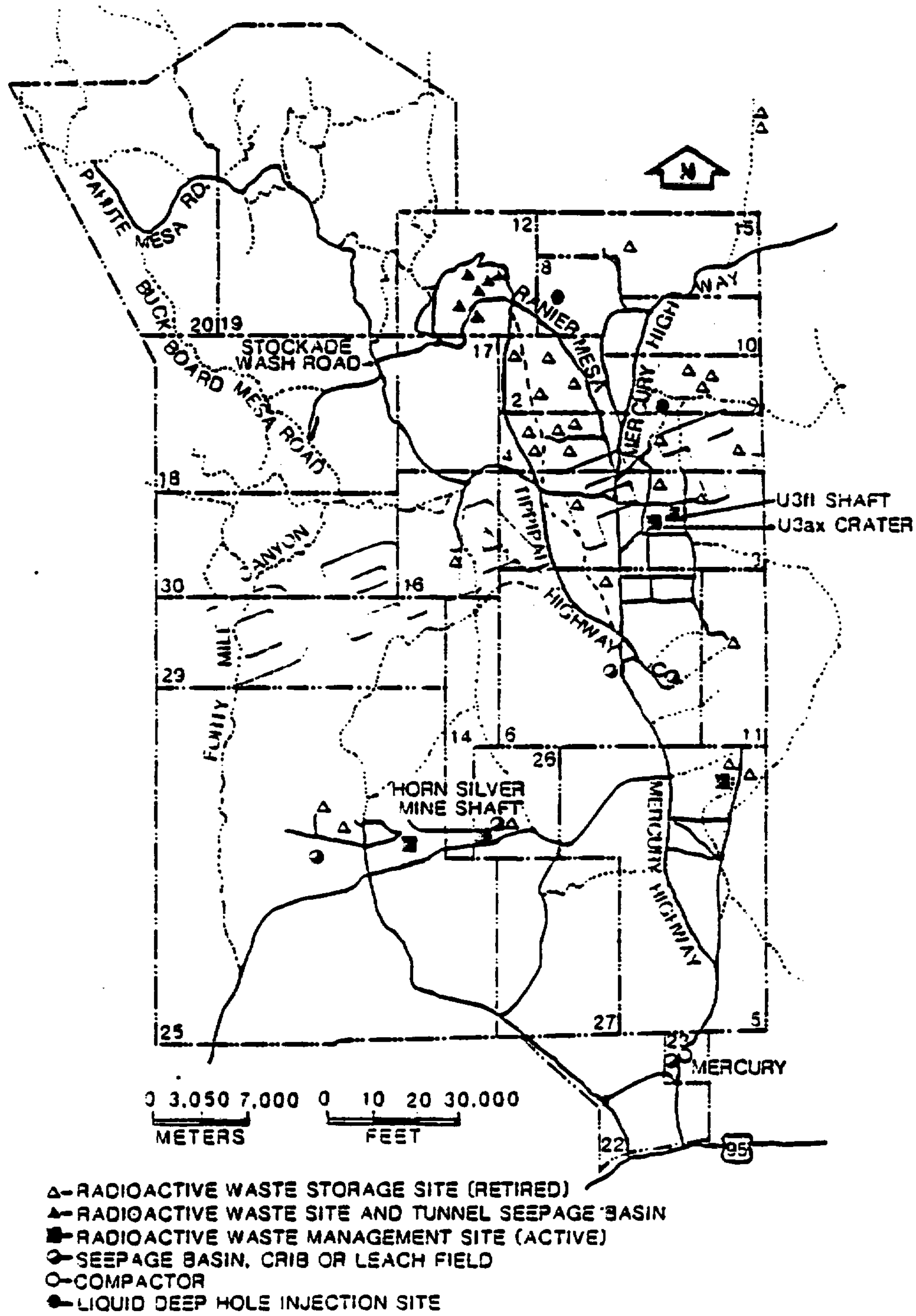

Figure 3-18. Locations of radioactive waste areas at the Nevada Test Site. (Source: ERDA, 1977)

Samples of air, water, and milk are routinely collected and analyzed, and external radiation exposures are measured. Radioactivity attributable to the resuspension of dust particles in the air from contaminated areas on the Nevada Test Site has never been detected in offsite samples. No contained underground tests have resulted in exposure to offsite residents which exceeded the radiation protection standards applicable to releases from nuclear facilities. It is predicted that future containment will be as good or better (ERDA, 1977). No radioactivity attributable to the Nevada Test Site during 1982 was detected off the site by any of the monitoring networks (Black et al., 1983).

A recent major innovation in this long-term monitoring program has been the establishment of a network of Community Monitoring Stations in 15 offsite communities (Douglas, 1983) (see Figure 3-19). It differs from other network in the offsite radiation monitoring and public safety program in that it incorporates Federal, State, and local Government participation. DOE's Nevada Operations Office and EPA's Environmental System Monitoring Laboratory provide technical guidance for the program. Those directly connected with the program feel that after one year of operation, it is worthwhile, and that it will bring visibility and credibility to the data it provides (Douglas, 1983).

<u>Dose assessment</u>

Using the measured quantities of radioactivity in various environmental media, the maximum dose to a hypothetical individual living at the Nevada Test Site boundary may be estimated. This was done by calculating the fifty-year committed dose equivalent for the individual receiving a one-year intake of air and water conservatively assumed to be contaminated with radionuclides at concentrations measured on the site. The maximum calculated dose to the total body, bone, and lung was 0.18 mrem, 2.0 mrem, and 0.24 mrem, respectively. These doses to the hypothetical individual at the Nevada Test Site boundary represent increases of less than 0.5 percent over natural background for total body and lung, and less than 1.5 percent over natural background for bone (Scoggins, 1983).

Although no radioactivity released from the Nevada Test Site during 1982 was detected offsite, the theoretically possible dose to the offsite population

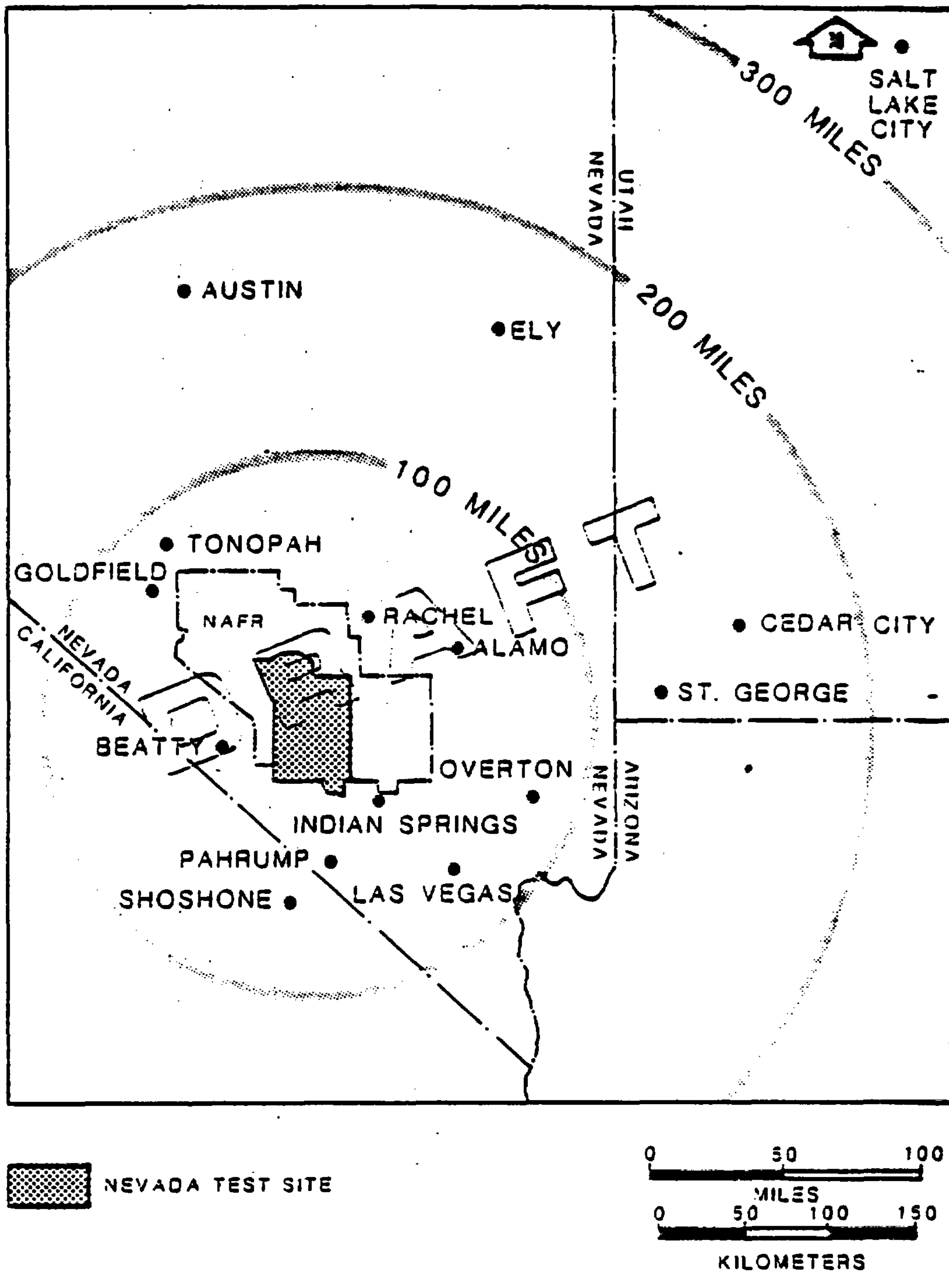

Figure 3-19. Community monitoring stations around the Nevada Test Site. (Source: Douglas, 1983)

from releases on the Nevada Test Site can be calculated by using annual average weather data and atmospheric diffusion equations. Based on noble gas releases reported on the Nevada Test Site (Black et al., 1983) (Table 3-8), the estimated annual population dose to the 4600 people residing within 80 km of a central point on the Nevada Test Site was 9.9×10^{-6} man-rem. For comparison, the annual integrated population dose to this same population from natural background radiation is approximately 4.1×10^{2} man-rem.

The highest estimated dose was 3×10^{-6} mrem per year to an individual living in Rachel, with lesser amounts to individuals in the town of Amargosa Valley, Beatty, and Indian Springs, Nevada. Natural radioactivity in the body causes individual annual internal doses ranging from 26 to 36 mrem/yr and environmental background averages 88 mrem/yr. Therefore, the maximum theoretical dose estimate of 3×10^{-6} mrem/yr from airborne radionuclide emissions during 1982 on the Nevada Test Site represents a very small fraction of the natural internal and external radiation background.

3.1.5 Transportation

This section describes the existing and projected transportation network in the vicinity of the site. This information will be used in Chapters 4, 5 and 6 to evaluate the potential impact of transporting people, materials, and radioactive waste.

3.1.5.1 Highway infrastructure and current usage

Figure 3-20 shows the existing highway network around the site. U.S. 95, a four-lane road between Las Vegas and Mercury, is the major artery over which construction material and people would be transported. West of Mercury, U.S. 95 becomes a two-lane road. Access to the site would be via a proposed 25-km (15-mi) access road from Highway 95. This access road would only be used by site-related traffic because the site is located on undeveloped Federal land.

Table 3-10 presents traffic counts along U.S. 95 for 1982. Annual average daily traffic (AADT) represents the average number of vehicles passing over a road segment for any day of the year. The average annual weekday traffic

Table 3-8. Total airborne radionuclide emmisions at the Nevada Test Site during 1982 (Black et al., 1983)

Radionuclide	Half-life (days)	Quantity released (Ci)
Tritium	4500	165
Iodine-131	8.04	0.0001
Xenon-133	5.29	74
Xenon-133m	2.33	2.5
Xenon-135	0.38	4.2

Table 3-9

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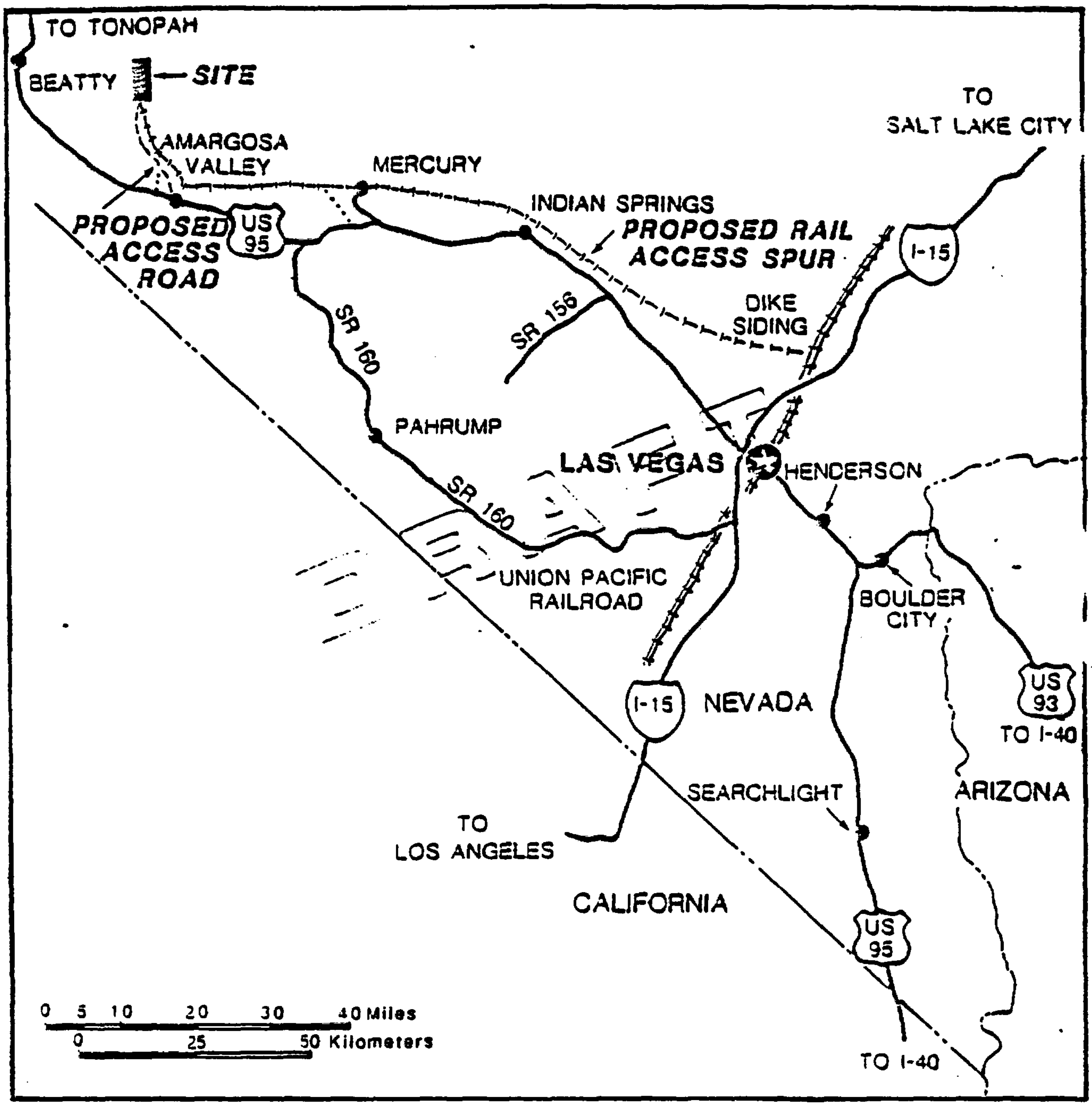

····· NRDS ROAD, CLOSED TO TRAFFIC

Figure 3-20. Regional transportation network and proposed road and rail access to the Yucca Mountain site.

Table 3-10. Traffic patterns on U.S. 95, 1982 (State of Nevada, Department of Transportation, 1983)

Highway segment[a]	Distance[b] (km)	Traffic volume: Average annual daily traffic	Traffic volume: Average annual weekday traffic	Peak hour traffic as a percentage of annual average weekday traffic: morning (6-7 a.m.)	Peak hour traffic as a percentage of annual average weekday traffic: evening (5-6 p.m.)
Northern city limits Las Vegas to SR156	22	3500	3579	7.49	9.3
SR156 to Indian Springs	21	3030	3098	7.49	9.3
Indian Springs to Mercury Intersection	29	2820	2883	7.49	9.3
Mercury Intersection to NRDS Rd.	5	1960	1937	2.5	6.0
NRDS Rd. to SR160	8	1785	1764	2.5	6.0
SR160 to Amargosa Valley	27	1685	1665	2.5	6.0
Amargosa Valley to Beatty	47	1450	1433	2.5	6.0

[a] See Figure 3-21 for location of highway segments.

[b] 1 km = 0.621 mi.

represents the average number of vehicles passing over the same road segment for any given 24-hour weekday of the year. When the annual average weekday traffic count exceeds the AADT, weekday traffic dominates weekend traffic. Therefore, Table 3-10 indicates that weekday usage of U.S. 95 dominates traffic flow between Las Vegas and Mercury. However, from Mercury west, weekend traffic dominates usage. This usage pattern reflects worker traffic between Las Vegas and the Nevada Test Site.

Worker traffic to the site from Las Vegas is characterized by morning and early evening peaks. As is typical for rush hour traffic, the evening peak dominates as shown in Table 3-10. Of critical importance is the ability of the roadway to handle the traffic volume or density during this peak period. This ability can be assessed by noting the level of service (LOS) realized during the peak period. The level of service describes the flow of traffic and propensity for traffic accidents at different traffic volumes. Table 3-11 presents a description of LOS at different traffic volumes. Table 3-12 compares evening peak hour traffic volumes and levels of service for each road segment. This table indicates that service level A is maintained along the entire four-lane segment of U.S. 95 from Las Vegas to Mercury. For a short distance, approximately 13 km (8 mi), west of Mercury, the service level drops to B as site workers travel from Mercury toward Pahrump. Beyond the turnoff for Pahrump, the level of service returns to service level A.

Traffic levels through metropolitan Las Vegas are high and certain sections of U.S. 95, south of the northern city limits, and I-15 are congested. Congested streets include the following: Fremont Street (U.S. 95) from Charleston Boulevard to Bruce Street; I-15 northbound from Sahara Avenue to Charleston Boulevard; I-15 southbound from U.S. 95 to Charleston Boulevard; U.S. 95 eastbound from "D" Street to I-15 (Clark County, 1975). The following ramps for I-15 and U.S. 95 interchange are also congested: I-15 South to U.S. 95 West; U.S. 95 West to I-15 South; and U.S. 95 East to I-15 South (Clark County, 1975).

Table 3-11. Traffic service levels and characteristics (Carter et al., 1982)

Level	Characteristics
A	• Highest level of service • Free flow with little or no restrictions on speed or maneuverability due to presence of other vehicles • Lane density is approximately 10 vehicles/mile
B	• Zone of stable flow • Operating speed is beginning to be restricted, however restrictions on maneuverability by other vehicles is still negligible • Typical design criteria for rural highways • Lane density is approximately 20 vehicles/mile
C	• Still a zone of stable flow • Speed and maneuverability is becoming constrained • Typical design criteria for urban highways • Lane density is approximately 30-35 vehicles/mile
D	• Approaching unstable flow • Tolerable average speeds can be maintained but are subject to considerable and sudden variation • Probability of accidents has increased • Most drivers would consider these conditions undesirable • Lane density is 40-50 vehicles/mile
E	• Unstable flow • Wide fluctuation in flow • Little independence in speed selection and maneuverability • Lane density is 70-75 vehicles/hour
F	• Forced-flow operations • Speed may drop to zero for short periods • Lane density continues to increase, reaching "jam density" at approximately 150 vehicles/hour

Table 3-12. Evening peak hour (5-6 p.m.) traffic patterns on U.S. 95, 1982[a] (State of Nevada, Department of Transportation, 1983)

Highway segment[b]	Distance[c] (km)	Traffic volume	Maximum service volume (passenger car/hr) Service Level A	Service Level B	Service Level C
Northern city limits Las Vegas to SR 156	22	333	996	1,660	2,490
SR 156 to Indian Springs	21	288	996	1,660	2,490
Indian Springs to Mercury Intersection	29	268	996	1,660	2,490
Mercury Intersection to NRDS Rd.	5	116	66	442	929
NRDS Rd. to SR 160	8	106	61	427	875
SR 160 to 5 mi. east of Amargosa Valley	19	100	228	684	1,053
5 mi. east of Amargosa Valley to Amargosa Valley	8	100	304	810	1,134
Amargosa Valley to Beatty	47	86	285	822	1,104

[a] Traffic data for the highway section between Las Vegas and Mercury represent actual counts. Data for the section beyond Mercury has been calculated from average annual daily traffic data.

[b] See Figure 3-21 for location of highway segments.

[c] 1 km = 0.621 mi.

3.1.5.2 Railroad infrastructure and current usage

As noted in Figure 3-20, the closest rail line to the site is the Union Pacific line which passes through Las Vegas. This line connects Salt Lake City with Los Angeles. To access the site, a spur line of approximately 142 km (85 mi) would have to be built from Dike Siding, which is 18 km (11 mi) northeast of Las Vegas, as shown in Figure 3-20.

The Union Pacific line passing through Las Vegas is designated as a class A mainline. A class A mainline meets at least one of the following three tests (DOT, 1977):

1. High Freight Density Test, which involves carrying at least 20 million gross tons per year.

2. Service to Major Markets Test.

3. National Defense Test, which requires a rail route of the highest physical category in corridors designated as essential in the Strategic Rail Corridor Network for national defense.

Class A mainline routes carry most of the nations rail traffic. Furthermore, they typically show the best economic performance based upon unit cost for maintenance and operation, and return on investment.

The line is primarily single track with frequent sidings, i.e., areas at which trains can pull off the main track to the "side". There is a total of 88 sidings on the 721 km (448 mi) section between Salt Lake City and Barstow, California, which is an average of approximately one every 8 km (5 mi). Train operations are controlled by a Centralized Traffic Control system in Salt Lake City. From Daggett, which is just east of Barstow, California, to Salt Lake City, the majority of the line is continuously welded rail (Nunn, 1983). A number of safety devices are included throughout the mainline route including hot box, wide- and high-load detectors, dragging-equipment detectors, high-water detectors, slide-fence detectors, and a microwave communication system (WESTPO Study, 1981).

A hot box is used to detect overheated conditions. Wide- and high-load detectors are used to ensure that loads are within design limits for the track. High-water detectors are placed in areas that are prone to flooding. Slide-fence detectors are used to detect breaching in fencing used to constrain mud and rock slides. Dragging-equipment detectors are used to ensure that equipment (such as brake rods and air hoses) dragging along the track are identified. Dragging-equipment detectors lower the possibility of derailment caused by such equipment becoming lodged between wheels and rails. These detectors also lower the possibility of damage to turnout equipment at sidings (WESTPO, 1981).

The average number of trains passing along the mainline section through Las Vegas from 1978 to 1983 is given in Table 3-13. Table 3-13 also lists the average number of cars per train and the average number of tons per freight train. An analysis of the capacity of the principal Union Pacific mainlines that was prepared under the auspices of the Western Governors' Policy Office (WESTPO, 1981), estimated that centralized traffic controlled lines could accommodate between 25 and 54 trains daily. Because of its centralized traffic control system, good maintenance, and frequent sidings, the Salt Lake City to Barstow section of the Union Pacific line should be at the high end of this range.

A conservative estimate that the line could accommodate 30 trains per day would suggest the following:

1. The line has not operated at over 71 percent capacity in the past six years.

2. The line has operated at an average of 60 percent capacity over the past six years.

3. The line operated at 53 percent of capacity in 1983.

Table 3-13. Recent railroad traffic patterns[a]

	Average number of trains[b] per day (both directions)		Average number of cars per freight train[c]		Average number of tons per freight train	
Year	Freight	Passenger	Eastbound	Westbound	Eastbound	Westbound
1978	14.4	2	68	65	3077	5599
1979	17.4	2	70	65	3000	6138
1980	16.7	2	73	65	3040	6279
1981	19.2	2	68	64	3042	6500
1982	13.2	2	NA[d]	NA[d]	3206	5799
1983	13.9	2	70	61	3168	5908

[a] Source: Written communication from Ms. N. Nunn, Marketing Manager, Union Pacific Railroad Company, Omaha, Nebraska, 1983.

[b] Number of trains is equally distributed between eastbound and westbound traffic.

[c] Passenger trains average five cars in each direction.

[d] NA = not available.

3.1.6 Socioeconomic conditions

This section describes existing and expected future baseline social and economic conditions in the region surrounding the Yucca Mountain site. This provides the basis for the impact estimates which appear in Chapters 4, 5 and 6.

The social and economic impacts, if a repository were located at Yucca Mountain, would occur in Nye County, where the site is located, and neighboring Clark County. Current settlement patterns of DOE and contractor employees who work at the Nevada Test Site indicate that almost all of the Yucca Mountain project work force would reside in this area, which is shown in Figure 3-21.

3.1.6.1 Economic conditions

Since World War II, Nevada has experienced rapid economic expansion led by the hotel and gaming industry. This industry was more than 100 times larger in 1982 than in 1945 in nominal terms, i.e., including inflation. The hotel, gaming, and recreation industry in Nevada directly employs over 121,000 persons, about 30 percent of total jobs in the State, with perhaps as many other jobs indirectly dependent on this same industry. This means that the incomes of Nevada residents depend greatly on this one sector of the local economy. Other key employers include: other services; transportation, communications, and public utilities; construction; trade; finance; real estate and insurance; and government.

The Nevada economy is expected to continue its strong historical growth well into the future. In real terms, total personal income is projected to grow nearly eight-fold by 2030, a four percent annual growth rate. Real per capita income is expected to increase by a factor exceeding 2.5, an annual average growth rate of 1.8 percent. This income growth will continue to be led by the hotel, gaming, and recreation industry, although this sector's share of total income is expected to decline slightly over the forecast period (McBrien and Jones, 1983).

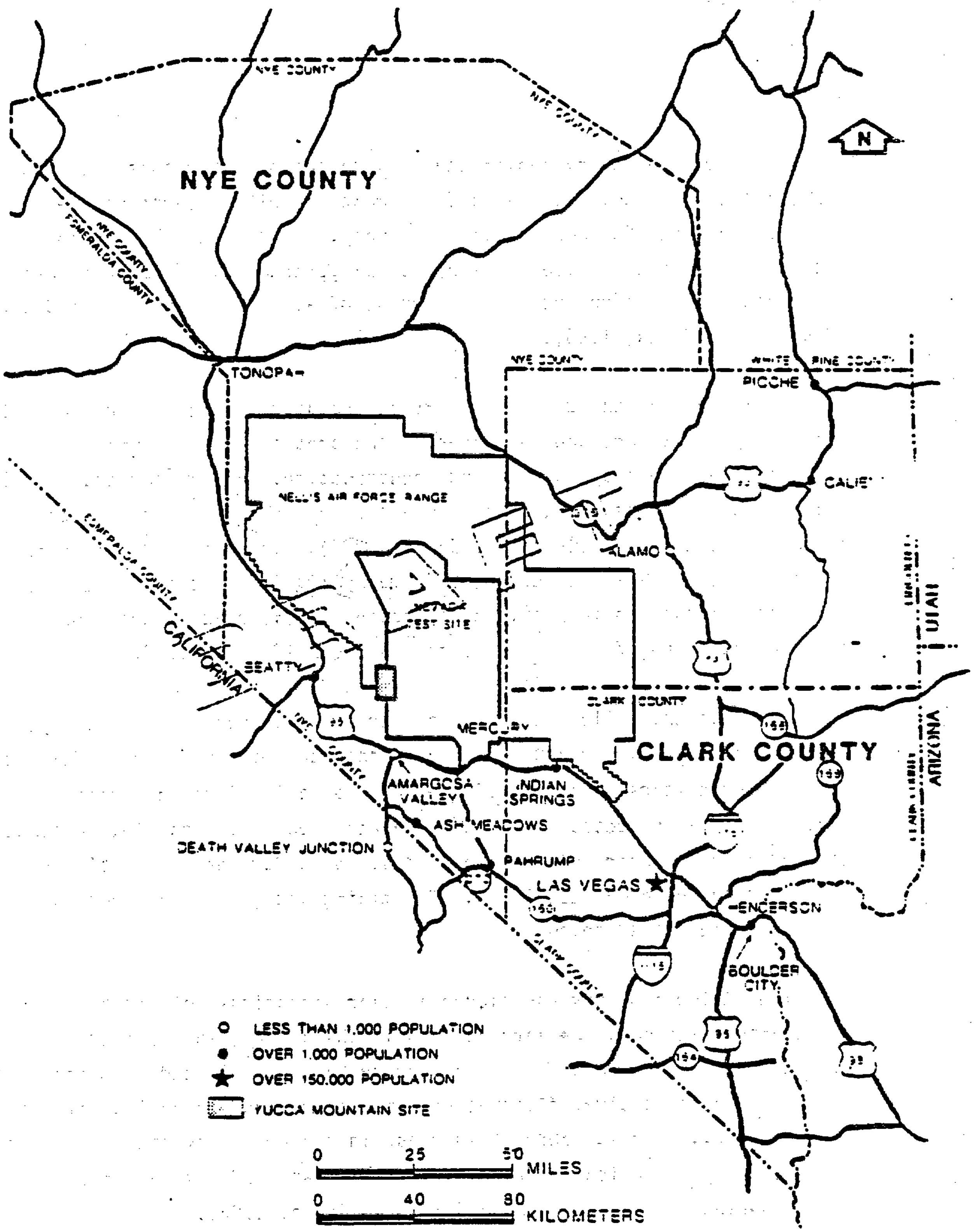

Figure 3-21. Bicounty area surrounding the Yucca Mountain site.

Nye County

In 1980, Nye County public and private sector activities employed 6740 workers (State of Nevada, Nevada Employment Security Department, 1981). In 1982, there were 7508 workers in Nye County. Most of them were employed in either mining, the service industry, or by government. Taken together, these three activities accounted for 80 percent of all employment in Nye County (McBrien and Jones, 1983).

As in most of the U.S., the service industry is the number one employer in Nye County. However, the character of the area is better expressed in terms of its other large employers: mining, construction, and government. Baseline employment forecasts for each of these sectors of the Nye County economy are shown in Table 3-14 (McBrien and Jones, 1983). The data indicate that, in the absence of the NNWSI Project, mining employment is expected to decline slightly over the forecast period while construction is expected to grow very modestly at an annual rate of about 1.1 percent between 1978 and 2030.

In addition, while not among the largest employers in the county, agriculture is an important activity in the Pahrump and Amargosa Valleys. Primary agricultural products of the Pahrump Valley include alfalfa, cotton, hay, and dairy products. In 1980 there were about 6000 ha (14,000 acres) of hay and alfalfa under cultivation, and about 28,000 head of cattle in Nye County (McBrien and Jones, 1983). The mining and government sectors of Nye County are described below.

The mining industry has played a major historical role in the economy of Nye County. Tonopah, the largest town in the county, was founded as a silver mining center, and the town and the county have experienced boom and bust periods since that time, fluctuating with the demand for various minerals found in the county. The 160 percent increase in mining employment (an average of 17 percent per year) which occurred between 1975 and 1981 is an example of a recent period of rapid growth (McBrien and Jones, 1983).

Table 3-14. Employment in selected industries in Nye County, 1978-2030 (McBrien and Jones, 1983).

Employment category/growth	1978	1990	2000	2030
	Year			
Mining	735	777	750	692
Average annual growth	NA[a]	0.5	-0.4	-0.3
Construction	467	616	706	831
Average annual growth, percent	NA	2.3	1.4	0.5
Government	785	1,055	1,260	1,562
Average annual growth, percent	NA	2.5	1.8	0.7
Services	3,742	6,088	7,616	9,881
Average annual growth, percent	NA	4.1	2.3	0.9
Total (includes other categories)	7,909	11,543	14,468	18,850
Average annual growth, percent	NA	3.2	2.3	0.9

[a] NA = not applicable.

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The primary Federal government activities in Nye County are located at the Nevada Test Site and the Nellis Air Force Range. However, most employees of these facilities reside in Clark County and commute to their jobs. A 1983 survey of the NTS project work force indicated that less than 15 percent, or about 600, of these workers lived in Nye County (SAI, 1984). Along with Federal employees, Nye County has more than 500 county and State government employees. These persons provide education, police and fire protection, and other government services throughout the county (McBrien and Jones, 1983). The government sector employed nine percent of the 1982 Nye County workforce.

Clark County

More than half of the 1980 Nevada work force was employed in Clark County (State of Nevada, Employment Security Department, 1981). One-third of these workers, or more than 70,000 individuals, were directly employed by the hotels, gaming and recreation industry. Major employers in Clark County are the service industries, which include hotels, gaming and recreation (48 percent); trade industries (21 percent); government (12 percent); transportation and public utilities (6 percent); and construction (6 percent). The retail trade industry, a primary component of the wholesale and retail trade industry in the Las Vegas area, depends heavily on the hotel and gaming industry to bring buyers into the region. The mining industry employed 500 workers in 1980 (State of Nevada, Governor's Office of Planning Coordination, 1981).

Overall, employment in the hotel/gaming industry is forecasted by the Department of Commerce, Office of Business and Economic Research Service (OBERS) to more than double from 1978 through 2030. At the same time, total labor and proprietors' income in these industries is expected to increase by a factor of seven. In response to this growth, and a forecast of rapid growth in manufacturing in the Las Vegas area, the trade industry is expected to increase its employment levels more than sevenfold. Table 3-15 shows projected growth in the construction and service industries through the year 2030 (McBrien and Jones, 1983). Just as in Nye County, baseline construction employment shows very modest growth of 1.1 percent per year between 1978 and 2030.

Table 3-15. Employment in selected industries in the Las Vegas standard metropolitan statistical area, 1978-2030 (McBrien and Jones, 1983).

Employment category/growth	Year			
	1978	1990	2000	2030
Construction	14,909	19,636	22,508	26,502
Average annual growth, percent	NA[a]	2.3	1.4	0.5
Services	89,886	125,273	146,240	182,930
Average annual growth, percent	NA	2.8	1.6	0.7
Total (includes other categories)	208,002	325,158	407,099	529,503
Average annual growth, percent	NA	3.8	2.3	0.9

[a] NA = not applicable.

3.1.6.2 Population density and distribution

While the region of interest as defined above is the bicounty area of Nye and Clark counties, population forecasts that form the basis of impact assessments are based on state population growth projections. These projections are presented below, followed by a description of existing and likely future demographic conditions in Nye and Clark counties.

The future growth of Nevada's state and local populations is subject to a degree of uncertainty which increases as the forecast period increases. The forecasts presented here rely implicitly and explicitly on many assumptions about future economic, demographic, and social conditions. Forecasts presented in this section are based on revised forecasts of population growth developed by McBrien and Jones (1983) based on projections made by the Office of Business and Economic Research Service (OBERS), Bureau of Economic Analysis, U.S. Department of Commerce. Although some other forecasts are available, especially for Clark County, the revised OBERS projections were selected because they alone cover the period of interest, 1990-2030 (McBrien and Jones, 1983).

The State of Nevada and Clark County population forcasts appearing below were made by OBERS after results of the 1980 census became available. While OBERS will not publish these forcasts until 1985, they are documented in McBrien and Jones (1983), and are based on discussions with the Department of Commerce. Nye County population forecasts are derived from the State forecast by assuming that the Nye County share of State population remains constant over time.

Existing and baseline population of the State of Nevada

Nevada's recent historical population growth has been the greatest of any of the 50 states: 63.8 percent, or an average annual increase of 4.9 percent between 1970 and 1980. Eighty-four percent of this growth came from net inmigration associated with growing job opportunities in the area (State of Nevada, Employment Security Department, 1981).

Nevada population growth forecasts for the 1985-2030 period appear in Table 3-16. According to these projections, the state population is expected to grow at an average annual rate of 2.9 percent from 1985-1990, with the growth rate declining to less than one percent per year between 2020 and 2030. As the population growth rate declines, the age composition of the state population is expected to change. The retired (ages 65 and over) population's fraction of the State total is expected to rise from 10.5 percent to 16.9 percent. The school-age population (ages 5 to 19) is projected to decline slightly, from 22.7 percent in 1990 to 20.5 percent in 2030.

Existing and baseline population of Nye County

Nye County has 1.7 percent of the state population: 15,490 persons, according to a 1983 estimate. Approximately 30 percent of the county population lives in each of the three largest townships: Tonopah, Pahrump, and Beatty (UNR, 1983; McBrien and Jones, 1983). The county is largely rural. Tonopah, located 218 km (136 mi) from the proposed site, is the only community having a population greater than 2,500. The smaller communities of Amargosa Valley and Beatty are each within 48 km (30 mi) of the site (see Figure 3-21); Ash Meadows and Pahrump are farther to the south.

Population growth in Nye County had paralleled that of the State until 1980, when it increased significantly and the county share of the State population rose from 1.1 percent in 1980 to 1.7 percent by 1983. McBrien and Jones (1983) project Nye County population using the assumption that the county will maintain its 1982 share of State population through the year 2030. This forecast has been updated here to reflect the growth in Nye County population as a share of the State total which occurred in 1983. This forecast appears in Table 3-17.

Existing and baseline population of Clark County

The 1983 population of Clark County was 535,150 (UNR, 1983). Although 96 percent of Clark County's 1980 population resided in the Las Vegas Valley area, the county's rural population of 9767 exceeded Nye County's total population for that year. The Las Vegas Valley area includes the incorporated cities of

Table 3-16. Population forecasts by age and sex for State of Nevada, 1985-2030 (McBrien and Jones, 1983)

	Population (in thousands)						
Category	1985	1990	1995	2000	2010	2020	2030
Total population	942	1,091	1,254	1,417	1,738	1,963	2,143
Under 5 years	84	95	103	110	132	138	144
5 to 19	212	248	293	335	383	418	441
20 to 40	382	441	490	532	618	669	713
45 to 64	173	192	231	283	400	453	482
65 and over	91	115	137	157	205	285	362
Male, all ages	475	549	629	708	865	973	1,062
Under 5 years	43	49	53	56	68	71	74
5 to 19	108	127	150	171	196	213	225
20 to 44	195	223	244	263	308	335	359
45 to 64	87	96	118	145	199	220	235
65 and over	42	54	64	73	94	134	169
Female, all ages	467	542	625	709	837	990	1,081
Under 5 years	43	46	50	54	64	67	69
5 to 19	104	121	143	164	188	205	233
20 to 44	186	218	246	269	310	334	347
45 to 64	86	76	113	138	201	232	242
65 and over	48	61	73	84	110	152	190
Total average annual growth rate, percent	NA[a]	3.0	2.8	2.5	2.1	1.2	0.9

[a] NA= Not applicable

Table 3-17. Population of Nye County, 1970-2030

Population/growth	Year 1970	1980	1985	1990	2000	2030
Nye County population	5,599	9,048	15,897	18,412	23,913	36,165
Average annual growth, percent	NA[a]	4.9	11.9	3.0	2.6	1.4

[a] NA = not applicable.

Henderson, Las Vegas and North Las Vegas as well as the unincorporated towns of East Las Vegas Town, Enterprise, Grandview, Lone Mountain, Paradise Town, Spring Valley Town, Sunrise Manor Town, and Winchester Town. The area had a 1980 population of 443,730 according to the U.S. Census, covering about 760 square miles (584 person per square mile). The remainder of Clark County, which makes up 90 percent of its geographic area, had a 1980 population density of about 2.7 persons per square mile.

Clark County population grew 69.5 percent between 1970 and 1980 (or an average annual rate of 5.3 percent) making it the second fastest growing standard metropolitan statistical area in the nation for that decade. As the county population has grown, its rate of growth has declined over the past 30 years, from 163.00 percent between 1950 and 1960 (9.7 percent annual average growth) to 115.2 percent between 1960 and 1970 (7.7 percent) to the 69.5 percent figure cited above between 1970 and 1980. This pattern follows that of the nation (Clark County Dept. of Comprehensive Planning, 1983). As was the case for the State as a whole, net inmigration accounted for 84 percent of county population growth in the 1970's.

Baseline forecasts of Clark County's residential population growth appear in Table 3-18. As shown in Table 3-19, this forecast lies within the range of other population forecasts that have been developed for Clark County.

3.1.6.3 Community services

The services described in this section include housing, education, water supply, wastewater treatment, solid waste disposal, energy, public safety services (police and fire), medical services, social services, transportation and roads. While county-wide data are presented, the emphasis of the description is on those portions of Clark and Nye Counties which might experience impacts from project-induced population growth. As will be discussed in Chapter 5 future community services requirements were projected under the assumption that present ratios of services to population (e.g., police officers per 1000 persons) would be valid in future years. The current values of these ratios are presented here.

Table 3-18. Population of Clark County, 1970-2030[a]

	Year					
Population/growth	1970	1980	1985	1990	2000	2030
Clark County population	273,288	463,087	547,237	633,796	823,180	1,244,937
Annual average growth, percent	NA[a]	5.4	3.4	3.0	2.6	1.4

[a] Source: Clark County Department of Comprehensive Planning, 1983a; McBrien and Jones, 1983.

[b] NA = not applicable.

Table 3-19. Population forecast comparisons for Clark County through year 2000

Year	Population (in thousands)												McDonald & Orefe[f]	State planning coordi-nator's office
			UNR[c]			CCRPC[d]			SWP[e]					
	OBERS[a]	BEA[b]	Low	Medium	High	Low	Medium	High	Low	Medium	High			
1980	463	403	401	405	409	420	435	460	473	483	500	461	411
1985	547		454	460	496	495	520	555	568[a]	601	635	550	527
1990	634	524	512	519	527	560	600	650	662	715	770	664	660
1995			552	562	572	535	680	755	739*	810	885*	766	757
2000	823	628	594	606	618	700	750	850	816	894	1,000	891	867

[a] Office of Business and Economic Research Service (OBERS) projection, series E population (source: McBrien and Jones, 1983)

[b] Disaggregation by State Planning Coordinator's Office of state projections by the Bureau of Economic Analysis (1978).

[c] University of Nevada, Reno (UNR), Bureau of Business and Economic Research (1977).

[d] Clark County Regional Planning Council (CCRPC) (1973).

[e] State Water Plan (SWP). Forecasts for the Future - Population, Volume 5, Water for Nevada (* indicates projections were obtained from 1995 State Water Plan unpublished estimates) (1973).

[f] McDonald and Orefe, Inc. 1977 Unconstrained Estimates (1977).

[g] State of Nevada, Office of the Planning Coordinator (1978).

Source: All data except OBERS data (footnote [a]) cited in Clark County Department of Comprehensive Planning, 1983a.

Housing

Table 3-20 summarizes housing characteristics for Clark and Nye Counties. While the number of persons per unit is almost equal for the two counties, other characteristics differ significantly. Nye County has a higher percentage of mobile homes (44 vs. 11 percent), while Clark County has a higher percentage of apartments (29 vs. 9 percent). The vacancy rate in 1980 was 8.4 percent in Clark County and 17.9 percent in Nye County. Las Vegas is primarily an "adult" community; only two out of five households have children under 18 years of age.

Education

Statistics on public and private schools in Clark and Nye Counties are summarized in Table 3-21. In Nye County, two of the elementary schools and one of the high schools are located in Tonopah. Beatty, Gabbs, and Pahrump each support an elementary school and a high school. In addition to these schools, two one-room, ten-student contract schools have been operated in the county for grades K-8. There are no private schools in the county. As seen in Table 3-21, ratios of schools per 1000 residents are much larger in Nye County than in Clark County because the schools in Nye County are smaller. The educational personnel ratio is slightly lower in Nye County.

Of the Clark County schools, 66 elementary, 17 junior high, 10 senior high, and 2 special education schools are located in the greater Las Vegas area. The student/teacher ratio in Clark County is about 19 to 1. Specific data on the number of private schools or their operating costs are not available. Enrollment estimates are included in Table 3-21. Finally, the University of Nevada, Las Vegas (a four-year college) and Clark County Community College had a combined 1980-81 enrollment of 18,972 (McBrien and Jones, 1983).

Water supply

In Nye County, municipal water supply services are available only in Beatty, Tonopah, Mercury and Gabbs (State of Nevada/NOCS, 1982b). About 64 percent of the County's population was served by these utilities in 1980. The

Table 3-20. Housing characteristics in Clark and Nye Counties, 1980-1983

Characteristic	Clark County[a] 1980	Clark County[a] 1983[c]	Nye County[b]
Composition and housing types			
Total housing units	190,607	207,153	4,292
Occupied units	173,891	199,078	3,434
Vacant units	15,969		768
Seasonal and second homes	747		90
Units within urban areas	178,686		0
Units within rural areas	7,896		4,292
Owner occupied units	102,555		2,291
Renter occupied units	71,336		1,143
Year-round housing types			
Single family units	114,316		1,916
Multiple family units	54,815		393
Mobile homes	20,730		1,893
Persons per occupied unit	2.64		2.61
Housing values and rents			
Median value for single family and mobile home units	$67,800		$35,600
Median cash rent	$264/month		$155/month
Median value for condominiums	$73,000		0
Government assisted housing[d]			
Units receiving construction, operation, and/or rental payment assistance	12,732[e]		56
Units receiving home construction or purchase assistance or both (not including Federal Housing Authority loans)	4,700		7

[a] Source: Clark County Nevada Profile (State of Nevada/NOCS, 1982a), except where otherwise noted.

[b] Source: Nye County Nevada Profile (State of Nevada/NOCS, 1982b).

[c] Source: Clark County Department of Comprehensive Planning (1983).

[d] Federal or State assistance during 1981.

[e] May include double counting.

Table 3-21. School facilities and enrollment in Clark and Nye Counties

Characteristic	Clark County (1982-1983) Number	Clark County (1982-1983) Number per 1,000 Residents[a]	Nye County (1982) Number	Nye County (1982) Number per 1,000 Residents[b]
Number of public schools				
Elementary	78	0.150	9[c]	0.681
Junior high	18	0.035	4[d]	0.303
Senior high	15[d]	0.029		
Contract schools (K-8)	0	0	2	0.151
Total	111	0.214	15	1.135
Enrollment				
Elementary	44,100	85.0	980	74.1
Junior high	19,600	37.8		
Senior high	19,200	37.0	900[d]	68.1
Special education	6,800	13.1	130	9.8
Contract schools (K-8)	0	0	20	1.5
Total	89,700	172.9	2,030	153.5
Average daily attendance	86,500	166.7	ND[e]	ND
Educational personnel				
Administrative staff	174	0.335	14	1.06
Elementary school teachers	2,007	3.868		
Secondary school teachers	1,945	3.749	92	6.96
Special education	609	1.174	ND	ND
Total	4,735	9.126	106	8.02
Private school enrollment				
Kindergarten	454	0.875	0	0
Elementary	2,664	5.135	0	0
High school	1,020	1.966	0	0
Total	4,138	7.975	0	0

[a] Source: Based on 1982 population estimate (Clark County Department of Comprehensive Planning, 1983).

[b] Based upon 1982 population estimate by the University of Nevada (UNR, 1983).

[c] Includes some middle schools.

[d] Includes some combination junior/senior high schools.

[e] ND = No data.

Source: Clark County data obtained by McBrien and Jones (1983) from the 1982-1983 Clark County School District Budget. Nye County data from Nye County Nevada Profile (State of Nevada/NOCS, 1982b).

remainder of the county's homes and industries depend upon private wells. Table 3-22 summarizes available information on supply sources and amounts in those portions of Clark and Nye Counties near the Nevada Test Site. A total of 4.202 million gallons per day (mgd) (which does not include use at the Nevada Test Site) was used by 6308 residents. Thus, the water demand is estimated to be 2502 m^3/day (0.666 million gallons per day) per 1000 persons.

The main areas of existing and potential future agricultural water use are the Amargosa and Pahrump valleys. Present water use in the Amargosa valley is unknown, and the potential for future use is limited by marginal soil and meteorological conditions. Certified appropriations and development permits for ground water in the Pahrump valley totaled 112 x 10^6 m^3 (91,000 acre-feet) per year in 1970, although in recent years actual exploitation has averaged about 49 x 10^6 m^3 (40,000 acre-feet) per year. In the last ten years, real estate developers have purchased agricultural land (with appurtenant water rights) for construction of single-family homes in subdivisions. There has thus been a transfer of use from agricultural to domestic. An overdraft situation (i.e., a long-term excess of withdrawal over replenishment to the aquifers used for water supply) apparently exists, and the likelihood of certification of water use permits beyond the present total appears unlikely.

Available rights to surface water in the Las Vegas Metropolitan area are currently about 320 x 10^6 m^3/yr or an average of about 878 x 10^3 m^3 (232 million gallons) per day (State of Nevada/NDCNR, 1982). The present use of ground water in Las Vegas Valley is about 89 x 10^6 m^3/yr (64 million gallons per day), but the State Engineer has adopted a goal to reduce this to 62 x 10^6 m^3/yr (45 million gallons per day). Present delivery systems are adequate for current needs but, as will be discussed in Section 5.4.3, there is uncertainty whether supply will be sufficient for the demand projected for 2020 and later years.

Table 3-23 shows how water is provided to metropolitan areas of Clark County. The Colorado River and wells are the source of 62 and 38 percent, respectively, of the county's municipal and industrial water supply. Metropolitan areas are served by 7 water systems managed by 22 distribution companies (State of Nevada/NOCS, 1982a), while rural users rely upon private

Table 3-22. Current (1980) water supply in nonmetropolitan areas of Clark and Nye Counties

Community	Estimated population	Water sources[a]	Estimated water use[a,b] acre-ft/yr	mgd
Amargosa Valley	65	Domestic wells 320 feet deep	44	0.039
Ash Meadows and Amargosa Farms	2235	ND[c]	1687	1.506
Beatty	900	Two municipal wells supplying 250 customers; third well is source of water for industry	686	0.612
Crystal	42[d]	Domestic wells 160 feet deep	33	0.029
Indian Springs	912	Municipal well capable of supplying 0.8 mgd to 53 customers, plus approximately 80 domestic wells with unknown capacity	686	0.612
Indian Springs Air Force Base	500	Two wells supplying 0.2 mgd potable water	326	0.291
Johnnie	2[e]	ND	0.12	<0.001
Mercury	300	Three municipal wells coupled with a distribution system	237	0.212
Nevada Test Site	ND	Six wells supplying 1.2 mgd	1344	1.200
Pahrump	1358	Domestic wells 70 feet deep	1006	0.898
Rhyolite	4[f]	Served by pipeline from water tank at new Beatty well at Indian Springs; other family uses bottled water	2.4	0.002

[a] Source: MITRE, 1983, Table 2-11.

[b] 1 acre-ft = 1234 m^3; mgd = million gal/day.

[c] ND = no data.

[d] 20 families.

[e] 1 family.

[f] 2 families.

Table 3-23. Water supply in metropolitan areas of Clark County (Nevada Development Authority, 1983)

Community	Suppliers	Sources	Maximum capacity (mgd)[a]	Peak demand (mgd)
Boulder City	Southern Nevada Water System, U.S. Bureau of Reclamation	Lake Mead	14.8	7.8
Henderson	Southern Nevada Water System, Las Vegas Valley Water District, BMI	Lake Mead	19.3	13.6
Las Vegas[b]	Las Vegas Valley Water District	Lake Mead (60%) Wells (40%)	479.0	195.1
North Las Vegas	City of North Las Vegas	Lake Mead (60%) Wells (40%)	45.9	23.3
Totals			559.0	239.8

[a] mgd = million gallons per day; 1 gal = 0.0039 m^3.

[b] Includes unincorporated areas of Clark County.

wells. The metropolitan water systems' aggregate capacity is about 2 x 10^6 m^3 (559 million gallons) per day. Peak demand represents about 43 percent of tnis capacity. Thus, peak demand in 1982 was 1750 m^3 (0.462 million gallons) per day per 1000 persons.

Sewage treatment

Waste-water treatment facilities in Nye County operate in Beatty, Gabbs and Tonopah; the remainder of the county uses private waste-water treatment systems (e.g., septic tanks) (State of Nevada/NOCS, 1982b). Approximately one third of the water consumed in Clark County enters the County's sewage system (McBrien and Jones, 1983). This waste water is treated in 11 facilities operated in Boulder City, Henderson, Las Vegas, Overton, and other sites throughout the County (State of Nevada/NOCS, 1982a). Table 3-24 summarizes waste-water treatment in Clark County and southern Nye County.

Solid waste

Trash collection in Nye County is handled by private contractors. Major landfills are located in Pahrump, Tonopah and Gabbs. Refuse in Las Vegas, North Las Vegas, Henderson, and the unincorporated portions of Clark County is collected by Clark Sanitation Company, Silver State Disposal, and Automated Transfer Services, which comprise one private collection service. Fees are collected from residents by these companies, who pay a percentage to the County and to the cities. The major landfill in the study area is Sunrise, which is owned by the U.S. Bureau of Land Management, leased by Clark County, and operated and maintained by Clark Sanitation. The landfill's 130 ha (320 acres) are adequate for current needs (personal communication from N.T. Raja, Clark County Facilities Department, April, 1984). Other major landfills are located at Boulder City and Nellis Air Force Base.

Energy utilities

In Nye County, propane and heating oil are supplied by four and three distributors, respectively. The main sources of electrical energy for Clark County are the hydroelectric plant at Hoover Dam and Nevada Power Company's

Table 3-24. Waste-water treatment facilities in Clark and Nye Counties

Community	Type of facility	Maximum capacity (mgd)[a]	Peak demand (mgd)
Amargosa Valley	Septic tanks	ND	ND
Ash Meadows	ND[b]	ND	ND
Beatty	Evaporation ponds	ND	ND
Boulder City	Facultative ponds	2.0	1.0
Clark County unincorporated	Advanced secondary treatment (trickling filter)	90.0	38.0
Crystal	Septic tanks	ND	ND
Henderson	Secondary treatment (trickling filters), Imhoff tanks, oxidation ponds, aerated lagoon system	6.4	2.5
Indian Springs	Evaporation ponds	ND	ND
Indian Springs AFB	Primary treatment (Imhoff tanks); sludge disposal in pits	ND	ND
Johnnie	ND	ND	ND
Las Vegas	Secondary treatment (trickling filters), chemical treatment for phosphorus removal	37.5	30.0
Mercury	Oxidation ponds	ND	ND
Nevada Test Site	ND	ND	ND
North Las Vegas	Uses City of Las Vegas plant	-	-
Pahrump	Septic tanks	ND	ND
Rhyolite	Septic tanks	ND	ND

[a] mgd = million gallons per day. 1 gallon = 0.0039 m^3.

[b] ND = no data.

Source: MITRE (1983); Nevada Development Authority (1983).

fossil-fueled Clark Generating Station (near Las Vegas) and Reid Gardner Generating Station (near Moapa). Power in Nye County is distributed by the Sierra Pacific Power Company, the Valley Electric Association and the Overton Power District. Piped natural gas is available only in Clark County. Table 3-25 summarizes electrical and natural gas supply services in the two counties.

Public safety services

The Nye County Sheriff's Office provides police protection for the entire county except for the City of Gabbs. The Sheriff's Office employs 44 deputies and 14 dispatchers to cover 5 million ha (12 million acres) of the county; the City of Gabbs employs an additional three deputies (State of Nevada/NOCS, 1982b). Thus there are about 3.55 commissioned police officers for every 1000 people in the county. This relatively high ratio is explained in large part by the large area of the county, and the long distances between towns.

Nye County has 12 fire departments, which operate 14 fire stations, staffed by 128 firefighters, all but 14 of whom are volunteers. The largest stations are the Amargosa Volunteer Fire Department and the Tonopah Fire Department, each of which has 25 firefighters. The Tonopah Fire Department has four paid employees, and 10 of the 20 firefighters at the Anaconda Copper Corporation are paid. The 12 fire departments own a total of 36 major pieces of equipment (State of Nevada/NOCS, 1982b). As is the case with police protection, the number of firefighters (9.68 per 1000 people) is relatively large, given the population of the county. This large figure is largely attributable to the social nature of the volunteer fire departments as well as the geographic characteristics of the region.

The Las Vegas Metropolitan Police Department, which is responsible for the City of Las Vegas and unincorporated portions of Clark County, employs 738 police officers, including 27 in its airport section (LVMPD, 1984). This force is supplemented by 17 officers in Boulder City, 41 in Henderson, and 97 in North Las Vegas (Fay, 1984). The County had 893 police officers for a total 1983 population of 528,250, or about 1.69 commissioned officers per 1000 residents. The four police departments operated about 430 vehicles in that year (McBrien and Jones, 1983). According to a recent study by the Las Vegas

Table 3-25. Energy distributors in Nye and Clark Counties

Utility	Service area	Supplier	Capacity	
			Total	Maximum daily
Boulder City Electrical Department	Boulder City	DOE and Colorado River Commission	28.3 MW[a]	27.2 MW
C.P. National	Henderson	El Paso National Gas Company	3.1 MMSCFD[b]	ND[c]
Nevada Power Company	Henderson, Las Vegas, N. Las Vegas, unincorporated areas	Nevada Power Company	1,792.0 MW	1,528.0 MW
Overton Power District	Bunkerville, Logandale, Mesquite, Overton	Colorado River Commission[d]	ND	13.735 MW[e]
Sierra Pacific Power Company	Nye County	ND	ND	ND
Southwest Gas Company	Boulder City, Las Vegas, N. Las Vegas, unincorporated areas	El Paso National Gas Company	160.0 MMSCFD	150.4 MMSCFD
Valley Electric Association	Beatty, Amargosa Valley, Pahrump, Scotty's Junction	Colorado River Commission[d]	ND	ND

[a] MW = megawatts capacity

[b] MMSCFD = million standard cubic feet per day of natural gas.

[c] ND = no data.

[d] Clark County Comprehensive Energy Plan (Clark County Comprehension Planning Department, 1982).

[e] Summer peak = combined capacities of Parker Dam and Colorado River Storage Project.

Source: State of Nevada Development Authority (1983), except where otherwise noted.

Metropolitan Police Department (LVMPD, 1983), sheriff stations and detention facilities in many of the nonurban communities are inadequate, especially in those areas with rapid growth in tourism.

Clark County is served by 24 fire departments through 41 fire stations. Five fire departments are located on government facilities and at private industrial complexes. All but four of the remaining fire departments are manned by volunteers. There are 218 volunteer firefighters in the 15 Clark County volunteer fire departments. There are also 525 paid firefighters at the nine private and public stations. Thus, the county has 0.413 volunteer and 0.994 paid firefighters for every 1000 people in the county. Clark County Fire Department uses 105 major equipment pieces, including pumpers, tankers, security and emergency items, and squad cars. Most departments own one or two pieces of equipment, although the Clark County Fire Department has 33 major pieces of equipment and Nellis Air Force Base has 10 (State of Nevada/NOCS, 1982a).

Medical services

In 1982 there were 676 physicians in Clark County and 6 in Nye County, or 1.30 and 0.454 per 1000 residents, respectively. At the end of 1982, Clark County had 215 dentists, or 0.414 per thousand residents. All of Nye County has been ranked as a "1" priority health manpower shortage area by the U.S. Public Health Service; i.e. it has the highest priority for the allocation of health manpower recruited by the Health Service Corps (State of Nevada/NSHCC, 1982). Areas of Clark County having a priority of 1 include Searchlight-Davis Dam-Southpoint, Indian Springs, Virgin Valley, Moapa Valley, Lake Mead, Jean-Goodsprings, Sandy Valley, Blue Diamond-Lee Canyon, Mount Charleston, and Central and North Central Las Vegas. The Paiute Indian Colonies in Las Vegas Valley and Moapa Valley have the lowest priority rating, a 4.

Acute care facilities in the two counties are listed in Table 3-26, along with the average number of beds in various service classes in 1982. In addition, Clark County has 11 long-term care facilities having a total of 1047 beds. Thus Clark County hospitals had, at the end of 1982, 2997 beds, or 5.78 per 1000 residents. Nye County has 22 acute care hospital beds and 24

Table 3-26. Hospital facilities in Nye and Clark Counties, 1982: Average number of allocated hospital beds per classification (State of Nevada/NSHCC, 1982)

Facility	Total beds[b]	Class 1	2	3	4	5	6	7	8	9	10	11
Community hospitals												
Boulder City	38	31.0	5.0	0	2.0	0	0	0	0	0	0	0
St. Rose de Lima	78	59.1	14.9	0	4.0	0	0	0	0	0	0	0
Desert Springs	222	179.5	0	0	18.8	22.8	0	0	0	0	0	0
Southern Nevada Memorial	356	152.4	26.8	33.0	35.9	22.0	0	0	30.0	30.0	11.6	8.0
Sunrise	670	459.4	56.0	42.0	72.0	0	5.0	35.0	0	0	0	0
Valley	298	210.0	0	12.0	20.0	25.0	0	0	31.0	0	0	0
Women's	61	40.0	21.0	0	0	0	0	0	0	0	0	0
North Las Vegas	131	115.0	0	6.0	16.0	0	0	0	0	31.0	0	0
Nye General	22	17.4	2.0	0	2.0	0	0	0	0	0	0	0
Subtotal	1876	1253.8	125.7	93.0	170.7	69.8	5.0	35.0	61.0	61.0	11.6	8.0
Special Hospitals												
Raleigh Hills	34	0	0	0	0	0	0	0	0	0	33.5	0
Las Vegas Mental Health Center	40	0	0	0	0	0	0	0	40.0	0	0	0
Total	74	0	0	0	0	0	0	0	40.0	0	33.5	0
Federal hospitals												
Nellis AFB	35	32.5	0.5	2.5	0	0	0	0	2.0	0	0	0
Total	1985	1296.3	126.2	95.5	170.7	69.8	10.0	35.0	103.0	61.0	45.1	8.0

[a] Bed classes are as follows: 1 = Medical/Surgical, 2 = Obstetrical, 3 = Pediatric, 4 = UCU/CCU, 5 = Intermediate care, 6 = pediatric intensive care unit, 7 = Neonatal intensive care unit, 8 = Psychiatric, 9 = Rehabilitation/physical medicine, 10 = Alcohol treatment, 11 = Jail (security).

[b] This column shows total licensed beds as of December 31, 1982. The sum of the average number of allocated beds in each bed class may differ from the total licensed beds for a given hospital, since more or fewer beds may have been available during the year.

long-term care beds (all at Nye General Hospital), for a total of 3.48 per 1000 residents.

An important factor in evaluating health care systems in the area is the impact of the large visitor population on health services. In 1980 the Las Vegas area had nearly 12 million visitors who stayed an average of 4.3 nights. This translates into about 141,000 persons per day (over 25 percent of the resident population) who may require some degree of health care, primarily emergency services. About 130 acute care hospital beds were allocated for use by out-of-area patients in 1982. The hospital admission rate for visitors to Clark County has been estimated at 0.5 per 1000 visitors. According to the State of Nevada Health Coordinating Council (1982), 6.9 percent of the admissions to Clark County Hospitals are out-of-state residents.

Library facilities

Library services are provided by four library districts in Clark County. Boulder City, Henderson and North Las Vegas maintain municipal systems, while the Clark County Library District is responsible for the City of Las Vegas and unincorporated areas of the county. Branches are located in Blue Diamond, Bunkerville, Goodsprings, Indian Springs, Mesquite, Mount Charleston, Overton, and Searchlight. The four districts have a total of 565,909 books and employ the equivalent of 102 full-time staff members, including professional librarians and administrative staff (State of Nevada, NSL, 1984). Nye County does not have a county-wide library system. Individual systems are located in Beatty, Gabbs, Amargosa Valley, Manhattan, Round Mountain and Tonopah. No information on books or staffing is available.

3.1.6.4 Social conditions

This section is a preliminary description of existing sociocultural characteristics of southern Nevada. The focus is on those communities which could be affected by inmigrating repository workers, since communities that would lie on transportation routes are as yet unidentified. The data provide the basis for the assessment of potential sociocultural impacts that could be caused by a repository if it were located at Yucca Mountain, described in

Chapter 5. This type of description is sometimes classified as describing the "quality of life" in the affected area and involves the measurement of both objective and subjective components of community social life. A single index of the quality of life has not been determined for all residents in the study area because southern Nevada, which has experienced rapid and dynamic change, has a wide diversity of cultures and social organizations. This section is comprised of four components: (1) social organization and structure, (2) culture and lifestyle, (3) community attributes, and (4) a preliminary assessment of citizens' concerns about the repository.

Existing social organization and social structure

The terms "social structure" and "social organization," as used in the following section, refer to the major social groupings and the network of social relationships that exist among residents in a given location.

In contrast to the social impacts documented in the traditional boomtown literature (Wilkinson et al., 1982; Murdock and Leistritz, 1979; Cortese and Jones, 1977), the study area of southern Nevada comprises two distinct social settings: (1) a rural component, which includes all of Nye County and the nonurban sections of Clark County, and (2) an urban component, which includes 96 percent of Clark County's population. Table 3-27 summarizes selected social characteristics of Nye and Clark counties, which form the basis for the following discussion of social organization and structure.

Rural social organization and structure

As shown in Table 3-27, Nye County overall exhibits a high rate of population growth and inmigration, as compared with the national average. Between 1980 and 1983, Nye County population grew at an average rate of 17.9 percent per year (UNR, 1983); and in 1980 only 25 percent of residents were born in the state. Historically, a high rate of inmigration and population turnover associated with boom and bust mining activities has occurred both in the state overall and in Nye County (Elliot, 1973; DOI, 1975). These data and also the high rates of suicide and homicide suggest the absence of community cohesion, defined as "social forces which draw and keep persons together"

Table 3-27. Comparison of selected social characteristics by region[a]

Characteristic	U.S.	Western States	Mountain States	State of Nevada	Nye County	Clark County
Persons per square mile	64.0	24.6	13.3	7.3	0.5	58.8
Percent urban	73.7	83.9	76.4	85.3	0.0	95.5
Ethnic composition (percent)						
White	83.4	81.5	88.1	87.8	92.2	84.8
Black	11.7	5.2	2.4	6.4	0.3	10.0
Spanish origin	6.5	14.5	12.7	6.8	5.5	7.6
American Indian, Eskimo, Aleut	0.7	1.8	3.3	1.8	4.7	0.8
Males per 100 females	94.5	98.0	98.7	102.4	115.7	101.7
Percent aged 65+	11.3	10.0	9.3	8.2	9.0	7.6
Percent population increase 1970-80	11.4	23.9	37.2	63.8	61.6	69.5
Percent born in-state	63.9	45.3	44.1	21.4	24.9	18.5
Percent owner-occupied homes	64.5	60.3	67.2	59.6	66.7	59.0
Percent one person households	22.7	23.5	21.6	24.6	26.6	35.6
Crime rate[b]	5397	6923	6384	8485	2980	9075
Marriage rate[c]	10.4	23.14	29.78	140.3	11.7	116.8
Divorce rate[c]	5.3	7.04	8.07	16.3	7.3	16.9
Suicide rate[c]	12.8	17.11	18.31	27.8	24.0	22.5
Homicide rate[c]	9.7	8.31	9.25	17.4	26.4	20.4

[a] Except where footnoted, data were obtined from DOC, 1983b.

[b] Values were calculated from data obtained from the U.S. Department of Justice, 1977-1980, and from the State of Nevada, Department of Law Enforcement Assistance, 1980. Data are expressed as a rate per 100,000 inhabitants and averaged over a four-year period.

[c] Values were calculated from data obtained from the State of Nevada, Department of Human Resources, (Section of Vital Statistics), 1983. Marriage and divorce are expressed as a rate per 1000 inhabitants; crime, suicide and homicide are expressed as a rate per 100,000 inhabitants. Rates were averaged over a five-year period.

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(Finsterbusch, 1980). Other indicators however, point to the existence of a greater degree of social cohesion in Nye than in Clark County. In Nye, home ownership rates are higher, divorce rates and crime rates are lower, and the population is fairly homogeneous, since it is 100 percent rural and predominantly white (although it includes a relatively high percentage of Native Americans). These indicators also appear to be characteristic of rural sections of Clark County. In addition, Nye County has a relatively high ratio of males to females.

The most striking feature of the area surrounding the Yucca Mountain site is the sparseness of population (personal communication from S. Black, Environmental Protection Agency, Las Vegas, April, 1983). As shown in Table 3-27, Nye County has only 0.5 persons per square mile. On one side, the site is bounded entirely by the Nevada Test Site; on the remaining sides, the population is dispersed over a wide geographical area. Forms of social organization include individual farms and ranches, settlements, and communities. Settlements include company housing complexes such as those established for workers at the American Borate Company, noted below, and for Nevada Test Site workers at Mercury.

Data on settlement patterns of recent DOE and contractor employees at the Nevada Test Site indicate that some rural communities may be affected by inmigrating repository workers. Inmigrants would be most likely to settle in those rural communities which provide services and amenities. Three of the communities which lie closest to the site are Amargosa Valley, Beatty, and Pahrump. Several distinct features of these communities may be discerned and are described below.

Amargosa Valley--25 km (15 mi) from Yucca Mountain--is the nearest population center to the proposed site. The U.S. Environmental Protection Agency estimates a population of 1500 in the Amargosa Farm Area which is approximately 18 km (11 mi) from U.S. Highway 95, and a population of 280 at the American Borate Housing Complex on Nevada State Route 373 near the California state line (personal communication from S. Black, Environmental Protection Agency, 1983). According to a 1975 report (DOI, 1975), much of the land in the area can be classified as "agriculturally marginal"; however, under irrigation, it produces some pasture, alfalfa and small grains. Most of the farms are operated on a part-time basis with the owner working fulltime at another job (DOI, 1975).

Beatty, population 900 (McBrien and Jones, 1983), is located approximately 48 km (30 mi) north of Amargosa Valley. Originally established during the mining boom of the early twentieth century, and an important supply center to several boomtowns after construction of the Tonopah and Tidewater railroad, Beatty was the only town to survive after early mines were abandoned (Writer's Program, 1940; DOI, 1975). Mining continues to be important. Recently, rapid growth has occurred in Beatty and the surrounding area.

Pahrump is the farthest of the three Nye County communities from Yucca Mountain and has both the land and tax base to support expansion. Unlike most of Nevada, nearly 50 percent of the land is privately owned. Within the past decade, large areas of agricultural land have been subdivided, and some attractive permanent housing constructed. The population has grown at an average annual rate of 16 percent between 1976 and 1982, to a 1982 population of 3965 (Mooney et al., 1982). Surveys of community residents indicate that almost 50 percent view the optimum Pahrump population at between 10,000 and 20,000, and another 20 percent would like to see population at 20,000 to 40,000. The proportion of construction and mining employment relative to agricultural employment has increased between 1976 and 1982, and the trend has been for residents to work in Pahrump or the Nevada Test Site rather than Las Vegas. An increase has also occurred in the proportion of retirees, while younger persons have been leaving the area (Mooney et al., 1976 and 1982).

Social organization and structure in urban Clark County

The most striking features of Clark County are its high population growth and inmigration rate (Table 3-27). While the total U.S. had a 1 percent average annual population growth rate in the decade between 1970 and 1980, Clark County grew at a 5.3 percent average annual growth rate. Also notable are the high percentage of one-person households, the heterogeneous racial and ethnic mix, and the relatively low percentage of homeowners. These data, when examined in light of the dependence of the economic base on the gaming and tourism industries, suggest a complex and transient social entity. Indicators of social stress, such as rates of suicide, homicide, divorce and crime, which are high relative to national and regional data (Table 3-27), also are affected by the tremendous influx of out-of-state vacationers. Considerable variations exist, however, among the governmental entities (outlined in Section 3.1.6.5) which form urban Clark County. Their histories have been different, and census tract data show that social characteristics and indicators of social problems vary (DOC, 1983a).

Political and economic relationships in Clark County are more formal and bureaucratic that those in rural Nye County. Metropolitan Las Vegas is the most complex social grouping in the study area, with numerous subgroups including civic and social organizations. As might be expected, those groups having the greatest stake in the economic base play the greatest role in formulating the direction and development of the area (Greater Las Vegas Chamber of Commerce, 1981). Also significant are four Federal installations (Hoover Dam, Basic Magnesium Industries, Nellis Air Force Base and the Nevada Test Site) in southern Nevada that have played an important role in Clark County's growth since 1930 (Clark County Department of Comprehensive Planning, 1982).

Culture and lifestyle

Culture, as used in the following discussion, is defined as the enduring and deeply felt set of attitudes and beliefs held by an identifiable group of people. The overt part of culture is manifested in actual behavior--in the institutions, associational life, artifacts, traditions and overall lifestyle of the group. Essentially, however, these are the expressions of group ideas, values, and beliefs. The rich diversity of cultures and lifestyles exhibited in Nye and Clark Counties is outlined in the following section. The absence of a homogeneous culture, coupled with the large numbers of inmigrants who have been assimilated over the past few decades, are important features of the area. They suggest that a wide variety of subcultures can be assimilated and accepted easily and provide the basis for the assessment, presented in Chapter 5, of the potential impact of inmigrating repository workers on the existing cultural environment.

Rural culture

Available data for Nye County suggest an informal, personal organization and lifestyle. In 1982, the county supported 9 churches, 13 motels or hotels, 11 service organizations, and 5 fraternal organizations (State of Nevada, 1982b). A rich social life, based on less formal organizations, also exists (Pahrump Valley Times-Star, August, 1982 through March, 1984). In addition, the Nye County government is relatively informal.

Noteworthy aspects of the rural culture include pride in a western heritage, "boom and bust" mining history, plus religious, tribal, and ethnic influences. Pride in the western heritage is shown by the number of commemorative celebrations such as Jim Butler Days in Tonopah, Amargosa Valley Days, and the Harvest Festival Rodeo at Pahrump. There are frequent reminders of the boom and bust associated with the mining activities that figure so prominently in Nevada's history; these include railroads that have been removed and ghost towns such as Rhyolite, former population 6,000, but now abandoned in the desert. Nevada has the lowest percentage of church adherents in the U.S. (26.2 percent in Nye County, 29.7 percent in Clark County) (Quinn et al., 1980), with the apparent exception of the communities of Bunkerville, Overton, and Logandale in eastern Clark County, which were settled by members of the Church of Jesus Christ of Latter Day Saints (Clark County Department of Comprehensive Planning, 1982b). Two Indian reservations, the Moapa River Paiute Reservation in eastern Clark County and the Duckwater Shoshone Reservation in northern Nye County, are distant from Yucca Mountain. There are also Native American groups living outside the reservation in Beatty, Pahrump, and Death Valley (Knack, 1984).

Urban culture

The most notable aspect of Las Vegas is its image as "the gaming capital of the world": the Strip, with its "highrises, explosive colors of night-lighting, and reflective surface materials" is visually, and culturally, the most dominant feature of the area (Clark County Department of Comprehensive Planning, 1982b). Regardless of background, all citizens must reach some accommodation between gaming and other cultural values (Adams, 1978; Gottlieb and Wiley, 1980). A basic division, however, may be discerned between the lifestyles of the transient (associated with gaming and tourism) and relatively more settled population groups. "Two faces" of Nevada cities such as Reno and Las Vegas have been noted, where residents insist on separating the gaming city from the residential city of schools, homes, and churches with emphasis on family and neighborhood values (Elliott, 1973).

Greater Las Vegas, with its many social and civic organizations, exhibits cultural characteristics common to cities of its size. The area's marked cultural diversity is demonstrated most strikingly by the fact that, in addition to many out-of-state visitors, only 18 percent of Clark County residents were born in Nevada. Among minorities, Blacks constitute a subculture which is defined in part by residential settlement patterns (Clark County Department of Comprehensive Planning, 1982), and a Paiute Indian reservation also exists in the urban area (Inter Tribal Council of Nevada; Alley, 1977). Hispanic people, who comprised 7.6 percent of the population in 1980, appear to have been more readily assimilated, as they are more evenly spread throughout the metropolitan area.

Community attributes

An important component of the "quality of life" in any region or community is the subjective evaluation of persons who live there. Residents' opinions about their community indicate characteristics which could be negatively or positively affected by repository activities. From this, it may be possible to anticipate public reaction to repository siting. In the absence of an NNWSI Project survey of Nevada citizens, the following data are based on two attitudinal surveys recently undertaken for other activities.

First is a survey undertaken for the Governor of Nevada and published in Report of the Governor's Commission on the Future of Nevada (List, 1980). The survey was not systematically distributed; however, the number of surveys returned was roughly proportional to the population of each county. Second is a survey of citizens' perceptions of the proposed U.S. Air Force MX Missile system undertaken by Dr. James Frey of the University of Nevada, Las Vegas

(Frey, 1981). In this survey, a proportionate stratified random sample of counties throughout the state was selected. The sample size permitted an overall rural/urban comparison only. It should be noted that the proposed MX mobile missile system would have been a significantly larger construction project than the proposed repository, employing as many as 22,000 workers at peak (Department of the Air Force, 1980).

Significant findings from the Governor's survey include the following: (1) More than 80 percent of Nye and Clark County residents would like their region to grow at a slow or moderate pace. (2) The three most valued features of Nevada life for Nye County residents were the open spaces, relaxed lifestyle and freedom, clean air and lack of pollution; and for Clark County residents, were the climate, open spaces and relaxed lifestyle and freedom. (3) The most serious problems facing the Nye County area were the housing availability, water and sewage facilities, and road conditions; and for the Clark County area were roads/transportation, crime, the environment, and unregulated growth. (4) Changes which Nye County residents would be most unwilling to accept are reduced access to open spaces, a deterioration in air quality, increased Federal regulation, and water scarcity; and, for Clark County, a deterioration in air quality, water scarcity, reduced access to the outdoors, and increased traffic congestion.

From the UNLV survey, findings included: (1) A majority of Nevadans are satisfied with their state as a place to live. Satisfaction is particularly pronounced among rural residents, 79 percent of whom rated Nevada as very desirable. (2) Urban counties rated drug abuse, crime, and road conditions as the most serious problems facing the area; rural counties rated the availability of housing, medical care, and recreational facilities as problems. (3) Urban areas rated the friendliness of other residents, medical care, and recreational facilities as non-problems; rural areas rated air pollution, friendliness, raising children, and police protection as non-problems. (4) Although both urban and rural groups welcomed the jobs that the MX project would bring, all other possile impacts of the proposed project were rated negatively. Rural groups were particularly opposed to the social disruption (crime and drug abuse, for example) which they feared would accompany the project.

Attitudes and perceptions toward the repository

Attitudes and perceptions regarding the possible siting of the repository at Yucca Mountain are important for understanding social impacts because they form the basis from which social changes may occur. No definitive assessment of residents' attitudes has been undertaken to date. However, in a very recent general survey a substantial majority of Clark County residents opposed locating a repository at Yucca Mountain (UNLV, 1984).

Citizens' views expressed during March 1983, Las Vegas and Reno public hearings on the potential repository were reviewed as a means of discerning specific concerns of Nevada residents. A simple frequency count of the number of times a particular topic was mentioned suggests the witnesses' greatest concerns were: (1) health and safety, (2) transportation, and (3) socioeconomic and community impact. Although not a specific nuclear waste concern, many witnesses also expressed distrust of the Federal government and a desire for public participation (DOE/NVO, 1983).

3.1.6.5 Fiscal and government structure

This section describes the fiscal and governmental structure of the region surrounding the Yucca Mountain site. Governmental entities lying within Nye and Clark counties include: unincorporated areas, both rural and urban; the incorporated cities of Las Vegas, North Las Vegas, Henderson, Boulder, and newly-incorporated Mesquite; and the incorporated towns of Amargosa, Beatty, Pahrump, and Tonopah. In 1983, more than half of Clark County residents and more than 90 percent of Nye County residents lived in unincorporated portions of those counties.

While the incorporated cities are responsible for the provision of public services within their boundaries, county commissions are responsible for providing services to residents in the unincorporated areas. In Nye County, three county commissioners are elected to four-year terms from individual geographic districts. Day-to-day government operations are handled by a professional manager and staff. In Clark County, seven commissioners have jurisdiction over the unincorporated portions of the county. They are elected in even-numbered years from single-seat geographic districts, three in one election year and four the next. The county employs a professional manager and extensive staff to implement commission policy on a full-time basis.

Within the unincorporated towns, provision of services is administered by town councils and town advisory boards, who are either elected or appointed by the County Commission.

Some local government entities have been granted the power of taxation by the Nevada Legislature. For example, in Clark County, the incorporated cities of Las Vegas, North Las Vegas, Henderson, Boulder City, and Mesquite; the Clark County School District; and a variety of special districts including library, water, and fire protection districts, have specific taxing authority. In addition, several government entities receive taxes or other public monies but do not have specific taxing authority.

Revenue sources for some governmental entities in the region are shown in Tables 3-28 and 3-29. Fiscal year 1982-83 was chosen to represent the most recent fiscal data in light of substantial changes in Nevada tax law during the previous legislative sessions. The presence of legalized gaming in Nevada gives the state a unique fiscal structure. Gaming revenue contributed almost half--about $230 million--of the state's general fund in the 1982-83 fiscal year. Other major sources of state income included sales and insurances taxes (State of Nevada, Nevada State Budget, 1983).

At the local level, sources of revenue for the various categories of governmental units are similar, although the amounts of revenue received by individual units from these sources vary widely. At the local level, sources of revenue include property taxes (ad valorem taxes on real property); "other taxes" (city and county relief taxes paid to local governments by the state and income from franchises granted by local governments); licenses and permit fees (business, liquor and local gaming licenses, etc.); intergovernmental resources (cigarette and liquor taxes, local gaming taxes, motor vehicle privilege taxes, etc.); charges for services (recreation, sewer, building inspections, etc.); fines and forfeits (court fines and forfeited bail); and miscellaneous revenues.

Table 3-28. School revenue sources for Nye and Clark Counties

Revenue source	Nye County[a]		Clark County[b]	
	Amount (dollars)	Percent of Budget	Amount (millions of dollars)	Percent of Budget
State	3,700,000	52.2	105,800,000	52.0
County	2,300,000	42.8	86,800,000	43.0
Federal	70,000	1.0	2,160,000	1.0
Other	27,500	4.0	7,800,000	4.0

[a]Source: Nye County School District Audit 1982-83.

[b]Source: Annual budget 1982-83, Clark County School District.

Table 3-29. Local government revenue sources in southern Nevada, 1982-83[a]

Funding Category	Nye County	Clark County	City of Las Vegas	City of North Las Vegas	City of Henderson	City of Boulder City
Property taxes	0.819[b] (7%)	51.0 (14%)	9.17 (8%)	1.21 (4%)	0.382 (2%)	0.084 (7%)
Other taxes	2.34 (20%)	56.1 (16%)	6.85 (6%)	4.88 (16%)	0.616 (2.5%)	1.47 (20%)
Licenses and permits	0.237 (2%)	34.0 (9.5%)	7.07 (6.5%)	1.73 (5.5%)	0.783 (3.5%)	0.183 (2%)
Intergovernmental resources	2.42 (21%)	15.9 (4.5%)	62.6 (57%)	11.0 (36%)	5.16 (23%)	1.68 (21%)
Charges for services	4.74 (42%)	139.0 (40%)	19.3 (17.5%)	9.38 (31%)	0.240 (1%)	4.43 (41%)
Fines and forfeits	0.700 (<1%)	2.38 (<1%)	2.06 (2%)	0.964 (3%)	0.225 (1%)	0.056 (<1%)
Miscellaneous	0.838 (7%)	57.7 (16%)	3.47 (3%)	1.33 (4%)	14.8 (67%)	0.481 (7%)
Total	17.5	356.0	110.0	30.5	22.2	8.4

[a] Source: Schedule S-1, State of Nevada Taxation Department, Carson City, Nevada.

[b] Percentage of total budget.

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Chapter 4

EVALUATION OF EFFECTS OF SITE CHARACTERIZATION ACTIVITIES ON THE ENVIRONMENT

This chapter describes site characterization activities at the Yucca Mountain site and their effects on the environment. The Nuclear Waste Policy Act of 1982 (NWPA) defines "site characterization" as:

> "activities, whether in the laboratory or in the field, undertaken to establish the geologic condition and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken."

The purpose of this chapter is (1) to describe the proposed site-characterization activities at Yucca Mountain and (2) to evaluate the effects of those activities on the environment. Site-characterization activities have been proposed in recent drafts of the Mission Plan for the Civilian Radioactive Waste Management Program (DOE, 1984) and in the Generic Requirements for a Mined Geologic Disposal (DOE, 1984a) that are not described in this chapter. These activities include the excavation of a second large shaft that is similar to the Exploratory Shaft. Because the Mission Plan and the Generic Requirements documents have been issued as drafts and because a preliminary design of a second large shaft at Yucca Mountain is not yet available, no evaluation of potential impacts was attempted in this chapter. Although Yucca Mountain has not been recommended for site characterization, to facilitate readability, this chapter has been written as if Yucca Mountain has been recommended. The reader should not conclude that the decision has been made to conduct site characterization studies at Yucca Mountain.

4.1 SITE CHARACTERIZATION ACTIVITIES

This section contains a description of the site characterization activities planned for the Yucca Mountain site. The activities are categorized as field studies, Exploratory Shaft activities, and other studies that will be conducted away from the site, such as laboratory studies.

If Yucca Mountain is recommended for site characterization, the DOE will issue a Site Characterization Plan (SCP), which describes the tests necessary to adequately characterize the site's potential for repository development. The Nuclear Regulatory Commission (NRC) will review the DOE plan initially; and, the plan will be reviewed at six-month intervals to provide an independent technical appraisal of the research and testing program.

4.1.1 Field studies

Since 1978, the DOE has been conducting tests and surveys in the vicinity of the Yucca Mountain site to obtain information on the geologic, hydrologic, and geophysical characteristics of the site and surrounding region. These tests and surveys include borehole drilling and testing, geophysical surveys, and geologic mapping. Similar tests and surveys will be conducted if Yucca Mountain is recommended for site characterization. Laboratory rock-property tests also will continue if Yucca Mountain is recommended for site characterization.

4.1.1.1 Borehole drilling

Borehole drilling and testing activities provide data that allow three-dimensional characterization of the geology, hydrology, and geochemistry of the site and the surrounding area. Borehole drilling provides for: (1) collection, geologic description, geochemical analysis, and physical property characterization of cores; (2) geophysical investigations below the surface (e.g. logging); (3) measurement of in situ stress; (4) hydraulic testing beneath the water table; (5) testing and monitoring of the unsaturated zone; and (6) collecting water samples for chemical analysis.

Since 1978, the DOE has drilled several boreholes and conducted geohydrologic tests at Yucca Mountain. Becuase a Site Characterization Plan has not been completed for the Yucca Mountain site, the following assumptions have been made for the purposes of assessing the type and magnitude of impact that might be expected from further borehole drilling if Yucca Mountain is recommended for site characterization:

- Twenty new deep boreholes will be drilled to complete characterization of the site's hydrology and geology.
- The new boreholes will be drilled within 8 km (5 mi) of the Yucca Mountain site.
- Each borehole will require construction of an access road about 8 km (5 mi) long (this is a worst-case assumption used for calculating impacts).
- Access roads will be bladed smooth, boulders will be pushed aside, fill dirt will be added as required, and hillside cuts will be made and some roads will be graveled to achieve the desired grade.
- Road width, including shoulders, will average 15 m (50 ft).
- Roads will be sprinkled with water both to aid soil compaction and to provide dust control.

access roads

Each deep borehole site must be prepared to accomodate a drill rig and crew. Site preparation activities include clearing and grading the site and staging area, constructing a raised and leveled drill pad, excavating fill dirt from either adjacent or nearby areas, and constructing a mud and cuttings pit. An average of 1 ha (2.5 acres) per drill site is assumed to be disturbed by site preparation activities.

Drilling activities include drilling to depth, logging, and testing. Equipment and facilities that will be used at the drill site include a diesel-powered drill rig, drilling-fluid circulation pumps, drill pipe, drilling and coring tools, two trailers for supervisory and lab space, an electric generator, and an air compressor. Solid waste will be hauled from the site to an existing landfill on the Nevada Test Site (NTS). The water that will be used for drilling, dust suppression, compaction, and human consumption will be trucked daily to the drill site. Disposal of waste fluids and cuttings will be in mud and cuttings pits.

Borehole logging by means of contained radiation sources is common in geologic characterization. Borehole logging radiation sources are used to remotely determine water content, density, and other physical characteristics; and they are licensed by the Nevada Division of Radiologic Health. The licensing of these sources requires that the contractor receive formal training in radiologic safety and in the use of the logging source. In addition, the NTS radiation safety program provides safety and use requirements that are comparable to those required by the State.

4.1.1.2 Geophysical surveys

Certain geophysical surveys provide a means by which to obtain information about the subsurface geology without drilling deep boreholes. The surveys can be used to map the geometry of geologic structures at depth and to recognize discontinuities in stratigraphic sequences. Some geophysical techniques are useful for detecting major at-depth changes in rock density, magnetic and electrical properties, which may reflect the presence of a metallic ore body, a salt dome, or an igneous intrusive body (pluton). The geophysical techniques described in this section include seismic reflection and refraction, gravity, magnetic, and electrical surveys.

Seismic reflection and refraction surveys involve generating sound waves that travel through earth materials. Either seismometers or geophones are used to detect, amplify, and record the resulting motion of the ground at nearby points. Reflection and refraction of the sound waves are caused by changes in rock properties (density and sonic velocity) along the travel paths from the seismic source to the receiver. The resultant seismic reflection and refraction patterns are then mathematically analyzed and used to determine the types of rock materials and three-dimensional structures that would be expected to produce the observed patterns.

Seismic reflection surveys at Yucca Mountain have been conducted using dynamite charges set off in 22 shot holes that have been drilled 60 m (200 ft) deep and arranged in a linear pattern. These holes did not require drill pads, but some vegetation was cleared for vehicle access and geophone positioning. In addition, low-frequency sound waves for seismic reflection surveys were generated by use of a large, specially designed four-wheel-drive truck with a large plate attached to its bottom. Hydraulic jacks were used to press the plate against the ground while simultaneously lifting the truck and vibrating it on the plate. A full-scale test of this type was conducted in the eastern foothills of Yucca Mountain on a 200- by 3400-m (700- by 11,000-ft) grid with eight test lines spaced 30 m (100 ft) apart. Each test line was covered by three machines in tandem that advanced in 1.5-m (5-ft) increments. Data were recorded from an array of geophones that were placed on the ground surface at specific distances from the trucks. Similar seismic reflection studies may be conducted during site characterization.

A seismic refraction survey was conducted as part of the preliminary investigations of Yucca Mountain. A north-south line approximately 80 km (50 mi) long was located in the eastern portion of Crater Flat. Seven holes were drilled with a truck-mounted rig to emplace explosives. The holes were 200 mm (8 in) in diameter, 37 m (120 ft) deep, and each contained approximately 680 kg (1500 lb) of explosive which was detonated to generate sound waves. An array of geophones was deployed to collect the refraction data. Another refraction survey was conducted east of Yucca Mountain along the road to Drill Hole Wash. Small drill pads were constructed at each of 20 sites where 15-m (50-ft) holes were drilled for emplacement of explosive sources. Similar seismic refraction surveys may be conducted during site characterization.

Gravity surveys are conducted to measure small differences in the strength of the earth's gravitational field to detect subsurface geologic features such as plutons, ore bodies, and salt domes. Positive and negative gravity anomalies that are the result of differences in the density of underlying rock materials are recorded and interpreted. Gravity measurements are taken at discrete locations defined by a grid system consisting of cells that are typically 60 by 60 m (200 by 200 ft). In addition to the gravity measurements, considerable surveying and some geological reconnaissance may be required. The surveys and reconnaissance are made either on foot, or by using off-road vehicles or helicopters. Some gravity surveys have been made in the Yucca Mountain area and additional surveys are planned during site characterization.

Magnetic surveys are conducted to measure differences in the earth's magnetic field from place to place and are used to determine the subsurface configuration of rocks having differenct magnetic properties. Field crews may either conduct magnetic surveys on the ground, or they may equip airplanes to conduct magnetic surveys. Both airborne and ground-magnetic surveys have been made at Yucca Mountain and additional surveys are planned during site characterization.

A number of other geophysical techniques may be used to better understand the position and characteristics of rock units in the subsurface. Electrical surveys which measure the response of earth materials to passage of electrical currents have been made in the vicinity of Yucca Mountain. Another technique which is commonly used in the petroleum industry is vertical seismic profiling (VSP). This technique is useful for fracture mapping and for determining the extent of interconnection of the fractures. Attenuation of high-frequency electromagnetic waves by fluid-filled fractures has also been used successfully to map fractures. Field surveys for all of the above would be similar to those which were used for seismic reflection or refraction.

4.1.1.3 Geologic mapping

Geologic mapping is conducted to record the surface features and characteristics of exposed rock in the area. This mapping utilizes aerial photography and detailed field observations on foot. Occasionally, the surface study is supplemented by shallow subsurface investigations requiring a limited amount of trenching by a bulldozer. Typically, trenches are approximately 2 m (8 ft) wide, range from 1 to 3 m (4 to 10 ft) deep, and are from 30 to 60 m (100 to 200 ft) long. The walls of shallow trenches are kept straight and smooth, and as near vertical as possible. Deeper trenches are terraced for safety reasons, and they may be as wide as 8 m (25 ft). Some trenching and additional geologic mapping will be done during site characterization.

4.1.1.4 Field experiments in preexisting G-Tunnel facilities

In situ physical, chemical, and mechanical properties of tuffaceous rocks are being measured under simulated repository conditions in G-Tunnel, a preexisting test facility at the NTS. G-Tunnel is being used for preliminary investigations because it provides a layer of welded tuff that has thermal and mechanical properties that are similar to some of the welded tuffs at Yucca Mountain. Completed or ongoing tests include small-diameter heater tests and a heated block experiment. The purpose of these experiments is to measure thermal and mechanical behavior of welded tuff in situ. Predictions can then be made of the rock's response to heat imposed during radioactive waste storage. The heated block experiment utilized an in situ, 2-m (6-ft) square block of welded tuff bounded by vertical slots. Both stress and thermal loads were imposed on the block to achieve combinations of stress and temperature for evaluating the deformation, thermal conductivity, thermal expansion, and fracture permeability. Moisture changes within the block were monitored with piezometers, ultrasonic instruments, and a neutron probe. These tests will provide valuable experience in the use of instrumentation and in the development of field techniques that will be used during in situ testing during site characterization.

4.1.1.5 Reclamation of areas disturbed by field studies

When the DOE determines that the boreholes are no longer needed for gathering data, the boreholes will be sealed. State of Nevada requirements, along with cooperative agreements with the BLM and the U.S. Air Force, call for the proper sealing and capping of boreholes upon abandonment or termination of DOE activities at the borehole site. All boreholes that are not currently in use are temporarily capped. If a decision is made to abandon a borehole, it will be sealed according to accepted practice with specific sealing requirements determined by using data that has been obtained during site characterization. In general, the boreholes will be sealed with a ground-matching grout that has a density that corresponds to the surrounding geologic medium. The grout will be injected in increments to prevent fracturing the surrounding medium. The formulation of the grout will be determined by using data from cores that have been taken during drilling. Following the injection of ground-matching grout, the surface casing will be filled with concrete to the surface, and a concrete cap will be poured around the sealed hole. A permanent marker that gives pertinent data about the borehole will be erected following surface restoration.

Reclamation and habitat restoration in fragile, arid ecosystems are not completely understood. Generally, arid ecosystems require long periods of time to reestablish climax vegetation associations, and the effectiveness of varic levels of intervention during habitat restoration is not clear. Consequently, each requirement for reclamation will be individually evaluated.

The following reclamation measures will be implemented:

1. Removing and disposing of the surface debris and any concrete drill pads in the NTS landfill.

2. Disking or ripping of the compacted, stabilized drill-pad area to relieve compaction.

3. Filling the mudpit with stockpiled topsoil following removal of drilling fluids or sludge, as appropriate.

4. Contouring to reestablish natural drainage patterns, minimize erosion, and blend with surrounding land contours.

5. Distributing available stockpiled topsoil over the recontoured area and introducing microtopographic features to minimize erosion and to encourage moisture retention.

6. Initiating additional habitat restoration measures as identified in ongoing habitat restoration studies.

When restoration is complete, the unpaved roads will no longer be required to access the disturbed areas, and the land involved will be restored. The following activities are representative of such restoration:

1. Disking or similarly treating roadways to break up compacted soil and to allow root penetration during revegetation.

2. Contouring roadways to reestablish natural drainage patterns, minimize erosion, and blend with the surrounding land forms.

3. Employing appropriate habitat restoration procedures based upon the results of the ongoing habitat restoration study. Techniques will, at a minimum, prevent erosion and provide enhanced moisture retention to facilitate revegetation.

About 0.10 km^2 (0.04 mi^2) of surface disturbance will be associated with geophysical and geological surveys. The disturbed exploration areas and off-road vehicle paths will be disked to relieve compaction and to encourage revegetation. Geological trenches will be filled with the material that was removed during excavation and the land will be restored to its original contours. If it is appropriate, and based upon the results of habitat restoration studies, the recontoured surface will be treated to encourage moisture retention and to hasten revegetation.

4.1.2 Exploratory shaft

The NRC procedural rule (10 CFR 60, 1981) for licensing high-level nuclear waste repositories requires in situ testing at depth during site characterization. If Yucca Mountain is recommended for characterization, the DOE plans to excavate an Exploratory Shaft to provide access to the potential host rock for in situ testing. Excavation of the Exploratory Shaft will be the major construction activity during site characterization. Figure 4-1 is an illustration of the proposed Exploratory Shaft and the associated surface facilities. The Exploratory Shaft will provide access to the potential host rock at depth and will allow detailed study of the overlying rock strata. The Exploratory Shaft also will allow both inspection and testing of the strata immediately below the potential host rock.

Construction of the Exploratory Shaft including the surface facilities and the in situ testing areas at Yucca Mountain will require about 28 months. The surface facility will take from five to six months to construct. The shaft and three breakout rooms will be finished about 15 months later. The main underground test facility, which will be constructed at the 370 m (1200 ft) level, will require from six to nine more months to complete. Testing will begin during shaft construction. The entire testing program is expected to be completed 2 1/2 years following the completion of the main underground test facility. Therefore, the time period for the Exploratory Shaft characterization activity will be from five to six years.

The surface facilities will support the mining and testing at the Exploratory Shaft site. The construction of surface facilities and the actual sinking of the shaft are discussed further in the following section. These activities have a greater potential for causing an environmental impact than all other planned activities. The in situ testing program is described in Section 4.1.2.2 although it contributes little to the potential for environmental impact. The selection of the first repository site will be made after site characterization is completed. If Yucca Mountain is not selected, the Exploratory Shaft will be decommissioned. However, if this site is selected, the Exploratory Shaft will be incorporated into the repository. Section 4.1.2.3 describes the final disposition of the Exploratory Shaft.

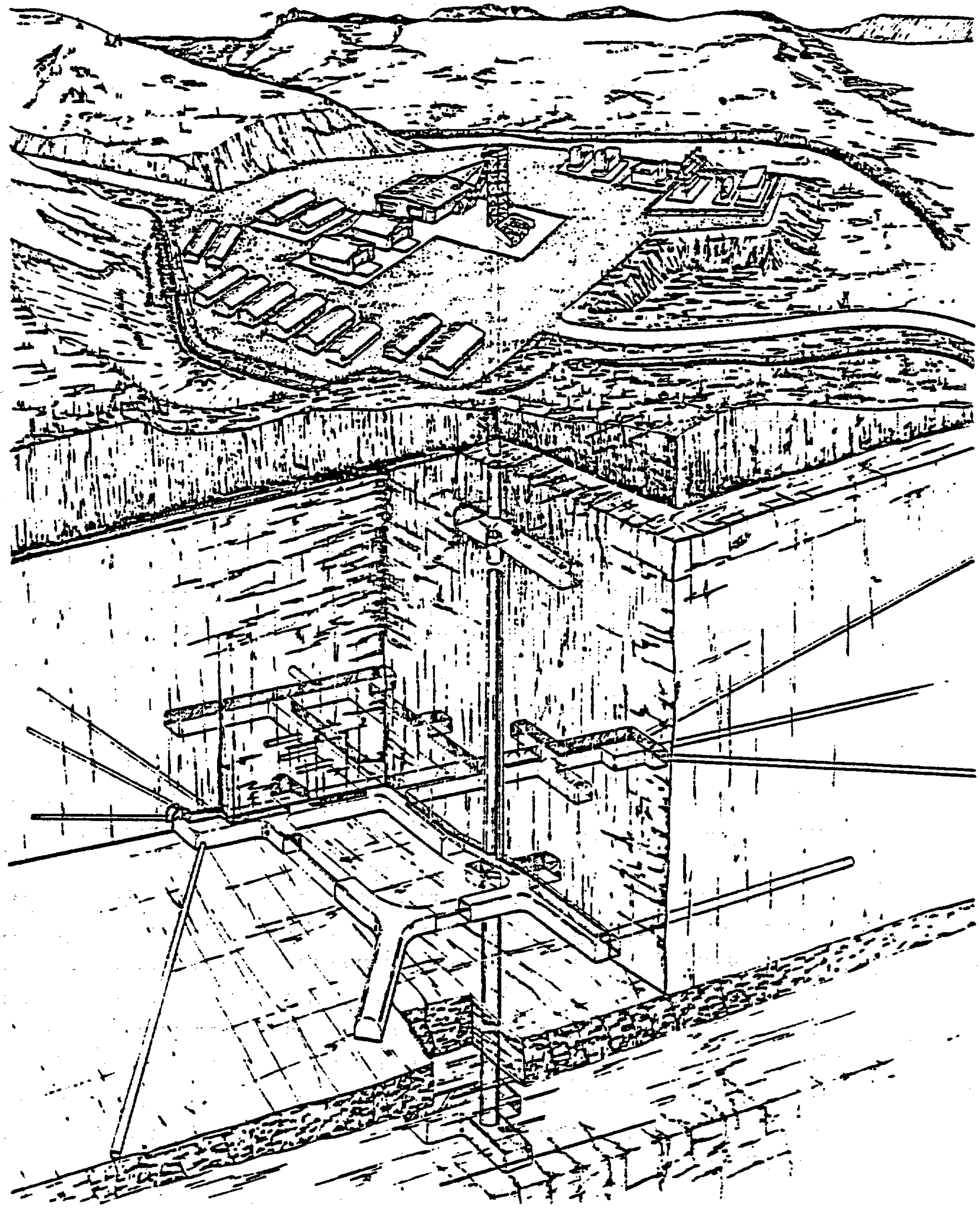

Figure 4-1. Illustration of Exploratory Shaft and surface facilities.

4.1.2.1 Exploratory Shaft construction

The Exploratory Shaft location is in Coyote Wash on the northeastern side of Yucca Mountain at an elevation of about 1300 m (4150 ft). Figure 4-2 shows the proposed shaft site, utility lines, and access road, as well as the administrative boundaries of the NTS, the Nellis Air Force Range (NAFR), and the Bureau of Land Management (BLM). The site plan and the original topography of Coyote Wash are shown in Figure 4-3.

Surface facility design and construction specifications require that equipment and systems meet the requirements set forth by the DOE (1983); the Mine Safety and Health Administration (MSHA) regulations (1977); and other applicable local, State, and Federal regulations. It is also required that construction disturb only the minimum amount of land necessary to accomplish the project. Design criteria include considerations of site restoration; the site will be restored to approximately its original condition if Yucca Mountain is eliminated from the list of potential repository locations.

Surface facilities

Construction of the surface facilities is expected to take from five to six months to complete. The site will first be cleared and graded; then it will be stabilized with 15 cm (6 in.) of gravel and a dust binder.

As shown on Figure 4-3, two existing drainage channels will be diverted to control potential runoff, which would result from a 100-year storm event. About 180 m (600 ft) of the channel was diverted in 1982 when the drill pad for the principal borehole, USW G-4, was constructed at the Exploratory Shaft location. Site preparation will require cut and fill to provide a level pad for the surface structures and the parking area. About 57,000 m^3 (2,000,000 ft^3) of fill material will be removed from areas east and west of the pad. The area that will be required for the surface facilities is about 8 ha (20 acres).

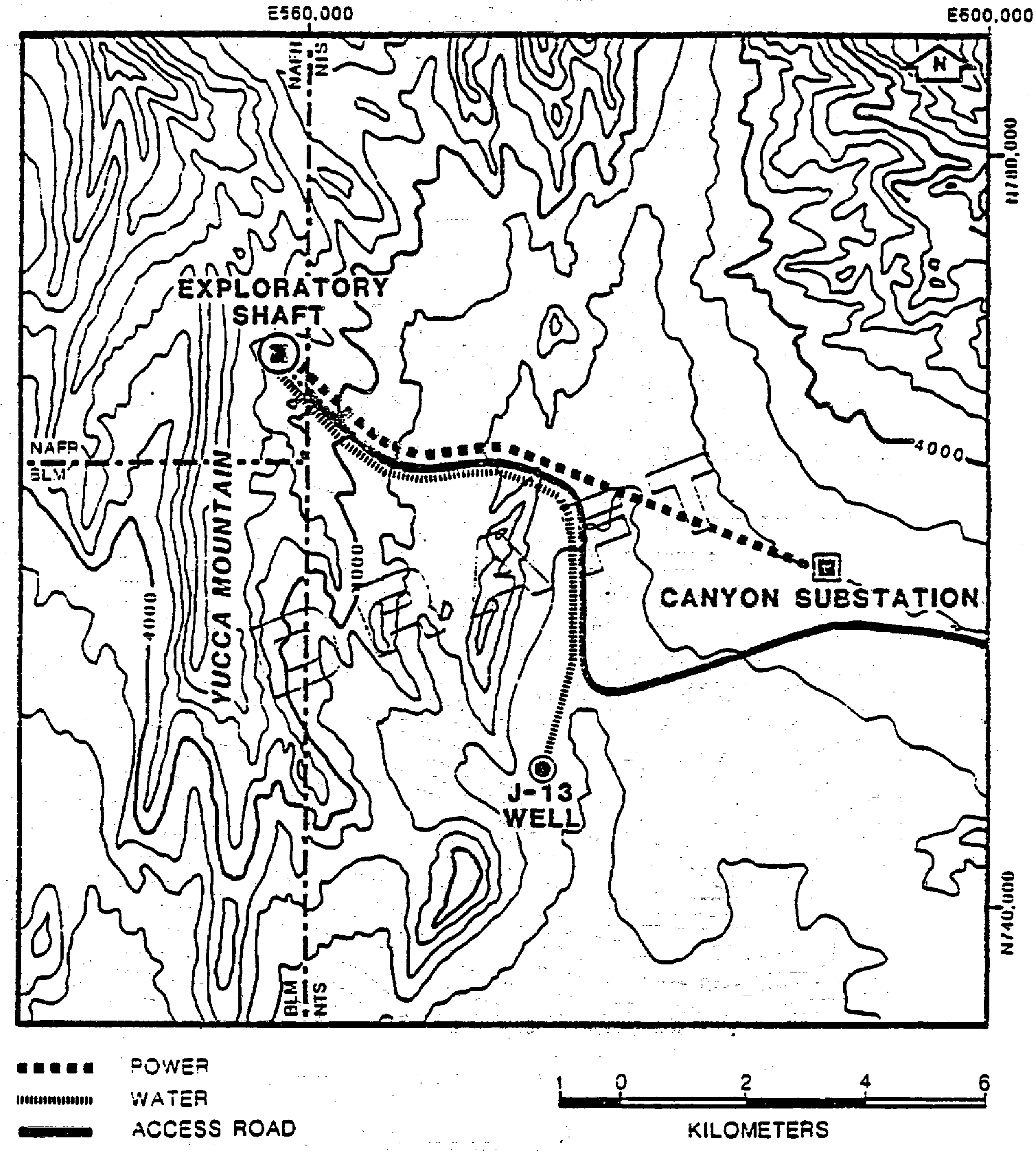

Figure 4-2. Location of proposed Exploratory Shaft and utilities.

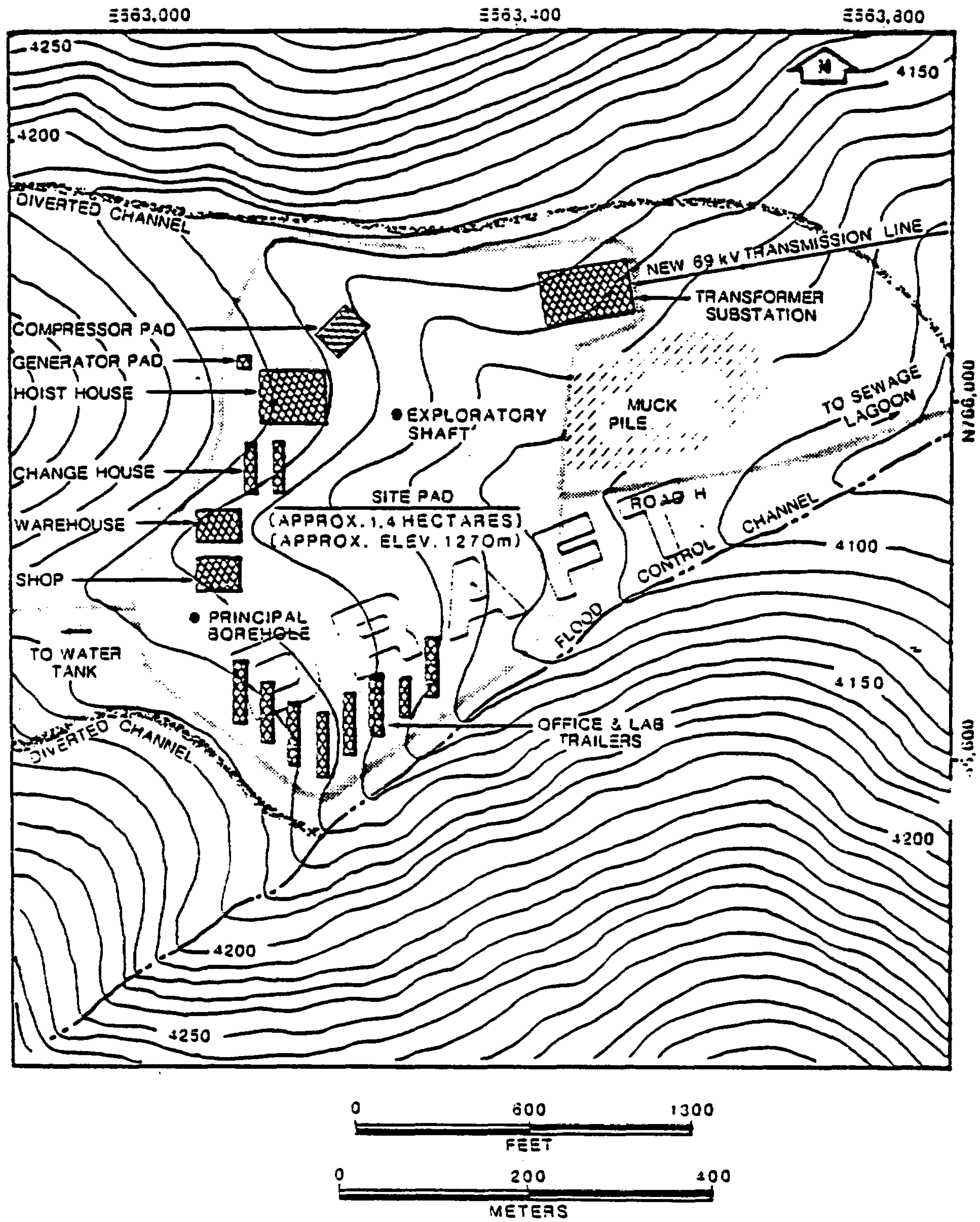

Figure 4-3. Approximate location of surface facilities for the proposed Exploratory Shaft in Coyote Wash on east side of Yucca Mountain.

The parking area and access road will be paved with double oil-and-chip. Access to the pad from the east will be controlled by a chain-link fence and gates. The natural terrain provides a barrier to vehicle access elsewhere on the site. The access road from Jackass Flats has been improved to accommodate heavy equipment. The road is 7 m (22 ft) wide, has 1-m (4-ft) shoulders, and is surfaced with double oil-and-chip. The remaining 400 m (1300 ft) of the road to the pad will be constructed on fill to maintain a grade that will not be greater than 10 percent. This road will disturb a path 50 m (160 ft) wide, including channel modification.

Prefabricated metal buildings, which will be assembled at the site on concrete foundations, will provide space for a shop, a warehouse, and a hoist house. All three buildings will be designed to withstand the maximum expected ground motion from either natural earthquakes or nuclear weapons testing. A 4.5-metric ton (5-ton) overhead crane will be installed in the shop area. The hoist house will accommodate two permanent hoists. Fire protection will be provided. Seven 4- by 17-m (12- by 56-ft) trailers will be located at the Exploratory Shaft site and will include space for two offices, four laboratories, a first-aid room, and a visitors' center. One 2.4- by 9-m (8- by 30-ft) trailer will provide additional office space. Two skid-mounted 4- by 15-m (12- by 50-ft) change-rooms will provide showers and lockers for the technical staff, and for the mining crew, which is estimated to be 20 persons per shift. Each structure will have restrooms, electric space heating and water heating, and air conditioning.

Three magazines are required for storage of explosives: one for powder, one for caps, and one for primer make-up. These magazines will be constructed in accordance with current regulations and California Mine Safety Orders. Two magazines will be located at least 600 m (2000 ft) from the shaft. The magazine for primer make-up will be located north of the pad and nearer the shaft. The size of the magazines will be determined by the powder requirem for shaft and underground construction.

The utilities and communication systems include the following: (1) above-ground electrical supply and underground distribution; (2) emergency electrical supply; (3) water supply and distribution; (4) sanitary, industrial, and refuse waste collection and disposal; and (5) telephone communications. An overhead power line 10 km (5 mi) long has been constructed from Canyon Substation in Jackass Flats to the NTS boundary. The 69-kV transmission line will provide power to the site substation. The site substation will include both a 5000-V transformer to supply 4.16-kV to the hoists, and secondary transformers to supply 480-V, 220-V, and 110-V power to the other surface facilities. The substation will require cutouts, distribution panels, conduit and wire, fencing, trenching, and some concrete work. Two distribution systems will supply the surface structures and the mine plant. A second power line 2 km long (1.5 mi) will be built to supply 4.16-kV to pump water to the site. Area floodlights on wood poles will provide night lighting. The emergency power generation system will have two 500-kVA diesel generators.

The water supply will be pumped from well J-13 on the NTS through a 10-km (6.5-mi) long, 15-cm (6-in.) diameter polyvinyl chloride pipe buried about 0.6 m (2 ft) below grade. The pipeline, which has been constructed in the old access roadbed to the NTS boundary, is adjacent to the new paved road and passes through two pumping stations; one is at J-13 and the other at about the half-way point. Water will be pumped to the 600 m^3 (150,000-gallon) water tank located 500 m (1600 ft) west of the site at an elevation of 1320 m (4325 ft). The water distribution system from the tank will supply water for construction, operation, and fire protection. A chlorination system will be provided for potable water.

Waste disposal will be in the sewage lagoon, on the rubble (muck) pile, and in the NTS landfill. The sewage lagoon, which is an area about 41 by 41 m (135 by 135 ft) located 1000 m (3300 ft) east of the site, will be able to handle sewage for 75 persons in a 24-hour period. It will be connected to a collection system by an underground sewer line from all buildings and trailers. The lagoon will be constructed in alluvium, which has high porosity. If the evaporation rate and the percolation rate are sufficiently higher than the sewage inflow rate, the sewage lagoon will not function properly unless more water is added to maintain the sewage decomposition balance; and water will be added as necessary. Water and other fluids removed with the muck from the shaft and underground rooms will be disposed of on the muck pile, which also will be built on alluvium. Fluids that will be used for core drilling include air-water mist, bentonitic mud with water control agents, and polymer foam. All of these fluids will be disposed of on the muck pile. Any possible excess water will be pumped to the sewage lagoon. Solid refuse from the site will be hauled to an existing landfill on the NTS.

A 12-channel surface-microwave link that is capable of accommodating 30 telephone sets will connect the site to a commercial telephone network. A two-way radio system will allow communication between the surface facilities and the hoist cage.

The ventilation fans will be capable of providing 850 m^3/min [30,000 cub: feet per minute (cfm)] of air to the underground shafts and rooms. The ventilation system will meet all MSHA requirements and will provide underground temperatures that will allow a work regimen of 75 percent work and 25 percent rest with a rock temperature of 27°C (80°F) at the 370-m (1200-ft) depth. The fans will have reverse-flow capability to exhaust smoke, fumes, and dust from blasting in the shaft or in underground rooms. Backup fans and emergency power for operation of the ventilation system will be provided. Two air compressors, each with a capacity to compress 40 m^3/min (1500 cfm) of free air to a gauge pressure of 860 kPa (125 psi) on a sustained basis, will support air drilling of underground boreholes. This system will include foundations and electrical supply controls, distribution piping, and a backup compressor. The air compressors and ventilation fans will be located near the power substation to provide noise separation from the shaft and buildings.

A mine dewatering system will be available; however, it is not expected that large quantities of water will be encountered in the Exploratory Shaft. It is possible that perched water zones and percolation seepages could pro: some water in the shaft during mine construction and testing. Such water w: be collected in a sump and then pumped to the surface and discharged on the muck pile. There will be a back-up sump pump and emergency power. A written record will be maintained of the source and volume of water lifted from the shaft by pumping or bailing.

The muck pile will be located just off the site pad, and east of the shaft. The muck removed from the shaft, from breakouts, and from the main underground test facility will be transported to the surface in a muck bucket and deposited adjacent to the shaft. From there, the muck will be collected and hauled to the edge of the pad where it will be dumped from the 9-m (30-ft) embankment. The 0.6-ha (1.5-acre) muck pile area is sufficient to accommodate the 28,000 m^3 (995,000 ft^3) of muck that will be produced during shaft and drift mining. Dust from the dumping operation will be controlled by appropriate wet suppression techniques. A berm will be constructed between the muck pile and the drainage channel to contain any chemicals or muck leachates and prevent them from reaching the drainage channel. This berm will be designed to contain a volume of 1400 m^3 (375,000 gal) of liquid.

Shaft and underground rooms

The current plans are to mine the Exploratory Shaft to a total depth of about 450 m (1480 ft), which is about 23 m (75 ft) below the contact between the overlying Topopah Spring Member and the underlying tuffaceous beds of Calico Hills. This total depth will provide about 15 m (50 ft) of penetration into the prevasively zeolitized interior of the Calico Hills unit and will leave undisturbed about 85 m (280 ft) of the Calico Hills unit above the water table. The design diameter of the excavated shaft is 4 m (14 ft).

The mining of the Exploratory Shaft will begin after the surface facility is complete. The Exploratory Shaft will be constructed by conventional drill-blast-muck mining techniques. In this technique, explosives are placed into small holes drilled in the rock. After the explosives have been detonated, the muck is collected and hoisted from the shaft. Conventional mining, instead of drilling, was selected as the Exploratory Shaft construction technique because it will provide the capability to examine geologic and hydrologic conditions above, below, and within the candidate host rock during Exploratory Shaft construction. Conventional mining will minimize the potential introduction of large quantities of drilling fluid into the unsaturated zone before Exploratory Shaft testing. Conventional mining techniques will also avoid the possibility that drilling fluid might adversely affect some tests that are designed to assess undisturbed moisture content of the rock and ground-water flux.

Three breakout levels are currently being considered at 160, 370, and 450 m (520, 1200, and 1480 ft). The breakout rooms are designed for specific tests that will be initiated as soon as each room is completed during the construction phase. Additional breakout levels may be required.

The mucking operation may be somewhat dustier than it would be in a typical mine because minimal amounts of water will be used for dust suppression in the shaft. Normally, the rubble is sprayed with water before mucking for additional dust control. However, in the Exploratory shaft, water will be used sparingly so that certain tests will not be adversely affected. In fact, all of the water used in shaft construction, including the water used for making liner concrete, will be tagged with a suitable tracer. The water entering the shaft, the humidity in the air supply, and exhaust ventilation air will be metered and recorded. The explosives used in shaft construction will have the minimum amount of chlorine content to prevent contaminating the natural pore waters that will be used for age determinations. Shaft ventilation after blasting (smoke-out) will be accomplished either by reversing the ventilation air flow to suck out the shot gasses or by using direct exhaust and waiting sufficient time before allowing workers to reenter the shaft.

After the breakout room at 370 m (1200 ft) is completed, the main underground test facility will be mined. Current plans are to mine the drifts using conventional drill-blast-muck methods. Because they may be more economical and offer other advantages for some of the planned tests, alternative methods, such as using a continuous miner also are being evaluated. The estimated construction time for the drifts for in situ tests is from 6 to 9 months.

4.1.2.2 Exploratory Shaft testing program

The goal of the Exploratory Shaft testing program is to obtain information that is required to assess the intrinsic ability of the geologic setting at Yucca Mountain to isolate high-level waste (HLW). Information will also be acquired that will assist the design of engineered components such as drifts, emplacement holes, canisters, etc. The tests under consideration are designed to provide information needed to address compliance with Federal regulations related to performance and siting criteria for HLW repositories. Engineering test plans will be prepared for individual Exploratory Shaft tests before beginning the tests.

A number of assumptions have been established to provide a consistent basis for planning the Exploratory Shaft testing program. The primary assumptions are as follows:

1. A single Exploratory Shaft will be constructed by conventional mining at the Coyote Wash site.

2. The Exploratory Shaft workings will be restricted to the unsaturated zone beneath Yucca Mountain.

3. The candidate host rock is the densely welded Topopah Spring Member of the Paintbrush formation.

4. Tests conducted in the Exploratory Shaft will be focused on obtaining the information necessary for site characterization.

5. Exploratory Shaft tests will be planned to provide timely input for the site characterization process.

All Exploratory Shaft construction, operations, and maintenance functions will be performed in accordance with established Federal, State, and Nevada Test Site safety codes and procedures. While the surface facilities, shaft, and test facility are being constructed, the safety of all personnel will be the responsibility of the prime construction contractor. During the period of testing operations, a designated safety officer will have overall responsibility for assuring safe operations of the Exploratory Shaft facility and of all testing operations.

The Exploratory Shaft tests that are being considered at this time can be grouped into two general categories.

1. Construction Phase Tests: Those tests initiated concurrently with shaft sinking (some construction phase tests will continue into the in situ test phase).

2. In Situ Phase Tests: Tests initiated after shaft sinking is complete.

Ten construction-phase tests are planned. One of the ten--shaft wall mapping, photography, and hand specimen sampling--will be conducted routinely following each blast round as the shaft is being sunk. This test is expected to require from 1 to 2 hours after each blasting round; an additional 1 or 2 hours will be needed when large block samples are collected. Three of the tests require large block samples that will be collected from 15 to 30 locations in the shaft. The pore waters that will be extracted from the large block samples will be chemically analyzed and dated by using chlorine-36 techniques. Laboratory measurements of geomechanical properties are also planned on these samples. The fifth test, unsaturated zone water sampling, will only occur if perched water is found during shaft sinking, which is considered to be highly unlikely. The remaining five tests will be at selected depths. The tests represent nonroutine operations and will require planned pauses in shaft sinking operations of from several hours to several days. These five tests include: (1) vertical coring; (2) lateral coring to confirm adequacy of geologic and hydrologic conditions prior to breakout at the 160 m (520 ft) level, at the 370 m (1200 ft) level, and at the shaft bottom at 450 m (1480 ft); (3) overcore drilling to measure in situ stress conditions; (4) the breakout room tests that will be performed to assess constructibility and stability of repository-sized drifts; and (5) shaft convergence tests between the 160 m (520 ft) and 370 m (1200 ft) breakouts.

Fifteen in situ-phase tests are planned. These tests will begin after the shaft has been completed to the required depth. Most of the in situ tests will be at the 370 m (1200 ft) level. The in situ-phase tests can be grouped by the categories of site information that will be obtained. Geological information on fracture frequency and orientations will be obtained by mapping the walls of the drifts in the testing area. Lateral coring will provide geological information on the continuity of the proposed host rock. Hydrologic data will be obtained from permeability and infiltration tests both in the Topopah Spring Member and in the underlying tuffaceous beds of Calico Hills. Geochemical tests will estimate the potential for retardation of radionuclide movement by various physical and chemical sorption processes. Geomechanical tests are planned that will simulate the effects on the host rock of temperature increases that will be caused by heat from radioactive decay of emplaced waste. Tests are also planned that will assess the stability of mined openings and that will obtain other in situ measurements that are required to design a safe repository. A final category of tests is planned that will investigate the physical and chemical characteristics of the very near-field emplacement environment to provide information necessary for proper design of waste packages and engineered barriers.

4.1.2.3 Final disposition

The Nuclear Waste Policy Act (NWPA) (Section 113) requires that the Site Characterization Plan for a candidate site contain provisions for the decontamination and decommissioning of the site. The current plans for site characterization at Yucca Mountain do not include the use of high-level radioactive waste. No decontamination of the site is expected to be required following site characterization. The final disposition of the Exploratory Shaft would depend upon whether or not Yucca Mountain is selected as a repository site. Potential Federal actions lead to three possible Exploratory Shaft dispositions:

1. Yucca Mountain may be shown by the Exploratory Shaft testing program to be unsuitable for a nuclear waste repository. In this case, the Exploratory Shaft would either be decommissioned or preserved for other uses.

2. The site may be shown to be suitable, but the first repository may be built at another site. In this case, the Exploratory Shaft would not be decommissioned until a final decision is made as to whether or not the site is needed.

3. The site may be shown to be suitable and be selected for the first repository. The Exploratory Shaft would be incorporated into the repository design.

Because final decisions about optimum techniques for shaft sealing may require data from site characterization, the following decommissioning strategies are only representative of those that would be implemented:

1. If an alternate use for the Exploratory Shaft is identified prior to decommissioning, a limited "standby decommissioning" will occur upon termination of site characterization. In this case, the utilities and shaft ventilation system would be left in place and periodic maintenance would preserve the structural integrity of the shaft until the alternative users assume possession of the facility. Adequate surface physical security would be retained to prevent unauthorized access and accidents.

2. A second strategy that would preserve the option of using the Exploratory Shaft in the future entails removing the utilities and any salvageable materials from the interior of the facility and welding a steel cover over the opening to prevent accidents or unauthorized access. Following the mitigation of surface disturbance, the sealed facility would be marked to identify pertinent history and details of the excavation. This sealing option would require a minimum degree of security to protect the shaft from vandalism and accidents resulting from unauthorized entry.

3. The third decommissioning strategy includes removing all utilities and salvageable material from the underground structure and closing of the Exploratory Shaft by backfilling with material that has been removed during the initial excavation. Depending upon the backfill technique used, about 50 percent of the muck removed from the facility would be used for backfill. Horizontal and vertical boreholes in the Exploratory Shaft would be sealed with an appropriate cement-based grout as required. The need and composition of any required sealing

grout will be more clearly identified during site characterization. Following closure of the Exploratory Shaft and surface restoration, a small concrete structure containing a marker will be installed that will detail pertinent historical data about the facility.

The primary decommissioning objectives are safety and site restoration. The Exploratory Shaft will be backfilled with muck by alternating cycles of fill and compaction to prevent future surface subsidence following surface restoration. However, if it is determined that sealing will be needed to preserve the geologic structure of the site, techniques affording greater compaction will be required. These techniques include replacing the excavated muck under pressure either with or without compacting additives, such as cement, and using a ground-matching grout that duplicates the density of the surrounding geologic formation. The technique to be used will be selected following site characterization and will take into consideration the actual geologic conditions encountered and the borehole sealing research conducted in the Exploratory Shaft. Following closure of the Exploratory Shaft and surface restoration, a small concrete structure containing a marker will be installed that details pertinent historical data about the facility.

In the event that the Yucca Mountain site is eliminated from consideration as a potential repository site, decommissioning of the site will begin as soon as possible after the decision. As is stipulated in the interagency agreements covering site characterization activities, decommissioning will be in accordance with the agreements reached during negotiations of reclamation plans.

A variety of subsurface utilities such as the water supply line, water distribution and collection pipes, and electrical cables will be installed in conjunction with the construction of the Exploratory Shaft. The cost and environmental disturbance associated with the excavation and removal of these structures generally exceeds the cost and disturbance associated with leaving them buried in place. Consequently, when the site is abandoned, any portion of the structure that extends above the ground will be cut off below grade, and the structures will be covered during the reclamation of surface disturbance.

When it is determined that they are no longer required, any other subsurface structures that are constructed during site characterization will be backfilled and closed using generally accepted procedures.

If the Yucca Mountain site is eliminated from consideration as a potential repository site, current plans and interagency cooperative agreements call for the removal of all buildings, fences, trailers, electrical distribution and communications equipment, explosives magazines, and standby electric generators either for reuse or salvage sale. Any mobile equipment brought in to the Exploratory Shaft to support construction and operation will be disposed of in a similar fashion.

If the Yucca Mountain site is chosen as a repository site, a limited removal of surface facilities will occur. Buildings and utilities that will be sufficient to support any required experimental activities and to maintain the integrity of the Exploratory Shaft and underground excavations will remain until their removal is dictated by repository development.

Reclamation

Reclamation techniques for disturbed lands will be determined jointly by the BLM and the DOE upon termination of activities according to the terms specified in cooperative agreements and permits. Because reclamation and habitat restoration in fragile, arid ecosystems are not completely understood, the DOE is currently conducting a study to assess habitat restoration options which can be used during reclamation at Yucca Mountain. Restoration experiments will be conducted at the Exploratory Shaft site. The results of these studies will be used to refine the following representative reclamation procedures.

Reclamation of disturbed surface areas will include:

1. Removal of paving and concrete pads and surface debris with subsequent disposal in the NTS landfill.

2. Breakup of the stabilized pad area to relieve compaction and cause mixing with the underlying soil.

3. Filling the sewage lagoon following complete evaporation.

4. Recontouring the site to establish natural contours and normal site drainage using appropriate techniques to reduce erosion and to enhance moisture retention.

5. Distribution of available topsoil on the recontoured fill and borrow areas.

6. Stabilization of the remaining muckpile by decreasing slope angles and applying available topsoil or fill to encourage revegetation.

7. Initiation of additional appropriate habitat restoration measures as identified in habitat restoration studies.

It is likely that the 10 km (6 mi) of improved roads, which will be developed to provide access to the Exploratory Shaft, will not be reclaimed regardless of any repository decision about the Yucca Mountain site. Not only would restoration be more disruptive to the area than simply abandoning the road, but future activities on the NTS could likely benefit from the access provided by the improved roadways.

Mitigation

In combination with a site selection strategy that considers the potential environmental impacts of characterization activities at various locations, the consideration of associated mitigation procedures during planning, design, and construction of site characterization facilities will help ensure that site characterization at Yucca Mountain will have the least possible environmental impacts. Additionally, such a selection/mitigation process will ensure that the adverse environmental impacts that do occur are easier to rectify when returning the site to its original condition.

Mitigation strategies that will be implemented during Yucca Mountain site characterization include:

1. Containing of fluids and effluents that have been generated during site characterization in either the muck pile or the sewage lagoon and establishment of a muck leachate monitoring program.

2. Stockpiling of topsoil, when possible, to take advantage of the seed bank and the beneficial soil microorganisms during later reclamation.

3. Controlling slope angles to minimize erosion and stabilize slopes.

4. Using scarification and microtopographic features to promote moisture retention on disturbed areas.

5. Siting borrow pits where the least damage will occur.

6. Avoiding sensitive biological species and habitats.

7. Minimizing dust either by spraying with water, using dust binding agents, or paving some roads.

8. Spacing of surface facilities and associated clearing of vegetation to reduce fire potential.

9. Conducting field studies before construction activities begin to identify and avoid Mojave fishhook cacti and desert tortoises.

10. Avoiding or salvaging archaeological sites.

In addition, all construction activities, to the extent practical, will observe a 50-m (160-ft) buffer zone surrounding significant archaeological sites, and a professional archaeologist will be employed to monitor all construction near these locations. Off-road travel will be restricted and workers in the area will be informed of policies regarding archaeological sites and the penalties for unauthorized collection and excavation of these sites. If necessary, important sites will be fenced.

4.1.3 Other studies

Some ongoing activities including both field and laboratory work will be continued to support site characterization. Dry horizontal drilling techniques will be developed to provide that capability if it is required in the Exploratory Shaft. Studies will be conducted of paleohydrology, tectonics, seismicity, volcanism, and weapons-test-induced ground motion. Laboratory analyses of cores and water from boreholes will be conducted. Repository sealing technology developed in the laboratory will be tested in the field.

4.1.3.1 Geodetic surveys

Geodetic surveys to monitor any tectonic movements that may occur in the Yucca Mountain area began in 1983 and will be continued during site characterization. Surveying utilizes a 70-km (44-mi) level line that extends from the southwest corner of Crater Flats at U.S. 95 along existing roads in Crater Flats, and then crosses Yucca Mountain, Jackass Flats, and Skull Mountain, and ends in Rock Valley. In addition, a quadrilateral network is installed across selected faults on Yucca Mountain. Both the installation of bench marks and the initial survey were completed in June 1983. A resurvey took place near the end of 1983, and yearly resurveys will be made to measure changes, if any, of the earth's crust in this area. Wherever possible, the bench marks required were installed along existing roadways. However, some were installed where no roads existed. Access to these bench marks will require the use of either an off-road vehicle or a helicopter.

4.1.3.2 Horizontal core drilling

Experimental horizontal core drilling from the surface was conducted at Fran Ridge to develop prototype dry-drilling techniques for use in the Exploratory Shaft. Surface core drilling at Fran Ridge required a bladed road for access, a drill pad about 30 by 46 m (100 by 150 ft) for emplacement of the horizontal boring machines, and a smaller pad, 18 by 6 m (60 by 20 ft) for electrical power generators. Additional prototype drilling activities may be conducted during site characterization.

4.1.3.3 Paleohydrology studies

Potential changes in the regional ground-water system in the future are being estimated based upon studies of past climates. These studies include investigation of the paleohydrology of the Amargosa Desert, coring of lake sediments in southern Nevada, and description of the late Quaternary climates based upon fossilized packrat middens. In addition, projection of future flood hazards are being made based upon evidence of past flood levels in Fortymile Wash and its tributaries. It is anticipated that these studies will continue during site characterization.

4.1.3.4 Tectonics, seismicity, and volcanism studies

The potential for faulting, earthquakes, volcanic activity, and accelerated erosion in the Yucca Mountain area is being assessed. These studies are investigating the rate, intensity, and distribution of faulting. Emphasis is being placed upon monitoring and interpreting present seismicity, studying the history of volcanism, and evaluating past rates of erosion and deposition. Volcanic and tectonic studies focus on the history of Pliocene and Pleistocene activity within the southern Great Basin, with an emphasis on the Yucca Mountain site. These studies utilize data from boreholes, trenches, mapping activities, geophysical surveys, and seismic-monitoring stations, and will be continued during site characterization.

4.1.3.5 Weapons test seismic studies

The purpose of the weapons test seismic investigations is to measure the ground motion at Yucca Mountain that is caused by underground nuclear explosions at the Nevada Test Site. These investigations relate ground motion at Yucca Mountain to such parameters as distance to the explosion site, depth of burial, and yield of the explosion. Measurements are made in boreholes and on the surface at Yucca Mountain. These investigations may be continued dur site characterization.

4.1.3.6 Laboratory studies

Laboratory activities necessary to characterize the tuff at Yucca Mountain include geochemistry, mineralogy/petrology, mineral stability, and geochronology. In addition, development of a technology for shaft and borehole sealing is being conducted in the laboratory. Most of the laboratory work for site characterization and technology development will be done using existing offsite facilities and equipment. No new offsite buildings or facilities will be required, and additional staff requirements are minimal.

4.2 EXPECTED EFFECTS OF SITE CHARACTERIZATION

The effects that might result from the site-characterization activities described in Section 4.1 are divided into two categories: effects on the physical environment, and effects on socioeconomics and transportation conditions. Both positive and negative effects are considered. A brief discussion of resource commitments also is provided. Finally, the environmental effects are summarized and possible mitigation measures are discussed.

4.2.1 Expected effects on the physical environment

The expected effects of site-characterization activities on the physical environment include effects on geologic and hydrologic conditions, land use, and surface soils. The expected effects on ecosystems, air quality, noise levels, aesthetic quality, and on cultural, historical, and archaeological resources are considered separately. The level of detail of the discussion is commensurate with the expected effect.

4.2.1.1 Geology, hydrology, land use, and surface soils

Geologic impacts

The activities scheduled for site characterization will have a negligible effect on the geology of Yucca Mountain. Rock will be physically removed during excavation of the exploratory shaft and from several boreholes, but only minor spalling is expected to occur along the insides of these openings (see Chapter 6 discussion of rock-characteristics guidelines). On the basis of the information now available, there are no site characterization activities scheduled that would significantly impact the geology of the Yucca Mountain site.

Hydrology

Perennial sources of surface water do not occur at Yucca Mountain. However, heavy precipitation may form ephemeral pools known as catch basins. Catch basins are the only sources of water for wildlife at Yucca Mountain. None of the runoff from the mountain is used by humans for any purpose.

Heavy rains can cause locally accelerated erosion and gullying of dirt roads, especially on steep slopes. Proper engineering designs of new access roads and other facilities will be used to reduce these impacts to the extent possible. A significant increase in flooding is not expected.

The water table is about 540 m (1780 ft) below the surface at the Exploratory Shaft location, and it is about 90 m (300 ft) below the bottom of the proposed Exploratory Shaft. Therefore, the water table will not be affected by the Exploratory Shaft. However, hydrologic exploratory boreholes will be drilled to the water table so that the water table can be mapped. These wells will be capped after completion of ground-water studies. Ground-water withdrawals for construction and operation activities during site characterization are not expected to impact the ground-water system. The planned site-characterization activities will not significantly impact the hydrologic conditions at Yucca Mountain.

Land use

The Yucca Mountain site is located entirely on Federally controlled lands that are not now being actively used, and there is no plan for either private or public use of the lands during the time proposed for site characterization. The U.S. Air Force considers the airspace over Yucca Mountain to be essential to support occassional tactical air missions into and out of the Nellis Air Force Range (NAFR). The proposed site characterization activities will not interfere with use of the airspace; therefore, no land use impacts are predicted.

The Nevada Nuclear Waste Storage Investigation (NNWSI) Project activities, which either have been or will be conducted on BLM land, are governed by BLM/DOE Cooperative Agreement FCA-N5-2-2 (Richards and Vieth, 1983). Preliminary site characterization investigations on the Nellis Air Force Range portion of the Yucca Mountain site were conducted under Air Force Permit No. DACCA09-4-80-332. Because Congress has not yet acted on a U.S. Air Force request for renewal of the withdrawal of the NAFR, administrative control of the land has reverted to BLM. BLM/DOE Cooperative Agreement FCA-N57-83-1 provides authority for the DOE to conduct preliminary investigations and site characterization activities on the land. Upon favorable Congressional action on the U. S. Air Force land withdrawal request, a new use permit will be negotiated between the DOE and the U. S. Air Force. The land that is covered under the agreement is significant because the bulk of the proposed site characterization activities, which includes the Exploratory Shaft, will occur in this area.

The BLM Cooperative Agreements and the U. S. Air Force permit were each accompanied by an Environmental Assessment (EA) of the activities proposed. Each Environmental Assessment resulted in a finding of no significant impact, and each agreement requires mitigation activities and restoration of disturbed areas.

Surface soils

Most field activities to be conducted during site characterization will occur within a 8-km (5-mi) radius of the Yucca Mountain site, and a small portion of this area will be disrupted. The soils will be disturbed during site-preparation activities for boreholes and for the Exploratory Shaft, and during construction of access roads and surface facilities for the Exploratory Shaft. Assuming construction of 20 borehole drilling access roads, each 8 km (5 mi) long and 15 m (50 ft) wide, a total of 246 ha (606 acres) of surface soils may be disturbed. Each borehole drilling pad with its associated facilities and equipment may disturb an additional 1 ha (2.5 acres) disturbed, which adds to a total of 20 ha (50 acres). An estimated 8 ha (20 acres) of soil will be cleared and graded in preparation for construction the Exploratory Shaft surface facilities. The above activities disrupt a total of approximately 280 ha (696 acres) of surface soils. In addition, geophysical and geodetic surveys and geologic mapping will disturb an additional acreage in the Yucca Mountain area because of off-road driving, constructing small drill pads, clearing and grading areas for geophysical studies, and trenching for fault studies.

Removal and compaction of soils during site characterization activities will disrupt the existing physical, chemical, and biotic soil processes. Disturbing the soil will temporarily accelerate wind and water erosion, although engineering measures can mitigate these potential impacts to some extent. Reclamation of these disturbed lands will be undertaken; the effectiveness of reclamation in arid environments presently is being studied. The acreage that will potentially be disturbed is relatively small compared with the tens of thousands of acres of relatively undisturbed desert land surrounding the site.

4.2.1.2 Ecosystems

The major impact associated with site characterization activities will be the removal of habitat. Drill pads, roads, utility lines, trenches, seismic lines, and off-road driving will result either in removal or compaction of soils and destruction of vegetation that will subsequently displace animals. Approximately 280 ha (696 acres) of habitat will be disturbed throughout the study area. Wildlife displaced from activity areas because of noise and movement of heavy equipment will probably return to the area after the activity ceases.

Before beginning any activity that will disturb an area, field surveys will be conducted to assess impacts and to assure protection of the desert tortoise and the Mojave fishhook cactus. Construction activities will be sited to avoid populations of the cactus and desert tortoise wherever possible. When found, tortoises will be relocated from activity sites.

Some natural water catchment basins may be destroyed, which will directly affect wildlife by reducing the availability of ephemeral water. If drilling fluid sumps are breached, vegetation in the effluent plume may be either damaged or destroyed. Muck that will result from excavation may cause similar problems.

Increased human activity could contribute to an increased potential for range fires during site characterization activities. The vegetation associations that are dominated by black brush are considered to present the greatest fire hazard. In wet years, the annual grass (desert brome) presents a hazard everywhere. Range fires can be ignited by catalytic converters on off-road vehicles, especially in stands of dry grasses. Fire hazard will be reduced by spacing buildings and removing vegetation in work areas.

4.2.1.3 Air quality

Site-characterization activities will generate particulate and fossil-fuel combustion-related emissions. Particulates will be generated by blasting, muck removal and stockpiling, the batch concrete plant, surface leveling, wind erosion, and travel over unpaved roads. The main fossil-fuel combustion emissions will be from diesel-powered equipment. These emissions will consist of carbon monoxide (CO), nitrogen oxides (NO_x), particulates (TSP), and hydrocarbons (HC).

Fugitive particulate emissions and dust vented from mining operations are expected to have the greatest effect on the existing air quality. Regulations established to control such emissions and their resultant concentration in the atmosphere (see Chapter 5) will define the allowable impact of these particulate emissions. Yucca Mountain is in an area where the existing air quality is considered to be better than State and Federal ambient air quality standards, and as such, may be subject to the U. S. Environmental Protection Agency's (EPA's) Prevention of Significant Deterioration (PSD) regulations. Because of the uncertainties of Exploratory Shaft emissions at this time, no determination has been made as to whether or not site characterization activities require PSD evaluation.

In the event that PSD regulations are deemed applicable, maximum project-related increases of TSP over existing concentrations would be limited to 37 $\mu g/m^3$ for a 24-hour average and 19 $\mu g/m^3$ annually. If the project is exempt from PSD regulations, then Nevada and National Ambient Air Quality Standards will apply; these are absolute (project plus background) values of 150 $\mu g/m^3$ (24-hour) and 60 $\mu g/m^3$ (annual). In either case, compliance with these standards probably will be determined from atmospheric dispersion modeling. The meteorological data collected in the vicinity of the site will be used in this effort.

4.2.1.4 Noise

Wildlife is the only sensitive noise receptor in the vicinity of site characterization activities. The effects of noise on wildlife are speculative. Laboratory experiments have shown both permanent and temporary physical and behavioral effects at levels in the 75 dBA to 95 dBA range (EPA 1971a; Brattstrom and Bondello, 1983; Ames, 1978.) To be conservative, 75 dBA will be assumed to be the level at which wildlife could be affected.

The construction of Exploratory Shaft surface facilities will produce the maximum sustained noise levels associated with site characterization activities. Other site characterization activities will not contribute significantly to these noise levels because of their small magnitude and location. Construction techniques have yet to be specified. Therefore, it has been assumed that construction equipment requirements will be similar to the construction of other large facilities. As can be seen on Table 4-1, maximum noise levels will have a resultant noise level of about 88 dBA at 150 m (500 ft) from the focal point of construction activities. Because the resultant level at 150 m (500 ft) is based upon the loudest instantaneous levels anticipated, it provides for a very conservative analysis. Based upon this resultant noise level, wildlife may be impacted within 0.7 km (0.4 mi) of the construction site.

Table 4-1. Noise from construction of the Exploratory Shaft

Equipment: Type	Equipment: Number	Resulting noise level at 15.2 m (50 ft) (dBA)
Bulldozers	1	80[a]
Earth movers	6	78[a]
Pile drivers	1	101[b]
Boring machines	1	98[b]
Front-end loaders	6	76[a]
Gravel elevators	1	88[b]
Grader scrapers	1	88[b]
Backhoes	1	85[b]
Shovels	1	82[b]
Cranes	6	83[b]
Steam rollers	1	75[a]
Air compressors	1	81[b]
Concrete mixers	1	85[b]
Drill rigs	1	101[a]
Truck handling conveyor	1	88[b]
Conveyors	1	88[b]
Service vehicles	30	88[b]
Resultant noise level at 150 m (500 ft): 88 dBA		

[a] Source: EPA, 1971b

[b] Source: EPA, 1974

4.2.1.5 Aesthetics

The two access roads from Fortymile Canyon to the top of Yucca Mountain can be seen from eastern Jackass Flats and Skull Mountain, both of which are on the Nevada Test Site. None of the activity areas that are located in washes can be seen, except from the site area. All of the construction areas are topographically screened from view so that none can be seen from the ground outside the NTS. However, the entire project area can be seen from the commercial airline flight path which follows U.S. 95 south of the Nevada Test Site. Considering this limited public visual exposure, the visual impact will not be significant.

4.2.1.6 Archaeological, cultural, and historical resources

In 1983, a survey was conducted by Pippin et al. (1983) to locate archaeological and cultural resources in the NNWSI Project area. This survey discovered 178 prehistoric and 6 historic sites. Direct impact to these sites may occur during Exploratory Shaft surface facility construction, mining, and decommissioning, during site preparation for borehole drilling, during geophysical surveys or other surface disturbing activities. Physical disturbance of archaeological sites by NNWSI Project activities could result in the loss of data that are important to archaeological research. Indirect impacts are those that result from either unauthorized excavation or collection of artifacts and can result from improved access to the area. Nonscientific excavation or collection can limit or reduce the research value of the sites. The removal of just a few chronologically or functionally sensitive artifacts can reduce or distort the cultural value of small sites. The sites identified in the 1983 survey will be avoided when possible. If a site cannot be avoided, the site will be salvaged and the findings will be documented so that the artifacts and important knowledge about the site will not be lost.

4.2.2 Expected effects on socioeconomic and transportation conditions

Evaluation of the expected effects of site characterization activities include considerations of the potential economic, demographic, community services, social, and fiscal and governmental impacts. For this analysis, the affected region is defined as the bicounty area of Nye and Clark counties (see Figure 3-22). Some project activities will take place in southern Nye County, which is near the Las Vegas urban area. Other NNWSI Project work will take place in the Las Vegas area, including work that will be performed at the existing DOE offices in Las Vegas.

The social and economic impacts of site characterization will be small and insignificant with the possible exception of the fiscal effect on State and local participation in the repository-related planning processes. Actions that would mitigate this potential effect are specified in the Nuclear Waste Policy Act.

4.2.2.1 Effect on economic conditions

The assessment of the effect on economic conditions in the region is based upon an evaluation of NNWSI Project employment and materials requirements and related population effects. As described below, this effect is considered positive but insignificant.

Employment

Direct regional labor requirements for site characterization consist of both onsite workers and offsite workers who would be located at the DOE and contractor offices in the Las Vegas area. The sum of onsite and offsite employment is the total direct labor impact on the region. Employees of national research organizations, such as the National Laboratories, would support the NNWSI Project and would conduct brief visits to the area; however, the regional employment effect of their presence would probably be small.

Table 4-2 shows the anticipated number of onsite and offsite workers directly required by the project. The table also indicates the level of indirect support employment that is likely to be associated with that direct employment. The peak total site characterization employment is estimated to be an increase of about 670 jobs over the employment level that has been projected without site characterization. This represents about 0.20 percent of projected 1985 Nye and Clark County employment (see Tables 3-14 and 3-15). Therefore, the employment impact of site characterization is considered insignificant.

Most of the direct work force shown in Table 4-2 would consist of individuals who are currently employed on DOE activities related to the NNWSI Project. Accordingly, only about forty percent of the 264 workers employed during the peak employment period would represent new NNWSI Project employees. As indicated on the schedule shown in Table 4-2, the southern Nevada labor market would experience an additional increased employment of only about 250 jobs over the first two years of site characterization. This same increase could occur over a period as brief as six months under alternate budgetary scenarios being considered by the DOE. In either case, the employment impact is positive and insignificant.

Materials

Most of the materials required for site characterization would be procured as part of the Exploratory Shaft project. Table 4-3 displays the estimated materials requirements for the Exploratory Shaft. While a substantial portion of these materials would be procured through contractors located in southern Nevada, it is anticipated that most of these nonlabor resources would ultimately be obtained from outside the bicounty region, with the possible exception of fuel and power (McBrien and Jones, 1983).

Table 4-2. Peak regional employment effects of site characterization

Category of employment	Surface construction (3/85-8/85)	Subsurface construction and testing (8/85-6/87)	Testing only (6/87-7/89)
Direct	198	264	222
Onsite	72	138	96
Offsite	126	126	126
Indirect	305	407	342
Total	503	671	564

Table 4-3. Resources committed to the Exploratory Shaft[a]

Resource	Surface construction	Shaft construction	Drift construction and testing	Decommissioning
Time period, months	5-6	15	Drift - 7 1/2 Test - 48	12
Personnel (includes indirect and support), persons per shift				
Day shift	135	200	135[b] 100[c]	100
Swing shift	135	200	85[b] 50[c]	50
Night shift	135	200	85[b] 50[c]	50
Energy				
Gasoline, L (gal)	3.8×10^5 (1.0×10^5)	3.8×10^5 (1.0×10^5)	15.2×10^5 (4.0×10^5)	3.8×10^5 (1.0×10^5)
Diesel fuel, L (gal)	9.0×10^5 (2.4×10^5)	4.5×10^5 (1.2×10^5)	4.5×10^5 (1.2×10^5)	4.5×10^5 $(1.2 \times 10^5$
Electricity, MWh	140	4,500	14,000	140
Explosives, kg (lb)		3.3×10^4 (7.2×10^4)	2.2×10^4 (4.8×10^4)	
Materials				
Cement, kg (lb)	6.0×10^4 (1.3×10^5)	7.7×10^5 (1.7×10^6)		
Steel, kg (lb)	1.4×10^4 (3.0×10^4)	2.3×10^5 (5.0×10^5)		
Copper wire, kg (lb)	3.6×10^4 (8.0×10^4)	2.3×10^3 (5.0×10^3)		
Wood power poles, each	90			

[a] For calculating transportation effects in Section 4.2.2.5, the following assumptions were used:

1. Concrete: 11.5 m^3/truck; 23 m^3/railcar.
2. Structural steel: 18 metric tons/truck; 90 metric tons/railcar.
3. Fuel: 56,800 L/truck; 11,400L/railcar.

[b] First 7 1/2 months.

[c] Remaining 40 1/2 months.

4.2.2.2 Effects on population density and distribution

The maximum population impact of site characterization would be to increase the bicounty population by 1790 residents. In other words, if the entire direct and indirect work force associated with the project were to leave the area at the completion of site characterization, then southern Nevada's population growth would decline by about 1790 persons. This is one-third of one percent of the 1983 population of that area. Thus, the population impact is considered small and insignificant. Furthermore, because many of the workers that are required to conduct the site characterization activity are already either directly or indirectly employed on other DOE activities in the same area, the actual population effect of site characterization is expected to be even less than described above.

4.2.2.3 Effects on community services

Effects on social conditions would be caused by significant changes in the service-area population. Because no significant population changes are projected, no effects on community services are expected from site characterization. Similarly, no significant effects on the existing transportation infrastructure are expected.

4.2.2.4 Effects on social conditions

Effects on social conditions would be caused by significant changes in the service-area population. Because no significant changes in either regional or local population levels will accompany Yucca Mountain site characterization activities, the sorts of social impacts that are often associated with changes in community population levels will not occur. However, some social effects may result from an increase in the public's awareness of the NNWSI Project. This might result if a decision to select Yucca Mountain for site characterization were to bring with it increased local and regional controversy and dissent over the prospect of a high-level radioactive waste repository at Yucca Mountain. The effects might include changes in social organization that is associated with the formation of opposition and/or support groups, disputes within existing groups, and a focused attention on repository-related issues.

4.2.2.5 Effects on fiscal and governmental structure

Effects on fiscal and government structure are related to employement, population, community services, and State and local government agency participation in site-characterization activities. The recommendation of Yucca Mountain as a candidate site is not expected to have significant impact either on regional and local employment or on population and community services. Therefore, no significant fiscal impacts are anticipated from either population or employment effects of site characterization. While the social effects of any changes in the level of controversy surrounding the NNWSI Project may affect the political organization and potentially the governmental structure of the area, such effects would probably be insignificant.

A potentially significant effect of recommending Yucca Mountain for site characterization would be an increase in State and local participation in planning activities. The Nuclear Waste Policy Act explicitly recognizes the fiscal implications of State participation and provides a mechanism for financial assistance for the following purposes:

1. To review DOE activities undertaken to assess the potential social, public health and safety, and environmental impacts of a repository.

2. To develop a request for impact assistance associated with the development of a repository.

3. To engage in any monitoring, testing, or evaluation activities with respect to site characterization programs.

4. To provide information to State residents about State and Federal actions concerning the potential repository.

5. To request information from, and to make comments and recommendations to, the Secretary of Energy regarding the siting of a repository (96 stat. 2221).

4.2.2.6 Expected effects on transportation

During site characterization transportation effects will be concentrated along U.S. 95 as workers and materials are transported to and from the site. Table 4-2 indicates that subsurface construction will employ a maximum work force of approximately 138 onsite people. As stated in Section 4.2.2.1, about 60 percent of these workers currently are employed at the Nevada Test Site. Therefore, little additional traffic is anticipated. Assuming each new worker will drive a private automobile, the resulting increment of approximately 55 vehicles during the evening peak hour from 5 P.M. to 6 P.M. will not cause the service levels to change on any segment of U.S. 95.

The transport of materials will occur during all phases of site characterization. Material requirements and time frames were listed in Table 4-3. By using the per-shipment quantities noted in Table 4-3, the maximum amount of daily shipments are expected to occur during Exploratory Shaft construction. Assuming 250 work days per year, approximately one truck shipment per day would be required. This would not present any adverse effects on any part of U.S. 95.

4.2.3 Irreversible and irretrievable commitment of resources

The majority of the resources that will be committed to site characterization will be devoted to the Exploratory Shaft. Therefore, this section will focus on resources committed to Exploratory Shaft construction and operation (Table 4-3). The quantities listed in Table 4-3 are estimates. Items such as gasoline consumption, steel weights of prefabricated buildings, and indirect manpower loadings are not customarily included as part of engineering construction design studies. As a result, the estimates in Table 4-3 were obtained by consulting several experienced engineers, and these estimates may change as additional information becomes available.

4.2.4 Summary of environmental effects

A summary of the characterization activities and their potential impacts is shown in Table 4-4. The table lists the activities and their impact-causing components, the expected impacts, and mitigation or restoration strategies.

Land-surface disturbance will be the most widespread and lasting impact on the physical environment. Wind and water erosion of disturbed soil will occur locally.

Restoration of the disturbed areas will require recontouring and either ripping or disking. Topsoil will be added where necessary. The surface soil will be prepared to reduce water erosion and to facilitate revegetation.

Impacts to archaeological sites are of concern. Most of the project area has been surveyed for archaeological sites, and the potentially significant sites that are threatened by either direct or indirect impact will be protected or salvaged.

Impacts on protected species are possible but unlikely. Two species will be protected because they have been under review for listing as threatened and endangered species by the U.S. Fish and Wildlife Service. The Mojave fishhook cactus will be avoided where possible. Desert tortoises will be avoided, or they will be moved out of danger. Tortoise burrows will be avoided where possible.

No significant socioeconomic or transportation impacts are expected. There will be virtually no aesthetic, surface-water, or ground-water impacts. Air quality impacts will be greatest for particulates (dust). Increased noise levels may disturb wildlife; noise impacts to humans are not expected.

Table 4-4. Site characterization activities, their effects and impacts, and mitigation/restoration strategies

Activity	Mitigation/restoration strategy	Effects/impacts
I. BOREHOLE DRILLING		
Clearing, cutting, and filling of about 160 km (100 mi) of access roads (about 246 ha or 606 acres): roadbed, borrow pit, staging area, cuts Disturbance of about 20 ha or 50 acres for all drilling sites: drill pad, mudpit, borrow area, staging area, parking area. Travel on unpaved roads	<u>Mitigation:</u> Preconstruction biological surveys for species of concern and archaeological surveys with site protection/salvage. Containment of effluent, stockpiling topsoil, wet suppression of construction dust <u>Restoration:</u> Rip of disk road surface, recontour to minimize erosion, reestablish natural drainage, and blend with natural landforms. Close and seal borehole, empty and fill in mudpit, regrade and contour drill pad, rip or disk disturbed surfaces to minimize erosion and enhance revegetation. Remove debris and drilling mud residue to NTS landfill. Distribute stockpiled topsoil over disturbed soil. Perform additional restoration, as appropriate	Change of contour, loss of topsoil, soil compaction, drilling mud residue, destruction of vegetation and burrowing wildlife, increased erosion and sedimentation, engine exhausts, dust, threat to archaeological sites, and noise

Table 4-4. (Cont'd.)

Activity	Mitigation/restoration strategy	Effects/impacts
II. GEOPHYSICAL SURVEYS		
Off-road driving, clearing of survey lines, shot-hole pad construction, clearing staging areas, seismic lines	Mitigation: Avoid sensitive biologic species and habitats and archaeologic sites identified in preactivity surveys. Enforce restriction on off-road driving Restoration: Rip or disk vehicle trails, seismic lines, cleared areas, and pads. Perform additional restoration as appropriate	Off-road vehicle trails sometimes erode to deep ruts. Soil compaction of seismic lines
III. GEOLOGIC MAPPING		
Off-road vehicle driving: trenching, storage of trench material	Mitigation: Avoid sensitive biologic species and habitats and archaeologic sites identified in preconstruction surveys. Enforce restriction on off-road driving Restoration: Fill in trench, contour surface. Perform additional restoration as appropriate.	Soil excavation, mixing of topsoil and subsoil, storage of soil, destruction of vegetation in access trail and trench/storage area, off-road driving
IV. ROCK MECHANICS FIELD EXPERIMENTS		
Excavation of short drifts in G-tunnel, muck disposal	Mitigation: none Restoration: none	Dust

Table 4-4. (Cont'd.)

Activity	Mitigation/restoration strategy	Effects/impacts
V. EXPLORATORY SHAFT		
Site preparation Grade, fill, level, pave/stabilize three-acre pad. Disturb 20 acres for access roads, power lines, water line, 60,000 m borrow area. sewage lagoon, muck pile, diversion channel, water tank	Mitigation: Preconstruction biological and archaeological surveys; no sensitive species or archaeological sites in area. Minimization of area disturbed. Trucking debris and trash to landfill. Stockpiling of topsoil from borrow area Restoration: Remove paving and concrete pads, surface debris, dispose in NTS landfill. Break up stabilized pad and mix with underlying soil. Fill in sewage lagoon. Recontour site and regrade to reduce erosion and enhance moisture retention. Distribute topsoil. Perform additional habitat restoration as appropriate	Change of contour, loss of topsoil, soil compaction, destruction of vegetation and burrowing animals, displacement of wildlife, dust, engine exhaust, construction debris, engine exhaust, and noise
Surface facility construction Install concrete pads and foundations, erect buildings and install trailers, water tank, electrical substantion, fans, compressors, fence, utilities revetments	Mitigation: Wet suppression of dust, avoid driving over flammable vegetation, provide firebreak around site and building, truck debris to landfill. Replace topsoil on borrow area to start revegetation Restoration: (See Site preparation)	Dust, accidental fire, engine exhaust, construction debris, and noise

Table 4-4. (Cont'd.)

Activity	Mitigation/restoration strategy	Effects/impacts
V. (Cont'd.)		
<u>Exploratory Shaft Construction</u> Mine out shaft and rooms, line shaft and install internals, install headframe and hoists, construct muck pile, drill exploratory boreholes	<u>Mitigation:</u> Wet suppression of muck dust, covering over of zeolite muck pile (berm prevents dispersion on surface), monitor leachate and control further, if necessary, and truck construction and batch plant waste to landfill	Dust from muck, zeolite dust, blasting dust and gases, dewatering effluent, muck pile leaching, concrete batch plant dust and residue, construction debris, engine exhaust, and noise
<u>Exploratory Shaft Operation</u> In situ test borehole drilling, travel on unpaved roads	<u>Mitigation:</u> Dispose of drilling effluents on muck pile, truck trash and debris to NTS landfill, control fire on site, maintain sewage decomposition balance, control travel on unpaved roads	Shaft effluent fluids, dust operational trash and debris, accidental fire, engine exhaust, and noise
VI. OTHER ACTIVITIES		
<u>Geodetic surveys, paleohydrology study, and weapons test seismic study</u> Off-road driving	None	Soil compaction and increased erosion potential
<u>Horizontal core drilling</u> Access road, drill pad, generator pad	Same as borehole drilling	Same as borehole drilling
<u>Tectonics, seismicity and volcanism study</u> Off-road driving, borehole drilling, trenching	Same as borehole drilling and geologic mapping	Same as borehole drilling and geologic mapping
<u>Laboratory studies</u>	None	None

DRAFT

Table 4-4. (Cont'd.)

Activity	Mitigation/restoration strategy	Effects/Impacts
VII. DECOMMISSIONING		
Final Disposition of Exploratory Shaft (Strategy 3, Section 4.1.2.3) Remove internals, backfill from muck pile, cap shaft; remove all buildings and equipment, water tank, utility stations, etc.	Mitigation: Wet suppression of dust from muck, trucking debris to Nevada Test Site landfill Restoration: See Exploratory Shaft site preparation	Backfilling dust, construction debris, engine exhaust, and noise
Boreholes Either cap boreholes with a plate or seal with ground matching grout	Mitigation: Wet suppression of dust, trucking debris to Nevada Test Site landfill Restoration: See Exploratory Shaft site preparation	Dust, engine exhaust, and noise

4.3 ALTERNATIVE SITE CHARACTERIZATION ACTIVITIES

Alternatives to the proposed Exploratory Shaft design include alternate methods of shaft construction, varying the number of boreholes, and varying the size, number, and location of underground test facilities. Some variations in the design of surface support facilities and in the degree of site disturbance before site preparation and Exploratory Shaft construction would also occur as a function of the shaft design. For example, preconstruction site disturbance for a drilled shaft would require sinking two confirmatory boreholes that would be used for geologic and hydrologic testing. Only one confirmatory hole would be required if the shaft is mined, which would result in less surface disturbance. In addition, maintaining access to the additional borehole for future testing would reduce the area available to optimally site other surface support facilities.

Drilling of the Exploratory Shaft would also require the inclusion of a lined mudpit for the separation of cuttings and drilling fluid. The volume of cuttings to be removed from the shaft would exceed the capacity of a mudpit that would be located adjacent to the shaft. The size of such a mud pit is constrained by the topography of the site. Thus, this limited capacity would require both periodic dredging of a mudpit by either dragline or similar mechanical means and transport of the cuttings to a second lined pit located away from the immediate shaft vicinity.

During the drilling process, the shaft is partially filled with driller's mud, which is a drilling fluid consisting of water, clay, and polymer. This fluid provides hydrostatic support to the shaft wall, lubricates and cools the drill bits and reamers, and carries rock chips from the face of the cutting head to the surface. These construction practices severely limit the ability to characterize the unsaturated zone. The most important potential adverse impact of drilling would be the masking effect it would have on in situ moisture conditions because the drilling fluids are injected under hydrostatic pressure.

In conclusion, the drilling alternative to shaft mining is not considered to be a viable alternative. Underground test facility alternatives will have either little or no impact on the environmental consequences of this proposed project because most of the impacts will result from Exploratory Shaft construction and off-road driving.

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Chapter 5

REGIONAL AND LOCAL EFFECTS OF LOCATING A REPOSITORY AT YUCCA MOUNTAIN

If the Yucca Mountain site is recommended for site characterization, it could be found suitable for subsequent selection and development as a repository. A preliminary conceptual design for a repository at Yucca Mountain has been completed (Jackson, 1984a). Section 5.1 summarizes this design and constitutes a description of a proposed action for the subsequent sections, which assess the regional and local impacts of locating a repository at Yucca Mountain. Alternative repository designs have been proposed in the Mission Plan for the Civilian Radioactive Waste Management Program (DOE, 1984a) and in Generic Requirements for a Mined Geologic Disposal (DOE, 1984b). These alternative designs involve inclusion of lag storage at the repository site, receipt of five-year old spent nuclear fuel elements, and repository construction and operation on phased schedules that are different than those assumed in this chapter. None of these alternatives are described or evaluated in this chapter.

For the sake of readability, this chapter has been written as if Yucca Mountain has been recommended for development as a repository. The reader should not conclude that the decision has been made either to initiate site characterization or to construct the first repository at Yucca Mountain. The repository siting process is defined in the Nuclear Waste Policy Act of 1982.

5.1 THE REPOSITORY

This section describes the construction, operation, and decommissioning of a nuclear-waste repository at Yucca Mountain. A repository consists of a surface facility, a subsurface facility, and a means of access from one to the other. An artist's rendition of a nuclear-waste repository is shown on Figure 5-1.

The function of a repository is the permanent isolation of spent fuel, of solidified high-level waste from reprocessing, and of other nuclear wastes associated with the commercial generation of nuclear power such as transuranic (TRU) waste. In addition, low-level waste generated at the repository from the handling of incoming wastes will also be emplaced in the repository. The total amount of waste to be emplaced at the repository is limited by the NWPA to the equivalent of 70,000 metric tons of uranium (MTU) until a second repository is in operation. Emplacement of 70,000 MTU is assumed for purposes of this analysis.

The Yucca Mountain site is located approximately 22 km (14 miles) due north of the town of Amargosa Valley. The surface facility will be along the eastern foothills of Yucca Mountain. The subsurface facility will be located approximately below the ridgeline of Yucca Mountain. The proposed highway and rail access routes to the site are shown on Figure 5-2. The proposed highway access will originate at U.S. 95 approximately 1.0 km (0.5 mi) west of the town of Amargosa Valley and extend about 25 km (15 mi) northward to the site. The proposed rail line will originate at Dike Siding 18 km (11 mi) northeast of downtown Las Vegas and extend approximately 142 km (85 mi) to the site.

Locating a repository at Yucca Mountain may result in regional and/or local impacts over a preclosure period of approximately 60 years. The preclosure period includes the construction, operation, possible retrieval, and decommissioning phases. Surface facilities will be constructed and some of the subsurface area will be excavated during the 5-year construction phase. Nuclear waste will then be received and emplaced over the next 30 years during the operations phase. Excavation of subsurface facilities will continue in tandem with waste emplacement for the first 28 years of the operations phase. During the 20-year retrievability phase, the facilities as well as the surrounding environment will be monitored, and the surface and subsurface facilities will be maintained so that the emplaced wastes could be retrieved if necessary. A decision to retrieve the emplaced wastes could be made at any time during this phase. If a decision to retrieve the waste was made during the last year of the retrievability phase, the lifetime of the project would be extended for up to 30 years. The repository will be decommissioned and closed during the 5-year decommissioning period. The following paragraphs describe

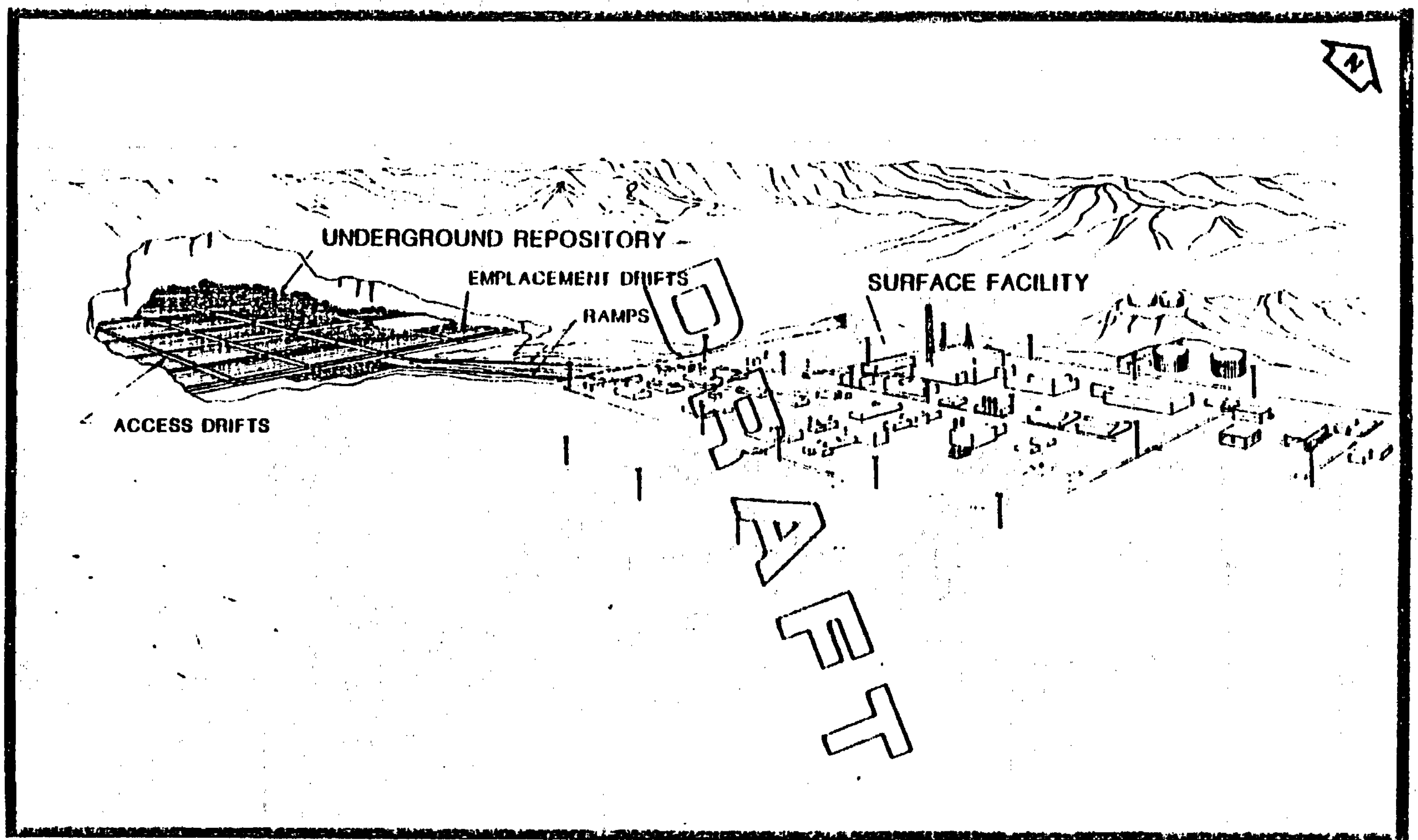

Figure 5-1. Artist's rendition of the proposed Yucca Mountain repository.

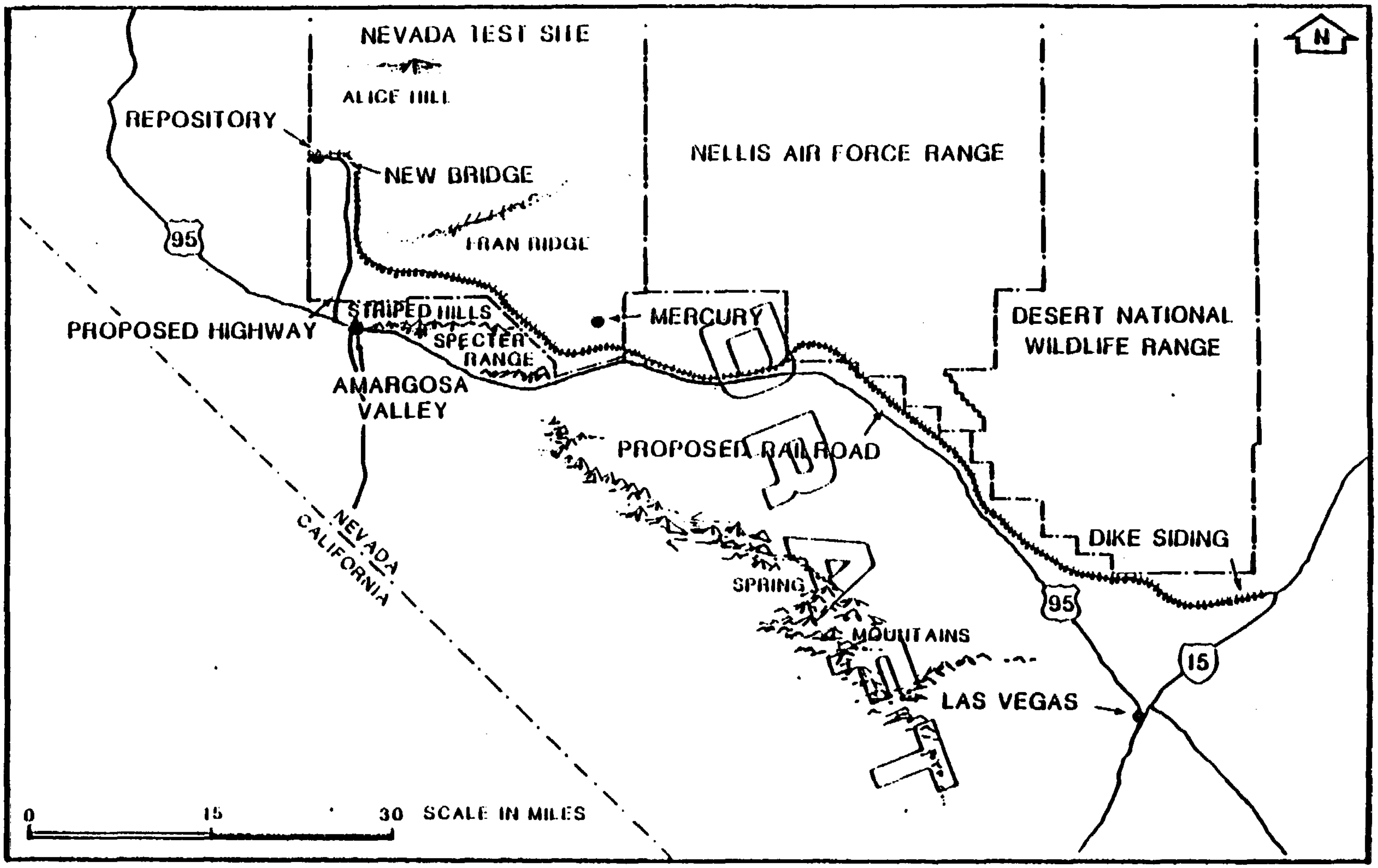

Figure 5-2. Proposed highway and rail access route to the Yucca Mountain repository.

the activities proposed during the construction, operation, retrievability, and decommissioning phases. The activities and design are based on a preliminary conceptual design of a repository at Yucca Mountain and are expected to change if the Yucca Mountain site is recommended for further study.

5.1.1 Construction

Construction of the repository will include construction of utilities, buildings, and other structures on the surface, sinking of shafts and ramps to the subsurface, and the development of all underground areas. Most surface construction will occur at the main surface facility. Construction away from the main facility (offsite) will include construction of highways and railroad connections, mine ventilation buildings, and other ancillary facilities.

5.1.1.1 The surface facilities

The surface facilities at Yucca Mountain will encompass approximately 30 ha (75 acres) of land, all of which would be enclosed by a security fence. These facilities will be located along the gently sloping east side of Yucca Mountain, as shown on Figure 5-3.

The surface facilities will be used to conduct waste-handling, to support the underground operations, to handle mined material, and for general repository support services. The underlying material along the east side of Yucca Mountain is considered suitable for conventional foundations for construction of the surface facilities. A preliminary layout of the surface facilities at Yucca Mountain is shown on Figure 5-4.

The waste-handling and packaging facilities will include buildings and equipment that will receive and package all incoming wastes (see Section 5.1.2.2 for more details). A facility will also be constructed to handle and package all of the solid, liquid, and gaseous radioactive wastes that are produced onsite such as protective clothing, decontamination streams, ventilation filters, etc. Similar, though smaller, facilities have been constructed elsewhere for remote handling activities, and the construction of these facilities at Yucca Mountain are not expected to present any technical difficulties.

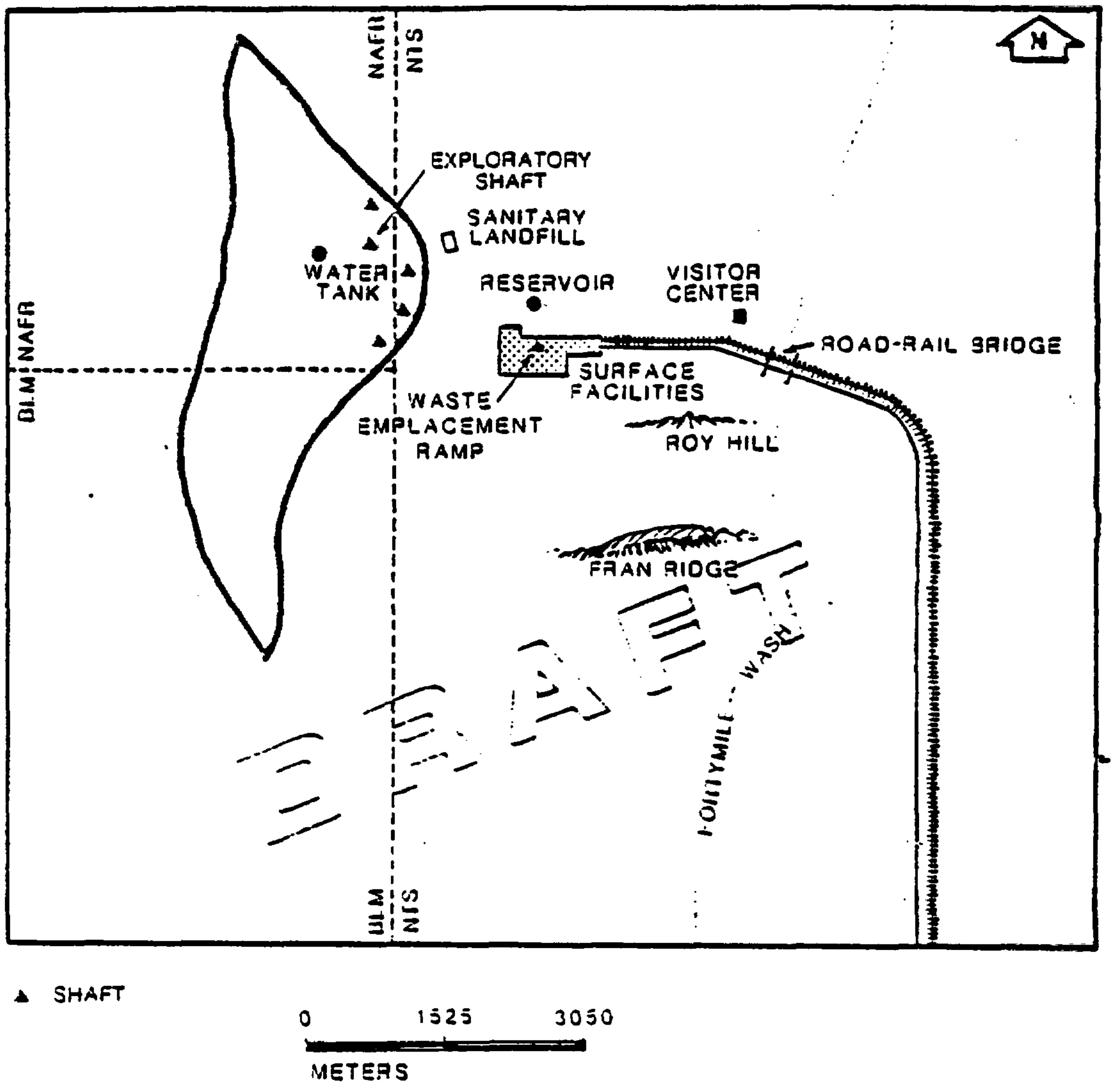

Figure 5-3. Location of surface facilities for the Yucca Mountain repository showing ramp and shaft locations. (Source: Sandia, 1983)

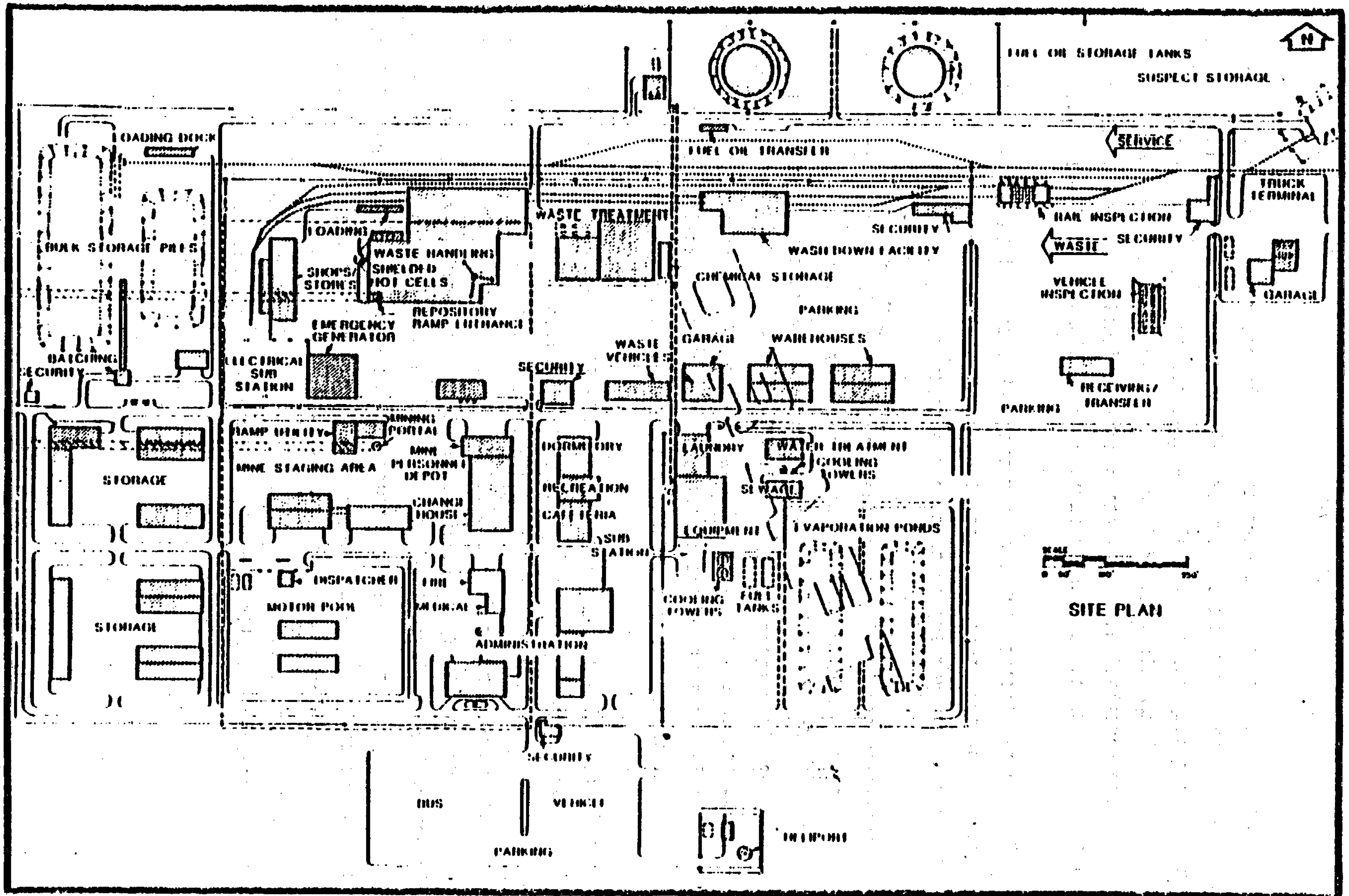

Figure 5-4. Preliminary site plan for the Yucca Mountain repository.

Surface facilities in support of the underground operations include personnel change-rooms and showers as well as space to store mining equipment. Ventilation-supply shafts will also be constructed, and separate surface facilities will contain fans, filters, and other equipment needed for large-volume ventilation. Ventilation exhaust facilities will be located away from the main complex, and are described in Sections 5.1.1.2 and 5.1.1.4.

Surface facilities for receiving the rock that will be mined during construction of the underground openings include a surge bin for temporary storage and a conveyor system to move the crushed rock to stockpiles.

Facilities that will support the repository include buildings to house administrative, management, and engineering staff. Other support facilities will include a firehouse, a medical center, a training center, a computer center, a vehicle maintenance shop, a security building, a machine and sheet metal shop, and an electrical shop. Warehouses will be constructed to store bulk materials, equipment, spare parts, and supplies. Facilities for environmental and instrument laboratories will also be constructed.

Utilities which support the repository will include an electric power building with emergency electrical generating equipment. Electric transmission lines will be extended to Yucca Mountain from existing local utility lines. A new substation will be constructed at the site. Steam-generating equipment, compressor and chiller systems, and cooling towers with water treatment equipment will be included if needed. A system for treating and distributing potable water and for supplying a source of water for fighting fires will be required. Existing wells east of Yucca Mountain are expected to supply all the water required during construction and operation of the repository. A sewage treatment plant and evaporation ponds would also be constructed. Finally, fuel stations containing gasoline and diesel fuel will be required at the site.

5.1.1.2 Access to the subsurface

Two concepts for access to the subsurface at Yucca Mountain have been developed (Jackson, 1984a). These concepts are as follows: (1) vertical shafts with appropriate hoisting mechanisms; or (2) gently sloping ramps through which wheeled vehicles are driven. Ramp access for waste transfer operations is the preferred concept and is assumed for the impact analyses in this chapter. Personnel, materials, and muck will be transported through either a shaft or a ramp. Ventilation intake and exhaust will occur through shafts.

Six openings for access to and from the emplacement horizon are included in the preliminary conceptual design (Figure 5-3). Table 5-1 lists these openings and indicates the opening size for each of two proposed emplacement methods. Future design studies will establish the number, function, type, and size of each opening.

5.1.1.3 The subsurface facilities

The subsurface facilities will be located within Yucca Mountain, approximately one mile west of the proposed surface facilities location (Figure 5-3). This facility will encompass roughly 615 ha (1520 acres) of subsurface area. On the basis of the current understanding of the Yucca Mountain site, the depth to the floor of the underground openings will be greater than 200 m (650 ft) below the surface within the Topopah Springs Member of the Paintbrush Tuff. The water table in the vicinity of Yucca Mountain is approximately 100 to 200 m (325 to 650 ft) below the level of the underground openings. Except for possible scattered pockets of perched water, the underground openings are expected to be dry. A profile of the subsurface facilities showing the ramp waste transfer configuration is shown on Figure 5-5.

The subsurface facilities consist of main access corridors to the emplacement areas, the emplacement drifts, and service areas near the shafts and ramps. The layout of the facilities is based upon the configuration of waste emplacement: either vertical or horizontal. For vertical emplacement, which is currently the preferred conceptual design, waste canisters are to be

Table 5-1. Subsurface access dimensions for vertical and horizontal waste emplacement (Jackson, 1984a)

Purpose of openings	Diameter of opening: Vertical emplacement	Diameter of opening: Horizontal emplacement
Men, materials, and muck		
Shaft access	7.6 m (25 ft)	6.1 m (20 ft)
Ramp access[a]	4.6 m x 6.1 m (15 ft x 20 ft)	4.6 m x 6.1 m (15 ft x 20 ft)
Waste transfer (ramp)[a]	4.6 m x 6.1 m (15 ft x 20 ft)	4.6 m x 6.1 m (15 ft x 20 ft)
Ventilation intake (shaft)	6.1 m (20 ft)	4.3 m (14 ft)
Ventilation exhaust (shaft)	4.9 m (16 ft)	4.3 m (14 ft)
Mine development exhaust (shaft)	4.9 m (16 ft)	3.0 m (10 ft)
Exploration (shaft)	3.7 m (12 ft)	3.7 m (12 ft)

[a] Dimensions are height by width.

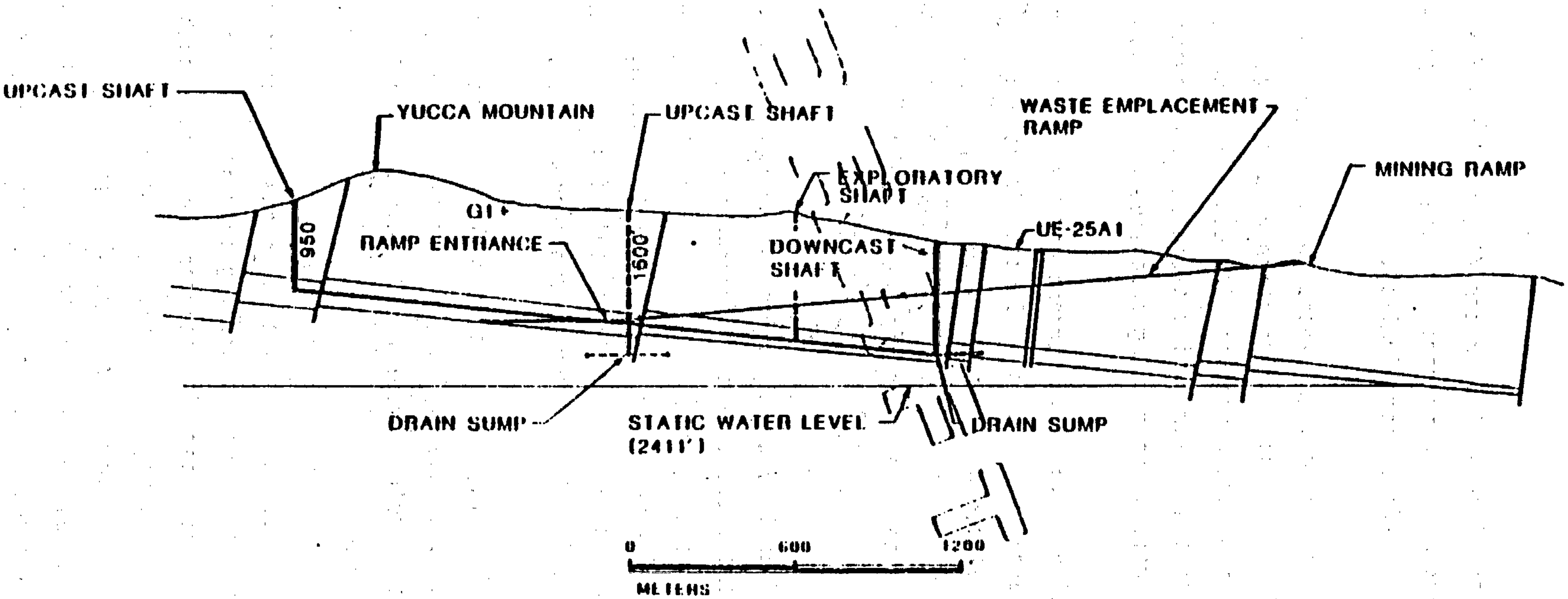

Figure 5-5. Subsurface profile for the proposed Yucca Mountain repository.

emplaced in vertical boreholes in the floors of the emplacement drifts. For horizontal emplacement, waste canisters are to be emplaced in horizontal boreholes in the drift pillars (walls).

Conceptual design work completed to date indicates that areal and geometric requirements, mine ventilation requirements, stability of the underground workings and retreivability considerations will be satisfied by conventional room and pillar mining techniques. Excavation may be conducted using either a drill-blast-mucking technique or a mobile mining machine.

An extraction ratio of 25 percent has been adopted for the vertical emplacement alternative (Jackson, 1984a). About 315 km (190 mi) of access corridors and emplacement drifts will be mined, and about 200 ha (500 acres) will be excavated. Cross-sectional dimensions of these openings are listed in Table 5-2. The total amount of rock excavated for the facility will be about 11,200,000 m^3.

The subsurface layout for horizontal waste-emplacement requires considerably less excavation. With an extraction ratio of about 6 percent, 49 ha (120 acres) will be excavated, which is about 83 km (50 mi) of corridors and drifts. Table 5-2 lists the dimensions of the openings for horizontal waste-emplacement. Approximately 700,000 m^3 (915,500 yd^3) of tuff will be excavated and stored onsite for the horizontal emplacement case.

Conventional mining equipment as well as machinery designed specifically to transport wastes to the emplacement locations will be required underground. The service areas required underground include medical facilities, warehouses, and maintenance areas.

The excavated rock will be stored on the surface at the site. Rock-storage piles will be constructed using conventional muck handling equipment, and dust will be suppressed with standard procedures such as water spray. Runoff from precipitation will be intercepted by dikes, ditches, and liquid-collection sumps. The present conceptual design does not require backfilling of the excavated access and emplacement drifts to maintain the structural integrity of the undergrund openings. If backfilling of a portion of the

Table 5-2. Dimensions of underground openings for vertical and horizontal waste emplacement (Jackson, 1984a)

	Vertical Emplacement		Horizontal Emplacement	
Opening	Height	Width	Height	Width
Access corridors	3.7 m (12 ft)	6.1 m (20 ft)	3.7 m (12 ft)	6.1 m (20 ft)
Emplacement drifts	6.7 m (22 ft)	6.1 m (20 ft)	3.7 m (12 ft)	6.1 m (20 ft)

repository is required before closure and decommissioning, some of the excavated rock could be used for that purpose.

5.1.1.4 Offsite construction

Construction away from the main site will consist primarily of a highway connection from U.S. 95, a rail line from Dike Siding, and facilities above each upcast shaft. The rail line will also require the construction of a railroad facility at Dike Siding and a bridge over Fortymile Wash. The highway connection leading northward from U.S. 95 will also utilize a portion of the railroad bridge to traverse Fortymile Wash. Other areas of minor construction such as storage tanks, explosive material magazines, etc., will be required in the vicinity of the surface complex but at some distance outside of the fence. An additional 10 ha (25 acres) will be required for offsite structures, i.e., ventilation buildings, visitors center, landfill, and water tower.

Highway

A highway will be constructed between U.S. 95 and the site for truck and automobile access (see Figure 5-2). The highway will originate approximately 1.0 km (0.5 mi) west of the town of Amargosa Valley at an existing guard portal. The road will be two lane, 9 m (30 ft) wide, and will be rated for 36 metric tons (80,000 lb) gross vehicle-weight trucks. Each roadway shoulder will be 2.5 m (8 ft) wide. The total required right-of-way will be about 15 m (50 ft), and the total land area needed will be about 36 ha (90 acres).

The highway will cross Fortymile Wash via a 6-m (20-ft) high, 300-m (1000-ft) long bridge. The present preconceptual design is for a single bridge carrying both highway and rail traffic, although construction of two separate bridges will be considered.

Railroad

For rail access to the site, a rail spur will be constructed from the Las Vegas area (see Figure 5-2). The rail line will originate in the vicinity of Dike Siding, approximately 18 km (11 mi) northeast of downtown Las Vegas. A railhead facility will be constructed at Yucca Mountain to provide railcar handling, and buffer storage. Details on this facility have not yet been formulated.

The rail connection from Dike Siding will require approximately 142 km (85 mi) of track and a bridge over Fortymile Wash. The route shown on Figure 5-2 is preliminary and could change as additional information is gathered. A right-of-way of 18 m (60 ft) will be required; thus, the land committed to the rail line will total about 250 ha (620 acres).

Upcast Shafts

Upcast shafts for ventilation will be located away from the surface complex. The exact location will depend on whether shaft entry or ramp entry for personnel and materials is used. The configuration for the ramp-entry is shown on Figure 5-3. At the surface, either ventilation-exhaust facilities or rock-transfer equipment will be installed. The ventilation facilities will be fenced and will require less than 1.0 ha (about 1 to 2 acres) each. Exhaust stacks at each site would extend about 10 m (35 ft) above the land surface. Improved roads will connect these sites to the surface complex. The rock-handling equipment will be used to construct the above-grade tuff storage piles.

Other offsite facilities

Other facilities away from the surface complex include the tuff storage pile, the visitors' center, the water tower, explosive magazines, and a sanitary landfill. The layout of these facilities is shown on Figure 5-3. Improved roads will connect these facilities to the main complex.

5.1.1.5 Schedule and labor force

The initial construction phase (preparation for waste emplacement) is scheduled for five years. During that time, all surface facilities are to be constructed, shafts (and ramps) will be excavated, and enough of the subsurface facilities will be excavated to permit waste transfer and emplacement to begin.

During the next 28 to 30 years, the remainder of the subsurface facilities will be excavated concurrently with waste emplacement. Waste emplacement will continue for about 2 years after all subsurface areas have been excavated, which equals a total emplacement or operations period of 30 years. A 20-year period during which waste retrieval may be initiated, if necessary, follows the operation phase, therefore, retrieval could be initiated at any time from year 35 to year 55 (or up to 50 years after the first waste has been emplaced). If waste retrieval is necessary, this phase would continue for up to an additional 30 years. The retrieval phase is followed by a 5-year decommissioning phase.

The size of the labor force during construction will depend on whether vertical or horizontal emplacement is used. Vertical emplacement will require more personnel. Estimates of the work force required at Yucca Mountain for both emplacement configurations are shown on Figure 5-6 (McBrien and Jones, 1983). Preliminary estimates of the labor force requirements by skill level have been prepared by McBrien and Jones (1983) and are shown in Table 5-3 for vertical emplacement, and in Table 5-4 for horizontal emplacement.

The number of workers onsite at any one time will vary with the shift. Mining activities are to be conducted on a three-shift basis for 250 days per year. While most surface operations will be on a one-shift basis, some activities will require three shifts. In all cases, the day shift, which is to be from about 8 A.M. to 4 P.M., will be the most labor-intensive. The average day-shift onsite work force throughout the repository lifetime is estimated to be:

- Construction phase - 1568
- Operational phase - 778
- Retrievability phase - 243
- Decommissioning phase - 541

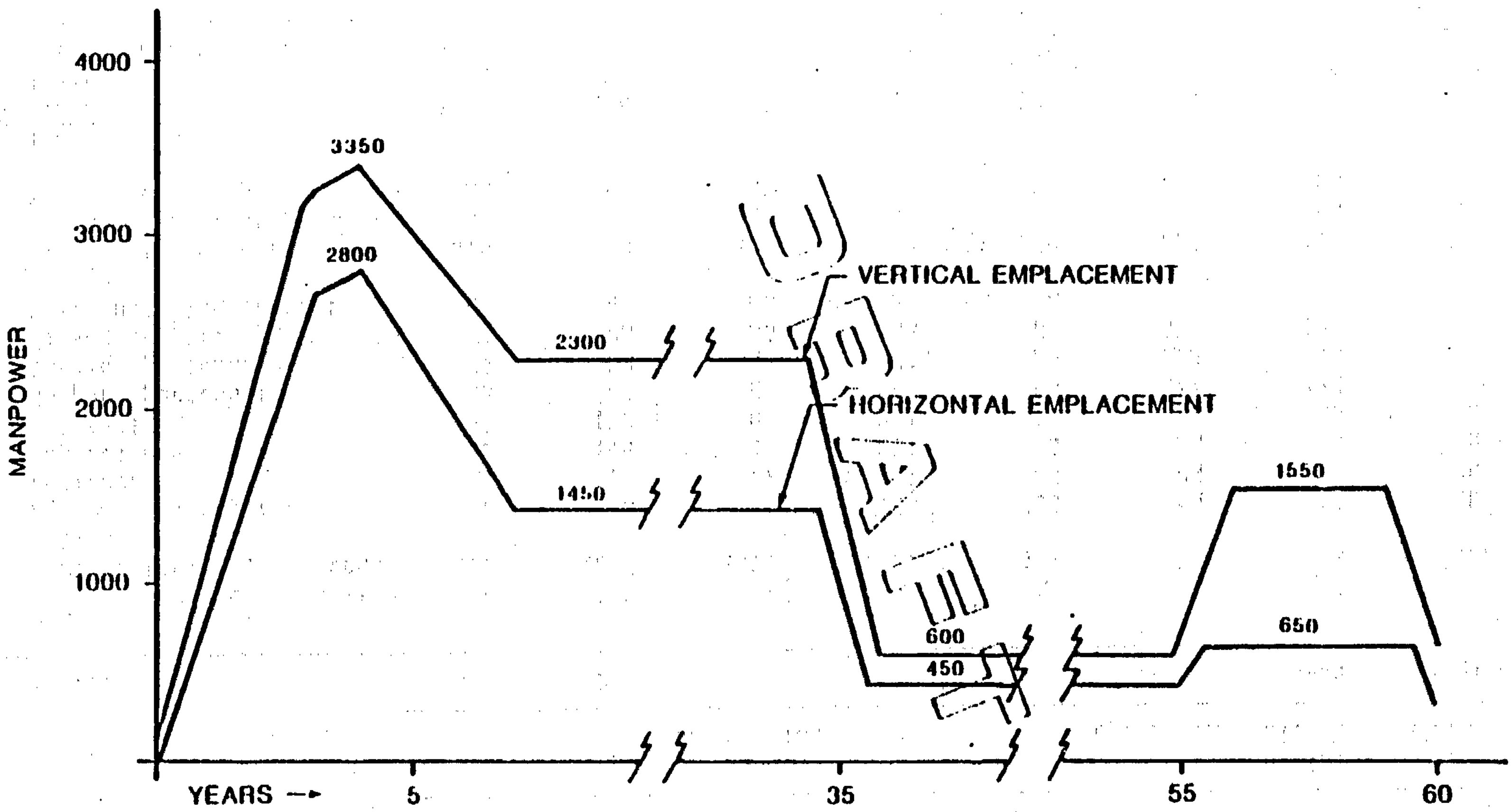

Figure 5-6. Estimated work force for the Yucca Mountain repository.

Table 5-3. Labor force size by skill for vertical emplacement (McBrien and Jones, 1983)

	Phase and year							
	Construction					Operations	Retrieva-bility	Decommis-sioning
Location/skill	1	2	3	4	5	6-35	36-55	56-60
Surface								
Road and rail construction	160	110	NA[a]	NA	NA	NA	NA	NA
Surface facility construction	429	1287	1929	1287	427	NA	NA	NA
Equipment installers	0	0	0	766	765	NA	NA	NA
Engineers	18	51	77	81	46	NA	NA	NA
Supervisors	49	146	219	234	136	NA	NA	NA
QA staff	46	139	208	221	128	NA	NA	NA
Support personnel	NA	NA	NA	NA	NA	517	172	342
Service personnel	NA	NA	NA	NA	NA	193	90	104
Mining support	NA	NA	NA	NA	NA	354	185	478
Waste handling support	NA	NA	NA	NA	NA	313	32	152
Subsurface								
Mining/mine workers[b]	519	683	806	760	760	728	115	472
Waste emplacement personnel	NA	NA	NA	NA	NA	81	NA	NA
Emplacement support personnel	NA	NA	NA	NA	127	127	NA	NA
Total employment								
Direct	1221	2416	3239	3348	2389	2313	594	1548
Indirect[c]	1880	3721	4988	5156	3679	3562	915	2384
Total project related	3101	6137	8227	8504	6068	5875	1509	3932

[a] NA = not applicable.

[b] Includes miners, mechanics, electricians, carpenters, pipefitters, engineers, supervisors.

[c] Assumes 1.54 indirect workers for each direct worker.

Table 5-4. Labor force size by skill for horizontal emplacement (McBrien and Jones, 1983)

Location/skill	Construction 1	Construction 2	Construction 3	Construction 4	Construction 5	Operations 6-35	Retrievability 36-55	Decommissioning 56-60
Surface								
Road and rail construction	160	110	NA[a]	NA	NA	NA	NA	NA
Surface facility construction	425	1276	1913	1276	425	NA	NA	NA
Equipment installers	NA	NA	NA	744	744	NA	NA	NA
Engineers	18	51	76	80	46	NA	NA	NA
Supervisors	49	144	216	228	132	NA	NA	NA
QA staff	43	130	193	204	119	NA	NA	NA
Support personnel	NA	NA	NA	NA	NA	355	118	235
Service personnel	NA	NA	NA	NA	NA	193	89	104
Mining support	NA	NA	NA	NA	NA	167	91	100
Waste handling support	NA	NA	NA	NA	NA	313	102	115
Subsurface								
Mining/mine workers[b]	162	211	269	268	268	252	56	99
Waste emplacement personnel	NA	NA	NA	NA	NA	42	NA	NA
Emplacement support personnel	NA	NA	NA	NA	120	120	NA	NA
Total employment								
Direct	857	1922	2667	2800	1854	1442	456	653
Indirect[c]	1320	2960	4107	4312	2855	2221	702	1006
Total project related	2177	4882	6774	7112	4709	3663	1158	1659

[a] NA = not applicable.

[b] Includes miners, mechanics, electricians, carpenters, pipefitters, engineers, supervisors.

[c] Assumes 1.54 indirect workers for each direct worker.

Construction of the highway and rail line is to begin during the first year of the construction phase and is to be completed during the initial five-year construction phase. To construct the rail-access route, approximately 70 workers will be required for two years (Yellvington, 1983). Construction of the highway will require 50 workers for one year, and construction of the bridge(s) will require about 40 workers for two years.

5.1.1.6 Material and resource requirements

Building materials and other resources will be delivered to the main site and to the sites of road and railroad construction. The amount and type of construction materials for the repository are only estimates at this time. Since concrete and steel represent the greatest quantities of construction materials, estimates of these are given as an indication of the quantities of materials that will be required. Estimated amounts of these construction materials and energy resources that will be required annually for the repository are listed on Table 5-5 for vertical emplacement and on Table 5-6 for horizontal emplacement. Requirements will decrease when the subsurface excavations are completed, which will occur around year 35.

Construction materials will be shipped to the repository via highway and rail. The estimated number of annual shipments of material over the repository lifetime is shown on Table 5-5 for vertical emplacement and on Table 5-6 for horizontal emplacement. During the first two years of construction, all shipments will be by truck while the rail line from Dike Siding is being constructed. Upon completion of the rail line, materials will be shipped to the site by train. Because of the volumes of construction materials required and the remoteness of the site, railroads will be an efficient means of material supply. Therefore, for the analysis of transportation impacts, it is assumed that 70 percent of construction materials will arrive by train and the remainder will arrive by truck.

Materials required for construction of the highway and rail line have been estimated by Yellvington (1983) and are listed on Table 5-7. Materials for the bridge(s) over Fortymile Wash are included in these estimates. The number of

Table 5-5. Annual requirements for construction materials, fuel and power, and shipments to the repository for vertical emplacement[a] (McBrien and Jones, 1983)

	Years[b]					
	1-2	3-5	6-35	36-55	56-60	Total
Concrete[c]						
1,000 m^3	34	34	6.9	0.38	7.6	423
Railcars	NA	630	130	7	140	NA
Trucks	3,000	900	180	10	200	NA
Steel[c]						
Metric tons	2,700	2,700	340	NA	NA	23,700
Railcars	NA	21	3	NA	NA	NA
Trucks	150	45	6	NA	NA	NA
Diesel fuel[c]						
1,000 liters	3,860	3,860	6,270	341	1,430	221,400
Railcars	NA	24	37	2	9	NA
Trucks	68	20	33	2	8	NA
Electrical power						
Million kWh	31	31	137	9	38	4,635
Total annual shipments						
Railcars	NA	675	170	9	149	
Trucks	3,218	965	219	12	208	

[a] The following assumptions were used for shipping loads:
(1) Concrete: 11.5 m^3/truck; 23 m^3/railcar
(2) Steel: 18 metric tons/truck; 90 metric tons/railcar
(3) Diesel fuel: 56,800 liters/truck; 113,600 liters/railcar.

[b] Years 1-2: shipment by truck only.
Years 3-60: 70 percent of materials and fuel are shipped by rail; the remainder by truck.

[c] Conversions: 1 m^3 = 1.31 yd^3; 1 metric ton = 1.1 ton; 1 U.S. gal = 3.79 L.

Table 5-6. Annual requirements for construction materials, fuel and power, and shipments to the repository for horizontal emplacement[a]

	Years[b]					
	1-2	3-5	6-35	36-55	56-60	Total
Concrete[c]						
1,000 m^3	21	21	2.8	0.19	1.9	202
Railcars	NA	380	50	4	35	NA
Trucks	1,800	540	70	5	50	NA
Steel[c]						
Metric tons	2,500	2,500	180	NA	NA	17,900
Railcars	NA	20	2	NA	NA	NA
Trucks	140	40	3	NA	NA	NA
Diesel fuel[c]						
1,000 liters	1,760	1,760	3,580	151	691	122,700
Railcars	NA	11	22	1	4	NA
Trucks	31	9	19	1	4	NA
Electrical power						
Million kWh	19	19	82	9	17	2,820
Total annual shipments						
Railcars	NA	411	74	5	39	NA
Trucks	1,971	589	92	6	54	NA

[a] The following assumptions were used for shipping loads:
(1) Concrete: 11.5 m^3/truck; 23 m^3/railcar
(2) Steel: 18 metric tons/truck; 90 metric tons/railcar
(3) Diesel fuel: 56,800 liters/truck; 113,600 liters/railcar.

[b] Years 1-2: shipment by truck only.
Years 3-60: 70 percent of materials and fuel are shipped by rail; the remainder by truck.

[c] Conversions: 1 m^3 = 1.31 yd^3; 1 metric ton = 1.1 ton; 1 U.S. gal = 3.79 L.

Table 5-7. Highway and rail construction materials[a] (Yellvington, 1983)

Material[b]	Highway[c]		Rail[d]	
	Quantity	No. Shipments	Quantity	No. Shipments
Limestone (m^3)	30,600	2,700	210,000	5,000
Asphalt (metric tons)	36,000	2,000	0	0
Prime Tar (liters)	359,000	6	0	0
Tar (liters)	359,000	6	0	0
Paint (liters)	946	1	0	0
Concrete (m^3)	3,000	275	3,000	80
Fencing (m)	48,200	80	0	0
Rails - steel (metric tons)	0	0	18,000	200
Railroad ties	0	0	255,000	500
Drain pipe (m)	0	0	1,400	10

[a] Includes bridge(s) over Fortymile Wash.

[b] Conversions: 1 m = 3.28 ft; 1 metric ton = 1.1 ton; 1 U.S. gal = 3.785 liters; 1 m^3 = 1.31 yd^3.

[c] Assumes all shipments are via truck from U.S. 95 and all are brought in during the first year. Each shipment is one truck load.

[d] Assumes all shipments are via rail to Dike Siding and all materials brought in during two years. From Dike Siding, materials are brought up along the right-of-way. These are numbers of railcar loads.

shipments of these materials to the various sites along the routes are also indicated on Table 5-7.

Equipment requirements for the construction of the repository and the access routes are shown on Table 5-8. Most of this equipment is to be removed after construction. Some equipment, however, will remain during the operation, retrievability, and decommissioning phases. The number and schedule of shipments of equipment to the sites are listed on Table 5-9.

Over the lifetime of this project, various resources, such as water, electric, diesel fuel, etc., will be required at the repository. Estimates of the amount of these resources are listed on Table 5-10.

5.1.2 Operations

The operations phase of a nuclear-waste repository at Yucca Mountain will begin 5 years after construction of the facility begins and will continue for 30 years thereafter.

5.1.2.1 Waste receipt

Nuclear waste would be shipped to the repository by rail or by truck in Federally licensed casks. Waste emplaced at the repository will consist of either spent fuel, that has been discharged directly from nuclear power reactors after a 10-year decay period, or of wastes generated by the reprocessing of spent fuel. For purposes of this analysis, it was assumed that a reprocessing facility will be located at Barnwell, South Carolina. Reprocessing wastes are categorized as commercial high-level wastes (CHLW), which are fission products and actinides solidified in a borosilicate glass matrix; fuel cladding hulls (hulls); remote-handled transuranics (RHTRU); and contact-handled transuranics (CHTRU). The four bounding scenarios assessed herein assume that the repository will receive either 70,000 MTU of spent fuel, or the equivalent amount of reprocessing wastes, and that the waste is shipped either 100 percent by truck or 100 percent by rail. Details on the packaging of these wastes are included in Jackson (1984a). Quantities of each type of waste for

Table 5-8. Estimated construction equipment requirements[a]

Type	Quantity
Bulldozers	30
Earthmovers	30
Dump trucks	35
Pile drivers	4
Drilling machines	8
Front-end loaders	40
Gravel elevators	4
Graders/scrapers	22
Backhoes	5
Shovels	20
Cranes	25
Earth compactors	15
Air compressors	5
Concrete mixers	30
Drill rigs	2
Mucking elevators	2
Scaling machines	5
Rockbolting machines	5
Boring machines	5
Truck cranes	10
Services vehicles	140

[a] Based on typical requirements for the construction of large facilities.

Table 5-9. Number of shipments of construction equipment over Nevada roads by year[a]

Site/route	Year 1[b]	2[c]	3	4-5[d]	6-28	29-30[e]	55-56[f]	59-60[g]
Repository								
To site	250-300	25-50	25	25	10		25-50	
From site				300-350	10	25-50		25-50
Road construction								
To site	100-125							
From site	100-125							
Rail construction								
To site	50-75							
From site		50-75						

[a] Shipments consist of tractor-trailer rigs. Some of which will be wide loads.

[b] Equipment for construction of repository, railroad, and road.

[c] Construction of rail effort diminishing.

[d] Initial phase of repository construction effort diminishing.

[e] Final repository construction effort diminishing.

[f] Preparing for decommissioning and closure.

[g] Decommissioning and closure effort diminishing.

Table 5-10. Total (60 yr) resource requirements for vertical emplacement

Resource	Requirement	
	ha	acres
Cleared land		
Surface facilities	30	75[a]
Offsite facilities	10	25[a]
Rock storage piles[b]	37	92
Railroad spur	250	620[c]
Highway construction	36	90[c]
Electric transmission line	(d)	(d)
Water pipeline	(d)	(d)
Undisturbed or little disturbed Land commitment for controlled area	42,200[e]	104,000[e]
Water use (45 yr)	400 acre-ft/yr[a]	
Diesel fuel (60 yr)	221 million liters[a] (58.4 million gal)	
Electrical power (60 yr)	4635 million kWh[a]	
Labor (60 yr)	97,000 person-years[a]	

[a] Source: McBrien and Jones, 1983.

[b] Assumes that pile is 30 m (100 ft) high and varies according to emplacement concept. Stockpile consists of rock from excavation assuming no backfilling. Volume determined from McBrien and Jones, 1983.

[c] Calculated: Railroad right of way is 18 m (60 ft) wide by 142 km (85 mi) long. Road right of way is 15 m (50 ft) wide by 25 km (15 mi) long.

[d] These would already be in place for the exploratory shaft phase, but may have to be upgraded.

[e] Based on 10 CFR 60. A qualified controlled area extending 10 km from the outer boundary of the subsurface area.

the four scenarios are shown in Table 5-11. In addition, onsite generated low-level waste will be disposed of in the repository, but the expected quantities of these wastes are not available at this time.

It is assumed that the wastes will arrive either entirely by rail or entirely by truck. Spent fuel will be shipped from reactor power plants, while the other wastes (described above) will be shipped from a reprocessing plant or from a fuel-fabrication plant. The average one-way shipping distance is assumed to be about 3300 km (2000 mi) (Sandia, 1983).

For simplicity, it is assumed that an equal amount of waste will arrive at the site each year. The number of shipments by truck or rail per year required to fill the repository in 30 years are given for each scenario in Table 5-11. Assuming 250 working days per year, average daily shipments range from 2 to 16, depending on the scenario.

Upon arrival at the repository, the shipping casks will remain on their carrier in either a rail or a truck yard until space is available in the waste-handling building. A shipping cask is then brought into the building, lifted by crane from the railcar or truck, and placed in a shielded transfer-cell where the waste is removed by remotely operated machines. After inspection of the cask, the spent-fuel assemblies will be unloaded and packaged, or they may be disassembled and individual fuel rods packaged into specially designed waste packages. This description assumes that the facilities for packaging the spent-fuel assemblies will be located at the repository. The length of time a loaded shipping cask will remain in the yard will be minimized by having an appropriate number of transfer cells for the expected volume of incoming waste and by minimizing the time required for the unloading operation.

5.1.2.2 Waste emplacement

Spent fuel and CHLW will be sealed in high-integrity packages prior to disposal. These waste packages will be designed to meet the minimum lifetime requirements set by the U.S. Nuclear Regulatory Commission (Code of Federal Regulations, 1984). To meet this requirement, minimum waste package lifetimes will be between 300 and 1000 years under the expected subsurface environment of

Table 5-11. Waste quantities by waste category for each scenario[a]

Scenario[b]	Waste type[c]	Total quantity	Annual receipt	No. of shipments/yr[d] Truck	Rail
I	Spent fuel - PWR	98,600 assemblies	3,300 assemblies	1,650	0
	Spent fuel - BWR	136,000 assemblies	4,500 assemblies	900	0
			Total	2,550	0
II	Spent fuel - PWR	98,600 assemblies	3,300 assemblies	0	275
	Spent fuel - BWR	136,000 assemblies	4,500 assemblies	0	140
			Total	0	415
III	CHLW	30,900 canisters	1,030 canisters	1,030	0
	Hulls	10,500 canisters	350 canisters	350	0
	RHTRU	52,800 canisters	1,760 canisters	1,760	0
	CHTRU	375,000 drums	12,500 drums	780	0
			Total	3,920	0
IV	CHLW	30,900 canisters	1,030 canisters	0	85
	Hulls	10,500 canisters	350 canisters	0	90
	RHTRU	52,800 canisters	1,760 canisters	0	440
	CHTRU	375,000 drums	12,500 drums	0	240
			Total	0	855

[a] Reflects 70,000 metric tons of uranium (MTU) of either spent fuel or CHLW based on data in Sandia, 1983.

[b] I - 100% spent fuel/100% truck; II - 100% spent fuel/100% rail; III - 100% CHLW/100% truck; IV - 100% CHLW/100% rail.

[c] PWR - pressurized water reactor; BWR - boiling water reactor; CHLW - commercial high-level waste; Hulls - cladding hulls; RHTRU - remote-handled transuranic waste; CHTRU - contact-handled transuranic waste.

[d] For 30 years.

the repository. High-integrity packages are one component of a system of engineered barriers. Other engineered barriers may be used as part of the repository system. Such engineered barriers for this purpose include waste forms, overpacks, sleeves, and backfill materials.

The high-level and transuranic wastes that are shipped from reprocessing facilities and fuel-fabrication plants are assumed to arrive in canisters. These canisters are unloaded from the shipping casks in a shielded transfer-cell and sealed in a waste package.

When the waste packages have been determined to be suitable for emplacement, they will be held temporarily in a surge-storage area. This surge storage will allow incoming waste to be unloaded and prepared for disposal at a faster rate than the emplacement operation, thus it will reduce the yard-storage time. The design rate of waste emplacement, however, will also be determined to minimize the length of time required for surge storage. After surge storage, the waste packages are transported to the waste shaft or ramp by remotely operated machines and either lowered or driven into the underground facility. The waste packages arrive at subsurface transfer stations where they are placed in shielded transporters and carried to the waste-emplacement rooms. The waste packages are then placed either in vertical holes in the floors of the storage drifts (vertical emplacement) or in long horizontal holes in the drift pillars (horizontal emplacement). If placed horizontally, each borehole would contain 30 to 60 waste packages; if vertical, each hole would contain one waste package (Jackson, 1984a).

Canisters of hulls and RHTRU would be handled remotely throughout the facility. Upon arrival, they would be inspected in shielded hot-cells and, if accepted, they would be transferred to the subsurface facilities for emplacement. Provisions would be made for the upgrading of unacceptable canisters. Drums of CHTRU will be contact handled (i.e., using forklifts), inspected, and transferred to the subsurface for disposal.

All the surface and subsurface facilities at the repository that handle radioactive wastes will be operated at less than atmospheric pressure. Exhaust air from these facilities will be processed through a high efficiency particulate filter train before being discharged into the atmosphere. Exhaust from the underground waste-storage rooms will be directed to a surface building where the exhausts will be filtered and then discharged into the atmosphere. Ventilation during underground construction will be physically separated from the waste-emplacement ventilation circuit.

The requirements for materials and other resources for the operation phase (years 6-35) are listed in Tables 5-5, 5-6, 5-7, and 5-10. The labor requirements are shown on Figure 5-6. This work force will be in place for the 30-year operational period. This force will work three shifts for 250 days per year. The size of the operational staff is dependent on the emplacement configuration used.

5.1.3 Retrievability

The Yucca Mountain repository will be designed to allow retrieval of all waste as required by the NRC (Code of Federal Regulations, 1984). The requirements state that waste must be retrievable for a period of up to 50 years after waste emplacement begins. The requirements also state that if retrieval becomes necessary, the waste must be retrieved in the same amount of time that was devoted to the initial emplacement of the waste (up to 30 years if the repository has reached capacity).

Designs for the subsurface facilities will incorporate features to insure that the openings will remain intact for at least 80 years (a 30 year operations phase, a 20 year phase during which retrieval could be initiated, and a 30 year retrieval phase). These features include minimizing the extraction ratio, minimizing rock temperatures, and using steel sleeves for horizontal emplacement holes. In addition, periodic inspections and maintenance programs will be used to monitor and verify stability of the subsurface openings throughout the retrievability period.

During the period when retrieval could be initiated, which is years 35-55 as shown on Figure 5-6, a standby work force will be needed. This staff, which is dependent on the emplacement configuration, will be onsite for security, surveillance, monitoring of repository performance, and maintenance.

5.1.4 Decommissioning and closure

Following the retrieval phase, decommissioning and final closure is to begin. This phase is estimated to require five years to complete. To decommission the subsurface facilities, all subsurface access areas (shafts and ramps) will be sealed. These openings will be sealed using multiple materials and techniques to assure that the seal offers the same or improved isolation properties as the host rock (Fernandez, 1983).

All surface structures will then be decontaminated and dismantled. Some contaminated material may be placed underground prior to the sealing of shafts. The surface areas will be reclaimed. Permanent markers will be erected to inform future generations about the presence of the repository. Development of such markers or a marking system is currently under way. All records concerning the repository will be maintained by appropriate Federal, State and local agencies. It is expected that the records and markers will be kept in perpetuity. The labor force for decommissioning activities is shown on Figure 5-6; materials and resources are listed in Tables 5-5, 5-6, 5-7, and 5-10.

5.2 EXPECTED EFFECTS ON THE PHYSICAL ENVIRONMENT

This section describes the potential local and regional impacts that may result from locating a repository at Yucca Mountain. The topics that are discussed include possible impacts to the geologic and hydrologic environments, land use, ecosystems, air quality, noise, aesthetics, archaeological, cultural, and historical resources, and background radiation levels.

5.2.1 Geologic impacts

Locating a repository at Yucca Mountain is expected to have minimal impact on the geologic environment. Excavation of the repository represents an insignificant disturbance to the overall competence of the rock units at Yucca Mountain. Heat and radiation, which will be introduced into the rocks by decay of radioactive material in the repository, will affect only a small volume of rock and will neither result in loss of competence nor in loss of structural stability. Future exploration and development of any local mineral or energy resources will be excluded on approximately 420 km^2 (160 mi^2) of Federal land. A class I resource survey, (Bell and Larson, 1982) found no evidence of mineral or energy resources in the region surrounding Yucca Mountain and therefore future exploration and development is not anticipated. The following paragraphs describe the potential impacts associated with the construction, operation, retrievability, and decommissioning phases of the repository.

5.2.1.1. Construction

Studies by St. John (1983), Hustrulid (1984), and Dravo (1984a, 1984b) indicate that a repository can be built at Yucca Mountain using standard construction techniques (see Section 6.3.3.2). Access drifts and underground openings can be supported by conventional rockbolts, wire mesh, and shotcrete. Intersections of fault zones and drifts could be supported, if necessary, by steel or by concrete.

The presence of lithophysae, small voids in the host rock, have been considered in the mining analyses (Section 6.3.3.2). The current conceptual design indicates that rocks with less than 15-20 percent lithophysae are preferable. On the basis of current information, there is an adequate thickness of host rock in which to locate the underground facility that contains less than 15-20 percent lithophysae. Conventional mining techniques in welded tuff have been demonstrated by construction of the G-Tunnel at Rainier Mesa north of Yucca Mountain. Both experience gained at the G-Tunnel and results of the engineering studies previously described indicate that the excavations at Yucca Mountain should remain serviceable for over 80 years with only routine maintenance.

5.2.1.2 Operation

To date, there are no physical or chemical characteristics of either the Topopah Spring tuff or of the geochemical environment to suggest that the isolation capability of the host rock could be reduced because of the heat and radiation generated by the emplaced wastes (Johnstone and Wolfsberg, 1980; Nimick and Williams, 1984; Bish et al., 1984; Tillerson et al., 1984). Furthermore, there are no indications that the retrieval of wastes, if required, would be hampered because of the effects of heat and radiation on the rock. Calculations predict that only minor thermally induced fractures extending less than 10 cm (4 in.) into the rock may occur around the waste-emplacement boreholes. Any possible difficulty in retrieving the wastes due to thermally induced fracturing could be either reduced or avoided by using steel sleeves in the waste-emplacement boreholes. Chapter 6, in particular Sections 6.3.1.2, 6.3.1.3, 6.3.3.2 and 6.3.3.3, discusses the analyses that support the above conclusions.

5.2.2 Hydrologic impacts

Potential hydrologic impacts of locating a repository at Yucca Mountain are discussed in this section. These discussions include regional effects from ground-water withdrawals at Yucca Mountain (Section 5.2.2.1), the potential for release of radionuclides into the ground water (Section 5.2.2.2), the potential for flash floods at the repository (Section 5.2.2.3); and the possibility that future generations might consider Yucca Mountain to be a significant source of ground water (Section 5.2.2.4).

5.2.2.1 Water use

It has been estimated that the water requirements for a repository at Yucca Mountain will average 4900 m^3 (400 acre-ft) per year over a 45 year period that includes the construction, operation, and closure phases (McBrien and Jones, 1983). This water can be adequately supplied by existing wells, primarily well J-13 (see Figure 4-2).

The regional effects of withdrawing ground water for a repository at Yucca Mountain are expected to be negligible. Thordarson (1983) reports that the water level in well J-13 has remained essentially constant after long periods of pumping between 1962 to 1980. The large volume of water produced from this well, along with the minor drawdown during pumping tests (Young, 1972), suggest the aquifers underlying Yucca Mountain can produce an abundant quantity of ground water for long periods of time without lowering the regional groundwater table.

5.2.2.2 Potential contamination of ground water

Both preliminary assessments of the long-term performance of a repository at Yucca Mountain (Sinnock et al., 1984; Thompson et al., 1984) and a preliminary performance assessment described in Sections 6.3.2 and 6.4.2 of this Environmental Assessment indicate that a repository at Yucca Mountain will meet the proposed EPA standards for radionuclide releases to the accessible environment (40 CFR 191). The analyses indicate that the natural barriers to radionuclide migration at Yucca Mountain, which are the inherent attributes of the geologic and hydrologic setting, will adequately limit exposure to the accessible ground water and to the public for the required period of 10,000 years.

The evidence compiled to date suggests that climatic changes during Quaternary time, the last 1.8 million years, had a negligible effect on the hydrologic system at Yucca Mountain. Furthermore, there is no evidence to suggest that during the next 10,000 years the water table will rise to a level that could flood the repository. The details in Section 6.3.1.4 support these conclusions.

5.2.2.3 Flooding

Parts of each of the six areas that are being considered for construction of the surface facilities at Yucca Mountain lie within an area that would be partly inundated by the 500-year and regional maximum floods along Fortymile Wash (Squires and Young, 1983). During construction of the surface facilities, a combination of surface grading and construction of both flood barriers and diversion channels would be used to prevent flooding of the repository surface facilities.

5.2.2.4 Potential for future exploitation of ground water

It seems reasonable to expect that future generations will continue to consider the mountainous areas in the Great Basin as less desirable targets for ground-water withdrawal than the adjoining valleys. This assumption together the results of a study of ground-water potential in this area by Sinnock and Fernandez (1982), indicate that future generations will probably view Yucca Mountain as a poor prospect for ground water as opposed to adjoining parts of Jackass Flats to the east of Yucca Mountain and Crater Flat to the west.

5.2.3 Land use

The Nevada Test Site and the Nellis Air Force Base have been withdrawn from public use for more than 30 years. Continued restriction of public access is not expected to affect either the current or the future economic and recreational requirements of the people in this region.

In addition to use of Nevada Test Site land, about 21,000 ha (50,000 acres) of public land that is administered by the Bureau of Land Management, U.S. Department of Interior, would be withdrawn from public use. Because Yucca Mountain is not a prime location for other uses, withdrawing this land should have essentially no effect on land use in the area. Construction of the rail line will require an additional withdrawal of 35 ha (85 acres) of public land. Assuming that access to lands north of the proposed rail line to the Sheep and Las Vegas ranges is neither restricted nor reduced, adverse impacts are not expected to occur to users of these areas. The proposed new access road will be located on the Nevada Test Site with the exception of a small segment from the NTS to U.S. 95 which is on BLM land.

5.2.4 Ecosystems

This section describes the effects that locating a repository at Yucca Mountain may have on terrestrial and aquatic vegetation and wildlife. Possible adverse effects are greatest for the construction period and are a result of removing vegetation and increasing transportation in the vicinity of the site. Beneficial effects are anticipated during decommissioning and the postclosure period.

The primary ecological effect of repository construction would be the permanent removal of vegetation during the construction of the surface facilities. Over 360 ha (900 acres) of land will be cleared. Table 5-10 itemizes the acreage that would be disturbed. Clearing this land is not expected to be ecologically significant because the affected areas are very small compared with surrounding undisturbed areas that have similar vegetation.

The ecological effects that may result from construction depend on the nature, the size, the location, and the duration of the disturbance. If the disturbance is restricted to the surface without removing the soil, then revegetation from an existing seed source or from root stock will occur in 10 to 20 years (Wallace et al., 1980). If the disturbance includes removing the soil, then natural revegetation may require hundreds of years (Wallace et al., 1980). The development of new vegetation is usually inhibited by the very low precipitation in the area and is influenced by soil characteristics and animal feeding habits.

A secondary ecological effect of removing the vegetation is the alteration of the habitats for wildlife. The vegetation provides wildlife with food, structures for nesting and with shelter from predators and from climatic extremes. When the vegetation of an area is destroyed, the wildlife that is dependent on that area is displaced into the surrounding, undisturbed areas. After displacement, the wildlife often die because of competition with other wildlife that live in the undisturbed areas. It is thought that the effect of vegetation removal is the greatest on birds because many species nest in the vegetation that may be removed. These shrubs require more time to grow back than is required by herbaceous vegetation. Although other groups of animals, such as mammals and reptiles, also use the vegetation for food and shelter; these animals are better able to use the herbaceous vegetation. However, the net potential effect upon the animal community will probably not be significant because the areas that will be disturbed are not ecologically unusual, and because the potentially effected biota represents only a very small percentage of the surrounding, undisturbed biota in this region.

Indirect ecological effects may also be caused by combustion emissions, fugitive dust, sedimentation, and noise. The projected concentrations of the combustion emissions, which are described in Section 5.2.5.1, are not high enough to cause any significant adverse effects to the plants and animals in the region. However, fugitive dust deposition on the leaves of desert shrubs can increase the loss of leaves (Beatley, 1965). Over several years, deposition of dust could result in the death of shrubby vegetation near disturbed areas. Increased levels of fugitive dust will be minimized to the extent possible by mitigative measures such as wetting the surface of the disturbed areas. Also, erosion of disturbed areas and sedimentation both during and after storms could bury the vegetation surrounding the disturbed areas. However, erosion of the disturbed areas would be controlled to the extent possible by maintaining moderate slopes and by applying soil stabilizers, if necessary. Construction noise may affect some animal communities; but, a study by Ames (1978) indicated that the effects of noise on some species are temporary because individuals become acclimated to the noise. Potential noise impacts are discussed in Section 5.2.2.4.

Although there are no Federally listed threatened or endangered species in the vicinity of Yucca Mountain, two species that occur in the area are being reviewed for inclusion on the Federal list (O'Farrell and Collins, 1983). These species are the Mojave fishhook cactus (Sclerocactus polyancistrus) and the desert tortoise (Gopherus agassizii). The distribution of these species is described in Section 3.1.4. Impacts on the Mojave fishhook cactus during construction are expected to be minimal because the densest populations are on the west side of Yucca Mountain, and the surface facilities are to be constructed on the east side of Yucca Mountain. The effects of construction on the desert tortoise will depend directly on the number of tortoises found in the construction zones. If a tortoise is encountered, it will be moved to a safe area. The density of desert tortoise in the project area ($< 8/km^2$ or $< 20/mi^2$) is lower than in other parts of its range (O'Farrell and Collins, 1983).

Riparian habitats do not exist on Yucca Mountain or in Fortymile Wash because of the absence of seasonal surface water. Therefore, impacts to aquatic ecosystems are not expected. Ash Meadows, which is located about 40 km (25 mi) south of Yucca Mountain, contains approximately 30 springs that have populations of rare pupfish and many unusual plants. Three endangered species of fish occur in this area: Devil's Hole Pupfish (Cyrinodon diabolis), Amargosa Pupfish (Cyprindon nevadensis pectoralis), and Pahrump killfish (Empetrichthys latos) (Collins et al., 1982). In addition, two endangered species of fish and their critical habitats were recently listed by the U.S. Fish and Wildlife Service (USFWS, 1983): Ash Meadows Amargosa pupfish (Cyprinodon nevadensis mionectes) and Ash Meadows speckled dace (Rhinichthys osculus nevadensis). Nine plant species in the Ash Meadows area are also under review for protection (Collins et al., 1982). As explained in Section 3.3.2, ground-water withdrawals for the repository are not expected to have any impact on maintenance of the water levels in the Ash Meadows area, and impacts to the area are not expected.

The secondary effects of repository operations are similar to those discussed for construction, and include the loss of some plants and animals from combustion emissions, noise, fugitive dust, and sedimentation. During operations, the transportation of materials, equipment, and waste to the repository would result in increased road kills.

Decommissioning of the repository will generally have positive ecological effects. Decommissioning will result in a reduced level of human activity and a reduction in all types of emissions. The presence of the repository may restrict the development of the region for other purposes. Therefore, the region will remain undisturbed for the foreseeable future.

Heat generated by the wastes will gradually increase the temperature at the surface (Johnstone et al., 1983). The maximum increase is expected to be less than 1°C (2°F) approximately 3000 years after waste emplacement, and the heat will dissipate slowly thereafter. The surface area that will be affected by the 1°C isotherm will probably be generally circular and will encompass approximately 2000 acres, which is the areal extent of the repository. The ecological consequences of increasing the surface and near-surface temperatures over the repository cannot be quantified with the information currently available. However, significant ecological impacts would not be expected because of the relatively small area to be affected, and because the heat increase will be temporary.

5.2.5 Air quality

The development of Yucca Mountain as a repository would result in emissions of several substances into the atmosphere. This section will discuss the impacts associated with emissions from construction, operation, and subsequent decommissioning of the repository and the relationship of these impacts to applicable regulations. Only nonradiological emissions have been considered in this section. Section 5.2.9 discusses the potential for radiological emissions.

5.2.5.1 Ambient air quality regulations

Both the State of Nevada and the U.S. Environmental Protection Agency (EPA) have promulgated regulations that are designed to protect the air quality of Nevada, and they are expressed as ambient air quality standards. The standards that apply to the development of Yucca Mountain are outlined on Table 5-12. Before construction can begin, the State of Nevada requires a registration certificate that outlines limits on, and controls of, the emissions from facilities. After operation begins, an operating permit is required to verify that the source is operating within the limits of its registration certificate.

Particulate emissions are expected to be of the most concern in development of Yucca Mountain as a repository. The State of Nevada's regulatory intent concerning fugitive particulate emissions is that "no person shall cause or permit the handling, transporting, or storing of any material in a manner which allows, or may allow, controllable particulate matter to become airborne." Compliance with this mandate would be incorporated into the registration certificate. However, because of the preliminary stage of the repository design at Yucca Mountain, only uncontrolled or minimally controlled (i.e., worst-case) particulate emissions have been assumed in this analysis.

In addition to these regulatory requirements, the project could be subject to review under the Prevention of Significant Deterioration (PSD) provisions of the Clean Air Act Amendments of 1977 (the Clean Air Act). Three classes of areas were established under the Clean Air Act to maintain specified levels of air quality. The classes allow for some industrial development by specifying incremental increases in ambient pollutant levels. These increments are small percentages of the National Ambient Air Quality Standards (NAAQS) and are outlined on Table 5-13. Class I areas are to remain pristine and allow only limited development, such as for national parks and wilderness areas. All other parts of the country that are subject to PSD regulations, including the Yucca Mountain site, were initially designated as Class II areas. Class III areas are allowed to reach, but not to exceed, the NAAQS. At the present time, it is not clear whether or not the repository would be subject to PSD review. The applicability of PSD requirements is related to significant emission levels below which PSD review is not required. When specific details of repository emissions are known, the State of Nevada will be required to make a determination of applicability of PSD requirements. If review is required, it would entail a control technology review and could require either air quality or meteorological monitoring.

5.2.5.2 Potential impacts from construction

A preliminary assessment of the emissions and ambient air quality impacts of construction of the Yucca Mountain repository has been made by Bowen and Egami (1983). It was determined that emissions may result from site preparation, mine construction, movement of mined rock to storage piles, wind erosion of stored material, concrete preparation, and combustion of fossil fuels. Although Bowen and Egami (1983) assumed a seven-year construction period, these values have been corrected to reflect the five-year period now envisioned for Yucca Mountain. Table 5-14 presents estimated particulate emissions based upon three eight-hour shifts working 250 days per year, and Table 5-15 presents estimated gaseous emissions associated with construction of the project. These emission rates do not represent absolute values, however,

Table 5-12. Ambient air quality standards (State of Nevada, NAQR, 1982)

Pollutant	Time period	Nevada standard µg/m^3 (ppb)[a]	Federal primary standard µg/m^3 (ppb)	Federal secondary standard µg/m^3 (ppb)
Sulfur dioxide	3 hour	1,300	---	1,300 (500)
	24 hour	365 (140)	365 (140)	---
	Annual arithmetic mean	80 (30)	80 (30)	80 (30)
Total suspended particulates	24 hour	150	260	150
	Annual geometric mean	75	75	60
Oxidant (ozone)	1 hour	235 (120)	235 (120)	235 (120)
Nitrogen dioxide	Annual arithmetic mean	100 (50)	100 (50)	100 (50)
Carbon monoxide	1 hour	40,000 (35,000)	40,000 (35,000)	40,000 (35,000)
	8 hour	10,000 (9,000)	10,000 (9,000)	10,000 (9,000)

[a] ppb = parts per billion.

Table 5-13. Maximum allowable pollutant increments assuming PSD requirements

Pollutant	Time period	Increments[a] ($\mu g/m^3$) Class I	Class II	Class III
Sulfur dioxide	3 hour	25	512	700
	24 hour	5	91	182
	1 year	2	20	40
Particulates	24 hour	5	19	37
	1 year	10	37	75

[a] For any period other than annual, increase may be exceeded not more than one day per year at any one location.

Table 5-14. Estimated particulate emissions from repository construction (Bowen and Egami, 1983)

Source	Total (metric ton)[a]	Emission rate (g/s)[b]
Surface facilities[c]	1296	86.5
Mine construction[d]		
Shaft drilling/blasting	58	0.54
Subsurface[e]		
Drilling/blasting	4.4	0.04
Rockmoving		
Loading	13	0.12
Dumping	0.68	0.006
Surface rock transport		
Loading	1500	13.9
Hauling	2700	25.0
Dumping	77	0.7
Wind erosion	1000	6.5
Concrete		
Batching	20	0.19
Sand and gravel processing	17	0.15
Transportation related[f]	7.0	0.06

[a] 1 metric ton = 2.205×10^3 lb.

[b] 1 gram/sec = 2.205×10^{-3} lb/sec.

[c] Total emissions and emission rate for one-year assumed duration of this activity.

[d] Conventional drill/blast/muck-removal techniques have been assumed.

[e] Emissions calculated assuming conventional subsurface controls.

[f] Includes diesel fuel useage.

emission rates do not represent absolute values, however, and will need to be revised as more accurate information on specific construction practices becomes available.

Bowen and Egami (1983) attempted to quantify the ambient impact of project related emissions by applying the air-quality simulation model known as "Valley." Valley is an EPA-approved, complex-terrain model that is most frequently used as a screening-level model for 24-hour periods. Screening indicates that many physical parameters are not well known such as exact emission rates and locations, plume rise and velocity, and onsite meteorology. Thus, assumptions are made that result in worst-case ambient concentrations.

For modeling purposes, short-term worst-case meteorological conditions are defined as a very stable atmosphere and a constant wind speed of 2.5 m/s (8.2 ft/s) in one of 16 compass directions for 6 of 24 hours. These conditions would most likely occur during late evening and early morning, and they do not necessarily correspond to peak working hours at the repository. In fact, emissions during this stable period could be at a minimum.

Two possible locations for the exploratory shaft have been modeled: one is along the ridge of Yucca Mountain, and the other is on the eastern slope of Yucca Mountain. For modeling purposes, the repository was assumed to be a square area of 280 ha (700 acres) with a uniform emission rate over the entire area. Because the Valley model was developed for evaluating the impacts from a single, elevated-point source, this assumption is not entirely appropriate; however, it provides a screening-level assessment.

For mathematically linear models such as Valley, ambient concentrations are directly proportional to emission rates. Thus, the modeled concentrations that had been obtained by assuming a 7-year construction period (Bowen and Egami, 1983) can be extrapolated to a 5-year construction period. The Valley-predicted maximum 24-hour concentrations are shown on Table 5-16. The worst-case emission scenario, in which all activities indicated in Tables 5-14 and 5-15 occur simultaneously, is also shown in Table 5-16.

Table 5-15. Estimated total potential gaseous emissions during repository construction[a] (Bowen and Egami, 1983)

Pollutant	Total (metric ton)	Emission rate g/s[b] (5 years)
Carbon monoxide	22.0	0.20
Hydrocarbons	8.0	0.07
Nitrogen oxides	114.4	1.06
Sulfur dioxide	7.2	0.07

[a] From internal combustion engines.

[b] 1 g/s = 2.205×10^{-3} lb/sec.

Table 5-16. Estimated maximum 24-hour concentrations from repository construction[a] (Bowen and Egami, 1983)

Pollutant	Emission rate (g/s)[b]	Predicted impact ($\mu g/m^3$)	
		Ridge location[c]	Valley location[d]
Total suspended particulate	133.7	130	132
Carbon monoxide	0.2	0.2	0.2
Hydrocarbons	0.1	0.1	0.1
Nitrogen oxides	1.1	1.1	1.1
Sulfur dioxide	0.1	0.1	0.1

[a] Modeled year includes surface facility construction that would not last the duration of the 5-year period.

[b] 1 gram/sec = 2.205×10^{-3} lb/sec

[c] Maximum concentration occured 1.5 km (1 mi) SSW of the repository location.

[d] Maximum concentration occured 1.0 km (0.6 mi) ENE of the repository location.

A comparison can be made of the predicted construction impacts (Table 5-16) with the ambient air quality standards presented earlier (see Table 5-13). Such a comparison indicates that none of the predicted pollutant concentrations will violate applicable standards.

If the project were subject to PSD requirements, these impacts would also have to be evaluated against applicable pollutant increment levels. Because of the uncertainties involved in many of the emission estimates and modeling assumptions, however, evaluation of PSD-related impacts have not been addressed.

In addition, the analyses described in the preceding section have assumed that fugitive-dust control measures will not be used. However, such measures are available, and could be used to further reduce emissions. For example, watering exposed surfaces twice daily will reduce emissions by about 50 percent, and chemical suppressants can reduce emissions by 80 percent on completed cuts and fills (EPA, 1974a). In general, by using proper techniques, emissions during construction of the repository could be reduced to a level less than one-half of that assumed in this conservative analysis.

Emissions from completed dirt roads can be reduced by traffic control. They can also be reduced 85 percent by paving, 50 percent by treating the surface with penetrating chemicals, and 50 percent by working soil-stabilization chemicals into the road bed (Bowen and Egami, 1983). Storage piles of waste rock could be treated with chemicals to inhibit resuspension, and the waste pile area could be revegetated.

5.2.5.3 Operation and transportation

Nonradiological emissions associated with operation of the repository include both dust from surface handling of mined materials and combustion products from burning diesel fuel. Dust emissions from surface handling of mined materials were discussed in Section 5.2.5.2 and were represented in Table 5-14. Based upon estimates of diesel-fuel usage (McBrien and Jones, 1983) and emission factors (URS, 1977), the total emissions from 60 years of operation are shown on Table 5-17.

Table 5-17. Estimated emissions for 60 years of repository operation based upon diesel fuel use (McBrien and Jones, 1983)

	Pollutant[a]				
Years	CO	HC	NO_x	SO_2	Particulates
1-5					
Total (metric tons)[b]	22.0	8.0	114.4	7.2	7.0
Emission rate[c] (g/s)[d]	0.20	0.07	1.06	0.07	0.06
6-35					
Total (metric tons)	214.5	78.3	1114.2	70.4	67.9
Emission rate (g/s)	0.33	0.12	1.72	0.11	0.10
36-55					
Total (metric tons)	7.8	2.8	40.4	2.6	2.5
Emission rate (g/s)	0.02	0.01	0.09	0.01	0.01
56-60					
Total (metric tons)	8.1	3.0	42.3	2.7	2.6
Emission rate[e] (g/s)	0.11	0.04	0.60	0.04	0.04

[a] CO = carbon monoxide; HC = hydrocarbons; NO_x = nitrogen oxides; SO_2 = sulfur dioxide.

[b] 1 metric ton = 2.205×10^3 lb.

[c] Based on three 8-hour shifts, 250 days per year.

[d] 1 g/s = 2.205×10^{-3} lb/sec.

[e] Based on two 8-hour shifts, 250 days per year.

Based upon the results of the preliminary Valley modeling, these emission rates do not indicate future violations of any ambient air standards. Furthermore, part of the diesel emissions would be underground and would be filtered before being released to the atmosphere; this would slightly reduce both the amount and the rate of emissions as listed on Table 5-17.

Emissions would also occur from commuter traffic to and from the site. Total emissions have been estimated on the basis of gasoline usage estimated in a report by URS (1977) for a 35-year emission duration, and they are shown on Table 5-18. Considering the diverse area over which emissions would occur and the long duration of the emissions, these emission levels should have no significant impact on ambient air quality.

Wind erosion from waste-rock storage piles would cause resuspension of some particles. Also, unpaved roads at the site will be a source of fugitive dust emissions during repository operation. The amount of fugitive dust that could be generated depends upon the extent of such roads and the control measures to be employed; neither factor is known at this time.

Transport of nuclear wastes to the repository will result in emissions from trucks and trains. Because the amount of waste to be transported by each mode is not known at this time, it was assumed that emissions would be generated either 100 percent by rail or 100 percent by truck. Using estimates of diesel fuel consumption (Table 5-10) and related emission factors (EPA, 1981; URS, 1977), emission estimates from transportation of waste to the site were calculated and are shown in Table 5-19.

Wilmot et al. (1983) states that the total one-way shipping distance by rail is 55×10^6 km (34×10^6 mi) and 300×10^6 km (186×10^6 mi) for truck. The estimated emissions, when dispersed over this distance during the life of the project, should have a negligible effect on ambient air quality.

5.2.5.4 Closure and decommissioning

Closure and decommissioning could consist of partially backfilling the mined shafts and drifts with material from the storage piles and restoring the surface to a condition that would be similar to its original topography. This would cause fugitive dust emissions from loading, hauling, dumping, and surface restoration. Gaseous and particulate emissions would occur from construction equipment and commuter traffic (Bowen and Egami, 1983). No particulate emission rate other than for diesel fuel combustion (Table 5-17) can be determined at this time. In any case, the extent of these activities would be limited in comparison to construction activities and are not expected to create significant ambient impacts when spread over the five-year closure period.

5.2.6 Noise

Wildlife is the only sensitive receptor in the uninhabited desert. The effects of noise on wildlife are speculative. Laboratory and field experiments have shown both permanent and temporary physical and behavioral effects at levels in the 75 dBA to 95 dBA range (EPA, 1971a; Brattstom and Bondello, 1983; Ames, 1978). For purposes of this analysis, continuous 75 dBA noise was assumed to be the level at which wildlife would be affected.

Investigators studying incremental noise levels that affect humans have concluded that an annual increment of 5 dBA should be considered significant (EPA, 1974b). Assuming that small towns in the vicinity of Yucca Mountain experience an annual average noise level of 50 dBA, this increment would increase the annual level to 55 dBA for the small towns characterized in Chapter 3. A composite annual day/night noise level (L_{dn}) of 55 dBA has been declared to be the level that will protect public health and welfare (EPA, 1974b). Therefore, this analysis will use an annual L_{dn} of 55 dBA as the level above which people in residential areas may begin to experience some annoyance.

Table 5-18. Estimated total emissions from commuter traffic (URS, 1977)

Pollutant	Total emissions (metric ton)[a]
Carbon monoxide	27,075
Hydrocarbons	946
Nitrogen oxides	804
Sulfur oxides	36
Total suspended particulates	50

[a] 1 metric ton = 2.205×10^3 lb

Table 5-19. Estimated emissions from transportation of radioactive wastes (URS, 1977)

Pollutant	100% rail transport (metric tons)[a]	100% truck transport (metric tons)
Carbon monoxide	3,290	8,630
Hydrocarbons	2,390	3,130
Nitrogen oxides	9,370	44,800
Sulfur oxides	1,440	2,830
Total suspended particulates	630	2,730
Aldehydes	140	0
Organic acids	171	0

[a] 1 metric ton = 2.205×10^3 lb

5.2.6.1 Construction

Construction noise sources include the use of construction equipment and the transportation of workers and materials to the site. Construction activities that will produce noise include building the surface facilities, the rail line, the bridge over Fortymile Wash, an access road, and mining the repository shaft. All five of these activities are expected to occur simultaneously during the first two years of repository construction.

Neither construction techniques nor routes for the road(s) and the rail have been specified yet. In the absence of this information, it has been assumed that construction equipment and manpower requirements are similar to those required in the construction of other large facilities. Maximum noise levels attributed to each piece of construction equipment are listed in Tables 5-20 through 5-24. These tables also list the area to be affected, sensitive receptors, and the resultant noise levels at 150 m (500 ft) from the focal point of construction activities. Because the resultant levels at 150 m (500 ft) are based on the loudest instantaneous levels possible, the analysis is conservative. Furthermore, the analysis assumes that geometric divergence of the sound waves provides the only attenuation. Again, this represents a conservative analysis because it excludes possible attenuation due to absorption and barrier effects. Table 5-25 summarizes the noise levels from construction and indicates the radial distances required to attentuate the construction noise to below 75 dBA (the level assumed to affect wildlife) or 55 dBA (the level asumed to affect humans). In developing the radial distance required to achieve an annual L_{dn} of 55 dBA, it was assumed that construction would last 10 hours per day, 250 days per year, for all off site construction activities. Repository-related construction activities are assumed to be 24 hours per day, 250 days per year.

The radial distances associated with reaching an annual L_{dn} level of 55 dBA suggests that impacts may occur. The access road is expected to pass within 0.8 km (0.5 mi) of the town of Amargosa Valley. The radial distance of 1.4 km (0.9 mi) for the access road suggests that some residents may experience noise-related annoyance while construction operations are within 1.4 km (0.9 mi) of town. Construction of the rail line also carries a 1.4 km (0.9 mi)

Table 5-20. Estimated maximum noise levels from surface facility construction equipment

Equipment	Noise level (dBA at 15 m)	Number and location of vehicles anticipated	
		Surface facilities	Each shaft
Bulldozers	80[a]	1	1
Earth movers	78[a]	6	1
Pile drivers	101[b]	1	1
Boring machines	98[b]	1	1
Front end loaders	76[a]	6	1
Gravel elevators	88[b]	1	1
Grader/scrapers	88[b]	1	1
Backhoes	85[b]	1	1
Shovels	82[b]	1	1
Cranes	83[b]	6	1
Steam rollers	75[a]	1	1
Air compressors	81[b]	1	1
Concrete mixers	85[b]	1	1
Drill rigs	101[a]	1	1
Truck handling conveyors	88[b]	1	1
Service vehicles	88[b]	30	5

Resultant noise level at 150 m (500 ft):
Surface facilities: 88 dBA
Each shaft location: 86 dBA

Area affected: Uninhabited desert
Receptors affected: Wildlife

[a] EPA, 1971b

[b] EPA, 1974b

Table 5-21. Noise levels from construction of the access road

Equipment	Noise level (dBA at 15 m)	Number of vehicles
Bulldozers	80[a]	5
Earth movers	78[a]	5
Graders	88[b]	5
Rollers	80[b]	5
Concrete mixers	85[b]	5
Cranes	83[b]	2
Shovels	82[b]	2
Dump trucks	88[a]	5
Front-end loaders	76[a]	5
Service vehicles	88[a]	10

Resultant Noise level at 150 m (500 ft): 82 dBA

Area affected: Uninhabited desert, town of Amargosa Valley
Receptors affected: Wildlife, Humans

[a] EPA, 1971b.

[b] EPA, 1974b.

Table 5-22. Noise levels from construction of the rail spur

Equipment	Noise level (dBA at 15 m)	Number of vehicles
Bulldozers	80[a]	5
Earth movers	78[a]	5
Graders	88[b]	5
Rollers	80[b]	5
Cranes	83[b]	5
Shovels	82[b]	5
Concrete mixers	85[b]	5
Dump trucks	88[a]	5
Front-end loaders	76[a]	5
Service vehicles	88[a]	10

Resultant Noise Level at 150 m (500 ft): 82 dBA

Area affected: Uninhabited desert, Indian Springs, Mercury
Receptors affected: Wildlife, humans

[a] EPA, 1971b

[b] EPA, 1974b

Table 5-23. Noise levels from construction of the rail-spur bridge over Fortymile Canyon

Equipment	Noise level (dBA at 15 m)	Number of vehicles
Bulldozers	80[a]	5
Earth mover	78[a]	5
Graders	88[b]	2
Dump trucks	88[a]	5
Concrete mixers	85[b]	2
Shovels	82[b]	5
Pile drivers	101[b]	3
Cranes	83[b]	2
Boring machines	98[b]	1
Front-end loaders	76[a]	5
Service vehicles	88[b]	5

Resultant Noise Level at 150 m (500 ft): 86 dBA

Area affected: Uninhabited desert
Receptors affected: Wildlife

[a] EPA, 1971b.

[b] EPA, 1974b.

Table 5-24. Noise levels from construction of the transmission line[a]

Equipment	Noise level (dBA at 15 m)	Number of vehicles
Crane	83[b]	1
Boring machine	98[b]	1
Service vehicles	88[b]	2

Resultant Noise Level at 150 m (500 ft): 79 dBA

Area affected: Uninhabited desert, Indian Springs, Mercury
Receptors affected: Wildlife, humans

[a] Assumes that the transmission line is placed along the right of way for the rail line and that construction follows clearing for the rail line.

[b] EPA, 1974b.

impact radius. This will affect residents in Indian Springs. People in Mercury and users of Floyd R. Lamb (formally Tule Springs) State Park should not be affected by noise because the rail will probably not pass within 1.4 km (0.9 mi) of Mercury or of the park. Impacts to wildlife should be limited to the immediate vicinity of the construction sites.

Noise will also occur during transportation of workers to and from the site and from transportation of materials to the site. Based upon preliminary information on transportation, as is detailed in Section 5.3, worker transport during the night shift will have the greatest noise impacts. Incremental noise has been estimated and is based on the following:

1. Existing or baseline noise has been assumed using the 1996 projected traffic flows (see Section 5.3).
2. Off-peak traffic flow is evenly distributed throughout the remainder of the day.
3. The average speed of vehicles is 80 km per hour (50 mph).
4. Nevada Test Site traffic patterns will prevail.

Based upon these assumptions, incremental noise is anticipated to be approximately 4 dBA. It is generally accepted that 4 dBA is just over the value at which people begin to perceive a noise change. Assuming a 4 dBA increment during all three shifts, the annualized increment level would be approximately 2 dBA. This is below the EPA's significant level of 5 dBA. Therefore, no significant noise problems due to worker transport are anticipated at either the town of Amargosa Valley or at Indian Springs. It is estimated that wildlife that is farther than 300 m (1000 ft) from the noise source will experience noise levels of 25 dBA or less.

5.2.6.2 Operation

During operation of the repository, major noise sources will include underground rock-handling equipment, rail and truck waste transportation, and worker transport. Table 5-26 lists the type and number of vehicles expected to be used during operation, the equipment noise-levels, the area affected, the sensitive receptors, and the resultant noise levels at 150 m (500 ft).

Table 5-25. Summary of noise impacts from construction activities

Construction activity	dBA level at 150 m	Radius to achieve an average annual L_{dn} of 55 dBA (km)[a]	Radius to achieve a level of 75 dBA (km)[a]
Repository			
Surface facilities	88	NA	0.7
Shaft locations	86	NA	0.5
Access road	82	1.4	0.3
Rail spur	82	1.4	0.3
Bridge	86	NA	0.5
Transmission line	79	1.3	0.2

[a] 1 km = 0.621 mi.

Table 5-26. Noise levels from operation of the repository

Equipment	Noise level (dBA at 15 m)	Number of vehicles
Rock elevators	88[b]	2
Bulldozers	80[a]	2
Earthmovers	78[a]	5
Front-end loaders	76[a]	5
Service Vehicles	88[b]	25

Resultant Noise Level at 150 m (500 ft): 82 dBA

Area affected: Uninhabited desert
Receptors affected: Wildlife

[a] EPA, 1971b.

[b] EPA, 1974b.

Rail transport will average one train per day and will consist of a locomotive and from two to four cars. Maximum noise levels at 30 m (100 ft) have been established by the EPA as 90 dBA for moving locomotives and 93 dBA for rail cars exceeding 72 km per hour (45 mph) (EPA, 1980). For a train with one locomotive and four cars, the noise level at a distance of 150 m (500 ft) would be approximately 86 dBA. This would result in instantaneous levels greater than 55 dBA at Indian Springs, Floyd R. Lamb State Park, and Mercury. When the results are annualized, the resultant annual L_{dn} level would be approximately 55 dBA at 150 m (500 ft). This is the level at which people may begin to perceive some annoyance. However, if rail shipments of waste occur at night when people are most sensitive to intrusive noise, more severe problems should be anticipated in nearby communities. The resultant radius at which there would be no impacts to wildlife would be 300 m (1000 ft).

Truck transport of concrete, steel, and diesel fuel could average 17 vehicle trips per day during the first two years of repository construction. Given an average daily traffic count of 1450 in the town of Amargosa Valley, 247 of which are trucks (State of Nevada, DOT, 1983), no noise impacts are anticipated to the residents. The resultant radius to avoid impacts to wildlife along the access road is 47 m (150 ft) assuming a truck noise level of 85 dBA at 15 m (50 ft).

During the operational period, worker transport will be less than it will be during construction. Furthermore, background, or existing, traffic is expected to increase. Therefore, increased noise due to an incremental traffic increase will be less than that predicted for the construction period. As with the construction period, however, no significant impacts are expected either for the communities of Amargosa Valley or Indian Springs.

5.2.6.3 Decommissioning

Decommissioning operations will result in elevated noise levels from operation of construction equipment and from worker transport. The postclosure period would not contribute to noise.

Construction equipment that will be used during decommissioning is listed in Table 5-27. This table also indicates the location and number of construction vehicles, noise levels of the equipment, resultant noise levels at 150 m (500 ft), and the areas and the sensitive receptors that could be affected. Based upon these values, the resultant impact radius is 300 m (1000 ft) for decommissioning of surface facilities and 150 m (500 ft) for decommissioning of shafts.

Worker transport has yet to be quantified for this period. Therefore, no final estimate on incremental noise can be made. However, it is not expected to be greater than that which was calculated for the construction period.

5.2.7 Aesthetic resources

The construction and operation of a repository and its supporting facilities will have an impact on the visual aesthetics of the area. However, this impact is not expected to be either significant or controversial.

During the construction of the railway and access road, equipment and construction crews will be visible along U.S. 95. When they are in place, the rail line, the transmission lines, and the paved road will be visible to travelers along U.S. 95. Most of the construction crews, and equipment at Dike Siding, will be far from population centers. In addition, the repository surface facilities will be constructed in a limited-access area and will not be visible from U.S. 95. Overall, aesthetic impacts will be minimal.

5.2.8 Archaeological, cultural, and historical resources

Both direct and indirect impacts have been considered in evaluating the potential impacts to the archaeological resources. Direct impacts, including destruction of archaeological sites, may occur during repository construction, operation, closure, and decommissioning. Direct impacts can also result from road and railway construction, drilling, stockpiling of mined material, and construction of surface facilities.

Table 5-27. Noise levels from decommissioning operations

Equipment	Noise level (dBA at 15 m)	Number and location of vehicles anticipated	
		Surface facilities	Each shaft
Bulldozers	80[a]	6	1
Concrete mixers	--	1	1
Earth movers	78[a]	1	1
Graders	88[b]	1	1
Dump trucks	88[a]	6	1
Cranes	83[b]	1	1
Front-end loaders	76[a]	1	1
Shovels	82[b]	1	1
Service Vehicles	88[b]	12	2

Resultant noise level at 150 m (500 ft):

Surface facilities: 81 dBA
Each shaft location: 75 dBA

Areas affected: Uninhabited desert
Receptors affected: Wildlife

[a] 1 m = 3.28 ft.

[b] EPA, 1971b.

[c] EPA, 1974b.

Indirect impacts can result either from unauthorized excavation and collection of artifacts or from vandalism of cultural sites. Both favorable and adverse indirect impacts can result from improved access to the area. Improved access will facilitate authorized studies, excavations, and removal of artifacts. However, easier access may also have an adverse impact because unauthorized personnel may either remove artifacts or vandalize the cultural sites.

Archaeological and historical sites in outlying areas may also experience indirect impacts from construction and operation of the repository. In July 1983, a survey identified 145 historic and prehistoric sites within an 140 km (87 mi) radius of, but not on, the Nevada Test Site. These sites include petroglyphs, early Mormon settlements, ranches, and mining communities. All sites are close enough to Las Vegas and to the Nevada Test Site to be considered easy one-day or weekend trips for repository workers. Most of the archaeological sites encountered were insignificant lithic scatters that, if disturbed, would not result in a loss of cultural resource. None of the significant archaeological sites will be disturbed by the project. However, it should be noted, that these sites are also accessible to residents of the Las Vegas area who are not affiliated with the repository. Therefore, it is impossible to differentiate the impact that the increased population associated with the repository would have, although it is reasonable to assume that a larger number of people could result in a greater impact to these resources.

Physical disturbance of archaeological sites during construction and operation could result in the loss of data that are crucial for interpreting archaeological sites. Nonscientific excavation or collection can either limit or destroy the research value of the sites. The removal of even a few chronologically or functionally sensitive artifacts can reduce or distort the cultural value of small sites. Therefore, mitigation will take place both before and during the construction of the repository. Mitigation measures could include a 50 m (165 ft) fenced buffer zone around significant sites, and the employment of a professional archaeologist to monitor all construction near sensitive locations. Significant cultural resources will be avoided during construction, and information regarding archaeological sites will be incorporated into the early stages of planning.

To avoid indirect adverse impacts, off-road travel will be restricted. As is specified under the Archaeological Resource Protection Act of 1979, employees of the repository will be informed of policies regarding archaeological sites and the penalities for unauthorized collections and excavation at these sites. If necessary, important sites will be fenced.

In a study by Pippin et al. (1983), the authors recommended a program of data recovery that consisted of "an adequate, representative and scientifically based sample of cultural resources." This program could apply to the entire Yucca Mountain area, including the areas that contain supporting facilities, and would provide a scientific data base of the cultural resources of part of southern Nevada.

Impacts from repository operation will be less than those associated with repository construction. No further construction is expected to take place during the operations phase, except for the possible installation of an additional transmission line. No additional impacts are expected during closure and decommissioning because no new areas will be disturbed.

5.2.9 Radiological effects

This section discusses the possible radiological effects from repository construction and operation. Since much of the following discussion focuses on radiological effects, a brief review of the relevant terminology is in order.

A curie (Ci) is a unit used to describe the number of atoms undergoing radioactive decay as a function of time. One Ci is equal to 3.7×10^{10} disintegrations per second. The International System of Units (SI) unit for radioactivity is the Becquerel (Bq), where 1 Bq is equal to 1 disintegration per second. The mass of a 1-Ci amount of radioactive material can vary dramatically depending on the half-life (i.e., the time it takes for one-half of the atoms initially present to decay) of the isotope. For example, 1 Ci of Co-60 is equal to less than 1 mg, 1 Ci of Ra-226 is 1 g, and 1 Ci of U-238 is about 3000 kg (6600 lb). The measure of activity as a function of mass is referred to as specific activity, and the unit of specific activity is Ci/g.

Absorbed radiation dose is a measure of the amount of ionizing radiation that is deposited in a given mass of absorbing medium. The unit of absorbed radiation dose is the rad; 1 rad is equal to 100 erg/g. The SI unit for absorbed radiation dose is the Gray (Gy), where 1 Gy is defined as an amount of absorbed dose equal to 1 Joule per kilogram (J/kg). 1 Gy is equal to 100 rads.

Since the biological damage inflicted by different types of radiation can vary, the quality factor (Q) is used as a measure of the relative biological effectiveness of a given type of radiation. The quality factor is directly related to the linear energy transfer (LET) of the radiation, which is a measure of the energy deposited per unit of path length. The unit of LET is a thousand electron volts (KeV) per micron. Densely ionizing (high LET) particles such as protons, neutrons, and alpha particles are assigned a quality factor of ten, while sparsely ionizing (low LET) radiation such as beta particles, X rays, and gamma rays are assigned a quality factor of unity. In essence, this means that densely ionizing radiation is approximately ten times as effective at inflicting biological damage per rad as sparsely ionizing radiation.

The concept of dose equivalent is used to describe the effectiveness of a given unit of absorbed radiation dose. The unit of dose equivalent is the rem; 1 rem is the product of 1 rad and the quality factor for the radiation in question. Thus, an absorbed dose of 1 rad of gamma rays is equal to a dose equivalent of 1 rem, and a dose of 1 rad of alpha particles is equal to a dose equivalent of 10 rem. The SI unit of dose equivalent is the Sievert (Sv); 1 Sv is the product of 1 Gy and Q (i.e., 1 Sv = 100 rem).

5.2.9.1 Repository construction

Two families of radioactive heavy elements (the uranium and thorium series) are found in most rocks and soils, and they account for about one-third of the natural background radiation to which humans are exposed. For example, the concentration of uranium in rocks ranges from more than 300 parts per million (ppm) in phosphatic rocks in South Carolina, to from 1 to 4 ppm in other sedimentary rocks. These radioactive heavy elements exist in rocks in equilibrium with their decay products, and some of them are gaseous. The breaking and crushing of rocks, such as that which occurs in mining operations, may release these decay products to the atmosphere in much larger quantities than those that escape naturally through the fractures and pores of the rocks. The estimated quantities of these decay products that are released annually to the atmosphere due to mining activities are listed in Table 5-28. The quantity released is directly proportional to the volume of rock that is mined annually. In the vertical waste-emplacment repository design, approximately 2.5 times as much rock is mined as in the horizontal waste-emplacement design. Values in Table 5-28 were estimated from those given for a repository constructed in granite (DOE, 1980), which has approximately the same uranium and thorium content as Yucca Mountain rocks, by scaling with the ratio of total mined volume.

The enhanced release of naturally occurring radionuclides is estimated to result in whole-body dose commitments of 5 man-rem to the regional population for the horizontal waste-emplacement design and 12 man-rem for the vertical waste-emplacement design. A regional population of 4600 people within an 80 km (50 mi) radius of a central point on the Nevada Test Site will receive an annual dose of 410 man-rem from natural background radiation (Black et al., 1983).

5.2.9.2 Repository operation

The operating life of the repository will span 30 years. During that period, workers will be exposed to radiation from receiving, handling and packaging, and emplacing of wastes. The permissible dose equivalent limit for worker exposure is 5 rem per year (10 CFR 20) with a prescribed design objective. The facilities will be designed to reduce the annual exposure to individual workers and to the total repository work force to the lowest levels reasonably achievable.

Two types of high-level wastes are assumed to be shipped to the Yucca Mountain repository: spent reactor fuel (SF) and commercial high-level waste (CHLW). The repository is being designed to accept the equivalent of 70,000 metric tons of heavy metal (MTHM). The occupational exposures that have been calculated and reported in the following paragraphs are for an assumed waste

Table 5-28. Estimated releases of naturally occurring radionuclides to the atmosphere from repository construction

Nuclide	Releases (curies/yr)	
	Horizontal emplacement	Vertical emplacement
Radon-220	1.6	3.8
Radon-222	1.6	3.6
Lead-210	1.2×10^{-4}	3.0×10^{-4}
Lead-212	2.3×10^{-3}	5.7×10^{-3}
Lead-214	1.5	3.6
Bismuth-210	1.5	3.6

composition of 50 percent SF and 50 percent CHLW. These dose estimates will not change substantially if other waste compositions (e.g., 100 percent SF or 100 percent CHLW) are assumed.

Worker exposure during normal operation

Specific operations were identified, individual tasks were listed, and operation times were allocated so that estimates could be made of the radiation exposure to workers at the repository during the receipt, handling and emplacing of high-level wastes (Dennis et al., 1983). The number of individual workers assigned to crew positions was estimated from the annual waste receipts and anticipated facility operations time. The annual worker exposure for each task and each individual was calculated from the anticipated operations time, the estimated worker exposure times for each task, the radiation field in which the operation was performed, and the annual receipt and handling rates of SF and CHLW.

Gamma-ray and neutron source intensities were calculated using the isotope generation and depletion code ORIGEN2. Shipping cask designs were used in conjunction with the three-dimensional radiation transport code, PATH, to develop dose rate maps around SF and CHLW shipping casks. The results of these analyses are presented in Table 5-29.

The total annual worker exposure at the repository is estimated to be about 79 man-rem during receipt, handling and emplacing high-level radioactive wastes. Over the 30-year life of the repository, the estimated collective worker radiation dose is 2365 man-rem.

Public exposure during normal operation

The two principal pathways by which the offsite population may be potentially exposed from normal (nonaccident) repository operation are external exposure to direct radiation during receipt, handling, and emplacing high-level wastes; and exposure to airborne effluents. The former pathway would result in insignificant public exposures both because of the shielding and packaging measures that will be taken to reduce occupational exposures and large distance (several miles) that separates the source from the receptor. Exposure to airborne effluents is not significant because of the negligible quantities of these emissions coupled with the dilution of effluent concentrations over the transport distance. In light of these facts, a quantitative estimate of public exposures resulting from normal repository operation was not made.

Accidental exposure during operation

The potential causes of accidental releases to the general public and to repository operations personnel can be divided into three categories: natural phenomena, external man-made events, and operational accidents (Tables 5-30 and 5-31). Under natural phenomena, three scenarios are postulated that could cause radionuclide releases: flooding, tornadoes and earthquakes. The external man made events which could cause a release are aircraft impact and underground nuclear weapons testing (Jackson et al., 1984a). The five operational accidents considered to be potential sources of radionuclide release are: (1) a fuel assembly drop in a hot cell; (2) a transportation accident and fire outside the surface facility involving spent fuel; (3) a transportation accident outside the surface facility involving commercial high-level waste; (4) a transportation accident and fire on the waste handling ramp; and (5) a transportation accident and fire in an emplacement drift.

The principal exposure pathway for the accident scenarios analyzed is atmospheric transport. Immersion in contaminated flood water is an exposure mechanism only for workers in the flooding scenarios. No significant water ingestion pathway was identified. Ingestion of meat, milk, and crops grown on land contaminated by radionuclides is considered to be a minor exposure pathway for the general public because of the low level of agricultural activity in the surrounding area. Fifty-year dose commitments were calculated for the maximally exposed individual, for the general public, and for operations personnel for each of the 10 accident scenarios. The maximally exposed individual is a member of the public whose location and habits tend to maximize the radiation dose he receives from a postulated accident. In this analysis, this individual is located just outside the exclusion boundary, which is 4 km (2.5 mi) directly west of the surface facility. The results of this analysis (Jackson, 1984) are given in Table 5-30.

Table 5-29. Summary of expected occupational exposures from repository operation (Dennis et al., 1983)[a]

Operation	No. of workers	Average worker dose (rem/yr)	Cumulative worker dose (man-rem/yr)[b]
Receiving	35	1.28	44.8
Handling and packaging	16	0.43	6.9
Surface storage to emplacement horizon	14	0.43	6.0
Emplacement			
Vertical	18	0.69	12.4
Horizontal	7	1.25	8.7

[a] See text for assumption.

[b] Cumulative for all workers.

Table 5-30. Estimated population dose commitments from postulated accidents (Jackson, 1983a)

	Maximum individual	General population	
Scenario[a]	Whole-body equivalent dose (rem)	Population exposed (number)	Whole-body equivalent dose (man-rem)
Natural phenomena			
Flood	1.59×10^{-5}	29[b]	4.61×10^{-4}
Earthquake	2.34×10^{-4}	19,900	3.07×10^{-3}
Tornado	2.34×10^{-4}	19,900	3.07×10^{-3}
Man-made external events			
Underground nuclear explosives test	2.34×10^{-4}	19,900	3.07×10^{-3}
Aircraft impact	3.28×10^{-1}	19,900	1.21×10^{2}
Operational accidents			
Fuel assembly drop in hot cell	5.14×10^{-6}	19,000	8.21×10^{-5}
Transportation accident and fire outside facility			
Spent fuel	2.42×10^{-4}	19,900	4.04×10^{-3}
CHLW	4.35×10^{-5}	19,000	4.76×10^{-4}
Transportation accident and fire on waste handling ramp	9.64×10^{-9}	19,900	1.32×10^{-7}
Transporation accident and fire in repository emplacement drift	9.64×10^{-9}	19,900	1.32×10^{-7}
Radiation safety levels in 10 CFR 60: 0.5 rem/accident whole-body dose			

[a] Except for the transportation accident outside facility where both spent fuel and CHLW are evaluated, all scenarios are based on spent fuel.

[b] Only population in the zone directly south of Drillhole Wash is exposed.

Table 5-31. Estimated operations dose commitments from postulated accidents (Jackson, 1984a)

Scenario[a]	Single worker whole-body equivalent dose (rem)	Worker exposed (number)	Whole-body[b] equivalent dose (man-rem)
Natural phenomena			
Flood	1.30×10^{-11}	87[c]	1.57×10^{-9}
Earthquake	5.71×10^{-1}	87[c]	4.97×10^{1}
Tornado	5.71×10^{-1}	87[c]	4.97×10^{1}
Man-made external events			
Underground nuclear explosives test	5.71×10^{-1}	87	4.97×10^{1}
Aircraft impact	6.16×10^{3}	327[d,e]	2.01×10^{3}
		347[d,e]	2.14×10^{3}
Operational accidents			
Fuel assembly drop in hot cell	1.25×10^{-2}	414[d,f]	5.18×10^{0}
		434[d,f]	5.43×10^{0}
Transportation accident and fire at loading dock			
Spent fuel	3.34×10^{2}	17[g]	5.68×10^{3}
	4.45×10^{-2}	397[d,g]	$1.77 \times 10^{[illegible]}$
		417[d,g]	1.36×10^{1}
CHLW	3.34×10^{1}	17[g]	5.83×10^{2}
	4.98×10^{-3}	397[g]	1.98×10^{0}
		417[d,g]	2.08×10^{0}
Transportation accident and fire on waste handling ramp	7.23×10^{1}	5[h]	4.34×10^{2}
	$4.98 \times 10^{[illegible]}$	40[d,i]	$2.30 \times 10^{[illegible]}$
	$1.29 \times 10^{[illegible]}$	50[d,i]	7.58×10^{2}
	7.50×10^{-2}	368[i]	$2.76 \times 10^{[illegible]}$
Transporation accident and fire in repository emplacement drift	1.36×10^{2}	40[d,j]	7.44×10^{3}
	1.37×10^{1}	50[d,j]	9.42×10^{2}
	7.50×10^{-2}	374[j]	2.81×10^{1}

Worker exposure limit in 10 CFR 20: 5.0 rem/yr; 3 rem/qtr.

[a] Except for the transportation accident and fire at the loading dock where both spent fuel and CHLW are evaluated, all scenarios involve spent fuel.

[b] Each of the calculated dose commitments reported in this study is made up of an acute component and a chronic component. Depending on the radionuclides involved, chronic exposure can be received primarily in the first year after the accident, as from Ru-106 or be distributed more equally over the 50 yr for which that dose is calculated, as from Pu-241.

[c] Only waste-handling facility workers are assumed to be exposed.

[d] Horizontal emplacement of waste canisters requires an estimated 40 subsurface workers; vertical emplacement requires an estimated 50 subsurface workers.

[e] All waste-handling facility workers are assumed killed. Other surface and subsurface personnel are assumed to be exposed as a consequence of the accident.

[f] All surface and subsurface personnel are assumed to be exposed equally as a consequence of the accident.

[g] Workers at the waste-handling facility loading dock receive the maximum dose; remaining personnel receive the smaller dose.

[h] Workers in the waste-handling ramp area receive the maximum dose.

[i] Waste emplacement workers receive a smaller dose than workers in the ramp area. Remaining personnel aboveground receive the smallest dose.

[j] Waste emplacement workers receive a greater dose than aboveground operations personnel.

All exposures to the maximally exposed individual and to the general public are less than the radiation exposure limit set (0.5 rem/accident) by the NRC (Code of Federal Regulations, 1984). The most severe exposure to the maximally exposed individual is 0.328 rem from the postulated aircraft impact scenario.

5.3 EXPECTED EFFECTS OF TRANSPORTATION ACTIVITIES

Transportation effects stem from (1) the use of the existing and projected transportation network to move people and materials to and from the proposed Yucca Mountain repository site and (2) the use of the projected transportation network to move high-level waste through the state to the site.

This section discusses the expected effects for these two activities for the repository construction, operation, and decommissioning periods. Because the retrievability period would have the smallest effects, its effects are not analyzed.

5.3.1 Traffic volume impacts

The impacts of increased traffic volumes on highway and railroad transportation networks during the construction, operation, and decommissioning phases are discussed in the following sections.

5.3.1.1 Highway impacts

Effects on the highway infrastructure will be limited to those associated with increased traffic because no roads are planned to be improved for the sole purpose of transporting people and material to the repository site.

Construction

For purposes of this analysis, it is assumed that construction will begin in 1993 and will reach its peak in 1996 when approximately 1570 workers will be employed during the day shift (see Section 5.1). This represents the peak work force that is expected for the most intensive scenario (i.e., vertical emplacement of waste); therefore, it represents the worst-case scenario. Impacts from both night-shift and swing-shift workers will be less than those from the day shift because there are fewer workers involved and there is less traffic during these hours.

The projected travel patterns of these day-shift workers are derived from current Nevada Test Site employee residence patterns as shown in Table 5-32. Figure 5-7 indicates that U.S. 95 between the junction with the site access road and Las Vegas will be the most severely impacted. This highway will carry 98 percent of the day-shift employees. Seventy-six percent of the work force will terminate their trip in Las Vegas and another 6 percent will travel beyond Las Vegas.

The transport of material would peak during the first two years of construction (Table 5-5). However, the peak for workers would not occur until the third year of construction (i.e. 1996). To conservatively estimate the impacts to U.S. 95 traffic flow the following assumptions have been made:

1) All truck traffic will approach the site from Las Vegas along U.S. 95;

2) Vertical emplacement of waste will occur; and

3) Peak transport of material will coincide with peak worker traffic.

These conservative assumptions should more than compensate for any material transport that was not accounted for in Section 5.1. By using these assumptions, the estimated material requirements (Table 5-5) and assuming 250 delivery days per year, it has been determined that during the first two years of construction there will be 13 round trips per day of trucks carrying material. Assuming that construction equipment is brought into the site over the first six months of construction, trucks carrying construction equipment will average four round trips per day. Assuming these trips will be spread evenly throughout the day shift, about 4 trucks per hour will pass any given point along the route. To be conservative, the following analysis assumes five trucks per hour.

The projected repository traffic must be evaluated against likely conditions in 1996. As noted in Section 3.1.5, evening peak-hour traffic flow is of critical importance. Table 5-33 compares 1996 traffic patterns on U.S. 95 with and without the repository during the evening peak hour. In developing Table 5-33, several of the highway segments shown on Figure 5-7 were subdivided. This was done to account for traffic volumes that were not related to the repository and to account for varying road conditions, both of which would affect the level of service. (The level of service categories are discussed in Section 3.1.5.)

Table 5-33 indicates that the level of service will decline beginning 8 km (5 mi) east of Amargosa Valley to Las Vegas. The decline is moderate for the segment between the site access road and SR 160, but the level at the Mercury interchange approaches undesirable conditions. (See Table 3-11 for definitions of service levels). Baseline traffic for segment E has the lowest level of service for 1996 along any of the evaluated segments of U.S. 95. Furthermore, the incremental traffic due to the repository would not be as great for this segment as for segments B and C. In segments B and C, traffic increases due to the repository are more than twice the baseline traffic; and for segment E the increase is from 1.5 to 1.8 times baseline traffic. This suggests that baseline traffic volumes and road conditions are prime factors contributing to a low service level. This two-lane road segment has very poor passing capabilities. However, this low service level is only expected to occur during the worst-case year (1996).

As can be seen from the preceding discussion, repository construction traffic will have its greatest impact on U.S. 95 between the site access road and Las Vegas. Predicted accidents for 1996 along U.S. 95 both with and without repository-related traffic are shown in Table 5-34. These predictions were calculated by assuming a linear relationship between vehicle-miles traveled and accident rate data (State of Nevada, DOT, 1983). Table 5-34 shows that under worst-case conditions approximately 13 additional accidents may be expected due to peak construction-related traffic. These additional accidents could result in six additional injuries and one additional death over a one-year period.

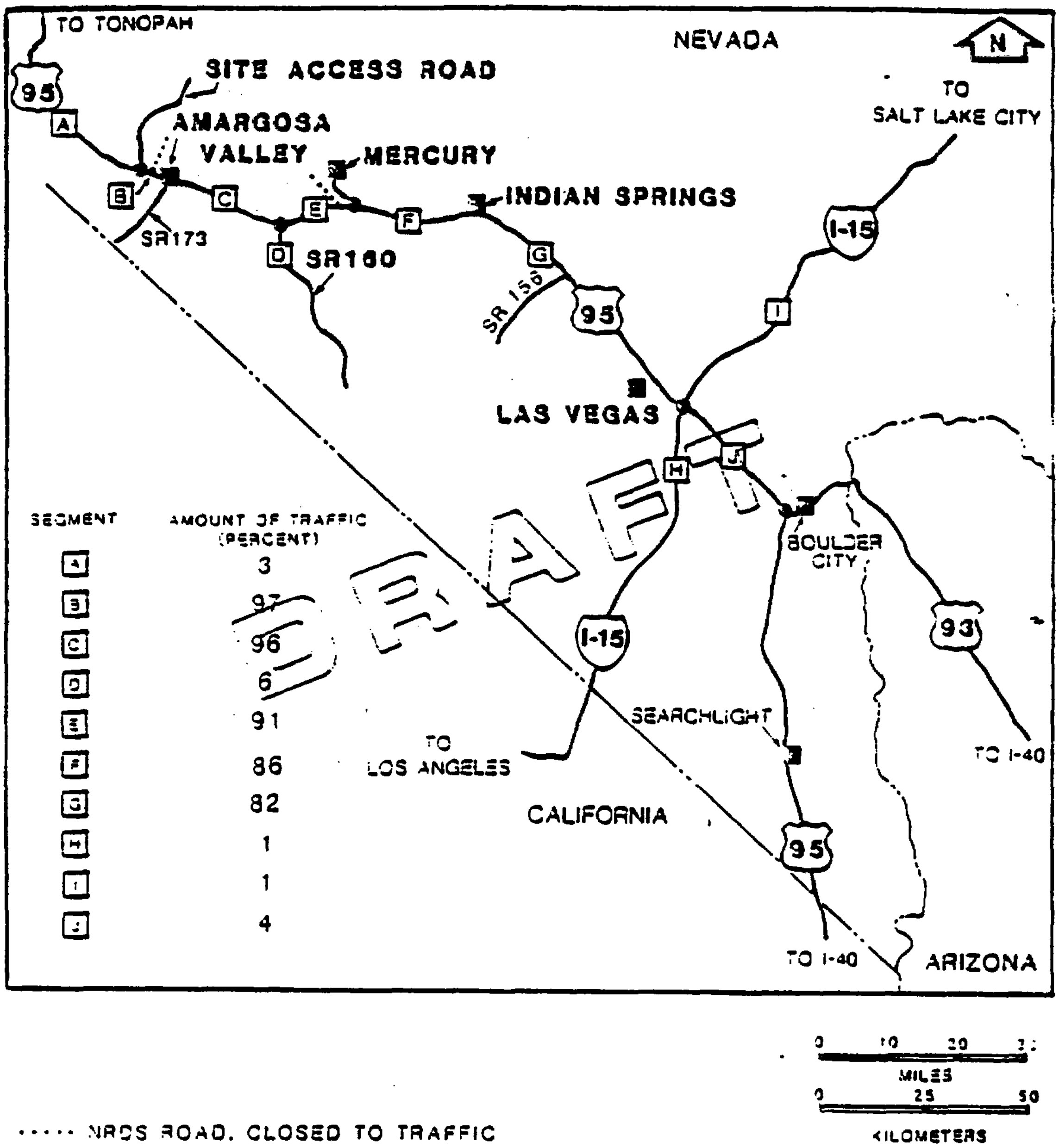

Figure 5-7. Employee travel patterns for the Yucca Mountain repository.

Table 5-32. Settlement patterns of Nevada Test Site employees[a]

Location	Percent of employee residences
Urban Clark County (Las Vegas)	66.1
North Las Vegas	9.5
Pahrump	6.0
Mercury	4.8
Indian Springs	4.0
Henderson	3.0
Tonopah	1.8
Alamo	0.6
Beatty	0.1
Boulder City	0.4
Town of Amargosa Valley	0.3
Other Nevada towns	1.6
California	0.7
Utah	0.5
Arizona	0.4
Other	0.2
Total	100

[a] Source: Preliminary information based on ZIP codes of NTS personnel and contractors, 1983.

Table 5-33. Projected traffic patterns on U.S. 95 during evening peak hour (5-6 p.m.), 1996 (State of Nevada, DOT, 1984)

	Highway segment (see Figure 5-7)	Without repository (baseline)			With repository		
		Number of cars	Number of trucks	Service level obtained[a]	Number of cars	Number of trucks	Service level obtained[a]
B	Site access road to the town of Amargosa Valley	119	24	B	422	63	B
C	Town of Amargosa Valley to 5 mi east of the town of Amargosa Valley	153	30	B	454	68	B
C	5 mi east of the town of Amargosa Valley to SR 160	153	30	B	454	68	C
E	SR 160 to NRDS Road	156	30	B/C	438	66	D
E	NRDS Road to Mercury interchange	188	23	B/C	469	59	D
F	Mercury interchange to Indian Springs	319	81	B	585	116	C
G	Indian Springs to SR 156	336	86	B	590	119	C
G	SR 156 to northern city limits of Las Vegas	376	96	B	630	130	C

[a] See Table 3-11 for definition of service levels.

Table 5-34. Projected annual accidents on U.S. 95, 1996 (State of Nevada, DOT, 1983)

Highway segment (see Figure 5-7)		Without repository (baseline)				With repository			
		Vehicle mi x 10^3	Accidents	Injuries	Fatalities	Vehicle mi x 10^3	Accidents	Injuries	Fatalities
B	Site access road to the town of Amargosa Valley	442	0	0	0	530	1	0	0
C	The Town of Amargosa Valley to 5 mi east of the town of Amargosa Valley	5,651	5	3	1	6,526	5	3	1
C	5 mi east of the town of Amargosa Valley to SR 160	13,111	11	7	3	15,140	13	8	3
E	SR 160 to NRDS Road	5,532	9	5	6	6,322	11	6	6
E	NRDS Road to Mercury interchange	3,780	6	3	1	4,257	7	3	1
F	Mercury interchange to Indian Springs	34,318	32	16	1	37,172	35	17	1
G	Indian Springs to SR 156	25,905	23	18	3	27,858	25	20	3
G	SR 156 to northern city limits of Las Vegas	30,336	30	18	2	32,378	32	19	3
	Total		116	70	17		129	76	18

accidents is segment E which is between SR 160 and the Mercury interchange. This estimate is consistent with the results shown on Table 5-33, which indicates that this segment has the lowest level of service either with or without the repository. For this segment, peak repository-related construction traffic would be expected to cause an additional three accidents, which includes one injury over a one-year period.

Operation

It is assumed that operation of the repository will begin in 1998. During the 30 years the repository is to be in operation, traffic will be generated by workers and their families and by delivery of both construction and high-level radioactive waste material. The construction-related transportation analysis showed U.S. 95 evening peak-hour traffic would be most sensitive to increased traffic volume.

After operations have begun, about 780 workers will be employed during the day shift (assuming vertical emplacement, see Section 5.1). Travel by these workers during the evening peak could coincide with that of the empty trucks leaving the repository. Assuming 250 delivery days per year, approximately one construction-related (Section 5.1) and up to 16 waste-related trucks (Section 5.3.2) could enter and leave the repository daily. Thus, an average of 4 trucks would pass a given point in any one-hour period (assuming an 8-hour delivery day). As with construction, to be conservative, 5 trucks per hour has been used to predict resulting traffic. By using both these estimates and the same assumptions given previously for construction activities, Table 5-35 projects traffic for 1998, both with and without repository-related traffic. Values in this table indicate that incremental traffic due to operations of the repository would only cause a drop in the level of service achieved for segment E (between SR 160 and the Mercury interchange). This segment would drop to service level D, as it did during the peak of construction activities. However, the incremental repository-related traffic that would cause this drop in service is much less than that during construction. The increase is less than the amount attributable to the baseline traffic. This means that the baseline or nonrespository-related traffic is much more of a factor in the resultant level of service than is the repository traffic. As repository-related traffic

Table 5-35. Projected traffic patterns on U.S. 95 during evening peak hour (5-6 p.m.), 1998 (State of Nevada, DOT, 1984)

	Highway segment (see Figure 5-7)	Without repository (baseline)			With repository		
		Number of cars	Number of trucks	Service level obtained[a]	Number of cars	Number of trucks	Service level obtained[a]
B	Site access road to the town of Amargosa Valley	125	26	B	276	47	B
C	The town of Amargosa Valley to 5 mi east of the town of Amargosa Valley	163	31	B	313	52	B
C	5 mi east of the town of Amargosa Valley to SR 160	163	31	B	313	52	B
E	SR 160 to NRDS Road	166	32	C	306	52	D
E	NRDS Road to Mercury interchange	200	25	C	339	45	D
F	Mercury interchanges to Indian Springs	339	87	B	471	106	B
G	Indian Springs to SR 156	357	92	B	483	110	B
G	SR 156 to northern city limits Las Vegas	399	102	B	525	121	B

[a] See Table 3-11 for definition of service levels.

remains constant over the 30-year operational period of the repository, the regional traffic along the segment will grow. Therefore, the incremental impacts due to repository operational traffic will diminish over time, which would make the first year a worst-case for the operations period.

Traffic accidents for this first year of repository operations are projected in Table 5-36. The incremental repository traffic is estimated to cause an additional seven accidents including four injuries over this one-year period. No additional deaths are predicted. The additional accidents and injuries would be less than those predicted during peak construction (see Table 5-34). Furthermore, as was noted previously, these effects of increased traffic volume will become relatively smaller during the 30-year operational periods of the facility.

Decommissioning

Decommissioning of the repository will entail an estimated maximum employment of approximately 540 day-shift workers for vertical emplacement. Only about one truck per day of construction material will be required (Table 5-5). Traffic along U.S. 95 will have increased due to regional growth. The increment of this work force on the local and regional highway network is not expected to create any significant effects as this increment is only one third of that which was previously analyzed for construction activities, in which the effects were minimal.

5.3.1.2 Railroad impacts

During the construction period, rail use would be zero during the first two years while the rail spur to the repository is being constructed. Maximum use of the rail line is expected to occur from year three to year five of construction. Projections of future Union Pacific rail use without the repository are unavailable. The incremental rail use due to repository requirements is evaluated against the maximum Union Pacific rail use over the past six years. During years three through five of construction, it is estimated that three rail cars per day would be required to supply the site with material (assuming vertical emplacement, see Table 5-5). As before, 250

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Table 5-36. Projected annual accidents on U.S. 95, 1998 (State of Nevada, DOT, 1983)

Highway segment (see Figure 5-7)		Without repository (baseline)				With repository			
		Vehicle mi x 10^3	Accidents	Injuries	Fatalities	Vehicle mi x 10^3	Accidents	Injuries	Fatalities
B	Site access road to the town of Amargosa Valley	467	0	0	0	514	1	0	0
C	The town of Amargosa Valley to 5 mi east of the town of Amargos Valley	6,019	5	3	1	6,477	5	3	1
C	5 mi east of Amargosa Valley to SR 160	13,965	12	7	3	15,027	13	8	3
E	SR 160 to NRDS Road	5,876	10	5	6	6,290	11	6	6
E	NRDS Road to Mercury Interchange	4,023	6	3	1	4,274	7	3	1
F	Mercury Interchange to Indian Springs	36,529	34	17	1	38,033	36	18	1
G	Indian Springs to SR 156	27,536	25	19	3	28,567	26	20	3
G	SR 156 to northern city limits of Las Vegas	32,170	32	19	3	33,248	33	19	3
	Total		124	73	18		131	77	18

delivery days per year have been assumed. In 1981, the Union Pacific line carried an average of 19.2 freight trains per day with an average of 66 cars per freight train (Section 3.1.5), or 1257 rail cars per day. The increment of 3 rail cars per day, or one 66-car train every 22 work days, equates to an increase of less than 0.2 percent of usage. In 1981, the line was operating at about 71 percent of capacity (Section 3.1.5). Therefore, no impacts on rail line capacity are predicted.

During the 30 years of repository operation, the railroad may be used to transport both construction materials and high-level radioactive waste. The maximum number of shipments of construction material is estimated to be approximately one railcar per day (Table 5-5). High-level radioactive waste shipments by rail are estimated to average 3-1/2 rail cars per day (Section 5.3.2) each weighing approximately 90,700 kg (200,000 lb) (Sandia, 1983). Including construction material shipments, the total could be from four to five cars per day. This is approximately the same increase as that estimated for the construction phase and little or no impact on rail line capacity is expected. Furthermore, the weight of the loaded rail cars is not expected to cause problems because the line can handle weights up to 119,300 kg (263,000 lb) (written communication from Union Pacific.)

During decommissioning, railroad usage is expected to drop to less than one car per day (Table 5-5). At that level, no impacts are predicted.

5.3.2 Transportation of nuclear wastes

Specific routing requirements apply to packages containing quantities of radioactive material designated as a highway route controlled quantity. These requirements (49 CFR 177) will apply if the wastes are shipped by truck to Yucca Mountain. Federal regulations specify driver training requirements (49 CFR 177.825) and require that a written route plan be submitted that lists specifics such as planned stops, estimated departure and arrival times, and telephone numbers for emergency assistance in each state traversed. Variations from the route plan are allowed only under certain circumstances, and they require 30 days notice.

The rationale underlying routing regulations and the role of State and local governments in selecting a route that maximizes safety are explained in a notice in the Federal Register (46 FR 5298, Monday, January 18, 1981). Basically, the overall goal is to reduce risk by reducing the amount of time the radioactive material is in transit. Therefore, interstate highways have been selected as preferred routes for truck transport. In addition to reducing the amount of time in transit, interstate highways also have lower accident rates than do the alternate routes that were considered. However, State routing agencies, which were established by the states and defined in 49 CFR 171.8, may designate alternate routes in accordance with Department of Transportation (DOT) guidelines (DOT, 1981). The DOT guidelines require State routing agencies to consider all categories of risk, and not simply the high-consequence, low-probability categories. For example, travel through population centers should be considered if it can be demonstrated that the risks are lower in them than travel through less populated areas.

In Nevada, the State Routing Agency is composed of three members; all of whom are elected public officials. They include the Governor, the Attorney General, and the State Comptroller. To date, the State Routing Agency has not identified the preferred transportation routes within the State. Similarly, entry points into the State have not yet been identified. However, an examination of the locations of waste origination can be used with information regarding the current and projected status of regional highways and rail systems to identify the principal candidate routes into the area. Some assumptions regarding waste entry points are necessary to assess the regional impacts of waste transportation.

5.3.2.1 Radiological effects of nuclear waste transportation

This section addresses the radiological and nonradiological impacts associated with the transportation of high-level waste (HLW) on both a national and a regional scale. The HLW mixture for which these impacts are assessed consists both of spent fuel that has been discharged directly from nuclear power reactors after a 10-year decay period, and of wastes generated by the reprocessing of spent fuel. Reprocessing wastes are categorized as commercial high-level wastes (CHLW), wnich are fission products and actinides solidified in a borosilicate glass matrix; fuel cladding hulls (hulls); remote-handled transuranics (RHTRU); and contact-handled transuranics (CHTRU). The bounding scenarios assessed herein assume that the repository will receive 70,000 MTU of spent fuel, or the equivalent amount of reprocessing wastes, and that 100 percent of the waste is shipped either by truck or by rail.

Under accident-free operating circumstances, no radioactive material will be released from the shipping containers during transport. Nevertheless, because of the penetrating radiation emitted by certain components of the radioactive wastes, people will be exposed to low levels of radiation in the vicinity of the shipping containers. The radiological impacts of transporting the waste are expressed in terms of radiation dose to individuals and groups of individuals. The calculations are for both transportation workers and the nearby population along the routes of shipment from the point of origin of the wastes to receipt at the Yucca Mountain repository. The radiation dose calculations are based upon the information from Wilmot et al. (1983).

Transportation accidents that are severe enough to release radioactive materials from a shipping container are extremely unlikely. However, because there is a small probability that some releases may occur that would expose people to radiation, the analysis in this section addresses the radiological impacts of transportation accidents.

Nonradiological health impacts also result from high-level waste transportation. These impacts may include health effects such as latent cancers associated with transport vehicle emissions, and fatalities or injuries resulting from transportation accidents both to the work force and to the general population.

Potential radiation doses from transporting spent fuel and reprocessing wastes are presented for each of the following categories: (1) transportation workers, (2) the general population along the transportation route, and (3) an individual in the public referred to as the maximum individual and defined as a person standing about 30 m (100 ft) from either the rail or truck shipment route and is exposed to all shipments. The transportation work force consists of railroad workers for rail transport and truck drivers for truck transport. These workers will usually receive the highest individual radiation doses however, it is not clear that they will be classified as radiation workers because the occupational standards for radiation exposure do not necessarily apply to them.

For purposes of this analysis, it has been assumed that the spent fuel will be shipped by the nuclear power reactor operators either directly to the repository or to Barnwell, South Carolina, for reprocessing. All of the reprocessing wastes are to be shipped from Barnwell, South Carolina, to the repository. The distances of travel from each of the waste sources to the Yucca Mountain repository have been estimated by assuming 21 reactor centroid locations. Centroid locations have been designated to simulate the approximately 80 actual reactor locations. The number of shipments that are assumed to originate from these locations is presented in Table 5-37 according to waste category and transport mode. The distances used in this analysis were derived from the highway and rail routing models HIGHWAY (Joy et al., 1982) and INTERLINE (Joy et al., 1984), respectively, and are shown in Table 5-38.

The amount of time that a shipment stops during transit is an important consideration in the calculation of the radiation dose to the population. In this analysis, the stop-time values are assumed to be 0.011 hours per kilometer travel for truck shipments and 0.086 hours per kilometer travel for rail shipment (Wilmot et al., 1983).

Table 5-39 presents the calculated values for cumulative radiological impacts. Although the number of shipments is reduced by using rail transport, the impact per MTU of rail transport is greater than that of truck transport because trains travel slower than trucks, stop for longer periods, and generally must travel longer distances to reach the same destination from the same origin. Accidents are not expected to contribute substantially to the radiological impact of transportation because it is unlikely that an accident resulting in a release of material will occur. Even if an accident should occur, experimental evidence suggests that the consequences would not be great (Wilmot et al., 1981; Sandoval and Newton, 1982). The greatest radiological risk of exposure of the public is from stops during shipment. However, the

Table 5-37. Number of shipments required over 30-year period by waste type and transport mode (Wilmot et al., 1983)

Waste type[a]	Number of shipments	
	100% Trucks	100% Rail
100% Spent fuel	80,178	13,039
100% Reprocessing wastes		
CHTRU	23,026	7,086
Hulls	10,525	2,632
CHLW	30,704	2,559
RHTRU	52,637	13,160

[a] CHTRU = contact-handled transuranic wastes; Hulls = cladding hulls; CHLW = commercial high level waste; RHTRU = remote-handled transuranic waste.

Table 5-38. Estimated highway and rail distances between waste origin locations and Yucca Mountain (Wilmot et al., 1983)

Origin	Highway: Yucca Mt. (km)[a]	Highway: Barnwell (km)	Rail: Yucca Mt. (km)	Rail: Barnwell (km)
Reactor centroid				
Indiana	3228	977	3447	1378
Ohio	3566	1003	3769	1608
Michigan	3315	1444	3570	1643
Texas	2316	1642	2926	2120
New Jersey	4200	1123	4519	1136
New York	4232	1382	4464	1524
Maine	4706	1551	4859	1872
Minnesota	2858	1996	2937	2253
Iowa	2326	1886	2412	2166
Illinois	2876	1524	2989	1772
Wisconsin	3203	1677	3304	1909
Tennessee	3206	612	3636	771
North Carolina	3795	248	4426	364
Georgia	3513	317	4253	391
Florida	4049	753	4942	834
Virginia	4060	682	4714	676
Louisiana	2599	1127	3639	1828
Kansas	2264	1662	2826	2023
So. California	595	3695	571	4347
No. California	970	4352	1138	5248
Washington	1608	4397	2081	4960
Reprocessing location				
Barnwell, SC	3681	NA[b]	4575	NA[b]

[a] 1 km = 0.621 mi.

[b] NA = not applicable.

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total radiological risk is very low when compared to the radiological and nonradiological risks that exist from natural background factors.

The estimated doses to the maximally exposed individual by HLW transportation are presented in Table 5-40. While the truck mode appears to result in a significantly lower dose to the maximally exposed individual, the doses are very low for all categories of exposure and represent a minimal amount of incremental risk.

Regional radiological impacts

Additional assessments were performed to characterize the regional radiological impacts (i.e. those that may be incurred within the State of Nevada) of HLW transport. These assessments are necessarily based on a set of assumed conditions regarding both the number and type of shipments and the routes by which the shipments enter and travel about the State. The assumed routes of transport are used for purposes of analysis only, and their use neither presumes nor implies that these will be the actual routes. Also, the RADTRAN II risk analysis method, upon which these regional impacts are based, is not well-suited for fine-scale or region-specific analyses. These assessments were performed to characterize the general impacts on a regional scale and to determine whether or not these risks vary for different routing patterns.

Two routing scenarios, Scenarios I and II, are considered. For each scenario, Table 5-41 and Table 5-42 present the number of shipments entering the State according to waste type, transport mode, and entry point. As in the national impact assessment, it is assumed that either 100 percent spent fuel or 100 percent reprocessing wastes are shipped either entirely by truck or by rail.

The results of the regional impact assessments are presented in Table 5-43. As can be seen from this table, the differences in assumed routing do not substantially affect the resultant doses. Furthermore, the magnitude of the total population dose commitment (100 to 250 man-rem/yr) for each category is low compared to the dose that would be received by a regional population

Table 5-39. Estimated radiation doses (man-rem) from the transportation of waste to Yucca Mountain

Transportation mode/ Exposure category	Spent fuel		Reprocessing wastes	
	30 yr total (man-rem)	Annual (man-rem)	30 yr total (man-rem)	Annual (man-rem)
Truck				
Normal				
Occupational	10,208	340	12,639	421
Nonoccupational	46,667	1,556	58,333	1,944
Accident[a]	34	1.1	97	3.2
Total	56,909	1,897	71,069	2,368
Rail				
Normal				
Occupational	24	0.8	29	1
Nonoccupational	121,538	4,051	170,139	5,671
Accident[a]	97	3.2	194	6.5
Total	121,659	4,055	170,362	5,678

[a] The total exposed population in the accident scenarios includes both occupationally and nonoccupationally exposed individuals.

Table 5-40. Dose to maximally exposed individual from transportation of waste to Yucca Mountain

Transportation mode/ dose category	Spent fuel	Reprocessing wastes
Truck transportation		
Total (mrem)	72	45
Annual (mrem/yr)	2.4	1.5
Rail transportation		
Total (mrem)	12	7.8
Annual (mrem/yr)	0.4	0.26

annually from natural background sources, which is approximately 410 man-rem/yr for 4600 people within an 80 km (50 mi) radius of a central point on the Nevada Test Site (Black et al., 1983). The regional impact estimates are probably higher than those that would actually occur because of the radiological unit factors used by the RADTRAN II method; for example, most of the transport within the State would be through rural environments and RADTRAN II assumes a mean density of six people/km^2 based on a national average. However, the actual mean density for Nevada is much lower than this value, and in many areas it is close to zero. Thus, the man-rem per kilometer of rural travel is probably significantly lower than the value shown in Table 5-43.

5.3.2.2 Nonradiological effects

The factors used to calculate nonradiological effects are presented in Table 5-44. These factors are categorized according to both normal and accident conditions of transport for either truck or rail mode. The unit factors for normal transport are for urban areas only and are for nonoccupationally exposed people. These values are expressed in terms of latent cancer fatalities per kilometer that result from pollutants emitted by the truck or train. Table 5-45 presents values for the assumed percent of travel in rural, suburban, and urban population zones along truck and rail routes.

The accident factors are for both fatalities and injuries. The nonoccupationally exposed population includes all people except those that comprise the truck and train crews, which are included in the occupationally exposed group.

The results of the nonradiological impact assessments for transportation of HLW that are presented in Table 5-46 indicate the following: (1) nonradiological transportation risk is substantially greater than the corresponding radiological risk; (2) members of the general public are subjected to the highest level of risk; (3) the nonradiological risk associated with truck transport is much greater than that associated with rail transport; and (4) the total nonradiological impact is small relative to that associated with general commercial transportation activities. Accidents are the dominant factor for nonradiological fatalities. The primary reason that fatalities associated with

Table 5-41. Assumed regional transport conditions for Scenario I

Transportation mode/ Entry point	Number of shipments					Distance/shipment (km)[b]		
		Reprocessing wastes[a]						
	Spent fuel	CHTRU	Hulls	CHLW	RHTRU	Rural	Suburban	Urban
Truck								
I-15S	46,838					344	13	13
I-15N	3,712					275	19	16
U.S. 93N	24,763	23,026	10,525	30,704	52,637	236	25	16
I-80E	4,866					512	92	6
Rail (Union Pacific)								
From Utah	8,390					250	5	0
From Arizona	3,926	7,086	2,632	2,559	13,160	150	27	16
From California	723					216	13	16

[a] CHTRU = contact-handled transuranic; Hulls = cladding hulls; CHLW = commercial high-level waste; RHTRU = remote-handled transuranic.

[b] 1 km = 0.621 mi.

Table 5-42. Assumed regional transport conditions for Scenario II

Transportation mode/ Entry/point	Number of shipments					Distance/shipment (km)[b]		
		Reprocessing wastes[a]						
	Spent fuel	CHTRU	Hulls	CHLW	RHTRU	Rural	Suburban	Urban
Truck								
I-15S	46,838					344	13	13
I-15N	33,340	23,026	10,525	30,704	52,637	275	19	16
Rail (Union Pacific)								
From Utah	8,390					250	5	0
From California	4,649	7,086	2,632	2,559	13,160	216	13	16

[a] CHTRU = contact-handled transuranic; Hulls = cladding hulls; CHLW = commercial high-level waste; RHTRU = remote-handled transuranic.

[b] 1 km = 0.621 mi.

Table 5-43. Estimated 30-year radiological impacts (man-rem) resulting from transportation of high-level waste within the State of Nevada for scenarios I and II[a]

Transportation mode/ exposure category	Spent fuel		Reprocessing waste	
	I	II	I	II
100% Truck				
Normal operation				
Occupational	1000	960	510	550
Nonoccupational	4600	4400	2400	2600
Accidents	3	2	8	7
Total[a]	5600	5400	2900	3200
100% Rail				
Normal operation				
Occupational	1	1	1	1
Nonoccupational	7100	7500	4500	5700
Accidents	3	3	23	22
Total	7100	7500	4500	5700

[a] Estimated on the basis of results contained in Wilmot et al., 1983 (see text for assumptions). Results are whole numbers rounded to two significant figures.

Table 5-44. Nonradiological unit factors for transportation impact analysis (Wilmot et al., 1983)

Exposure category	Truck			Rail[a]		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Normal						
Nonoccupational (Latent cancers/km)[b]	---	---	1.0×10^{-7}	---	---	1.3×10^{-7}
Accident						
Nonoccupational Fatalities/km (Injuries/km)	5.3×10^{-8} (8.0×10^{-7})	1.3×10^{-8} (3.8×10^{-7})	7.5×10^{-9} (3.7×10^{-7})	1.7×10^{-8} (3.3×10^{-8})	1.7×10^{-8} (3.3×10^{-8})	1.7×10^{-8} (3.3×10^{-8})
Occupational Fatalities/km (Injuries/km)	1.5×10^{-8} (2.8×10^{-8})	3.7×10^{-9} (1.3×10^{-8})	2.1×10^{-9} (1.3×10^{-8})	1.4×10^{-9} (1.9×10^{-7})	1.4×10^{-9} (1.9×10^{-7})	1.4×10^{-9} (1.9×10^{-7})

[a] Based on railcar kilometers.

[b] 1 km = 0.621 mi.

Table 5-45. Percent of travel in various population zones along routes[a] (Wilmot et al., 1983)

Transportation mode/ destination	Population zone[a] Rural (percent)	Suburban (percent)	Urban (percent)
Truck			
Barnwell, South Carolina	70.7	27.7	2.2
Yucca Mountain	83.7	15.2	1.1
Rail			
Barnwell, South Carolina	69.5	28.1	2.4
Yucca Mountain	83.1	15.5	1.4

[a] Rural corresponds to 6 people/km^2 (mean density). Suburban corresponds to 719 people/km^2 (mean density). Urban corresponds to 3816 people/km^2 (mean density).

truck transport are greater than those associated with rail transport is because trucks have a much greater accident rate. For instance, in 1980 truck-related accidents resulted in 2528 fatalities, whereas rail transport resulted in only 1242 fatalities (Smith and Wilmont, 1982). When they are projected for 30 years, these values become 75,800 for truck travel and 37,300 for rail travel.

Nonradiological health impacts on the regional population are impossible to assess without knowing the number of waste shipments for specific routes. Because this information is not yet available, it has been assumed that waste shipments would enter the State as described in either of the two scenarios discussed previously. The results of this assessment are presented in Table 5-47. These impacts are minor and follow the same general pattern as that for nonradiological impacts on a national scale.

5.3.2.3 Costs of nuclear waste transportation

This section assesses the total costs associated with the transportation of nuclear waste over the life of the repository. The cost results presented here are based on the methods and data of Wilmot et al. (1983), which are presented in detail in Appendix A.

The total transportation cost associated with each fuel cycle scenario, 100 percent spent fuel and 100 percent reprocessing, is the sum of costs incurred for each of the following items:

1. Capital costs, which are the costs of the transportation packaging and associated trailer or railcar.

2. Maintenance costs, which are costs associated with maintenance and licensing activities.

3. Shipping costs, which are based on studies of published tariffs or conservative estimates of actual shipping rates.

Table 5-46. Nonradiological impacts associated with truck or rail transport of nuclear wastes (Wilmot et al., 1983)

Transportation mode/ impact category	Spent fuel	Reprocessing wastes
Truck		
Normal		
Nonoccupational[a]	0.58	1.8
Accident - fatalities		
Occupational	7.5	15
Nonoccupational	26	51
Total fatalities	34	67
Accident - injuries		
Occupational	15	28
Nonoccupational	417	814
Rail		
Normal		
Nonoccupational[a]	0.21	0.6
Accident - fatalities		
Occupational	0.15	0.4
Nonoccupational	1.8	5.0
Total fatalities	2.2	6.0
Accident - injuries		
Occupational	2.0	55
Nonoccupational	3.5	9.6

[a] Nonoccupational impacts from normal transport are latent cancer fatalities.

Table 5-47. Nonradiological impacts associated with truck or rail transport of nuclear wastes within the State of Nevada for Scenarios I and II

Transportation mode/ impact category	Spent fuel		Reprocessing wastes	
	I	II	I	II
Truck				
Normal				
Nonoccupational[a]	0.11	0.11	0.19	0.19
Accident - fatalities				
Occupational	0.39	0.39	0.42	0.49
Nonoccupational	1.4	1.3	1.6	1.7
Total fatalities	1.9	1.8	2.2	2.4
Accident - injuries				
Occupational	0.75	0.74	0.83	0.95
Nonoccupational	21	21	24	28
Rail				
Normal				
Nonoccupational[a]	0.01	0.01	0.053	0.053
Accident - fatalities				
Occupational	0.0043	0.0046	0.0069	0.0087
Nonoccupational	0.052	0.056	0.083	0.11
Total fatalities	0.066	0.071	0.14	0.17
Accident - injuries				
Occupational	0.58	0.62	0.93	1.2
Nonoccupational	0.1	0.11	0.16	0.21

[a] Nonoccupational impacts from normal transport are latent cancer fatalities.

The results of these assessments (Table 5-48) indicate that the total transportation cost for the spent fuel scenario would be about $1.2 billion for truck or $1.1 billion for rail. For the reprocessing fuel scenario, these costs would be $2.6 and $2.8 billion, respectively. These costs are for a repository of 70,000 MTU capacity and are expressed as 1981 dollars. Other transportation-related costs are not included in these estimates, such as the costs of constructing access roads.

5.4 EXPECTED EFFECTS ON SOCIOECONOMIC CONDITIONS

This section describes the potential economic, demographic, and social impacts of locating a repository at Yucca Mountain. There are several important factors to consider when determining potential social and economic effects and the subsequent development of a mitigation plan. These factors include the local availability of workers, the extent of inmigration, and perceptions and attitudes about the safety of waste transportation and disposal. For purposes of this analysis, it has been assumed that safety questions about waste transportation and disposal will be resolved prior to repository construction. In the absence of detailed information on work force skill mix, a worst-case demographic analysis was assumed in which all project workers would, come from outside the bicounty region (i.e., Clark and Nye counties). This assumption is relaxed in the economic impact section, which provides a preliminary evaluation of local labor availability. Although fiscal impacts have not yet been quantified, preliminary estimates of potential effects on community services are presented. These suggest the magnitudes of potential fiscal effects. Section 5.4.5 presents an overview of DOE commitments for fiscal impact mitigation under the Nuclear Waste Policy Act of 1982. Other types of impact mitigation, such as mitigation by avoidance, will be identified as part of ongoing system design studies.

5.4.1 Economic conditions

Potential economic impacts in the areas of labor, materials, income, land use, and tourism are described in this section. Only private-sector activity is considered in this section. Public-sector implications are discussed in Sections 5.4.3 and 5.4.5. This analysis is based on preliminary estimates of

Table 5-48. Summary of total transportation costs by waste type, transportation mode, and cost category (Wilmot et al., 1983)

Waste type and mode	Cost (millions of dollars)
100% Spent fuel scenario	
100% Truck	
Capital	224
Maintenance	144
Shipping	869
Total	1,237
100% Rail	
Capital	243
Maintenance	146
Shipping	674
Total	1,063
100% Reprocessing wastes scenario	
100% Truck	
Capital	432
Maintenance	304
Shipping	1,850
Total	2,586
100% Rail	
Capital	569
Maintenance	488
Shipping	1,770
Total	2,827

the demand for project labor and materials, and on preliminary studies of future baseline market conditions. Construction is assumed to begin in 1993. In that year, the bicounty region would experience significant increases in demand for mine workers, construction workers, and other skilled workers and materials. This demand would decline sharply at three different points in the 60-year project schedule: at the end of construction (in 1997), and at the end of the operations period (in 2027), and at the end of the retrievability period (in 2047). Unless southern Nevada is experiencing rapid growth during those times, they could resemble some of the periods of slower economic growth that the bicounty region has experienced during previous fluctuations in the mining and construction industries.

5.4.1.1 Labor

Table 5-3 presents preliminary estimates of labor force size by skill for vertical emplacement. Table 5-4 presents this same information assuming the horizontal-emplacement alternative. Local purchases of repository materials and expenditures by repository workers will result in increased demands for local goods and services. Indirect employment is defined as the increase in trade and service sector and other employment that can be attributed to this increased demand for goods and services. The project's total employment effect is the sum of the repository labor force (direct employment) and indirect project employment. Tables 5-3 and 5-4 provide estimates of the indirect employment effect based on the assumption that 1.54 indirect jobs would be created for each direct job (McBrien and Jones, 1983; Nevada Development Authority, 1982).

Assuming vertical emplacement, the project would employ 1200 workers in its first year, 1993. This number would rise to a peak of 3350 workers in 1996. Mining employment would rise from a 1993 level of 500 to a peak of about 800 workers in 1995. Between the construction and operation phases of the project (in 1997 and 1998) employment would decline markedly, to a level of 2300 workers by 1999. This number, which includes about 700 mining employees, would be sustained throughout the operations period, or for about 30 years.

At the start of the retrievability phase, which would cover the period 2028-2047, project employment would decline by about 1700, to 600 workers. At the end of this 20-year period, the project would hire an additional 900 workers to decommission the repository. No workers would remain at the site on a regular basis after 2053.

Total project-induced employment would increase and decline over time with the size of the direct project work force. The total annual employment impact would reach a peak of about 8500 jobs in 1996. At the end of the construction period, in 1997, this number would decline markedly, decreasing to 5900 in 1999. This level of employment would be supported for about 30 years until 2027. Although not reflected in Tables 5-3 and 5-4, the project would also employ workers during the operation period for traffic escort and control, emergency preparedness, road and rail maintenance, and operation of locomotives, trucks and other vehicles. Estimates of employment levels for these activities are not yet available.

Data on the recent settlement patterns of the Nevada Test Site work force suggest that employees of the project would reside in communities in Nye and Clark counties. Settlement patterns of the 1983 Nevada Test Site work force are shown in Table 5-32. These data suggest that about 80 percent of the repository labor force would reside in the Las Vegas Valley area, and about 20 percent would locate in the smaller communities of Indian Springs, Pahrump, Tonopah, Amargosa Valley, and other communities surrounding the site. The current settlement patterns of Nevada Test Site employees also indicate that workers have been drawn from a labor market which includes residents of other Nevada counties, California, and Utah, as well as Clark and Nye counties.

Potential labor market implications of the project include inmigration of workers having the required skills (such as mining and construction skills), with possible upward pressure on wages and salaries as a means of inducing these workers to come into the area. Labor-market impacts would depend on the local and regional availability of workers and their supply elasticities at various phases of the project, especially construction (1993-1997), when direct work force requirements reach their peak. Peak labor demand would be less than one percent of baseline bicounty employment in 1996 (see Tables 3-4 and 3-5).

Estimates of project labor requirements indicate that the greatest demand would be for construction and mining workers. The peak construction work force of the project (about 2000 workers, see Table 5-3) would represent a 9 percent increase over baseline construction employment levels in the bicounty area (see Tables 3-14 and 3-15). Mining employment in the area would increase by about 100 percent for over thirty years under the vertical emplacement scenario. This indicates that the development of a repository at Yucca Mountain would be a project of significant size for the local construction and mining sectors. While the horizontal emplacement method would reduce by about two-thirds the number of mining jobs generated by the project, the construction work force requirement would be about the same.

Thus, many mining and construction workers would come from outside the bicounty area. The extent to which this would occur depends upon the presence of other large projects in the early 1990s in the area, the state of the national economy at that time, and the unemployment rates in those skill areas.

In summary, the project would significantly affect the total demand for construction and mining workers in the bicounty area. Potential wage and salary escalation in these areas would probably be mitigated by inmigration of skilled workers from other areas such as California and Utah. Another mitigating factor is the long duration of the project, especially of the underground activities. If the decision to construct a repository at Yucca Mountain were publicly announced in advance, then inmigrating workers might anticipate employment opportunities and move into the area in advance of the project start date.

5.4.1.2 Materials and resources

The average annual requirements for some construction materials and resources are shown in Tables 5-5 and 5-6. A preliminary analysis of materials supplies in southern Nevada indicates that it is reasonable to assume that concrete, fuel, and electrical power would be purchased in the area (McBrien and Jones, 1983). However, many of the materials that will eventually be required may not be available in southern Nevada. The retrievability phase would generate only a small requirement for materials. During the decommissioning phase, the project would require heavy equipment and materials both to seal the shafts and tunnels and to dismantle surface facilities. Materials required to decommission the surface facilities would probably be shipped to the site from outside the area (McBrien and Jones, 1983).

5.4.1.3 Cost

Preliminary cost estimates for the construction, operation, and decommissioning of a repository at Yucca Mountain are summarized in Table 5-49. The cost of maintaining the repository during the retrievability period has not been determined. The cost estimates in Table 5-49 are preliminary and are useful for this analysis, but they are not appropriate for budget projections. In particular, the costs for operation and decommissiong should not be used for purposes other than comparison with similar costs for other repositories from the same source. Conceptual cost estimates cannot be completed until engineering designs are further developed and operating, and decommissioning requirements have been assessed in greater detail. All costs are shown in 1983 dollars and include allowances for engineering, design, and inspection; contingency; construction management; and quality assurance.

The cost estimates are based on the emplacement of single canisters of spent fuel in vertical holes in the floor of the emplacement drifts. The total savings that could be realized have not yet been determined if horizontal emplacement of multiple canisters in long horizontal holes is determined to be feasible. Facility operations costs are based upon receiving a total of 70,000 metric tons of heavy metal (MTHM) as spent fuel during a 30-year emplacement period. The maximum annual receipt rate is assumed to be 3000 MTHM per year.

5.4.1.4 Income

Increases in DOE spending on labor and materials during the construction and operation of a repository at Yucca Mountain will contribute to growth in the region. Suppliers of labor and materials will benefit through a direct increase in demand for their resources. Increased DOE spending would also generate growth in support sectors, such as the trade and services industries.

Table 5-49. Preliminary cost estimate for the Yucca Mountain repository (Weston, 1984)

Category	Cost estimate (millions of 1983 dollars)			
	Construction	Operations	Decom-missioning	Total
Waste preparation	531	1629	70	2209
Repository system				
Site	369	83	49	501
Waste handling and emplacement	195	570	13	778
Underground workings and rock handling	399	398	87	884
Ventilation	310	514	43	867
Support/utilities	193	568	92	853
Totals	1976	3762	354	6092

Wage-related impacts to the bicounty area from a repository at Yucca Mountain are shown in Table 5-50 assuming vertical emplacement of the waste. The same information is shown in Table 5-51 for horizontal emplacement waste. These projections are based on preliminary studies that project an annual wage of $25,400 for both construction and operations workers, $14,000 for secondary workers in 1983 dollars (McBrien and Jones, 1983). The peak annual economic stimulus of repository spending on wages alone would be $157.2 million during the five-year construction period under the vertical emplacement scenario, and $131.5 million under the horizontal emplacement scenario.

5.4.1.5 Land Use

Land use requirements for a repository at Yucca Mountain would involve the withdrawal of public land, including surface and subsurface rights associated with it. It is unlikely that the land would be used for grazing if it is not withdrawn for a repository since approximately 255 ha (630 a) are required to support one cow in this area (Collins et al., 1982).

The area immediately surrounding the site has limited, if any, potential for energy and mineral resources. Resources considered include (1) low- to moderate-temperature geothermal resources, (2) small precious and base metal deposits, and (3) a variety of industrial rocks and minerals such as clays, zeolites, alunite, fluorite, and bulk construction materials. It is not realistic to assume that prices could rise enough to make these geologic resources, with no current economic value economically significant. According to the Level 1 Resource Appraisal (Bell and Larson, 1982), the geothermal, metal and industrial rock and mineral resources that may occur in the Yucca Mountain area are available in greater abundance elsewhere. Thus, the mineral resource cost of withdrawing rights to their use appears to be insignificant (see Section 3.1.2.4).

5.4.1.6 Tourism

Because of the importance of the tourism industry to the State and local economies, even small changes in tourism levels could have a significant economic impact. Public comments show concern that the potential for adverse public perception of a repository and associated waste transportation may adversely affect the growth of this industry. The importance of public perception lies in the attractiveness of Las Vegas' image to potential visitors. While no evidence has been identified to indicate what effect planned operation of a repository would have on tourism, the potential for such an effect will be the subject of further research. Results of past investigations of this question are summarized below.

According to preliminary descriptions of a Yucca Mountain repository, the repository itself would not be visible to tourists. The site is far from major population centers and public recreation areas, and it is not visible from public highways. However, transportation of repository materials would be visible to tourists. In the early 1990s, construction of a road that will lead from the site to a point one-half mile west of the town of Amargosa Valley will be visible from the highways and from the town of Amargosa Valley. Construction of a rail line from Dike Siding to Yucca Mountain would be visible from highways, residences, and Floyd Lamb State Park outside Las Vegas.

Waste transportation activities would also be visible to tourists. The routes that would be used to transport radioactive waste to Yucca Mountain are not yet known (see Section 5.3), however, routing of waste through Las Vegas is a possibility. Shipments would be placarded radioactive. Such shipments on local highways would be visible in transit in the area.

Visitors may become further aware of the repository through extensive news coverage of the waste-disposal program. Preliminary research on the potential effects of visibility or awareness of the waste-disposal program on local tourism levels has identified several theories on the nature of the link between tourism and the repository. Firstly, tourism levels could decline because of safety concerns even if DOE design studies were to indicate that a repository would not present a credible safety threat to visitors or to residents. If the absence of a significant safety threat were established before construction of the repository began, and if this information were publicized, then it appears unreasonable to expect that safety concerns alone would result in decreases in tourism. Secondly, tourism could decrease because of an adverse effect on the aesthetic appeal of Las Vegas and surrounding

Table 5-50. Potential annual wage expenditures associated with vertical emplacement (millions of 1983 dollars)

	Phase and year							
	Construction					Operations	Retrieva-bility	Decommis-sioning
Category	1	2	3	4	5	6-35	36-55	56-60
Direct project employees[a]	31.01	61.37	82.27	85.04	60.68	58.75	15.09	39.32
Indirect workers[b]	26.32	52.09	69.83	72.18	51.51	49.87	12.81	33.37
Total	57.33	113.46	152.10	157.22	112.19	108.62	27.90	72.69

[a] Includes wages of both construction and operation workers. Assumes an average salary of $25,400 (McBrien and Jones, 1983).

[b] Assumes an average annual salary of $14,000, the average annual wage of persons in the trade industry in southern Nevada (McBrien and Jones, 1983).

Table 5-51. Potential annual wage expenditures associated with horizontal emplacement (millions of 1983 dollars)

	Phase and year							
	Construction					Operations	Retrieva-bility	Decommis-sioning
Category	1	2	3	4	5	6-35	36-55	56-60
Direct project employees[a]	21.77	48.82	67.74	71.12	47.09	36.63	11.58	16.59
Indirect workers[b]	18.48	41.44	57.50	60.37	39.97	31.09	9.83	14.08
Total	40.25	90.26	125.24	131.49	87.06	67.72	21.41	30.67

[a] Includes wages of both construction and operation workers. Assumes an average salary of $25,400 (McBrien and Jones, 1983).

[b] Assumes an average annual salary of $14,000, the average annual wage of persons in the trade industry in southern Nevada (McBrien and Jones, 1983).

tourist attractions that extend beyond safety concerns. The presence of nuclear-weapons testing at the NTS does not appear to have had a significant effect on tourism, and this suggests that the repository would not change the total aesthetic appeal of the Las Vegas area. In addition, preliminary studies of the effects of safety concerns following well-publicized accidents, such as the 1980-1981 Las Vegas hotel fires and the Three Mile Island incident, yield no evidence of any long-term effect of publicized safety concerns on tourism levels (SAI, 1983).

5.4.2 Population density and distribution

Table 5-52 shows a preliminary forecast of the maximum regional population influx that could be associated with locating a repository at Yucca Mountain, assuming vertical emplacement of waste. This same information is shown in Table 5-53 for the horizontal emplacement scenario. These estimates have been made under the conservative assumption that all workers would come from (and return to) areas other than Nye and Clark counties, and, that each household has only one labor-market participant. Thus, the estimates overstate the likely upward (or downward) responses of bicounty population to increases (or reductions) in project labor requirements. These conservative assumptions are used in Section 5.4.3 to estimate worst-case impacts on community services.

During peak employment (in 1996), the project could result in a worst-case population increase of 25,500 over baseline projections, or 3 percent of the baseline bicounty population. If primary and secondary employees follow the settlement patterns of workers currently employed by the DOE and its contractors at the Nevada Test Site, Clark County would receive 83 percent of the project-related population increase, or a maximum of about 21,200 people, during construction. Nye County, which would receive about 13 percent of the total, could experience a maximum influx of about 3318 people. Assuming vertical emplacement of the waste, during the 1998 to 2027 period, the project-related population increment would decline to about 20,400 people: 16,900 residing in Clark County and 2,700 residing in Nye County. The average annual growth during the first year of construction for the two counties would be as follows: Clark County, 3.8 percent; Nye County, 8.9 percent. Without the

Table 5-52. Projected maximum total population increase for Clark and Nye Counties for vertical emplacement[a]

Category	Construction 1	Construction 2	Construction 3	Construction 4	Construction 5	Operations 6-35	Retrievability 36-55	Decommissioning 56-60
Direct project employees	1,221	2,416	3,239	3,348	2,389	2,313	594	1,548
Direct project employee dependents	1,563	3,092	4,146	4,285	3,058	5,713	1,467	1,981
Indirect employees	1,880	3,721	4,988	5,156	3,679	3,562	915	2,384
Indirect employee dependents	4,644	9,190	12,321	12,788	9,087	8,798	2,259	5,888
Maximum population impact of project	9,309	18,419	24,693	25,624	19,213	20,386	5,235	11,802
Total population projection with project[b]	714,723	742,561	767,976	788,463	801,422			
Annual growth rate, %	4.0	3.9	3.4	2.7	1.6			
Baseline population projection without project[b]	705,414	724,142	743,283	762,939	783,209			
Annual growth rate, %	2.7	2.7	2.7	2.7	2.7			

[a] Assumptions: 2.47 dependents per operations or retrievability worker;
1.28 dependents per construction or deocommissioning worker;
1.54 indirect jobs generated by each direct job;
All workers come from outside the area.
Construction begins in 1993.

[b] Projected 1992 population without repository is 687,200.

Table 5-53. Projected maximum total population increase for Clark and Nye Counties for horizontal emplacement[a]

Category	Construction 1	Construction 2	Construction 3	Construction 4	Construction 5	Operations 6-35	Retrievability 36-55	Decommissioning 56-60
Direct project employees	857	1,922	2,667	2,800	1,854	1,442	456	653
Direct project employee dependents	1,097	2,460	3,414	3,584	2,373	3,562	1,126	836
Indirect employees	1,320	2,960	4,107	4,312	2,855	2,221	702	1,006
Indirect employee dependents	3,260	7,311	10,144	10,651	7,052	5,486	1,734	2,485
Maximum population impact of project	5,634	14,653	20,332	21,347	14,134	12,711	4,018	4,980
Total population projection with project[b]	711,948	738,795	763,615	784,286	797,343			
Annual growth rate, %	3.6	3.8	3.4	2.7	1.7			
Baseline population projection without project[b]	705,414	724,142	743,283	762,939	783,209			
Annual growth rate, %	2.7	2.7	2.7	2.7	2.7			

[a] Assumptions: 2.47 dependents per operations or retrievability worker;
1.28 dependents per construction or deocommissioning worker;
1.54 indirect jobs generated by each direct job;
All workers come from outside the area.
Construction begins in 1993.

[b] Projected 1992 population without repository is 687,200.

project, the average annual growth in these counties is projected to be 2.7 percent for Clark County and 2.7 percent for Nye County (see Tables 3-17 and 3-18).

5.4.3 Community services

5.4.3.1 Summary

Increased population growth typically results in an increase in the demand for local, state, and regional public services. It is assumed that service providers, such as school districts and police departments, will attempt to maintain current per capita service rates (e.g. the number of police officers per 1000 residents).

Preliminary studies indicate that some potentially significant impacts on community services may accompany project-related population growth in the sparsely populated areas of Nye and Clark counties. Overall, the requirements for increased services in Clark County under the most likely settlement pattern would not exceed 3 percent over forecasted baseline service levels during the period of greatest impact, which indicates that effects on urban areas may be insignificant.

Several important types of existing community services were described in Section 3.6.3. Table 5-54 summarizes per capita service rates based upon these current service levels. Future baseline service levels have been computed by multiplying service rates by the projected total population for each county.

The size and probable settlement patterns of the inmigrant population are subject to uncertainty; thus, their effects on community services are also uncertain. Inmigrants can become a burden to small communities because they may place a strain on housing, schools, and other services. In a larger community, where the inmigrants represent a smaller proportion of a growing population, they may have a less significant effect on public services. This analysis assumes that 100 percent of the jobs that are created by construction and operation of the repository will be filled by inmigrating workers. This

Table 5-54. Ratios used to forecast community services requirements

Type of service	Clark County			Nye County		
	Ratio[a]	Base year	Source[b]	Ratio[a]	Base year	Source[b]
Elementary schools	0.150	1982	1	0.681	1982	2
Secondary schools	0.064	1982	1	0.303	1982	2
Teachers and staff	9.126	1982	1	8.018	1982	2
Police officers	1.694	1983	3	3.555	1982	2
Police vehicles	0.814	1983	4	ND[c]	ND	ND
Voluntary firefighters	0.413	1983	4	8.623	1982	2
Paid firefighters	0.994	1983	4	1.059	1982	2
Fire equipment pieces	0.202	1982	4	2.723	1982	2
Physicians	1.303	1982	4	0.454	1982	6
Hospital beds	5.776	1982	6	3.480	1982	7
Waste disposal trucks	0.116	1982	4	0.116	(d)	(d)
Water (million gallons per day)	0.462	1982	7	0.666	(e)	(e)
Library books (1000)	1.091	1983	8	ND	ND	ND
Library staff	0.193	1983	8	ND	ND	ND

[a] Number per 1000 residents.

[b] Sources: 1-McBrien and Jones (1983) from the 1982-1983 Clark County School District Budget; 2-Nye County Nevada Profile, 1983 (State of Nevada, NOCS, 1982b); 3-Las Vegas Municipal Police Department (1984); North Las Vegas Police Department (Fay, 1984); 4-McBrien and Jones (1983); 5-Nye County Nevada Profile, 1983 (State of Nevada, NOCS, 1983); 6-1982-1983 Nevada State Health Plan (State of Nevada, NSHCC, 1982); 7-Nevada Development Authority (1983); 8-Nevada Library Directory and Statistics - 1984 (State of Nevada, NSL, 1984).

[c] ND = no data on which to compute a ratio.

[d] Assumed to be same for the two counties.

[e] Based upon ratio between reported use and number of people served by public and private water systems.

Table 5-55. Incremental service requirements associated with the location of a repository at Yucca Mountain (vertical emplacement)[a]

Service	Clark County: Construction	Clark County: Operation	Clark County: Retrievability	Clark County: Decommissioning	Nye County: Construction	Nye County: Operation	Nye County: Retrievability	Nye County: Decommissioning
Expected population increments	7,726-21,185[b]	16,920	4,345	9,705	1,210-3,318	2,650	681	1,534
Education								
Schools								
Elementary	1-3	3	1	2	1-2	2	0	1
Secondary	0-1	1	0	1	0-1	1	0	0
Teachers	71-193	154	40	89	10-27	21	5	12
Police								
Officers	13-36	29	7	17	4-12	9	2	5
Vehicles	6-17	14	4	8	1-3	2	1	1
Fire								
Volunteer fire fighters	3-9	7	2	4	11-29	23	6	13
Paid fire fighters	8-21	17	4	10	1-4	3	1	2
Trucks and other equipment	2-4	3	1	2	3-9	7	2	4
Medical services								
Doctors	10-28	22	6	13	1-2	1	0	1
Hospital beds	45-122	98	25	57	4-12	9	2	5
Water (millions of gallons)	4-10	8	2	5	1-2	2	0	1
Library services								
Books (thousands)	8-23	18	5	10	1-4	3	1	2
Staff	1-4	3	1	2	0-1	1	0	0

[a] Construction is assumed to begin in 1993, operation in 1998, retrievability in 2028, and decommissioning in 2048.

[b] Range indicates range of impacts over years of project shown in table heading.

Table 5-56. Incremental service requirements associated with the location of a repository at Yucca Mountain (horizontal emplacement)[a]

Service	Clark County: Construction	Clark County: Operation	Clark County: Retrievability	Clark County: Decommissioning	Nye County: Construction	Nye County: Operation	Nye County: Retrievability	Nye County: Decommissioning
	Incremental service requirements							
Expected population increments	5,423-17,718[b]	10,550	3,335	4,183	849-2,775	1,652	522	647
Education								
Schools								
Elementary	1-3	2	1	1	1-2	1	0	0
Secondary	0-1	1	0	0	0-1	1	0	0
Teachers	49-162	96	30	38	7-22	13	4	5
Police								
Officers	9-30	18	6	7	3-10	6	2	2
Vehicles	4-14	9	3	3	1-2	1	0	1
Fire								
Volunteer fire fighters	2-7	4	1	2	7-24	14	5	6
Paid fire fighters	5-18	10	3	4	1-3	2	1	1
Trucks and other equipment	1-4	2	1	1	2-8	4	1	2
Medical services								
Doctors	7-23	14	4	5	0-1	1	0	0
Hospital beds	31-102	61	19	24	3-10	6	2	2
Water (millions of gallons)	3-8	5	2	2	1-2	1	0	0
Library services								
Books (thousands)	6-19	11	4	4	1-3	2	1	1
Staff	1-3	2	1	1	0-1	0	0	0

[a] Construction is assumed to begin in 1993, operation in 1998, retrievability in 2028, and decommissioning in 2048.

[b] Range indicates range of impacts over years of project shown in table heading.

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Housing

Future baseline housing demand in Clark and Nye counties is shown in Table 5-57. Repository-related effects upon projected housing demand in the area will follow the forecasted population changes that are associated with the project. During the initial construction phase, the housing demand will increase according to the influx of workers and dependents. The outmigration of workers at the start of the operation phase will introduce a slight period of decline in housing requirements. During the decommissioning phase, the increased demand will be small enough to allow the forecast number of housing units to easily absorb the additional population.

This qualitative analysis reflects preliminary assessments of effects to the housing market, which are related directly to the growth or decline of population and to the overall level of economic activity in the study region. Current uncertainty about the location, price, and quality of available housing, and the preferred location and preferences of individuals who will be moving into the area, make estimates of housing effects uncertain. As this uncertainty is resolved, mitigative measures, such as temporary housing during the construction phase, may be identified as an appropriate means of avoiding potentially significant housing effects.

Education

The potential effects on the Nye County education system may be substantial. For example, the additional three schools required in Nye County during the construction phase will represent a 20 percent increase in the baseline requirement in the year 2000. On the other hand, the effect upon Clark County educational services will be small. During construction of the repository, up to 193 additional teachers may be required in Clark County. This will represent a 2.9 percent increase over the forecasted requirement for teachers between 1990 and 2000. If no additional teachers were to be hired above the baseline forecasted requirements, then an average of one student per class would be added to existing classrooms.

Table 5-57. Projected future baseline (without repository) housing demand in Clark and Nye Counties, 1980-2030 (McBrien and Jones, 1983)

	Housing units									
	Clark County					Nye County				
Type of housing	1980	1985	1990	2000	2030	1980	1985	1990	2000	2030
Single family units	114,315	134,566	155,851	202,420	306,132	1,916	3,366	3,899	5,064	7,658
Multiple family units	54,815	65,040	75,328	97,837	147,964	393	690	800	1,039	1,571
Mobile homes	20,730	24,670	28,573	37,110	56,124	1,893	3,326	3,852	5,003	7,566
Totals	189,860	224,366	259,752	337,367	510,220	4,202	7,383	8,551	11,105	16,795

[a] 1980 housing demand based upon Nye County Nevada Profile (State of Nevada, NOCS, 1982b).

Water supply

At present, the size of municipal and private utility systems in most communities near Yucca Mountain appears adequate for current and future population levels, although it is doubtful that most systems could be expanded rapidly enough to meet the demand of a sudden population influx. Rapid development could disrupt the present level of services in these communities. Several systems plan improvements that will require a number of years to complete, such as new wells and water distribution and sewer lines, that are designed to accommodate projected baseline growth in the immediate vicinity of these communities. The major problems presently associated with this expansion are the identification of additional potable water sources (e.g., from within lower carbonate aquifer) and obtaining adequate development capital from revenues because many areas have large mobile home populations with few permanent dwellings.

According to an investigation sponsored by the State of Nevada Department of Conservation and Natural Resources (1982), there is both legal and technical uncertainty as to the ability of existing sources to meet the water supply needs of the Las Vegas Valley beyond the year 2020, or when the population reaches about 1 million people, if present rates of water use continue. Several recommendations have been made that are designed to extend and increase the water supply, including increased conservation, reliance upon ground water for peak demand, and use of aquifers for storage of temporary surface water surpluses.

Sewage treatment

Additional treatment facilities may be necessary in the smaller communities to accommodate the increased water use associated with repository construction. In Nye County, sewage is either disposed of through private septic tanks or is discharged from sewage-collection systems to evaporation pits in the desert. The capacity for wastewater treatment is not likely to be more severely affected than that of water-supply systems. However, extensive settlement close to the work site in Nye County could require additional facilities.

Public safety services

Special training and other assistance will be necessary to prepare local police and fire departments to respond to potential accidents involving nuclear waste transportation (see Section 6.2.1.8). However, the quality of law enforcement and fire protection will not be significantly affected by the population increase associated with construction of a repository. Such increases in police and fire-service personnel are likely to be accommodated by normal expansion plans that are commensurate with anticipated growth. However, as was noted in Section 3.1.6.3, present service levels in rapidly-growing nonurban areas of Clark County are considered inadequate. Additional personnel may be required if the project work force is responsible either for greater numbers or for different types of crimes than that which would accompany similar growth in the existing population. During operation of the repository and subsequent phases of the project, the demand for services will be less than anticipated in the construction phase.

Medical services

A small increase in the demand for health-care facilities and personnel will result from construction of the repository. Projected inmigration will probably generate an increase in the need for doctors and hospital beds that will range from less than 1 percent to about 3 percent over future baseline requirements in 1998 to 2053. The significance of these increases in demand will probably be greatest in smaller communities, in which relatively few medical facilities are available. One possibility is that the tendency might be intensified for Nye County residents to turn to Las Vegas area facilities for major health care services. These results have assumed that the spectrum of health needs of the construction workers and their dependents will be similar to those of existing residents. This assumption will be evaluated as further information becomes available about characteristics of the project work force.

Table 5.58. Projected annual average daily traffic on U.S. 95 in Las Vegas, 1996

Highway segment	Without repository (baseline)			With repository		
	Number of cars	Number of trucks	Total vehicles	Number of cars	Number of trucks	Total vehicles
Decatur - Valley View	77,414	2,394	79,808	79,582	2,461	82,043
Valley View - Rancho	80,578	2,492	83,070	82,834	2,562	85,396
Rancho - Highland	94,294	2,916	97,211	96,934	2,998	99,932
Highland - I 15 Int.	111,914	3,461	115,375	115,048	3,558	118,606
I 15 Int. - Casino Ctr.	91,058	1,858	92,917	93,608	1,910	95,518
Casino Ctr. - D Town Exp.	64,794	1,322	66,117	66,608	1,359	67,967
D Town Exp. - L.V. Blvd.	64,947	1,325	66,272	66,766	1,362	68,128
L.V. Blvd. - Charleston	75,091	1,532	76,624	77,194	1,575	78,769
Charleston - Sahara	92,801	2,870	95,671	95,399	2,950	98,349
Sahara - Lamb	92,758	2,869	95,627	95,355	2,949	98,304
Lamb - Flamingo	90,126	2,787	92,913	92,650	2,865	95,515
Flamingo - Nellis	100,703	3,115	103,818	103,523	3,202	106,725
Nellis - Tropicana	98,384	3,043	101,427	101,139	3,128	104,267
Tropicana - L.V. NLV[a]	70,479	2,180	72,658	72,452	2,241	74,693
L.V. NLV - NUL[b] Henderson	66,527	2,058	68,585	68,390	2,116	70,506
NUL Henderson - Sunset Rd.	66,527	2,058	68,585	68,390	2,116	70,506
Sunset Rd. - SR 146	64,023	2,668	66,691	65,816	2,743	68,559
SR 146 - Henderson	31,135	---	31,135	32,006	---	32,006

[a] NLV = North Las Vegas.

[b] NUL - Northern Urban Limits.

Table 5-59. Projected annual average daily traffic on I-15 in Las Vegas, 1996

Highway segment	Without repository (baseline)			With repository		
	Number of cars	Number of trucks	Total vehicles	Number of cars	Number of trucks	Total vehicles
Craig - Northern city limits of Las Vegas	11,091	2,948	14,039	11,402	3,031	14,433
Craig - Cheyenne	25,841	4,560	30,401	26,565	4,688	31,253
Cheyenne - Lake Mead	39,442	4,382	43,824	40,546	4,505	45,051
Lake Mead - D & Washington	64,320	5,593	69,913	66,121	5,750	71,871
D & Washington - D. Town Exp.	70,274	6,111	76,385	72,244	6,282	78,526
D. Town Exp. - Charleston	101,595	6,485	108,079	104,440	6,667	111,107
Charleston - Sahara	111,348	7,107	118,456	114,466	7,306	121,772
Sahara - Spring Mountain	109,379	6,982	116,361	112,442	7,177	119,619
Spring Mountain - Dunes Flamingo	93,930	7,070	101,000	96,560	7,268	103,828
Dunes Flamingo - Tropicana	77,031	7,618	84,649	79,188	7,831	87,019
Tropicana - Las Vegas Blvd.	42,549	10,637	53,187	43,740	10,935	54,675

Transportation

Major improvements to existing highway systems are planned for U.S. 95 through metropolitan Las Vegas. It will be completely rebuilt from Railroad Pass to I-15 and will become I-515 along one section. By 1992, the new freeway is scheduled to be completed to Russell Road. By the year 2000, the entire freeway should be completed to Railroad Pass. Despite improvements, a number of streets, including sections of I-15 and U.S. 95, are projected to be either at or over capacity during peak-hour use for the population levels that are expected by the year 2000 (Clark County Transportation Study, 1980).

To estimate the effects of repository-related traffic in Las Vegas, the highest impact year, 1996, annual average daily traffic for the in-town portions of U.S. 95 and I-15 has been compared both with and without the repository. Repository-related population increases (see Section 5.4.2) have been used to project 1996 traffic volumes on various segments of these highways. These projections are shown on Tables 5-58 and 5-59 along with State of Nevada Deparment of Transportation baseline projections. These projections indicate a two to eight percent increase due to repository-related population growth. This increment is not considered significant.

Rail capacity will be adequate to meet additional demands for service caused by baseline and project-related growth.

5.4.4 Effects on sociocultural conditions

The following is a preliminary assessment of potential sociocultural effects that may be expected in communities near Yucca Mountain. The assessment is preliminary because of the limited data base (see Chapter 3) and because of the uncertainty about the number and location of expected inmigrants.

A distinction is made between standard and special sociocultural effects that may accompany nuclear projects (Murdock and Leistritz, 1983). Standard effects result from the influx of population that typically accompanies the construction of large projects in rural areas. Special effects stem from concerns about radioactive material. Because radioactive materials will be transported through the region, these special effects may occur in both rural and urban areas. The concerns include the following: (1) effects on health and safety; (2) the fairness of the site selection process; (3) institutional issues related to security, handling, and transportation; and (4) public participation and monitoring (DOE, 1983; Hebert et al., 1979; Murdock and Leistritz, 1983).

5.4.4.1 Effects on social structure and social organization

Standard effects typically involve: conflicts between inmigrating workers and existing residents; changes from an informal, neighborly lifestyle to a more formal bureaucratic mode; and signs of social disruption during the transition. Special effects may be evident in the form of mobilization (that is, commitment of resources), and formation of opposing and supporting groups.

Standard effects on social structure and social organization

If current Nevada Test Site settlement patterns are followed, much of the population influx will be absorbed by urban Clark County. In light of the small size of the increment relative to projected baseline population and the complex nature of the existing social structure in urban Clark County, the effects should not be significant. Further study is required to assess if the effects are adverse or beneficial. Inmigration could aggravate existing signs of social stress; conversely, the project may provide an opportunity to diversify the area's economic base and offer a stable source of employment.

Nye County is a rural area in which previous experience indicates that significant standard effects could occur. However, preliminary assessment suggests that inmigrating construction workers are likely to become assimilated within the existing county structure. Relevant factors in this assessment include: (1) the compatibility between inmigrating workers and the communities of Nye County; and (2) a long lead time that permits adequate planning.

Certain characteristics of the existing rural structure, which would reduce the possibility of conflict between existing and inmigrating groups, appear to be compatible with inmigration. Historically, Nye County communities have had large percentages of miners, and mining continues to be important in the area. A recent trend in Pahrump has been an increase in construction and mining work relative to agricultural employment. Some residents of the town of Amargosa Valley depend upon employment outside of the immediate area to supplement their farm income. In addition, separate employee housing complexes such as housing at Mercury for Nevada Test Site workers and the American Borate Housing Complex, which is south of the town of Amargosa Valley, appear to be accepted features of the existing social structure.

Increasingly formal relationships, which can occur as rural communities expand, may be more likely if growth is concentrated in any one rural community. The possibility of growth being accompanied by an increase in social problems is a valid concern in a region that has had negative effects from rapid growth cycles. However, the possibility may be reduced by the nature of the project itself. A long lead-time, combined with an impact mitigation process, should allow adequate time to plan for initial population and for changes that may occur over the entire repository lifecycle. Moreover, it is likely that repository operation will provide employment stability. As noted in Chapter 3, at least one rural Nye County community appears to seek expansion. The degree to which each community is prepared for, and willing to accept, inmigration is a critical factor in determining the potential for standard effects (Cortese, 1977).

Special effects on social structure and social organization

Concerns about radioactive material provide the basis for possible changes in existing social structure and social organization. Special effects may include the mobilization and formation of groups opposing and supporting the repository, and increased controversy in the community. These effects have been occurring since the time the State of Nevada was notified of the potential siting of the repository and the hearings were held (DOE, 1983). Opposition groups have formed and several area organizations have made public statements of support or opposition to the repository. Networks exist through which mobilization of groups could occur, such as those formed to oppose siting the MX missile system in Nevada and Utah (Albrecht, 1983).

5.4.4.2 Effects on culture and lifestyle

Because of the diversity of the existing cultural environment, inmigrating workers will likely be able to select a compatible cultural environment and are likely to be readily assimilated into the community. Those construction workers who continue to be employed during the operation phase will be the most completely assimilated.

5.4.4.3 Effects on attitudes and perceptions

Attitudes and perceptions are an integral part of the social impact process and are factors in the social group mobilization that was previously discussed. The following preliminary assessment identifies conditions that are unique to southern Nevada which may interact with the specific concerns outlined in Chapter 3 to affect the development of attitudes on the repository issue. These conditions include: past experience; the salience of the issue to an individual or to a group; and its relationship to issues on which an attitude has already been formed.

Economic considerations and the potential for changes in lifestyle also contribute to the formation of public attitudes (see Surveys cited in Chapter 3). Preliminary analysis suggests that the repository could be considered more economically beneficial by Nye County communities than by Clark County communities, although there may be varied reactions within either county. Towns such as Amargosa Valley and Pahrump could welcome the potential for growth and increased employment, particularly for the skilled workers and young persons who might otherwise leave the area. It should be noted, however, that indications of Nye County support should be tempered by the survey findings, which were cited in Chapter 3, that demonstrate a desire for growth without social disruption. This support may depend on the extent to which Nye County residents are convinced that growth can be managed and problems can be mitigated.

In contrast, urban Clark County residents could view the repository, especially waste transportation, as negatively affecting the tourism image on which the economy is based. Moreover, it is possible that repository-related traffic (other than waste) could aggravate transportation problems already cited by residents (List, 1980; Frey, 1981). Las Vegas newspapers and the UNLV survey (1984) suggest that many Clark County residents may oppose locating a repository at Yucca Mountain.

Issues which may contribute to the formation of public attitude about the repository include: (1) resentment of the high percentage of Federal land ownership, symbolized in the Sagebrush rebellion (Brodhead, 1980); (2) the belief, which is evident in the public hearings, that Nevadans have "done their share" by giving land for Nevada Test Site activities and should not have to accept waste from other states when Nevada produces none; (3) distrust of the Federal government, which is also evident in the hearings and reinforced by perception of a dual role played by the government in managing both the development of nuclear power and radioactive waste disposal. This last issue may be particularly important because of the role which credibility plays in attitude formation.

5.4.5 Fiscal conditions and government structure

The location of a repository at Yucca Mountain would increase both the revenues and expenditures of State and local government entities in the affected area. Although no quantitative estimates of potential net fiscal effects are presently available, this section will describe some of the qualitative revenue and expenditure implications. A description of key fiscal impact mitigation provisions of the Nuclear Waste Policy Act (the Act) is also provided.

The earliest expenditure will result from the increased planning activity required at the State, county, and local government levels to enable affected government entities to prepare for and participate in a decision to locate a repository at Yucca Mountain. At the onset of construction in 1993, an influx of workers from outside the area will increase the demand for community services, as described in Section 5.4.3. During operation of the repository, additional outlays will be associated with road maintenance, traffic escort and control, and emergency preparedness. This will be at least partially offset by increases in government revenues at the State level through increased sales and use taxes, motor fuels taxes, and other highway use and general fund revenues; and, it will be offset at the local level through increased sales, property and other tax revenues and user fees.

In addition, to ensure mitigation of any potential adverse net fiscal effects of a repository, the Act explicitly provides a number of different ways for state and local governments to obtain financial assistance. The Act recognizes the fiscal implications of preconstruction planning activities as well as the fiscal effects of the physical presence of the repository and its related work force. Under the Act, the Secretary of Energy must make grants to a State that has been notified that a repository may be located within its boundaries so that it can participate in the review of assessments of the economic, social, public health and safety, and environmental implications of a repository (Sections 116 and 117). Also, States that have sites that have been approved for site characterization will receive Federal grants for the following purposes:

1. To review activities undertaken to assess potential social, public health and safety, and environmental impacts of a repository.

2. To develop a request for impact assistance associated with the development of a repository.

3. To engage in monitoring, testing, or evaluation activities with respect to site characterization programs.

4. To provide information to state residents about State and Federal actions concerning the potential repository.

5. To request information from, and to make comments and recommendations to, the Secretary of Energy regarding the siting of a repository [Section 116(c)(1)(B)].

Finally, the Act provides for financial and technical assistance to the state in which repository construction is authorized for purposes of mitigating the impacts of repository development [Section 116(c)(2)(A)]. Additional studies will be performed by the DOE as part of the site selection environmental impact statement. In addition to this financial assistance, the Act requires that the Federal government make payments in lieu of real property taxes to State and local governments in the affected area. These payments must be equal to the amounts that would be paid if the State and local government entities were authorized to tax site-characterization development and operation activities as they would any other real property and industrial activities occurring the in area.

In addition, Section 117(c)(5) requires that, pursuant to a Consultation and Cooperation Agreement negotiated with States selected for characterization, DOE is to assist both the State and "units of general local government" in resolving a number of concerns such as State liability arising from accidents, necessary road upgrading and access to the site, ongoing emergency preparedness and emergency response, monitoring of transportation of high-level waste and spent nuclear fuel through such state conduct of baseline health studies of inhabitants in neighboring communities, and reasonable periodic monitoring thereafter, and monitoring of the repository site upon any decommissioning and decontamination.

As in the case of community services impacts, the significance of potential fiscal impacts of the project will depend upon the extent to which workers are obtained from outside the southern Nevada area and the settlement patterns of those inmigrating workers. While the assessment of community services impacts in Section 5.4.3 suggests that the fiscal effects may be observable yet insignificant for the urban areas of Clark County, the influx of inmigrants to the rural communities of Clark and Nye counties could have a potentially significant effect on the fiscal and governmental structure of those communities. Further information of inmigration and settlement patterns will be required to accurately quantify these impacts for purposes of identifying a detailed approach to fiscal and governmental impact mitigation.

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Chapter 6

SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR SITE CHARACTERIZATION AND FOR DEVELOPMENT AS A REPOSITORY

The purpose of this chapter is to satisfy the requirements stated in Section 112.(b)(E)(i,ii) in the Nuclear Waste Policy Act of 1982. These subparts (i,ii) describe the procedure and content of the environmental assessment required to accompany the nomination of a candidate site, which has been determined to be suitable for site characterization. The evaluation of whether a site should be recommended for site characterization is to be done under the general DOE guidelines (10 CFR 960), which were developed to satisfy Section 112.(a) of the NWPA of 1982.

General regulatory standards considered in this environmental assessment for determining whether a site is suitable for isolation and containment of radioactive wastes are proposed by the Environmental Protection Agency as working draft 2 of 40 CFR 191 (EPA, 1983) and promulgated by the Nuclear Regulatory Commission as 10 CFR 60 (NRC, 1983). The DOE has developed a set of general guidelines as required by the NWPA of 1982 (10 CFR 960). These guidelines specify the requirements for recommendation of sites as candidate sites for characterization, and the recommendation of a characterized site for the development of a repository (Section 960.3-2-3 and 960.3-2-4, respectively).

The 10 CFR 960 guidelines are organized in several major categories. The two of interest for this chapter are subpart C, postclosure guidelines, and subpart D, preclosure guidelines. The postclosure and preclosure time periods are addressed separately to distinguish between the unique purpose of a repository (i.e., long-term isolation of wastes) and the activities necessary during the next few decades to build, operate, and close a facility that will arry out this purpose. The postclosure and preclosure guidelines are further divided into two types: system and technical. The system guidelines directly address performance of the entire repository system. The technical guidelines address attributes of the components of the repository system.

The Postclosure System Guideline requires compliance with those NRC and EPA regulations that are intended to ensure that the health and safety of the public and the quality of the environment will be protected. The Preclosure System Guidelines establish the overall objectives to be met by the site of a repository during site characterization, repository construction, operation and closure. Three distinct groups of qualifying conditions are addressed: (1) radiological safety; (2) environmental protection, socioeconomic welfare of affected people and safe transport of wastes to a repository; and (3) feasibility, safety, and economics of building repository facilities. Table 6-1 presents these system guidelines and gives references for them.

System guidelines address the ability of the natural system components and the system of engineered barriers to serve their intended purposes. At the pre-site-characterization stage of the siting process, sufficient data are not available to allow a complete evaluation that considers all pertinent repository and site components, including the degree of confidence associated with performance of each component. Therefore, the technical guidelines were developed as surrogates for the system guidelines for use in guiding siting decisions in lieu of a complete and reliable evaluation of the entire repository system. Table 6-2 presents the technical guidelines and gives references for them.

In the absence of complex system analyses, the technical guidelines provide a listing of qualifying, favorable, potentially adverse, and disqualifying conditions for particular site features. These conditions, in turn, provide a set of standards against which a site can be evaluated with reasonable confidence before site characterization. Evaluations of these technical conditions can strongly indicate, but not demonstrate, whether a site has the necessary features to protect public health and safety. The presence of many favorable conditions indicates a high likelihood that a site will be able to adequately achieve its purpose. Conversely, the presence of numerous

Table 6-1. Listing of system guidelines

Title	Reference
Postclosure system guideline (long-term repository behavior)	10 CFR 960.4-1
Preclosure system guidelines	10 CFR 960.5-1
Radiological safety	10 CFR 960.5-1(a)(1)
Environment, socioeconomics, and transportation	10 CFR 960.5-1(a)(2)
Ease and cost of construction, operation, and closure	10 CFR 960.5-1(a)(3)

Table 6-2. Organization of technical guidelines

I. Postclosure Technical Guidelines	
A. Characteristics and processes affecting expected repository performance	
1. Geohydrology	10 CFR 960.4-2-1
2. Geochemistry	10 CFR 960.4-2-2
3. Rock characteristics	10 CFR 960.4-2-3
B. Potentially disruptive process and events	
1. Climatic changes	10 CFR 960.4-2-4
2. Erosion	10 CFR 960.4-2-5
3. Dissolution	10 CFR 960.4-2-6
4. Tectonics	10 CFR 960.4-2-7
5. Human interference and natural resources	10 CFR 960.4-2-8
Natural resources	10 CFR 960.4-2-8-1
Site ownership and control	10 CFR 960.4-2-8-2
II. Preclosure Technical Guidelines	
A. Preclosure radiological safety	
1. Population density and distribution	10 CFR 960.5-2-1
2. Site ownership and control	10 CFR 960.5-2-2
3. Meteorology	10 CFR 960.5-2-3
4. Offsite installations and operations	10 CFR 960.5-2-4
B. Environmental, socioeconomics, and transportation	
1. Environmental quality	10 CFR 960.5-2-5
2. Socioeconomic impacts	10 CFR 960.5-2-6
3. Transportation	10 CFR 960.5-2-7
C. Ease and cost of construction, operation, and closure	
1. Surface characteristics	10 CFR 960.5-2-8
2. Rock characteristics	10 CFR 960.5-2-9
3. Hydrology	10 CFR 960.5-2-10
4. Tectonics	10 CFR 960.5-2-11

potentially adverse conditions may suggest a reason for utmost caution before proceeding at a site. The technical guidelines are used as surrogates to compile system guideline evaluations, and thereby determine if a proposed site meets the overall objectives for a repository. For the technical guidelines which contain disqualifying conditions, a judgment that a disqualifying condition is present at a site automatically eliminates that site from further consideration.

The full demonstration of compliance with the guidelines must await site characterization and final repository design. Therefore, definite conclusions about whether Yucca Mountain will comply with the guideline requirements are not possible or expected at this time. Rather, judgments will be made in this chapter about whether there is currently sufficient confidence that the site will be shown to comply with such requirements after site characterization.

The Nuclear Waste Policy Act (NWPA) and 10 CFR 60 define site characterization. On the basis of this very specific definition, the technical guidelines have been regrouped for presentation in this chapter into (1) guidelines that can be addressed without data from site characterization, and (2) guidelines requiring the kind of data collection activities performed in site characterization before they can be addressed. Section 6.1 elaborates on the basis for distinguishing between these two categories of guidelines.

Guidelines not requiring site characterization correspond to preclosure technical and system guidelines dealing with radiological safety during repository operations, and issues concerning environmental, socioeconomic, and transportation conditions. One postclosure technical guideline, site ownership and control, is also in this category as is the postclosure system guideline, and the preclosure system guideline for ease and cost of construction, operation, and closure. The rest of the technical guidelines given in Table 6-2 are considered guidelines requiring site characterization. This division of the guidelines forms the basic organization of two of the three sections of this chapter. Evaluations in Section 6.2 will address the preliminary assessment of the Yucca Mountain site in relation to technical and system guidelines that do not require data from site characterization. Section 6.3 presents preliminary evaluations for technical and system guidelines requiring data from site characterization.

Preliminary quantitative analyses of expected system performance with supporting comparison with the system guidelines are summarized in the final part of the chapter (Section 6.4). Individual performance is evaluated for each of the three major subsystems of the proposed Yucca Mountain repository system: the waste package; the engineered barrier subsystem; and the geohydrologic subsystem. A reference case system configuration is established and used for a preliminary assessment of total system performance. Subsystem and total system performance are evaluated in terms of the applicable technical criteria of 10 CFR 60 and the proposed 40 CFR 191.

6.1 GUIDELINES THAT DO AND DO NOT REQUIRE SITE CHARACTERIZATION

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6.2 SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR DEVELOPMENT AS A REPOSITORY: EVALUATION AGAINST THE GUIDELINES THAT DO NOT REQUIRE SITE CHARACTERIZATION

Evaluations in this section address the preliminary assessment of the Yucca Mountain site in relation to technical and system guidelines that do not require data from site characterization.

6.2.1 Technical guidelines

The technical guidelines that were developed for use in guiding siting decisions are discussed in this section. For each technical guideline, a discussion of the objective of the guideline is followed by a description of the relevant data, and an evaluation of whether or not the proposed site possesses the qualifying, favorable, potentially adverse, or disqualifying condition(s) listed in 10 CFR 960.

6.2.1.1. Postclosure site ownership and control, 10 CFR 960.4-2-8-2

I. INTRODUCTION

This Site Ownership and Control Technical Guideline is a subpart of the postclosure Human Interference Technical Guideline included under the heading potentially disruptive processes and events. The objective of this guideline is to ensure that the Department of Energy (DOE) obtains land ownership, in accordance with the requirements of 10 CFR 60.121, in order to establish passive controls following closure of the repository and thus decrease the likelihood of future human activities that would compromise the integrity of the repository. Passive controls include permanent markers on the surface above the repository and records available to future generations.

The postclosure Site Ownership and Control Guideline consists of one qualifying condition, one favorable condition, and one potentially adverse condition. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

The proposed Yucca Mountain site is wholly on Federally owned land. However, three different agencies currently have jurisdiction and control over portions of the parcel. The eastern portion of the proposed site is within the boundaries of the Nevada Test Site (NTS) under control of the Department of Energy (DOE). The northwestern portion is on the Nellis Air Force Range (NAFR) under control of the U. S. Air Force (USAF). The southwestern portion is on land in the public domain under the jurisdiction of the Bureau of Land Management (BLM) of the Department of the Interior. See map on Figure 3-1 for the location of these parcels.

The following is a synopsis of the nature and extent of the jurisdiction and control currently exercised over the three segments of the proposed Yucca Mountain site (Amick and Gassman, 1984):

Nevada Test Site Segment: All land is under the jurisdiction and control of DOE. DOE has jurisdiction over "the mineral resources and mineral and vegetable materials" (DOE, 1961, see Section 6.2.1.3). DOE has control over all other surface and subsurface rights, including water rights from points of extraction on the Nevada Test Site. The private acquisition of any surface and subsurface rights is also presently precluded by the public land order.

Nellis Air Force Range Segment: Withdrawal legislation for the Nellis Air Force Range is currently before Congress. Until such time as this legislation is enacted, BLM serves as the official protector of the land and custodian of all surface and subsurface rights. Private acquisition of any rights on or in the land is presently precluded pursuant to Section 204 of the Federal Land Policy and Management Act of 1976.

Bureau of Land Management Segment: All land is in the public domain under the jurisdiction and management of the BLM and has not been segregated from the operation of the public land laws.

The above lands are currently free and clear of encumbrances arising under lease, right of entry, deed, patent, mortgage, appropriation, prescription, or otherwise (Bell and Larson, 1982). A plan has been developed (Richards and Vieth, 1983) that describes the land use and withdrawal actions necessary for site characterization, construction of the exploratory shaft, and for developing a high-level nuclear waste repository. The plan contains the actions necessary for land acquisition to meet the requirements of 10 CFR 60.121.

Assumptions and Data Uncertainties: Uncertainties in the site ownership and control issue are related to interagency negotiations involving the USAF and the BLM over land withdrawal and restrictions.

III. QUALIFYING CONDITION

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

Evaluation: Control of the Yucca Mountain site presently resides with the DOE, the BLM, and the USAF. Richards and Vieth (1983) have prepared a plan for the DOE to acquire jurisdiction over the necessary land from the BLM and the USAF, and formal agreements with those Federal agencies are underway. Implementation of Congressional action necessary for permanent transfer to the DOE has been deferred pending selection for a repository. Permanent markers will be used to mark the controlled area, which extends horizontally no more than 10 km in any direction from the boundary of the underground facility and subsurface area committed to repository use. A permanent marker system could use four types of messages (Kaplan, 1982) consisting of: (1) an obvious notification to possible intruders that something is located there; (2) a warning that what is located at the site is dangerous (e.g., the symbol for radioactive material); (3) basic information such as what actions must be avoided, what is located at the site, who placed it there, and where to find additional information; and (4) a full record of information, such as plans, drawings, and environmental impact statements. The markers and records will be used to discourage future generations from deliberately or inadvertently disturbing the Yucca Mountain site after closure.

Conclusion: The plan by which the DOE would acquire jurisdiction and control over all surface and subsurface rights for the Yucca Mountain site will be implemented if the Yucca Mountain site is selected for a repository. No impediments to eventual complete ownership and control by the DOE have been identified. Therefore, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITION

Present ownership and control of land and all surface and subsurface rights by the DOE.

Evaluation: Control of the parcel of land where the proposed site is located currently resides with the DOE (the Nevada Test Site portion), the USAF (the Nellis Air Force Range portion), and the BLM. Permanent withdrawal and reservation of jurisdiction and control over surface and subsurface rights requires an act of Congress. This transfer could be implemented following the plan prepared by Richards and Vieth (1983).

Conclusion: Presently, the DOE exercises jurisdiction and control over only a portion of the Yucca Mountain site; the remaining portions are under the jurisdiction and control of the USAF and the BLM. Therefore, at the present time the Yucca Mountain site does not possess this favorable condition. However, because the remaining portions of the proposed site are owned by the Federal government, it is anticipated that, at a later date, the DOE will acquire complete jurisdiction of all surface and subsurface mineral and water rights.

V. POTENTIALLY ADVERSE CONDITION

Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Evaluation: The land use and withdrawal plan prepared by Richards and Vieth (1983) shows that interagency transfers of only small tracts of land would be required. The USAF land adjacent to the western Nevada Test Site border is part of a flight corridor for military aircraft, but this activity would not impact surface or subsurface development. Because no ongoing programs of either the USAF or the BLM would be affected by land withdrawal, no barriers to agency-to-agency transfers are expected.

Conclusion: All land in question is now owned by the Federal government, and a plan to transfer the necessary land to the DOE through withdrawal action has been prepared. No causes for potential dispute in agency-to-agency transfers have been identified. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

6.2.1.2 Population density and distribution, (10 CFR 960.5-2-1)

I. INTRODUCTION

The Population Density and Distribution Technical Guideline is one of several preclosure guidelines within the subject heading preclosure radiological safety. The objective of the guideline is to ensure that a repository site will be sufficiently remote from members of the public such that risks from possible releases of radioactivity during the operational and closure periods will be minimal and below standards established by the Environmental Protection Agency and the Nuclear Regulatory Commission regulations.

The guideline consists of one qualifying condition, two favorable conditions, two potentially adverse conditions, and three disqualifying conditions. The Yucca Mountain site is evaluated with respect to all these conditions in the following sections.

II. RELEVANT DATA

In 10 CFR 960.2, a highly populated area is defined as

"any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2500 or more persons, or any census designated place (as defined and delineated by the Bureau) of 2500 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-km (6-mi) radius of the proposed site; all land within this radius is currently Federally controlled and not open to settlement. The proposed site is located on the common boundary of Census Enumeration Districts 745 and 746. The combined populations of Enumeration Districts 745 and 746 in April 1980, according to the 1980 U.S. Census (DOC, 1982), was 223 persons. The towns nearest to Yucca Mountain are

Amargosa Valley (formerly known as Lathrop Wells), 26 km (16 mi) south, and Beatty, 26 km (16 mi) west. According to the U.S. Environmental Protection Agency, Amargosa Valley had a 1983 population of 45 and Beatty had a population of 800; thus neither town presently qualifies as a highly populated area. The Nevada Test Site (NTS) and Nellis Air Force Range (NAFR) surround the Yucca Mountain site on three sides. About 5000 individuals work but do not reside at the Nevada Test Site and several hundred may occasionally remain overnight in Mercury and other NTS locations; however, there are no permanent residences or private property on the NTS or NAFR. The southwest side of the Yucca Mountain site is bounded by land controlled by the Bureau of Land Management and is closed to permanent settlement but is open to public access.

The nearest Standard Metropolitan Statistical Area (SMSA) is composed of Las Vegas and surrounding communities in the Las Vegas Valley area of Clark County, about 150 km (95 mi) southeast of Yucca Mountain. Las Vegas Valley had a population of 443,730 in 1980 (DOC, 1982).

The potential radiological doses for the public residing within an 80-km (50-mi) radius of the site have been estimated for postulated accidental releases of radionuclides from repository operations (Jackson, 1983a). In no instance did the accident-related dose to the maximally exposed individual in an unrestricted area exceed the limits allowable under the requirements specified in 10 CFR 960.5-1(1). The accident-related dose to the maximally exposed individual, located at the edge of a postulated exclusion area of 7900 acres, was 0.3 rem. The worst-case population dose estimated for the same set of accidents would result in an estimated population dose of 120 person-rem. Background radiation is 1790 person-rem/yr for the same population (Jackson, 1984).

Population projections have been made for the State of Nevada and for Clark County through the year 2030 (DOC, 1981a), which includes the period of repository operation. These projections, modified by 1980 census data, predict a 2.6-fold increase in population by 2030 for the State of Nevada and Clark County (McBrien and Jones, 1983). If the towns of Beatty and Amargosa Valley increase in population at this rate, the populations will be 3080 and 117, respectively, in 2030.

Population data supporting the analysis in this guideline come from the 1980 U.S. Census (DOC, 1982). Additional 1980 U.S. Census data for Clark County appear in Clark County Comprehensive Planning report (1983), which also gives the geographic boundaries and areas of Clark County entities. Supplementary geographic data are available through the Nevada Department of Transportation, Map Division. Data on the populations of small unincorporated towns appear in Richards-Haggard (1983).

Assumptions and Data Uncertainties: Long-term changes in population density and distribution are difficult to predict. For example, increased employment opportunities at the Yucca Mountain site during repository construction, operation and closure could result in greater than anticipated population increases in the nearby towns of Amargosa Valley and Beatty.

Release of natural radioactivity from the volcanic rocks of the Yucca Mountain site during construction results in a population whole-body dose of 5 to 12 man-rem. This is much smaller than the calculated accidental releases; therefore, doses to individuals in unrestricted areas due to normal operations also should be indistinguishable from background radiation.

III. QUALIFYING CONDITIONS

(1) The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in Section 960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limits allowable under the requirements specified in Section 960.5-1(a)(1).

Evaluation: The nearest highly populated area, based on 1980 census information is the Las Vegas Valley, which is 150 km (95 mi) from the Yucca Mountain site. Preliminary accident-related radiological dose calculations (Jackson, 1984b) for the maximally exposed individual located 4 km (2.4 mi) from the surface facility at the outer limit of a postulated exclusion boundary enclosing 7900 acres are well below the limits specified in 10 CFR 960.5-1(a)(1). This indicates that the expected average radiological dose to any individual within 80 km (50 mi) of the site will be indistinguishable from the background radiation dose.

Conclusion: The site is located in an area of extremely low population density, remote from any highly populated areas. Preliminary calculations of accident-related radiological dose commitments to individuals in any highly populated area or in an unrestricted area indicate that the expected average radiological dose will be indistinguishable from background radiation and will not exceed the limits of 10 CFR 960.5-1(a)(1). Therefore, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITIONS

(1) Remoteness of the site from highly populated areas

Evaluation: The Yucca Mountain site is in southern Nye County, Nevada. Southern Nye County is bordered by Clark, Lincoln, and Esmeralda Counties. These counties are about 50 to 65 km (30 to 40 mi) from the site. In 1980, neither Lincoln County nor Esmeralda County contained any highly populated area. Tonopah, which is a Census Designated Place in Nye County, had a population of 1952 according to the 1980 U.S. Census (DOC, 1982). Tonopah is approximately 180 km (110 mi) northwest of Yucca Mountain. The highly populated areas in Clark county are all in the Las Vegas Valley about 150 km (95 mi) southeast of Yucca Mountain.

The unincorporated towns of Amargosa Valley and Beatty lie closest to the Yucca Mountain site, at distances of 26 and 25 km (16 mi), respectively. U.S. Census Bureau population estimates for these towns are unavailable, but the U.S. Environmental Protection Agency estimates that the 1983 population of Beatty was 800 and Amargosa Valley was 45 (Richard-Haggard, 1983).

Conclusion: The Yucca Mountain site is remote from any highly populated area. The nearest highly populated area is about 150 km (95 mi) away. Therefore, the Yucca Mountain site possesses this favorable condition.

(2) <u>A low population density in the general region of the site</u>.

<u>Evaluation</u>: The Yucca Mountain site is in Nye County, which had a 1980 population density of 0.5 persons per square mile (DOC, 1982). This is low when compared with the 1980 population density of the U.S., which was 64.0 persons per square mile. The two counties adjacent to Nye County to the northwest and northeast of the site are Esmeralda and Lincoln counties. These counties have respective 1980 population densities of 0.22 and 0.35 persons per square mile.

The nearest urban area is 150 km (95 mi) away in Clark County. This area, the Las Vegas Valley, includes the incorporated cities of Henderson, Las Vegas, and North Las Vegas as well as the unincorporated areas of East Las Vegas Town, Enterprise, Grandview, Lone Mountain, Paradise Town, Spring Valley Town, Sunrise Manor Town, and Winchester Town. The Las Vegas Valley, had a 1980 population of 463,097 (DOC, 1982) and covers about 2000 km^2 (760 square mi). The remainder of Clark County, about 90 percent of its geographic area, had a population density of about 2.7 persons per square mile. The average population density of Clark County was 58.8 persons per square mile in 1980.

<u>Conclusion</u>: The county containing the proposed site has a population density of 0.5 persons per square mile, which is substantially below the U.S. average density of 64 persons per square mile. Two adjacent counties also have population densities well below the U.S. average. Outside of Las Vegas Valley, Clark County has a population density of only about 2.7 persons per square mile. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) <u>High residential, seasonal, or daytime population density within the projected site boundaries</u>

<u>Evaluation</u>: Surface facilities that would be associated with a repository at Yucca Mountain would be located in the center of an uninhabited area with a radius of at least 10 km (6 mi).

Other than the work force currently engaged in preliminary site investigations at Yucca Mountain as part of the Nevada Nuclear Waste Storage Investigations Project, there is no daytime or seasonal use of the area. Preliminary estimates of the peak day shift worker population is approximately 1600 workers during the fourth year of construction, depending upon the waste emplacement plan (see Section 5.3).

Conclusion: The projected boundaries of the Yucca Mountain site presently contain no seasonal, daytime or residential population, except for those daytime personnel associated with ongoing investigations of the site for radioactive-waste disposal. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. Census.

Evaluation: The nearest highly populated areas are in the Las Vegas Valley area about 150 km (95 mi) southeast of Yucca Mountain. This is also the nearest area 1 mile by 1 mile having a population of at least 1000 individuals.

Conclusion: The Yucca Mountain site is about 150 km (95 mi) away from the nearest highly populated area. It is equally remote from any area having at least 1000 individuals in an area 1 mile by 1 mile as defined by the 1980 census. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

VI. DISQUALIFYING CONDITIONS

There are three disqualifying conditions with regard to population density and distribution, and any one of these conditions is sufficient to disqualify site. To avoid repetition of data and information, the disqualifying conditions (stated below) are evaluated together. Separate conclusions are given for each disqualifying condition.

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 1000 individuals as enumerated by the most recent U.S. Census; 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, 10 CFR 60, Subpart I, "Emergency Planning Criteria."

Evaluation: There are no residential inhabitants within a 10 km (6 mi) radius of the proposed Yucca Mountain site. The nearest highly populated area is Las Vegas, at a distance of 150 km (95 mi); this is also the distance to the nearest area 1 mile by 1 mile with a population of greater than 1000 persons.

An existing Emergency Preparedness Plan covers accidental release of radionuclides as a result of weapons testing by the DOE at the Nevada Test Site (DOE/NVO, 1983a). This plan addresses gaseous emissions following weapons tests; no problems are anticipated in preparing a plan addressing airborne or water-borne releases at an operating repository.

Conclusion for Disqualifying Condition 1: The nearest highly populated area to Yucca Mountain is about 150 km (95 mi) away. Consequently, surface facilities at Yucca Mountain would not be located within a highly populated area. Therefore, the Yucca Mountain site is not disqualified by this condition.

Conclusion for Disqualifying Condition 2: The Yucca Mountain site is not located adjacent to any area 1 mile by 1 mile having a population of 1000 or more. The nearest such area is in Las Vegas about 150 km (95 mi) to the southeast. Therefore, the Yucca Mountain site is not disqualified by this condition.

Conclusion for Disqualifying Condition 3: The DOE can prepare an emergency preparedness plan for Yucca Mountain; it already has prepared such a plan for current activities at the Nevada Test Site. Therefore, the Yucca Mountain site is not disqualified by this condition.

6.2.1.3 Preclosure site ownership and control (10 CFR 960.5-2-2)

I. INTRODUCTION

This Site Ownership and Control Technical Guideline is one of several preclosure guidelines included under the topic heading preclosure radiological safety. The objective of this Site Ownership and Control guideline is to ensure that the Department of Energy (DOE) obtains land ownership, in accordance with the requirements of 10 CFR 60.121, in order to control and limit entry of people onto the site during operations and closure and thus minimize the risk of radiological exposure.

The preclosure Site Ownership and Control Guideline consists of one qualifying condition, one favorable condition, and one potentially adverse condition. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

The proposed site is controlled by the Department of Energy, the U.S. Air Force (USAF) and the Bureau of Land Management (BLM). The respective portions of the proposed site that these agencies control are the Nevada Test Site, which is the eastern portion of the parcel; the Nellis Air Force Range, which is the northwestern portion of the parcel; and land held in public trust by the BLM, which is the southwestern portion of the parcel. Permanent withdrawal and reservation of jurisdiction and control over surface and subsurface rights requires an Act of Congress (Coldiron, 1981). These lands have been determined to be currently free and clear of encumbrances arising under lease, right of entry, deed, patent, mortgage, appropriation, prescription, or otherwise (Bell and Larson, 1982). A plan has been developed (Richards and Vieth, 1983) that outlines the land withdrawal actions necessary for the purpose of site characterization, construction of the exploratory shaft, and for developing a high-level nuclear waste repository. This plan contains the actions necessary for land acquisition to meet the requirments of 10 CFR 60.121.

Presently, agreements are in effect between the DOE and the BLM and the USAF for exploratory use of that portion of the Yucca Mountain site outside the Nevada Test Site. The part of the Nevada Test Site containing Yucca Mountain was withdrawn from the Public Domain by Public Land Order 2568 on December 19, 1961, and presently it is controlled by the DOE. The DOE has a use permit (DACA09-4-80-332) with the U.S. Army Corps of Engineers acting on behalf of the USAF for the land located on the NAFR. Cooperative agreements between DOE and BLM (FCA N57-83-1, FCA N5-2-2) are in effect for the southwestern portion located on the Nellis Air Force Range adjacent to the Nevada Test Site. This encompasses the Exploratory Shaft site--USW ES-1.

Assumptions and Data Uncertainties: Uncertainties in the site ownership and control issue involve interagency negotiations with the USAF and the BLM over land withdrawal and restrictions.

III. QUALIFYING CONDITION

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

Evaluation: Control of the Yucca Mountain site presently resides with the DOE (the eastern portion on the Nevada Test Site), the USAF (the northwestern portion on the Nellis Air Force Range), and the BLM (the south-eastern portion). Richards and Vieth (1983) have prepared a plan, for the DOE to acquire jurisdiction over the necessary land from the BLM and USAF, and formal agreements with those Federal agencies are underway. Implementation of Congressional action necessary for permanent transfer of title to the DOE has been deferred pending selection of the site for a repository. A plan to control and limit access to the Yucca Mountain site during the operations and closure of a repository will be prepared in accordance with DOE policies and procedures limiting access to restricted areas.

Conclusion: A plan has been prepared by the DOE to effect permanent withdrawal and jurisdiction of all surface and subsurface rights for the potential repository site at Yucca Mountain; it will be implemented when a decision is made that the Yucca Mountain site is recommended for site characterization and/or selected for a repository. No impediments to eventual complete control by the DOE have been identified. Therefore, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITION

Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.

Evaluation: Control of the parcel of land where the potential repository site is located currently resides with the DOE (the Nevada Test Site portion), the USAF (the Nellis Air Force Range portion), and BLM. Permanent transfer of the required areas to the DOE, including all surface and subsurface rights, would require an act of Congress, and could be implemented following the plan prepared by Richards and Vieth (1983).

Conclusion: Presently the DOE has jurisdiction over only a portion of the Yucca Mountain site; the remaining portions are controlled by the USAF and BLM. Therefore, at the present time, the Yucca Mountain site does not possess this favorable condition. However, because the remaining portions of the proposed site are owned by the Federal government, it is anticipated that the DOE will acquire complete jurisdiction of all surface and subsurface mineral and water rights.

V. POTENTIALLY ADVERSE CONDITION

Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Evaluation: The land use and withdrawal plan prepared by Richards and Vieth (1983) shows that interagency transfers of only small tracts of land would be required. The USAF land adjacent to the western Nevada Test Site border is used occasionally as a flight corridor for military aircraft, but this activity would not impact surface or subsurface development. Because no ongoing programs of either the USAF or the BLM would be affected by land withdrawal, no barriers to agency-to-agency title transfers are expected.

Conclusion: All land in question is now owned by the Federal government and a plan to transfer the necessary land to the DOE has been prepared. No reasons for potential dispute in agency-to-agency transfers have been identified. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

6.2.1.4 Meteorology (10 CFR 960.5-2-3)

I. INTRODUCTION

The Meteorology Technical Guideline addresses the concern that radioactive releases could be preferentially transported to populated areas surrounding the repository site during operations and before repository closure. The principal objective of this preclosure guideline is to ensure that the weather conditions at the proposed site are favorable for the atmospheric dispersion of any radioactive emissions. Also of concern is the potential for extreme weather phenomena that could affect the operation and safety of the repository.

The Meteorology Guideline consists of one qualifying condition, one favorable condition, and two potentially adverse conditions. The Yucca Mountain site is evaluated with respect to all those conditions in the following sections.

II. RELEVANT DATA

Long-term measurements of meteorological data have not been collected at Yucca Mountain. A weather station was operated from 1956 to 1978 at Yucca Flat, approximately 40 km (25 mi) east of Yucca Mountain. Data from the station have been compiled covering the 18 years from 1961 through 1978 (Bowen and Egami, 1983), and the 7 years from 1957 to 1964 (Quiring, 1968). Since mid-1982, a meteorological measurement system consisting of two monitoring stations (instrumented at the 10 and 3 m levels, one on the ridge and one to the east of Yucca Mountain) has been operated by the Desert Research Institute as part of proposed site investigations. Data from this system are available (Church et al., 1983). The National Weather Service has been recording meteorological data since 1914 at Beatty, approximately 25 km (16 mi) west of Yucca Mountain. This data is on file at the National Oceanic and Atmospheric Administration (NOAA), National Climatic Center, Asheville, North Carolina.

Statistical information on severe weather and storms in southern Nevada is contained in reports by Bowen and Egami (1983), the U.S. Nuclear Regulatory Commission (NRC, 1981), the U.S. Department of Commerce (DOC, 1981b), Fujita (1981), Thom (1963), Houghton (1975), and the U.S. Department of Commerce (DOC, 1969). Regional atmospheric diffusion and dispersion characteristics are discussed by Bowen and Egami (1983), Holzworth (1972), and the U.S. Department of Commerce (DOC, 1970).

Assumptions and Data Uncertainties: Much of the available meteorological data is not site specific. However, the Yucca Flat and Beatty measurement stations are close enough to Yucca Mountain that their data should be representative of regional conditions. Terrain-induced diurnal wind flow patterns are very localized and would not contribute significantly to regional atmospheric dispersion. The regional-scale winds, which primarily influence long-range transport, should be adequately represented by the available data.

The historical information on severe weather and storms is based on data from a relatively sparse distribution of observation stations in the region; the frequency of occurrence of these phenomena could be slightly underestimated. Because the observed frequency is low, it is unlikely that the error is significant.

III. QUALIFYING CONDITION

The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

Evaluation: Records of historical meteorological data for Yucca Flat and Beatty, combined with statistical evaluations of severe weather phenomena, indicate that occurrences of severe weather are infrequent and would not be expected to significantly affect repository construction, operation, or closure. Deep atmospheric mixing in the region would contribute to effective dispersion of airborne radionuclides. Prevailing wind directions are variable, and would not cause preferential airborne transport toward regional population centers. Extreme weather phenomena are rare in the vicinity of the proposed repository site, except for sandstorms and occasional heavy precipitation which may cause localized flash flooding (see Section 6.3.3.3). However, available engineering and technology is considered adequate to guarantee that the public health and safety is protected.

Conclusion: No severe meteorological conditions have been recorded or are expected to occur in the region that would contribute to radionuclide releases greater than those allowable under the requirements specified in Section 960.5-1(a)(1) to an unrestricted area. Therefore, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITION

Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.

Evaluation: Wind conditions should result in effective atmospheric dispersion at the proposed site because they would be similar to those measured at Yucca Flat, even though patterns will vary somewhat with altitude. Relatively high average wind speeds have been measured at Yucca Flat [13.2 km/h (8.2 mph) averaged over an 18-year period of record]. Calculations prepared by Holzworth (1972) indicate that extreme limitations to atmospheric dispersion should rarely occur over the proposed repository site. Isopleths of mean annual mixing heights (Holzworth, 1972) show that the region surrounding the proposed site experiences some of the deepest atmospheric mixing layers in the United States.

Conclusion: Wind flow patterns and atmospheric diffusion characteristics in the region of the proposed site will contribute to the effective dispersion of radionuclide releases. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Prevailing meteorological conditions such that radioactive emissions from repository operation or closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.

Evaluation: Because of the sparse distribution of cities and towns in southern Nevada, establishing an average population density is difficult. In addition, some of the small towns close to Yucca Mountain may experience population increases if it is selected as a repository site. For these reasons, it is prudent to assess the likelihood of preferential atmospheric transport toward the smaller nearby towns as well as the larger cities in the region. The nearest city with a higher than average population density is Las Vegas (population 463,087) (DOC, 1980), which is located approximately 150 km (95 mi) southeast of the site. The 15-year meteorological record at Yucca Flat (Bowen and Egami, 1983) reveals that northwest winds (which would transport material to the southeast) have occurred less than 10 percent of the time on the average. The town of Beatty (population 900) (DOC, 1980) is located approximately 26 km (16 mi) west of the site. The Yucca Flat meteorological data indicates that winds which would transport material to the west are very infrequent.

Conclusion: Regional meteorological flow patterns will not cause the preferential transport of radioactive releases from the site toward regional population centers. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) History of extreme weather phenomena--such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms--that could significantly affect repository operation or closure.

Evaluation: Historically severe weather in the proposed repository area includes high winds, thunderstorms, tornadoes, hail, and sandstorms. Thunderstorms have been observed on the average of 14 days per year at Yucca Flat (Bowen and Egami, 1983). Significant lightning strikes have averaged only

18 per year for the entire State of Nevada (NRC, 1981). Tornadoes are very rare in Nevada, with the probability of a tornado striking Yucca Mountain calculated to be 7.5 x 10^{-4} per year (Thom, 1963). Hail with a diameter of 1.9 cm (0.75 in.) or larger was observed on 7 days in Nevada between 1955 and 1967 (DOC, 1969). Sandstorms are common but rarely severe in Nevada. Annual average snowfall at Yucca Flat is 21 cm (8.3 in.) (Bowen and Egami, 1983). Data for Beatty indicates a return period of 25 years for occurence of a 24-hour precipitation event greater than 2 in.

Conclusion: Available statistical summaries reveal that the Yucca Mountain area has one of the lowest frequencies of occurrence of extreme weather in the United States. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

6.2.1.5 Offsite installations and operations (10 CFR 960.5-2-4)

I. INTRODUCTION

The Offsite Installations and Operations Technical Guideline is one of several preclosure technical guidelines included under the heading preclosure radiological safety. The objectives of this guideline are (1) to ensure that the impacts of nearby activities upon a repository during the preclosure period are adequately considered and (2) to ensure that any radionuclide emissions from nearby activities, when combined with emissions that might occur from repository operations, do not exceed regulatory limits.

The Offsite Installations and Operations Guideline consists of one qualifying condition, one favorable condition, and two potentially adverse conditions. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

Installations and operations adjacent to Yucca Mountain are the Nevada Test Site on the east and Nellis Air Force Range (NAFR) to the northwest. The primary mission of the Nevada Test Site is the underground testing of nuclear devices. Nuclear test yields are limited to a maximum of 150 kilotons by the Threshold Test Ban Treaty and the Treaty on Underground Nuclear Explosions for Peaceful Purposes (Vortman, 1979). The number of nuclear tests has been averaging 10 to 12 per year and is expected to remain at that level for the foreseeable future (DOE/NVO, 1983b). At present, tests are conducted at Yucca Flat, Rainier Mesa, and Pahute Mesa (see Figure 6.2.1.5-1). Yucca Flat has a yield limit (based on potential of damage to offsite facilities) of about 250 kilotons and Pahute Mesa has a 1000 kiloton limit (Vortman, 1979). Buckboard Mesa, a potential test area, has a 700 kiloton yield limit (Vortman, 1979). The yield limit for Mid Valley, another potential test area, is likely to be similar to that for Yucca Flat.

Underground nuclear explosions generate seismic energy and resultant ground motion comparable, but not equivalent, to that generated by natural

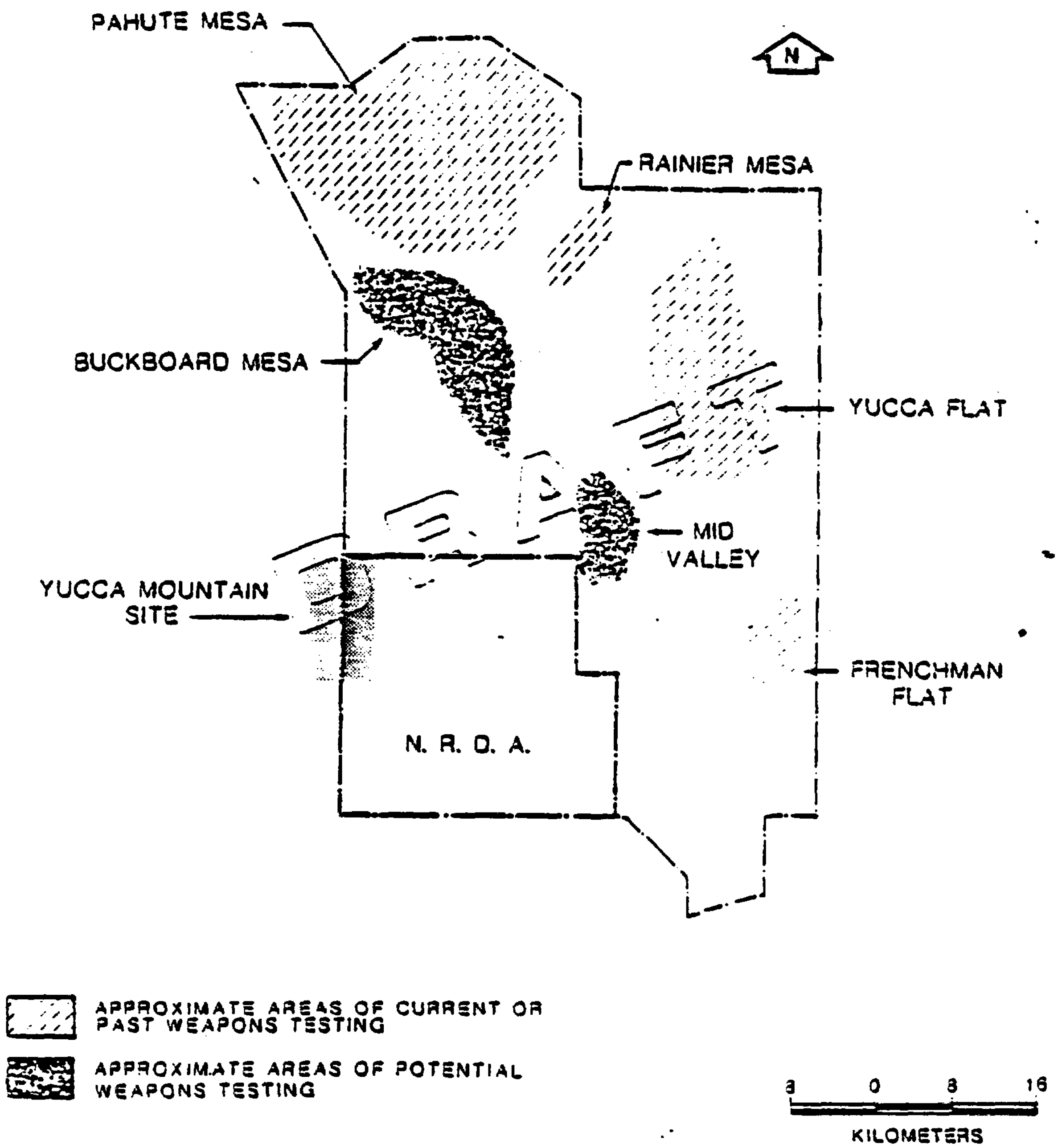

Figure 6.2.1.5-1. Past, current, or potential future weapons testing areas on the Nevada Test Site.

earthquakes. The ground motion produced by underground nuclear explosions has been extensively investigated by the Environmental Research Corporation (ERC, 1974) and by Vortman (1979, 1980, 1982a, 1982b, 1982c, and 1983). Because of a concern for offsite damage, equations have been developed to predict ground motion from underground nuclear explosions at Pahute Mesa and Yucca Flat where nuclear tests are routinely conducted (ERC, 1974). These test areas are 41 to 56 km (25 to 35 mi) north and east of Yucca Mountain.

Data collected from underground nuclear tests conducted since 1971 indicate that radiological emissions from underground nuclear tests can be contained (ERDA, 1977). Onsite sampling for airborne tritium and *noble* gases shows that average concentrations of tritium and xenon-133 are slightly higher than ambient offsite levels (Scoggins, 1983). The tritium enters the atmosphere by evaporation from soil moisture in and around past experimental areas, from holding ponds that receive water drained from tunnel areas, and from gas seepage. Xenon-133 may be released in small quantities as it seeps upward to the surface from underground detonation points. Postshot reentry drilling operations may release small quantities of radioactive noble gases. However, for the most recent reporting period, (Black et al., 1983) detectable levels of radioactivity from the nuclear test program were not observed by any of the monitoring networks.

A commercial low-level waste burial site is located about 30 km (19 mi) west of Yucca Mountain near Beatty, where radiation monitoring is conducted continuously by the Environmental Protection Agency (Black et al., 1983).

The NAFR is used primarily for aerial bombing and gunnery practice. The Tonopah Test Range, an area of 1,615 km^2 (600 mi^2) located in the northwestern part of the Nellis Air Force Range, is operated for the DOE by Sandia National Laboratories primarily for airdrop tests of ballistic shapes (ERDA, 1975a).

Assumptions and Data Uncertainties: It is possible that future underground nuclear tests will be conducted on the Nevada Test Site at places other than Pahute Mesa, Rainier Mesa, and Yucca Flat. Two possible places that have been identified are the Buckboard Mesa area which is 23 to 37 km (14 to 23 mi) from Yucca Mountain, and Mid Valley, which is 25 to 30 km (16 to 19 mi).

Vortman (1980) concluded that a given size of underground nuclear test in the Buckboard Mesa area would produce about the same ground motion as would result from the same-size test on Pahute Mesa because the rock properties that control ground motion are similar at the two locations. However, ground motion at Yucca Mountain resulting from Buckboard Mesa area tests would be greater than from tests at Pahute Mesa because Buckboard Mesa is closer to Yucca Mountain. Similarly, tests at Mid Valley would produce greater ground motion at Yucca Mountain than would be caused by the same size test at Yucca Flat, because Mid Valley is closer to the potential repository site at Yucca Mountain.

No new industrial or defense-related activities are planned in the vicinity of Yucca Mountain.

III. QUALIFYING CONDITION

The site shall be located such that present and projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository construction, operation, or closure or can be accommodated by engineering measures and (2), when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

Evaluation: A repository at Yucca Mountain will be designed and constructed to withstand the ground motion predicted from nuclear weapons testing at the Nevada Test Site and from natural earthquakes. Design of earthquake-resistant structures will incorporate engineering experience and consider the maximum potential natural or induced ground motion. There were no detectable offsite radionuclide releases from the Nevada Test Site or from the Beatty low-level waste disposal site during the most recent monitoring period (Black et al., 1983). The portion of NAFR near Yucca Mountain is used only occasionally for military aircraft overflights. These overflights will increase noise in the area, and there is a remote chance that an airplane might crash at the site.

<u>Conclusion:</u> Nearby industrial and military installations and operations will not significantly affect a potential repository at Yucca Mountain during construction, operation, or closure. Short-term interruption of activities at a repository by weapons tests is not considered a significant effect. Any potential emissions from a repository during operation and closure, in combination with those that might occur from activities at the Nevada Test Site, will not lead to radionuclide releases to an unrestricted area greater than allowable under present regulations. Therefore, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITION

<u>Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.</u>

<u>Evaluation:</u> The regulation 40 CFR 191, Subpart A, applies to radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel and high-level radioactive wastes. The nuclear activities at the Nevada Test Site are defense related and are not controlled by 40 CFR 191, Subpart A. These activities and conditions under which radionuclide releases could occur are described in the the Nevada Test Site Final Environmental Impact Statement (ERDA, 1977). Releases from these nuclear activities are governed by DOE Order 5480.1, Standards for Radiation Protection (DOE, 1981).

<u>Conclusion:</u> No nearby nuclear installations or operations regulated by 40 CFR 191, Subpart A, exist in the region surrounding the Yucca Mountain site. On very infrequent occasions, underground nuclear explosions at the Nevada Test Site release small amounts of radioactivity to the atmosphere. None of this radioactivity was detected off the site in the most recent monitoring period (Black et al., 1983). In addition, 40 CFR 191, Subpart A, does not apply to releases from underground nuclear explosions. Therefore, the Yucca Mountain site possesses this favorable condition.

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V. POTENTIALLY ADVERSE CONDITIONS

(1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.

Evaluation: The portion of the Nellis Air Force Range near Yucca Mountain is used only rarely for military aircraft overflights enroute to and from target areas. The impact upon a repository from such overflights would be increased noise levels and a remote chance of an airplane crash at the site.

The primary mission of the Nevada Test Site is the underground testing of nuclear weapons. Much of the data regarding weapon tests at the Nevada Test Site is classified, but based on the limited information available (DOE/NVO, 1983b), two or three nuclear tests per year may require temporary suspension of repository activities, usually not exceeding 12 hours. The DOE exercises control over the schedule of activities at the Nevada Test Site, thereby allowing compatible arrangements for nuclear testing and repository construction-operation activities. Removal of workers from the underground facility would be a standard industrial practice to guarantee safety of workers. The infrequency and short duration of the removal of workers from the facility is not expected to affect repository construction, operation, or closure. The removal of workers is not likely to include repository surface facilities, and waste packages could simply be stored on the surface for a slightly longer period while the underground facility is closed.

If a nuclear waste repository is built at Yucca Mountain, it must be built to withstand the ground motion from natural earthquakes and from underground nuclear explosions. An acceleration-prediction equation has been developed based on experimental data from 21 tests at Pahute Mesa (Vortman, 1980). Using the equation, the predicted mean peak vector ground acceleration at Yucca Mountain from underground nuclear explosions at the maximum allowable yield [250 kilotons at Yucca Flat (36 km from Yucca Mountain), 1000 kilotons at Pahute Mesa (41 km from Yucca Mountain), and 700 kilotons at Buckboard Mesa (23-27 km from Yucca Mountain) based on offsite damage restrictions], is 0.061 g. The mean ground acceleration plus three standard deviations (99 percent of all probable values) based on the preceding value of predicted mean peak vector ground acceleration, is 0.32 g. The mean plus three standard deviations is a very conservative design criterion, because nuclear reactor siting requires only mean ground acceleration plus one standard deviation (68 percent of all probable values) (Vortman, 1980). In addition, these yields and resultant ground accelerations are well above the values that could be experienced at Yucca Mountain under the current 150 kiloton yield limit imposed by the Threshold Test Ban Treaty.

An estimate of the seismic hazard for Yucca Mountain has been made (Carr et al., 1984) using methods like those described in Rogers et al. (1977). The analysis shows that an earthquake occurring on the 17-km (11-mi) long Bare Mountain fault with a credible maximum magnitude of 6.8 on the Richter Scale would produce a maximum ground acceleration at the Yucca Mountain site of about 0.4 g. Therefore, the maximum acceleration expected due to natural earthquakes is comparable to the mean plus three sigma peak vector ground acceleration (0.32 g) produced by underground explosions at the maximum allowable yields for testing areas on the Nevada Test Site. This value exceeds the accelerations expected from nuclear tests currently allowed by the Threshold Test Ban Treaty. The repository facilities will be designed to withstand the maximum credible ground acceleration expected at Yucca Mountain.

Conclusion: There is no indication that present or projected activities on the Nevada Test Site and Nellis Air Force Range will adversely affect repository operation or closure. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) Presence of other nuclear installations and operations subject to the requirements of 40 CFR Part 190 or 40 CFR Part 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.

Evaluation: The provisions of 40 CFR 190 apply to (a) radiation doses received by members of the public and (b) radioactive materials introduced into the general environment as a result of nuclear fuel cycle operations. The nuclear fuel cycle includes operations associated with producing electrical power for public use through nuclear energy, but it does not include waste management activities. Subpart A of 40 CFR 191 applies to radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel and high-level radioactive wastes, to the extent that these operations are not subject to the provisions of 40 CFR 190.

Neither regulation applies to the nuclear weapons testing at the Nevada Test Site, nor to the low-level radioactive waste disposal site, 30 km (19 mi) west of Yucca Mountain near Beatty.

The Environmental Protection Agency conducts an Offsite Radiological Safety Program, which includes monitoring of the Nevada Test Site. This program uses several monitoring networks for measuring radioactivity and radiation levels in the site environs. Detectable levels of radioactivity were not observed off the site during 1982 (the most recent year for which data are available) by any of the monitoring networks. About 165 Ci of tritium and 80 Ci of radioactive xenon were released to the air in 1982 from reentry drilling, but these releases were not detected off the site because of the large distance from the release point to the nearest offsite sampling station (Black et al., 1983).

Conclusion: There are no nuclear installations or operations in the vicinity of the Yucca Mountain site with potential releases governed by 40 CFR 190 or 40 CFR 191, Subpart A. No underground tests designed for containment have resulted in exposure to offsite residents (ERDA, 1977). Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

6.2.1.6 Environmental quality (10 CFR 960.5-2-5)

I. INTRODUCTION

The preclosure Environmental Quality Technical Guideline is concerned with protection of the health and safety of the public and the quality of the environment throughout all stages of the geologic-repository program.

The Environmental Quality Guideline contains one qualifying condition, two favorable conditions, six potentially adverse conditions, and three disqualifying conditions. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

The following information was used to evaluate the Yucca Mountain site against the Environmental Quality Guideline: (1) published reports describing the archaeology, biology, hydrology, meteorology, and radiology of the Yucca Mountain area (see Chapter 3); (2) a preliminary investigation of the regulatory requirements that could apply to a repository at Yucca Mountain (see Favorable Condition (1)); (3) a variety of land-status maps published by the State of Nevada and by the Bureau of Land Management [see Potentially Adverse Condition (2)]; and (4) the results of analyses in Chapter 5 that describe the expected near- and long-term environmental consequences if a nuclear waste repository were constructed, operated, and decommissioned at Yucca Mountain.

Assumptions and Data Uncertainties. Assumptions and uncertainties in the data used to evaluate the Environmental Quality Guideline are a result of having only preliminary design studies available for a conceptual nuclear waste repository at Yucca Mountain (see Chapter 5). Because only preliminary information is available for the design and operation of a repository at Yucca Mountain, the evaluation of impacts to the health and safety of the public and to the environment must also be considered preliminary. Specific assumptions and uncertainties in the data used to evaluate this Technical Guideline are described in Chapter 5.

Assessing the significance of environmental impacts from any large project has inherent uncertainties related to (1) the preliminary nature of the conceptual design; and (2) the uncertainties in the criteria and the validity of the assumptions used to evaluate the significance of the environmental impacts. In general, easily verifiable impacts, such as the conflict of a site with Federally protected lands, can be evaluated with a high degree of certainty because the significance of the impact is defined clearly in this Technical Guideline. In contrast, the estimated significance of impacts to biotic communities or to ground water from constructing and operating a repository is generally less certain. Because of these uncertainties, the judgment of environmental specialists is the only way to estimate the significance of potential environmental impacts that cannot be defined precisely. These uncertainties will be minimized through ongoing investigations, the results of which will be described in environmental impact statements if Yucca Mountain is selected as a repository site.

III. QUALIFYING CONDITION

The site shall be located such that (1) the health and welfare of the public and the quality of the environment in the affected area during this and future generations will be protected during repository siting, construction, operation, closure, and decommissioning; (2) projected significant adverse environmental impacts in the affected area can be mitigated to the extent practicable, taking into account technical, social, economic, and environmental factors; and (3) the requirements specified in Section 960.5-1(a)(2), can be met.

Evaluation: To investigate adverse environmental impacts that would result from the construction, operation, and decommissioning of a repository at Yucca Mountain, an evaluation of the results of preliminary environmental studies was undertaken. On the basis of these current studies and an understanding of the Yucca Mountain site, it appears that the health and welfare of the public and the quality of the environment can be protected for this generation and future generations. Furthermore, on the basis of these preliminary studies, there are no potentially significant adverse environmental impacts that will result from the construction, operation, and decommissioning of a repository at Yucca Mountain.

Adequate time exists to incorporate all applicable Federal, State, and local environmental requirements into the repository design. Therefore, no major conflict with these requirements is expected. The adverse environmental impacts expected from constructing, operating, and decommissioning a repository at Yucca Mountain can either be avoided or mitigated to an insignificant level by relatively inexpensive methods. The proposed repository and its supporting facilities, including a rail line and roads, would not result in any significant adverse environmental impacts to Federal or State-protected lands nor would facilities impact any known threatened or endangered species or their habitats.

Conclusion: The health and welfare of the public and the quality of the environment can be protected during construction, operation, and closure of a repository at the Yucca Mountain site. No projected significant adverse impacts have been identified. The requirements specified in 960.5-1(a)(2) are expected to be met without undue difficulty. Therefore, the Yucca Mountain site meets this qualifying condition.

IV. FAVORABLE CONDITIONS

(1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.

Evaluation: The repository design process will take into account all requirements and criteria set forth in the Nuclear Waste Policy Act of 1982. Because of the time available, there is no reason to believe that the DOE will not be able to make the repository design comply with all the requirements and obtain all the necessary permits. The repository will be designed to meet all applicable Federal environmental laws, regulations, and executive orders, as well as all State and local environmental requirements.

A preliminary list of laws and other legal requirements expected to apply to a repository at the Yucca Mountain site has been developed. In some instances, the law cited requires that the DOE obtain several different types of permits; in other instances the requirements of the law are that the DOE consult with or notify the appropriate agency. Local requirements have not yet been determined. Identified Federal and State laws, regulations, and requirements for a repository at Yucca Mountain include the following:

1. <u>Waste-related laws and regulations (hazardous and solid waste)</u>

   Nuclear Waste Policy Act; Hazardous Materials Transportation Act; Resource Conservation and Recovery Act; Nevada regulations governing solid waste management and individual sewage systems (Nevada Revised Statutes, Chapters 444.440 through 444.620); State Radiation Control, Nevada Revised Statutes, Chapter 706.441,4.

2. <u>Land-related laws and regulations</u>

   Federal Land Policy and Management Act; Materials Act; Fish and Wildlife Coordination Act; National Wildlife Refuge Systems Administration Act; Department of Transportation Act; Nevada land-related regulations (Nevada Revised Statutes, Chapters 459.010 through 459.290; 444.700 through 444.778, 512.160, 535, 278, 322, 439.200, 444, 445, and 446).

3. <u>Air-related laws and regulations</u>

   Clean Air Act; Nevada air quality regulations (Nevada Revised Statutes, Chapters 445.401 through 445.601).

4. <u>Water-related laws and regulations</u>

   Clean Water Act; Safe Drinking Water Act; Federal Land Policy and Management Act; National Wildlife Refuge Systems Administration Act; Endangered Species Act; Wilderness Act; Nevada's water pollution control regulations and regulations concerning public water supply and public water systems (Nevada Revised Statutes, Chapters 445.131 through 445.354, 533, and 534).

5. Biologic-related laws and regulations

Endangered Species Act; Federal Land Management and Policy Act; Nevada wildlife regulations (Nevada Administrative Code 504.510 through 504.550).

6. Historic- or archaeologic-related laws and regulations

Archaeological Resources Preservation Act; National Historic Preservation Act; National Trails System Act.

7. Other laws and regulations

Federal Aviation Act; Nevada regulations concerning occupational health and safety (Nevada Revised Statute 618).

Conclusion: All Federal, State, and local environmental requirements that apply to this project will be met prior to initiation of construction. Therefore, the Yucca Mountain site possesses this favorable condition.

(2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account technical, social, economic, and environmental factors.

Evaluation: The adverse environmental impacts associated with construction, operation, and decommissioning of a repository at Yucca Mountain are described in Chapter 5 of this Environmental Assessment. These impacts include (1) destruction of approximately 370 ha (900 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. Release of radionuclides to the ground water in excess of limits set by 40 CFR 191 is not expected to occur during operation or for thousands of years after decommissioning (see Section 6.4.2). The significance of impacts to the biota from constructing and operating a repository at Yucca Mountain are described in the evaluation of Potentially Adverse Condition (6).

Emissions of fugitive dust will result from surface preparation and manipulation of the excavated rock and earth during construction, operation, and backfilling of the repository. Dust emissions will also result from the disturbance of approximately 250 ha (620 acres) during construction of a railroad to the repository, and from the disturbance of 36 ha (90 acres) during construction of an access road from U.S. 95 north to the site. 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 repository operation, increase again during backfilling, and will be least during decommissioning.

During construction, the maximum estimated ambient concentrations of carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen should not exceed the air-quality limits of 40 CFR 50 at the boundary of the controlled area. The maximum estimated concentration of suspended particulates at the point of nearest human habitation, assuming no dust suppression measures are used, is estimated at 28 micrograms per cubic meter (see evaluation of disqualifying conditions). This impact is below the ambient air-quality standards for fugitive dust specified in 40 CFR 50 which indicates a maximum allowable 24-hr concentration of 260 micrograms per cubic meter should not be exceeded more than once per year. Because dust suppression measures are expected to be used, actual particulate concentrations would be reduced to an insignificant level.

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 excavated soil and rock. During construction, exposure of the surrounding population to these emissions would result in a population whole-body dose of about 5 man-rem for the horizontal emplacement option and 12 man-rem for the vertical emplacement option. The dose to this same population from natural background sources per year would be about 0.37 to 0.39 man-rem (Dennis, 1984). 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 identified as having the most severe radiological consequences is a transportation accident and fire, either in the waste handling ramp or in the repository emplacement drift. Radioactive materials released from such an accident would result in an estimates whole-body equivalent dose to the general population of 1.3×10^{-7} man-rem. The worst-case accident not resulting from operations is an aircraft impact accident which would result in an estimated population dose of 120 man-rem. Dose from this accident to the maximally exposed individual at a postulated exclusion boundary located 4 km (2.5 mi) from the facilities would be about 9.6×10^{-9} rem for the transporation accident and 0.3 rem for the aircraft accident. The individual doses are below the 10 CFR 60 exposure limit for individuals of 0.5 rem per accident, and the population dose is small compared with the dose to the same population over one year from natural background sources (about 1790 man-rem) (Jackson, 1984a).

Conclusion: The adverse environmental impacts expected from constructing, operating, and decommissioning a repository at Yucca Mountain are either insignificant or can be mitigated to an insignificant level by relatively inexpensive methods. Therefore, the Yucca Mountain site meets this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Projected major conflict with applicable Federal, State, or local environmental requirements.

Evaluation: No major conflict with applicable Federal, State, or local environmental requirements is expected since the design process for the proposed repository will take all such requirements into account. The DOE will be required to obtain all necessary permits. A list of the regulations expected to apply to repository siting is given under the evaluation of the Qualifying Condition.

Conclusion: It is anticipated that all the Federal, State, and local environmental requirements that are necessary for this project will be satisfied. Therefore, the Yucca Mountain does not possess this potentially adverse condition.

(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.

Evaluation: The basis for concluding that the environmental impacts that would stem from locating a repository at Yucca Mountain can be mitigated and/or avoided are described above in the evaluation sections of Favorable Condition (2) and Potentially Adverse Condition (6).

Conclusion: All adverse environmental impacts expected from constructing, operating, and decommissioning a repository can be mitigated or avoided. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.

Evaluation: The surface and underground facilities at Yucca Mountain would be located entirely on Federal lands currently administered by the DOE and the U.S. Air Force and on public-domain lands under the jurisdiction of the Bureau of Land Management. Site ownership and control are detailed in Sections 6.2.1.1 and 6.2.1.3. As noted, the proposed facilities will have no impact on Federal lands that are protected for environmental reasons.

If a repository is located at Yucca Mountain, a railroad would be constructed from Yucca Mountain to a point a few miles northeast of Las Vegas (see map of probable rail routing, Chapter 5). At some points, the rail line would be within a few miles of the southern boundary of the Desert National Wildlife Range administered by the U.S. Fish and Wildlife Service (Lutsey and Nichols, 1972). Large parts of the Wildlife Range are administratively endorsed as suitable for inclusion in the National Wilderness Preservation System (BLM, 1981). The impacts to the Desert National Wildlife Range from construction and operation of the rail line, even if parts of this area are ultimately included in the Wilderness Preservation System, are expected to be minor. This is because (1) the rail line will not traverse lands within the Wildlife Refuge and (2) the rail line would be constructed across the alluvial fan at the base of Sheep Mountain where it would have relatively little, if any, effect on the animals and people that use the Wildlife Range.

Two wilderness study areas (WSAs) administered by the BLM are contiguous with the southern part of the Desert National Wildlife Range (BLM, 1982). If Yucca Mountain were eventually chosen as the site of the first repository and if, at that time, the two areas are still being managed by the BLM as potential wilderness areas, it would probably be required that the rail line be built south of these WSAs. But because these study areas are not a component of the National Wilderness Preservation System, impacts to them are not presently an issue.

The boundary of Death Valley National Monument lies approximately 30 to 40 km (20 to 25 mi) 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 could result in some effect on 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 proposed repository site would be approximately 8 km (5 mi) south of the Timber Mountain Caldera National Natural Landmark. 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 Range and the Nevada Test Site and access is restricted.

Devil's Hole, located in Ash Meadows about 50 km (30 mi) from Yucca Mountain contains several Federally protected endangered species of pupfish. The U.S. Fish and Wildlife Service has designated 11 springs and their outflow channels plus immediately adjacent land areas as critical habitat for the pupfish. Construction and operation of a repository at Yucca Mountain will not affect the outflow of these springs (Dudley and Larson, 1976; Waddell, 1982). In a recent development, the U.S. Fish and Wildlife Service proposed to purchase land in the Ash Meadows area from The Nature Conservancy (USFWS, 1984). The entire area could then become a National Wildlife Refuge. Potential environmental impacts to this refuge from repository workers are projected to be negligible because land use in the area would be restricted by the U.S. Fish and Wildlife Service.

Conclusions: The proposed repository and its supporting facilities (including a railroad line that would be constructed in southern Nevada and a paved road that would be constructed from U.S. 95 northward to Yucca Mountain) would not result in any significant adverse environmental impacts to Federally protected lands such as parks, monuments, recreation areas, wildlife areas, wilderness areas, or lands administered by the U.S. Forest Service. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.

Evaluation: The surface and underground facilities at Yucca Mountain would be located entirely on Federal lands administered by the U.S. Department of Energy, the U.S. Air Force, and public-domain lands under the jurisdiction of the Bureau of Land Management (Lutsey and Nichols, 1972). Sections 6.2.1.1 and 6.2.1.3 discuss site ownership and control in detail. If a repository were constructed at Yucca Mountain, a 142 km (85-mi) rail line would be built to the site from Dike Siding a few miles northeast of Las Vegas. The rail line would pass approximately 2 km (1 mi) north of Floyd R. Lamb State Park (formerly called Tule Springs Park; Secs. 3, 4, and 9, T 19 S, R 60 E). Composite annual day/night (L_{dn}) noise levels in the park from both construction and operation of the rail line will be below EPA limits. Therefore, significant adverse impacts to this State Park are not anticipated from the construction and operation of a rail line in this area.

Conclusion: The repository and its supporting facilities (including a railroad that would be constructed in southern Nevada and a paved road that would be constructed from U.S. 95 northward to Yucca Mountain) would not pose significant adverse environmental impacts to State protected lands, such as parks, recreation areas, or wildlife areas. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

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(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.

Evaluation: Most of the Yucca Mountain site has been surveyed for cultural artifacts by Pippin et al. (1982). A total of 178 prehistoric and 6 historic sites were discovered, many of which consist of only flakes and scattered debris. Archaeological surveys have not yet been conducted along the railroad corridor or along the paved road that would be constructed to Yucca Mountain from U.S. Highway 95.

Artifacts at those sites that cannot be preserved during construction or that cannot be protected during operations will, upon approval of the Nevada State Historic Preservation Office, be collected and (or) catalogued. These artifacts, along with the physical circumstances of their occurrence, can then be displayed and described in museums. Thus, although some sites may be affected during construction of the repository, the artifacts and information contained at these sites will be recorded and (or) preserved.

Conclusion: Construction and operation of the repository is not expected to have a significant impact on cultural resources in this region.

Although some archaeological and historical sites may be affected during construction of the proposed repository, the Nevada State Historical Preservation Office will be informed before construction begins so that artifacts at these sites can be collected and (or) catalogued. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.

Evaluation: Approximately 370 ha (900 acres) of land will be cleared during repository construction and operation and during construction of the supporting transportation facilities in southern Nevada (see Chapter 5). 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, found in the Yucca Mountain area by O'Farrell and Collins (1983), 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. These species are the Mojave fishhook cactus (Sclerocactus polyancistrus) and the desert tortoise (Gopherus agassizi). On the basis of field surveys conducted by O'Farrell and Collins (1983), populations of the cactus do not coincide with areas where the surface facilities would be constructed. Also, preliminary analyses show that population densities of the desert tortoise are low in the Yucca Mountain area compared with other areas in the southwest United States (O'Farrell and Collins, 1983). During repository construction and operation individual tortoises may be transported from the disturbed areas to remote undisturbed locations. The survival of these transported individuals, however, is uncertain, and some of the habitat for the species would be destroyed during construction of the repository. Efforts will be made to avoid dense populations of the cactus and important habitat for the tortoise consistent with economic and safety considerations.

As discussed in the evaluation section for Potentially Adverse Condition (3), the U.S. Fish and Wildlife Service is in the process of designating 11 springs and their outflow channels in Ash Meadows, plus the land that is immediately adjacent to these springs, as critical habitat for two proposed endangered species of pupfish. As described in Chapter 5, repository construction and operation at Yucca Mountain should not affect the outflow of these springs, which are about 50 km (30 mi) from Yucca Mountain. Recent developments suggest that a large part of Ash Meadows will eventually be included in the National Wildlife Refuge System (USFWS, 1984). Therefore, repository employees are unlikely to be allowed to settle in Ash Meadows in large numbers. This land-use restriction should adequately protect the pupfish habitat.

Conclusion: The repository or its supporting facilities are not expected to have a significant adverse impact on the two species proposed as threatened or endangered, and land-use restrictions in Ash Meadows will be sufficient to protect the habitat of the pupfish. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

VI. DISQUALIFYING CONDITIONS

There are three disqualifying conditions with regard to environmental quality. The disqualifying conditions in this guideline (stated below) are evaluated together to avoid repetition. Separate conclusions are given for each disqualifying condition.

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.

Evaluation: The adverse environmental impacts that may be associated with construction, operation, and/or decommissioning of a repository at Yucca Mountain include (1) disruption of approximately 370 ha (900 acres) of desert habitat, (2) fugitive dust emissions, (3) vehicle emissions, and (4) radiological releases during excavation and operation of the repository and from accidents at the repository. Release of radionuclides to the ground water in excess of limits set by 40 CFR 191 is not expected to occur during construction, operation, and closure (see Section 6.3.2).

Approximately 370 ha (900 acres) of land will be cleared during repository construction and operation and during construction of the supporting transportation facilities in southern Nevada. Surveys to date (O'Farrell and Collins, 1983) indicate that no threatened or endangered plant or animal species, or their critical habitats, occur in the immediate Yucca Mountain area. However, two species found in the Yucca Mountain area 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. These species are the Mojave fishhook cactus (*Sclerocactus polyancistrus*) and the desert tortoise (*Gopherus agassizi*). On the basis of preliminary analyses, populations of the cactus do not occur in areas that will be used for surface facilities. Preliminary analyses also show that population densities of the desert tortoise are low in the area of the Yucca Mountain site and tens of thousands of acres of undisturbed habitat will surround the repository site. During repository construction and operation individual tortoises may be transported to remote undisturbed locations. Where possible, populations of the cactus and locations of known turtle habitat identified during preconstruction surveys will be avoided.

Fugitive dust emissions will result from surface preparation, excavation, and manipulation of the excavated earth and rocks during construction, operation, and backfilling. Dust emissions will also result from the disturbance of approximately 250 ha (620 acres) during the construction of a railroad line to the repository and disturbance of 36 ha (90 acres) during construction of an access road to the site from U.S. 95. Dust emissions during construction are not expected to exceed 8 metric tons/day, which would result in an estimated maximum ambient concentration of 28 micrograms per cubic meter and a deposition rate of 0.19 gram per square meter per year at the nearest point of human habitation, approximately 26 km (16 miles) from the site. This concentration is below the ambient air quality standard for fugitive dust specified in 40 CFR 50, which indicates a maximum allowable 24 hour concentration of 260 micrograms per cubic meter should not be exceeded more than once per year. Because dust-suppression measures are expected to be used actual ambient concentrations and deposition rates will be less.

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, increase again during backfilling, and will be least during decommissioning. During construction, the maximum estimated ambient concentrations of carbon monoxide at the boundary of the controlled area are not expected to exceed air-quality limits specified in 40 CFR 50.

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 excavated rock and earth. During construction, exposure of the surrounding population to these emissions would result in a population whole-body dose of about 5 man-rem for the horizontal waste emplacement option and 12 man-rem for the vertical emplacement option. The estimated annual background radiation dose to a population of 4600 people within 80 km (50 mi) of the Nevada Test Site is 410 man-rem (Black et al., 1983). Estimated routine releases from radon in the excavated rock and earth during backfilling are expected to be negligible. On the basis of these estimates, the environmental impact from radiological releases during normal significant.

The operational accident identified as having the most severe radiological consequences is a transportation accident and fire, either on the waste handling ramp or in the repository emplacement drift. Radioactive materials released from such an accident would result in an estimated whole-body equivalent dose to the general population of 0.06 man-rem. The worst-case accident not resulting from operations is an aircraft impact accident, which would result in an estimated population dose of 120 man-rem. Doses to the maximally exposed individual at a postulated exclusion boundary located 4 km (2.5 mi) from the transportation and aircraft impact accidents would be about 9.6×10^{-9} and 0.3 rem, respectively. The individual doses are below the 10 CFR 60 exposure limit for individuals of 0.5 rem per accident, and the population dose is small compared with the annual population dose from natural background sources (about 1790 man-rem to a population of 19,908 people within a 80-km (50-mi) radius) (Jackson, 1984b).

The surface and underground facilities at Yucca Mountain would be located entirely on Federal lands administered by the Department of Energy and U.S. Air Force, and public-domain lands under the jurisdiction of the Bureau of Land Management. None of these Federal lands are protected for environmental reasons. A railroad would be constructed from Dike Siding, a point a few miles northeast of Las Vegas, to Yucca Mountain. 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 administered by the U.S. Fish and Wildlife Service. Part of this wildlife range has been proposed for inclusion in the National Wilderness Preservation System. The impacts to the animals and to the management of the wildlife range that may result from the construction and operation of the railroad, even assuming that part of the range is ultimately included in the Wilderness Preservation System, are expected to be insignificant because the railroad will not cross the range. It will be constructed across the alluvial fan at the base of Sheep Mountain where it will not adversely effect animals or people that use the range. Therefore, there are no irreconcilable conflicts with current or proposed use of the Desert National Wildlife Range.

The boundary of Death Valley National Monument lies approximately 32 to 40 km (20 to 25 mi) west and southwest of the Yucca Mountain site. 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. Devil's Hole hot spring, located in Ash Meadows contains several Federally protected endangered species of pupfish. The U.S. Fish and Wildlife Service has designated 11 springs and the spring outflow channels plus immediately adjacent land areas in Ash Meadows as critical habitat for two additional subspecies of pupfish. The outflow of these springs will not be affected by construction and operation of a repository at Yucca Mountain (Dudley and Larson, 1976; Waddell, 1982). In addition, The Nature Conservancey recently purchased 5121 ha (12,654 acres) of private land in the vicinity of Devil's Hole. Current plans call for the U.S. Fish and Wildlife Service to purchase this land from The Nature Conservancy and to establish the area as a unit within the National Wildlife Refuge System (USFWS, 1984). This will restrict potential land use by repository workers in the Ash Meadows area.

The northern part of the controlled area surrounding the repository site would be approximately 8 km (5 mi) south of the Timber Mountain Caldera National Natural Landmark. 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 Range and the Nevada Test Site. It presently has, and will continue to have, restricted access.

<u>Conclusion for Disqualifying Condition 1</u>: On the basis of preliminary assessments, the construction, operation, closure, or decommissioning of a repository located at Yucca Mountain would not result in any unacceptable adverse environmental impacts that would threaten the health or welfare of the public or the quality of the environment. Therefore, the Yucca Mountain site is not disqualified on the basis of this guideline.

<u>Conclusion for Disqualifying Condition 2</u>: Neither the restricted area nor the supporting facilities for a repository at Yucca Mountain, would be located within the boundaries of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the

National Wild and Scenic Rivers System. Therefore, the Yucca Mountain site is not disqualified on the basis of this guideline.

<u>Conclusion for Disqualifying Condition 3</u>: Neither the restricted area nor the supporting facilities for a repository at Yucca Mountain, would irreconcilably conflict 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. Therefore, the Yucca Mountain site is not disqualified on the basis of this guideline.

6.2.1.7 Socioeconomics (10 CFR 960.5-2-6)

I. INTRODUCTION

The preclosure Socioeconomics Technical Guideline is concerned with the interaction between repository-related activities and the existing economic, demographic, and social conditions of the area during construction, operation, decommissioning, and closure of the repository.

The guideline contains one qualifying condition, four favorable conditions, and four potentially adverse conditions. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

The results of preliminary assessments of the socioeconomic impacts of a potential repository at Yucca Mountain are described in Chapter 5. For purposes of this guideline, the affected region is defined to include the areas of Nye County, where the site is located, plus neighboring Clark County. Although the DOE intends to consider a larger geographic area in its ongoing studies of potential project impacts, preliminary studies indicate that the characterization of bicounty effects are indicative of the nature and extent of the total social and economic impact.

Information about the potential social and economic impacts of locating a nuclear waste repository at Yucca Mountain is contained in reports by McBrien and Jones (1983) and Science Applications, Inc. (1983). These are preliminary studies describing work in progress about the regional and local impacts of siting a repository at Yucca Mountain, including potential impacts on local tourism. These reports contain additional reference citations that form the basis for assessments of the potential social and economic impacts of a repository at Yucca Mountain.

Assumptions and Data Uncertainties: The assumptions and analyses of social and economic impacts which form the basis for this evaluation appear in detail in Section 3.1.6 (existing and baseline conditions) and Sections 5.1 and 5.4, which includes assumptions about project resource requirements.

III. QUALIFYING CONDITION

The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consulting among the DOE, affected state and local government jurisdictions, and affected Indian tribes; and, (2) the requirements specified in Section 960.5-1(a)(2) can be met.

Socioeconomic parameters that will be considered include but are not limited to requirements for labor; impacts on the existing economic base of the affected area, including tourism, recreation, and agriculture; increases in direct and indirect employment and in business sales; competition for resources such as land, water, and construction materials; impacts on state and local community infrastructure and transporation; impacts on housing supply and demand; public-agency revenues and expenditures; impacts on lifestyle and on the quality of life; and increases in social problems, such as crime, alcoholism, and conflicts between in-migrants and long-time residents.

Evaluation: An analysis of the adverse impacts of locating a repository at Yucca Mountain must consider the following areas: significant adverse impacts on labor; on the primary, or basic, sectors of the economy; on direct and indirect employment and business sales; on competition for water resources; on the community service sector; on housing supply and demand; and on public-agency revenues and expenditures. In some cases, these investigations assume that the DOE takes reasonable mitigative or compensatory action.

Preliminary analyses of project land use, local construction materials demand, impacts on lifestyles and on the quality of life, and increases in social problems (such as conflicts between inmigrants and long-time residents) reveal no potentially significant impacts. (These socioeconomic parameters are discussed in Chapter 5.)

Impacts on state and local community infrastructure and transportation are expected to be mitigable, as discussed in Chapter 5 and in Favorable Condition (3). In these areas, as in others, the DOE maintains a commitment to work jointly with responsible State and local governments to identify specific areas where adverse impacts could occur and then to develop appropriate measures to mitigate these impacts. Ongoing research and analysis on potential impacts on tourism will further assess the potential for adverse effects of a repository at Yucca Mountain. No unmitigable adverse impacts have been identified.

A summary of an ongoing evaluation of socioeconomic impacts is given in Chapters 3 and 5 and in reports referenced in the Relevant Data section. This evaluation will include developing a plan to mitigate impacts in consultation with State and local government experts. As more specific system-design information becomes known or as impact issues are raised, other means of protecting the socioeconomic welfare of the general public in the affected area will be identified. Socioeconomic welfare is understood to mean social welfare (i.e., the aggregate well-being of area residents).

Conclusion: The proposed repository is not expected to generate any significant adverse socioeconomic effects on the surrounding region that cannot be offset by reasonable mitigation. This assessment is based on preliminary design and impact studies. Therefore, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITIONS

(1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

Evaluation: This favorable condition addresses both community service and housing impacts. In the absence of detailed community service capacity and housing forecasts, population changes are considered to significantly affect community services and housing when the percent population increase in any year exceeds that historically experienced by the area. This evaluation considers impacts at the county level. Subsequent analyses will consider, in detail, impacts on the incorporated cities of Las Vegas, North Las Vegas, Boulder City, Henderson, and Mesquite and on other governmental units responsible for providing public services.

The maximum one-year increase in population that would occur during repository development is 3.8 percent for Clark County and 8.9 percent for Nye County. These rates of growth, occurring during the first year of construction (1993), are less than maximum historical one-year rates of growth for those counties. This indicates that the affected area would be able to absorb the project-related population changes without significant disruptions in community services or significant impacts on housing supply and demand.

Judging significance through comparisons with historic growth rates implicitly assumes either that the historic growth did not result in significant impacts on housing and community services or, more likely for periods of very large growth, that the responsible local governments and the DOE have acquired a base of experience that significantly enhances their ability to plan cooperatively to avoid significant future impacts on community services and housing. It is assumed that the DOE would work in cooperation with the responsible entities to plan for growth in community services and housing demand, including the provision of adequate financial resources, as appropriate.

While historic population growth provides the responsible governmental entities and the private sector with experience in planning for and responding to future growth, there are some impacts on housing and community services that may occur regardless of the ability of these organizations to respond. These impacts involve aesthetics; for example, a change in housing mix (e.g., more mobile homes) associated with growth may be regarded as undesirable by some community residents. These aesthetic preferences are not uniform across communities. Individual community preferences will be taken into account in ongoing research. As appropriate, the DOE would develop a plan that would encourage or discourage workers from moving into specific communities. For example, this plan might include transportation subsidies for project employees commuting along specific routes, or the provision of worker housing at Mercury (or other locations).

In summary, the affected area would be able to absorb the project-related population changes without significantly disrupting community services or significantly impacting housing supply and demand. This conclusion is based on the observation that no one-year population growth rate experienced during repository development would exceed historic population growth rates in the affected areas. The DOE is assumed to work with the responsible entities to develop mitigation plans that would include financial aid, and measures to influence project employee settlement patterns, as appropriate.

Conclusion: The affected area, including the Las Vegas urban area, has the ability to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand. Therefore, the Yucca Mountain site possesses this favorable condition.

(2) Availability of an adequate labor force in the affected area.

Evaluation: At peak, the project would employ about 3400 workers. This level, which would be reached in 1996, is less than one percent of the projected bicounty labor force (see Section 3.1.6). Evaluating adequacy through comparison of the total project labor requirement with the size of the baseline labor force indicates that the available labor force would be adequate. Further, baseline projections indicate that the region will contain significant numbers of workers having many of the skills required to develop a repository.

Preliminary estimates of project labor requirements indicate that the greatest demand would be for construction and mining skills. At peak, the project would increase regional construction employment by about 2000 workers, which is 9 percent of forecasted baseline bicounty construction employment (see Tables 3-14 and 3-15). Assuming vertical emplacement, mining employment would increase by about 100 percent over the forecasted baseline. This employment level would be maintained for about thirty years. Preliminary estimates of project mining employment include all underground workers. (While horizontal emplacement would require about two-thirds as many mining workers as vertical emplacement, the construction work force requirement would be about the same for both). Thus, the development of a repository would be a project of significant size for the local construction and mining sectors and, consequently, many mining and construction workers would be drawn from outside the bicounty area. The extent of this would depend on the presence of other large projects in the early 1990s, the state of the national economy at that time, and the unemployment rates in those skill areas.

In summary, the total labor requirement of the project appears small when compared with the size of the bicounty labor force. This labor force is projected to include significant numbers of mining and construction workers, which are the two largest skill requirements of the project. The development of a repository at Yucca Mountain would lead to the inmigration of additional workers having these and other skills. Therefore, while an adequate work force would be available to develop the repository at Yucca Mountain, it is concluded that the available (i.e., baseline) work force would be inadequate.

<u>Conclusion:</u> The labor force in southern Nevada, including the Las Vegas urban area, is sufficiently large that development of a repository at Yucca Mountain would not have a significant impact on the total labor force. However, some of the project workers would be drawn from outside the bicounty region. Thus, although an adequate work force would be available to develop a repository at Yucca Mountain, it is concluded that the available (i.e., baseline) work force would be inadequate. Therefore, the Yucca Mountain site does not possess this favorable condition.

(3) <u>Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.</u>

Evaluation: Preliminary analyses of the impact of locating a repository at Yucca Mountain, summarized in Chapter 5, indicate that a maximum of 8500 jobs would be created in the southern Nevada area by the repository project. The potential annual wage-related increases in area income could reach the $157 million level during the project's peak construction phase. These and other direct and project-induced expenditures would result in increased State and local government tax revenues, which may be offset by increased outlays.

Where State and local government outlays would exceed revenue generated by the project, the Federal government would take action to provide financial aid (see Section 5.4). As a result, incremental State and local government outlays would not exceed incremental revenues and might actually be less. Additional data and analysis will be required to quantify the potential fiscal effects and appropriate levels of financial assistance.

Similarly, where ongoing assessments indicate that the quality of community services could be adversely affected, the DOE will work with the affected communities and the responsible government entities to mitigate those effects through financial aid, by avoiding the settlement of repository workers in particular areas, or by other appropriate measures developed during the planning process. It also is possible that the proposed repository project could increase the quality of community services. For example, old facilities could be replaced by new facilities to serve a larger population, the increased population could support more diverse community services, and facilities could be acquired that would not otherwise be developed. Thus, the impact on the quality of community services would not necessarily be negative and could be positive.

In summary, preliminary analyses indicate that locating a repository at Yucca Mountain would result in projected net increases in employment and business sales and could result in improved community services and increased government revenues in the affected area. It is assumed that the DOE would work with State and local government entities to identify potential adverse fiscal effects requiring mitigation and that Federal financial assistance would be provided, if necessary, to offset such potential effects. This includes the fiscal effect of increased spending by State and local entities responsible for providing community services.

Conclusion: The construction and operation of a repository at Yucca Mountain would increase employment opportunities and business sales in southern Nevada communities. Community services could be improved and net government revenues could increase, but studies to date are insufficient to establish a firm conclusion. Therefore, based upon the available information, it is concluded that the Yucca Mountain site possesses this favorable conclusion.

(4) No projected substantial disruption of primary sectors of the economy of the affected area.

Evaluation: A primary, or basic, sector of the economy is one that produces goods sold outside the region. Interest in such sectors stems from the assumption that regional growth is intimately tied to the growth of primary sectors. Expansion of the primary sector is assumed to result in increased production by secondary, or support, sectors of the economy. Preliminary analysis indicates that in Clark County, the important primary sector is tourism and in Nye County, it is mining.

Even though increases in population due to the repository may have a small positive effect on tourism, analyses to date have only investigated the possibility of a negative impact. Preliminary results from an ongoing evaluation of the potential impacts of repository operations on tourism (see SAI, 1983 and Chapter 5), suggest that the repository would not have a substantial effect on tourism. Safety concerns are assumed to be resolved before repository construction would begin. Because of public concerns about impacts on tourism, the importance of the tourism sector to the local economy and the preliminary nature of the available data, this impact issue will be the subject of continued research.

The location of a repository at Yucca Mountain would increase the number of mining jobs in Nye County by 250 to 800 between 1995 and 2027, depending on the waste emplacement method. As shown in Chapter 5, this increase in jobs would lead to general economic growth through its positive effect on support sectors of the economy. Thus, the impact of the proposed repository on mining is considered to favorably affect the primary sector of the economy.

In summary, no substantial project-induced disruption of the economic primary sectors (including tourism and mining) of the affected area is envisioned.

Conclusion: The primary sectors of the economy in southern Nevada are tourism and mining. Studies to date suggest that the project would have no significant effect on tourism and would significantly increase employment in the mining sector. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.

Evaluation: The ability of southern Nevada to absorb project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand is discussed under Favorable Condition (1). Furthermore, the effect on the finances of State and local government agencies in the affected area may be favorable [see Favorable Condition (3)]. Even if the fiscal effect were negative in the absence of mitigation, the substantial lead time during the preconstruction licensing review would allow fiscal impacts to be mitigated.

Conclusion: Impacts on community services and housing supply and demand would not be significantly adverse. The affected area, including the Las Vegas urban area, has the ability to absorb project-related population changes without significant disruptions in community services and without significant impacts on housing supply and demand. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) Lack of an adequate labor force in the affected area.

Evaluation: Availability of an adequate labor force in the affected area is discussed under Favorable Condition (2).

Conclusion: The labor force in southern Nevada, including the Las Vegas urban area, is sufficiently large that development of a repository at Yucca Mountain would not have a significant impact on the total labor force. However, some of the project workers would be drawn from outside the bicounty region. Thus, although an adequate work force would be available to develop a repository at Yucca Mountain, it is concluded that the available (i.e., baseline) work force would be inadequate. Therefore, the Yucca Mountain site possesses this potentially adverse condition.

(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.

Evaluation: According to preliminary analyses, the repository will require 490,000 m^3 (400 acre-feet) of water per year for 45 years. This rate and quantity of withdrawal should not impinge on existing water rights and should not affect other water users in the region [see Favorable Condition (2) in Section 6.3.1.1 (Geohydrology)]. Analyses to date conclude that sufficient water to support the repository can be obtained from new or existing well(s) on the Nevada Test Site (see Section 6.3.3.3).

Conclusion: Preliminary analyses of water supply and demand indicate that repository-related water use will not significantly affect present or future development in the region surrounding Yucca Mountain. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(4) Potential for major disruptions of primary sectors of the economy of the affected area.

Evaluation: The absence of any projected substantial disruption of the primary sectors of the economy of the affected area is discussed under Favorable Condition (4).

Conclusion: The primary sectors of the economy in southern Nevada are tourism and mining. Studies to date suggest that the project would have no significant effect on tourism and would significantly increase employment in the mining sector. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

6.2.1.8 Transportation (10 CFR 960.5-2-7)

I. INTRODUCTION

The Preclosure Transportation Technical Guideline addresses: (1) the requirements related to constructing access routes from existing local highways and railroads to the proposed site; (2) the access of existing local highways and railroads to regional highways and railroads; (3) projected risks, costs, and other impacts of waste transportation; and (4) compliance with applicable Federal, State, and local regulations.

The guideline contains one qualifying condition, nine favorable conditions, and four potentially adverse conditions. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

Preliminary design drawings and cost estimates have been used as the basis for evaluating proposed access routes to the proposed site from existing local highways and railroads. A Bureau of Land Management wilderness status map (BLM, 1981) was used to assess the location of these routes in relation to land ownership and resource areas addressed in Section 6.2.1.6, Disqualifying Conditions (2) and (3).

Atlases, published by the Nevada Department of Transportation and Rand McNally were used to calculate distances from the site to local and regional highways and railroads. Information on railroad interchange points was provided by the Union Pacific Railroad (personal communication from Ms. N. Nunn, Marketing Manager, Union Pacific Railroad Company, Omaha, Nebraska, 1983). The costs and risks of transporting nuclear wastes to five sites in the United States, including the Yucca Mountain repository site, were estimated by Wilmot et al. (1983).

The statutes and regulations of Nevada and adjoining states were obtained from the Legislative Data Base at Oak Ridge National Laboratory and from the National Conference of State Legislatures' report (October, 1983). They were compared with U. S. Department of Transportation regulations specified in Appendix A of 49 CFR 177 and with 10 CFR 71.5a, and 10 CFR 73.37.

Information on emergency response to accidents during radioactive waste transport in the State of Nevada was obtained from the State of Nevada's Radiological Emergency Response Plan (State of Nevada, 1982) and the Department of Energy, Nevada Operations Office (DOE/NVO, 1983a).

Information on regional meteorological phenomena, was obtained from publications by Eglinton (1984), Bowen and Egami (1983), Thom (1963), the U.S. Department of Commerce (DOC, 1974, 1969, 1957, and 1952), and the U.S. Nuclear Regulatory Commission (NRC, 1981).

Data and methods used to estimate the radiological impacts are those described by Wilmot et al. (1983). The computer program used to calculate the impacts is RADTRAN II (Taylor and Daniel, 1982). Highway and rail travel distances are derived from the HIGHWAY (Joy et al., 1982) and INTERLINE (Joy et al., 1982) routing models.

Assumptions and data uncertainties: Information on the costs and risk of transporting wastes to the Yucca Mountain site along highways and rail lines must be regarded as best estimates only, in view of the very preliminary nature of the repository design. Because the conceptual design is currently in preparation and will not be completed until the fall of 1985, many of the problems related to engineering and rights-of-way are still being addressed.

III. QUALIFYING CONDITION

The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable radiological or nonradiological risk to the public health and safety or unacceptable environmental impact; and (2) the requirements of Section 960.5-1(a)(2) can be met.

Evaluation: The rail and highway access routes for the Yucca Mountain site are almost entirely located on government-controlled lands and no Federal condemnation proceedings are expected. Access routes constructed to the site from existing local highways and railroads will not conflict irreconcilably with the previously designated use of any resource listed in Section 6.2.1.6 (Environmental Quality). These routes can be constructed using reasonably available technology. Transportation system components can be designed to meet applicable Department of Transportation and Nuclear Regulatory Commission regulations.

Construction costs for such routes should not be unreasonable because the terrain is generally flat or gently sloping and no tunnels and only one bridge would be required. The local roads and railroads provide ready access to the regional transportation system without significant upgrading. Also, the Union Pacific railroad system directly serves many distant points, minimizing the need for equipment and crew changes. Southern Nevada has one of the lowest frequencies of severe weather in the United States so transportation should not be adversely affected by meteorological conditions. The State of Nevada has completed plans and procedures for responding to transportation accidents involving radiological wastes. Transportation activities will not result in an unacceptable environmental impact as discussed in Section 6.2.1.6 (Environmental Quality).

Conclusion: The Yucca Mountain site has adequate access to transportation routes and access routes can be constructed with reasonably available technology without excessive cost. Transportation operations can be conducted without causing unacceptable environmental radiological or nonradiological risk to the public or unacceptable environmental impact. Thus, it is concluded that the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITIONS

(1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:

(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.

Evaluation: Highway access to the site would originate at U.S. 95 approximately 1.0 km (0.5 mi) west of the town of Amargosa Valley and extend about 25 km (15 mi) northward to the site. The rail line would originate at Dike Siding 18 km (11 mi) northeast of downtown Las Vegas and would extend approximately 142 km (85 mi) to the site.

Unit (per mile) and total cost for access routes for the salt and BWIP sites have not been received to date. Costs will depend on surface characteristics. Because the Yucca Mountain site has relatively flat terrain, it is possible that unit costs will be higher for the Basalt Waste Isolation Project (BWIP) and for the salt sites which are located in terrain with shallow water tables, or with deep canyons. It is considered unlikely that total costs for the other sites will exceed those for Yucca Mountain.

Conclusion: Although the data are not available, it is considered unlikely that total cost for access routes at the Yucca Mountain site will be exceeded by the other sites. Therefore, the Yucca Mountain site does not possess this favorable condition.

(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.

Evaluation: The proposed road and rail access routes are located primarily on Federal lands administered by the U.S. Department of Energy, the U.S. Air Force, and public domain lands under the jurisdiction of the Bureau of Land Management (Site Ownership and Control are discussed in Sections 6.2.1.1 and 6.2.1.3). Dike Siding, proposed the connecting point for rail access, is located on private land. At this time, there has not been any opposition to the purchase of land and the subsequent construction (by the Union Pacific railroad) of a rail transfer point at this location.

Conclusion: The proposed access routes are located almost entirely on government-controlled land. Some private land may be required near Dike Siding for construction of the rail spur. There is no reason to believe that this could not be purchased. There is also no reason to believe that Federal condemnation will be required. Therefore, the Yucca Mountain site possesses this favorable condition.

(iii) Cuts, fills, tunnels or bridges are not required.

Evaluation: The terrain along the route for both road and rail is gently sloping. Preliminary design estimates indicate that no tunnels and only a minimum amount of excavation will be required. Some minor drainage structures and a new bridge spanning Fortymile Canyon will be constructed. The bridge will have a total span of 90 to 120 m (300 to 400 ft) and will have a minimum height above the wash of 6 m (20 ft). It does not present any engineering or construction problems.

Conclusion: This favorable condition is met for tunnels only. However, the number of required cuts and fills will be minimal and the only significant surface feature to be encountered is Fortymile Canyon. Therefore, the Yucca Mountain site does not possess this favorable condition.

(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rockslides.

Evaluation: The railbed will be designed for maximum grades of 1 percent for trunks and 3 percent for spurs. Curves will be limited to approximately 2 degrees. The roadbed will be designed for a maximum 3 percent grade and will be free of sharp curves. Landslides or rockslides are unlikely to occur.

Conclusion: The terrain for both rail and load access routes is gently sloping and no difficult design or engineering problems are expected. Thus, the site at Yucca Mountain possesses this favorable condition.

(v) Such routes bypass local cities and towns.

Evaluation for rail: According to very preliminary design drawings, alignment of the track will bypass the towns of Cactus Springs, Indian Springs, and the facilities at Indian Springs Air Force Base. However, the rail line will originate 21 km (13 mi) northeast of downtown Las Vegas. Rail shipments to the proposed site at Yucca Mountain are likely to pass through or near populated areas in the Las Vegas Valley.

Evaluation for highway: The proposed access road to the site will intersect U.S. 95 approximately one half mile west of Amargosa Valley. No population centers are located along the proposed route.

Conclusion: On the basis of preliminary information, the rail route to the proposed Yucca Mountain site will not bypass local cities and towns. The highway access route from U.S. 95 will bypass existing cities or towns. Therefore, the Yucca Mountain site does not possess this favorable condition.

Summary Conclusion: The Yucca Mountain site possesses this favorable condition. To have this favorable condition, only one of the characteristics need apply; for Yucca Mountain, three apply.

(2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.

Evaluation for highway: The new access road to be constructed will provide direct access to U. S. 95, a regional highway. A preliminary assessment discussed in Chapter 5 indicates that significant upgrading or reconstruction will not be required.

Evaluation for railroad: The railroad spur will connect directly to the national rail network. Consequently, no upgrading or reconstruction of local rail lines is required.

Conclusion: The Yucca Mountain site possesses this favorable condition.

(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.

Evaluation: The new access road to be constructed will provide direct access to U. S. 95, a regional highway providing access to Interstates 15, 40, and 80, all of which are part of the national transportation system. The new railspur to be constructed will connect directly to the main Union Pacific line. This is a class A mainline, which among other things means it is part of the Strategic Rail Corridor Network and therefore is part of the national network.

Conclusion: This condition is met for highways and mainline railroads. No access exists to inland waterways. Therefore, because of access to regional highways and mainline railroads, the Yucca Mountain site possesses this favorable condition.

(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.

Evaluation of equipment changes: According to an official of the Union Pacific Railroad (personal communication from Ms. N. Nunn, Marketing Manager, Union Pacific Railroad Company, Omaha, Nebraska, 1983), Union Pacific could interchange at Ogden, Utah, with the Southern Pacific Railroad. This may not be required however, because of the areas served directly by Union Pacific: (1) the recently acquired Western Pacific line to San Francisco, California; (2) the eastern United States as far east as St. Louis, Missouri, Chicago, Illinois, and Memphis, Tennessee; (3) the Pacific Northwest; and (4) the Gulf ports in Texas and Louisiana. Locomotives almost always go straight through from Salt Lake City to at least Yermo, California, and often on to Los Angeles.

Evaluation of crew changes: Crew change locations along the Union Pacific line between Salt Lake City and Los Angeles are at Salt Lake City and Milford, Utah; Las Vegas, Nevada; and Yermo and Los Angeles, California.

Conclusion: A minimum number of interchange points exists. The Yucca Mountain site, therefore, possesses this favorable condition.

(5) Total projected life-cycle cost and risk for the transportation of all wastes designated for the repository which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.

Evaluation: Projected life cycle cost and risk for the transportation of all wastes designated for the repository have been compared for all national candidate sites. Results are presented in a report by Wilmot et al. (1983). The comparison included the transportation of wastes both directly from existing locations and from the reprocessing plant at Barnwell, South Carolina. The long distance involved in travel from the East produces relatively high cost and risk for the Yucca Mountain site. The location of interim storage facilities and other subsequent repositories was not considered.

Conclusion: The Yucca Mountain site has the second highest transportation cost and risk of the proposed national sites. Therefore, the site does not possess this favorable condition.

(6) Availability of regional and local carriers--truck, rail, and water--which have the capability and are willing to handle waste shipments to the repository.

Evaluation: Although it is not possible to identify carriers and their willingness to carry waste at this stage, it is reasonable to expect that local and regional businesses will be developed and the necessary arrangements will be made for equipment and services. The long lead time involved between announcement of the selected repository site and the beginning of emplacement activities will allow carriers adequate time for planning. The analysis in Chapter 5 indicates that the Union Pacific railroad does have the capacity to carry the extra shipments associated with waste transport. Maximum truck usage is expected to be approximately 16 trucks per day. This is not expected to cause any truck hauling capacity shortfalls in the local area or the region.

Conclusion: It is expected that regional and local carriers will be available when an opportunity exists to engage in a profitable undertaking. Therefore, Yucca Mountain possesses this favorable condition.

(7) Absence of legal impediment with regard to compliance with Federal Regulations for the transportation of waste in or through the affected State and adjoining States.

Evaluation: State and local statutes in Utah and Oregon are in compliance with Federal regulations. In Nevada the advance notification requirement (State Radiation Control Chap. 706.441,4) is less stringent than the controlling Nuclear Regulatory Commission prenotification requirement contained in 10 CFR 71 for large quantities of radioactive materials and in 10 CFR 73 for spent fuel. It does not therefore constitute a legal impediment.

Some State and local statutes in California and a local ordinance in Tucson, Arizona, may not be compatible with Federal regulations: A local ordinance in Tucson, Arizona, which bans most large quantities of radioactive material from the streets may be inconsistent with the requirements of 49 CFR 177. Under 49 CFR 177, Appendix A. IIIB, a local routing rule is inconsistent if it prohibits or otherwise affects transportation on routes or at locations either authorized by Part 177 or authorized by a State routing agency in a manner consistent with Part 177, whereas Nuclear Regulatory Commission regulations, which are controlling, only discourage the use of heavily populated areas and require escort through such areas for spent fuel shipments [10 CFR 73.37(c)].

In California, a prenotification requirement is less stringent than the controlling NRC requirement for Type B packages decribed in 10 CFR 71.5(b) and is not an impediment. A State Time of Day Requirement [Ch. 875, Sec. 25651(e)] is inconsistent with 49 CFR 177, Appendix A.

Several local ordinances may be inconsistent with 49 CFR 177. For example, the banning of nuclear waste shipments in Humboldt and Marin Counties, California and from the Caldecott Tunnel may be inconsistent with 49 CFR 177. At this time, states have not designated routes for the movement of high-level waste. However, it appears as though the regulations described above will not restrict the transportation of waste except from Humboldt County.

Conclusion: The Yucca Mountain site meets this favorable condition. All potential repository sites have potential legal impediments in California due to a local restriction in Humboldt County, and in Arizona, due to a local ordinance in Tucson.

(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.

Evaluation: The State of Nevada Radiological Emergency Response Plan (1982), identifies the agencies and individuals to be notified in the event of radiological emergency, provides guidance for plan participants, and establishes procedures for requesting and providing assistance.

Through an agreement with Region 7 of the Department of Energy, and in accordance with the Memorandum of Understanding on responses to hazardous materials accidents, the DOE Nevada Operations Office is the primary contact for coordination of the initial response for radiological assistance within the State of Nevada. Telephone calls are answered by the 24-hour guard station at the main DOE office building in Las Vegas; cards containing this number have been distributed to State, county, and city authorities by the Nevada State Division of Emergency Management. In southern Nevada, a Radiological Assistance Team that has a specially equipped vehicle is also available. Duty officers assigned on a rotating schedule ensure immediate 24-hour contact with the DOE guard station via a beeper and can be immediately mobilized when needed. Radiological Assistance Team notification procedures are published by the DOE/NVO (1983a). In northern Nevada, the State's Emergency Response Team, composed of State and university personnel, is responsible for emergency response.

The DOE's capability for responding to radiological emergencies, in terms of trained personnel, equipment, and facilities is well developed. Professional personnel, including health physicists, medical specialists, physical and biological scientists, and technical personnel such as radiological monitors, instrumentation specialists and radioactive material handlers are included on the Radiological Assistance Team. In addition, a trained public affairs person accompanies the team whenever it is called upon. Equipment is available for personnel protection, transportation, communications, and radiation monitoring; facilities exist for biological assay analysis, chemical analysis, and decontamination. Also available are materials for radiation shielding and contamination control and support services, such as personnel dosimetry and analytical laboratory work. Regional capability includes, in addition to the Radiological Response Cleanup Team, and an Aerial Measurements Systems Group that has the ability to rapidly assess very large land areas. First-on-scene training courses have been developed and conducted for ambulance operators and Nevada State law enforcement personnel. Civil defense radiation monitoring instrument kits have been given to each state highway patrolman and selected minicipal and county officers who complete the course. The kits are maintained on a regular basis. This experience can provide the basis on which an emergency response program can be developed to include emergency State and local participation. With this participation, a comprehensive emergency response plan can be developed with adequate levels of training and equipment.

Conclusion: The State of Nevada has completed plans, procedures, and capabilities for response to accidents from transporting radioactive waste. Therefore, the Yucca Mountain site possesses this favorable condition.

(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

<u>Evaluation</u>: Historical occurrences of severe weather in the state include thunderstorms, snow storms, tornadoes, hail, and sand storms. Thunderstorms have been observed on the average of 14 days per year at Yucca Flat (Bowen and Egami, 1983), 11 days per year at Winnemucca to the north, 14 days per year at Reno to the northwest, and 31 days per year at Ely, to the northwest (DOC, 1952). Approximately 60 to 70 percent of these thunderstorms occur during the summer season. Tornadoes are very rare in Nevada, with the probability of a tornado striking Yucca Mountain calculated as 7.5×10^{-4} per year, or once in 1333 years (Thom, 1963). Occurrences of tornadoes elsewhere in the state are equally rare, with no tornado-related deaths reported for Nevada for the period 1916 to 1953 (DOC, 1957). Hail with a diameter of 1.9 cm (0.75 in) or larger was observed on seven days in Nevada between 1955 and 1967 (DOC, 1969). Sand storms are common in Nevada, but the storms are rarely severe enough to affect transportation. The greatest 24-hour snowfall measured at Yucca Flat was only 21 cm (8.3 in.) (Bowen and Egami, 1983). Annual total snowfalls of up to 150 cm (60 in) have been observed in some of the higher elevations in the state but these areas are relatively limited in extent (DOC, 1974). Annual precipitation amounts for Nevada are generally low, with the northern half of the state receiving more precipitation than the arid southern region. Extremely hot weather can sometimes be disruptive to transportation; however, because hot weather is routine for the region, it can be anticipated and planned for.

Although it is not strictly a routine meteorological condition, but rather, the result of the regional meteorology, the possibility of flash flooding will be taken into account in the design of access routes. Beatty rainfall patterns should be indicative of the southwestern Nevada Test Site. Greater than 2.00 in. of precipitation in 24 hours has a reoccurrence period of 25 years for Beatty (Bowen and Egami, 1983). Hurricanes have not been reported in the State.

<u>Conclusion</u>: Available data suggest that southern Nevada has one of the lowest frequencies of occurrence of severe weather in the United States. In addition, possible transportation routes through the northwest or northeast sections of the State would not be subject to abnormally severe meteorological

conditions. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.

Evaluation: The evaluation is preliminary and incomplete because data for the other potential repository sites is unavailable.

Conclusion: It is unlikely that total cost for access routes for the Yucca Mountain site will be exceeded by the other sites as discussed in Favorable Condition (1). However, unit costs (per mile) may be less expensive than for the other sites because the terrain is relatively flat and dry. Therefore, the Yucca Mountain site presently possesses this potentially adverse condition.

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(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access roads to the site.

Evaluation: The terrain along the road and rail access routes is gently sloping. [See also, Favorable Conditions (1)(iii) and (iv)].

Conclusion: Preliminary plans indicate that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or other potential sources of hazard to incoming waste shipments will not be encountered along access routes to the proposed site. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.

Evaluation of rail route: Construction of the proposed railspur from the site to Dike Siding will provide direct access to the national railroad system. Hence, there will be no upgrading or reconstruction of existing local networks.

Evaluation of highway route: According to preliminary assessments contained in Chapter 5, it is not expected that significant upgrading or reconstruction will be required along U.S. 95, which is part of the regional network leading to the national network.

Conclusion: The Yucca Mountain site does not possess this potentially adverse condition for highways or railroads.

(4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.

Evaluation: The population density in the area covered by access routes for rail and highway is very low as discussed in the Preclosure System Guideline for Radiological Safety (Section 6.2.2.1). There are no permanent residents within a 10 km (6.2 mi) radius of the site. The costs are not expected to be unreasonable for constructing either route because the terrain is generally flat or gently sloping and no tunnels and only one bridge are required. Data is not available for discussion of comparable siting options.

Conclusion: There is no known local condition that would cause transportation-related costs to be significantly greater at the Yucca Mountain site than for other siting options. However, no data has been received for the other potentially acceptable repository sites. Low population density in the region ensures very limited risks to public health and safety from waste transportation operations. No specialized technology is required for construction of the rail line or highway. Much of the land is already Federally controlled. Environmental impacts from access road construction and utilization will be minimal and all applicable local, State and Federal regulations can be easily met.

6.2.2 Preclosure system guidelines

The system guidelines discussed in this section will be used to evaluate (1) the natural and engineered barrier components of the proposed site, and (2) the impacts that preclosure activities at the proposed site might have on environmental, socioeconomic, and transportation conditions in the area.

6.2.2.1 Preclosure system guideline: radiological safety (10 CFR 960.5-1(a)(1))

Introduction

The Radiological Safety System Guideline establishes the overall objectives to be met by a potential repository site at Yucca Mountain during the preclosure phase (construction, operation, and closure). The preclosure phase relies on high-integrity engineered structures, water and air treatment systems and monitors to meet the 10 CFR 60 performance objective for radiation safety. Preclosure operating procedures will be based on designs that will ensure that radiological exposures are as low as is reasonably achievable.

The Qualifying Condition for this Guideline is stated as follows:

Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60 and 40 CFR Part 191, Subpart A.

Supporting data and information about the engineered components that will control releases of radioactive materials are summarized in the Preliminary Repository Concepts Report (Jackson et al., 1984a) and the Preliminary Safety Assessment Study for the Nevada Nuclear Waste Storage Investigations (NNWSI) Repository Conceptual Design (Jackson et al., 1984b). Primary references that detail the waste form, the waste canister, and waste packages for a potential repository at Yucca Mountain include Baxter (1981), Slate et al. (1981), and Gregg and O'Neal (1983). The design of sealing systems is discussed by

Fernandez and Freshley (1983). Bowen and Egami (1983) have compiled meterological data from a station at Yucca Flat. Bowen and Egami (1983) and Holzworth (1972) provide regional atmospheric diffusion and dispersion characteristics.

Evaluation of the Yucca Mountain site

The evaluations in this guideline include those for Population Density and Distribution (Section 6.3.2.2); Site Ownership and Control (Sections 6.2.1.1 and 6.2.1.3); Meteorology (Section 6.2.1.4); and, Offsite Installation and Operations (Section 6.2.1.5). Evaluations of favorable and potentially adverse conditions in these technical guidelines are used as surrogate measures of system performance before site characterization.

The objective of the Population Density and Distribution guideline is to ensure that the site will meet Environmental Protection Agency and Nuclear Regulatory Commission regulations with minimum risk to the public. The area around the site is one of the most sparsely populated regions in the contiguous 48 states. Present site ownership and control provide the basis for limiting entry of people onto the site during operation and closure. The eastern portion of the site is located on the Nevada Test Site (NTS), which is controlled by the Department of Energy; the northwestern portion of the site is located on the Nellis Air Force Range (NAFR), which is controlled by the U.S. Air Force; and the southwestern portion of the site is held in public trust by the Bureau of Land Management (BLM). If unforeseen conflicts of ownership and control were to arise that could not be resolved, it could potentially impact the ability of DOE to guarantee public health and safety.

Because of the current land control, there are no permanent residents within a 10 km (6.2 mi) radius of the site. Access to the NAFR and Nevada Test Site is restricted. Approximately 4600 people live within a 80-km radius of a central location on the Nevada Test Site. The population density within a 150 km radius of the site is about 0.5 persons/mi^2 (Black et al., 1983). The nearest towns are Amargosa Valley (population 45) 26 km (16 mi) south of the site, and Beatty (population 800) 25 km west of the site. The nearest highly populated area, or area 1 mile by 1 mile having a population of 1000 or greater is the Las Vegas Standard Metropolitan Statistical Area (SMSA), 150 km (95 mi) southeast of the site (DOC, 1982).

The engineered components that function to control releases of radioactive materials include the waste form, waste package, waste-handling facilities, surface and underground ventilation systems, seals, and any backfill used to prevent or retard radionuclide transport to the accessible environment. Based upon the assumed waste quantities and properties shown in Table 6.2.2.2-1, and the known site conditions, a preliminary safety assessment study was performed (Jackson et al., 1984b). The BLM land that borders the site on one quadrant is open to public access, and an individual could be temporarily in the area 4 km (2.5 mi) from the surface facility location. Assuming this person to be the maximally exposed individual, preliminary calculations of the worst-case accidental radionuclide exposure to the maximum individual are 0.3 rem, which is below the limits specified in 10 CFR 20, 10 CFR 60, and 40 CFR 191. Accident-related exposure of the general public living within an 80 km (50 mi) radius of the site to worst-case radionuclide releases is 120 man-rem, which compares to annual background radiation doses of 1790 man-rem to 4600 people. No health effects (additional cancer deaths) are expected in this population.

Radionuclides released to the environment can be transported by several mechanisms. At the Yucca Mountain site, surface water pathways are not considered likely because of the activity of the climate and the absence of surface water. The Yucca Mountain site is located in one of the most arid regions of the United States, with an average annual rainfall of less than 10 cm (4 in). Most of it evaporates leaving little water available for recharge (Quiring, 1965; Winograd and Thordarson, 1975). The ground-water pathway is also not considered likely during the operation of the repository owing to the long ground-water travel time in the unsaturated zone, potential for retardation of radionuclides in the zeolitized tuffaceous beds of the Calico Hills, and the great distance between the site and a down gradient populati: center where ground water is withdrawn. The air pathway may therefore represent the most likely pathway of radionuclide travel.

Table 6.2.2.1-1. Preliminary waste-form characterization for the proposed Yucca Mountain repository

Waste type[a]	Type	Disposal package: Dimensions[a] cm (in)	Disposal package: Weight kg (lb)	Total packages	Packages/yr	Initial thermal power (W)	Initial surface dose rate (mrem/hr): gamma	Initial surface dose rate (mrem/hr): neutron	Remarks
Spent fuel PWR	Canister	50 OD x 450 (19.7 OD x 177.2)	4,500 (9,900)	7,339	336	3,050	1.7 x 10^7	3.9 x 10^3	Canister contains fuel rods from 6 PWR assemblies
Spent fuel BWR	Canister	57 OD x 450 (22.4 OD x 177.2)	5,590 (12,300)	4,031	173	3,000	~1.3 x 10^7	~2.3 x 10^3	Canister cont[illegible] fuel rods [illegible] assemblies
Cladding waste	Canister	61 OD x 300 (24 OD x 118.1)	1,460 (3,210)	12,290	484	~68	~5.0 x 10^5	~0	Hulls compacted with 2:1 volume reduction ratio
Spent fuel hardware waste	Canister	61 OD x 300 (24 OD x 118.1)	1,975 (4,350)	1,932	83	~0	>200	~0	Nozzles, spacers, etc., from fuel rod packaging operations
CHLW	Canister	32 OD x 300 (12.75 OD x 118.1)	825 (1,815)	15,350	560	1,344 (BWR) 2,244 (PWR)	~1.1 x 10^3	~2.7 x 10^4	Waste will be blended from 2.28 MTU fuel charged to PWRs and BWRs
DHLW (DWPF)	Canister	61 OD x 300 (24 OD x 118.1)	1,935 (4,260)	6,720	500	470	5.5 x 10^5	~0	Equilibrium product with 28 weight percent waste loading
WVHLW	Canister	61 OD x 300 (24 OD x 118.1)	1,935 (4,260)	300	TBD[a]	~300	~4.0 x 10^5	~0	Solidification process not defined
TRU waste (reprocessing)	6-packed 55-gal drums	188 x 125 x 90 (74 x 49 x 36)	Variable (<2,000 kg)	1,143	49	~0	≤200	~0	Compacted with overall volume [illegible] tion
TRU waste (reprocessing)	SAND box	173 x 137 x 98 (68 x 54 x 38.5)	Variable (<2,000 kg)	677	29	~0	≤200	~0	Compacted with [illegible] overall volume reduction
TRU waste (reprocessing)	Canister	61 OD x 300 (24 OD x 118.1)	Variable (<2,000 kg)	10,734	460	TBD	>200	~0	Compacted with 3:1 overall volume reduction
TRU waste (MOX fuel fabrication)	6-packed 55-gal drums	188 x 125 x 90 (74 x 49 x 36)	Variable (<2,000 kg)	4,527	194	~0	<10	~0	Compacted with 3:1 overall volume reduction
TRU waste (MOX fuel fabrication)	SAND box	173 x 137 x 98 (68 x 54 x 38.5)	Variable (<2,000 kg)	2,707	116	~0	<10	~0	Compacted with 3:1 overall volume reduction

[a] BWR - Boiling water reactor.
CHLW - Commercial high-level waste.
DHLW - Defense high-level waste.
DWPF - Defense Waste Processing Facility (Savannah River)
MOX - Mixed uranium and plutonium oxide.
OD - Outside diameter.
PWR - Pressurized water reactor.
TBD - To be determined.
TRU - Transuranic waste.
WVHLW - West Valley high-level waste.

Meteorological data from Yucca Flat (40 km, or 25 miles, east of Yucca Mountain) shows that the site should be well ventilated. The typical air flow pattern locally is air drainage from north to south, down Fortymile Canyon. During the night, the average velocity is 6.5 m/s (15 mph). During the day, thermal currents move up the canyon to the north, with an average velocity of 6.4 m/s (Quiring, 1968). Similar diurnal changes in wind directions due to topographic effects are recognized in the data from Yucca Flat (Bowen and Egami, 1983). The 18-year period of wind speeds shows that the average wind velocity at Yucca Flat is high, 3.6 m/s (8.2 mph).

Isopleths of mean annual mixing heights (Holzworth, 1972) show that the region experiences some of the deepest atmospheric mixing layers in the United States (Holzworth, 1972). Inversions are uncommon because of the excellent dispersion and mixing. Meteorological data from Yucca Flat (Bowen and Egami, 1983) also suggest that wind speeds are high, and directions are variable. Prevailing wind directions would not result in preferential transport to areas of higher than average population density.

The impacts of nearby atomic energy defense activities on either the NAFR or the NTS are discussed in the Offsite Installations and Operations Guideline. There are no detectable offsite radionuclide releases from nuclear weapons tests at the NTS, or from a low-level waste disposal site at Beatty. These are the only potential sources of radionuclide releases in the area, and neither are regulated by 40 CFR 191. Extreme weather phenomena are not likely to cause disruptions in repository operation or closure activities because this region has one of the lowest frequencies of severe storms in the United States.

Conclusion on Qualifying Condition for Preclosure System Guideline: Radiological Safety

An analysis of the system elements pertinent to the Preclosure Radiological Safety System Guideline shows that any projected radiological exposures to the general public and any projected releases of radioactive materials during repository operation and closure should meet applicable safety requirements set forth in 10 CFR 20, 10 CFR 60, and 40 CFR 191, Subpart A.

During the preclosure period, the primary radionuclide transport mechanism is the air pathway. The history of extreme weather phenomena at the Nevada Test Site indicates that waterborne transport and migration through the subsurface will not contribute significantly to radiation doses on or off the proposed site. Meteorological data for Yucca Flat indicate that preferential transport of radionuclides to population centers is highly unlikely.

The proposed site is in an area that has a low population density and the nearest population center (Amargosa Valley) is 26 km (16 mi) to the south. There are no permanent residents within 10 km (6.2 mi) of the site and there are no highly populated areas and no areas 1 mile by 1 mile with a population of 1000 according to the 1980 Census (DOC, 1982) within 150 km (95 mi) of the proposed site. A preliminary safety assessment for accidents postulated to occur at a repository surface facility, shows that doses to the maximally exposed individual, located 4 km (2.5 mi) from the facility, would be well below the limits specified in 10 CFR 20, 10 CFR 60, and 40 CFR 191, and doses to the general public living in an 80 km (50 mi) radius are below background radiation levels.

In addition to the favorable site characteristics governing radionuclide transport and the sparse population of permanent residents surrounding the site, a number of engineered components will serve to contain the waste and retard radionuclide migration. The waste form and canister will contribute to the confidence that the regulatory release limits will be met during repository operation and closure.

Data obtained over the next several years from the weather towers installed on Yucca Mountain will be used to refine the radionuclide dispersion calculations that are based on data from Yucca Flat, and to verify that Yucca Mountain conditions have been accurately predicted. As they are developed during the design process, details of the engineered components of the repository will be examined either to determine if the preliminary information used in evaluating the technical guideline was correct, or to alter designs based on new site characterization information.

The Yucca Mountain site is considered to meet this preclosure system guideline.

6.2.2.2 Preclosure system guideline: environment, socioeconomics, and transportation [10 CFR 960.5-1(a)(2))

Introduction

This system guideline establishes the overall objectives for protecting the environment and guaranteeing the socioeconomic welfare if repository construction, operation, and closure were to occur at Yucca Mountain.

The qualifying condition for this system guideline is stated as follows:

To the extent practicable, the repository and its support facilities sha be sited, constructed, operated, closed, and decommissioned to (1) protect the quality of the environment in the affected area and mitigate significant adverse environmental impacts considering technical, social, economic, and environmental factors, and (2) protect the socioeconomic welfare of the general public in the affected area. The projected risks, costs, and other impacts of waste transportation operations shall be conducted in compliance with applicable Federal regulations and with those applicable State and local regulations and ordinances that are consistent with Federal regulations.

Assessing the potential impacts on the environmental quality, socio-economic conditions, and transportation system for any large project has inherent uncertainties. This is particularly true for projects with very extended lead times. For the project, the preliminary conceptual nature of the repository design provides severe constraints, and requires that many assumptions be made to perform this preliminary assessment. Uncertainties include reliability of the design data, and the applicability of the criteria and assumptions used to estimate the significance of potential impacts.

Evaluation of the Yucca Mountain site

The evaluations used to compile this system guideline evaluation include those for the Technical Guidelines for Environmental Quality (Section 6.2.1.6), Socioeconomics (Section 6.2.1.7), and Transportation (Section 6.2.1.8). Some of the favorable and potentially adverse conditions contained in these three

Technical Guidelines have not been evaluated fully because the data required to assess these conditions were unavailable or uncertain. Studies are under way that will help eliminate some of this uncertainty.

Evaluation of this system guideline has been conducted on the basis of existing data and represents a preliminary assessment of the expected environmental impacts from construction, operation, decommissioning, and closure if a repository were located at Yucca Mountain. As long as waste isolation or public health and safety are not compromised, environmental concerns have been considered in facility design.

The data used to evaluate the potential environmental impacts of the repository consist of (1) surveys and published reports on the biology, archaeology, and hydrology of the Yucca Mountain area (see Chapter 3) and (2) analyses in Chapter 5 on the near- and long-term environmental consequences of constructing, operating, decommissioning, and closing a nuclear-waste repository at Yucca Mountain. Chapter 5 also presents preliminary results of continuing studies of the potential impacts of a repository at Yucca Mountain on the socioeconomics of the region. These studies are in the following areas: (1) impacts on the existing economic base of the affected area, such as tourism, recreation, and agriculture; (2) increases in direct and indirect employment and in business sales; (3) competition for resources, such as land, water, and construction materials; (4) impacts on State and local community infrastructure and transportation; (5) impacts on housing supply and demand; (6) public-agency revenues and expenditures; (7) impacts on lifestyle and the quality of life; and (8) potential conflicts between immigrants and long-term residents.

As discussed in Chapter 5, the potentially significant adverse environmental impacts associated with constructing, operating, decommissioning, and closing a repository at Yucca Mountain include the following: (1) destruction of approximately 370 ha (900 acres) of desert habitat; (2) fugitive dust emissions that will result from surface preparation, excavation, and manipulation of spoils piles; (3) vehicle emissions resulting from waste transport, personnel transport, materials transport, and operation of construction equipment; and (4) radiological releases during (a) repository excavation (from naturally occurring radon and decay products in volcanic rocks), (b) normal operation of the repository, and (c) accidents. Potential impacts to surface water and ground water are considered insignificant chiefly because there is no perennial surface water in the area, and ground water is several hundred meters beneath the repository horizon (see Section 6.3.1.1, Geohydrology, for more discussion). Other potential impacts, such as diversion of natural runoff and leaching of materials from excavated rock are being considered in the repository design, and they are not expected to pose significant environmental problems.

Dust and vehicle emissions released to the atmosphere will be greatest during construction, decline during operation, increase during backfilling, and will be least during decommissioning. During construction, the maximum estimated ambient concentrations of carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen should not exceed the air-quality limits of 40 CFR 50 the boundary of the controlled area. The maximum estimated concentration of suspended particulates at the point of nearest human habitation, assuming no dust suppression measures are used, is estimated to be 28 micrograms per cubic meter [see Section 6.2.1.6, Disqualifying Condition (1)]. These impacts are below the ambient air-quality standards for fugitive dust specified in 40 CFR 50. Because dust suppression measures are expected to be used, actual particulate concentrations and deposition should be reduced to an insignificant level.

The potential socioeconomic impacts from a repository at Yucca Mountain are currently being studied. Information now available indicates that the affected area will be able to absorb the project-related population changes without significantly disrupting community services and without significant impacts on the supply and demand for housing. Even though Yucca Mountain is 150 km (95 mi) from Las Vegas, it is sufficiently close that project-related demands for community services and housing may be fulfilled by the Las Vegas area. Currently, 80 percent of the DOE work force at the Nevada Test Site resides in Clark County. The maximum one-year increase in population that would occur during repository development is 3.8 percent for Clark County and 8.9 percent for Nye County (see Section 6.2.1.7). There is a possibility that past settlement patterns may not be maintained and settlement of inmigrants could occur in sparsely populated areas. If this occurred, the DOE, in concert with State and local agencies, would take action to mitigate such impacts. Mitigation could take the form of fiscal aid, temporary housing, subsidized transportation of the work force, and other forms of direct and indirect assistance.

Preliminary analyses of the demand for labor (see Section 5.4.1) indicate requirements for about 250 to 800 miners, and about 2000 construction workers. The demand for miners represents an inrease of about 100 percent over the thirty-year scenario. The peak for construction work force represents a 9 percent increase over baseline construction work forces in Clark and Nye counties (see Tables 3-14 and 3-15). The horizontal emplacement method wou reduce the number of mining jobs about two-thirds, but the construction work force requirements would be about the same. Although the required local work force will certainly include inmigrants, the Yucca Mountain region offers a substantial resource base from which the project work force may be obtained. Consequently, some adverse impacts on the local labor force are anticipated, but they are not expected to be significant.

Analyses indicate that in 1996 a maximum of about 3400 jobs would be created during construction and operation of the repository depending upon the emplacement configuration (see Section 5.4.1.1). The potential wage-related economic activity could reach $157 million during peak employment. These expenditures, as well as other direct and indirect project-related expenditures, would result in increased revenues for State and local governments. In addition, preliminary analyses of possible adverse impacts that a repository might have on the existing economic base in the region, specifically the hotel and gaming industry (tourism), have been unable to establish any significant adverse consequences. The only impact identified to date from a repository at Yucca Mountain is favorable and is related to population growth in the Las Vegas area.

Detailed analyses of the potential impact of the repository on the finances of State and local government agencies have not been conducted. The DOE recognizes that it has a responsibility under the Nuclear Waste Policy Act to ensure that no adverse fiscal impacts would occur. Negative fiscal impacts are not expected in view of DOE policies and probable aid programs.

The only industry for which any significant impact has been identified the transportation sector. These impacts are not anticipated to be disruptive, and may in fact be favorable due to an increase in the capacity and quality of the transportation system in southern Nevada. For rail access to Yucca Mountain, a class 5, short-line railroad extending approximately 142 km (85 mi) from existing mainline rail facilities at Dike Siding (northeast of Las Vegas) would be the most technically and economically feasible route (Yellvington, 1983). The route would be almost entirely on government-controlled lands administered by the DOE, the U.S. Air Force, and public-domain lands under the jurisdiction of the Bureau of Land Management. Acquisition of some private land, however, may be required near Dike Siding.

The terrain over which the rail would cross is gently sloping. No tunnels and only a minor amount of excavation and backfill would be required. A bridge would be required at Fortymile Wash several miles east of Yucca Mountain. This bridge would span 90 to 120 m (300 to 400 ft) and would be a maximum of 6.1 m (20 feet) above the wash. The construction of the proposed rail line from the proposed site to Dike Siding would provide direct access to the national railroad system. Although it has not been determined as necessary, an interchange with the Southern Pacific railroad system is available at Ogden, Utah.

For highway access to the proposed site, a route is projected from U.S. 95, originating approximately one half mile west of Amargosa Valley. U.S. 95 is a regional highway providing access to the I-15, I-40 and I-80, which are all part of the national transportation system. The roadway access would be constructed chiefly on Federally controlled lands that slope gently and would pose no significant engineering problems. No tunnels and only a minor amount of excavation would be required. Some minor drainage structures and a bridge spanning Fortymile Wash would be required (unless the bridge for the railroad was also used for the road). The major part of U.S. 95 between

Las Vegas and Mercury consists of a four-lane divided highway that is unlikely to require upgrading or construction. U.S. 95 north of Mercury to the access road near Amargosa Valley is a two-lane highway that may require upgrading. The extent of possible upgrading is currently being assessed. In addition, if waste shipments were routed to the proposed site along I-40, upgrading of U.S. 95 between I-40 and Las Vegas may be required. Studies of this possibility are as yet incomplete.

A preliminary review of State and local statutes has been conducted to determine if there are legal impediments related to compliance with Federal regulations for the transport of nuclear waste in or through the affected Stat and adjoining States. The States of Utah and Oregon are in compliance with Federal regulations. In Nevada, the advance notification requirement contained in State Radiation Control Chapter 706.441,4 is less stringent than the controlling NRC prenotification requirement contained in 10 CFR 71 for large quantities of radioactive materials and also in 10 CFR 73 for spent fuel, and therefore does not constitute a legal impediment. Certain State and local statutes in California and Arizona may not be compatible with Federal regulations. For example, the banning of nuclear waste shipments in Humboldt and Marin counties, California, and from the Caldecott Tunnel may be inconsistent with 49 CFR 177. These statutes do, therefore, constitute a potential legal impediment, and they are possibly subject to Federal preemption because they are inconsistent with U.S. Department of Transportation regulations specified in 49 CFR 177, Appendix A, Section III A and B and Section IV. All potential repository sites will have the same legal impediments due to a local restriction in Humboldt County, California.

Conclusion on Qualifying Condition for Preclosure System Guideline: Environmental Quality, Socioeconomics and Transportation

The repository and its support facilities could be sited, constructed, operated, closed, and decommissioned at Yucca Mountain while protecting environmental quality and socioeconomic welfare. Furthermore, measures exist or can be developed that will adequately mitigate any expected significant adverse environmental impacts. All efforts will be made to preserve the socioeconomic welfare of the general public in the affected area and to protect the socioeconomic welfare and the social and aesthetic values of the region. The projected risks, costs, and other impacts of waste transportation are being considered in the evaluation of the Yucca Mountain site, and there is no evidence to suggest that transportation of wastes cannot be conducted in compliance with applicable Federal regulations, and with State and local regulations that are applicable and consistent with these Federal regulations. The Yucca Mountain site is considered to meet this preclosure system guideline.

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6.3 SUITABILITY OF THE SITE FOR SITE CHARACTERIZATION: EVALUATION AGAINST THE GUIDELINES THAT DO REQUIRE SITE CHARACTERIZATION

The evaluations in this section address the preliminary assessment of the Yucca Mountain site in relation to the technical and system guidelines that require data from site characterization.

6.3.1 Postclosure technical guidelines (10 CFR 960.4-2)

The postclosure technical guidelines discussed in this section address geohydrology, geochemistry, rock characteristics, climatic changes, erosion, dissolution, tectonics, human interference and natural resource conditions of the Yucca Mountain site.

6.3.1.1 Geohydrology (10 CFR 960.4-2-1)

I. INTRODUCTION

The Geohydrology Technical Guideline is one of several postclosure guidelines included under the topic heading characteristics and processes affecting expected performance. The geohydrology guideline addresses the potential effects of past, present, and future characteristics of a site, and processes operating within the geohydrologic setting on the waste-isolation capabilities of a site. The most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by ground water. To evaluate this potential for release in the postclosure time period, it is necessary to characterize the volume of water, paths, and times for ground-water travel.

The Geohydrologic Technical Guideline consists of one qualifying condition, seven favorable conditions, three potentially adverse conditions, and one disqualifying condition. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

Because the proposed repository at Yucca Mountain is above the water table, discussions about radionuclide movement must consider unsaturated rocks as well as saturated rocks. The geohydrologic system at Yucca Mountain is composed of a thick [about 300 to 750 m (1000 to 2500 ft)] unsaturated section and a deep saturated flow regime. The relevant data for analyzing the saturated system include the standard hydrologic parameters of permeability (or similar parameters, such as transmissivity and hydraulic conductivity), hydraulic gradient, effective porosity, and water flux. For the unsaturated zone, these same parameters are needed, but must be augmented with information on infiltration rates, moisture content of the rock, its effects on moisture potential, and hydraulic conductivity. For both saturated and unsaturated zones, an understanding of the spatial distribution of these properties is needed. This, in turn, requires a knowledge of the stratigraphy and structure of the proposed site, including the dip, character, thickness, depth, and lateral variations of the rock units and the locations, densities, and orientations of fractures, faults, and other structures.

Five drill holes at Yucca Mountain (UE-25a#1, USW G-1, USW G-2, USW G-3/GU-3, and USW G-4) were continuously cored to depths ranging from 760 m to 1825 m (2300 to 6000 ft). Stratigraphic descriptions have been published for several of these holes (Spengler et al., 1979; Spengler et al., 1981; Maldonado and Koether, 1983; Scott et al., 1983; Spengler and Chornack, 1984). Test hole UE-25b#1 was cored from approximately 580 m to 1220 m (1900 to 4000 ft) (Lahoud et al., 1984). One test hole penetrated pre-Tertiary rocks (UE-25p#1; Craig and Johnson, 1984) and provided stratigraphic data from both cuttings and core samples of rocks of Paleozoic age that underlie the section of Tertiary rocks east of Yucca Mountain (Craig and Robison, 1984). In addition, cuttings and core from many nearby hydrologic test holes provide additional data on positions of stratigraphic contacts.

A geologic map of Yucca Mountain (Scott and Bonk, 1984) shows patterns of structural features (Scott et al., 1983). The major normal faults that break Yucca Mountain into a series of blocks tilted slightly to the east have been known for about 20 years (Christiansen and Lipman, 1965; Lipman and McKay, 1965), and fit the descriptions of basin-range style faults that occur elsewhere in the Great Basin (Scott et al., 1983). A number of major normal faults that have more than 75 m (250 ft) of vertical displacements have been determined by aeromagnetic surveys (Bath and Jahren, 1984) and can sometimes be located where they occur under alluvium. Attitudes of faults and fractures at depth in drillholes are similar to those on the surface (Scott et al., 1983; Scott et al., 1984; Maldonado and Koether, 1983; Spengler and Chornack, 1984). Swadley et al. (1984) have dated movement on Quaternary faults in the vicinity of Yucca Mountain. Other references on the nature and rates of tectonic activity at Yucca Mountain are discussed in Section 6.3.1.7.

Two-dimensional modeling of flow in the saturated zone on a regional scale has been accomplished (Waddell, 1982; Czarnecki and Waddell, 1984). Bulk saturated hydraulic conductivity of the Topopah Spring welded unit is known from pumping tests of wells J-12 and J-13 (Young, 1972; Thordarson, 1983). Results of pump tests and packer-injection tests on eight test holes in the immediate vicinity of Yucca Mountain are presented in Rush et al. (1983), Lahoud et al. (1984), Whitfield et al. (1984) and Craig and Robison (1984). Chemical analyses of ground water from wells and springs in the Yucca Mountain area are discussed in Benson et al. (1983), Classen (1983), and Winograd and Thordarson (1975).

Conceptual models for flow through the unsaturated zone have been developed by Scott et al. (1983) and Montazer and Wilson (1984). Information concerning the in situ distribution of moisture in the unsaturated formations at Yucca Mountain is available from three boreholes: UE-25a#1 (Anderson, 1981), USW H-1 (Weeks and Wilson, 1984), and USW UZ-1 (Montazer et al., 1984). Hammermeister and Montazer (1984) measured rock-mass permeabilities to air in the Topopah Spring Member. Porosity values for the tuffaceous beds of the Calico Hills, which underlie the Topopah Spring Member are given in Anderson (1981a), Weeks and Wilson (1984), Blair et al. (1984) and Montazer and Wilson (1984).

Meteorological data exist for several stations in the region and are presented by Bowen and Egami (1983). Relevant climatological data are presented in Section 6.3.1.4, Climatic Changes. Water-budget studies for Nevada are described by Eakin et al. (1951) and Malmberg and Eakin (1962).

Assumptions and data uncertainties: The principal assumptions that must be made concerning the hydrologic system of Yucca Mountain involve the amount of recharge and related ground-water flux through the unsaturated zone and the mechanisms by which water moves in the densely welded, fractured unsaturated tuffs. Also, uncertainty remains about the most representative values for hydraulic conductivities and moisture contents of the various rock units traversed by the subsurface water at Yucca Mountain. Effective porosities, especially in the saturated zone are also subject to considerable uncertainty. Most assumptions in this section are conservative to compensate for the inherent uncertainty in the existing information. Though the uncertainty for many of the hydrologic properties remains large, ample evidence exists to suggest that the assumptions reasonably bound a conservative possible range of hydrologic behavior at Yucca Mountain. In addition, several conceptual models (Scott et al., 1983; Montazer and Wilson, 1984) are used to assess the hydrologic system, lending another degree of conservatism in the analyses. Therefore, despite the uncertainty about the exact conditions and processes of the hydrologic system at Yucca Mountain, especially the unsaturated zone, the conservative nature of the assumptions is adequate to allow confidence in the general conclusions drawn about the hydrologic system.

Both quantitative and qualitative analyses are used in the following discussions. Quantitative analyses are used to predict the expected ground-water travel time from the repository to the accessible environment and to predict the expected releases of radionuclides at the accessible environment, in support of addressing the disqualifying and qualifying conditions. Qualitative analyses are used to establish whether Yucca Mountain possesses the several favorable and potentially adverse conditions. Semiquantitative discussions are used in these analyses to help draw conclusions from the available site information and any other pertinent information on reasonable analogues of the proposed site.

III. QUALIFYING CONDITION

The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment, and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology.

Evaluation: The quantitative assessment of ground-water flow time from the repository to the accessible environment under current conditions shows the flow time probably is more than 20,000 years. Effective porosities are about 20 percent in the Calico Hills nonwelded unit between the Topopah Spring Member and the water table. Hydrologic processes that operated at Yucca Mountain during the Quaternary Period include cyclic fluctuations in precipitation and small changes in water-table altitude, possible trends of increased aridity, and possible long-term changes in ground-water levels. Analyses show that if these processes continued into the future, they would not significantly affect or would favorably affect waste isolation. Any geohydrologic features not easily modeled can still be reasonably modeled using uncertainty analyses.

The low magnitude of ground-water flux through the unsaturated zone and the high retardation capacity of the geologic system provide expectation that total releases of radionuclides to the accessible environment in 10,000 years will be less than those allowed by the system guideline, 10 CFR 960.4-1.

The quantitative prediction of radionuclide releases shows that only three radionuclides, carbon-14, technetium-99, and iodine-129 might be released at the accessible environment (or even at the water table) during the next 10,000 years. Even under the conservative assumptions used for these predictions, the total curies released by two of these radionuclides would be about 100 times less than (about one to a few percent of) the allowable releases under the system guideline, which incorporates the Environmental Protection Agency's release standards of 40 CFR 191. Carbon-14 cannot be evaluated at this time due to uncertainty in the inventory and form of carbon that would be released from the waste forms. If diffusion of radionuclides into the matrix of the rock is taken into account, it is expected that no radionuclides would be able to migrate to the accessible environment in 10,000 years. Therefore, considering the characteristics and processes operating in the geologic setting, Yucca Mountain appears to meet the qualifying condition for geohydrology that calls for compliance with the system guideline.

Conclusion: This qualifying condition is addressed using several lines of evidence. First, the site has five of six favorable conditions and only one of the potentially adverse conditions. Second, the releases calculated by quantitative analyses of expected radionuclide releases to the accessible environment over the next 10,000 years are within the requirements specified in the system guideline (see discussion of the Postclosure System Guideline, Section 6.3.2). Third, analyses of ground-water flow time, ground-water flux, and radionuclide retardation support the position that the Yucca Mountain site does not possess the geohydrology disqualifying condition.

Radionuclide release from the engineered barrier system is shown to be less than one part in 100,000 of the 1000 year inventory in Section 6.3.1.2, Favorable Condition (4). This conclusion is based on a combination of favorable geochemical conditions and a low volumetric flow rate in the host rock at Yucca Mountain. Therefore, the Yucca Mountain site meets the qualifying conditions for geohydrology.

IV. FAVORABLE CONDITIONS

(1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.

Evaluation: A complete discussion of ground-water travel time is included under the Disqualifying Condition. That discussion shows that for the likely condition of a flux through the repository of 1 mm/yr (0.04 in/yr) or less, the ground-water travel time within the host rock unit of the repository is 5,000 years or more. Between the host rock unit and the water table the travel time is 20,000 years or more, and the travel time within the saturated zone from the areal boundary of the repository block to the accessible environment is at least 500 years.

Conclusion: Presently available data and current understanding of the geohydrologic system indicate that total ground-water travel time from the disturbed zone to the accessible environment probably is greater than 25,000 years. Therefore, the Yucca Mountain site possesses this favorable condition.

(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

Evaluation: The Quaternary Period was characterized by cyclic fluctuations of climate, with wetter, cooler pluvial periods alternating with dryer, warmer interpluvial periods. Thus, at times, changes in hydrologic phenomena were related to increasing available moisture, and, at other times, changes were associated with drying conditions. Principal changes in hydrologic processes associated with the onset of pluvials occurred most recently about 9000 to 13,000 years ago and probably included increasing recharge flux and rising water table, with attendant increasing hydraulic gradients and upgradient movement of ground-water discharge sites. Even though the directions of the changes were such that if they occurred in the future they could adversely affect isolation capability, the small magnitude and reversible nature of these changes indicate that any adverse effects on isolation capabilities would be very small and temporary.

The most recent major change in trend was the shift from pluvial to interpluvial conditions that has led to the conditions observed today (Winograd and Doty, 1980). This trend (decreasing recharge flux, declining water table, and down-gradient shifts in ground-water discharge sites) if continued, would favorably affect the ability of the geologic repository to isolate waste. In addition, the postulated long-term trend in increased aridity and the identified long-term decline in ground-water base level, if continued into the future, also would favorably affect isolation ability. Cyclic fluctuations are expected to continue; thus pluvial conditions are expected to return.

Conclusion: Hydrologic processes that operated at Yucca Mountain during the Quaternary Period include cyclic fluctuations in precipitation and small changes in water-table altitude, possible trends of increased aridity, and possible long-term changes in ground-water base levels. The nature and rates of these processes, if continued into the future, would not significantly affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years. In addition, the past rates of other hydrologically related processes, such as erosion, mineral dissolution, and precipitation, remained at a low and relatively constant rate during the Quaternary Period. Therefore, the Yucca Mountain site meets this favorable condition.

(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.

Evaluation: The geologic setting is relatively complex, with rocks ranging in age from Precambrian through Holocene, and the area has undergone many periods of structural deformation. Because of the weapons-testing activities conducted at the Nevada Test Site since the early 1960s, extensive geologic, geophysical, and hydrologic studies have been completed, and the geology and hydrology of the weapons-testing areas are relatively well known. Extensive study of the nearby Yucca Mountain area started in 1978. Since that time, the geologic and hydrologic knowledge of the Yucca Mountain area has greatly expanded.

Yucca Mountain is composed of block-faulted Tertiary ash-flow, air-fall, and bedded tuffs. Material properties used to model the geohydrology (such as porosity, matrix permeability, fracture permeability, moisture content-matric potential relationships, and geochemical characteristics) vary substantially. In addition, the physics of moisture movement in unsaturated, fractured rocks is complex and not well understood.

In spite of some difficulties, investigations and modeling of the important aspects of the containment and isolation capabilities of Yucca Mountain and the surrounding geologic setting are feasible. Much investigation of the site has already been done with respect to geology of the saturated and unsaturated zones, hydrology of the saturated zone, and regional hydrology and geology. More work remains to be done in characterizing the hydrology of the saturated and unsaturated zones.

The stratigraphic features of Yucca Mountain are well known as a result of studies completed or in progress as listed in the Relevant Data section.

The general structural character of Yucca Mountain is also well known. A geologic map of Yucca Mountain (Scott and Bonk, 1984) shows patterns of structural features (Scott et al., 1983). Attitudes of faults and fractures at depth in drill-holes are similar to those on the surface (Scott et al., 1983; Scott et al., 1984; Maldonado and Koether, 1983; Spengler and Chornack, 1984). Thus, major surface structural features can be used to characterize the subsurface geology of Yucca Mountain.

A relationship between lithology and permeability based upon well yields for welded tuffs, rhyolites, and bedded tuffs beneath eastern Pahute Mesa was demonstrated by Blankennagel and Weir (1973). A similar relationship may exist at Yucca Mountain. Laboratory tests of core from both the geologic and hydrologic test holes (Anderson, 1981a, 1981b; Rush et al., 1983; Weeks and Wilson, 1984; Blair et al., 1984; Lappin et al., 1982) indicate that porosity and hydraulic conductivity of the matrix decrease as the degree of welding increases; however fracture porosity increases and bulk permeability may increase with increased welding. Winograd and Thordarson (1975) and Scott et al. (1983) concluded that fracture frequency increases with the degree of welding in the tuffs. These data and observations, together with the stratigraphic and structural data, have been used to develop conceptual models for the flow through the unsaturated zone (Scott et al., 1983; Montazer and Wilson, 1984).

The hydrostratigraphy of tuffs in the unsaturated zone [see discussion of geologic units in Table 6.3.1.1-1 in the evaluation section of Favorable Condition (6)], consists of the following hydrogeologic units: the Tiva Canyon welded unit; the Paintbrush nonwelded unit; the Topopah Spring welded unit (including the proposed repository horizon); and, the Calico Hills nonwelded unit. The water table is generally within the Calico Hills nonwelded unit. Flux in the unsaturated zone at Yucca Mountain is quite low, probably less than 1 mm/yr (0.04 in./yr) (Montazer and Wilson, 1984). Bulk saturated hydraulic conductivity of the Topopah Spring welded unit is known from pumping tests of wells J-12 and J-13 (Young, 1972; Thordarson, 1983), where this unit occurs in the saturated section. Matrix hydraulic conductivity of the Topopah Spring unit, as well as of other units, has been obtained from laboratory measurements of cores and cuttings (Montazer and Wilson, 1984; see Disqualifying Condition).

The Calico Hills nonwelded unit is composed of the following stratigraphic units: the nonwelded base of the Topopah Spring Member; the tuffaceous beds of the Calico Hills; and, the upper part of the Prow Pass Member (Montazer and Wilson, 1984). Fracture frequency within this unit is much lower than in the overlying Topopah Spring welded unit, and the available data indicates that porous flow through the matrix, rather than fracture flow, dominates under the prevailing flux. Therefore, flow through this unit can be modeled with less difficulty than through unsaturated units in which fracture flow may predominate. Both vitric and zeolitic tuffs occur within the Calico Hills nonwelded unit, and their general distributions are known from test holes.

Extensive hydrologic testing of the saturated zone has been performed on 8 test holes in the immediate vicinity of Yucca Mountain. These tests have included both pumping tests of all or part of the saturated zone penetrated by the wells and packer-injection tests of isolated intervals within the holes. Both hydraulic-conductivity and water-level data have been collected. Results of these tests are presented in Rush et al. (1983), Lahoud et al. (1984), Whitfield et al. (1984), and Craig and Robison (1984). In addition, 14 other holes have been drilled that provide data on altitudes of the water table (Robison, 1984).

Ground-water flow in the saturated zone at Yucca Mountain is mainly through fractures in the welded tuffs. Productive intervals in test holes are controlled mostly by the distribution of permeable fractures intercepted rather than by stratigraphic position within the densely welded units. Therefore, attempts at defining the position or geometry of hydrostratigraphic units based only on testing results have not been successful. However, the relationship between lithology and fracture frequency at Yucca Mountain has been documented by Scott et al. (1983) and may allow the general distribution of transmissive zones to be determined.

The data just described about the geometry and hydrologic properties of the hydrogeologic units at Yucca Mountain are sufficient to allow both flow paths and flow properties along them to be defined for a range of alternatives. These alternatives are amenable to analyses of flow geometry and flow velocities by both computer modeling and simple mathematical calculations. Therefore, a range that limits the possibilities of flow conditions at Yucca Mountain can be defined with reasonable confidence. As more data is collected and more sophisticated hydrologic computer models are developed during site characterization, the range that encompasses possible flow conditions will be narrowed. Statistical methods will be used to determine the sensitivity of hydrologic flow conditions to the uncertainty in data and models. Conclusions about the hydrologic system of Yucca Mountain can then be drawn based on either of two approaches:

1. By using a set of reasonably conservative properties in analyses, i.e., use values from each end of the uncertainty range that would give the shortest flow time or greatest flow volume.

2. By statistically sampling from the distribution of values for each property to develop a probability distribution of net flow conditions.

When considered together, these two approaches will provide confidence about the possible range and most likely condition for the hydrologic system at Yucca Mountain.

The degree to which the uncertainty must be reduced depends on whether or not the uncertainty jeopardizes the ability to meet performance standards. Further reduction in uncertainty may be desirable to provide confidence that the hydrology is sufficiently understood. Therefore, the hydrology of Yucca Mountain can be characterized and modeled with reasonable certainty in the context of the decision such modeling must support.

Conclusion: Detailed geologic mapping and drilling at Yucca Mountain and vicinity have demonstrated that the stratigraphic and structural features of Yucca Mountain can be characterized and modeled with reasonable certainty. The development of flow and transport models is always difficult and always accompanied by a degree of uncertainty. However, characterization and modeling of ground-water flow at Yucca Mountain from the land surface to the repository, from the repository to the water table, and laterally from the water table to the accessible environment can be accomplished with modeling techniques that incorporate uncertainty analysis. Therefore, the Yucca Mountain site meets this favorable condition.

(4) A high effective porosity along paths of likely radionuclide travel between the host rock and the accessible environment.

Evaluation: Paths of likely radionuclide transport in the unsaturated zone at Yucca Mountain are through the matrix of the Calico Hills nonwelded unit, the unit with the longest expected residence time between the host rock and the accessible environment given the prevailing flux of water through the unsaturated zone. Preliminary data indicate this unit has a high effective porosity which results in a conductivity high enough to pass the prevailing flux.

Most of the porosity values available for this unit have been calculated from bulk- and grain-density measurements. This method provides a value for the total porosity of the sample which is equal to or greater than the effective porosity. Values for total porosities of samples of this unit range from 30 to 48 percent (Anderson, 1981b; Weeks and Wilson, 1984; Blair et al., 1984; Montazer and Wilson, 1984).

Reasonable values of effective matrix porosity can be estimated by extrapolation to a moisture content at zero matric potential on moisture content-matric potential curves. Such curves are available for several samples of the Calico Hills nonwelded unit (Gee, 1984). Effective porosities calculated by this method for three samples are 20 to 30 percent. The total porosities of these samples, which range from 32 to 47 percent are similar to those reported for the unit as a whole. Therefore, the effective porosities of these three samples probably are representative of the Calico Hills nonwelded unit.

In the unlikely case that unsaturated flux were greater than 1 mm/yr (0.04 in/yr), fractures with low effective porosity (about 0.002) would be required to transmit the flux in the zeolitic portion of the Calico Hills nonwelded unit because its matrix hydraulic conductivity is only about 1 mm/yr (0.04 in/yr). However, even for a relatively high flux, the vitric portion of the unit, with a matrix hydraulic conductivity of 2600 mm/yr (100 in/yr), would still be able to pass the water through the matrix due to the high effective porosity.

Conclusion: The unsaturated Calico Hills nonwelded unit, which occurs along paths of likely radionuclide travel between the host rock and the accessible environment has a total porosity of more than 30 percent and an effective porosity of more than 20 percent. Therefore, the Yucca Mountain site has this favorable condition.

(5) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:

(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.

(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.

(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.

Evaluation: For discussion, see the evaluation of the Disqualifying Condition.

Conclusion: Inasmuch as the proposed host rock at Yucca Mountain is in the unsaturated zone, not the saturated zone, this favorable condition does not apply to Yucca Mountain. However, ground-water flow between the potential repository and the accessible environment includes flow paths in the saturated zone as well as the unsaturated zone. The hydraulic gradient in the saturated zone in the direction of the accessible environment is very low, about 3.4 x 10^{-4} (1/3 m/km, or 1/2 ft/mi). Under the most likely prevailing flux, the applicable hydraulic conductivity of the host rock and surrounding units is determined by the rock matrix and is very low (< 1 mm/yr). In addition, current information indicates that the hydraulic gradient in the host rock is downward. Therefore, Yucca Mountain possesses each of the conditions, but they are not strictly applicable because disposal is not proposed for the saturated zone.

(6) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:

(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.

(ii) A water table sufficiently below the underground facility such that the capillary fringe does not encounter the host rock.

(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.

(iv) A host rock that provides for free drainage.

(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.

Evaluation for saturation: Information concerning the in situ distribution of moisture in the unsaturated formations at Yucca Mountain is available from three boreholes: UE-25a#1 (Anderson, 1981b), USW H-1 (Weeks and Wilson, 1984), and USW UZ-1 (Montazer et al., 1984). Of these, only USW UZ-1 was drilled dry; the other two were drilled with either foam or mud. Therefore, moisture contents from the latter two boreholes probably are overestimated.

Based on preliminary data from USW UZ-1 (Montazer et al., 1984), saturations in the Topopah Spring welded unit range from 10 to 80 percent, with a mean of about 40 percent and standard deviation of about 30 percent. The wide band of error in the saturation values is mainly due to the low porosity and permeability of the matrix of the Topopah Spring welded unit (Montazer et al., 1984). A small change in water content causes a substantial change in saturation when porosity is small.

High saturations in a rock formation do not necessarily correspond with high water contents or high fluxes; a rock may have high water saturations but have very little water content available for movement under gravitational force. Data from cuttings and cores indicate low water contents (generally less than 5 percent by weight) throughout the Topopah Spring welded unit (Montazer and Wilson, 1984). The low moisture contents in this unit also correspond to high negative matric potentials (5 to 25 bars) (Montazer et al., 1984) and low relative permeabilities (about 0.01) (Weeks and Wilson, 1984). These conditions dictate extremely low effective hydraulic conductivities of about 0.01 mm/yr (0.0004 in./yr) and corresponding very low fluxes in the matrix of about 0.01 mm/yr (0.0004 in./yr).

The degree of saturation in the host rock probably is relatively constant in time and space. Evidence provided by the paleohydrologic investigations (see Climatic Changes, Section 6.3.1.4) indicates probable low and long-term constancy of flux which should result in constancy of saturation. Throughout the Yucca Mountain block, the pores of the Topopah Spring welded unit are very small, and the unit has very low matrix permeability. Thus, the spatial distribution of saturation probably is relatively uniform in the host rock and immediately surrounding units because large differences would cause a strong hydraulic gradient that could not be maintained in a steady state condition.

Evaluation for capillary fringe: For this discussion, capillary fringe is defined as the zone immediately above the water table that is nearly or fully saturated and that has less than atmospheric pressure. Within the capillary fringe, saturation decreases with height above the water table to a minimum value at the top of the fringe. Under static conditions, this minimum value is equal to the residual saturation. Under conditions of steady-state recharge, the minimum value is greater than the residual saturation. Residual saturation is defined as the minimum saturation that can occur due to gravitational forces alone in the absence of recharge.

The water table generally is greater than 200 m (325 to 650 ft) below the repository level in the host rock, and at some locations the water table is more than 400 m (1300 ft) below the repository horizon (Robison, 1984; see discussion in Disqualifying Condition). The capillary fringe probably does not extend more than about 30 m (100 ft) above the water table, based on data on pore-size distribution and relationships between pore size and capillary pressure (Montazer and Wilson, 1984). Further, it is likely that the capillary fringe could extend no higher than the top of the Calico Hills nonwelded unit, because the contrast between the fractured Topopah Spring welded unit and the porous Calico Hills nonwelded unit probably causes a capillary barrier between the two units. Under this condition, water could not flow upward from the pores of the Calico Hills nonwelded unit into the fractures of the Topopah Spring welded unit. Water could move into the matrix of the Topopah Spring welded unit, but only at an extremely low rate because of the low permeability. In addition, upward capillary pathways are likely to be interrupted by horizontal fractures. Even in the extreme case that the capillary fringe is assumed to extend to the top of the Calico Hills nonwelded unit, the host rock would still be more than 30 m (100 ft) above the top of the capillary fringe.

Evaluation for diversion of infiltration: The Paintbrush nonwelded unit that overlies the Topopah Spring welded unit is highly porous and relatively unfractured (Scott et al., 1983). The Topopah Spring welded unit, on the other hand, is highly fractured and has extremely low matrix permeability (Montazer and Wilson, 1984). The contrasts between these two hydrogeologic units probably create capillary and permeability barriers that retard the downward flow of water from the matrix of the Paintbrush nonwelded unit into the Topopah Spring welded unit. The capillary barrier probably is formed between the matrix of the Paintbrush nonwelded unit and the fractures of the Topopah Spring welded unit. This barrier forms where water-filled pores in the nonwelded unit are smaller than the apertures of fractures in the underlying welded unit. The low matrix permeability of the Topopah Spring welded unit (Table 6.3.1.1-1) restricts the downward movement of water into the matrix of this unit to less than 1 mm/yr (0.04 in/yr) under a unit hydraulic gradient. Therefore, the combined effect of the capillary and permeability barriers is to limit the downward flux to a maximum of 1 mm/yr (0.04 in/yr) under unsaturated conditions.

The Paintbrush nonwelded unit has an eastward dip of about 8 degrees. This dip provides sufficient gradient to divert potentially as much as 2000 mm/yr (80 in/yr) of flux under near-saturation conditions, provided that the capillary barrier conditions remain effective.

Reverse conditions exist at the upper contact of the Paintbrush nonwelded unit. The Tiva Canyon welded unit, which overlies this nonwelded unit and crops out at the surface, is highly fractured and transmissive. The bulk permeability of this welded unit is estimated to be as much as a thousand times higher than that of the underlying nonwelded unit. According to current conceptual models, during a major infiltration event, recharging water would readily percolate down the fractures of the Tiva Canyon welded unit. If the event were intense and short lived, water that reached the upper boundary of the Paintbrush nonwelded unit would tend to move down dip at this boundary. This down-dip flow would occur because of the initial contrast in permeability between the two units and because the pulse of water would create air entrapment within the upper part of the nonwelded unit and, thereby, decrease the permeability significantly. This lateral movement at the upper boundary would continue until structural features with high permeability were encountered or until saturated conditions developed within the welded unit. If saturation developed, the capillary barrier of the fractures would be overcome and downward flow into the Topopah Spring welded unit could occur. According to current understanding, saturation is very unlikely to occur under current or anticipated climatic conditions, and the major faults and fracture zones that might enhance downward flow are located at the boundaries of the repository

Table 6.3.1.1-1. Dual classification of Tertiary volcanic rocks at Yucca Mountain, stratigraphic units reflecting origin and hydrogeologic units reflecting hydrologic characteristics and properties (Modified from Winograd and Thordarson, 1975)

STRATIGRAPHIC UNIT	HYDROGEOLOGIC UNIT		APPROXIMATE THICKNESS (METERS)	SATURATED MATRIX HYDRAULIC CONDUCTIVITY (MONTAZER AND WILSON, 1984)	COMMENTS
Alluvium	Unsaturated Zone	Alluvium	0-30+	Generally high	Underlies washes; thin layer on flats.
Paintbrush Tuff: Tiva Canyon Member	Unsaturated Zone	Tiva Canyon welded unit	70-150	1 mm/yr	Caprock that dips 5-8° eastward at Yucca Mountain. High fracture density.
Paintbrush Tuff: Pah Canyon Member	Unsaturated Zone	Paintbrush nonwelded unit	0-200	19,000 mm/yr	Vitric, nonwelded, porous, poorly indurated, bedded in part. Low fracture density.
Paintbrush Tuff: Yucca Mtn. Member	Unsaturated Zone	Paintbrush nonwelded unit		77,000 mm/yr	
Paintbrush Tuff: Topopah Spring Member: Nonwelded	Unsaturated Zone	Paintbrush nonwelded unit			
Paintbrush Tuff: Topopah Spring Member: Vitrophyre Welded	Unsaturated Zone	Topopah Spring welded unit	290-360	1 mm/yr	Densely to moderately welded; several lithophysal (cavity) zones; intensely fractured. Central and lower part is candidate host rock for repository. Bulk hydraulic conductivity in saturated zone east of the site (at well J-13) about 1.0 m/day.
Paintbrush Tuff: Topopah Spring Member: Nonwelded	Unsaturated Zone	Calico Hills nonwelded unit	100-400	Vitric: 2600 mm/yr	Beneath Yucca Mountain, base of unit for unsaturated zone determined by water table. Unit is vitric in southwest Yucca Mountain, zeolitized in east and north. Includes bedded units. Bulk hydraulic conductivity in saturated zone from pumping tests about 0.2 m/day.
Tuffaceous Beds of Calico Hills: Vitric / Zeolitized	Unsaturated Zone	Calico Hills nonwelded unit			
Crater Flat Tuff: Prow Pass Member: Nonwelded	Unsaturated Zone	Calico Hills nonwelded unit		Zeolitic: 1 mm/yr	
Crater Flat Tuff: Prow Pass Member: Welded	Saturated Zone (below Water Table)		100-200	20 mm/yr	
Crater Flat Tuff: Bullfrog Member	Saturated Zone		120-170	62 mm/yr	
Crater Flat Tuff: Tram Member	Saturated Zone		170-350	51 mm/yr	
Lava	Saturated Zone		0-250	Very low	Occurs in northwest part of repository block.
Lithic Ridge Tuff	Saturated Zone		80-190	Very low	
Older Volcanics	Saturated Zone			Very low	In USW H-1 hydraulic head about 50 m higher than water table.
Pre-Tertiary Rocks	Saturated Zone			Unknown	Occurs 2.5 km east of proposed repository at depth of 1250 m in UE-25p#1, where hydraulic head is about 20 m higher than water table. Bulk hydraulic conductivity high, probably due to high fracture density.

(Scott et al., 1983; Scott et al., 1984). Therefore, this unit is believed to act as an effective buffer that would divert downward percolation of water beyond the limits of the emplaced waste.

<u>Evaluation for free drainage</u>: Rock-mass permeabilities to air have been determined for the Topopah Spring welded unit to about 100 m (325 ft) below land surface (Hammermeister and Montazer, 1984). The results show that this unit has permeabilities to air of 1×10^{-8} to 1×10^{-10} cm^2 (approximately equivalent to saturated hydraulic conductivities of 1 to 0.001 m/day). Permeabilities in this range must be dominated by fractures because measurements of saturated matrix hydraulic conductivities are on the order of 1 mm/yr (0.04 in/yr). Similar conditions are expected deeper in the Topopah Spring welded unit, based on data from USW UZ-1 and known high fracture frequencies (Scott et al., 1983). The ratio of permeabilities to air and water for unsaturated rocks indirectly indicates the potential for drainage (Montazer, 1982). The high rock-mass air permeabilities measured by Hammermeister and Montazer (1984) are indicative of the free-draining characteristics of the host rock for water flux greater than about 1 mm/yr (0.04 in/yr). This condition is also indicated by the drilling records of some test holes (e.g., USW G-1) that show that large volumes of fluids have been lost during drilling in this unit (Spengler et al., 1981).

<u>Evaluation for climatic regime</u>: Meteorological recording stations have not been operational at Yucca Mountain long enough to obtain historically significant precipitation records. Such records do exist for several stations in the region (Bowen and Egami, 1983). Annual average precipitation at Yucca Flat, 40 km (25 mi) east of Yucca Mountain is 146 mm (5.7 in). At Beatty, 26 km (16 mi) west of Yucca Mountain, the annual average is 122 mm (4.5 in). Precipitation at Yucca Mountain probably is slightly more than at Yucca Flat or Beatty, because of topography and a higher elevation.

Potential evapotranspiration was estimated by an empirical method devised by Thornthwaite (Thornthwaite and Mather, 1957) that uses a yearly heat index and mean monthly temperatures. Potential evapotransportation for Yucca Mountain, corrected for actual sunshine hours, is about 530 mm/yr (24.8 in/yr).

Therefore, average annual precipitation, of about 150 mm (5 to 6 in.) is about 20 percent of annual potential evapotranspiration.

Conclusion: The host rock and the immediately surrounding hydrogeologic units are characterized by low water contents and saturations. The host rock is at least 200 m (500 ft) above the water table and completely above the capillary fringe. The highly fractured host rock provides free drainage for any water in excess of about 1 mm/yr (0.04 in/yr). The Paintbrush nonwelded unit, about 30 m (100 ft) in thickness, overlies the Topopah Spring welded unit (the host rock) and may serve as a buffer to divert pulses of flux. Precipitation is low compared with potential evapotranspiration. Therefore, the Yucca Mountain site posseses all five of the favorable conditions for disposal in the unsaturated zone.

(7) Groundwater with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the disturbed zone to the accessible environment.

Evaluation: All samples of ground water obtained to date from wells and springs throughout the region, including the Yucca Mountain area, have total dissolved solids of less than 300 parts per million (Benson et al., 1983; Winograd and Thordarson, 1975). Thus, ground water with 10,000 parts per million or more of total dissolved solids probably does not occur along any path of likely radionuclide travel from the disturbed zone to the accessible environment.

Conclusion: Reported analyses on local ground water indicate that it is unlikely that the total dissolved solids could reach or exceed 10,000 ppm in the ground water along any path of likely radionuclide travel. Therefore, the Yucca Mountain site does not possess this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units--sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.

Evaluation of climatic changes: Geohydrologic conditions can change because of both construction-induced and naturally occurring processes. Construction-induced changes generally would be confined to a small volume immediately surrounding the repository and its facilities, such as access and ventilation shafts. Such changes are discussed further under the guideline for Rock Characteristics in Section 6.3.1.3.

Natural changes may occur either in the immediate vicinity of the repository or at greater distances. Changes that might be expected in geohydrologic conditions due to natural processes include: (1) a change in the rate of ground-water recharge, due to climatic changes; (2) increased hydraulic conductivity or changes in the spatial relationships among geohydrologic units due to tectonic movements; and (3) changes in the effective porosity caused by an increase in the number of fractures, or by an increase or decrease of their apertures.

Major global climatic fluctuations probably will occur within the next 100,000 years, based on current knowledge of the dynamics of climate and of geological and climatic records of past changes. Among those things that can cause climatic changes are increases in global atmospheric carbon dioxide (CO_2), changes in the earth's orbit and possible change of the earth's magnetic field, which has reversed about every 700,000 years. The possible climatic effects of these changes (Spaulding, 1983) are summarized below.

A substantial increase of CO_2 in the atmosphere would increase radiative heating of the earth's surface and result in melting of the Antarctic ice cap (Etkins and Epstein, 1982; Kukla and Gavin, 1981). The subsequent rise in sea level would not directly affect the Yucca Mountain site, but temperatures could increase by 3°C (5°F) or more, and summer rainfall would increase.

The configuration of the earth's orbit partly controls solar radiation received by the earth, and changes in precession, obliquity, or eccentricity of the orbit may be the principal causes of ice ages (Imbrie and Imbrie, 1980). If so, orbital changes would continue to influence the cooling trend of the last 6,000 years and would result in a glacial stage in about 23,000 years and a glacial maximum in 60,000 years, similar in magnitude to that of the late Wisconsinan maximum (about 18,000 years ago). Return to a pluvial climate would mean an increase in effective moisture, but valley floors would remain semiarid. Annual precipitation would be 30 to 40 percent greater, with a pronounced scarcity of summer rainfall. Mean annual temperature would be 6 to 7°C (11 to 13°F) lower than present.

Evaluation for change in recharge rate: Effects of an increase in recharge rate include the possibility of an increase in hydraulic gradient in the saturated zone, resulting in a higher position of the water table beneath Yucca Mountain. Also, flow paths in the saturated zone may change and flow rates increase.

Preliminary computer modeling of ground-water flow near Yucca Mountain indicates that ground-water flow paths would not significantly change as a result of increased recharge at and north of Yucca Mountain (Czarnecki, 1984). Saturated and unsaturated flow velocities would increase approximately proportional to the estimated percentage increase in total recharge. Estimated travel times would be correspondingly shorter. Effects on radionuclide releases to the accessible environment probably would be quite small because of the high sorptive capacity of the Calico Hills nonwelded unit (see Section 6.3.1.2).

The likely amount of water table rise is addressed under Climatic Changes (see Section 6.3.1.4). The water table probably would not rise enough to inundate the repository, but might rise enough that much of the Calico Hills nonwelded unit would be saturated. Hydraulic conductivity of this unit would increase because of the increase in saturation, but the effective matrix porosity would increase and the hydraulic gradient would decrease substantially, from approximately unity under present conditions of vertical unsaturated flow to an amount necessary to transmit water under saturated conditions. The geochemical barrier provided by the Calico Hills nonwelded unit would still retard the movement of radionuclides, although movement could be more rapid than during periods of less recharge.

If the rise of the water table were enough to saturate part of the Topopah Spring welded unit, part of the water would not pass through the Calico Hills nonwelded unit and, for that part of the flux through the repository, radionuclide movement would be more rapid. Retardation would still occur by sorption and matrix diffusion. The required water table rise is unlikely, but the possibility of such an event is still being studied.

Although, no evidence of modern or Quaternary springs or seeps at Yucca Mountain has been observed, water from any springs or seeps that might develop on the flanks of Yucca Mountain during periods of increased recharge would not pass through the repository, for the flow would be perched and the repository would be at a lower altitude than such springs. Water moving through the repository would enter the saturated ground-water system locally, and travel toward the regional discharge areas.

Evaluation of tectonic movement: The Basin and Range Province is tectonically active and is characterized by earthquakes, above average heat flow, and past volcanic activity (see Section 6.3.1.7). Faults of Quaternary age occur near Yucca Mountain, although none are known within the repository block (Swadley et al., 1984). Reactivated movement along these faults, or new faults could result in changes in the geohydrologic system. The effects of these changes are probably insignificant to the performance of the repository, as discussed in Section 6.3.1.4.

The repository block is relatively free from faulting as compared to the surrounding areas; however, the proposed host rock is a densely welded tuff, and frequency of fractures is expected to be high. The unsaturated host rock is free draining, and an increase in the number of fractures caused by renewed faulting generally would not be detrimental. Movement along a fault cutting the repository is not likely to have a significant effect on flux of water through the host rock, which would be expected to remain quite low (Montazer and Wilson, 1984). Any effect on the dissolution rate of waste also would be slight because of the low flux.

Tectonic movement at Yucca Mountain could result in an increase in the number of fractures in the Calico Hills nonwelded unit. However, increase in fracturing within this unit probably would have no effect on flow in the unsaturated zone. Data on the hydrology of the Calico Hills nonwelded unit indicate that, where the unit is unsaturated, fracture flow probably does not occur under the most likely prevailing flux. The matrix hydraulic conductivity of the Calico Hills unit generally is high enough for this unit to transmit flux that enters from the overlying Topopah Spring welded unit. Matrix flow rather than fracture flow occurs because matric potential (suction) is higher in the matrix than in the fractures.

Even within the saturated zone, fracture flow probably is not significant in the Calico Hills nonwelded hydrogeologic unit. Observations in drill holes indicate that the Calico Hills nonwelded unit is generally less fractured than welded tuffs in the section. In addition, hydraulic data for the Calico Hills nonwelded unit within the saturated zone at well J-13 indicate that fracture permeability is low (Thordarson, 1983). At well UE-25b#1, the unit is more permeable (Lahoud et al., 1983; 1984); this site is in Drill Hole Wash, where fractures not typical of most of Yucca Mountain could account for the higner permeability.

Within the saturated zone, an increase in fracture frequency probably would increase flow rates slightly. Such an increase in fracture frequency probably would also result in a decline in the attitude of the water table where it occurs within the Calico Hills nonwelded hydrogeologic unit, because a lesser gradient would be required to move water through the unit.

An increase in fracture frequency in the units below the Calico Hills nonwelded unit would have little effect on flow rates. Drill-hole data indicate that most of the flow occurs within fractures, which are already quite common in the moderately to densely welded tuffs. The resulting small increase in hydraulic conductivity probably would not be significant.

The rate of fault movement is low enough that displacement of hydrogeologic units over the next 10,000 years is expected to be insignificant (see Section 6.3.1.7).

Evaluation of changes in effective porosity: Potential changes in effective porosity probably would have a negligible effect on the transport of radionuclides to the accessible environment. In the tuffs where fracture flow is dominant, a decrease in effective porosity would be accompanied by a larger decrease in hydraulic conductivity because effective porosity is a function of the aperture size, while conductivity is a function of the square of the aperture size. In the unsaturated zone, an increase in effective porosity could occur as a result of fracture formation, which probably would increase the ability of the host rock to freely drain excess water, a favorable characteristic. In the saturated zone, effective porosity could increase by fracture formation, or decrease by mineral precipitation. Retardation within the saturated zone probably would be minimally affected. On the other hand, a decrease in effective porosity by precipitation of minerals in fractures would be more than offset by increased sorption; fracture coatings (zeolites, smectites, and manganese oxides) have very reactive surfaces that greatly increase retardation.

Conclusion: No changes in geohydrologic conditions are expected that would significantly increase the transport of radionuclides to the accessible environment. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.

Evaluation: The probable ground-water flow paths away from the proposed repository are generally to the south or southeast toward Jackass Flats and the Amargosa Desert (Waddell, 1982; Robison, 1984). Possible ground-water sources along those flow paths are defined in the guidelines as "aquifers that have been or could be economically and technologically developed as sources of water in the foreseeable future."

Ground water withdrawn from the Yucca Mountain area, as from wells J-12 and J-13, has been mostly used as drilling water for exploratory holes and locally at the Nevada Test Site and not for irrigation.

Beneath Yucca Mountain, the water-resources potential is low compared with other areas in the vicinity of the Nevada Test Site due to topographic drilling constraints (Sinnock and Fernandez, 1982). In the vicinity of Fortymile Canyon and western Jackass Flat, the potential is considered higher; however, everywhere within the controlled area, the depth to water is 250 m (800 ft) or more, and pumping lifts for ground water are likely to be uneconomical for irrigation.

From the standpoint of the commercial value of ground water, irrigation is not of major concern in the site area primarily because of the poor characteristics of the alluvium, which makes the site undesirable for agricultural use. The alluvium is coarse grained and drains rapidly except in the playa areas, where concentration of salts makes it unlikely that crops could be grown. Pressure to develop ground water locally for human consumption is not likely to occur because land use is restricted.

Conclusion: Ground-water sources suitable for crop irrigation and human consumption are present at Yucca Mountain along ground-water flow paths between the host rock and the accessible environment. However, because of land-use restrictions, great depths to ground water, and topographic conditions, the ground-water resources potential is small compared with that in nearby areas, such as the Amargosa Desert. Nonetheless, the Yucca Mountain site possesses this potentially adverse condition.

(3) The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets--if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.

Evaluation: The available reports and conclusions about the general complexity of the Yucca Mountain area are discussed under Favorable Condition (3) of this section.

The surface geology at Yucca Mountain is well known from detailed mapping (Scott and Bonk, 1984). Because of the numerous drill holes and geophysical data, unexpected features in the subsurface environment are improbable. Locations and displacements of normal faults can be estimated with reasonable certainty. Zones with small displacement occur north of the repository block; the high hydraulic gradient in the area where they occur (Robison, 1984) indicates that the permeability along these zones probably is low, except for along the lower part of Drill Hole Wash. Numerous drill holes have been drilled in or near Drill Hole Wash to characterize the zone. Small basaltic dikes have been observed on the flank of Yucca Mountain northwest of the proposed repository block, but there is no evidence to indicate that they extend into the block itself.

Two-dimensional modeling of flow in the saturated zone on a regional scale has been accomplished and it includes recharge, discharge, and structural feature (Waddell, 1982; Czarnecki and Waddell, 1984). Conceptual models of flow mechanisms in the unsaturated zone have been developed based on limited data from a few drill holes (Montazer and Wilson, 1984).

Conclusion: Faults, fracture zones, and dikes are known to exist at and near the Yucca Mountain site, but they do not prevent characterizing and modeling the geohydrologic system. No sills, folds, dissolution effects, or brine pockets are known to occur at Yucca Mountain. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

VI. DISQUALIFYING CONDITION

A site shall be disqualified if the expected pre-waste-emplacement ground-water 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 ground-water 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.

Evaluation: The time required for water to travel from the proposed repository location to the accessible environment depends upon the hydraulic properties of the formations through which the water will flow, the hydrologic conditions, and the lengths of flow paths. The flow path of interest at Yucca Mountain includes segments in both the unsaturated and saturated zones. The rocks at Yucca Mountain consist mainly of ash-flow tuff, bedded tuff, and lava that extend to depths greater than 1800 m (6000 ft). Depths to the water table range from 300 to 750 m (1000 to 2500 ft) below the land surface. A summary of stratigraphic and hydrogeologic units is shown on Table 6-5.

A portion of the precipitation that falls on Yucca Mountain infiltrates below land surface. Percolation is vertical through the unsaturated zone, driven by a vertical hydraulic gradient of unity due to gravity. Flux is determined by the volume and rate of infiltration and by the hydraulic properties of rocks in the unsaturated zone. Upon reaching the water table beneath Yucca Mountain, this water joins other ground water in transit from sources of recharge north or northwest of Yucca Mountain. The ground water then moves generally horizontally to the accessible environment, driven by a hydraulic gradient approximately equal to the slope of the water table and controlled by the hydraulic properties of the intervening rocks.

A discussion of expected percolation rate (flux) past a repository is presented below, followed by calculations of ground-water travel times along distinct segments of likely flow paths. The sum of the travel times of the segments along a given flow path equals total travel time from the disturbed zone to the accessible environment. Several calculated values of travel time are presented for flow through the unsaturated zone because

1. The extent, and, therefore, the outer boundary, of the repository disturbed zone is not yet defined.

2. Distinct travel paths exist through two different parts of the Calico Hills nonwelded unit, each of which has a different permeability.

Infiltration-Percolation-Recharge: The study of movement of water through the unsaturated zone requires values of recharge flux. At the repository location, the most likely value for infiltration of precipitation (flux) below land surface probably is less than 1 mm/yr (0.04 in./yr). This conclusion was reached after considering a variety of approaches to estimating recharge flux as described below.

Annual precipitation, in the Yucca Mountain area is approximately 150 mm per year (see Section 6.3.1.4). Less than 3 percent of the annual precipitation is expected to provide recharge to the ground-water system (Rush, 1970). Therefore, based on inferred regional relationships among climate, infiltration, and ground-water budget, recharge at Yucca Mountain would be less than 4.5 mm/yr (0.18 in./yr). However, these regional relationships are not reliable for determining the recharge at a particular site, where the actual value depends on microclimate, soil condition, vegetation, surface slopes, and other local factors that influence recharge.

The most direct evidence for low flux through the host rock of the proposed repository is provided by recent data from borehole USW UZ-1 (Montazer et al., 1984). Moisture contents of drill cuttings (about 5 percent by weight) from the Topopah Spring welded unit correspond to a saturation of about 80 percent; the low matrix hydraulic conductivity and matric potential of greater than 20 bars in the matrix of the cuttings indicate that no significant liquid-phase flow is occurring in the matrix. Preliminary data from field measurements in UZ-1 show that matric potentials of 5 to 25 bars occur at depths of 150 to 300 m (500 to 1000 ft). These values support the drill cutting data and also indicate that very little water is moving through the

Topopah Spring welded unit. The suction pressure of the rock matrix indicated by the measurements would be sufficient over a long period of time to pull any water into the matrix; this strongly indicates that very little, if any, water is moving through the fractures. As a result, fracture flow is not likely because water moving through most fractures could travel only a few tens of meters at most before being drawn into the matrix by the high matric potential (suction). Saturated matrix hydraulic conductivities of both the Topopah Spring welded unit and the zeolitic portion of the Calico Hills nonwelded unit (the latter underlies northern and eastern Yucca Mountain) are about 1 mm/yr (Montazer and Wilson, 1984). These values set an upper limit on the amount of flux moving through the matrix in the unsaturated portions of these units, where the hydraulic gradient is unity. Known empirical relationships between field hydraulic conductivity and percentage saturation indicate that field values are normally one-tenth to one-hundredth of the saturated conductivity, even for saturations as high as 80 percent, which is the maximum values observed in the cuttings from the Topopah Spring welded unit at UZ-1 (Weeks and Wilson, 1984; Montazer et al., 1984). Thus, the actual average flux through the matrix of the Topopah Spring welded unit probably is only a fraction of 1 mm/yr (0.04 in/yr), probably 0.1 mm (0.0004 in/yr) or less.

Travel time calculations: Ground-water travel times were calculated using a flux of 1 mm/yr. Case A represents matrix flow through the Topopah Spring welded unit, and through the 100 m (300 ft) thick zeolitic part (hydraulic conductivity = 1 mm/yr) of the Calico Hills nonwelded unit. Case B similarly represents matrix flow through the welded Topopah Spring; however, for Case B, flow in the Calico Hills unit occurs through the vitric portion, which is 250 m (800 ft) thick and has a hydraulic conductivity of 2600 mm/yr (102 in./yr).

Figure 6.3.1.1-1 shows maps of the proposed repository block at Yucca Mountain and indicates the location of the hydrogeologic section which is shown in Figure 6.3.1.1-2. Figure 6.3.1.1-2 shows the expected ground-water flow paths. The following presents the calculation for the unsaturated zone and the saturated zone.

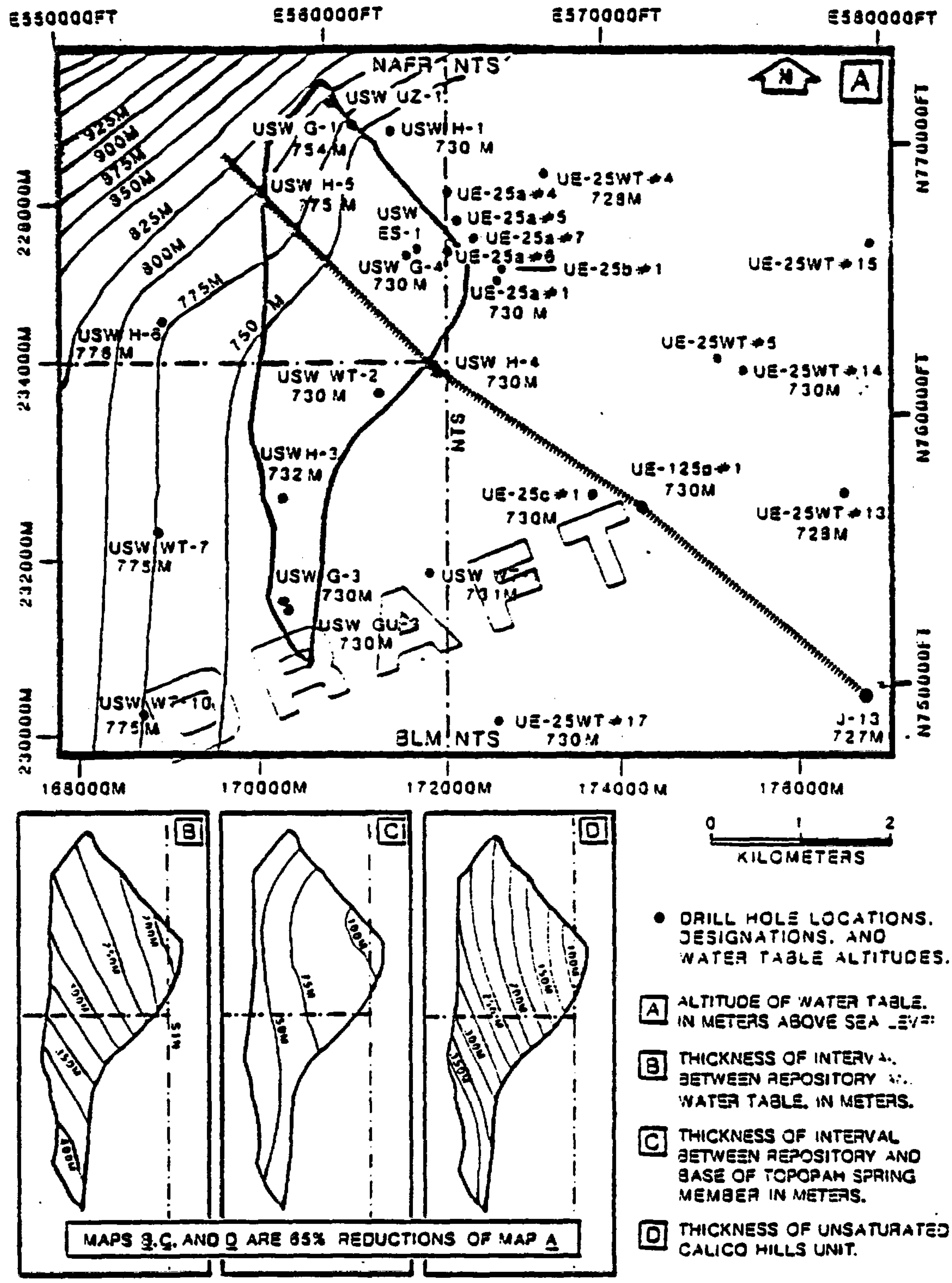

Figure 6.3.1.1-1. Maps of proposed repository block at Yucca Mountain showing location of drill holes and hydrogeologic section for Figure 6.3.1.1-2. (A) altitude of water table in meters above sea level, (B) thickness of material between repository and water table in meters, (C) thickness of interval between repository and base of Topopah Spring Member, and (D) thickness of Calico Hills nonwelded unit above water table.

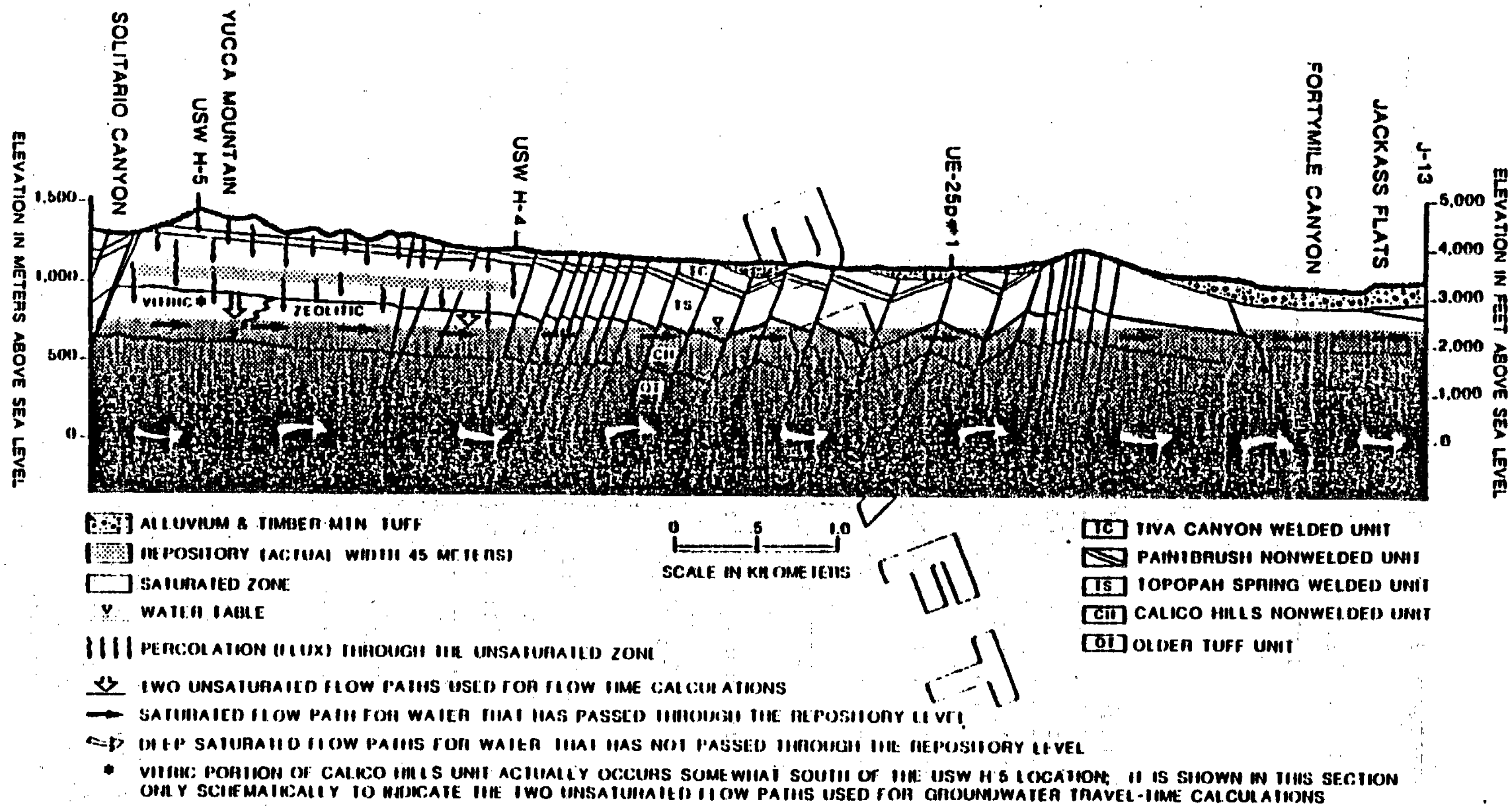

Figure 6.3.1.1-2. Conceptual hydrogeologic section from Solitario Canyon, northwest of the site, to well J-13, in Jackass Flats. See Figure 6.3.1.1-1 for location of cross section.

1. Unsaturated zone: flux = 1 mm/yr or less (1 mm = 0.04 in)

Case A. Matrix flow through Topopah Spring welded unit and zeolitic part of the Calico Hills nonwelded unit:

	Topopah Spring welded unit	Zeolitic Calico Hills nonwelded unit
Hydraulic gradient (i)	1.0	1.0
Hydraulic conductivity (k_s)	1 mm/yr	1 mm/yr
Effective porosity (n_e)	0.1	0.2
Minimum thickness (d)	50 m	100 m
Particle velocity (v_s), where $v_s = k_s i/n_e$	10 mm/yr	5 mm/yr

Travel time = thickness/particle velocity

Travel time (Topopah Spring welded unit):

$$\geq \frac{>50 \text{ m}}{10 \text{ mm/yr}} \geq 5{,}000 \text{ yr}$$

Travel time (Zeolitic Calico Hills nonwelded unit):

$$\geq \frac{>100\text{m}}{5 \text{ mm/yr}} \geq 20{,}000 \text{ yr}$$

(Minimum thickness of Topopah Spring welded unit along any vertical flow path does not coincide with minimum thickness of Calico Hills nonwelded unit; therefore, summation of travel times would be conservatively low.)

Case B. Matrix flow through Topopah Spring welded unit and vitric part of the Calico Hills nonwelded unit:

	Topopah Spring welded unit	Zeolitic Calico Hills nonwelded unit
Hydraulic gradient (i)	1.0	1.0
Hydraulic conductivity (k_s)	1 mm/yr	2,600 mm/yr
Effective porosity (n_e)	0.1	0.2
Minimum thickness (d)	50 m	250 m
Particle velocity (v_s)	10 mm/yr	5 mm/yr

For the vitric Calico Hills nonwelded unit, maximum v_s is

$$v_s = \frac{2,600 \text{ mm/yr} \times 1.0}{0.2} = 13,000 \text{ mm/yr}$$

However, the overlying Topopah Spring welded unit limits the flux available to the Calico Hills nonwelded unit to 1 mm/yr or less; therefore, the actual maximum is

$$v_s = \frac{1 \text{ mm/yr} \times 1.0}{0.2} = 5 \text{ mm/yr}$$

Thus, Travel time (Topopah Spring welded unit)

$$\geq \frac{>50 \text{ m}}{10 \text{ mm/yr}} \geq 5,000 \text{ yr}, \quad \text{and}$$

Travel time (vitric Calico Hills nonwelded unit)

$$\geq \frac{>250 \text{ m}}{5 \text{ mm/yr}} \geq 50,000 \text{ yr}$$

2. Saturated zone - from the eastern edge of the repository block along a southeastward flow path for a distance of 10 km (6 mi) to the accessible environment.

Forty percent or more of ground-water flow path [4 km (2.5 mi)] would be through the tuffaceous beds of the Calico Hills nonwelded unit and 60 percent or less of the flow path [6 km (4 mi)] would be through the welded (Topopah Spring Member) or welded Crater Flat Tuff (Prow Pass or Bullfrog) (see Figure 6.3.1.1-2). Based on water-level altitudes of 730.8 m (2398 ft) at USW H-4 and 727.3 m (2386 ft) at well J-13 (Robison, 1984) the average hydraulic gradient (i) between the repository block and the accessible environment is

$$i = \frac{730.8 \text{ m} - 727.3 \text{ m}}{10.3 \text{ km}} = \frac{3.5 \text{ m}}{10.3 \text{ km}} = 3.4 \times 10^{-4}$$

The average saturated hydraulic conductivity for the Calico Hills nonwelded unit is conservatively assumed to be 0.16 m/day (0.5 ft/day), based on values of 0.26 m/day (0.8 ft/day) for bulk conductivity determined from pumping tests in test well UE-25b#1 (Lahoud et al., 1984) and 0.06 m/day (0.2 ft/day) from well J-13 (Thordarson, 1983). Hydraulic conductivity for

Paintbrush Tuff and Crater Flat Tuff is assumed to be about 1 m/day (3.3 ft/day), based on analyses of USW H-1, UE-25b#1, and J-13 data (Rush et al., 1984; Lahoud et al., 1984; Thordarson, 1983). Saturated flow probably occurs principally in fractures. Lacking data on tuffs from Yucca Mountain, an upper bound of 0.005 is assumed for effective porosity and a lower bound of 0.002.

For the Calico Hills nonwelded unit, the particle velocity v_s is calculated as follows:

$$v_s = \frac{0.16 \text{ m/day} \times 3.4 \times 10^{-4}}{0.005 \text{ to } 0.002}$$

$$= 0.011 \text{ to } 0.027 \text{ m/day}$$

$$= 4 \text{ to } 10 \text{ m/yr}$$

$$\text{Travel time (Calico Hills nonwelded unit)} = \frac{4 \text{ km}}{4 \text{ to } 10 \text{ km/yr}}$$

$$= 400 \text{ to } 1000 \text{ yr}$$

Similarly, v_s for Paintbrush/Crater Flat is as follows:

$$v_s = \frac{1 \text{ m/day} \times 3.4 \times 10^{-4}}{0.005 \text{ to } 0.002}$$

$$= 0.068 \text{ to } 0.17 \text{ m/day}$$

$$= 25 \text{ to } 62 \text{ m/yr}$$

$$\text{Travel time (Paintbrush/Crater Flat)} = \frac{6 \text{ km}}{25 \text{ to } 62 \text{ km/yr}}$$

$$= 100 \text{ to } 240 \text{ yr}$$

$$\text{Therefore, total saturated-zone travel time} = (400 \text{ to } 1000 \text{ yr}) + (100 \text{ to } 240 \text{ yr}) = 500 \text{ to } 1200 \text{ yr}$$

Summary of travel times: The summary below shows that for expected conditions at Yucca Mountain, the travel time from the disturbed zone to the accessible environment exceeds 20,000 years. This is based on the conservative assumption that the disturbed zone extends from the repository to the base of the Topopah Spring welded unit as indicated in the final row of the travel time summary. The travel time through the 50 to 100 m (160 to 330 ft) of the Topopah Spring welded unit between the repository and the top of the Calico Hills nonwelded unit has not been considered.

Travel Time Summary

	Travel Times (years) Flux < 1 mm/yr	
	Zeolitic	Vitric
Unsaturated Topopah Spring welded unit	5,000	5,000
Unsaturated Calico Hills nonwelded unit	20,000	50,000
Saturated zone	500-1,200	500-1,200
Total travel time (including Topopah Spring welded unit)	>25,500	>55,500
Total travel time from disturbed zone to accessible environment (not including Topopah Spring welded unit)	>20,500	>50,500

Radionuclide release: Because of retardation by sorption, travel times of radionuclides would be very long, and integrated release at the accessible environment for 10,000 years would be zero, except for technetium, carbon, and iodine radioisotopes, which would only be released at a few percent of the allowable limits (see Section 6.4.2). Because of this and the very low ground-water flux past the repository, total release of radionuclides to the accessible environment in 10,000 years will be less than that specified in 10 CFR 960.4-1(a). Therefore, even in the unlikely case of unsaturated flow restricted only to fractures, the Yucca Mountain site would not be disqualified under this guideline.

<u>Conclusion:</u> Analysis of field and laboratory data indicates that the expected pre-waste-emplacement ground-water travel time at Yucca Mountain along all paths of likely radionuclide travel from the disturbed zone to the accessible environment exceeds 1000 years. Based on bounding performance (see Section 6.4.2) calculations, the total release of radionuclides to the accessible environment in 10,000 years will be less than allowed by 10 CFR 960.4-1(a), and thus by 40 CFR 191. This conclusion is based on the very low volume of ground water expected to flow through the unsaturated zone and the high retardation capacity along the flow paths between the repository and the accessible environment. Therefore, the Yucca Mountain site is not disqualified based on this disqualifying condition.

VII. PLANS FOR SITE CHARACTERIZATION

Various hydrologic tests are planned during site characterization, including the construction phase and in situ phase of Exploratory Shaft testing at Yucca Mountain. Radial boreholes from within the shaft will be used to determine vertical permeability and to evaluate the extent of mining induced changes in vertical permeability near the shaft. Vertical flux and flux mechanisms, particularly across hydrogeologic boundaries, will be evaluated by injection tests and continuous monitoring in boreholes. Samples of pore water will be dated and used to determine the relative proportion of fracture flow and matrix flow. Thermal logs will be used to estimate potential vertical fluid movement in the unsaturated zone, important for confirming estimates of infiltration.

A bulk permeability test will be conducted during the in situ phase of testing and used to establish the hydrologic characteristics of a larger volume of the host rock than can be sampled in a borehole test. Results from this test will be used to improve hydrologic models and to make comparisons to borehole and laboratory-scale measurements. An infiltration test is planned to obtain the hydraulic properties of the host rock, including permeability and flow characteristics, and to provide data for permeability-matric potential curves.

Hydrologic testing of the Calico Hills nonwelded unit, which underlies the potential repository host rock, is also planned. Transport properties and/or barrier characteristics of this unit will be extremely important in establishing the value of this unit for retardation of radionuclides.

6.3.1.2 Geochemistry (10 CFR 960.4-2-2)

I. INTRODUCTION

The Geochemistry Technical Guideline addresses the present and expected geochemical characteristics of the proposed Yucca Mountain site and provides the basis for demonstrating compatibility with performance objectives for waste containment and isolation as specified in the Nuclear Regulatory Commission and the Environmental Protection Agency technical criteria.

The Geochemistry Guideline contains one qualifying condition, five favorable conditions, and three potentially adverse conditions. The Yucca Mountain site is evaluated with respect to all those conditions in the following sections.

II. RELEVANT DATA

The mineral content, mineral composition, and petrographic texture of the minerals at and near Yucca Mountain (Lipman et al., 1966) have been determined from drill core rock samples and bit cuttings (Heiken and Bevier, 1979; Sykes et al., 1979; Bish et al., 1982; Carroll et al., 1981; Caporuscio et al., 1982; Vaniman et al., 1984; Levy, 1984; Bryant and Vaniman, 1984). The potential host rock at Yucca Mountain is the Topopah Spring Member, which is composed of approxomately 98 percent quartz, feldspar, and cristobalite with lesser amounts of zeolites and clays (Bish et al., 1982)

The equilibrium chemical behavior of radionuclides is still under active study; however, enough is known to predict the general behavior of most elements (Apps et al., 1983; Allard, 1982). Solubilities of waste elements in water from Yucca Mountain and in similar waters have been calculated using equilibrium thermodynamic methods (Wolfsberg et al., 1982; Apps et al., 1983; Allard, 1982). A program to experimentally determine spent fuel and borosilicate glass dissolution rates is under way (Oversby, 1983). The solubility of spent fuel in an oxidizing environment compared with a reducing environment has been calculated using data compiled by Lemire and Tremaine (1980).

The minerals present in Yucca Mountain that contribute significantly to sorption have been identified as the zeolites clinoptilolite, mordenite, and the clay minerals smectite and illite (Daniels et al., 1982). Sorption ratios, K_d, have been measured for many radionuclides for a large variety of tuff samples using batch sorption techniques. More than 40 tuff samples from 9 different tuff units have been studied (Ogard et al., 1983a, 1983b; Wolfsberg et al., 1983; Bryant, et al., 1984). Temperatures to be expected in the repository have been calculated (Johnstone et al., 1984; Travis, 1984). The location of the sorbing minerals in Yucca Mountain is largely determined (Bish et al., 1984; Vaniman et al., 1984) although details of sorptive stratigraphy remain to be resolved. Reaction chemistry for certain sorbing minerals has been investigated (Smyth, 1982); more information is needed on sorptive mineral stabilities (Bish and Semarge, 1982).

The recharge rate of water into the unsaturated zone at Yucca Mountain has been estimated based on several lines of evidence by Montazer et al. (1984). Water from wells in the vicinity of Yucca Mountain has been analyzed and species naturally present in the water can be estimated (Daniels et al., 1983; Benson et al., 1983). Little quantitative information is available about the formation of colloids or the particulate content of water from the vicinity of Yucca Mountain (Rai and Swanson, 1981; Kim et al., 1983; Olofsson et al., 1983; Newton and Rundberg, 1983). The effects of matrix diffusion on the movement of radionuclides relative to the water in fractured rock with a low matrix permeability has been studied by Neretnieks (1980). The porosity of Yucca Mountain tuffs has been measured (Johnstone and Wolfsberg, 1980). The effective diffusivities of tuffs from Yucca Mountain and Rainier Mesa have been measured (Daniels et al., 1983; Walter, 1982).

Reactions of Topopah Spring tuff with Yucca Mountain groundwater at 90°C and 150°C (194°F and 302°F) have been studied (Knauss et al., 1983). Data on the laboratory synthesis of some of the minerals in the tuff are available (Hawkins, 1981; Chi and Sand, 1983) and can be supplemented by the results of hydrothermal experiments (Wolfsberg et al., 1983) and thermodynamic calculations (Daniels et al., 1983). The corrosion of a reference waste container material (304 L stainless steel) in the repository environment has been studied by McCright et al. (1983).

Assumptions and Data Uncertainties: Indirect methods will be used to estimate the initiation and duration of geochemical processes resulting in alteration because techniques for direct age dating of alteration products at the Yucca Mountain site have not been fully developed. Clinoptilolite and mordenite now present in Yucca Mountain are assumed to have been there for about 10 million years. A temperature increase from 35 to 60°C (95 to 140°F) is assumed not to produce significant increases in the kinetics of the breakdown of clinoptilolite and mordenite.

For discussion about precipitation and complex formation, equilibrium chemical behavior is assumed; this assumption is generally valid. Discussions about colloid formation are based on empirical observations. For sorption, the minerals in the entire crushed rock are assumed to be those sorbing in fractures. This should be a conservative assumption because the altered minerals typical of fracture fillings are probably more sorptive than the average matrix minerals. Retardation factors are calculated based on the assumption of equilibrium conditions.

There is uncertainty in the flux and flow mechanisms of water at Yucca Mountain, and for conservatism, the expected maximum flux was used in this analysis. Although water from Yucca Mountain has been characterized, the solubilities of many waste elements in that water have not been experimentally determined and are, therefore, estimated by calculations using a computer model at this time (Wolfsberg et al., 1982). The model used to estimate waste element dissolution rates incorporates a number of assumptions about water flow, waste element diffusivities in the water, and solid waste form characteristics (Kerrisk, 1984). The assumptions that were made for the analysis are considered conservative.

Another area of uncertainty involves fracture attributes. Important fracture attributes affecting water flow, such as fracture aperture, fracture spacing, and connectivity, are sufficiently known to develop a hydrologic model [Section 6.3.1.1, Favorable Condition (3)]. However, if fracture flow is important, chemical retardation factors based on equilibrium conditions may not be accurate; with fracture flow, the kinetics of adsorption or absorption could become important. If fracture flow were to occur, then solute transport could be enhanced over that which occurs under matrix flow conditions. If significant transport occurs by colloid or complex formation, then there will be uncertainty about retardation coefficients and diffusivities. Finally, only liquid-borne radionuclide transport has been considered.

Analyses of precipitation, the formation of particulates, colloids, and inorganic or organic complexes are generally based on qualitative assessments of the general behavior of aqueous chemical systems. Geochemical retardation by sorption is estimated by using the retardation factor [as discussed in (c) of Favorable Condition (2)].

The dissolution rates of waste elements from a solid waste form at Yucca Mountain were estimated by using a model in which dissolution rates are limited by diffusion of elements into water flowing past the waste (Kerrisk, 1984). Waste elements are assumed to be saturated at the waste-water interface. This model has been proposed as being more realistic than leach-rate models (Chambre' et al., 1982). Experimental data are now becoming available that validate this proposal (Chick, 1983; Grambow and Strachan, 1983; Oversby, 1983). A second model, in which the total water flow through the repository area is assumed to become saturated with each waste element, is also discussed by Kerrisk (1984). Results from this model represent upper limits on the dissolution rates of waste elements, not expected values; therefore, they are conservative.

III. QUALIFYING CONDITION

The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1

<u>for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology</u>.

<u>Evaluation:</u> Identified geochemical processes involving mineralogic reactions have been inoperative at Yucca Mountain during the Quaternary Period or have, during this period, occurred at low enough rates and affected small enough areas not to affect the ability of the geologic repository to isolate waste during the next 100,000 years. Predictions of stability of processes affecting ground-water chemistry are less certain. The pH of the water from the vicinity of Yucca Mountain is in the range where most oxide and hydroxide precipitates (particularly actinides) show a minimum solubility. The matrix properties of the host rock and surrounding units favor diffusion, [see (b) of Favorable Condition (2)] and geochemical conditions at Yucca Mountain promote the sorption of radionuclides. The total organic content of water from the vicinity of Yucca Mountain is very low; no significant quantities of organic complexes containing waste elements are likely to form. The movement of particulates and colloids may be greatly inhibited by the presence of zeolitized tuff, which is located beneath the repository horizon and expected to have relatively few fractures. Although there may be minor decreases in the sorptive mineral content in some places in Yucca Mountain in the next 100,000 years, present knowledge indicates that the sorptive capacity will not significantly decrease; and that it may, in fact, increase. The expected geochemical conditions and water flow rate at Yucca Mountain will allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1000 years after permanant closure to be dissolved. There are several retardation processes that will decrease projected peak cumulative radionuclide release to the accessible environment by a factor of 10 as compared with release projections that are based on ground-water travel time without such retardation.

Water conditions in the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain are expected to be such that the solubility and chemical reactivity of the engineered barrier system will give satisfactory performance under expected repository conditions. Although the sorptive zeolites (clinoptilolite and mordenite) may break down over long periods of geologic time, very little reaction is expected in the next 100,000 years. Changes in the redox state of the water due to interaction with the 304L stainless steel waste containers could potentially mitigate the consequences of the chemically oxidizing pre-waste emplacement ground-water conditions.

Conclusion: The present and anticipated geochemical characteristics of the Yucca Mountain site provide reasonable expectation that radionuclide releases to the accessible environment and radionuclide releases from the engineered barrier system will meet the applicable limits and performance objectives. In Section 6.3.2, preliminary analyses suggest releases may be as low as 2 percent of the Environmental Protection Agency release standards at the accessible environment. The engineered barrier system is expected to meet performance objectives for containment and isolation because of the benign chemistry of the unsaturated emplacement environment and the extremely low water flux. Therefore, the Yucca Mountain site meets the qualifying condition for geochemistry.

IV. FAVORABLE CONDITIONS

(1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

Evaluation: The approach in responding to this favorable condition has been to divide geochemical processes into two categories: (1) those processes that could involve mineralogic reactions and changes in mineral assemblages within the potential host rock; and (2) unspecified geochemical processes that could affect the stability of the ground-water chemistry. The approach to establishing this favorable condition with regard to geochemical processes of the first category has been to identify all geochemical processes resulting in mineralogic changes and to determine the nature and rate of such changes.

The predominant geochemical processes resulting in mineralogic changes at Yucca Mountain are the alteration of volcanic glass to the zeolites clinoptilolite and mordenite and to minor clay minerals, and the recrystallization of this mineral assemblage to analcime, feldspar, quartz, and mica. Although the process of zeolitization is interpreted as diagenetic alteration of glassy tuffs near the water table, Hoover (1968) and Bryant and Vaniman (1984) present evidence for possible zeolitization above the water table. The alteration of glass to zeolites and clay is a favorable geochemical process because it increases the radionuclide sorptive capacity of the affected rock. Although this increased sorptive capacity is a favorable condition, there may be other unknown effects due to the increased water content that are not necessarily favorable. Therefore, a zeolitization rate that was close to zero during the Quaternary Period, which provides a basis for projecting a similar zeolitization rate for the next 100,000 years, may be the most favorable condition.

Petrofabric studies of the altered rocks, combined with information about the tectonic history of the area, indicate that zeolitic alteration of glasses at Yucca Mountain predated the Quaternary Period. Because this geochemical process has probably not been operating during the Quaternary Period (Bryant and Vaniman, 1984), the Quaternary rate of the process is inferred to be close to zero. Barring climatic changes that would significantly increase the ground-water recharge or raise the static water level at Yucca Mountain, zeolitization should be an inoperative or minor process during the next 100,000 years, although the effect on potential glass-to-zeolite reactions due to increased heat from waste emplacement can not yet be predicted. The potential for enhanced alteration is being evaluated by studies of the paleotemperatures of past zeolitization events. It would be likely for future zeolitization to occur either in the upper tuffaceous beds of Calico Hills or in stratigraphically higher rock units, if the environment becomes wet enough to cause saturation of these rocks.

Although future zeolitic alteration of glasses is not likely, studies of mineral assemblage transitions associated with increasing depth and subsurface temperature suggest that recrystallization of clinoptilolite-mordenite assemblages to analcime assemblages may have occurred during the Quaternary Period and may continue during the next 100,000 years. This recrystallization has taken place at Yucca Mountain at depths greater than about 945 m (3100 ft). The recrystallized rocks are overlain by an interval at least 488 m (1600 ft) thick in which the zeolitized tuffs contain the highly sorptive zeolites clinoptilolite and mordenite (Bish et al., 1981; Caporuscio et al., 1982; Vaniman et al., 1984.) Factors affecting the recrystallization include time, temperature, and pore fluid chemistry (Dibble and Tiller, 1981). The time required to reach equilibruim when an intermediate metastable zeolite mineral assemblage must recrystallize to a stable analcime assemblage was estimated as tens of millions of years by Dibble and Tiller (1981) from examination of numerous natural zeolite occurrences. This recrystallization is of interest because it could reduce the amount of zeolites present and thus reduce the radionuclide sorptive capacity at Yucca Mountain (Daniels et al., 1982). The rate and extent of present and future recrystallization can be estimated by examining the clinoptilolite-analcime boundary. The location at which clinoptilolite disappears and analcime becomes the dominant zeolite is an interval about 15 to 30 m thick (50 to 100 ft), in which clinoptilolite (with or without mordenite) coexists with small amounts of analcime (Bish et al., 1981; Caporuscio et al., 1982). This transition zone occurs at depths of 450 to 750 m below the repository level. If recrystallization is presently taking place within this interval and proceeds to completion within 100,000 years, then the amount of sorptive zeolites lost would be a very small proportion of the sorptive zeolites remaining in the overlying rocks; and this interval is not thought to be part of the ground-water flow path to the accessible environment. The loss of this sorptive zeolite should not affect the ability of the host rock to isolate nuclear waste.

The second category of unspecified geochemical processes can be evaluated in terms of the predictibility of the host rock performance in isolating waste for 100,000 years into the future. The composition of the ground water must remain unchanged or must exhibit only minor changes in oxygen, the bicarbonate ion, and dissolved organic carbon concentrations because these are the main constituents that affect speciation, sorption, and the solubility of waste elements in Yucca Mountain ground waters (Daniels et al., 1983.) To favorably affect the ability of the host rock to isolate waste, the amount of dissolved oxygen and/or the amount of bicarbonate ion (HCO_3) in solution would have to decrease because under the present oxidizing conditions of the ground water (Daniels et al., 1983), the multivalent waste elements exhibit higher solubilities than under reducing conditions and HCO_3 is the major complexing ligand (Wolfsberg et al., 1982). The organic content of vegetation and microbiological entities in the first meter of soil is a major reactant with the oxygen from the atmosphere that is carried along with percolating water. Because the amount of organics in the soil is low, and also not expected to increase drastically if the arid environment becomes semiarid during future pluvials (see Section 6.3.1.4), the oxygen concentration of the water is not expected to change with time. The low organic content of the ground water (Means, 1982) is also not expected to change drastically or contribute to waste element complexing [see Favorable Condition (2)]. The HCO_3 concentration in the ground water is probably dependent upon carbon dioxide in the air, respiration of plants and organisms in soil cover, infiltration rates, and the dissolution of carbonate-containing minerals along flow paths. At this time, it cannot be stated how large the change in HCO_3 could be during the next 100,000 years. Constraints will be established during site characterization and through laboratory and computer investigations.

Conclusion: Geochemical processes that produced zeolitization at Yucca Mountain predated the Quaternary Period and should be absent or minor during the mext 100,000 years. However, the available data is not sufficient to allow prediction of the nature and rates of unspecified geochemical processes that could affect the stability of the ground-water chemistry. With regard to these unspecified processes, site characterization must be conducted before sufficient information will be available to make an assessment, and these processes cannot be used in evaluation in this favorable condition. Therefore, the Yucca Mountain site possesses this favorable condition.

(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.

Because of the complexity of this favorable condition, the evaluation for each component is presented individually in the following sections.

a. Evaluation of geochemical conditions that promote the precipitation of radionuclides: The pH of water from wells near Yucca Mountain generally ranges from 7 to 8 (Daniels et al., 1983). Oxides of many waste elements, particularly the actinides, show high solubilities at low and high pH, with a minimum solubility in the pH range of 6 to 8 (Allard, 1982; Duffy and Ogard, 1982). Thus, the near neutral pH of water from the Yucca Mountain area provides conditions that favor minumum solubilities for these elements.

b. Evaluation of geochemical conditions that promote diffusion into the rock matrix: In fractured rock having a low matrix permeability, matrix diffusion has been shown to slow the movement of radionuclides relative to the water that moves primarily through fractures. Neretnieks (1980) calculated the extent of this effect for granite which has a porosity of from 0.001 to 0.01. It can be shown that for nonsorbing tracers that the travel time of the tracer (defined at some arbitrary concentration relative to the input concentration) relative to travel time of the water is proportional to the square of the porosity, all else being equal (Daniels et al., 1982). The porosity of Yucca Mountain tuff ranges from 0.11-0.50 (Johnstone and Wolfsberg, 1980). It was assumed that the matrix porosity is a constant percentage and that the pores are connected so that the diffusivity is not a function of scale. The permeability of the matrix is conservatively assumed to be neglible compared to the fracture permeability.

The effective diffusivities (Daniels et al., 1983; Walter, 1982) (i.e., tortuosity, constrictivity factors) measured in tuff from Yucca Mountain and Rainier Mesa are in good agreement with those observed in granite. The tortuosity/constrictivity factors are 0.07 to 0.12 as compared with 0.02 to 0.80 for granite (Skagius and Neretnieks, 1982). Thus, there should be no reduction in the diffusivity because of an unusual pore structure in the tuffaceous host rock.

c. Evaluation of geochemical conditions that promote the sorption of radionuclides: The probable flow paths from the repository host rock to the accessible environment cross stratigraphic zones that contain abundant highly sorptive minerals, particularly zeolites and clays. Current plans call for locating the repository in the unsaturated Topopah Spring Member. Water will flow from the repository downward to the water table and then laterally along paths defined by the hydraulic gradient and hydraulic conductivity of the rock. These paths will be through the tuffaceous beds of the Calico Hills, which contain significant quantities of zeolites and clays. Other formations that might also be part of the flow path, Prow Pass, Bullfrog and Tram Members of the Crater Flat Tuff, have zones containing zeolites and clays in variable abundances.

Sorption ratios, R_d, have been measured for many radionuclides for a large variety of tuff samples using batch sorption techniques. The sorption ratio is defined as

$$R_d = \frac{\text{activity of radionuclide on solid phase per unit mass of solid}}{\text{activity of radionuclide in solution per unit volume of solution.}}$$

Among the radionuclide elements studied are cesium, strontium, barium, radium, uranium, neptunium, plutonium, americium, technetium, europium, cerium, and to a limited degree, selenium and tin. More than 40 tuff samples from 9 different tuff units have been studied. The tuff samples were obtained from cores taken at varying depths from a number of drill holes at Yucca Mountain. Tables 6.3.1.2-1a, -1b, -2a, and -2b give average sorption and desorption results for the tuff samples using ground water obtained from well J-13. Details can be found in Daniels et al. (1982), Ogard et al. (1983a), Wolfsberg et al. (1983), Ogard et al. (1983b), and Bryant et al. (1984).

Sorption data for many of the elements studied can be correlated with mineralogy (Daniels et al., 1982). These results show that sorption of alkali metals (e.g., cesium) and alkaline earths (e.g., strontium, barium, and radium), which probably exist in ground water as uncomplexed ions and sorb by ion exchange, is directly correlated with the presence of clinoptilolite and the smectite clays that contain exchangeable cations. Sorption ratios on these

Table 6.3.1.2-1a. Average sorption ratios from batch sorption experiments on crushed tuff for Sr, Cs, Ba, Ra, Ce, Eu[a] (Daniels et al., 1983)

Strat. Unit	Sample	USW-G1 Depth (feet)	Sr	Cs	Ba	Ra	Ce	Eu
Tpc	JA-8	506	270(5)	2,700(400)	45(15)			2,100(200)
	TM-5	251	280(80)	5,800(800)[e]	1,100(200)		450,000 (240,000)	2,300,000 (40,000)[e]
Tpp	G2-547	547	255(10)[e]	13,300 (1,300)[e]	3,490(30)[e]			340(30)[e]
	G2-723	723	290(40)[e]	4,100 (600)[e,f]	3,500 (400)[e,f]			>10,000[e]
	GU3-433	433	45(9)[f]	530(20)[f]	310(100)			100(14)[f]
	GU3-855	855						
Tpt	TM-22	848	53(4)	290(30)	900(30)		1,270(40)	1,390(110)
	GU3-1203	1,203	42(1)	350(30)	640(40)			190(2)
	G1-1292	1,292	200(6)[e,f]	430(28)[e,f]	2,100(300)[e]	1,500(100)	56(8)[e]	140(14)[e,f]
	GU3-1301	1,301	29(4)	160(40)	570(60)			45(12)
	TM-30	1,264	260(80)	355(5)	3,400(1,500)		230,000 (100,000)	160,000 (50,000)
	JA-18	1,420	17,000 (3,000)	16,000 (1,000)	38,000 (13,000)		2,800 (1,400)[e]	1,400(200)[e]
Th	G1-1436	1,436	36,000 (3,000)	7,300 (600)	[illegible] (24,000)		59,000 (7,000)	10,000 (2,000)
	G2-1952	1,452	2,200(400)[e]	53,000 ([illegible])[e]	26,000 (3,000)[e]			39(14)[e]
	GU3-1436	1,436						
Bt	GU3-1531	1,531						
	TM-38	1,504	17,000 (2,000)	13,000 (2,000)	100,000 (10,000)		750(140)	1,600(200)
	TM-42	1,824	1,900(600)	17,000 (1,000)	94,000 (14,000)		49,000 (7,000)	52,000 (4,000)
Tcp	G1-1854	1,854	50,000 (14,000)	13,000 (2,000)	45,000 (7,000)			15,000
	TM-45	1,930	195(14)	520(30)	1,200(100)		730(100)	1,600(200)
	G1-1883	1,883	22(0.2)	137(3)	193(12)		1,420(20)	
	TM-46	2,002	190(60)	440(5)	14,000 (6,000)		310,000 (110,000)	207,000 (110,000)
	G1-1982	1,982	55(4)	1,120(110)	700(50)		550(40)[e]	970(150)
	TM-48	2,114	2,100(400)	9,000(4,000)	18,000 (6,000)		1,400(500)	2,200(500)
	TM-49	2,221	3,200(300)	36,000 (3,000)	42,000 (8,000)		550(100)	1,200(100)
	JA-26	1,995	95(35)	1,500(500)	300(100)			
Tcb	JA-28	2,001	94(20)	1,640(210)	520(50)			2,100(1,000)
	G1-2233	2,233	48,000 (3,000)[e]	12,500 (900)	250,000 (30,000)		1,400(300)	900(200)
	G1-2289	2,289	7,300(500)	37,000 (13,000)	56,000 (9,000)	46,000 (20,000)		797(10)
	TM-54	2,491	62(12)	180(40)	400(150)		150(40)	270(40)
	G1-2333	2,333	180(20)	1,400(130)	1,500(200)			2,300(400)
	G1-2363	2,363	64(3)	470(40)	235(9)	540(60)		730(50)
	G1-2410	2,410	169(1)	1,250(50)	1,730			440(30)
	JA-32	2,533	57(3)	123(4)	380(30)		82(14)	90(20)
	G1-2476	2,476	41(1)	730(40)	385(11)			3,200(100)
Tct	G1-2698	2,698	42,000 (3,000)[e]	7,700(400)[e]	63,000 (5,000)[e]		240(30)[e]	200(30)[e]
	G1-2840	2,840	360(1)	2,200(200)	2,070(70)			4,900(400)
	G1-2854	2,854	94(1)	1,080(120)	1,300(50)			1,300(200)
	G1-2901	2,901	68(1)[e]	1,290(110)[e]	1,600(200)[e]		42,000 (3,000)[e]	160,000 (50,000)[e]
	G1-3116	3,116	2,400(17)[e]	4,600(500)[e]	12,000 (4,000)[e]		100(10)[e]	760(60)[e]
	JA-37	3,497	297(14)	510(40)	760(150)			5,300(800)
Tl	G1-3658	3,658	13,000(0)	4,950(50)	13,500 (500)		1,300(200)[e]	530(40)
Tba	G2-3933	3,933	240(60)[e]	2,500(1,000)[e]	1,700(500)[e]			1,600(700)[e]

See footnotes at end of Table 6.3.1.2-2b.

Table 6.3.1.2-1b. Average sorption ratios from batch sorption experiments on crushed tuff for Am, Pu, U, Se, Tc, Np[a] (Daniels et al., 1983)

Strat. unit	Sample	USW-G1 Depth (feet)	Am	Pu	U	Se	Tc	Np
Tpc	JA-8	606						
	TM-5	251						
Tpp	G2-547	547	13,000(110)[e]	1,200(120)	9.4(0.1)	2(2)	0[e]	
	G2-723	723	890,000 (49,000)	>4,500	2.4(0.6)	19(2)	0[e]	
	GU3-433	433	3,400(200)[c]	330(60)[f]	0	15(3)	0	7.9(0.1)
	GU3-855	855			10(0.7)	10(0.4)		
Tpt	TM-22	848	1,200(130)[c,d]	64(20)[c]	1.8(0.2)[c]		0.3(0.14)[c]	7.0
	GU3-1203	1,203	1,100(120)[f]	360(40)[f]	0	(1)	0	2.7(0.1)
	G1-1292	1,292						
	GU3-1301	1,301	1,800(160)[f]	290(40)[f]	0	7(2)	0.03(0.001)	[illegible]
	TM-30	1,264						
	JA-18	1,420	180(30)	120(20)	2.5(0.4)			
Th	G1-1436	1,436						
	G2-1952	1,952	1,700(70)[e]	56(5)[e]		2(1)		2.7(0.1)
	GU3-1436	1,436			20(2)	3(10)		
Bt	GU3-1531	1,531			54(9)	5(1)		
	TM-38	1,504	14,600([illegible])	140(30)	5.3(0.2)			11.0
	TM-42	1,824						
Tcp	G1-1854	1,854						
	TM-45	1,930						
	G1-1883	1,883	470(300)					
	TM-46	2,002		77(11)				6.4
	G1-1982	1,982						
	TM-48	2,114						
	TM-49	2,221	4,300(1,400)				0.15(0.02)	
	JA-26	1,995		230(50)[d]			0.21(0.02)	9(3)
Tcb	JA-28	2,001						
	G1-2233	2,233						
	G1-2289	2,289				9(1)		
	TM-54	2,491	153(6)	30(20)	1.3(0.3)		4.2(0.5)	
	G1-2333	2,333						
	G1-2363	2,363		110		25(5)		
	G1-2410	2,410			2.2(0.3)			
	JA-32	2,533	130(30)					
	G1-2476	2,476						
Tct	G1-2698	2,698						
	G1-2840	2,840						
	G1-2854	2,854						
	G1-2901	2,901		400(70)[d]	4.5(0.3)			24([illegible])
	G1-3116	3,116						
	JA-37	3,497	29,000 (10,000)[d]					
Tl	G1-3658	3,658						
Tba	G2-3923	3,923	6,600(400)		1,500(30)	0	0(1)	[illegible]

See footnotes at end of Table 6.3.1.2-2b.

Table 6.3.1.2-2a. Average sorption ratios from batch desorption experiments on crushed tuff for Sr, Cs, Ba, Ce, Eu[a] (Daniels et al., 1983)

Strat. Unit	Sample	USW-G1 Depth (feet)	Sr	Cs	Ba	Ce	Eu
Tpc	JA-8	606	311(3)	4,600(400)	480(50)		10,000(3,000)
	TM-5	251	320(30)[c]	8,900(600)[c]	1,200(120)[c]	31,000(30,000)[c]	36,000(14,000)
Tpp	G2-547	547	210(10)[e]	3,700(550)[e]	2,900(200)[e]		1,700(600)[e]
	G2-723	723	330(4)[e]	4,300(4)[e]	4,200(10)[e]		>10,000[e]
	GU3-433	433	40(10)[f]	520(20)[f]	460(20)[f]		140(10)[f]
Tpt	TM-22	348	59(2)	365(7)	830(100)	6,500(800)	3,500(200)
	GU3-1203	1,203	47(1)	340(10)	720(30)		650(50)
	G1-1292	1,292	120(5)[e]	510(20)[e]	1,500(100)[d,e]	600(200)[e]	600(70)[e]
	GU3-1301	1,301	80(20)[f]	185(20)[f]	675(60)[f]		100(20)[f]
	TM-30	1,264	210(30)	1,500(100)	3,100(600)	170,000(15,000)	11,000(700)
	JA-18	1,420	15,000(2,000)	17,500(700)	280,000 (50,000)	1,600(500)[d]	2,400(300)[d]
Th	G1-1436	1,436	87,000 (12,000)	24,000(2,000)	340,000 (90,000)	6,700(600)	5,300(6[illegible])
	G2-1952	1,952	4,200(200)[e]	46,000(1,400)[e]	40,000 (1,000)[e]		1,600(200)
	TM-38	1,540	22,000	13,000	260,000	2,600	7,300
	TM-42	1,842	1,200(1,000)	21,000(2,000)	90,000 (30,000)	44,000(5,000)	64,000(3,000)
Tcp	G1-1854	1,854	72,000 (13,000)[d]	14,000(2,000)	150,000 (40,000)		4,300(700)
	TM-45	1,930	210(20)	620(110)	1,310(60)	5,800(600)	7,300(900)
	G1-1883	1,883	59(1)[e]	430(4)[e]	440(10)[e]	2,200(100)[e]	1,350(50)[e]
	TM-46	2,002	250(20)	1,300(300)	210,000 (3,000)	300,000 (50,000)	31,000(2,000)
	G1-1982	1,982	322(9)[e]	2,300(200)[e]	2,730(120)[e]	7,000(800)[e]	6,370(120)[e]
	TM-48	2,114	2,700(200)	27,000(4,000)	34,000(7,000)	123,000 (300)	8,100(1,200)
	TM-49	2,221	4,400(100)	39,000(1,000)	65,000(7,000)	1,040(40)	2,100(500)
	JA-26	1,995	39(3)	1,580(90)	450(13)		2,900(200)
Tcb	JA-28	2,001	114(3)	2,400(100)	1,160(20)		12,300(500)
	G1-2233	2,233	90,000 (40,000)[e]	23,000(6,000)[e]	40,000 (30,000)[e]	20,000 (13,000)[d]	5,000(2,000)[e]
	G1-2289	2,289					
	TM-54	2,491	97(9)	310(20)	660(20)	1,000(200)	1,840(110)
	G1-2333	2,333	140(13)[e]	1,230(100)[e]	1,460(130)[e]		3,900(1,200)[e]
	G1-2363	2,363	150(6)[e]	1,200(30)[e]	320(20)[e]	130,000 (5,000)[e]	6,100(300)[e]
	G1-2410	2,410	140(14)	1,120(100)	1,760(150)		6,000(3,000)
	JA-32	2,533	53(3)	175(11)	490(40)	530(120)	850(130)
	G1-2476	2,476	200(4)	1,520(0)			
Tct	G1-2698	2,698	210,000 (50,000)[e]	17,000(1,100)[e]	190,000 (80,000)	2,000(400)[e]	
	G1-2840	2,840	1,540(4)	2,300(130)	2,500(200)		9,000(1,100)
	G1-2854	2,854	96(1)	1,160(20)	1,300(0)		5,000(200)
	G1-2901	2,901	67(1)[d,e]	1,380(30)[e]	1,980(30)[e]	39,000(1,000)[e]	210,000 (50,000)
	G1-3116	3,116	24,000(13,000)[e]	11,000 (3,000)[e]	160,000 (80,000)	3,000(1,000)[e]	3,000(3,000)[e]
	JA-37	3,497	312(9)	850(50)	920(40)		11,000(2,000)
Tl	G1-3658	3,658	12,000(3,000)[e]	12,000(2,000)[e]	10,000(4,000)	9,000(4,000)[e]	9,000(3,000)
Tba	G2-3933	3,933	140(20)[e]	1,400(350)[e]	1,100(200)[e]		3,000(1,100)[e]

See footnotes at end of Table 6.3.1.2-2b.

Table 6.3.1.2-2b. Average sorption ratios from batch desorption experiments on crushed tuff for Am, Pu, U, Tc, Np[a] (Daniels et al., 1983)

Strat. Unit	Sample	USW-G1 Depth (feet)	Am	Pu	U	Tc	Np
Tpc	JA-8	606					
	TM-5	251					
Tpp	G2-547	547	17,000(1,400)	1,200(170)[e]			
	G2-723	723	2.8×10^{3} (2.5×10^{4})[e]	>47,000			
	GU3-433	433	9,300(1,780)[f]	920(40)[f]			
Tpt	TM-22	348	2,500(400)[c]	1,330(140)[c]	5(2)[c]	1.2(0.3)[c]	33(5)[c]
	GU3-1203	1,203	1,300(200)[f]	920(15)[f]		0	
	G1-1292	1,292					
	GU3-1301	1,301	2,500(600)[f]	1,300(460)[f]			
	TM-30	1,264					
	JA-18	1,420	1,100(300)	350(140)	9.3(1.4)		
Th	G1-1436	1,436					
	G2-1952	1,952	5,300(1,100)[f]	350(45)[f]			
	TM-38	1,540	7,100(1,200)	1,600(300)	14.3(1.0)		24(2)
	TM-42	1,324					
Tcp	G1-1854	1,354					
	TM-45	1,930					
	G1-1883	1,383	7,200(900)				
	TM-46	2,002		390(60)			36(10)
	G1-1982	1,982					
	TM-48	2,114					
	TM-49	2,221	3,400(400)[d]			1.5(0.2)	
	JA-26	1,395	720(90)			2.0(0.3)	12(4)
Tcb	JA-28	2,001					
	G1-2233	2,233					
	G1-2289	2,289					
	TM-54	2,491	550(30)	720(40)	12(3)	2.0(0.3)	
	G1-2333	2,333					
	G1-2363	2,363					
	G1-2410	2,410			8(2)		
	JA-32	2,533	2,200(600)				
	G1-2476	2,476					
Tct	G1-2698	2,698					
	G1-2840	2,840					
	G1-2854	2,854					
	G1-2901	2,901					
	G1-3116	3,116					
	JA-37	3,497	32,000(10,000)	1,400(300)	9.3(0.4)		170(50)
Tl	G1-3658	3,658					
Tba	G2-3933	3,933	1,200(410)	530(130)			

[a] Ambient conditions, air, 20 ± 4°C; fractions do not contain <75 micrometer-diameter particles except those designated by footnote e.

[b] Stratigraphic units are as follows: Tpc = Tiva Canyon Member; Tpt = Topopah Spring Member; Th = Tuffaceous Beds of Calico Hills; Bt = Bedded tuff; Tcp = Prow Pass Member; Tcb = Bullfrog Member; Tct = Tram Unit; Tl = older tuffs; Tba = older tuff.

[c] Nonweighted average; value in parentheses is the absolute-value standard deviation of the mean.

[d] Some data were rejected in averaging.

[e] Average of data for <500 micrometer-diameter particle-size fraction (contains some <75 micrometer particles); no other data available.

[f] Nonweighted average of samples shaken in two different positions.

minerals are 1000 to greater than 10,000 mL/g. There are large quantities of clinoptilolite in the Calico Hills and Prow Pass units, which are directly below the repository horizon, and the waste elements cesium, strontium, and radium should be strongly sorbed, and their movement along the flow path should be greatly retarded.

A correlation of sorption of cerium, europium, plutonium, and americium with mineralogy is also found, but the relation is not as clear as for the alkali metals. However, sorption ratios are high (100 to greater than 1000 mL/g). The sorption of these elements is undoubtedly influenced by the formation of hydroxy and carbonate complexes. Geochemical sorption will not offer much retardation for anionic species such as TcO_4^-.

Estimates can be made for the geochemical retardation by sorption. The retardation factor, R_f, is related to the sorption ratio, R_d, by the expression:

$$R_f = 1 + \frac{\text{bulk density x sorption ratio}}{\text{porosity}}$$ (Sherwood et al., 1975)

Table 6.3.1.2-3 lists representative values of measured sorption data for eight radionuclide elements on selected minerals from tuff units most likely to be in the ground-water flow path to the accessible environment. The retardation factors, which represent the ratio of the velocity of the water to the velocity of the radionuclide, are calculated using the above expression and assuming porous flow, which is reasonable for the nonwelded tuff units. Except for technetium, the retardation factors significantly exceed a value of 10 indicating that the average effective radionuclide travel time to the accessible environment will be increased by much greater than a factor at 10 relative to the average ground-water flow time to the accessible environment.

These estimates are based on retardation by sorption. Other chemical and physical retardation mechanisms, such as precipitation, matrix diffusion, and the use of appropriate packing and backfill materials, will almost certainly increase the retardation, especially for those elements exhibiting low sorption values in tuff. It is evident that sorption will provide significant

Table 6.3.1.2-3. Representative sorption ratios of measured sorption data and retardation factors for eight radionuclide elements with Yucca Mountain tuff

Tuff unit	Waste element	Sorption ratio, R (mL/g)	Retardation factor[a,b]
Welded tuff	Americium (Am)	1,200	25,000
Topopah Spring Member	Cesium (Cs)	290	6,000
porosity = 11%	Neptunium (Np)	7	150
	Plutonium (Pu)	64	1,300
	Strontium (Sr)	53	1,100
	Technetium (Tc)	0.3	7
	Uranium (U)	1.8	37
	Barium (Ba)	900	18,000
Bedded tuff	Americium (Am)	180	820
Topopah Spring Member	Cesium (Cs)	16,000	73,000
porosity = 35%	Neptunium (Np)	NA[c]	NA
	Plutonium (Pu)	120	540
	Strontium (Sr)	17,000	77,000
	Technetium (Tc)	2.5	12
	Uranium (U)	2.5	12
	Barium (Ba)	38,000	180,000
Bedded tuff - tuffaceous	Americium (Am)	4,600	21,000
beds of Calico Hills	Cesium (Cs)	7,800	35,000
porosity = 35%	Neptunium (Np)	11	50
	Plutonium (Pu)	140	630
	Strontium (Sr)	3,900	17,000
	Technetium (Tc)	NA	NA
	Uranium (U)	5.3	26
	Barium (Ba)	94,000	440,000
Partially welded tuff	Americium (Am)	470	2,900
Prow Pass Member	Cesium (Cs)	190	1,200
porosity = 29%	Neptunium (Np)	6.4	40
	Plutonium (Pu)	77	480
	Strontium (Sr)	22	140
	Technetium (Tc)	0.2	2
	Uranium (U)	NA	NA
	Barium (Ba)	182	1,100
Welded tuff	Americium (Am)	140	1,200
Bullfrog Member	Cesium (Cs)	180	1,500
porosity = 23%	Neptunium (Np)	NA	NA
	Plutonium (Pu)	80	670
	Strontium (Sr)	62	520
	Technetium (Tc)	4.2	36
	Uranium (U)	1.3	12
	Barium (Ba)	400	3,400
Nonwelded tuff	Americium (Am)	28,000	150,000
Tram Member	Cesium (Cs)	610	3,300
porosity = 32%	Neptunium (Np)	28	150
	Plutonium (Pu)	400	2,200
	Strontium (Sr)	290	1,600
	Technetium (Tc)	NA	NA
	Uranium (U)	4.6	25
	Barium (Ba)	760	4,000

[a] Retardation factor = 1 + R_d (bulk density)/porosity.
[b] Bulk density used was 2.5 g/cm^3.
[c] NA = no data available.

retardation of potential radionuclide transport through the anticipated flow path from Yucca Mountain to the accessible environment.

d. Evaluation of geochemical conditions that inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides: Species naturally present in the water at Yucca Mountain can form both solids and aqueous complexes with waste elements and thus have both favorable and unfavorable aspects (Daniels et al., 1983; Apps et al., 1983). The total organic content of water from wells near Yucca Mountain is less than 0.6 mg/L, and the organic species tend to have high molecular weights [greater than 300] (Means et al., 1982). This leads to organic concentrations of 1×10^{-6} moles/liter or less. The low organic content of water from Yucca Mountain will inhibit the formation of significant quantities of organic complexes with waste elements. The natural particulate content of water at Yucca Mountain has not yet been characterized; thus, it is not possible to know whether particulates containing waste elements will form. Certain actinides (plutonium, for example) are known to form colloidal particles in dilute, near-neutral aqueous solutions (Rai and Swanson, 1981; Kim et al., 1983; Olofsson et al., 1983: Newton and Rundberg, 1983). There is not enough information available at this time to know whether geochemical conditions at Yucca Mountain will inhibit formation of these colloids.

e. Evaluation of geochemical conditions that inhibit the transport of radionuclides by particulates, colloids, and complexes: Actinides in glass leachate are expected to occur in the form of colloids, as has been shown for americium by Avagadro et al. (1982) and Avagadro and DeMarsily (1983). The size distribution of americium colloids in low ionic strength ground water was measured by ultrafiltration. The results of these experiments showed that 70 percent of the colloid is > 0.1 μm in size and 95 percent is > 0.015 μm. In the absence of more complete size distributions for actinide colloids from glass leached in tuffaceous water, we can assume this distribution.

Although pore size distributions for the tuffaceous beds of Calico Hills (underlying the repository horizon) are not available, mercury intrusion porosimetry measurements have been performed on tuff samples from the zeolitized Tunnel Bed Tuff on Rainier Mesa. These measurements indicate a median pore size of this tuff of from 0.02 to 0.1 μm. If one assumes a log-normal pore size distribution, as much as 30 percent of the porosity is smaller than 0.01 μm.

In the unsaturated tuffaceous beds of Calico Hills, water movement will be primarily through the smaller pores. The saturation is about 50 percent, and therefore water will move through pores with a diameter less than the median pore size of the rock. Considering only mechanical filtration, and assuming the above colloid size distribution and pore size distribution, the bedded tuff underlying the potential host rock at Yucca Mountain should filter out some of the colloidal americium. This analysis ignores the potential interaction of these colloids with the tuff mineral surfaces, which could inhibit colloid movement even more. This analysis also does not allow for additional mechanical filtration due to the flow of water through a tortuous pore structure.

Very little modeling has been done on the transport of colloids, complexes, and particulates. Generally, all the remarks of Favorable Condition (5) discussed later in this section should apply qualitatively. Retardation and diffusion parameters will probably be different, however, from those used for simple ions.

Conclusion: The Yucca Mountain site possesses most of the geochemical conditions listed in the favorable condition statement. The pH of water from the vicinity of Yucca Mountain is in the range where most oxide and hydroxide precipitates (particularly actinides) show a minimum solubility. The physical properties of the tuffaceous rocks at Yucca Mountain will promote diffusion of radionuclides into the rock matrix. In addition, the movement of particulates and colloids may be greatly inhibited by the presence of zeolitized bedded tuff beneath the repository horizon. This bedded tuff may act as an efficient filter for the colloids, particulates, and/or complexes produced by the dissolution of nuclear waste.

Geochemical conditions at Yucca Mountain also promote sorption of radionuclides. Based solely on estimates of retardation by sorption, the tuffs of Yucca Mountain in the saturated and unsaturated zones will provide significant retardation of radionuclides along the anticipated flow paths from the repository to the accessible environment. There is not enough information available, however, to determine whether geochemical conditions at Yucca Mountain will inhibit the formation of particulates or colloids. There are no unusual conditions that would promote the precipitation of waste element solids other than oxides and hydroxides, or that would inhibit the formation of aqueous inorganic complexes with waste elements. The total organic content of water from the vicinity of Yucca Mountain is very low; no significant quantities of organic complexes with waste elements will form. Therefore, the Yucca Mountain site possesses this favorable condition.

(3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.

Evaluation: The minerals present in Yucca Mountain that contribute significantly to sorption are clinoptilolite, mordenite, and smectite clays (Daniels et al., 1982). For a repository in the Topopah Spring Member, at 348 m depth, the maximum temperature expected at 300 m below the repository (650 m total depth, 2100 ft) due to waste emplacement is about 60°C (140°F) at 10,000 years after waste emplacement (Johnstone et al., 1984). Most of the clinoptilolite and mordenite in Yucca Mountain is below this depth (Bish et al., 1984) and smectite clays make up only 1 to 3 percent of the rock at shallower depths. Within less than 20 m (65 ft) of the repository where the temperature conditions exceed the boiling point of water, these clays could reversibly collapse but will probably regain their cation-exchanging ability when the temperature again drops below the boiling point (Allen et al., 1983). Below the boiling point of water, the clays should remain stable.

The stability of the clinoptilolite and mordenite under the small temperature increase expected in zones containing these minerals at Yucca Mountain is less certain. Smyth (1982) has suggested that clinoptilolite and mordenite in Yucca Mountain would be stable to about 100°C (212°F). No rocks containing these zeolites are likely to exceed 100°C (Johnstone et al., 1984; Bish et al., 1984) because most of these zeolites are at depths of 300 m or more below the repository. However, the long-term stability of these minerals under present conditions at Yucca Mountain is questionable. They could react slowly (i.e., geologic time) to yield the assemblage of quartz, analcime, alkali feldspar, and possibly clays. Although the rate of such recrystallation is not known, the time has been estimated by Dibble and Tiller (1981) to be long (i.e., millions of years). It is therefore assumed that most of the clinoptilolite and mordenite present in Yucca Mountain has been there for most of the 10 to 12 million year lifetime of these rocks [see Favorable Condition (1)]. It is unlikely that significant zeolite decomposition will take place in 100,000 years, unless the kinetics of the reaction are significantly accelerated by very limited heating that will occur at the depths where zeolites are present. Only the very small amounts of zeolites that are found closer to the potential repository at the top of the basal vitrophyre of the Topopah Spring Member are close enough to be heated above 60°C (140°F) (Bish et al., 1984).

The distribution of zeolites described above suggests the following alternative interpretations: the kinetics of the clinoptilolite and mordenite recrystallization reaction allow reaction in 10 million years at 45°C; or that temperatures above 45°C have existed at shallow depths at Yucca Mountain in the past. Based upon clay mineralogy, Bish and Semarge (1982) suggest that the deeper zones (450-750 m below the repository level) where clinoptilolite and mordenite are absent were hydrothermally altered before the overlying younger tuffs were deposited, and that the upper tuffs were altered at temperatures less than 40°C (104°F). It is unclear whether small temperature rises in Yucca Mountain could affect the kinetics of the recrystallization of clinoptilolite and mordenite. However, very little clinoptilolite or mordenite is close enough to the repository to be heated above 60°C, and this small temperature rise would be of short duration (less than 50,000 years) (Johnstone et al., 1984). The length of time that clinoptilolite and mordenite have been present at Yucca Mountain compared with the length of the thermal pulse suggests that they will not decrease significantly for 100,000 years into the future.

<u>Conclusion:</u> The present high radionuclide-retardation capacity of the tuffs of Yucca Mountain, if subjected to repository conditions, is expected not to be significantly degraded and may in fact be increased. Therefore, the Yucca Mountain site possesses this favorable condition.

(4) <u>A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1000 years to be dissolved.</u>

<u>Evaluation:</u> Two models have been developed that can be used to estimate the dissolution rates of waste elements from a solid waste form at the proposed Yucca Mountain repository (Kerrisk, 1984). The purpose of developing these models and performing the analysis was to examine the effects of solubility and diffusion on limiting dissolution of radionuclides from spent fuel and high-level waste. The models can, however, be used to estimate the rates of dissolution of those radionuclides that contribute to the release of radioactivity from the solid waste form.

Two simple dissolution models were developed (Kerrisk, 1984). The first is a saturation (solubility)-limited dissolution model in which the entire volume of water flowing through the repository area is assumed to become saturated with each waste element. Application of this model requires a knowledge of only the water flow rate per unit of waste and the element solubilities. The saturation-limited model is very conservative in that it represents the upper limit on waste-element dissolution rates. It is an upper limit because the physical layout of a repository with large spaces between waste containers would allow much of the water to pass through the repository without becoming saturated. Water near a waste container may become saturated, but diffusion of the waste elements in the water will limit concentrations of these elements farther from the containers. The second model is a diffusion-limited dissolution model in which waste elements are assumed to be saturated at the waste-water interface; dissolution is limited by diffusion into water flowing past the waste. This model is a significant improvement over the saturation-limited model in that it accounts, in a physically realistic way, for a mechanism to transport waste elements from the solid into the adjacent water. However, in accounting for this process, the model requires information about the geometry of the solid waste, water flow in the surrounding medium, and element diffusivities. Thus, the results from the diffusion-limited dissolution model are more uncertain than those from the saturation-limited dissolution model.

Some waste elements have large solubilities; cesium is one example. It is unreasonable to assume that dissolution rates of such elements will be limited by solubility. Elements with large solubilities were assumed to be limited by dissolution of the bulk waste form (congruent dissolution). The bulk waste form was assumed to dissolve at a fractional dissolution rate of 1×10^{-4} per year. This represents a conservative estimate for spent fuel or high-level waste in borosilicate glass (Oversby, 1983; Kerrisk, 1984). A relatively high bulk dissolution rate was assumed for these calculations to maximize the effect of solubility on waste element dissolution rates. Although bulk dissolution rates lower than 1×10^{-4} per year seem likely, their use in this analysis would mask the influence of solubility (Kerrisk, 1984).

Calculations were done for 10 waste elements that represent approximately 99 percent of the spent fuel activity 1000 years after permanent closure. Table 6.3.1.2-4 lists the elements and the solubilities used. Most of the remaining activity not listed in the table comes from several low-solubility elements (niobium and zirconium, for example); including these elements would not significantly affect the results.

Results from the diffusion-limited dissolution model have been reported for spent fuel and high-level waste (Kerrisk, 1984). The discussion here is for an inventory that is one half spent fuel and one-half high-level waste (50-50 mixture). The water recharge rate was assumed to be 1 mm/yr (0.04 in./yr) (Montazer et al., 1984). The repository area associated with one metric ton of heavy metal (MTHM) waste was estimated based on the decay heat of spent fuel at 10 years after discharge (1135 W/MTHM, Croff and Alexander, 1980) and an assumed maximum repository areal thermal loading of 10 W/m^2. This gives 114 m^2 (1226 ft^2) for each MTHM. With 1 mm/yr recharge, a water flow of 114 L/yr (30 gal/yr) would pass through the area of 114 m^2 associated with each MTHM. This would represent the conditions for the maximum dissolution rate that would be calculated by the saturation-limited model. For the diffusion limited model, the solid waste form was assumed to be 0.25 m (0.82 ft) radius by 4.5 m (15 ft) long containing 3 MTHM for spent fuel, and 0.16 m (0.5 ft) radius by 3 m (10 ft) long containing 2 MTHM for high-level waste. For an 1 mm/yr recharge rate and a 10 percent porosity of the surrounding rock, the

Table 6.3.1.2-4. Solubilities of ten waste elements which represent ~99 percent of spent fuel radioactivity at 1000 years after repository closure[a]

Element	Solubility (moles/L)
Americium (Am)	2.0×10^{-8}
Plutonium (Pu)	1.8×10^{-6}
Uranium (U)	2.1×10^{-4}
Strontium (Sr)	9.4×10^{-4}
Carbon (C)	large
Cesium (Cs)	large
Technetium (Tc)	large
Neptunium (Np)	3.0×10^{-3}
Radium (Ra)	1.0×10^{-7}
Tin (Sn)	1.0×10^{-7}

[a] Solubilities at pH 7 and oxidizing conditions (Eh = 700 mV, where Eh is the oxidation reduction potential) in water that is characteristic of Yucca Mountain (Kerrisk, 1984).

pore velocity of water past the waste was 1×10^{-2} m/yr (0.03 ft/yr). Apparent diffusivities of waste elements in the water were taken as $1 \times 10^{-10} m^2/s$ ($1x10^{-9}$ $ft^2/5$), including the effects of matrix tortuosity and connectivity. Results from the diffusion-limited dissolution model for these parameters and the solubilities listed in Table 6.3.1.2-4 were obtained as outlined in Kerrisk (1984). The ratio of release rate to inventory for a 50-50 waste mixture at 1000 years after permanent closure is 3×10^{-6}/yr, or about a factor of 3 below the 0.001 percent per year limit in the favorable condition. This result is not a strong function of water recharge rate. If the bulk fractional dissolution rate is lower than the 1×10^{-4}/yr assumed for these results, then the ratio of release rate to inventory will be lower. Experiments presently under way indicate that the bulk fractional dissolution rate may be much less than 1×10^{-4} per year (Oversby, 1983).

Some idea of the uncertainty of this result can be obtained by comparison with the similar result for the saturation-limited dissolution model. The saturation-limited model gives the release rate-inventory ratio as 7×10^{-6} per year for a 50-50 waste mixture at 1000 years after permanent closure. This represents an upper limit for the release rate that is about two times greater than the diffusion-limited result and is still below the 0.001 percent limit in this favorable condition.

<u>Conclusion:</u> Because of the relatively benign geochemical setting and the limited vertical flux of less than 1 mm/yr in the unsaturated zone, the Yucca Mountain site is expected to allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1000 years after permanent closure to be dissolved; these calculations did not consider additional benefits that could be obtained from the presence of the waste canister. Therefore, Yucca Mountain possesses this favorable condition.

(5) <u>Any combination of geochemical and physical retardation processes that would decrease the projected peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those projected on the basis of ground-water travel time without such retardation.</u>

<u>Evaluation:</u> Geochemical and physical retardation processes include: (1) chemical adsorption of radionuclides onto host minerals, (2) matrix potential governed flow, (3) diffusion and dispersion of radionuclides due to fractures and geometrical effects.

Most of the radionuclides listed in 40 CFR 191, Table II, will chemically adsorb to the tuffs of Yucca Mountain. Retardation factors for these radionuclides as determined from equilibrium batch experiments (Daniels et al., 1982) range from a low of <1 for technetium-99 to almost 1 million for radium-226. There is considerable variation in retardation factors values from one stratigraphic unit to another. All the nuclides measured, except for technetium-99, have retardation factors well in excess of 10. For porous flow, effective velocity of radionuclides is found by dividing flow rate by the retardation factor. Technetium-99 will constitute only a few percent of the curie concentration in the water surrounding a repository (Croff and Alexander, 1980). Therefore, geochemical adsorption will greatly delay the arrival of the peak total radioactivity to the accessible environment. Moreover, the wide range of value for retardation factor will act to separate out the various radionuclides much like a chromatographic column. This will result in a spreading out or stretching in time of the cumulative release curve, resulting in a reduced release rate to the accessible environment (Travis, 1984). This effect is expected to apply along the entire path to the accessible environment, not just in the unsaturated zone.

The potential host rock at Yucca Mountain is a fractured, unsaturated tuff. The effect of fractures on flow and transport is not fully understood at this time, especially in the unsaturated zone. Preliminary analysis of water flow in fractures (Travis, 1984) indicates that narrow aperture cracks will not be able to transmit water very far because of strong capillary suction. If conditions do allow fracture flow in the unsaturated region (because of the presence of wide cracks in units with high saturation), diffusion out of cracks into the rock matrix will strongly retard the progress of radionuclides by at least a factor of 100 (Travis, 1984). In the unsaturated region, diffusion out of fractures will be enhanced because of matric potential (suction). Fracture flow in the saturated region is also likely and diffusion into the surrounding rock matrix will be effective in this part of the flow path as well. Diffusion from fractures could greatly retard transport compared with transport in fractures without diffusion [see Favorable Condition (2), part (b)].

Finally, geometric dispersion will act to diminish peak radioactivity as well as cumulative production at any point simply by lateral spreading. The extent of spreading is very uncertain because it depends on poorly known factors, such as flow path, fracture properties, matrix grain size distribution, and flow rates.

The discussion presented here is based primarily on analytic and computer parameter studies with the TRACR3D code (Travis, 1984) and the highest quality data presently available on Yucca Mountain geochemical properties reviewed in the relevant data section.

Conclusion: Chemical adsorption, extremely low flux under unsaturated conditions, and matrix diffusion of radionuclides all combine to decrease the projected peak cumulative radionuclide release to the accessible environment by at least a factor of 10 as compared with projections based on ground-water travel time without such retardation. Therefore, the Yucca Mountain site possesses this favorable condition.

IV. POTENTIALLY ADVERSE CONDITIONS

(1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier system to the extent that expected repository performance could be compromised.

Evaluation: The pre-emplacement water chemistry in the host rock is not presently known because samples from the Topopah Spring Member where it is in the unsaturated zone have not yet been obtained. However, because water in the saturated zone includes former vadose water, its basic chemical character should be similar to that of vadose water. Daniels et al. (1982) summarize the water chemistry of samples obtained from below the water table in drill holes at Yucca Mountain. The ground-water samples have similar chemical compositions, and when taken as a group are similar to water taken from well J-13. The J-13 well is located approximately 6.5 km (4 mi) southeast of Yucca

Mountain. At this location of the Topopah Spring Member lies below the water table and is the producing horizon for the well. Because of the relative uniformity of ground-water chemistry obtained from drill hole samples, and the similarity of the ground-water to that of J-13 well water, the J-13 well water is used as the reference composition for the repository horizon water. Samples of vadose water from the unsaturated tuff are expected to be obtained when the exploratory shaft is constructed. The reference repository water composition could then be revised and the effects of any differences between the vadose water and J-13 water can be assessed.

Table 6.3.1.2-5 gives the chemistry of J-13 well water. The major components are Na, Si, and HCO_3, with lesser amounts of Ca, K, Mg, SO_4, NO_3, Cl, and F. All other elements are present in concentrations less than 0.2 mg/L. The pH of the water is nearly neutral. Knauss et al. (1983) have reacted J-13 water with Topopah Spring tuff at 90°C and 150°C (190°F and 300°F) producing only very slight changes in anion concentrations in solution. The 150°C experiments were conducted to overcome kinetic effects; it is recognized that temperatures this high preclude the existence of liquid water. The principal changes in chemistry of the water was an increase in silicon to a level just below the solubility limit of cristobalite, a decrease in Mg, Ca and HCO_3 due to precipitation of $(Ca, Mg)CO_3$ at the higher temperatures, and an increase in aluminum (to approximately 0.5 mg/L at 90°C). Results obtained using samples of the Topopah Spring Member from drill cores USW G-1, USW GU-3, USW G-4, and Ue-25h#1 were consistent with those obtained using surface outcrop material collected from Fran Ridge. This suggests that lateral variation in the chemistry of the tuff is not likely to cause major variations in the host rock water chemistry.

To determine the effects of water chemistry on expected repository performance, one must consider the potential corrosion rates and mechanisms for the waste containers, and the dissolution rates of the various waste forms. The reference waste container material is 304L stainless steel. The expected amount of metal loss from the outside of a 1 cm thick canister wall due to uniform corrosion of this material in the repository environment has been calculated by McCright et al. (1983) to be less than 0.1 cm (0.04 in.) during the first 1,000 years after emplacement. The J-13 water chemistry both before

Table 6.3.1.2-5. Chemistry of J-13 well water (Daniels et al., 1982)

Component	Concentration (mg/L)	Standard[a] deviation
Cations		
Magnesium (Mg)	2.17	0.22
Manganese (Mn)	0.16	0.02
Silicon (Si)	30.7	2.3
Iron (Fe)	0.001	0.020
Strontium (Sr)	0.09	0.06
Barium (Ba)	0.021	0.014
Vanadium (V)	0.023	0.016
Titanium (Ti)	<0.000	0.013
Calcium (Ca)	12.2	1.2
Lithium (Li)	0.16	0.16
Potassium (K)	6.8	2.0
Aluminum (Al)	0.003	0.011
Sodium (Na)	51.7	3.5
pH	7.1	
Anions		
Fluorine (F)	2.0	(b)
Chlorine (Cl)	6.4	
Phosphate (PO_4)	0.1	
Nitrite (NO_3	9.6	
Sulphate (SO_4)	18.2	
Alkalinity as HCO_3	135	
pH	7.1	

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[a] Cation standard deviations about mean for well water collected over six-month intervals.

[b] Anion data is average of two samples taken six months apart.

and after hydrothermal reaction with Topopah Spring tuff has low concentrations of elements such as fluorine and chlorine. This reduces the likelihood of pitting or crevice corrosion of the 304L stainless steel. The water chemistry is also unlikely to enhance the stress-assisted corrosion. Thus, there are no known conditions in the pre- or post-emplacement environment water chemistry expected to compromise the performance of the metal barrier in the repository setting (McCright et al., 1983).

Testing of borosilicate glass waste forms in J-13 water, both with and without tuff present, is in progress. Results of testing PNL 76-68 glass show that the glass dissolves less in J-13 water in the presence of tuff than when tests are done without tuff (Oversby, 1983). Dissolution rates of PNL 76-68 glass in J-13 water without tuff are slightly lower than those found in deionized water (McVay, 1982). Thus, the water conditions expected in the host rock should not adversely affect the performance of borosilicate glass waste forms. On the contrary, the presence of silicon in the water due to reaction with the rock appears to greatly decrease the dissolution rate of the glass matrix (Oversby, 1983).

Testing of spent fuel has been completed only in deionized water to date. Tests using J-13 water will be initiated in the near future. Data from the testing of spent fuel in deionized water and a bicarbonate dominated granite ground water showed no significant differences in dissolution rate of the fuel (Johnson et al., 1981). Therefore, it is anticipated that there will be no detrimental effects on spent fuel behavior in the repository due to water chemistry in the host rock.

Conclusion: Water conditions in the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain are expected to be such that no degradation of repository performance will occur as the result of changes in the solubility and chemical reactivity of the engineered barrier system. Preliminary results for both the metal canister and waste forms show no detrimental effects due to host rock water chemistry. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock stength.

Evaluation: The zeolites clinoptilolite and mordenite are high silica zeolites. The Al:Si ratio for these zeolites is slightly variable but is generally near 3:15 (Caporuscio et al., 1982). For the sodium end member of such a zeolite the reaction to albite can be written: $Na_3Al_3Si_{15}O_{36} + 12H_2O = 3NaAlSi_3O_8 + 6SiO_2 + 12H_2O$.

Because clinoptilolite and mordenite are high in SiO_2 when they break down, usually to feldspars or analcime, SiO_2 is also produced. If the chemical potential of SiO_2 is high, the reaction will tend to move to the left forming zeolite. If the chemical potential of SiO_2 is low, there will be a tendency to form feldspar, or analcime if it is more stable.

Glass and cristobalite are metastable phases in tuff at Yucca Mountain and produce higher chemical potentials of SiO_2 than the stable silica mineral, quartz. Clinoptilolite and mordenite in tuffs form as an alteration product of glass and in Yucca Mountain tend to coexist with cristobalite but not with major amounts of quartz (Caporuscio et al., 1982; Bish et al., 1981; Hay, 1978).

Successful laboratory syntheses of clinoptilolite have used starting materials that produce a high chemical potential of SiO_2 (Hawkins, 1981; Chi and Sand, 1983). Fluid from 150°C (300°F) hydrothermal experiments with clinoptilolite-bearing tuff from the Calico Hills at Yucca Mountain contained 470 mg/L SiO_2, which is well above that which would be in equilibrium with quartz (Wolfsberg et al., 1983). Finally, calculations using estimated thermodynamic data for end member Na- and K-clinoptilolites and mordenites (Daniels et al., 1983) indicate that the silica concentration in solution for the zeolite to feldspar transition at temperatures between 25 and 200°C (77°F and 390°F) is near that for cristobalite saturation.

These observations lead to the conclusion that clinoptilolite and mordenite are metastable minerals at Yucca Mountain. With the gradual transition of the glass and cristobalite to quartz, the clinoptilolite and mordenite could gradually become unstable and recrystallize (over geologic time) to less sorptive minerals. However, as discussed under Favorable Condition (3) above, it is very unlikely that this transition will be sufficiently rapid to affect repository performance.

Conclusion: The sorptive zeolites found in Yucca Mountain (clinoptilolite and mordenite) are metastable with very slow reaction rates. Through time, the zeolites might begin to break down. However, as discussed under Favorable Condition (3), very little reaction is expected in the next 100,000 years. Sorption properties and host rock strength are not expected to be reduced by geochemical processes occurring at Yucca Mountain. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.

Evaluation: The potential host rock at Yucca Mountain lies above the water table and is the Topopah Spring Member of the Paintbrush Formation. Pores in the rock will be partially filled with water and partially filled with air. Consequently, the water can be expected to contain dissolved oxygen up to a level of 8.4 ppm, the 25°C - 1 atmosphere solubility of O_2 (Linke, 1965). There are no major mineral components in the potential host rock that can be expected to react with the dissolved oxygen. Trace minerals in the rock, such as biotite, amphibole, ilmenite, magnetite and smectite clays, contain ferrous iron. Reaction of these minerals could consume some of the dissolved oxygen.

Although the proposed repository is in an oxidizing environment, there are some factors which deserve consideration that could effectively reduce the amount of oxygen reaching the waste. Changes in the redox state of water could result from interaction with the 304L stainless steel waste containers. In addition, under mildly oxidizing conditions this material should develop a protective oxide film that would limit further corrosion of the container (McCright et al., 1983). Thus, the pre-emplacement oxidizing conditions may enhance the lifetime of the canister.

The release of radionuclides from glass waste forms in the Yucca Mountain environment is expected to be controlled by the matrix solubility of the glass, and to occur at levels less than 1 part in 100,000 per year of the 1,000 year inventory (Oversby, 1983). The pre-emplacement oxidizing conditions are not expected to adversely affect the release rate from glass waste forms. As mentioned above, if the oxidation state of the water contacting the waste forms may have been lowered by interaction with the metal canister. Water that contacts spent fuel waste forms may also be buffered by reaction with Zircaloy, a reaction that could cause further lowering of the oxidation state of the water.

Oxidizing conditions in water which contacts spent fuel waste forms could result in two potentially adverse effects. First, the solubility of spent fuel in an oxidizing environment will generally be greater than that in a reducing environment (Lemire and Tremaine, 1980). This could lead to larger release of radioactive elements from the engineered barrier system under oxidizing conditions relative to reducing conditions if all other factors are the same. Second, the presence of oxidizing conditions might adversely affect the lifetime of the Zircaloy cladding on spent fuel if the UO_2 were to become oxidized and cause stress rupture of the cladding.

<u>Conclusion</u>: The presence of pre-emplacement ground-water conditions that are chemically oxidizing may not be a true indicator of the post-emplacement environment of the waste packages. As discussed above, this condition could be altered after emplacement of waste packages and is not expected to cause serious problems with respect to engineered barrier system solubility or chemical reactivity. Nonetheless, the condition is expressed in terms of pre-waste-emplacement conditions. Therefore, the Yucca Mountain site possesses this potentially adverse condition.

VI. PLANS FOR SITE CHARACTERIZATION

A number of tests are planned to improve the understanding of geochemical conditions and processes at Yucca Mountain. Analysis of rock samples from lateral coring in the Exploratory Shaft and in drifts in the in-situ test facility will provide data to better establish the vertical and lateral mineralogical and geochemical variability in the tuffaceous rocks at Yucca Mountain. In addition, large blocks of rock will be obtained at various depths during construction of the Exploratory Shaft for chlorine-36 analyses of pore water age.

This analysis will provide supporting data for estimates of flow rates in the repository horizon. Pore water extracted from the samples will also be analyzed to understand the types and magnitudes of chemical reactions occurring within the unsaturated zone.

A diffusion test is also planned during the in-situ phase of testing. This test will be used to evaluate and confirm the diffusion processes and rates in the unsaturated Topopah Spring Member. Results of this test will aid in establishing confidence in the radionuclide retardation capability of the host rock.

6.3.1.3 Rock characteristics (10 CFR 960.4-2-3)

I. INTRODUCTION

The postclosure Rock Characteristics Technical Guideline is one of four technical guidelines collectively grouped under the topic of characteristics and processes affecting expected performance. These guidelines cover the conditions deemed most important in ensuring that the expected performance of the natural components of a repository system is appropriate for isolation and containment.

Postclosure rock characteristics are important to the long-term isolation capability of the host rock. The mining operations during repository construction and the heat generated by the emplaced waste must not lead to conditions that would significantly diminish the ability of the site to contain and isolate the waste. If extensive changes were induced in the host rock, new pathways or barriers for radionuclide migration from the repository could result, and the isolation capabilities of the host rock could be affected. The concern of the postclosure rock characteristics guideline is to ensure that the present and expected characteristics of the host rock and surrounding units can accommodate the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, the host rock, the ground water, and the engineered-barrier system.

The postclosure Rock Characteristics Guideline consists of one qualifying condition, two favorable conditions, and three potentially adverse conditions. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

The stratigraphic section at Yucca Mountain is composed of a sequence of welded and nonwelded tuffs; some strata are devitrified or altered and some remain vitric (Scott et al., 1983). The strata have been subjected to varying amounts of mineral alteration as described by (Bish et al., 1984). The Topopah

Spring Member of the Paintbrush Tuff has been selected as the potential host rock (Johnstone et al., 1984). The relevant data for analyzing the impact of rock characteristics on waste containment and isolation include geological, mineralogical, physical, thermal, and mechanical attributes of the relevant rock types. Geological attributes include thickness and lateral extent of units (Nimick and Williams, 1984) and structural features, such as fracturing and stress state. Many of the fracture attributes, such as orientation, frequency, length, and aperture, have not yet been measured. Preliminary measurements of in situ stresses have been made (Healy et al., 1982). Bish et al. (1984) describe the bulk mineralogical data for various stratigraphic layers which includes mineral identification, abundance, location, fracture filling, surface coating, etc. Tillerson et al. (1984) have described relevant physical properties including density and porosity, and heat capacity, thermal conductivity, and thermal expansion. Temperature and pressure effects are yet to be investigated. Mechanical properties required for design include elastic modulus, Poisson's Ratio, cohesion, angle of internal friction, and tensile strength for intact material and fracture properties such as shear and normal stiffness, cohesion, and coefficient of friction (Tillerson et al., 1984). The nature of variations in these properties as functions of water content, confining stress, and temperature, is under investigation.

<u>Assumptions and data uncertainties</u>: Rock conditions that are influenced by geochemistry and hydrology are discussed in the Geochemistry Guideline (Section 6.3.1.2) and the Geohydrology Guideline (Section 6.3.1.1). The nature of changes in rock attributes during operation of the repository (Section 6.3.3.2) can also be important to postclosure behavior of the repository. This guideline addresses the rock conditions after closure and how they impact containment and isolation. As discussed in Sections 6.3.3 and 6.3.4, the repository can be constructed, operated, and closed using available technology. To examine postclosure conditions, various waste emplacement configurations (vertical and horizontal), canister loadings [1.6 and 3.3 kW per canister for spent fuel and 2.16 kW per canister for commercial high-level waste (CHLW)], and repository gross thermal loadings (50 to 100 kW/acre) were assumed in order to evaluate the effects of heating on the very near, near, and far fields for periods to 50,000 years. Rock properties actually determined for the host rock and surrounding units were used, where available. In those instances where

specific properties for a particular unit were not available, the property was estimated by comparison with a similar rock unit. Virtually no data are available on properties of individual fractures or the effects of fractures on rock matrix properties, although experiments to measure such properties are currently underway in the laboratory and planned for the Exploratory Shaft.

All of the computer models used in the following analyses incorporated assumptions. The characteristics of the fractures used in these analyses is one of the most difficult aspects to model; for these analyses the fractures were modeled as planar, ubiquitous and nonintersecting. Models are being developed to better understand the influence of fractures. The current models also rely on sequential rather than fully coupled calculations. Often, evaluations were made using averaged properties. Whenever possible, average and bounding properties were determined by statistical analysis. The assumptions used in the analyses are considered to be conservative.

Some geologic uncertainty arises because the data are derived from surface mapping and a limited number of boreholes. Nevertheless, the three-dimensional geologic model of Yucca Mountain is reasonably well known (Nimick and Williams, 1984). The material properties of the stratigraphic units are determined from cores typically 5 cm (2 in.) or less in diameter. Because the sample size is small, the known properties are mainly limited to those of the matrix rather than the rock mass. Also because of the small sample size, discontinuities present in the rock mass are not necessarily included in the sample. Some of the thermal and mechanical matrix properties are relatively well known because a large number of samples have been measured. In these instances, the data has been statistically analyzed to yield average values and standard deviations.

Quantitative and qualitative analyses are used in the discussion of the favorable and potentially adverse conditions for rock characteristics. The quantitative analyses incorporate computer models to predict the thermal and thermomechanical behavior of the rock units. Qualitative and semiquantitative analyses are used to predict mineralogical response to heating due to waste decay, the thickness and lateral extent of the host rock, and the relation of rock characteristics to engineering requirements.

The uncertainty introduced by the computer models is poorly known at the present time. Evaluations are underway to reduce this uncertainty by comparing the results of different models solving the same problem. The models are also being used to predict and compare the results of specific experiments and field tests.

III. QUALIFYING CONDITION

(1) The present and expected characteristics of the host rock and the surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operations, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology.

Evaluation: The preclosure Rock Characteristics Guideline (Section 6.3.3.2) discusses repository construction, operation, and closure and their relationship to the rock characteristics. The results of that analysis show that currently available technology will be sufficient to meet all engineering requirements. In addition, no unusual or exotic materials will be required. The geohydrologic and geochemical conditions are described in Sections 6.3.1.1 and 6.3.1.2, respectively. In both sections, Yucca Mountain is considered suitable for site characterization as a potential repository site.

Johnstone et al. (1984) showed that the repository host rock can accommodate expected mechanical and thermal stresses after closure. They also note that the thermal load can be adjusted to account for unforseen problems. The study of interactions among waste, host rock, ground water, and engineered components is an ongoing task. To date, no difficulties have been identified. Because the repository would be located in the unsaturated zone, ground-water interactions with the waste package are limited to temperatures less than 100°C (212°F). Above 100°C the water evaporates and moves to a cooler region. Such behavior tends to increase effective thermal conductivity and decrease temperature in the rock mass near the heat source. As noted in Section 6.3.1.1, this steam condenses a short distance from the canisters. The effects of heat and water on the mechanical response of the Topopah Spring Member are under study. After closure, the fracture permeability could decrease during the increasing temperature portion of the thermal pulse, resulting in an increase in travel time if water was moving in the fractures. During the decreasing temperature portion of the thermal pulse, the fracture permeability could gradually increase, approaching the pre-waste-emplacement values. Opening, closing, or creation of fractures around the repository is not expected to affect steady state infiltration rates, because fracture flow is not expected in the repository host rock at the current estimates of <1 mm/yr flux (Montazer et al., 1984).

<u>Conclusion:</u> Preliminary analysis of the Yucca Mountain site indicates that the present and expected characteristics of the host rock and surrounding units will permit compliance with requirements specified in 960.4-1 and 10 CFR 60.113. Furthermore, as reviewed in Section 6.4.2, a preliminary performance assessment of expected flux and flow mechanisms at the Yucca Mountain site, using available rock characteristics data and a flux of <1 mm/year, lends considerable confidence to the expectation that detailed site characterization will support preliminary results.

For meeting the engineered barrier radionuclide release of no greater than 1 part in 100,000 of the 1000-year inventory, no data to date suggest that rock characteristics of the Yucca Mountain site will compromise the performance of the waste package. On the basis of current evidence, the Yucca Mountain site meets this Qualifying Condition.

IV. FAVORABLE CONDITIONS

(1) <u>A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.</u>

Evaluation: Four potential emplacement horizons in Yucca Mountain were evaluated (Johnstone et al., 1984), and the densely welded portion of the Topopah Spring Member was recommended as the target repository horizon. The other three units evaluated also met waste isolation performance requirements, but ranked below the Topopah Spring Member; therefore, the location of the underground facility is not limited to the Topopah Spring Member. The discussion on the thickness and lateral extent of the host rock that follows, however, is based on emplacement in the Topopah Spring Member in the densely welded portion containing less than 15 to 20 percent lithophysae.

To date, a value of 15 to 20 percent has been used to differentiate between the lower relatively lithophysae-free section of the Topopah Spring Member and the upper section where lithophysae are more abundant. At low percentages, lithophysae have little effect. For high percentages (probably near 30 percent), lithophysae could change the thermomechanical properties to the point that mineability and ground support requirements are affected. At what percentage the lithophysae become a concern will be determined during site characterization. For planning purposes, the underground facility has been placed in the relatively lithophysae-free section (less than 15 to 20 percent) (Mansure and Ortiz, 1984).

Available site data indicate that acceptable rock characteristics are present within areas 1, 2, 3, and 4, (see Figure 6.3.1.3-1) and perhaps even outside these areas (Mansure and Ortiz, 1984; Sinnock and Fernandez, 1982). Area 1 is the primary target for locating the underground facility. Therefore, the surface and subsurface geologic exploration of Yucca Mountain has concentrated on area 1 (the central block) and the immediately surrounding area which has a relatively low fault density (Lipman and McKay, 1965, Scott and Bonk, 1984).

Analysis of a three-dimensional computer graphics model of Yucca Mountain (Nimick and Williams, 1984) indicates that approximately 800 ha (1950 acres) of the total 2100 acres of area 1 is usable. Based on present waste inventories and repository design concepts (Mansure and Ortiz, 1984) 616 ha (1520 acres) are required for a repository. Area 2 contains over 550 ha (1350 acres) and is similar to area 1 in fault density. Data in area 2 are limited to that

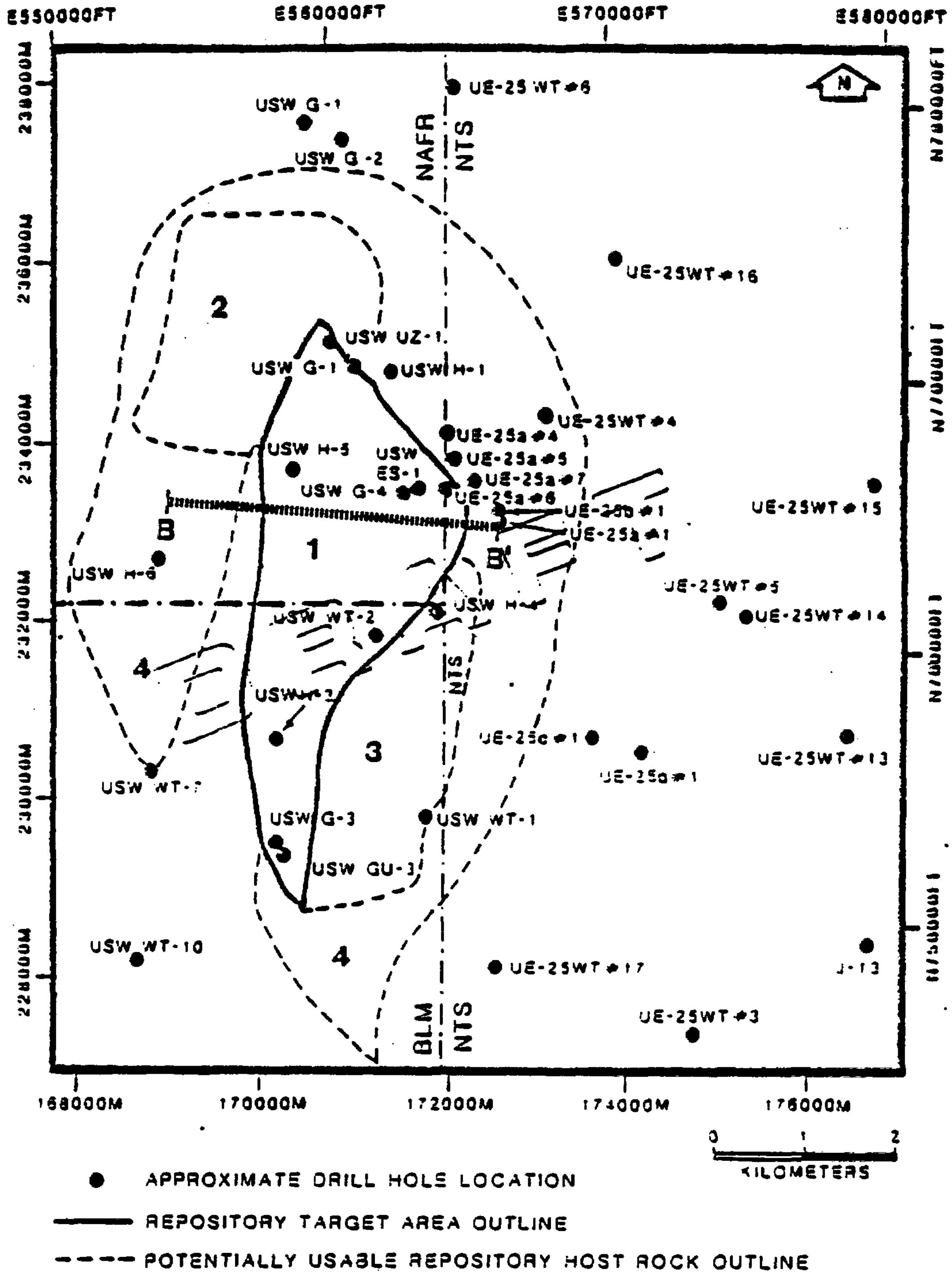

Figure 6.3.1.3-1. Potentially usable repository area; area 1 is the primary target for underground facility. See text for detailed discussion of areas 1, 2, 3, and 4.

obtained from surface mapping and extrapolation of drill hole data obtained mainly in and around area 1. Additional geologic characterization will be required to determine how much of this area is usable. Area 3 contains over 400 ha (1000 acres) and is also likely to meet waste isolation performance requirements, but possible complexity of the fault structure in this area may increase uncertainty in performance predictions. However, small portions of this area could violate the disqualifing condition requiring 200 m (650 ft) of overburden. Part of area 3 could, however, be used as a future extension of area 1, depending upon data obtained during exploration near the southeastern edge of area 1. Area 4 contains approximately 2000 ha (5000 acres) and also may have rock characteristics similar to the other areas, but less data exists for this area and it is farther from the primary target. As in area 3, portions of area 4 could violate the disqualifing condition for 200 m (650 ft) of overburden. Areas 1, 2, 3, and 4 contain over 3800 ha (9500 acres), or about six times the area needed to dispose of 70,000 MTU of waste (Mansure and Ortiz, 1984). Flexibility in lateral extent cannot be demonstrated at this time because data for areas 2, 3, and 4 are limited. Area 1 contains more than the required area for a repository and indications are that site characterization will reveal additional usable area.

Basic requirements for the thickness of the geologic section at the proposed site are that there be sufficient overburden to ensure a low probability of exhumation by erosion, and sufficient thickness of usable host rock to provide the volume envelope required for the underground facility. Figure 6.3.1.3-2 is a cross section of area 1 showing the possible location of the underground facility. The potential repository host rock is the lower portion of Tpt on this figure. A three-dimensional model of area 1 that incorporates surface and subsurface data (Nimick and Williams, 1984) was used to determine that the host rock has sufficient thickness for flexibility in selecting the depth, configuration, and location of the underground facility. In most of area 1, the thickness of the potential host rock is more than four times the approximately 45 m (150 ft) used as a conservative working basis for the envelope surrounding the underground facility (Mansure and Ortiz, 1984). Also shown in Figure 6.3.1.3-2 are the projected locations of some faults identified at the surface. The properties of these faults are, as yet,

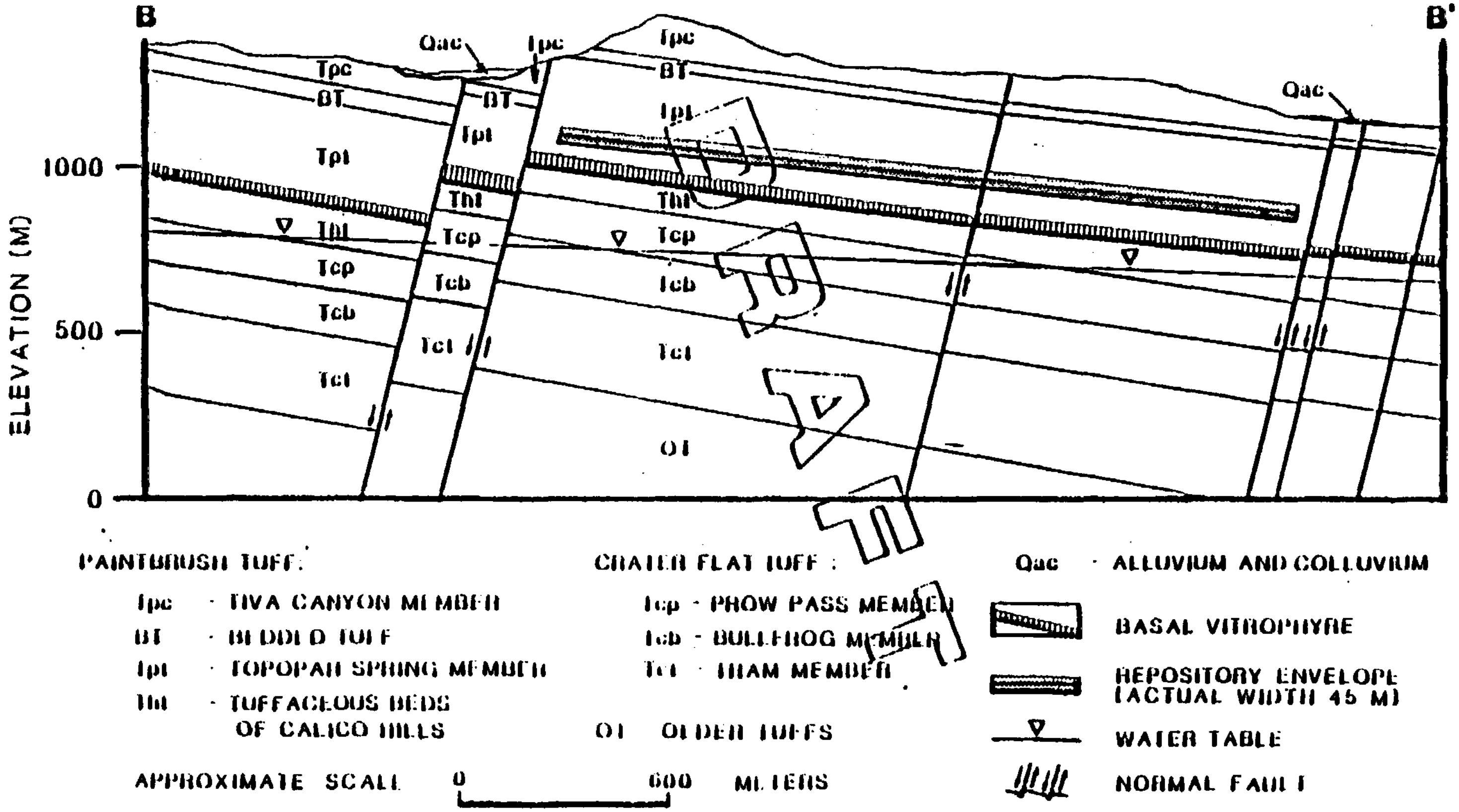

Figure 6.1.1.3-2. East-west cross section of area 1 from Figure 6.1.3.1-1 showing possible location of the repository envelope.

unknown. However, the simple presence of a fault is not necessarily detrimental, and current information suggests that faults may have little or no effect on the repository (Dravo Engineers, Inc., 1983a; Roseboom, 1983).

The thickness of the erosional barrier at Yucca Mountain is discussed in Section 6.3.1.5 (Erosion) and is more than 300 m (1000 ft) over much of area 1. Figure 6.3.1.3-3 shows the thickness of the overburden above the midplane of the repository envelope. To date, exploration in area 1 has revealed sufficient thickness of the potential host rock to contain and isolate the waste. The thickness of the host rock at Yucca Mountain is adequate to allow the depth and location of the underground facility to be chosen and later modified, if necessary, so as to avoid problem areas identified during either site characterization or construction activities.

Conclusion: The potential host rock is sufficiently thick to provide significant vertical flexibility in the placement of the repository. The central block, which has to date been the focus of exploration, provides limited flexibility in the lateral placement of the repository. Based on limited additional exploration and extrapolation of data from the central block, contiguous areas appear suitable for repository placement, but additional exploration would be necessary to claim significant lateral flexibility. At present, considering only the central block, the favorable condition can be claimed only for vertical flexibility in placement of the repository but not for lateral flexibility in placement. Therefore, the Yucca Mountain Site does not possess this favorable condition.

(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.

Evaluation of thermal conductivity and thermal expansion: Each of the three subconditions of this favorable condition is concerned with an aspect of repository performance that could affect isolation and containment. High thermal conductivity acts to prevent heat build-up by rapidly conducting the heat away from the waste canisters. A low coefficient of thermal expansion

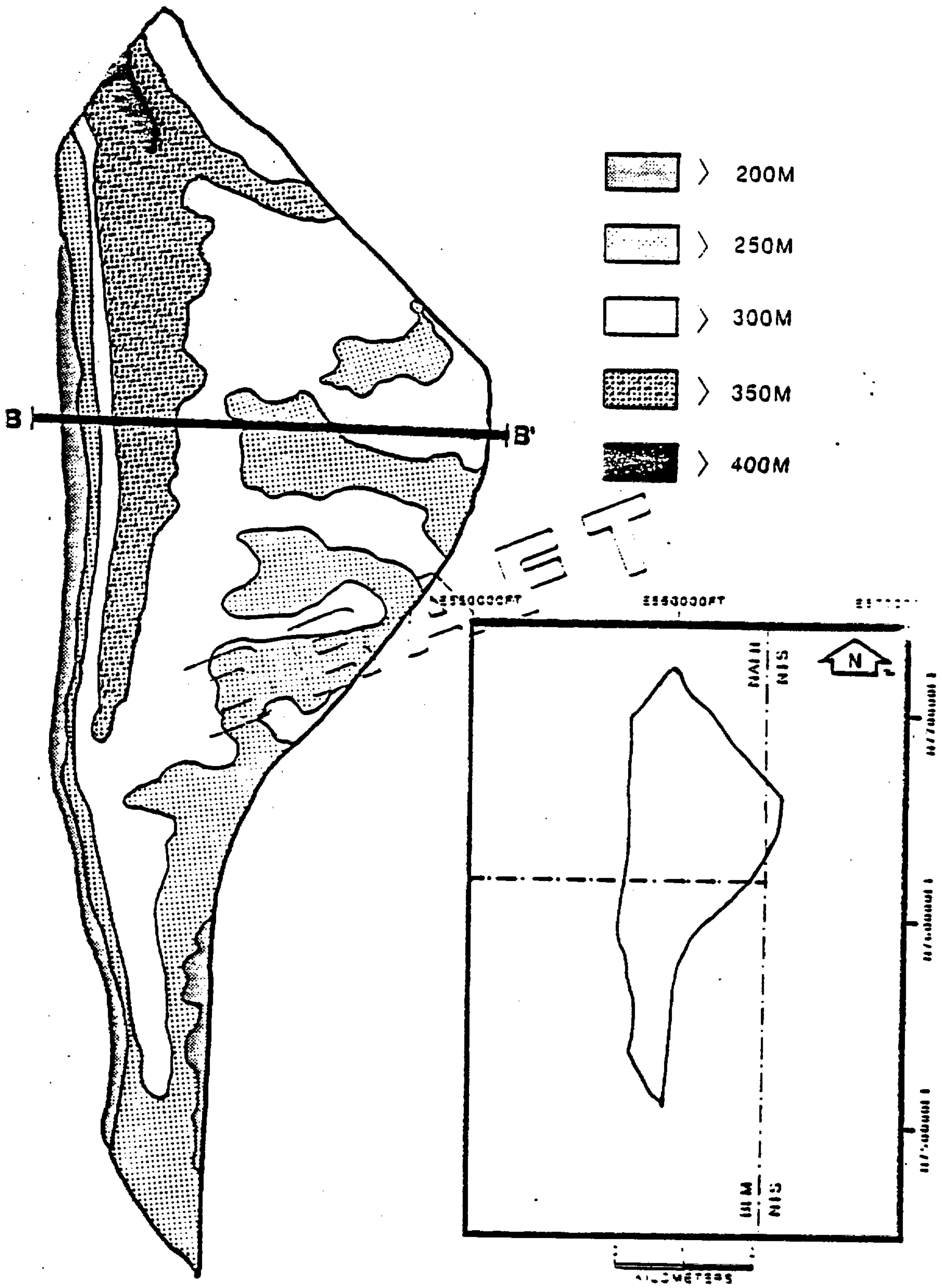

Figure 6.3.1.3-3. Thickness of the overburden above the midplane of the repository envelope. See Figure 6.3.1.3-2 for cross section B-B'.

minimizes the magnitude of induced stresses due to temperature rise. The combined intent of these two subconditions is to ensure that thermally induced fracturing will not compromise the host rock performance; sufficient ductility to seal fractures complements the first two subconditions by providing a mechanism to close any fractures created by thermal effects or other repository operations.

The discussion of the applicability of these guidelines to the Yucca Mountain site must also recognize two points that bear on the conclusions. First, the site is in an unsaturated zone at Yucca Mountain. Favorable Condition 6(iv) under Section 6.3.1.1 notes that for an unsaturated zone repository, freely draining strata are desirable, and the Yucca Mountain site meets this favorable condition. Second, the Topopah Spring Member is thought to be fairly highly fractured. In such a situation it is possible for limited thermally induced expansion to occur without generating sufficient stresses to cause new fracturing. Values for the thermal conductivity and coefficient of thermal expansion for the potential host rock fall within the range of values for other rocks being considered as potential repository host rocks. The Topopah Spring tuff has an average conductivity of 1.8 ± 4 W/m°C and a coefficient of thermal expansion of 10.7×10^{-6}/°C.

The thermal conductivity and coefficient of thermal expansion are only important when combined in an analysis that includes relevant physical properties, additional thermal and mechanical properties, repository design, canister loading, and gross thermal loading. Such analyses (Johnstone et al., 1984) have shown (a) that the impact of the repository on the surrounding rock is small because the rock can accommodate the expected mechanical and thermal stresses; (b) that considerable flexibility exists in repository design, canister loading, and gross thermal loading to minimize the impact of any as yet unidentified, adverse rock response. The analyses indicate that the thermal conductivity and coefficient of thermal expansion of the densely welded Topopah Spring Member at Yucca Mountain will not adversely affect the containment and isolation capabilities of the repository.

Evaluation of ductility to seal fractures: The ability to seal fractures is not a favorable condition for a repository in the unsaturated zone. The consequence of sealing fractures could be that the repository becomes saturated because of the formation of a barrier to water flow and development of a perched water zone that would not exist in a freely draining system.

The current data for the Topopah Spring matrix show essentially elastic behavior up to the onset of brittle failure. Typically, the axial strain to the point of failure in compressive tests does not exceed 1 percent. Studies on the effects of water and elevated temperatures on the mechanical behavior are under way, and results will be reported in the future. Based on present data, however, the Topopah Spring tuff does not have sufficient ductility to seal induced or preexisting fractures. As discussed in Potentially Adverse Condition (3), it is unlikely that sealing will occur by other processes, such as mineral solution deposition.

Conclusion: Analyses have shown that the thermal and mechanical behavior of the rock surrounding the repository leads to no mechanisms that compromise isolation and containment and therfore is well within acceptable limits. The analyses indicate that the thermal conductivity and coefficient of thermal expansion of the potential host rock are favorable for placing a repository at Yucca Mountain when considered in conjunction with expected ground-water flux. The host rock is not sufficiently ductile to seal fractures; this sealing is, in fact, undesirable in an unsaturated zone repository. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.

Evaluation: the evaluation of technology required to deal with rock conditions during the preclsure phase (Section 6.3.3.2) identified no situations which would require engineering measure beyond reasonable technology or impact waste contaiment or isolation. Other rock conditions that could seriously threaten waste package containment or isolation of the waste after the package is breached are considered in this evaluation. Conditions considered included the chemical environment, mechanical behavior (including the effects of heat), hydraulic conductivity, location of water producing zones, and shaft and borehole sealing. Most of the rock property data currently available are from surface mapping and measurements on core.

The chemical environment is benign with regard to corrosion and leaching of the waste package. The rock is expected to be strong with little likelihood that blocks would fall on the waste canissers and breach containment although mining experience will be needed to confirm this. Heat has been predicted to cause limited fracturing around the waste emplacement borehole. The rock fracturing is expected to have minimal impact on containment or isolation, but this has not been confirmed. Hole liners, emplaced to ensure retrievability, may both lessen and delay potential adverse effects but would not necessarily eliminate them. Nevertheless, if the thermally induced rock fracturing around boreholes does become a problem, it appears to be solvable with reasonably available technology. Work is continuing on the effects of heat and water on the mechanical behavior.

Hydrologically, the repository horizon is freely draining. At present, no difficulties have been identified regarding shaft and borehole sealing. In summary, no rock conditions have been identified or are anticipated that would require engineering beyond reasonable technology to ensure waste containment and isolation.

Conclusion: No rock conditions have been identified at the Yucca Mountain site that would require extraordinary engineering measures to ensure waste containment or isolation. Existing technology is adequate to handle the construction, operation, and closure of the repository in a manner consistent with waste containment and isolation objectives. Therefore, Yucca Mountain does not possess this potentially adverse condition.

(2) <u>Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.</u>

<u>Evaluation of thermally induced fractures</u>: The potential host rock at Yucca Mountain is the Topopah Spring Member, which is a highly fractured (Spengler et al., 1981, Scott et al., 1983), unsaturated densely welded tuff. A study by Johnstone et al. (1984) compared the suitability of the Topopah Spring Member for repository development with three other potentially suitable units in Yucca Mountain. Part of this study focused on the thermomechanical response of the rock in the near and far fields for short and long time periods. Calculations were made with state-of-the-art, finite element, thermomechanical computer codes that accounted for fractures (ubiquitous joint model) and geologic layering (stratigraphy). The physical, thermal, and mechanical properties included both average and limit values determined from samples specific to each layer or estimated by comparison with similar layers. In particular, thermal expansion coefficients that accurately describe the cristobalite phase transition in the Topopah Spring Member were used (see the evaluation of Potentially Adverse Condition (4), Section 6.3.3.2). In situ stresses were estimated because no measurements had been made at the Yucca Mountain site when the evaluation began. Subsequent measurements were in reasonable agreement with the estimates (Johnstone et al., 1984). For a repository in the Topopah Spring Member, with a gross thermal loading of 57 kW/acre, no thermally induced fracturing of the matrix was calculated in either the near or far field. Virtually all thermomechanical effects were accounted for by movement along existing fractures.

For relatively higher canister heat loads (3.3 kW/canister), other thermomechanical calculations predict the potential for rock fracturing in the immediate vicinity (very near field) of the waste emplacement borehole and extending less than 10 cm (4 in.) into the rock. Such fracturing is not expected to affect waste containment or isolation. In spite of the possible decrease in thermal conductivity, such fracturing may be desirable because of the increased surface area available for radionuclide retardation. Experimentally, borehole wall degradation has not been observed in deep underground, small diameter heater tests in tuff (Zimmerman, 1983).

For the conditions used in these calculations, the results indicate that the potential for thermally induced fracturing is very low. More importantly, however, the calculations suggest that the repository thermal loading can be adjusted if it is discovered that thermal effects could become potentially adverse. Another result of the thermomechanical behavior is the potential to decrease the fracture aperture in the far field, above and below the repository, thereby decreasing the permeability that could potentially result in longer water travel times, diversion of part of the water flux around the repository, or both.

Evaluation of hydration or dehydration of mineral components: The Topopah Spring Member contains little or no zeolites or glass in the horizon of interest. South of Drill Hole Wash, the member generally contains less than 3 percent smectite. More than 98 percent of the host rock within the potential repository block is composed of alkali feldspar, cristobalite, quartz, and tridymite; however, tridymite is generally not present in the potential repository horizon (Bish et al., 1984). The hydrous minerals in the repository horizon are not present in large enough quantities to cause significant dehydration effects. Rock units in Yucca Mountain below the repository horizon contain a variety of hydrous phases, including volcanic glass, smectite, clinoptilolite, mordenite, and analcime (Bish et al., 1983). The extent to which dehydration and contraction will affect waste isolation, however, will depend upon the distribution of hydrous minerals in the host rock, the temperature rise imposed on the minerals, and the water vapor pressure.

Assuming a gross thermal loading of 57 kW/acre, the maximum temperature experienced at 50 m (160 ft) below the repository horizon is predicted to be well below 100°C (212°F) (Johnstone et al., 1984). Under these conditions, smectites, zeolites, and glass will dehydrate only if the water vapor pressure is low (Bish, 1981; Bish et al., 1982). Travis et al. (1984) assumed a thermal loading of 50 kW/acre and calculated the temperature and percentage saturation as a function of time. At 140 years after waste emplacement, the dehydration front extended downward about 20 m (65 ft) from the repository at which point the rock temperature was approximately 100°C. Thus, dehydration and contraction would be possible only in the near field but as noted above, no hydrous phases are present in this region. Consequently, mineral dehydration and contraction are not anticipated in the repository.

Predictions of the importance of dehydration in the lower Topopah Spring Member below the target horizon, where smectites, clinoptilolite, and volcanic glass occur, must await final thermal models and repository conceptual designs. Dehydration reactions involving smectites, clinoptilolite, and mordenite are reversible when heating is below 200°C (392°F) (Bish, 1981), and the presence of water vapor significantly increases the temperature of dehydration for smectites (Koster van Groos, 1981) and probably for zeolites. Therefore, such reactions, even if they occur in the far field, will probably be reversible and will not affect waste isolation.

One additional factor that could affect the waste containment or isolation is the abundance of cristabolite in the very near field. Transition from alpha to beta cristabolite, occurring at 223° ± 27°C (433° + 49°F) in confined tests (Lappin, 1982), gives rise to a slightly increased thermal expansion. Because of the high transformation temperature, the potential for this transformation to occur is limited to the very near field of the waste package and should not affect waste isolation because cristabolite is not important in retardation.

Evaluation of brine migration: Brine is not found in the tuff at Yucca Mountain and brine migration is not an issue.

Conclusion: The potential host rock at Yucca Mountain is a physically and chemically stable, densely welded tuff that will be little affected by expected repository conditions. More than 98 percent of the rock is composed of feldspar, cristabolite, and quartz, all nonhydrous minerals. The potential host rock is highly fractured, and any additional thermally induced fracturing will be minor and will not adversely affect waste containment or isolation. Therefore, Yucca Mountain does not possess this potentially adverse condition.

(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with the pre-waste-emplacement conditions.

Evaluation: Three categories of thermal-related effects have been identified as potentially applicable to this host-rock isolation condition: (1) changes in the radionuclide retardation capability, (2) changes in host-rock permeability due to matrix dissolution, and (3) convective transport of radionuclide-contaminated ground water. The basis for evaluating each of these three concerns is discussed separately below.

Evaluation of thermal effects on radionuclide retardation: Both thermally driven rock and ground-water interactions along with absolute temperature increases could affect radionuclide sorption and thus the retardation capability of the host rock. The rock and ground-water interactions could accomplish this by altering the mineral phases present and the ground-water solution chemistry. However, elevated-temperature experiments on the interaction of Topopah Spring tuff with water from well J-13 indicate that very little change should occur in the ground-water chemistry and the primary mineralogy in the Topopah Spring Member from an emplaced heat source (Oversby, 1983). Additionally, this study noted that the anionic composition (radionuclide complexing agents) of the water remains relatively constant. Therefore, the effect of increased temperature on radionuclide solution chemistry should be minimal. The lack of significantly thermally induced mineral alteration is also addressed in the Favorable Condition (3) for Geochemistry (Section 6.3.1.2)

The direct effect of higher water temperatures on the sorption process has been superficially investigated (Daniels et al., 1982; Johnstone and Wolfsberg, 1980; Erdal et al., 1979). These limited studies showed, that in general, temperature changes between 20°C and 70°C (68°F and 158°F) have only a minor effect on sorption. For most elements studied, sorption is slightly greater at the higher temperatures (sorption coefficients increased by up to a factor of 5). The exceptions include a few lanthanides and actinides, which showed very little or a slightly negative temperature response. Additionally, as temperature is increased, retardation caused by matrix diffusion will become more competitive with sorption processes.

In summary, neither thermally induced enhanced rock-water interactions or increased sorption temperatures should decrease the isolation potential of the host rock.

Evaluation of host rock permeability changes: The heating and subsequent cooling of ground water as it flows through the host rock could induce mineral dissolution and precipitation processes which, in turn, would change the permeability. Currently, the sizes of the changes in permeability that would adversely affect isolation have not been identified. However, a study has been conducted that shows that, for anticipated quantities of both porous and fracture flow, the potential porosity/permeability changes are not significant (Braithwaite and Nimick, 1984). In this analysis, it was assumed that the infiltrating ground water would maintain equilibrium saturation with respect to amorphous silica. This is a reasonable bounding assumption because:

1. Dissolved silica concentrations constitute a major control on silicate phase dissolution (McVay, 1982; Wollast, 1967 White et al., 1980).

2. The predicted quantity of mass transfer is greater than that measured experimentally (Braithwaite and Nimick, 1984).

3. Rates of equilibrium of ground-water-rock interactions are very slow at the low temperatures predicted for waste isolation in the unsaturated zone (Oversby, 1983).

A predicted time-dependent temperature gradient was coupled with the amorphous silica compositional control assumption to determine the net change in porosity as a function of time and position. The results for both 57 and 90 kW/acre spent fuel loadings indicated that the maximum cumulative increase in porosity would be a volume fraction of only 0.00005 and that a decrease in porosity would only occur near the repository horizon. The net precipitation is mainly due to water vaporization and would decrease the void fraction by approximately 0.00001. This latter result probably addresses the critical issue since precipitation during downstream cooling represents a potential pore or fracture plugging problem. However, these small changes, even if restricted to existing fractures are not sufficient to significantly affect permeability.

Laboratory experiments using tuff samples from the Topopah Spring Member (Morrow et al., 1983; Byerlee et al., 1983) also support the idea that host rock permeability changes are likely to be very small. A 7.6-cm (3-in.) diameter sample was subjected to a temperature gradient of 100°C (180°F) between the inner and outer edge. Ground water from J-13 was passed through the sample under confining and pore pressures corresponding to a burial depth of 1.2 km (0.75 mi). Permeability of the tuff at room temperature was 3 μda. After heating to 150°C, the value increased to 6 μda, and slowly increased for one week to 10 μda and remained stable for two weeks. The pH of the fluids discharged from the low-temperature outer edge of the sample was very close to than of J-13 water, and the concentrations of ionized species remained low, near that of J-13 water.

<u>Evaluation of convective transport of radionuclide-contaminated ground water</u>: Thermally induced convective transport could conceivably reduce ground-water travel times through the host rock. If this process occurred in ground water that had contacted the waste form, a decrease in the isolation provided by the host rock could result. Convection can occur in both vapor and liquid phases.

Radionuclide leaching and transport will not commence until liquid water contacts the waste form [when temperatures have decreased below 100°C (212°F)]. Therefore, vapor phase convection (either forced or free) is not a viable radionuclide transport mechanism because radionuclides are insoluble in water vapor and the thermal gradient needed to drive forced vapor convection will not exist.

Free convection liquid water transport, which is caused by density differences or buoyancy effects, can occur in porous media that are saturated with water. A mechanism for free convection transport of liquid water (and therefore radionuclides) in the unsaturated zone is difficult to formulate. Nevertheless, free convection in the saturated zone would place an upper bound on the possible effect in the unsaturated zone. A preliminary study was conducted in which the effect of convection on energy transfer in a saturated tuff media was considered (Mondy et al., 1983). The results showed that even with a thermal driving force well over 100°C, the maximum impact of free convection (if it occurred) would be a very small temperature increase [2 to 3°C (4 to 5°F) occurring for less than 60 years]. The largest induced water velocities would be less than 1 mm/yr (0.0004 in./yr). Based on these results, the lower temperatures and the unsaturated conditions actually anticipated for Yucca Mountain should preclude a decrease in host rock isolation due to convection transport of radionuclide bearing ground water.

Conclusion: No combinations of geologic structure, geochemical and thermal properties, and hydrologic conditions have been identified that will respond to the heat load imposed by radioactive decay in such a way that the isolation characteristics of the host rock would be compromised.

The following heat-related effects on the isolation potential of the host rock were identified, evaluated, and subsequently shown to have minimal or no impact: (1) thermally enhanced rock and ground-water interactions should only minimally alter ground-water chemistry and host rock mineralogy; (2) radionuclide retardation due to sorption should not be adversely impacted at higher temperatures; (3) permeability changes due to host rock dissolution and precipitation processes should not be significant; and (4) convective transport of radionuclide-bearing ground water should not occur in the relatively low temperature, unsaturated conditions expected in the host rock at Yucca Mountain. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

VI. PLANS FOR SITE CHARACTERIZATION

A number of tests are planned to supplement the existing rock characteristics data base. Overcore tests to determine in situ stresses in Yucca Mountain will be performed at three levels during construction of the Exploratory Shaft. An Enhanced Heated Block Experiment is planned for the in situ phase of Exploratory Shaft Testing to determine the rock response to induced stress and thermal changes. Permeability changes in selected fractures under various stress and thermal loads will also be measured. A Canister Scale Heater Experiment will be conducted to evaluate the near field rock response to waste imposed thermal loads. Thermal, thermomechanical, and hydrothermal measurements will be made and used to establish the behavior of the host rock to be expected during postclosure thermal periods.

6.3.1.4 Climatic changes (10 CFR 960.4-2-4

I. INTRODUCTION

Climatic changes could, over time, alter the geohydrologic system at a site. This postclosure guideline on climatic changes is concerned with changes that may unfavorably affect the ability of a repository to isolate waste after closure. The purpose of the guideline is to ensure that the DOE will select sites where future climatic conditions are not likely to lead to radionuclide releases greater than those specified in the NRC performance objectives and the EPA technical criteria.

The guideline consists of one qualifying condition, two favorable conditions, and two potentially adverse conditions. The Yucca Mountain site is evaluated with respect to all these conditions in the following sections.

II. RELEVANT DATA

Contemporary climatic patterns at Yucca Mountain have been inferred by extrapolations of recorded climatic data from Beatty, Nevada, 26 km (16 mi) west of the site (DOC, 1965), and Yucca Flat, 40 km (25 mi) east of the site (Bowen and Egami, 1983) and from data presented by Quiring (1968). Contemporary recharge flux through the unsaturated zone of Yucca Mountain was estimated based on Rush (1970), Waddell (1982), Rice (1984), and Montazer and Wilson (1984).

Climates of the Nevada Test Site and its vicinity during the last 45,000 years have been reconstructed by Spaulding (1983) and Spaulding et al. (1984) largely on the evidence of plant macrofossils occurring in the middens of packrats (genus Neotoma). These references also review the literature on global and regional climatic changes and predict future climatic variations.

Some data and interpretations exist relevant to Pleistocene water-table levels, ground-water recharge, and pluvial lake formation in areas adjacent to

Yucca Mountain. Winograd and Doty (1980) described the late Pleistocene hydrology of the Ash Meadows ground-water subbasin; their interpretation is based on the distribution of calcite veins in alluvium and lake beds, as well as fossil-spring deposits of tufa. The mineralogy of matrix fines in samples of alluvium, taken from boreholes north of Frenchman Flat, reflects the stability of water-table levels during the Quaternary Period (Jones, 1982). The mechanisms of recharge to alluvium in the west central Amargosa Desert during 17,000 to 9000 yr B.P. have been inferred by Claassen (1983) from carbon, hydrogen, and oxygen isotopic data. Evidence for pluvial lakes in Nevada during the last glacial episode has been interpreted by Mifflin and Wheat (1979).

Assumptions and data uncertainties: Evidence that would allow reliable reconstructions of early-to-middle Pleistocene climates at Yucca Mountain is limited, because of the absence of glacial phenomena in the area and the incompleteness of the pedological and geological records. Consequently, it is assumed that the climatic extremes inferred by Spaulding (1983) and Spalding et al. (1984) from evidence of late Wisconsinan age would be typical of all Quaternary time. These estimates of future climatic changes were also adopted for some of the analyses in this section. The uncertainties implicit in these estimates are not quantifiable but probably are large, and the estimates should be used only to establish reasonable bounds on climatic parameters.

Reconstruction of late Pleistocene hydrology of Ash Meadows ground-water basin by Winograd and Doty (1980) does not specifically apply to Yucca Mountain because the site is in a different ground-water basin (that is, the Alkali Flat-Furnace Creek Ranch). No distinctive evidence of Quaternary water levels has been revealed during preliminary investigation of tuff minerals from Yucca Mountain [see Geochemistry Favorable Condition (1), Section 6.3.1.2]. The effects of pluvial conditions on flow paths and water levels beneath Yucca Mountain are being studied using mathematical models of the regional and local hydrology.

The relation between precipitation and recharge to the unsaturated zone at Yucca Mountain is not well understood. Conceptual models of flow in the

Yucca Mountain. Winograd and Doty (1980) described the late Pleistocene hydrology of the Ash Meadows ground-water subbasin; their interpretation is based on the distribution of calcite veins in alluvium and lake beds, as well as fossil-spring deposits of tufa. The mineralogy of matrix fines in samples of alluvium, taken from boreholes north of Frenchman Flat, reflects the stability of water-table levels during the Quaternary Period (Jones, 1982). The mechanisms of recharge to alluvium in the west central Amargosa Desert during 17,000 to 9000 yr B.P. have been inferred by Claassen (1983) from carbon, hydrogen, and oxygen isotopic data. Evidence for pluvial lakes in Nevada during the last glacial episode has been interpreted by Mifflin and Wheat (1979).

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The relation between precipitation and recharge to the unsaturated zone at Yucca Mountain is not well understood. Conceptual models of flow in the unsaturated zone are not yet sufficiently developed to permit quantitative studies of relations between recharge and precipitation amounts and distributions.

Analyses made to date are largely qualitative. When quantitative analyses are made, they will rely heavily on preliminary performance assessments that are summarized in Section 6.4.2 and described in Thompson et al. (1984), and on the preliminary analysis of system-parameter sensitivities by Sinnock et al. (1984).

III. QUALIFYING CONDITION

The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

In projecting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

Evaluation: Effects of predicted climatic changes on geohydrologic processes are not expected to be large; no new lakes or significant changes in surface drainage are expected. Climatic conditions during most of the Quaternary probably did not depart substantially from modern conditions and probably had minor effects on the main features of the present hydrologic system. No evidence indicates that the water table was as high as the proposed repository level during the Quaternary Period, and rock properties make it very unlikely that the water table will rise sufficiently to flood the repository. In addition, preliminary studies of the performance of a repository at Yucca Mountain (Sinnock et al., 1984) have demonstrated compliance with the EPA release limits for reasonably foreseeable releases (see 40 CFR 191, Table 1) under conditions that could reasonably be expected during climatic changes at Yucca Mountain.

Conclusion: Future climatic conditions would not be likely to lead to radionuclide releases from a repository at Yucca Mountain greater than those allowable under the requirements specified in 960.4-1. Therefore, the Yucca Mountain site qualifies under this condition.

IV. FAVORABLE CONDITIONS

(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.

Evaluation: Inasmuch as past geohydrologic events and processes are probably the best guide as to what may be expected in the future, a discussion of the regional climate during the Quaternary is included below.

Pluvial climates probably had little effect on the principal surface-water features of the region. By early Quaternary time, lakes of Tertiary age that had existed in the Amargosa Valley and Crater Flat areas had disappeared, although the range of ages of the associated lacustrine deposits is not well known [considered to be Quaternary-Tertiary in age by Hoover et al. (1981) and Swadley (1983)]. According to the reconnaissance studies of Mifflin and Wheat (1979), the pluvial climates that periodically occurred during the remainder of the Quaternary did not cause perennial lakes to form in southern Nevada, like those that existed in central and northern Nevada.

Surface-water drainage basins probably were well established by early Quaternary time, and the closed surface-water and ground-water basins that exist today existed throughout the Quaternary. Although Lake Amargosa may have continued into early Quaternary, throughout most of this period the Amargosa River drainage system was integrated with Death Valley. The tributary Fortymile Wash drainage system and the bedrock washes dissecting Yucca Mountain and other ranges were also established by early Quaternary time. In a process that continues today, numerous minimum shifts of channels of ephemeral washes occurred during the Quaternary in the alluvial basins, as shown by the distribution of various types of Quaternary alluvial deposits (Hoover et al., 1981).

Deep entrenchment, low rates of erosion, and present topographic divides make it unlikely that the largest probable climatic change, from arid to semiarid, would cause a significant change in location or size of the drainage system at the proposed site. Such climatic changes would not produce long-term impoundments of water closer than Death Valley.

Materials to form landslides large enough to block drainages during a climatic change are not present on Yucca Mountain, and evidence of landslides on Yucca Mountain has not been observed. Eolian sands may have clogged some drainages on Yucca Mountain during early Quaternary time but such sands are very permeable and also are easily eroded. No evidence of water impoundment by these sands is known.

Conclusion: Surface-water systems in the region and at the Yucca Mountain site have changed little during at least the last several hundred thousand years of the Quaternary Period. The expected magnitude of effects of predicted climatic changes on geohydrologic processes is not large; no new water impoundments (lakes) nor significant changes in surface drainage are expected. Such changes that may occur are not likely to affect waste isolation adversely. Therefore, the Yucca Mountain site possesses this favorable condition.

(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.

Evaluation: Evidence that climatic changes did occur in the region during the Quaternary comes from the geologic record and plant-fossil record. A variety of types of deposits of Quaternary age occur in the region, including debris flows, fluvial sand sheets, eolian dunes, and coarse fluvial deposits (Hoover et al., 1981; Swadley, 1983). These units represent various environments of deposition that in turn reflect, in part, fluctuating climatic conditions. Although specific climates cannot be defined, the evidence is consistent with an arid to semiarid climate (Hoover et al., 1981). In addition, climatic changes can be inferred from the development of various landforms and rocks in the area, and from the occurrence of three regional unconformities.

Vegetative covers varied in type during the past 45,000 years, as indicated by variations in assemblages of plant macrofossils contained in packrat middens. These variations reflect changes in climate, in the sense that the assemblages are indicators of effective moisture available at the time the plants were growing. Analysis of packrat middens shows that, at different times during the last 45,000 years, the regional vegetative cover varied from well-developed juniper woodland to modern desertscrub at intermediate altitudes, from about 1200-1800 m (4000-6000 ft), and from subalpine conifer woodland, to pinyon-juniper woodland, and to a woodland-desert scrub mosaic at higher altitudes (above 1800 m) (Spaulding, 1983).

Evaluation of pluvial climates: Quaternary hydrologic conditions that differed the most from modern conditions probably were those that occurred during several pluvials, periods of presumably wetter conditions that alternated with interpluvials, periods during which climatic and hydrologic conditions were similar to those of today. If it could be demonstrated that the wetter period did not modify the hydrologic system in the Yucca Mountain area, then even more extreme climatic conditions would probably be necessary to significantly affect the hydrologic system.

Most evidence for estimating pluvial climates in the region is based on pluvials of late Wisconsin age; in southern Nevada, evidence for estimating early Wisconsin and pre-Wisconsin paleoclimates is virtually nonexistent, except for the qualitative evidence that landforms, paleosols, and unconformities provide. Therefore, reconstruction of climates that existed before late Wisconsin time in southern Nevada is tenuous. However, some evidence indicates that the climate in Nevada during each of the pluvials was similar, and, therefore, an analysis of the late Wisconsin pluvial climates and their hydrologic effects provides a sound basis for estimating maximum effects that occurred during the entire Quaternary. For example, on a global scale, similar climatic conditions probably prevailed during each of the major glacial epochs that occurred during the Quaternary (Spaulding, 1983). Mifflin and Wheat (1979) suggested that the pluvial lakes of Lahontan (Wisconsin) age that occurred in central and northern Nevada were generally as large, or perhaps even larger, than lakes that occurred in pre-Lahontan times, based primarily on the absence of evidence of older, higher lakes (although such evidence may have been destroyed by erosion). On the other hand, Spaulding et al. (1984) postulate, based on the plant macrofossil evidence, that the latest Wisconsin pluvial was wetter and warmer than the one that preceded it during the Wisconsin full-glacial time. Because of the higher temperatures, greater precipitation would have been required to maintain lake levels at altitudes similar to those that occurred during earlier, cooler pluvials.

Winograd and Doty (1980) hypothesized that progressive and continued uplift of the Sierra Nevada and Transverse Ranges during the Quaternary may have led to a long-term trend of increasing aridity in Nevada. Huber (1981) suggested that the Sierra Nevada has risen about 1000 m (3300 ft) since the Pliocene, and Hay (1976) postulated a rise of 1800 m (5900 ft) in the last 4.5 million years. The rising mountain ranges would have produced a rainshadow effect that would have modified the distribution and amount of precipitation in Nevada and resulted in increasing aridity (Winograd and Doty, 1980). This conclusion appears to contradict the Lahontan lacustrine evidence of reported pluvials having similar climatic characteristics and the paleoecological evidence of a wetter pluvial at the end of the Wisconsin time. Probably the trend toward increasing aridity was overwhelmed by the cyclic fluctuations.

Most workers believe, that even during pluvials, semiarid conditions persisted on the valley floors of southern Nevada, and that conditions no wetter than subhumid prevailed on the highest mountains (Winograd and Doty, 1980). From studies of packrat middens in the region, Spaulding (1983) and Spaulding et al. (1984) estimate that at the time of the global glacial maximum during late Wisconsin time (18,000 ± 3000 yr B.P.), temperatures in the region averaged 6 to 7°C below modern mean annual temperature. Average annual precipitation was 30 to 40 percent above the modern value. Winter precipitation was 60 to 70 percent above the modern average, while summer precipitation was 40 to 50 percent below. Mifflin and Wheat (1979) also concluded that full-pluvial climates in Nevada did not differ greatly from modern climates. Based on climatological and hydrologic analyses, they estimated that statewide full-pluvial mean annual temperature was about 3°C (5°F) lower and mean annual precipitation was about 68 percent higher than modern values; they further conclude that the absence of physiographic evidence for pluvial lakes in southern Nevada supports the concept of aridity in that area during pluvial climates.

Although the estimated departures from modern annual and seasonal precipitation may appear substantial on a percentage basis, they are minor when calculated on an absolute basis (in millimeters). Estimates of average precipitation for 1964 through 1981 at an altitude of 1200 m (4000 ft) in the vicinity of Yucca Mountain, based on maps presented by Quiring (1968, 1983), are: annual, about 150 mm (5.5 in.); cool season (October-April), 100 mm (4 in.); and warm season (May-September), 40 mm (1.6 in.). Estimates of full-glacial near-pluvial precipitation, based on these values and the percentage departures presented by Spaulding (1983), are: annual, about 180 to 195 mm (7 to 8 in.); cool season, about 160 to 170 mm (6 to 7 in.); and warm season, about 20 to 25 mm (0.9 to 1 in.).

As described by Spaulding et al. (1984), following the full-glacial (Wisconsin-maximum) pluvial, a trend toward warmer and drier conditions began. The drying trend was interrupted by a pluvial period that occurred during latest Wisonconsin time (12,000 to 10,000 yr B.P.) and early Holocene (10,000 to 8,000 yr B.P.) times. The climate during this pluvial probably differed substantially from the preceding full-glacial pluvial and from modern conditions. Compared with conditions during the Wisconsin maximum, average annual temperatures during the lastest Wisconsin pluvial were 4°C to 6°C (7°F to 11°F) higher, and the average annual precipitation probably was greater. Enchanced rainfull occurred during both the winter and summer half years. Compared with modern conditions, average annual temperatures probably were only about 2°C (4°F) lower and average annual precipitation may have been as much as 100 percent greater. These conclusions are based on the distributions of vegetation assemblages during the late Wisconsin and early Holocene and are consistent with predictions based on the astronomic theory of climatic change and with evidence of fluctuations of lake levels in the Great Basin (Spaulding et al., 1984).

If precipitation during the latest Wisconsin pluvial were 100 percent greater than modern, average annual precipitation at that time would have been about 280 mm (11 in.). Such a relatively high rainfall would have been required to maintain the high stands of Searles Lake and Lake Lahonton under the warm (near-modern) average temperature that probably prevailed (Spaulding et al., 1984).

Evaluation of hydrologic effects: Climatic changes resulting in pluvial conditions during the Quaternary probably had the following effects on the hydrologic system: increased recharge, increased altitude and gradients of the water table: upgradient shifts in discharge loci; and changes in surface-water drainage systems. Although little evidence exists in the immediate vicinity of Yucca Mountain to indicate the size of these effects, regional evidence indicates that, within the framework of the geologic setting and the arid-semiarid environment, the effects probably were relatively minor. An exception may be the amount of increased recharge, although the magnitude of recharge flux during pluvial periods is unknown at this time.

Pluvial climates during the Quaternary probably were periods when ground-water recharge rates were greater than modern rates. Claassen (1983) reported that a major recharge period occurred about 9,000 to 17,000 yr B.P., based on carbon-14 analyses of ground water from tuff and tuffaceous alluvium in the Yucca Mountain-Fortymile Wash-Amargosa Desert region. Probably the recharge was principally snowmelt and occurred as downward infiltration of surface runoff in major washes, such as Fortymile Wash (Claassen, 1983). During the span of this recharge period, two distinct pluvial events occurred, one at the Wisconsin maximum (18,000 ± 3000 yr B.P.) and one at the terminal Wisconsin (12,000-10,000 yr B.P.) (Spaulding et al., 1984). The specific pluvial climatic conditions at the Yucca Mountain area that resulted in these recharge conditions are being evaluated by analysis of plant macrofossils in pack rat middens in the area.

An increase in ground-water recharge would have been accompanied by an increase in moisture flux through the unsaturated zone. The mechanisms and controls on the rates and distribution of recharge are not well known, either for modern or pluvial conditions; therefore, the magnitudes of recharge during the last half of the Late Wisconsin are unknown at this time, but they may have been substantially greater than modern recharge. Investigations are underway to assess this condition.

The increased flux probably was not sufficient to modify significantly perched-water conditions in the unsaturated zone or the hydrologic system in the underlying saturated zone. Measurements of core samples of unsaturated rock units underlying Yucca Mountain indicate that the permeability generally is high enough to transmit water not only at modern fluxes (probably less than 1 mm/yr), but at postulated pluvial fluxes of much greater values (see the Geohydrology Disqualifying Condition Section 6.3.1.1). Thus, the postulated increase in recharge that occurred under pluvial climates probably did not significantly affect the potential for developing perched-water conditions.

Assessment of the affects of Quaternary climatic changes on the altitude of the water table is difficult, because tectonic and erosional as well as climatic factors could have affected the position of the water table. Discussion of potential water-table changes beneath Yucca Mountain is included under the potentially adverse conditions for this guideline.

Some evidence of Quaternary hydrologic conditions does occur in the region surrounding Yucca Mountain. Even though the evidence generally is not within the flow system underlying Yucca Mountain, the results can be used to provide a general indication of the magnitudes of the impacts that Quaternary climatic changes had on the regional hydrologic systems.

Maximum altitude of ground-water discharge points in the Ash Meadows ground-water subbasin during pluvials in the Quaternary Period probably was about 770 m (2500 ft), or about 50 m (160 ft) above the highest modern water level in the area [719 m (2359 ft) at Devil's Hole] (Winograd and Doty, 1980). This maximum altitude is based on the distribution and age of calcite veins and tufa in the Ash Meadows area and represents conditions in a highly transmissive carbonate aquifer. In central Frenchman Flat, 58 km (36 mi) northeast of Ash Meadows, the maximum water-table altitude in the carbonate aquifer probably did not exceed 30 m (100 ft) above the modern level (Winograd and Doty, 1980).

Jones (1982) examined cores of fine-grained alluvium from a borehole in Frenchman Flat (also within the Ash Meadows ground-water subbasin) for mineralogic evidence of former higher water tables. In the interval 0 to 50 m (0 to 165 ft) above the present water table, the alluvium contains an abundance of zeolites and smectite clays with expanded basal spacings and has relatively uniform clay hydration properties; these conditions suggest possible former saturation, but differences may also be related to environments of deposition. Jones (1982) concluded that the relative uniformity of clay hydration is consistent with the water table being close to its present position for a long time, perhaps throughout most of the Quaternary.

Death Valley and the Amargosa Desert are the principal discharge areas for both the Ash Meadows subbasin and the Furnace Creek Ranch-Alkali Flat ground-water basin (Winograd and Thordarson, 1975; and Waddell, 1982). Winograd and Doty (1980) reported that calcite veins of the Ash Meadows discharge area have been dated at 400,000 to 750,000 years B.P., using uranium-thorium techniques. Thus, these regions probably were ground-water discharge areas during most of the Quaternary. Within the Ash Meadows ground-water subbasin however, discharge from the carbonate aquifer occurred as much as 14 km (9 mi) northeast (upgradient) of the modern discharge line during the Pleistocene (Winograd and Doty, 1980). Similar upgradient discharge points may have existed during pluvials in the Furnace Creek Ranch-Alkali Flat basin although evidence is lacking.

Quaternary climatic changes probably produced cyclic fluctuations in both altitude of the water table and positions of ground-water discharge points of the Ash Meadows subbasin, but Winograd and Doty (1980) postulated a net direction of change in both of these hydrologic conditions during the Pleistocene Epoch. They suggested that the highest water-table position occurred in early Pleistocene and that a net downgradient migration of discharge sites and a net decline of the water table occurred from early to late Pleistocene time. They attributed these changes to the progressive integration of the Amargosa Valley and Death Valley watersheds, coupled with periodic faulting along the modern spring lineament in Ash Meadows. A long-term trend of increasing aridity, if it occurred, could also have contributed to these hydrologic changes. Similar changes may have occurred in the Furnace Creek-Alkali Flat basin in-which Yucca Mountain is located.

In the tuff and alluvium of the Furnace Creek Ranch-Alkali flat basin, in which Yucca Mountain occurs, no direct evidence has been observed for a water table that was higher during the Quaternary than now. Depth to water in the Yucca Mountain area is generally 300 to 750 m (980 to 2460 ft) (Robison, 1984). To estimate the effects of increased recharge on the altitude of the water table in the system, a two-dimensional flow model (Czarnecki and Waddell, 1984) was analyzed at various recharge rates. The modeling results indicate that the effects of pluvial climates on water-table altitudes were probably minor (Czarnecki and Downey, 1984).

Conclusion: Yucca Mountain occurs in a geologic setting in which climatic changes did occur during the Quaternary, but the evidence indicates that maximum departures from modern climatic conditions during most of the Quaternary probably were not substantial and probably had minor effects on the principal features of the present hydrologic system. These features include low recharge flux, deep water tables, closed ground-water and surface-water basins, long flow paths to discharge areas, and well established major surface-water drainage basins. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.

Evaluation: Several lines of evidence indicate that the water table will not rise enough during the next 10,000 years to flood a repository constructed in the Topopah Spring welded unit beneath Yucca Mountain. Discussions of changes in climatic conditions and the effects on the regional ground-water system are presented in Favorable Condition (2). The following discussion relates specifically to the potential for a water-table rise beneath Yucca Mountain.

The proposed repository is closest to the water table, at its northeastern edge. Here, the repository would be at an altitude of approximately 900 m (2950 ft), or approximately 200 m (650 ft) above the present water table (altitude 730 m). Therefore, the water table would have to rise almost 200 m (330 ft) before any of the proposed repository would be flooded.

Hoover (1968, p. 278) postulated that vitric pumice cannot remain unaltered for long periods of time in the saturated zone. Beneath the block at Yucca Mountain, nonwelded tuffs containing abundant vitric pumice occur at altitudes that range from 120 m (400 ft) (at boreholes USW H-5 and USW G-4) to 250 m (820 ft) (at borehole USW H-3) above the present water table. These altitudes range from 24 to 120 m (80 to 400 ft) below the repository horizon (Bish et al., 1984, Figures 3 and 4), and would be about 120 m (390 ft) or more if the repository horizon were nearly horizontal. Therefore, the rocks in the repository horizon probably were never below the water table, at least not for any substantial length of time.

The hydraulic conductivity of the densely welded, saturated Topopah Spring Member beneath Fortymile Wash is relatively high, approximately 1 m (3.3 ft) per day (Young, 1972; Thordarson, 1983), and may partly account for the very low hydraulic gradient in the saturated-zone Tertiary rocks between Yucca Mountain and Fortymile Wash. An increase in recharge would cause an increase in hydraulic gradient approximately proportional to the increase in recharge; the gradient would be partly controlled by the distance to the discharge area. In areas where the gradient is presently low, an increase in gradient would result in only small increases in hydraulic heads. In the Yucca Mountain area, the altitude of the water table is about the same (within 0.5 m) as the composite hydraulic potential of the upper few hundred meters of the saturated zone (Robison, 1984), so that hydraulic potential may be equated with position of the water table.

In the discharge area near Alkali Flat and upgradient, the water table is within a few meters of the land surface. Therefore, a small increase in the hydraulic gradient would cause springs to develop upgradient. The hydraulic gradient is greater approximately 15 km (9.5 mi) north of Death Valley

Junction, than immediately up and down gradient, indicating rocks of lower permeability in this area. Springs would develop upgradient of this area if recharge increased appreciably, permitting water to leave the ground-water system. If recharge increased enough (for example, three to four times that occurring today) to cause springs to develop in these potential discharge areas (altitude 760 m), the water level altitude at well J-12 could be expected to increase in time to about 790-825 m (2590-2700 ft). Because of the high transmissivity in western Jackass Flats, the water level beneath most of the repository would also be 800-825 m, but the lowest part of the repository is estimated to be greater than 900 m (2950 ft) above sea level. Further, there is no positive geologic evidence of Pleistocene spring discharge as high as 760 m (2500 ft) in the Amargosa Desert.

Conclusion: No evidence exists to indicate that the water table was as high as the proposed repository level during the Quaternary Period, and rock properties make it very unlikely that climatic changes could cause the water table to rise sufficiently to flood the repository. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.

Evaluation: Likely climatic changes over the next 10,000 years probably would be driven by increases in global atmospheric carbon dioxide (CO_2) and by changes in the earth's orbit. According to Spaulding (1984), in the near future Yucca Mountain might experience summer temperatures at least 3°C (5°F) higher and summer rainfall not more that 50 percent higher than today's value. On the other hand, changes in the earth's orbit could eventually override the effects of CO_2 and lead to a glacial stage in about 23,000 years and culminate in a glacial maximum 60,000 years After Present (A.P.). Pluvial conditions, which would coincide with the glacial stage, would not occur until after 10,000 years A.P.

The principal and most immediate effect of the anticipated 10,000-year climatic change on a waste repository at Yucca Mountain probably would be an increase in the recharge flux through the unsaturated zone and a consequent increase in the rates of radioactive waste release (assuming that canisters are breached) and transport through the unsaturated Calico Hills nonwelded unit below the repository. The magnitude of increased recharge that would result from a 50-percent increase in summer rainfall is unknown but probably would be minor. Under the anticipated conditions, summer rainfall would be about 60 mm (2 in.). The accompanying increase in average summer temperature of at least 3°C would tend to reduce any increased recharge, because evapotranspiration would also increase. The last known major recharge period, during the latest Wisconsin pluvial, resulted largely from increased snowmelt causing recharge through stream channels (Claassen, 1983) rather than from the increased summer precipitation that also occurred.

The postulated climatic change in the next 10,000 years could result in a slightly higher water table. However, because even during Quaternary pluvial times changes in water-table altitude and gradients probably were not great, no substantial changes in water table due to the slight increase in summer rainfall are expected in the next 10,000 years. In addition, calculations by Sinnock et al. (1984) show that, even for a recharge rate many times that of present, the EPA-allowed radionuclide release limits at the accessible environment in 10,000 years would be met.

<u>Conclusion</u>: Climatic changes expected during the next 10,000 years are not likely to affect significantly the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the water-table levels of the saturated zone at Yucca Mountain. Expected increases in precipitation may increase the recharge flux in the unsaturated zone at Yucca Mountain, but because the modern recharge flux is probably very low, any accompanying increase in the absolute rate of transport of radionuclides to the accessible environment would be insignificant. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

6.3.1.5 Erosion (10 CFR 960.4-2-5)

I. INTRODUCTION

The Erosion Guideline is one of several postclosure technical guidelines included under the heading potentially disruptive processes and events. The objective of this guideline is to ensure that erosional processes will not degrade the waste-isolation capabilities of a repository site. In evaluating the potential effects of erosion on waste isolation, the thickness of overburden above the potential repository host rock is most important. The proposed site should allow the underground facility to be placed deep enough to ensure that the repository will not be uncovered by erosion or otherwise adversely affected by surface processes.

The Erosion Guideline consists of one qualifying condition, three favorable conditions, two potentially adverse conditions, and one disqualifying condition. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

The nature of erosional processes operating during the Quaternary Period is delineated by the surficial geologic map of Yucca Mountain area by Hoover et al. (1984). Measurements of the depth of stream incision in dated alluvial deposits and in tuff in the vicinity of Yucca Mountain have been made, and the maximum rates of stream incision have been calculated (Carr et al., 1984). Average erosion rates for Yucca Mountain during the Quaternary period have not been determined because the field data necessary for such calculations are not yet available. Mansure and Ortiz (1984) have analyzed the depth to the potential host rock within the Topopah Spring Member.

Assumptions and Data Uncertainties: In addressing this guideline, rates of stream incision in alluvium and tuff are assumed to represent the average vertical erosion rates for the tuffs at Yucca Mountain. This assumption leads to overestimates of the probability of exhumation by erosion because average vertical erosion rates will always be much less than stream incision rates. In addition, the assumption is made that the erosional rates and processes operating during the Quaternary Period will continue during the life of the repository. This assumption appears valid because climatic conditions are not likely to change significantly (see Section 6.3.1.4), and local uplift or subsidence is not likely to be a significant factor (see Section 6.3.1.7).

III. QUALIFYING CONDITION

(1) The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

In projecting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

Evaluation: Geomorphic processes are the result of the combined effects of tectonic and climatic processes. The rates of tectonism are so low (see Section 6.3.1.7) that they are unlikely to induce changes in the erosional processes. For the period of climatic record (see Section 6.3.4.1), the magnitudes of expected climatic changes are also unlikely to cause changes in erosional processes.

Measurements of stream incision rates in the vicinity of Yucca Mountain suggest that the average incision rate has been less than 10^{-4} m/yr during the past 300,000 yr and certainly less than 10^{-4} m/yr for the past 10 million years. Exhumation of the water table downgradient within 10 km of the proposed site would be required before the isolation potential of Yucca Mountain could be affected as a result of erosion. This would require removal of about 380 m (1250 ft) of overburden and, at anticipated erosion rates, would take about 3.8 million years. In the next 10,000 years erosional processes are expected to remove only 1 meter of overburden from above the repository. Therefore, based on measured depths of past stream incision and dated alluvial materials, a repository at Yucca Mountain could not be exhumed, or the ground-water system sufficiently altered by erosion to adversely affect its present waste isolation capabilities.

Conclusion: Erosional rates and processes that have operated at the Yucca Mountain site during the Quaternary period are very likely to continue for tens of thousands to millions of years into the future and will not adversely affect the radioactive waste isolation capabilities of the site. Therefore, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITIONS

(1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the the directly overlying ground surface.

Evaluation: Figure 6.3.1.5-1 shows profiles of the 200 and 300 m (700 and 1000 ft) depths below the surface of Yucca Mountain along an east-west cross section (Mansure and Ortiz, 1984). It also shows the depth of a plane representing the preliminary location of an underground facility in which waste would be emplaced. It is located in a portion of the densely welded Topopah Spring Member that contains less than 15 to 20 percent lithophysal cavities and lies above the basal vitrophyre. Figure 6.3.1.5-2 shows contours of the overburden thickness above the midplane of the repository envelope (45 m thick), and the position of the cross section in Figure 6.3.1.5-1. In the central structural block, where site characterization has been focused to date, much of the waste could be placed below 300 m (1000 ft). To emplace all the waste below 300 m would require emplacement in the vitrophyre and lower units, or would call for a higher thermal-loading density (i.e., placing the canisters close together) than is currently used as a design basis. Other units deeper in Yucca Mountain have been considered as alternatives to the Topopah Spring Member (Johnstone et al., 1984a). Preliminary surface mapping and borehole data suggest that the use of areas adjacent to the central block may allow the emplacement of all the waste below 300 m, while remaining within the relatively lithophysae-free Topopah Spring Member. Thus, site conditions at Yucca

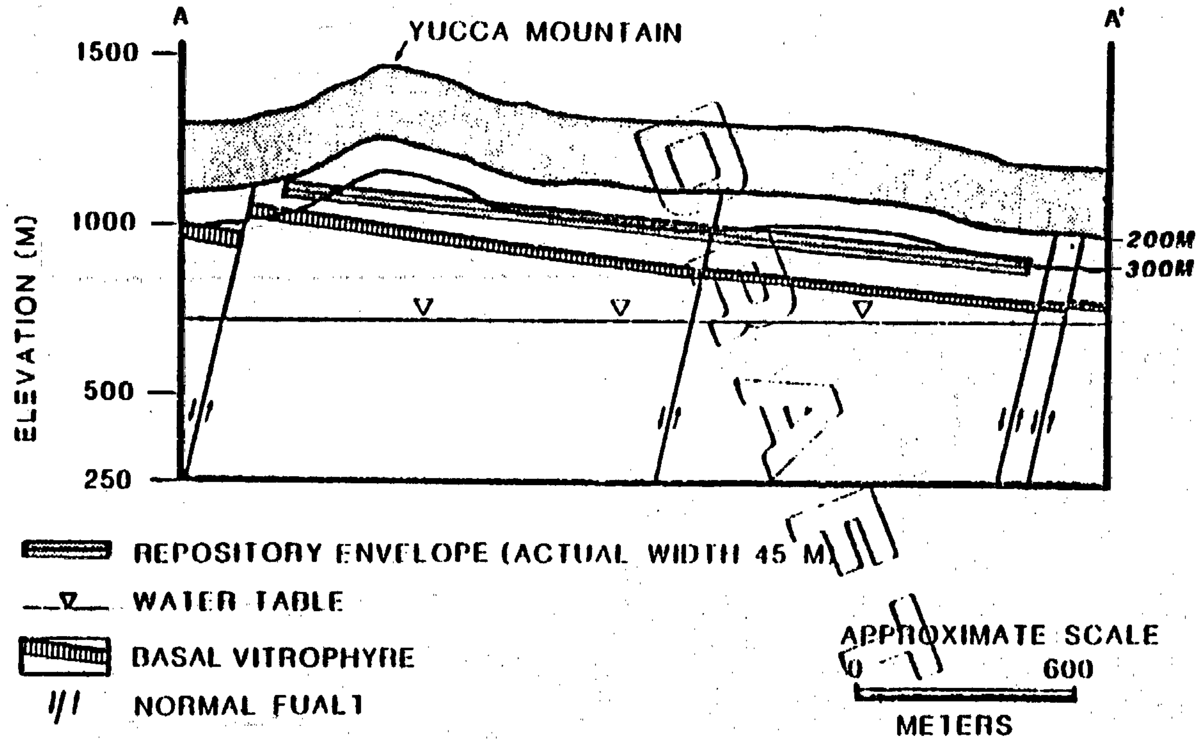

Figure 6.3.1.5-1. Profiles of the 200 m and 300 m depths below the surface of Yucca Mountain on east-west cross section.

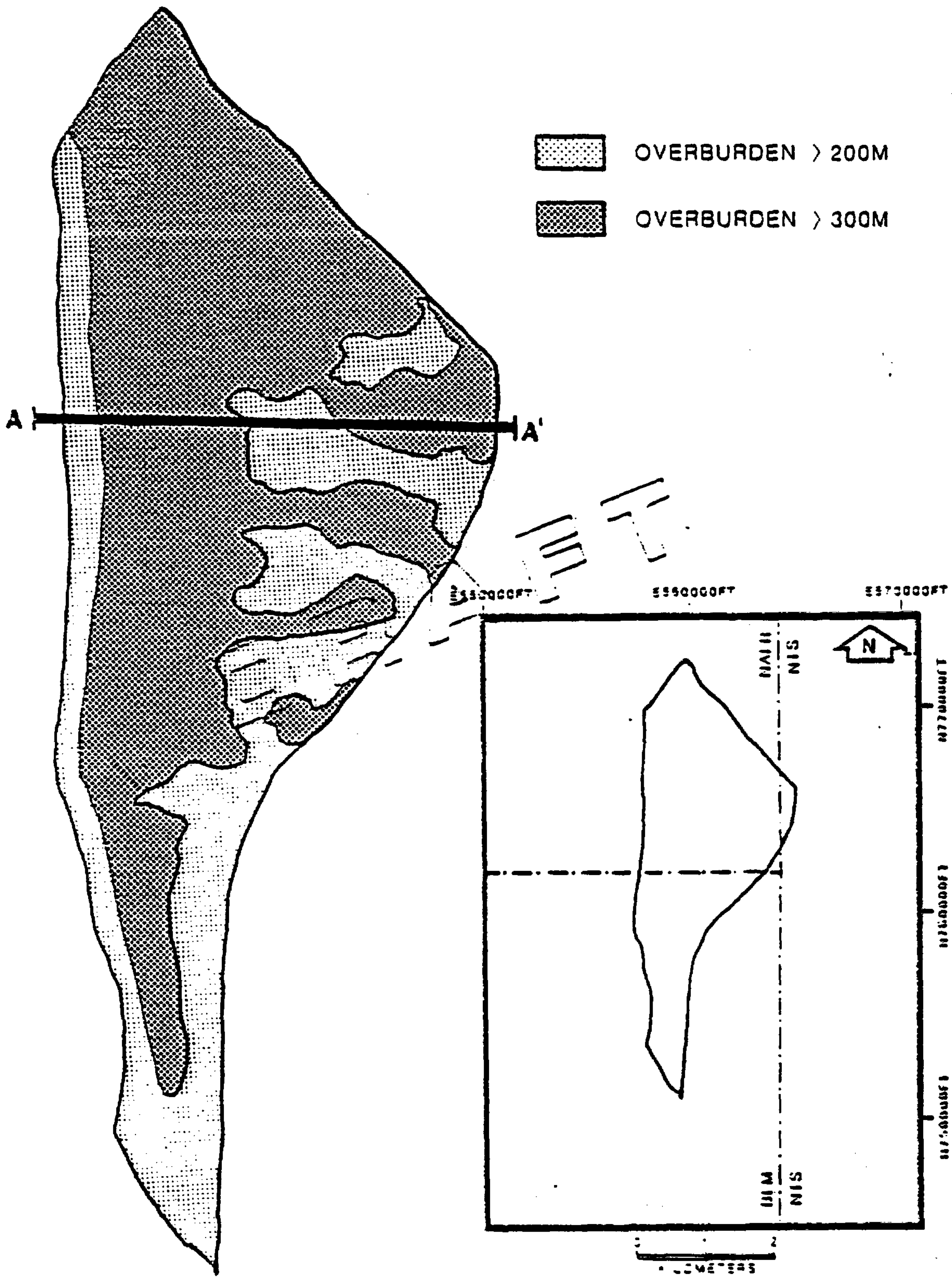

Figure 6.3.1.5-2. Contours of the overburden thickness above the midplane of the repository envelope. See Figure 6.3.1.5-1 for cross section A-A'.

Mountain are likely to permit the location of much of the underground facility in the relatively lithophysae-free, densely welded Topopah Spring Member at depths of 300 m or more below the directly overlying ground surface.

In spite of these expectations, further study of the areas adjacent to the central block is necessary before their suitability can be established to the same degree of certainty that is currently established for the central block. Furthermore, there are no current plans to use the vitrophyre and the units below the Topopah Spring Member. Further investigations may establish that all the waste can be emplaced at a depth of 300 m or more, but from a conservative position this favorable condition cannot yet be claimed.

Conclusions: At Yucca Mountain several formations, including the Topopah Spring Member, are suitable for emplacing waste at depths greater than 300 m (1000 ft) below the directly overlying ground surface. Presently available data do not establish that the host rock in the lower part of the Topopah Spring Member in the central block can accommodate all the waste at depths greater than 300 m. Therefore, Yucca Mountain does not possess this favorable condition.

(2) A geologic setting where the nature and rates of erosional processes that have been operating during the Quaternary Period are projected to have less than one chance in 10,000, over the next 10,000 years, of leading to releases of radionuclides to the accessible environment.

Evaluation: Erosional processes operating at Yucca Mountain could affect the potential for radionuclide releases to the accessible environment in at least two ways. One way is that the repository could be exhumed by erosion. The second way is that erosion could alter the ground-water system sufficiently to cause an increased chance of radionuclide release to the assessible environment.

Densely to moderately welded tuff of the Tiva Canyon Member of the Paintbrush tuff forms the surface in that portion of the proposed site that would contain the repository; the tuff dips 5 to 8 degrees eastward, resulting in a relatively planar, eastward sloping land surface. The resistant welded tuff along the crest at the western edge of Yucca Mountain is essentially undissected, but southeasterly draining channels with equilibrium profiles that are steeper than the dip of the tuff progressively dissect the Tiva Canyon Member to the east. Alluvium and residual patches of the weakly consolidated Rainier Mesa Member of the Timber Mountain tuff occur beneath modern channels and paleovalleys in the Tiva Canyon outcrop area (Scott and Bonk, 1984).

Measurements of the depth of stream incision relative to dated stratigraphic horizons were made at several places in the vicinity of the site, and maximum rates of incision were calculated (Carr et al., 1984). Based on two measurements in alluvium and one in the Tiva Canyon tuff, a mean rate of incision of 5×10^{-5} m/year was calculated. The time spans represented by the measurements suggest that the average incision rate has been less than 10^{-4} m/year during the past 300,000 years and certainly less than 10^{-4} m/yr for the past 10 million years.

Erosion could also affect hydrologic conditions in the vicinity of the site either by effectively moving ground-water discharge areas nearer to the proposed site or by exposing rock units that will allow more infiltration. An increase in the potential for local infiltration due to erosion is unlikely because the rocks making up the overburden are already capable of passing fluxes well in excess of current and future percolation expected under the likely climatic changes during the next 10,000 years (see Favorable Condition (2), Section 6.3.1.1). Therefore, complete exhumation of the water table downgradient from the proposed site would be required before the isolation potential of Yucca Mountain could be affected as a result of erosion. Exhumation to the depth of the water table within 10 km downgradient of the proposed site would require removal of about 380 m (1250 ft) of overburden (Robison, 1984). At a rate of 10^{-4} m/year, the expected time for erosion to this depth is 3.8 million years.

The probability of erosion to 380 m depth in 10,000 years or less can be estimated with a relatively simple probabilistic model for erosional processes (Campbell et al., 1978, p.67-68). Using the mean rate of 5×10^{-5} m/year based on three measurements given above and a variance of 9×10^{-6} m^2/year, this probability is a number on the order of 10 with an exponent of (10^{-5}) (or

$10^{-100,000}$), corresponding to an impossibility for exhumation of the water table within 10,000 years. From another perspective, exhumation to the depth of the water table at 380 m depth in 10,000 years would require an erosion rate of about 3.8 cm/yr (1.5 in/yr), which exceeds any rate known to have occurred anywhere on earth over any 10,000 year period. Therefore there is less than one chance in 10,000 that erosion would lead to loss of isolation at Yucca Mountain.

<u>Conclusions</u>: Average stream incision rates have been less than 10^{-4} m/yr for the past 10 million years. Projection of measured rates for the next 10,000 years shows that erosional processes would only be expected to remove 1 meter of overburden, which could not adversely affect waste containment and isolation. Therefore, the Yucca Mountain site possesses this favorable condition.

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(3) <u>Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.</u>

<u>Evaluation</u>: The minimum thickness of overburden for the underground facility is about 230 m (750 ft) at the western edge of the central block (see Favorable Condition 1). For most of Yucca Mountain, the overburden is greater than 300 m. At an erosion rate of 10^{-4} m/year, the expected time for exhumation of the repository at a minimum depth of 230 m would be 2.3 million years, and for a depth greater than 300 m, it would take at least 3.0 million years.

<u>Conclusion</u>: Assuming past average erosion rates continue in the future, a waste repository in Yucca Mountain would not be exhumed in the next one million years. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) <u>A geologic setting that shows evidence of sustained extreme erosion during the Quaternary Period.</u>

<u>Evaluation</u>: Measured maximum stream incision rates in the vicinity of the proposed site were between 2.2×10^{-5} and 8.2×10^{-5} m/year; these maximum rates are inferred by measuring depths of incision in Quaternary and in some instances Tertiary surfaces of ages between 160,000 and 10 million years. The mean of these rates, 5×10^{-5} m/year, agrees with an estimate for modern denudation rates based on calculations of annual sediment yield of 4.6×10^{-5} m/year. This value is much less than the 10^{-4} m/year which is used in the evaluation of the qualifying condition and in favorable conditions (2) and (3). Because modern denudation rates at the site are not considered extreme, the agreement between maximum former stream incision rates and modern rates provides evidence that there were no sustained periods of extreme erosion at the site during the past 300,000 years.

<u>Conclusions</u>: Available evidence suggests that average stream incision rates during the past 300,000 years were not extreme, and that there was little change in the patterns of erosional processes at the site during the Quaternary Period. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) <u>A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.</u>

<u>Evaluation</u>: Geomorphic processes are the result of the combined effects of tectonic and climatic conditions that create a local surface topography that provides the potential energy for erosion. The rates of tectonism are so low (see Section 6.3.1.7) and the magnitudes of expected climatic changes so small (see Section 6.3.1.4) that it is highly unlikely that significant changes in geomorphic processes at Yucca Mountain will occur during the next 10,000 years. Because the estimated past and current erosional rates have been shown to be incapable of affecting waste isolation for at least the next few million years, any credible change in these rates during the next 10,000 years would not adversely affect waste isolation.

Conclusions: No credible geomorphic process has been identified that could, in the next 10,000 years, adversely affect the isolation capabilities of the proposed site. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

VI. DISQUALIFYING CONDITION

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.

Evaluation: The midplane of the potential repository (Mansure and Ortiz, 1984) is sufficiently deep that all portions of the underground facility can be located below 200 m (650 ft), and much of the facility can be located at depths at least 300 m (1000 ft) below the directly overlying ground surface.

The 200 m overburden requirement is being used as a principal design constraint for locating the underground facility. According to stratigraphic data obtained during preliminary investigations of the Yucca Mountain site, the relatively low lithophysal-content portion of the density welded tuff of the Topopan Spring Member is thick enough at depths greater than 200 m to accommodate the underground facilities of a waste repository (Figure 6.3.1.5.2). As discussed under Favorable Condition (1) of Section 6.3.1.3, emplacement of wastes 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.

Conclusion: The densely welded tuff of the Topopah Spring Member is sufficiently thick and deep that all portions of the underground facility can be located in the zone of low lithophysal content at least 200 m (650 ft) below the directly overlying ground surface. Therefore, the Yucca Mountain site is not disqualified on the basis of this guideline.

VII. PLANS FOR SITE CHARACTERIZATION

During construction of the Exploratory Shaft at Yucca Mountain, walls of the shaft will be geologically mapped and photographed and the stratigraphic characteristics of lithologic units will be recorded. This will allow additional characterization of the history of the Yucca Mountain site with regard to major periods of erosion and deposition. In addition, 600 m (2000 ft) lateral boreholes drilled from the in situ test facility will allow confirmation of the lateral extent of usable host rock, providing additional information for the thickness of overburden throughout the potential repository horizon at Yucca Mountain. Field investigations will continue to improve the dating of Quaternary deposits and to better establish the local and regional geomorphic history of the Quaternary Period.

6.3.1.6 Dissolution (10 CFR 960.4-2-6)

I. INTRODUCTION

This is one of five guidelines that addresses potentially disruptive processes and events that might affect postclosure repository performance. The Dissolution Technical Guideline requires that any subsurface rock dissolution that is likely to occur will not create new pathways that might lead to radionuclide releases greater than those allowed by the Postclosure System Guideline, 10 CFR 960.4-1. The assessment of compliance with this requirement is to be based on evidence pertaining to dissolution in the geological setting of the site during the Quaternary Period.

The Dissolution Guideline contains one qualifying condition, one favorable condition, one potentially adverse condition, and one disqualifying condition. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

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; Bish et al., 1982; Byers and Warren, 1983; Caporuscio et al., 1982; Carroll et al., 1981; Heiken and Bevier, 1979; Levy, 1984; Maldonado and Koether, 1983; Scott and Castellanos, 1984; Spengler et al., 1981; Sykes et al., 1979; Vaniman et al., 1984). A current summary emphasizes the mineralogic simplicity of the host rock (Bish et al., 1984). No evidence of Quaternary dissolution fronts or other Quaternary dissolution features has been found.

<u>Assumptions and Data Uncertainties</u>: Major solution-deposition processes in silicic tuff are generally restricted to hydrothermal alteration (White et al., 1980). There is some evidence of pre-Quaternary hydrothermal systems in older and deeper rocks below the host rock at Yucca Mountain (Caporuscio et al., 1982; Bish and Semarge, 1982). The assumption that these systems are no

longer active is based on the intergrowth of younger low-temperature clays over earlier high-temperature clays in drill hole USW G-2 (Bish and Semarge, 1982), and on the currently lower temperatures [60°C (140°F)] in these once hydrothermally altered [180-230°C (350-450°F)] rocks (Caporuscio et al., 1982). The assumption that solution does not occur in the Topopah Spring Member at Yucca Mountain in low-temperature aqueous systems is supported by the absence of any solution features in drill hole J-13, where the host rock is located below the water table (Heiken and Bevier, 1979). Uncertainties in these data are limited to the remote possibility that hydrothermal alteration systems or low-temperature solution zones occur between the present distribution of drill holes and are therefore unobserved. Estimates of such sampling uncertainties are not yet developed but are anticipated to be very small.

III. QUALIFYING CONDITION

The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

In projecting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

Evaluation: For all practical purposes the volcanic rocks of Yucca Mountain are not subject to dissolution. This guideline applies to repositories in soluble rocks (eg., salt) that can dissolve at much higher rates than the tuffs of Yucca Mountain. In particular there is no evidence that the host rock within the site was subject to dissolution during the Quaternary Period, nor is there any reason to suspect that dissolution within the site would provide a hydraulic interconnection between the host rock and the immediately surrounding geohydrologic units. The minerals that compose the rock in and around the proposed site are considered insoluble and no significant dissolution is expected to occur even at the elevated temperatures in the near field. Consequently, the formation of active dissolution fronts is not a logical expectation for conditions at Yucca Mountain.

<u>Conclusion</u>: The minerals that compose the rock in and around the Yucca Mountain site are considered insoluble, and significant subsurface rock dissolution is not a credible process leading to radionuclide releases greater than those allowable under the requirements specified in 10 CFR 960.4-1. Therefore, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITION

<u>No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.</u>

<u>Evaluation</u>: The petrologic features of the host rock at Yucca Mountain include no dissolution fronts, or other dissolution features. This is true even to the east of the exploration block where the host rock is mostly within the saturated zone (Heiken and Bevier, 1979). None of the reports listed under Relevant Data of this section find any evidence of dissolution. A current summary of data about the mineralogy of the host rock emphasizes its mineralogic simplicity (Bish et al., 1984). The Topopah Spring host rock consists of more than 95 percent feldspar, quartz, and cristobalite, and the remainder consists of other silicate minerals and iron-titanium oxide minerals. Under expected repository conditions at Yucca Mountain, none of these minerals dissolve in water to any meaningful degree.

<u>Conclusion</u>: There is no evidence that the host rock at Yucca Mountain was subject to any dissolution during the Quaternary Period. None of the minerals in the host rock is considered soluble under expected repository conditions. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITION

<u>Evidence of significant dissolution within the site--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection between the host rock and an immediately surrounding geohydrologic unit could occur.</u>

Evaluation: As stated under the Favorable Condition, the petrologic features of the host rock at Yucca Mountain include no dissolution features. This is also true for other rocks of the site, as described in the reports listed under relevant data in this section. Even deeper zones of pre-Quaternary hydrothermal alteration are dense and nonporous due to secondary mineral precipitation (Caporuscio et al., 1982). Lithophysal cavities do exist within the host rock. These cavities were formed by entrapment of vapor-phase gas pockets during crystallization of the hot volcanic material about 12 million years ago, and are not Quaternary dissolution features (Lipman et al., 1966; Byers et al., 1976). Some lithophysal margins exhibit cross-cutting textures that were developed as the lithophysae formed and do not represent Quaternary dissolution fronts (Vaniman et al., 1984).

Conclusion: There is no evidence of significant dissolution within the site that would provide a hydraulic interconnection between the host rock and any immediately surrounding geohydrologic unit. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

VI. DISQUALIFYING CONDITION

The site shall be disqualified if, during the first 10,000 years after closure, active dissolution fronts will cause an 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.

Evaluation: The host rock of Yucca Mountain consists of the moderately to densely welded and devitrified portion of the unsaturated Topopah Spring tuff. About 95 percent of the host rock consists of alkali feldspars, quartz, and cristobalite. These minerals are not prone to dissolution in any significant quantities. No evidence of Quaternary dissolution fronts or other Quaternary dissolution features has been found.

The most unstable mineral present in significant quantities in the Topopah Spring Member is volcanic glass. In Rainier Mesa, which has vitric zones as does Yucca Mountain, the ground-water composition has been shown to be strongly influenced by the dissolution of glass (White et al., 1980) demonstrating that glass dissolution is operating in a similar setting. The maximum temperature expected within a few meters of the waste is about 140°C (280°F), based on the calculations of Travis et al. (1984) and Johnstone et al. (1984a). Liquid water cannot exist in the vicinity of the waste at a temperature above 95°C because it will boil away. Therefore, calculations based on temperatures of 140°C represent very extreme conditions. A 30 m (100 ft) thick vitric zone lies beneath the proposed repository in the unsaturated zone. The exact location of the repository will not be decided until completion of detailed investigation of the host rock during site characterization. To allow for the possibility of constructing the repository near the vitric zone, the following dissolution calculation is done using the maximum water temperature of 140°C (280°F), and assuming the SiO_2 in the vitric zone is entirely amorphous silica.

The solubility of amorphous silica at 140°C (280°F) is 8×10^{-3} molal (Walther and Helgeson, 1977). This corresponds to 480 mg/L of SiO_2. The infiltration rate is about 1 mm of water per year (Montazer and Wilson, 1984). With 1×10^{-4} L of water per cm^2 per year passing through the repository, 0.048 mg of SiO_2 per cm^2 per year could dissolve away. The SiO_2 composition of the vitrophyre is 77 percent (Lipman et al., 1966) and the density of the vitric layers is about 2.3 g/cm^3. Thus 2.75×10^{-5} cm of vitric rock could be dissolved per year if the temperature was to reach 140°C (280°F), and if all of the SiO_2 in the vitrophyre was amorphous silica. In 10,000 years, only 0.275 cm (0.11 in.) of the 30 m (100 ft) of vitric rock would dissolve. This very conservative estimate shows that a maximum of 0.01 percent of the vitric rock underlying the repository could be dissolved in 10,000 years. Even for this extreme case, the magnitude of dissolution is so small that no significant change in the geohydrologic system could reasonbly be expected.

Conclusion: The minerals that compose the rock in and around the Yucca Mountain site are considered insoluble and no 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 under the Dissolution Guideline.

VII. PLANS FOR SITE CHARACTERIZATION

Extensive sampling of the target horizon during sinking of the exploratory shaft and in situ testing is planned. A more complete detailed three-dimensional assessment of the mineralogic variability of the host rock will be possible after samples are obtained from six 600-m (2000-ft) boreholes to be drilled laterally from the in situ testing facility. Other in situ tests will determine the amount of host rock dissolution/precipitation that is possible in the near field high temperature zones.

6.3.1.7 Tectonics (10 CFR 960.4-2-7)

I. INTRODUCTION

This Tectonics Technical Guideline is one of several postclosure guidelines included under the topic heading potentially disruptive processes and events. The objective of the postclosure tectonics guideline is to ensure that tectonic processes are evaluated in terms of the waste-isolation capabilities of a potential repository system at the site. Tectonic processes and events that might adversely affect waste isolation during the postclosure period are (1) faulting that might create new ground-water pathways to the accessible environment, (2) uplift or subsidence that might increase erosion rates, and (3) physical transport of waste to the surface by volcanic activity.

The prediction of future geologic and tectonic processes is uncertain and difficult. The tectonic history of a site, particularly during the Quaternary period, must be thoroughly examined and the results of this examination must be used to forecast future tectonic activity and the possible effects of that activity upon the isolation capabilities of the site.

The postclosure Tectonics Guideline consists of one qualifying condition, one favorable condition, and six potentially adverse conditions. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

Much of the background data for the tectonic appraisal of the Nevada Test Site area has been developed through many years of surface and subsurface geologic and geophysical studies in support of nuclear weapons testing. The present investigations of Yucca Mountain and vicinity have built upon this data base by addressing specific subjects such as Quaternary stratigraphy and chronology (Hoover et al., 1981), faulting (Swadley et al., 1984), and volcanism (Crowe et al., 1982). However, much of the published data bearing upon the tectonic stability of the Yucca Mountain region are in the form of progress or preliminary reports, and much work remains to complete the data base. Seismological data of consistent quality have been obtained for only the last few years (Rogers et al., 1983), but two previous reports (Rogers et al., 1976, 1977) provide preliminary data applicable to Yucca Mountain. Geodetic data acquisition was begun in 1983, but several years of observations will be required before sufficient data are available for analysis.

Assumptions and Data Uncertainties: The principal assumption is that the geologic history, particularly the history of the Quaternary Period (approximately the last 1.8 million years), can be used as the basis for predicting the course of future events. Uncertainties in determining the Quaternary history of the geologic setting within a 50 km (30 mi) radius of the site arise from: (1) limited data on Quaternary deposits; (2) difficulty in determining the current tectonic state of this setting with respect to cycles of activity; and (3) difficulty in determining how future tectonic events might affect the containment and isolation capabilities of a repository at Yucca Mountain.

III. QUALIFYING CONDITION

The site shall be located in a geologic setting where future tectonic processes and events will not be likely to lead to radionuclide releases greater than those allowable under the requirement specified in Section 960.4-1.

In projecting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

Evaluation: To evaluate trends in tectonic activity, it is desirable to consider a period longer than the Quaternary Period (1.8 million years). But it may be inappropriate to consider the rates of tectonic events older than about 5 million years ago as predictors future events because the regional tectonic-stress regimes may have been different than those operating in the Quaternary Period. Presently available data and interpretations indicate that silicic volcanism ceased at least 5 million years ago. Rates of vertical tectonic adjustments as evidenced by displaced rock units of Quaternary age, have been much less than those of older episodes (Carr, 1984). Basaltic volcanic activity has continued during the last 6 to 8 million years, but in widely spaced episodes (Crowe et al., 1982) that are separated by millions of years to hundreds of thousands of years. The most recent episode near the proposed site occurred about 300,000 years ago. Magnetic arrays have been conducted (Kane & Bracken, 1983); a graity network has been established to assist in evaluating tectonic stability.

Future tectonic events including volcanism and faulting, will not directly affect waste containment unless they occur within the site and destroy or severely alter the either engineered or the natural barriers. Studies (Crowe et al., 1982) indicate a probability of less than one chance in 10,000 that basaltic volcanism will disrupt the Yucca Mountain site in 10,000 years.

Minor extensional faulting, strike-slip faulting, and minor rotational adjustments of blocks within fault zones have occurred within the Quaternary Period (Swadley et al., 1984). In addition, stress measurements suggest that the rocks may be extensionally stressed to near the point of failure along certain faults (Healy et al., 1982). Minor seismicity has been detected instrumentally (Rogers et al., 1983). Present data indicate that more than one episode of movement occurred during the Quaternary on faults within 10 km (6 mi) of Yucca Mountain, but no unequivocal evidence has been found that surface faulting occurred in the last 35,000 years (Swadley et al., 1984). Finally, geomorphic evidence suggests no major differential uplift has occurred at Yucca Mountain in the Quaternary Period.

Therefore, neither major tectonic activity nor the resumption of large-scale silicic volcanic activity in the area near Yucca Mountain is likely in the next 10,000 years because these kinds of events have not taken place for several million years (Carr, 1984). Important evidence for this conclusion includes the following. First, about 90 percent of the fault movement at Yucca

Mountain took place after emplacement of the Tiva Canyon Member of the Paintbrush Tuff and before eruption of the Rainier Mesa Member of the Timber Mountain Tuff (Lipman and McKay, 1965), dated at 12.9 million years and 11.6 million years, respectively (Marvin et al., 1970; corrected for new decay constants). Second, basalt lava flows as old as about 3.75 million years and 1.1 million years (Carr, 1982) are at the surface across the Crater Flat basin and have not been downfaulted or extensively buried by alluvium. Third, Crater Flat is mainly the result of graben formation more than 13 million years ago (Carr, 1982; Snyder and Carr, 1982). Drill hole VH-2 (Carr, 1984) shows that basalt flows buried by alluvium near the eastern foot of Bare Mountain are 11 million years old and are less than 450 m (1500 ft) below the surface. This is good evidence that the west side of Crater Flat, although appearing morphologically active tectonically, has actually undergone only minor tectonic adjustment in the last 10 million years. Finally, some faulting and tilting have occurred in the last few million years in the Amargosa Desert area 20 to 40 km (12 to 25 mi) south of the site but fine-grained sediments older than 2 million years have not suffered major deformation (Carr, 1984; Swadley, 1983).

It is conceivable, but unlikely, that a major change in the tectonic regime between the site and ground-water discharge points could affect the ground-water flow system in such a way that flow paths or velocities to the accessible environment could be changed locally. The effect could be either to retard or to accelerate the flow. Tectonic processes and events that are most likely to occur in the next million years would be similar to those of the past several million years, however, and their geohydrologic impacts also will be similar to those of the past. The role that existing large-scale structures plays in both local and regional flow has long been recognized (Rush, 1970; Blankennagel and Weir, 1973; Winograd and Thordardson, 1975; Waddell, 1982), and tectonic events that conceivably might occur during the life of a repository are not likely to significantly modify the present geohydrologic system.

Conclusion: Structural, stratigraphic, geophysical, and seismic evidence is used to evaluate this guideline. On the basis of presently available data and interpretations for Yucca Mountain, tectonic processes appear to have acted at very low rates in the Quaternary. Basaltic volcanic activity has occurred several times in the Pliocene and Quaternary within 8 to 15 km (5 to 10 mi) of the proposed repository site. It is considered unlikely that potentially disruptive tectonic events will occur in the period of concern for instruction, operation, and closure of a repository at Yucca Mountain. Therefore, on the basis of presently available data, the Yucca Mountain site possesses this qualifying condition.

IV. FAVORABLE CONDITION

The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than 1 chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.

Evaluation: The most recent probability calculations for basaltic eruptions at a site on Yucca Mountain (Crowe et al., 1982) range from 4.7×10^{-4} to 3.3×10^{-6} for a 10,000-year period. These numbers provide probability bounds for the worst and best cases and define the extremes of the probability range. The mean value of this range is less than one chance in 10,000 over the next 10,000 years.

Although no formal probability calculations are available for other tectonic processes in the area, the general rate of faulting at Yucca Mountain during the Quaternary has been low (<0.04 m/1,000 yr; Carr, 1984). Investigations to date have found no unequivocal evidence of surface faulting in the last 35,000 years (Swadley et al., 1984). Although this approach is too simplistic, it can be concluded that the probability of surface faulting is less than 1 in 35,000 for the next 35,000 years.

Conclusion: Yucca Mountain lies within the southern Great Basin, a large region that has been and is tectonically active. The Yucca Mountain site has been affected only slightly by tectonic processes and events during the Quaternary Period. On the basis of limited current data, it appears likely that future tectonic processes and events will not adversely affect the containment and isolation capabilities of a repository at Yucca Mountain, although numerical probabilities have not been determined for most processes. Investigations, such as long-term seismic monitoring, geodetic measurements, and studies of Quaternary faulting and erosion rates, are in progress to evaluate more fully the tectonic stability of Yucca Mountain and the surrounding area. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) <u>Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.</u>

<u>Evaluation</u>: Within a 10-km (6-mi) radius of Yucca Mountain, data at hand indicate no unequivocal evidence of fault movement at the surface in the past 35,000 years (Swadley et al., 1984). Within the same radius of the Yucca Mountain repository site, 16 faults have been identified as having some evidence of at least a small amount of movement during the Quaternary Period but older than 35,000 years (Swadley et al., 1984). A conservative conclusion from this information is that some of the faults in the Yucca Mountain area were active in the early or middle Pleistocene, and at least a few of these faults moved more than once during this time.

Basalt eruptions of Pliocene and Pleistocene age within 25 km (16 mi) of Yucca Mountain are listed in Table 6.3.1.7-1. Clearly, basaltic eruptions occurred in the Crater Flat area west and south of Yucca Mountain during the Quaternary Period, and there is evidence suggesting that, in at least one instance, surface faulting accompanied the volcanism (Swadley and Hoover, 1983; Carr, 1984).

<u>Conclusion</u>: There is evidence of recurrent faulting older than 35,000 years, and basaltic volcanism older than about 270,000 years in the Yucca Mountain region during the Quaternary Period (Swadley et al., 1984; Crowe

Table 6.3.1.7-1. Age of Pliocene-Pleistocene basalts in Yucca Mountain area (Carr, 1984)

Name	Ages (m.y.)[a]	Range in age (m.y.)	Average age (m.y.)
Lathrop Wells	0.29 ± 0.2 0.23 ± 0.02 0.30 ± 0.10	0.07	0.27
Western rift, Crater Flat	1.14 ± 0.3 1.07 ± 0.04 1.09 ± 0.3 1.07 ± 0.4 1.11 ± 0.3 1.50 ± 0.1	0.43 (0.07)[b]	1.16
Basalt of Buckboard Mesa	2.82 ± 0.05 2.79 ± 0.10 2.70 ± 0.2	0.12	2.77
Southeastern rift, Crater Flat	3.85 ± 0.05 3.64 ± 0.13 3.60 ± 0.1	0.25	3.67

[a] m.y. = million years.

[b] Excluding Red Cone 1.50 m.y. age.

and Carr, 1980). There also is evidence (Carr, 1984) of gentle regional tilting to the southeast of about 4 m/km (20 ft/mi) during the last few million years. Evidence of Quaternary diapirism, folding, uplift, or subsidence has not been observed in the vicinity of Yucca Mountain. Therefore, it is concluded that Yucca Mountain possesses this potentially adverse condition.

(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.

Evaluation: The largest ground accelerations at Yucca Mountain are likely to have been less than 0.1 g (Rogers et al., 1977) for any of the earthquakes that have occurred historically. Although surface faulting has occurred at Pahute Mesa and Yucca Flat in response to nuclear tests, the closest historical surface faulting accompanying natural earthquakes occurred in Owens Valley about 150 km (90 mi) west of the proposed site (Rogers et al., 1977, p. 1588). If the historic earthquakes recurred, they would not be large enough or close enough to Yucca Mountain to have any demonstrable effect on waste containment or isolation.

Conclusion: The relatively brief historical record does not show any large earthquakes at or near Yucca Mountain that, if they recurred, could adversely affect waste containment or isolation. Furthermore, the historical record discloses no evidence of damaging ground motion or historic faulting at or near Yucca Mountain. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

The following two potentially adverse conditions are discussed together:

(3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.

(4) More frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.

Evaluation: The Yucca Mountain Site is within the Basin and Range province and is situated adjacent to a zone of seismicity considered part of the southern Nevada East-West Seismic Belt. This belt connects the north-trending Nevada Seismic Zone, about 160 km (100 mi) west of the proposed site, with the north-trending Intermountain Seismic Zone about 240 km (150 mi) east of the proposed site. The largest historical earthquakes within the southern Nevada East-West Seismic belt are about a magnitude 6 on the Richter Scale. The largest earthquakes within the Basin and Range province have occurred in California, in the Nevada Seismic zone, approaching magnitude 8+ on the Richter Scale. The largest events in the Intermountain Seismic Zone have been magnitude 7, but fault scarp evidence in the this zone indicates the potential for events in the range of 7 to 8 on the Richter Scale (Cluff et al., 1970, 1973). Each of these zones of seismicity spans large areas that are heterogeneous in their geologic and seismologic properties (Thenhaus and Wentworth, 1982). Thus, the distribution of large events in these diffuse zones is expected to be uneven. The largest event in one zone is not necessarily the largest probable event in an adjacent or connected zone. At present, however, given current state of knowledge, it should be assumed that earthquakes could occur that are larger than those that have occurred historically in the region. The length of nearby major faults with Quaternary displacement, such as the Bare Mountain, Mine Mountain, Beatty, and Rock Valley faults, indicate that there is a potential for the occurrence of an earthquake approaching magnitude 7 on the Richter Scale as close as 15 to 33 km (9 to 21 mi) to the proposed site. The occurrence of two magnitude 6 (Richter Scale) earthquakes in the historic record elsewhere in the southern Nevada East-West Seismic Belt, shows that events of at least this magnitude could occur in the region, but the probability is low that events of this size or larger will occur at Yucca Mountain in the next few thousand years.

At present, Yucca Mountain, and a large area to the west and south, is nearly quiescent seismically (Rogers et al., 1983). Available geologic data indicate that faults at and near Yucca Mountain have not had large (>1 m) surface displacements in the last 250,000 years (Swadley and Hoover, 1983) and have had no unequivocally demonstrated surface displacement in at least the last 35,000 years (Swadley et al., 1984). The record of seismicity in the southern Nevada East-West Seismic Belt, however, shows that the age of most recent surface displacement on faults may not, by itself, be a reliable indicator of future seismic activity (Rogers et al., 1983). This is indicated by the abundant seismicity in fault zones with no record of Quaternary displacement and by the absence of seismicity in some areas of Quaternary faulting. One of the results of ongoing studies is an indication that fault orientation may be more important than evidence of recent movement in determining present seismic activity. Seismic data indicate that faults with strikes from approximately north to northeast appear to be more active seismically than faults of other orientations. Yucca Mountain faults have this general orientation. Even in active zones, however, areas exist that have been stable for hundreds of thousands of years (Wallace, 1978).

At present, little is known about seismic cycles and the relation between seismicity and age of faults in the Basin and Range province [see Thenhaus, (1983) for a summary of views]. Until there is a better understanding of why areas are stable or unstable in the same region, the chances for significant future seismic activity on faults near Yucca Mountain cannot be determined. In addition to the evidence discussed, this position is taken partly because (1) stress measurements at Yucca Mountain indicate a possibility that certain faults may be near failure (Healy et al., 1982) and (2) faults of orientation and style similar to those at Yucca Mountain exist on Pahute Mesa, where large nuclear tests have resulted in extensive stress release on faults approaching 10 km (6 mi) in length. Although movement on these faults was induced by nuclear explosions, the extent of faulting, the size of fault displacements, and the magnitude and depths of accompanying aftershocks indicate that these faults were tectonically stressed near the failure point, and slip was triggered by stress changes produced by the explosions. Although none of these data or arguments are conclusive, a combination of the stress data, the historic seismicity of the region, and the indication from current seismicity that fault activity depends more on fault orientation than fault age, suggests that a potential exists for renewed movement on faults near Yucca Mountain, despite geologic evidence of relative tectonic stability in the Quaternary period (Carr, 1984).

Conclusion: There is no evidence of any tectonic processes now occurring at or near Yucca Mountain that might indicate a future increase in the frequency or the magnitude of earthquakes. The nature of earthquake occurrence in this region is not well enough understood, however, to preclude the possibility that earthquakes larger than those that have historically occurred near Yucca Mountain may occur in the future. The frequency of earthquakes at and near Yucca Mountain during the several years of close monitoring is less than the that for the adjacent region; the magnitude of nearby earthquakes is the same or less than that for adjacent parts of the region. Therefore, the Yucca Mountain site does not possess these two potentially adverse conditions.

(5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.

Evaluation: Geologic and geomorphic evidence of landslides (Christiansen and Lipman, 1965; Lipman and McKay, 1965; Scott and Bonk, 1984) is limited to relatively small rock slumps along steep erosional slopes of Yucca Mountain. The largest of these slumps is on the northeast side of Yucca Mountain along Yucca Wash where a 500-m (1500-ft) wide set of blocks is slumping into the wash along a complex of 14 minor normal faults that strike parallel to the wash. There is no geomorphic evidence to suggest rapid movement of these blocks, and lateral transport seems to be limited to that which occurs along normal fault planes that dip 60 to 80 degrees. There is no geomorphic evidence that suggests that past slumping of blocks has dammed major drainageways. Also, there is no thick soil or thick colluvial material on slopes that would be available to slide and create dams.

There is no evidence that subsidence related to solution of rocks has occurred, nor are there soluble rocks at the surface or within at least several thousand feet of the surface of Yucca Mountain.

If basaltic eruptions were to occur within Yucca Mountain, they might temporarily dam south-trending washes. The most recent volcanism nearby [8 to

15 km (5 to 9 mi) west and southwest of the proposed site] occurred at several small basaltic cones whose ages range from about 3.7 million years to about 300,000 years. However, the likelihood of such future eruptions at Yucca Mountain is small (Crowe et al., 1983) during the lifetime of a repository. If similar basaltic eruptions should occur in the vicinity of Fortymile Wash, an event whose likelihood also is small, a lake might form upgradient from them. Such a lake would be short-lived because erosion of alluvium adjacent to the basalt would be rapid with a consequent draining of the lake. Effects of a temporary lake on the ground-water system might be an increase in the ground-water gradient from western Jackass Flats, slightly more rapid movement of water from or near the lake toward discharge areas 50 to 60 km (30 to 40 mi) away, and a slight rise in the water table.

Conclusion: Natural phenomena, such as landslides, subsidence, or volcanic activity, that could create large-scale surface-water impoundments are not likely to occur. If impoundments should occur because of future volcanic activity, they probably would be short-lived, and their effects on ground water would be minor and short-lived. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(6) Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system.

Evaluation: Calculations of the amount and rate of subsidence, uplift, or faulting in the southern Great Basin (Carr, 1984) show that over the last few million years Yucca Mountain and adjacent areas have been relatively stable, particularly in comparison with tectonically active areas, such as Death Valley and Owens Valley. The comparison tabulated in Table 6.3.1.7-2 is from Carr (1984). Folding has not been a tectonic process in the vicinity of Yucca Mountain for millions of years, although Pliocene and Quaternary tilting and folding have occurred in the Death Valley region. Work in progress suggests that gentle warping of Quaternary deposits might have occurred as close to Yucca Mountain as the west side of Crater Flat.

Table 6.3.1.7-2. Approximate rates of Neogene-Quaternary vertical tectonic adjustments or burial in the southwestern Great Basin (Carr, 1984)

Location	Rate (m/1000 yr)	Comment
Amargosa Desert: Ash Meadows	<0.01	Based on dated ash bed 5 m below surface.
Crater Flat: VH-2 drill hole	0.03	Burial of basalt about 11 m.y.[a] old.
Crater Flat: Western rift basalts	<0.01	Basalt 1.1 m.y. old is at the surface.
Crater Flat: Fault in trench 3	<0.02	Based on youngest age of last movements: 40,000 years.
Yucca Mountain: Largest basin-range faults	0.04	Based on maximum fault displacement of tuffs 11 m.y old.
	<0.01	Estimates for Quaternary based on maximum of 20 m fault displacement
Death Valley: Foot of Black Mountains	0.3	Based on displacement of Artists' Drive Formation in last 5 m.y.
Sierra Nevada Owens Valley-White-Inyo Mountains	0.4	Average of 9 estimates from the literature.

[a] m.y. = million years.

Presently available data on several specific faults in the Yucca Mountain area seem to show generally decreasing rates and amounts of offset through about the last 10 million years (Carr, 1984). The older data are obtained at locations where the offset of several volcanic units of known ages can be determined. Because the youngest volcanic units are about 8 million years old, control for dating events of the last 8 million years depends mainly on understanding and dating alluvial-stratigraphic units with limited vertical exposures, and which probably do not retain fault scarps for more than 1 to 2 million years. The absolute ages of some of these units are not presently well known.

Within a 100-km (60-mi) radius of Yucca Mountain, approximately 180 scarps or lineaments, which are presumed to be fault related, have been identified. About one-fourth of these are linear or curvilinear mountain fronts; the remaining 135 are actual fault scarps or lineaments in the alluvium. Most of the alluvial scarps are low and are subdued by erosion. Outside the tectonically active Death Valley-Panamint Valley area [more than 50 km (30 mi) from Yucca Mountain] (see Figure 3-4), only one fault (the Yucca Fault in Yucca Valley) with probable Holocene (about the last 10,000 years) displacement has been found, although slight Holocene movement cannot be ruled out on several other faults (Szabo et al., 1981). Additionally, the clustering of small earthquakes along part of the Rock Valley fault indicates it is seismically active.

Because rates of uplift and/or subsidence and faulting in the past have been very low, it is postulated that similar rates will prevail in the future. In the highly unlikely event of a major change in rates of uplift, subsidence, or faulting in a portion of the ground-water system relative to that of other portions of the system, the ground-water flow-path between the site and the accessible environment could be affected. Ground-water flow could be either retarded or accelerated. The possible magnitudes of effects on ground-water flow would be small because the present ground-water system is controlled by large regional geologic structures that probably would take geologically long periods of time to alter significantly.

Conclusion: At the Yucca Mountain site, the potential for tectonic deformations, such as uplift, subsidence, folding or faulting of a magnitude or scale that would affect regional ground-water flow, is probably very small. The regional groundwater system presently is controlled to a great degree by geologic structures of such complexity and large scale that it would not be significantly modified by any likely tectonic events within geologically long periods of time. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

VI. PLANS FOR SITE CHARACTERIZATION

During site characterization, field investigations will continue to evaluate tectonic activity of the Yucca Mountain site and surrounding region. These investigations will include (1) dating of past fault displacements, (2) monitoring of earthquake activity at the site and in the surrounding region, (3) monitoring of ground motion in drill holes, (4) precise monitoring of geodetic positions and elevations, (5) studies of geomorphic history during the Quaternary period, and (6) measurements of in situ stress in drill holes and underground workings. In addition, more data on the geohydrologic system will be obtained, which will enable the local ground-water system to be modeled in detail. This modeling will then permit the effects of credible tectonic events on ground-water flow and radionuclide transport to be described.

6.3.1.8 Human interference and natural resources technical guidelines (10 960.4-2-8 and 10 CFR 960.4-2-8-1)

I. INTRODUCTION

The postclosure Human Interference Technical Guideline contains the Natural Resources and the Site Ownership and Control Technical Guidelines. The guideline on natural resources addresses general concerns about surface and subsurface resources, including minerals, energy resources, and ground water. The guideline on site ownership addresses passive institutional controls. This section evaluates the Yucca Mountain site with respect to the overall qualifying condition for Human Interference and with respect to the conditions of the Natural Resources Guideline. Section 6.2.1.7 provides the evaluation with respect to the Site Ownership and Control Guideline.

The Natural Resources Guideline contains one qualifying condition, one favorable condition, five potentially adverse conditions, and one disqualifying condition. The Site Ownership and Control Guideline contains one qualifying condition, one favorable condition, and one potentially adverse condition.

II. RELEVANT DATA

Yucca Mountain has been mapped at a scale of 1:24,000 (Christiansen and Lipman, 1965). In addition, 20 exploratory holes have been drilled at or near the site. An exhaustive literature search was conducted by Bell and Larson (1982) to develop a Level 1 Resource Appraisal in accordance with the U.S. Department of the Interior guidelines for characterization of energy and mineral resources.

Hot springs in the areas were evaluated by Garside and Schilling (1979), and Trexler et al. (1979). The hot springs studied are located northwest and south of the Yucca Mountain site. Detailed discussions of the Energy and Mineral Resource Potential including assumptions and data uncertainties are presented in Chapter 3 of this assessment.

A Groundwater Resource Potential Map was prepared by Sinnock and Fernandez (1982). A regional ground-water flow model developed for the proposed site is discussed in detail in Chapter 3 and includes discussions of ongoing work.

III. QUALIFYING CONDITION

Human Interference

The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of the permanent markers and records required by 10 CFR Part 60, taking into account site-specific factors, as stated in Sections 960.4-2-8-1 and 960.4-2-8-2, that could compromise their continued effectiveness.

Natural Resources

The site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

Evaluation: A thorough examination of the proposed site has been made, including geologic mapping of the area and a resource potential survey. These studies indicate no known natural resources or naturally occurring materials that currently have significant commercial value. These resources and materials are also not likely to be commercially attractive in the future. No evidence of subsurface drilling, mining, or exploration has been found. Preliminary studies suggest that ground-water withdrawal near or at the site is unlikely to alter the regional flow paths to the extent that unacceptable radionuclide release rates at the accessible environment could result.

Conclusion: Currently, there are no known valuable natural resources and no potential natural resources of foreseeable value at the Yucca Mountain site that could encourage interference activities that could lead to unacceptable releases of radionuclides. An effective permanent marker system that provides both onsite and wide-spread information on the location, content, and warnings as to the danger of repository contents will discourage future human interference. Therefore, the Yucca Mountain site meets these qualifying conditions.

IV. FAVORABLE CONDITION

No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.

Evaluation: Present knowledge of the status of energy-related resources at or near the site suggests that (1) there are low-temperature springs in Oasis Valley and the Amargosa Desert, but not at Yucca Mountain, (2) there is no potential for hydrocarbon resources, and (3) there is no indication of uranium resources at Yucca Mountain. The energy resources appraised by Bell and Larson (1982) include hydrocarbons such as oil, gas, oil-shale, and coal; low- to high-temperature geothermal energy; and radioactive fuel materials such as uranium and thorium. The specific mineral resources appraised include base and precious metals (e.g., silver), and significant industrial minerals and rock materials (e.g., gravel).

Details and data supporting this evaluation are presented in Chapter 3 of this report, Energy and Mineral Resource Potential, and a resource map is shown in Figure 6.3.1.8-1.

Although ground water is used for irrigation in Ash Meadows and Amargosa Valley, the rugged topography and depth to the water table at Yucca Mountain would limit water development for irrigation. To be economical, underground pumped storage schemes require low permeability rock masses below shallow water tables. The depth to the water table at the site would make such a scheme

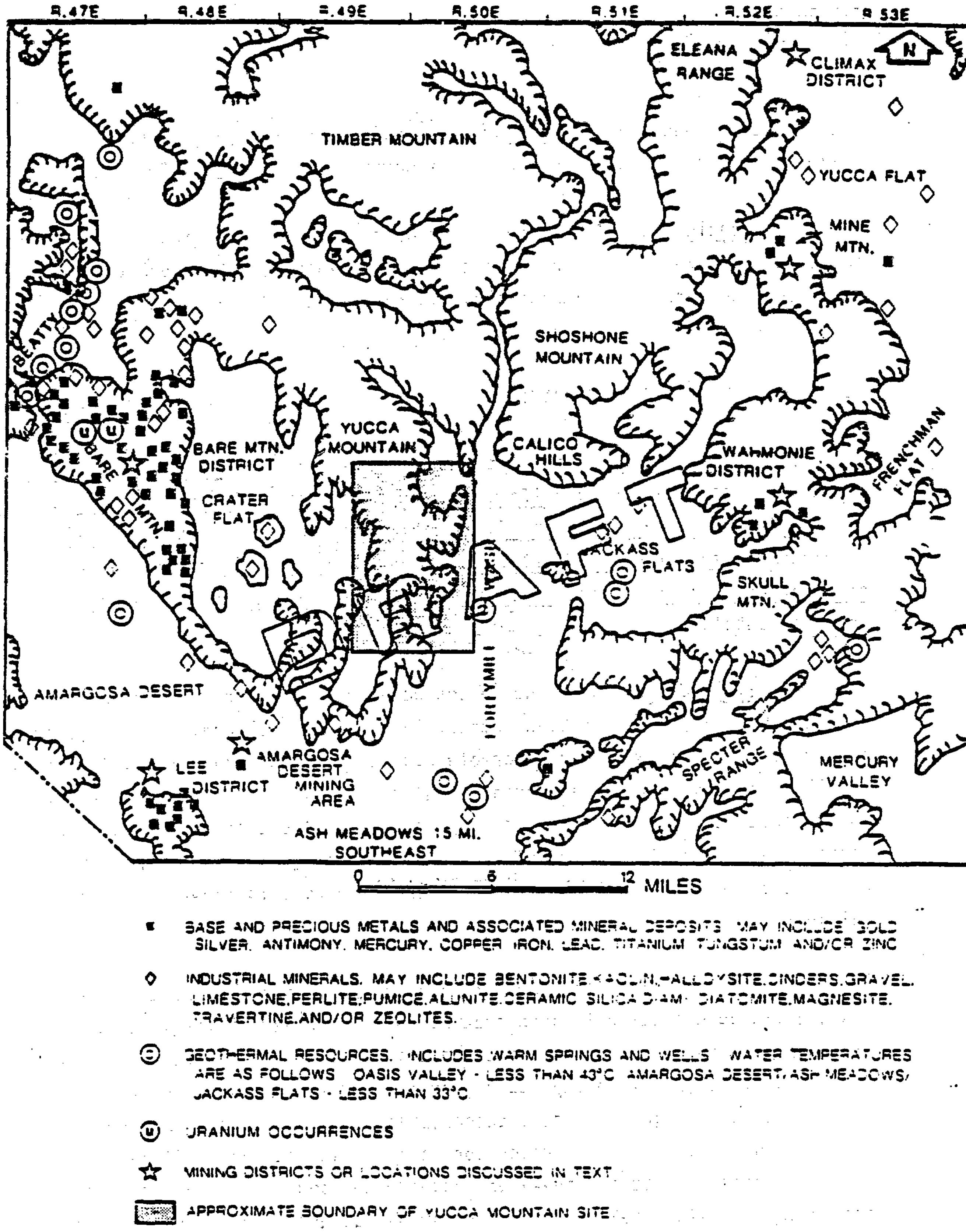

Figure 6.3.1.8-1. Location of metal deposits, industrial minerals, thermal waters, and mining districts in the vicinity of Yucca Mountain. (Source: Bell and Larson, 1982; Trexler et al., 1979)

uneconomical. Supporting data for this evaluation are given in Chapter 3, which discusses the uses and sources of water in the Amargosa Desert.

Conclusion: There are no known natural resources that have, or are projected to have in the foreseeable future, a value great enough to be considered commercially extractable. Therefore, the Yucca Mountain site meets possesses favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.

Evaluation: The resource potential survey of the region prepared by Bell and Larson (1982) has been thoroughly reviewed and detailed in Chapter 3 and briefly discussed in the favorable condition of this guideline. No energy, metallic, or nonmetallic resources unique to the site vicinity or critical to foreseeable national needs have been identified. Those resources identified within the site vicinity were of lower value than deposits in surrounding regions, and new discoveries of significant resources in ash-flow tuffs is unlikely as discussed in Chapter 3.

Conclusion: Yucca Mountain has no known energy or mineral resources, and the geologic setting is such that no new resources are likely to be discovered in the future. As pointed out in Potentially Adverse Condition (2), Section 6.3.1.1 (Geohydrology) some very limited water resources are present. However, depths to ground water, topographic conditions, and land-use restrictions at the proposed repository site limit the availability and attractiveness of this ground-water resource now and in the future. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) Evidence of significant subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.

Evaluation: The resource potential survey of the region did not identify any evidence of significant mining-related operations at the Yucca Mountain site. The entire area has been mapped by the U.S. Geological Survey, and no evidence of significant subsurface mining has been reported. There is little likelihood that unknown excavations other than shallow prospecting pits exist at the site.

Conclusion: There has been no subsurface mining or extraction for resources at Yucca Mountain. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(3) Evidence of drilling within the site for any purpose other than repository-site characterization to a depth sufficient to affect waste containment and isolation.

Evaluation: Before waste-storage investigations began, two boreholes existed in the area of the proposed site: water well J-13 located 7 km (4.4 mi) southeast of the site and J-12 located approximately 15 km (9.5 mi) southwest of the site. The site is within an area of Federally controlled lands, most of which were restricted in the early 1950s to prevent public access. The entire area has been mapped by the U.S. Geological Survey. Consequently, there is little likelihood that unknown wells, boreholes, or excavations other than shallow prospecting pits exist at the site.

Conclusion: There has been no drilling at Yucca Mountain except that for potential repository site evaluation. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.

Evaluation: The resource potential survey found no indication of material resources that were unique to the site or critical to national needs (see the favorable condition for this guideline). Significant mineralization does not correlate well with the type of volcanic rock present in the potential repository site area. Furthermore, the survey indicated that any resources found in the site vicinity are also found outside of this area. Those outside the area typically have more economic value or are more easily extractable.

Conclusion: There is no evidence of any significant concentration of potentially valuable natural resources at Yucca Mountain. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(5) Potential for foreseeable human activities--such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments--that could adversely change portions of the ground-water flow system important to waste isolation.

Evaluation: The potential for extensive ground-water extraction at or near the site is evaluated in detail in Potentially Adverse Condition (2) of Section 6.3.1.1 (Geohydrology). Although potable ground water is present beneath Yucca Mountain, future generations are not likely to drill and extract water from the top of Yucca Mountain because drilling and extraction would be easier and more ecomonical in the surrouning area. Extensive pumping of well J-13, which is located 7 km (4.4 mi) southeast of the Yucca Mountain site in Jackass Flats, and draws water from the volcanic aquifers, has not resulted in measurable drawdown. This suggests that ground-water extraction in Jackass Flats is not likely to induce change in the ground-water flow system. The depth of the water table at Yucca Mountain would make underground storage schemes uneconomical. Also, because of the low energy and mineral potential of the Yucca Mountain site, it is considered unlikely that any commercial or industrial development that would be utilizing water or requiring subsurface injections of fluids would be located in the area. No military activities that could result in impacts on the ground-water system are foreseen.

Conclusion: The Yucca Mountain area has very limited potential for any kind of large-scale water-resources development and, consequently, modification of the ground-water flow system is unlikely. The land on and near

Yucca Mountain is a buffer zone at the present time (see Sections 6.2.1.1 and 6.2.1.3). Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

VI. DISQUALIFYING CONDITION

<u>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.</u>

<u>Evaluation</u>: Thorough examination of the proposed repository site and comprehensive searches of literature and mining claim files, have disclosed no evidence of ground-disturbing activities. Searches have included:

1. Archaeological field surveys for historic artifacts, prospects, or other indicators of resource extraction activity on the site (Pippin et al., 1982).

2. A resource potential survey including searches of mining literature and claim files for records of past interest in or activity on the site (Bell and Larson, 1982).

3. Geologic mapping of the entire area by the U. S. Geological Survey.

It is extremely unlikely that unknown excavations exist at the site. The site is within an area of Federally controlled lands, most of which were restricted in the early 1950s to prevent public access, and thereby excluded from the development of even small-scale mining operations.

<u>Conclusion</u>: There have been no previous exploration, mining, or extraction activities for resources at the Yucca Mountain site. No signif 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 this disqualifying condition.

VII. PLANS FOR SITE CHARACTERIZATION

The effects of ground-water withdrawal in various parts of the area surrounding the Yucca Mountain site will be better established by increases in the hydrologic data base. Additional data on hydraulic gradients and relationships among ground-water basins and subbasins will be particularly useful for refining regional hydrologic models.

6.3.2 Postclosure system guideline (10 CFR 960.4-1)

I. INTRODUCTION

The Postclosure System Guideline is stated as a qualifying condition:

The geologic repository shall consist of a system of multiple natural and engineered barriers that will physically separate the radioactive waste from the accessible environment after closure in accordance with the requirements set forth in 10 CFR Part 60 and 40 CFR Part 191.

This guideline is one of four system guidelines meant to ensure that a geologic repository meets applicable standards and regulations. A second purpose, and the one most relevant to this document, is to facilitate the process of nomination of sites as suitable for site characterization for selection of a repository site. After a site has been nominated as suitable for site characterization, the DOE will recommend to the President that the site undergo site characterization. This recommendation is to be based on a judgment that current information indicates that the site will meet the system guidelines. The system guidelines incorporate the relevant portions of NRC and EPA regulations that will be used during licensing actions as the standards of judgment for site suitability. Therefore, the system guidelines are used to ensure that siting decisions are compatible with requirements to protect public health and safety and environmental and socioeconomic quality. In particular, the system guideline for postclosure performance requires the protection of public health and safety from radioactive waste materials for at least 10,000 years.

As explained in more detail in the introduction to this chapter, two kinds of postclosure guidelines, system (10 CFR 960.4-1) and technical (10 CFR 960.4-2), govern siting considerations. The postclosure system guideline addresses the ability of the entire repository system to protect the public health and safety from the danger posed by the emplaced waste. These concerns are considered the most important for guiding the selection of sites for characterization and potential repository development. The postclosure technical guidelines address individual site conditions that could influence the overall system behavior. They are primarily intended to ensure that no expected or potentially disruptive site characteristic or condition will adversely affect the repository performance after closure.

If a complete and reliable evaluation of the entire repository system were available, there would be no need to evaluate the site with respect to each technical guideline. At this stage of site evaluation, sufficient data are not available to allow a systematic analysis that considers all pertinent repository and site components, including the uncertainties associated with each component. Such an evaluation must await site characterization and final repository design. Therefore, definite conclusions about whether Yucca Mountain will comply with the postclosure system requirements are not possible nor expected at this time. Rather, judgments will be made about whether there currently is sufficient confidence that the site will comply with such requirements after site characterization.

The method of evaluation used in this section has two facets, one quantitive and the other qualitative. The quantitative approach predicts the amount of radionuclides that would be released from the repository and transported to the accessible environment during at least the next 10,000 years if present site conditions prevail. The quantitative predictions are based on limited site information and relatively simple modeling techniques. They are intended only to establish the general range of expected site performance. Because of unavoidable uncertainty about what the specific future conditions at Yucca Mountain (or any site) will be, it is assumed in the analyses that the site conditions expected during the future will be those now present. Details of some of the quantitative analyses are presented in Section 6.4.2. In this section, emphasis is placed on other quantitative studies that were performed independent of the preliminary performance assessment in Section 6.4.2, and can be used to broaden the interpretations presented in that section.

The qualitative approach subjectively balances the potential influences of the favorable and potentially adverse conditions existing at Yucca Mountain. This approach uses technical guidelines in place of the system guideline and is judgmental because the relative importance of particular favorable and potentially adverse conditions must be weighed in relation to their potential influences on site behavior in the context of the overall setting at Yucca Mountain. Evaluations of these surrogate conditions can strongly indicate, but not demonstrate, whether a site has the necessary features to protect public health and safety. Technical guidelines are particularly important before site characterization when neither site nor design information is adequate for a complete and reliable system evaluation. This qualitative approacn considers the particular strengths and weaknesses of the site independent of conclusions drawn from quantitative predictions, thus providing a reliability check. Because no quantitative predictions were made for potentially disruptive conditions (except perhaps erosion and climatic change), this approach provides the only means available for assessing the likelihood of site compliance with these aspects of the system guideline.

Because the postclosure system guideline requires multiple levels of protection of public health and safety by the geologic repository system, demonstrations of compliance will ultimately consider the effects of engineered barriers. However, the siting guidelines are intended to ensure sites are selected which have natural features that are advantageous for ensuring satisfactory isolation of wastes. Thus, the merits of site conditions have been evaluated independently from possible engineering features that might be used to augment isolation provided by the site. Thus, in judging the site's abilities to isolate the wastes, engineering features have not been considered, except where necessary to establish a reference condition for evaluating the potential effectiveness of particular site conditions (see Section 6.4.2). This should not be construed to mean that the site, in and of itself, must be able to ensure compliance with the system guideline. At this stage of the siting process, however, confidence in eventual compliance is based solely on favorable site conditions rather than on engineered barriers.

II. EVALUATION OF THE YUCCA MOUNTAIN SITE

The following discussion informally evaluates the Yucca Mountain site with respect to the system guideline. First, the results from currently published quantitative studies of system performance (Thompson et al., 1984; Sinnock et al., 1984) are summarized. These studies supplement the preliminary performance assessment of Section 6.4.2. The qualitative evaluation of the Yucca

Mountain site based on the favorable and potentially adverse conditions relative to the system guideline is then summarized.

Quantitative Analyses: The conclusions from the preliminary performance assessments are summarized in Section 6.4.2. Other analyses that support these conclusions are described in detail in Thompson et al. (1984) and Sinnock et al. (1984). The study by Thompson et al. (1984) was completed before the evidence was available that flux at the repository level is probably less than 1 mm/yr (Section 6.3.1.1). They chose a 5 mm/yr flux as simply the midpoint of the range of 1 to 10 mm/yr flux that was suggested by the work of Sass and Lachenbruch (1982). One assessment [Case 3 in Thompson et al. (1984)] assumes that the recharge flux at Yucca Mountain is 5 mm/yr (0.2 in/yr) and that this flux passes vertically through the repository to the water table. Release of radionuclides into this flux was assumed to begin 300 years after waste emplacement. The release rate was assumed to be determined by an overall dissolution rate of 1 part in 100,000 per year of the total mass of the waste forms (spent fuel and borosilicate glass). Sorption was the only retardation mechanism assumed to affect migration of the radionuclides in the moving water. Only two nonsorbing nuclides were predicted to reach the accessible environment within 10,000 years, carbon-14 and technetium-99. About 1 curie of carbon-14 and 8 curies of technetium-99 per 1000 metric tons of heavy metal (MTHM) were calculated to be released to a point 10 km (6 mi) horizontally distant from the repository. The proposed release limits of the EPA for these nuclides are, respectively, 100 and 10,000 curies per 1,000 MTHM. Thus, the preliminary quantitative analysis of Thompson et al. (1984) indicates that the site, in and of itself, would limit releases of radionuclides to the accessible environment to about 2 percent of those allowed by the current EPA release standards (Working Draft 4).

Another assessment analyzed the sensitivity of releases (both from the waste form and to the accessible environment) to variations in the water flux through the repository and to waste-form solubility (Sinnock et al., 1984). This analysis indicates that the EPA release limits could be met even for water flux up to about 50 mm/yr (2 in/yr), assuming that releases from the waste forms are limited by the solubility of uranium and glass. The results of this study also suggest that the NRC allowable release rate from the engineered barrier system of 1 part in 100,000 of the waste species present 1000 years after closure can be met without any other engineered barriers except the waste form. The amount of water likely to contact the waste is insufficient to dissolve it at rates above this limit. Three conclusions are derived from this study: First, the amount of waste released from the repository and transported to the accessible environment will depend heavily on the volume of water naturally passing through the repository level. Second, the mechanisms for, and solubility limits of, waste dissolution in the geochemical environment of the unsaturated zone will strongly influence releases of radionuclides. Third, geochemical retardation is not necessary to satisfy performance standards. The presence of a zeolitized zone beneath the proposed repository horizon provides additional assurance that transport and release will not occur even under extreme conditions. Waste dissolution models which were used could over-estimate dissolution rates by a factor of as much as 10,000 according to information presented in Section 6.3.1.2. For Yucca Mountain conditions, this analysis shows that the EPA release limits would be met for the expected case of flux of < 1 mm/yr (0.04 in/yr) through the unsaturated zone (see Section 6.3.1.1, Geohydrology).

The performance studies summarized above and in the preliminary performance assessment in Section 6.4.2 are a first step toward developing confidence in the ability of the Yucca Mountain site together with its geologic setting to limit expected waste releases. These studies do not, however, substitute for the detailed performance assessment that will be required after data is available from site characterization. These preliminary studies have used analytical and computational tools considered valid and reasonable but which have not been formally validated and verified. Furthermore, these preliminary studies have not considered specific, potentially disruptive events and processes that could alter the expected pattern of waste release. These potentially disruptive events and processes include those induced by climatic changes, tectonism, erosion, and human interference. Such events are unexpected only in the sense that their timing and magnitude is uncertain. A complete set of disruptive-event scenarios pertinent to Yucca Mountain cannot be identified until site characterization is completed.

These preliminary studies were conservatively designed to compensate for many of the uncertainties caused by limited site and design information. In particular, the following conservative assumptions were made.

1. In some of the studies, no credit was taken for engineered barriers, i.e., the site's natural conditions were used to predict performance of a repository composed of emplaced, unpackaged spent fuel and solidified high-level wastes. Though engineered barriers were not modeled, their potential effects cannot be ignored if a realistic evaluation is to be made.

2. In some of the studies, the percentage of the total water flux passing through the repository level that actually contacts and dissolves the waste was assumed to be higher than is likely [see Favorable Condition (1) in Section 6.3.1.1, Geohydrology].

3. The solubility of the waste forms was generally assumed to be higher than is likely [see Favorable Condition (4) in Section 6.3.1.2, Geochemistry].

4. Sorption was the only retardation mechanism accounted for. Diffusion of waste species into the rock mass and precipitation were ignored; these mechanisms, particularly diffusion, make it likely that no radionuclides will reach the accessible environment in 10,000 years [see Favorable Condition (2) in Section 6.3.1.2, Geochemistry].

5. In some of the studies, a conservative flux of 5 mm/year at the repository level was assumed. No consideration was given to likely diversion of some or all the percolating water away from the waste by stratigraphic, or structural features in the rock units underlying the repository, thus magnifying travel times to the accessible environment.

6. The potential effects of a freely draining host rock that might further reduce the volume of water contacting the waste or reduce the time of contact were not considered [see Favorable Condition (6iv) in Section 6.3.1.1, Geohydrology].

7. No credit was taken for vertical flow time or radionuclide retardation in the host rock, the densely welded Topopah Spring Member [see Favorable Condition (1) in Section 6.3.1.1, Geohydrology].

8. The time for vertical or horizontal ground-water flow through the saturated part of the tuffaceous beds of the Calico Hills to the highly transmissive aquifers was not considered [see Favorable Condition (1) in Section 6.3.1.1, Geohydrology].

9. In some of the studies, only 100 meters of the unsaturated highly sorptive tuffaceous beds of the Calico Hills unit was assumed for flow time and radionuclide transport calculations. However, the potential repository area is underlain by between 100 and 350 meters of unsaturated Calico Hills (see the Disqualifying Condition in Section 6.3.1.1, Geohydrology).

10. The potential drying effects of heat around the waste emplacement holes due to the increased rock temperature was not considered [see Favorable Condition (2) in Section 6.3.1.3, Geochemistry].

In combination, the conservatism of the quantitative predictions lends considerable confidence to the conclusion that Yucca Mountain will, following site characterization, qualify under the Postclosure System Guideline 960.4-1(a).

Qualitative Analysis with Respect to the Balance of Site Conditions: The Yucca Mountain site is qualified to proceed with site characterization for possible repository selection under all eight postclosure technical guidelines and is not disqualified under any of the four guidelines with a disqualifying condition. These conclusions are subject to reevaluation after site characterization when additional site data and design information will be available.

They provide only the framework for a decision to proceed with site characterization. Confidence in meeting the intent of each guideline is different, as suggested by the evaluations in Sections 6.3.1.1 through 6.3.1.8. Confidence is the highest for meeting the erosion, dissolution, and human interference guidelines, and only slightly less for the guidelines on geochemistry, rock characteristics, and climatic change. The potential behavior of the site with respect to the geohydrology guideline and the tectonics guidelines engenders the most uncertainty. In no instance, however, is confidence low enough to justify a claim that Yucca Mountain does not qualify, or is disqualified, with respect to any of the technical guidelines.

Remaining uncertainties in analyses of the postclosure technical guideline are associated with a scarcity of data or incomplete understanding about certain natural phenomena. Generally, these uncertainties correspond to the possible effects of rapid ground-water flow or the presence of potentially adverse conditions related to site behavior. In particular, the exact amount of unsaturated flux of water through Yucca Mountain is uncertain, although it is expected to be very low. The rate of dissolution of wastes exposed to this water in the oxidizing environment of the unsaturated zone could be higher than assumed. Neither the likelihood nor the potential effects of climatic changes or local tectonism on repository behavior are precisely established. The presence of fresh water aquifers along the likely paths of radionuclide travel is a source of possible concern related to human intrusion, although the great depth to the water table partly negates this potential problem.

These conditions are thoroughly evaluated in the appropriate sections in this chapter. Implications of the potential impacts on isolation performance are not fully understood at present, although certain preliminary observations can be made. Rapid ground-water flow time and oxidizing conditions around the waste might seem to indicate a potential for rapid and significant releases of radionuclides to the accessible environment. Current information about water flux and geochemical retardation at Yucca Mountain suggests just the opposite. As discussed below, the low flux thought to occur through the unsaturated zone at Yucca Mountain will increase travel times, and limit waste dissolution rates to extremely low levels. The effects of engineered waste packages will provide additional assurance that the oxidizing conditions, in particular, will not result in unsatisfactory performance.

With respect to potentially adverse conditions in the guidelines that consider disruptive processes and events, the parametric analyses by Sinnock et al. (1984) included evaluations of performance under fluxes up to 50 mm/yr (2 in./yr), a value 50 times the expected site conditions. Even those high fluxes did not cause predicted releases of radionuclides at the accessible environment in excess of EPA proposed standards. The current estimates of the most likely flux passing through Yucca Mountain indicate that fracture flow is not a significant factor, and therefore increases in fracture frequency due to tectonic processes is not likely to affect radionuclide migration. Also, the rocks of Yucca Mountain have been subjected to active tectonism for millions of years and are already highly fractured in those units which are brittle enough to fracture. Therefore, any increase in fracturing would tend to be relatively minor, unless the tectonic regime were to drastically change. Overall, tectonic processes will probably have negligible effects on flow mechanisms.

The presence of fresh ground-water supplies beneath the site may induce future generations to drill near the repository site to obtain water. No mechanisms, however, have been identified on how this drilling would significantly change the total amount of waste released to, or transported by, the hydrologic system, especially with the repository located in the unsaturated zone.

This discussion of general uncertainties encompasses the major concerns raised by the existence of certain potentially adverse conditions for post-closure performance at the Yucca Mountain site. However, balancing these concerns are numerous favorable conditions exhibited by the Yucca Mountain site. The favorable conditions of most significance generally are the hydrological aspects associated with the arid environment of Yucca Mountain and the geochemical nature of the altered volcanic tuffs that make up the site.

Yucca Mountain has a deep water table that allows wastes to be placed in unsaturated rocks hundreds of meters above the water table. The only water that could possibly reach and interact with the wastes would have to slowly percolate downward from the desert surface. The water currently in the unsaturated rocks near the wastes would tend to be vaporized and driven away during the first few hundred years because of the heat generated by radioactive decay. Much of this water could later seep downward past the wastes before they cool. As the wastes cool, the water could migrate toward the repository. Though not relied upon for protection in all studies, the waste packages required by the NRC will remain intact until after this cooling period. After this period, the only water able to move past the wastes will be the tiny amount (less than 1 mm/yr) that is (or was in past millenia) able to infiltrate deeply enough to escape evaporation in the arid desert climate. Current information suggests that this amount will be so low that it would be unable to dissolve enough radioactive wastes to exceed performance standards. In addition, the water is expected to move very slowly through the rock matrix, taking many thousands of years to reach the water table. The site location in the unsaturated zone is a strong favorable condition. The characteristics of the hydrology provide a formidable barrier to waste release and migration.

Any dissolved waste will have to migrate with the moving water through at least 100 m (300 ft) of volcanic tuff before it reaches the water table. The tuff is largely composed of zeolites, which are minerals that will strongly absorb most radionuclides, substantially delaying their movement toward the accessible environment. Thus, the geochemical conditions at Yucca Mountain also provide a very effective barrier to radionuclide movement.

In combination, the hydrologic and geochemical conditions are sufficiently favorable to allow a conclusion with high confidence that they will more than compensate for the risks posed by the potentially adverse conditions outlined above. Other favorable conditions for rock characteristics, climatic change, erosion, tectonics, and human interference indicate that neither existing nor potentially disruptive conditions at Yucca Mountain will seriously impair the favorable isolation qualities.

Therefore, even though Yucca Mountain possesses some potentially adverse conditions, the current understanding of these conditions leads to the conclusion that they will not cause significant risks for future generations. This conclusion must be more firmly established by quantitative analyses of both the likelihood (when possible) and the potential consequences of the adverse conditions. In addition, the satisfactory performance inferred from the presence of the favorable conditions currently thought to exist at Yucca Mountain must also be confirmed with more comprehensive analyses. Such analyses will proceed in parallel with site characterization, identifying the most important conditions for consideration and resulting in a carefully documented analysis of the realistic risks posed by a repository at Yucca Mountain.

III. SUMMARY AND CONCLUSIONS

In summary, preliminary quantitative performance studies have shown that a repository at Yucca Mountain will meet the requirements of the proposed EPA standards in 40 CFR 191 if contemporary hydrologic, geologic, and geochemical conditions (as presently understood) prevail for the next 10,000 years. Also, it is likely that the release rates from the engineered barrier system of 1 part in 100,000 allowed by the NRC can be met solely by site conditions, without reliance on engineered barriers.

The effects of projected disruptive events or processes, such as climatic change, volcanism, faulting, and extreme erosion, have not been addressed by system analyses, but no realistic and likely failure modes due to the events or processes have been identified. Qualitatively, the Yucca Mountain site is judged to qualify under all eight of the postclosure technical guidelines and not to disqualify under any of the four guidelines having a disqualifying condition. This conclusion is based on the overall balance of the relative influences of the favorable and potentially adverse conditions identified at Yucca Mountain. Though confidence varies about both the existence and effect of individual site conditions, the favorable aspects of water flux and geochemical retardation lend a high degree of confidence to the ability of the natural setting to effectively isolate the buried wastes.

Because the conclusion was drawn independently from several preliminary quantitative system analyses and qualitative judgments based on site conditions, the NNWSI Project concludes that the Yucca Mountain site qualifies for site characterization under the Postclosure System Guideline, 960.4-1(a).

6.3.3 Preclosure technical guidelines

The preclosure technical guidelines that require site characterization are addressed in this section. These guidelines are used to evaluate the surface and rock characteristics, and the hydrologic and tectonic conditions at the proposed Yucca Mountain site.

6.3.3.1 Surface characteristics (10 CFR 960.5-2-8)

I. INTRODUCTION

The Surface Characteristics Technical Guideline is one of several preclosure guidelines under the heading ease and cost of construction, operation, and closure. The objectives of the guideline are to ensure that (1) adverse surface characteristics would not require any technology other than that reasonably available for construction, operation, and closure of a repository, and (2) the associated costs will not be unreasonable relative to other available and comparable siting options.

The concerns to be addressed under this guideline are related primarily to topographic features that control placement of or otherwise impact surface facilities. Special measures may be necessary for repository construction, operation, and closure in sites prone to periodic flooding, located in rugged terrain, or with other adverse surface features.

This guideline consists of one qualifying condition, two favorable conditions, and one potentially adverse condition. The Yucca Mountain site is evaluated with respect to each of these conditions in the following sections.

II. RELEVANT DATA

The data needed to describe the surface characteristics were obtained primarily from a 1:24,000 topographic map with 6 m (20 ft) contour spacing and high-resolution aerial photographs (1:12,000 and 1:6,000) (USGS, 1961). The topographic data have been evaluated in concert with surface hydrography by Squires and Young (1983) to enable the determination of flood potential along the Fortymile Wash drainage basin. Geomorphic observations also are available to determine relative ages of surfaces and thereby allow an assessment of the general stability of these surfaces during the operational period.

Flood peaks were estimated for 100-year, 500-year, and regional maximum (most intense) floods for the eastern part of Yucca Mountain and Fortymile Wash by Squires and Young (1983). The prediction of the regional maximum flood was based on data from floods elsewhere in Nevada and in surrounding states. The water depths predicted along the major channels during flood peaks are based on the estimated runoff produced during extreme storm events and the capacity of the drainage system to carry it.

Assumptions and Data Uncertainties: Topographic data uncertainty originates in the accuracy of the photogrammetric process and field survey data. The accuracy of topographic data requires an evaluation relative to the purposes for which it is used. The 1961 USGS map complies with National Map Accuracy Standards and is adequate for preliminary repository planning. The aerial photographs and associated ground survey control are sufficient to provide the higher detail maps that will be required for construction purposes. The flood prediction and regional geomorphic interpretations are qualitative in part, but are based on prevailing scientific methods. No site specific flood or runoff data are currently available for the Yucca Mountain site.

III. QUALIFYING CONDITION

The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in Section 960.5-1(a)(3) can be met during repository construction, operation, and closure.

Evaluation: The conclusions reached regarding overall site suitability with respect to surface characteristics are largely qualitative, based on the engineering and scientific judgment of numerous professional civil engineers and geologists who have examined the site in the context of the available topographic, geomorphic, and flood potential data.

The eastern alluvial area is well drained but also subject to water overflowing the existing arroyos during extreme storm events (100-year, 500-year, and regional maximum floods). These floods are sufficiently infrequent and of such short duration that they pose no significant problem for repository construction, operation and closure using standard engineering practices. The effects of these extreme events, as well as debris flows in the incised valleys on Yucca Mountain, can readily be mitigated, if not totally avoided.

Conclusion: The surface and underground facilities can be located such that the surface characteristics do not adversely impact either the ease or the cost of construction, operation, or closure of a repository. Multiple locations for surface facilities have been identified on the flat eastern alluvial slopes of Yucca Mountain. These areas are well drained but are subject to infrequent and small floods, the impacts of which can be mitigated easily without major cost impacts. Therefore, the Yucca Mountain site meets the requirements of the qualifying condition.

IV. FAVORABLE CONDITIONS

(1) Generally flat terrain.

Evaluation: Six candidate locations for surface facilities occur on the east side of Yucca Mountain (Jackson et al., 1984a). All these locations are relatively flat and covered with alluvium derived from adjacent highlands. At these locations, the surface slopes less than five percent and in several places is less than three percent. The terrain directly above the proposed underground facility area is rugged with established drainage channels. However, the surface facilities and access routes would be located outside this area.

Access to the proposed repository surface facilities would be provided by rail and highway. Detailed descriptions of the characteristics of these access routes are provided in Section 5.3. A major design consideration is flood protection for a bridge on Fortymile Wash. The volumes of water and debris that move in the Wash during flooding will require measures to protect the integrity of the bridge. The costs of such construction measures are not major, but the bridge and supporting piers must be well designed to resist flood damage.

Conclusion: The surface facilities and access routes to them can be located in relatively flat areas with slopes of less than five percent. Therefore, the Yucca Mountain Site possesses this favorable condition.

(2) Generally well drained terrain.

Evaluation: The topographic map and aerial photographs were used to identify well-developed drainage systems. Effective drainage also occurs due to the porous alluvial soils. The average depth to the water table is 300 to 750 m (1000 to 2500 ft) (see Section 6.3.1.1), and the photograph in Figure 2-2 illustrates the eastward dipping slopes that also contribute to rapid drainage.

Conclusion: Yucca Mountain has a well-established drainage system. The consistency of slope direction coupled with the planar nature of the surfaces, the depth to the water table, and the porous nature of the alluvial soils, suggest that the area will not pond water. The Yucca Mountain Site therefore possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITION

Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.

Evaluation: Each of the six candidate locations for surface facilities is located entirely outside of the main-channel flood zones predicted for the 100-year flood (Squires and Young, 1983). Parts of the six candidate locations occur within an area affected by the 500-year and regional maximum floods predicted by Squires and Young (1983). These areas can be protected by channel lining and by diversionary measures during construction. Neither lining nor diversion is expected to be a major cost.

The washes emerging from Yucca Mountain have generally steep slopes and are capable of moving large volumes of water and debris, including large boulders. For example, the proposed Exploratory Shaft site in Coyote Wash is within 50 m (160 ft) of a small colluvial slump debris-flow deposit. Similar deposits probably are present elsewhere on Yucca Mountain, and concerted measures will be taken to avoid such depositional sites in the choice of potential locations for repository structures and ventilation shafts. Such facilities will not be placed in adverse locations or, alternatively, protective measures will be used. Relocation can be accomplished with minimal, if any, cost impact; likewise, protective measures, such as lining or diversion, are not expected to cause major cost impacts. There are no nearby existing or planned man-made surface-water impoundments that could affect a potential repository at Yucca Mountain. Failure of engineered components of the repository is not likely, because adequate safety factors will be used during design and construction.

The analysis of flooding potential of the Fortymile Wash system is a conservative estimate of conditions that can be expected during extreme meteorological events which are rare (see Section 6.2.1.4). The predictions are based on analysis of similar events in the region. The flood-potential maps are reasonable first estimates that can be used in planning, and the maps are subject to revision based on additional field geomorphic data. As a check on flooding predictions, additional field investigations, including collection of runoff data, are underway. This will include the mapping of areas that were subject to Holocene flooding.

Conclusion: The arroyo drainage system leading away from Yucca Mountain is subject to localized flooding and debris flows during rare extreme storm events. The impacts of this localized flooding can be mitigated during repository construction, operation, and closure. There are no existing or planned surface water impoundments. Therefore, the potential for damage can be mitigated by engineering measures during repository operation, construction, and closure, and the Yucca Mountain site does not possess this potentially adverse condition.

6.3.3.2 Rock characteristics (10 CFR 960-5-2-9)

I. INTRODUCTION

The preclosure Rock Characteristics Guideline is one of four technical guidelines used to collectively address the ease and cost of construction, operation, and closure of a repository. The purpose of the preclosure guideline on rock characteristics is to ensure that due consideration is given to the host rock characteristics that may affect (1) the ease and cost of repository construction, operation, and closure and (2) the safety of workers. Among those characteristics are the thickness and lateral extent of the host rock, geomechanical properties that are favorable for the stability of underground openings, and conditions that allow the construction of shafts and the underground facility with reasonably available technology.

The preclosure Rock Characteristics Guideline consists of one qualifying condition, two favorable conditions, five potentially adverse conditions, and one disqualifying condition. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

The data required to support a discussion of the impacts of rock characteristics on ease and cost of construction, operation, and closure of a repository are drawn from numerous sources. Defense related activities at the Nevada Test Site and ongoing investigations as a part of the Nevada Nuclear Waste Storage Investigations Project provide a large data base to support the present investigations. An understanding of the regional geology and stratigraphy is based, in part, on maps compiled by Christiansen and Lipman (1965) and Lipman and McKay (1965). Detailed site-specific geologic information was drawn from Orkild (1965), Byers et al. (1976), and Sinnock (1982). These data were supplemented by information obtained from preliminary exploratory drill holes reported by Spengler et al. (1979), Spengler and Rosenbaum (1980), and Spengler et al. (1981).

Surface geologic mapping and core samples from drill holes enabled the identification of four potential horizons for the location of underground facilities. Samples of these units, obtained from both core and surface outcrops, were analyzed for physical, mechanical, and thermal properties. These measurements were reported by Blacic et al. (1982), Olsson (1982), Olsson and Jones (1980), Price and Jones (1982), Price et al. (1982a), and Price et al. (1982b).

The relative suitability of the four potential horizons was compared on the basis of mineability, excavation stability, maximum gross thermal loading, far-field thermomechanical effects, and potential ground-water travel times (Johnstone et al., 1984). All four horizons were suitable for repository location. The horizon in the Topopah Spring Member of the Paintbrush tuff, located entirely above the water table beneath Yucca Mountain, was the most desirable and is being used for the repository conceptual design.

Thermomechanical analyses of the Topopah Spring Member were performed to establish the degree of ground support required, and the influence of waste emplacement configuration on excavation stability, drift temperatures, and ventilation requirements (Brasier et al., 1983).

Potential geologic and hydrologic concerns were identified and evaluated by means of detailed mapping at the proposed repository location (Scott and Bonk, 1984). Existing faults and fracture patterns were investigated (Daniels and Scott, 1981; Flanigan, 1981; Smith and Ross, 1982; Winograd and Thordarson, 1975; Spengler et al., 1979 and 1981; and Carr, 1974). Others have investigated regional structure conditions (Barnes and Poole, 1968; Carr, 1974; and Sinnock, 1982), as well as regional and site tectonics (Christiansen et al., 1965; Noble, 1972; Ekren et al., 1968; and Carr, 1974). The seismicity of the area was also considered (Willis et al., 1974; Rogers et al., 1977).

Water-related concerns were also investigated. The hydrogeologic properties of the proposed repository location were studied (Eakin, 1962, 1963 and 1966; Malmberg and Eakin, 1962; Walker and Eakin, 1963; Malmberg, 1967; Rush, 1970; Thordarson and Robinson, 1971; Winograd and Thordarson, 1975; and

Miller, 1977). Previous studies of recharge and drainage were also considered (Claassen and White, 1979; Claassen, 1983; Winograd and Thordarson, 1975; and Rush, 1970).

Assumptions and Data Uncertainties: The analyses of the suitability of site rock characteristics are based primarily on surface reconnaissance and borehole data. No major excavations have been made at the proposed site, and there is no experience with excavation of the proposed horizon elsewhere in the area. However, extensive tunnel systems have been excavated in bedded tuffs at Rainier Mesa on the Nevada Test Site. As part of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project, in situ experiments have been initiated in one tunnel (G-Tunnel) in a welded tuff unit with characteristics similar to those expected in the repository horizon. Repository design analyses are proceeding using the existing data base. Future construction of the exploratory shaft and related boreholes will significantly expand the existing data base. This may lead to some changes in repository design, but they are expected to be within the limits expressed in the current conceptual repository design (Jackson, 1984a). The degree of confidence in both the existing data for the proposed repository site and the analyses made using the data is considered more than sufficient for a preliminary assessment of the qualification of the proposed site.

III. QUALIFYING CONDITION

The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) the repository construction, operation and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) will be met.

Evaluation: The lateral extent of the proposed repository horizon is such that the area required for repository layout is available. Current information indicates that additional area exists that could be usable. The thickness of the Topopah Spring Member is such that multiple options exist for the depth and attitude of the proposed repository horizon. The eventual repository layout can accommodate areas where geomechanical conditions or structural features prove to be hazardous, or could lead to excessive costs for repository construction, operation, or closure.

Previous experience and presently available data [see Favorable Condition (2)] suggest that artificial support requirements for the proposed excavation will be minimal and will enable work to be performed without undue hazard to personnel, and at reasonable cost throughout the entire repository cycle, including retrieval, should retrieval become necessary. There is no present evidence to suggest that the geomechanical properties of the Topopah Spring Member, in response to waste-induced heat, will change in any way that would lead to hazardous conditions in the repository that could impact worker safety or preclude retrievability.

Conclusion: The thickness and lateral extent of the host rock at the proposed repository horizon provide adequate, but not unlimited flexibility for the areal layout, and reasonable flexibility for the vertical positioning of the proposed repository. Furthermore, information obtained to date suggests that lateral flexibility could be demonstrated during site characterization. Preliminary exploration activities have not identified any rock characteristics or aspects of behavior (such as roof falls) that would cause undue hazards to personnel. Repository construction, operation, and closure can be carried out with reasonably available technology. Because development costs for this and other sites are not presently available, a direct cost comparison cannot be made. There are, however, no indications that any aspect of construction, operation, or closure at the potential Yucca Mountain site would incur costs in excess of that for a comparable facility in other rock types. Therefore, the Yucca Mountain site meets the qualifying condition for the preclosure rock characteristics technical guideline.

IV. FAVORABLE CONDITIONS

(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility.

Evaluation: Flexibility in locating the repository is needed so that there will be sufficient options available to construct the underground facility away from areas of geologic anomalies, should they be found. No anomalies are known, or expected, that could have significant adverse affects on waste isolation or mine stability. Flexibility related to waste emplacement in horizons other than the Topopah Spring Member was discussed in Section 6.3.1.3 (Postclosure Rock Characteristics). This section only examines emplacement in the densely welded Topopah Spring Member that contains less than 15 to 20 percent lithophysae.

Available site data indicate that acceptable rock characteristics are present within area 1, and could be present in areas 2, 3, and 4 (Figure 6.3.3.2-1) and perhaps even outside these areas (Mansure and Ortiz, 1984; Sinnock and Fernandez, 1982). Area 1 is the primary target for locating the underground facility. Therefore, the surface and subsurface geologic exploration of Yucca Mountain has concentrated on area 1 (the central block) and the immediately surrounding area (Lipman and McKay, 1965; Scott and Bonk. 1984).

Analysis of a three-dimensional computer graphics model of Yucca Mountain (Nimick and Williams, 1984) indicates that approximately 800 ha (1980 acres) of the total 2100 acres of area 1 is usable. Acreage required for a repository based on present waste inventories and repository design concepts is approximately 615 ha (1520 acres) (Mansure and Ortiz, 1984). Area 2 contains over 550 ha (1350 acres) and is similar to area 1 in fault density. Data in area 2 are limited to surface mapping and extrapolation of drill hole data obtained mainly in and around area 1. Only minimal, additional geologic characterization should be required to determine how much of this area is usable. Area 3 contains over 400 ha (1000 acres) and is also likely to meet waste isolation performance criteria, but possible complexity of the fault structure in this area may increase uncertainty in performance predictions. In addition, small portions of this area could violate the disqualifying condition requiring 200 m (650 ft) of overburden. Part of area 3 could, however, be used as a future extension of area 1, depending upon data obtained during actual mining near the southeastern edge of area 1. Area 4 contains

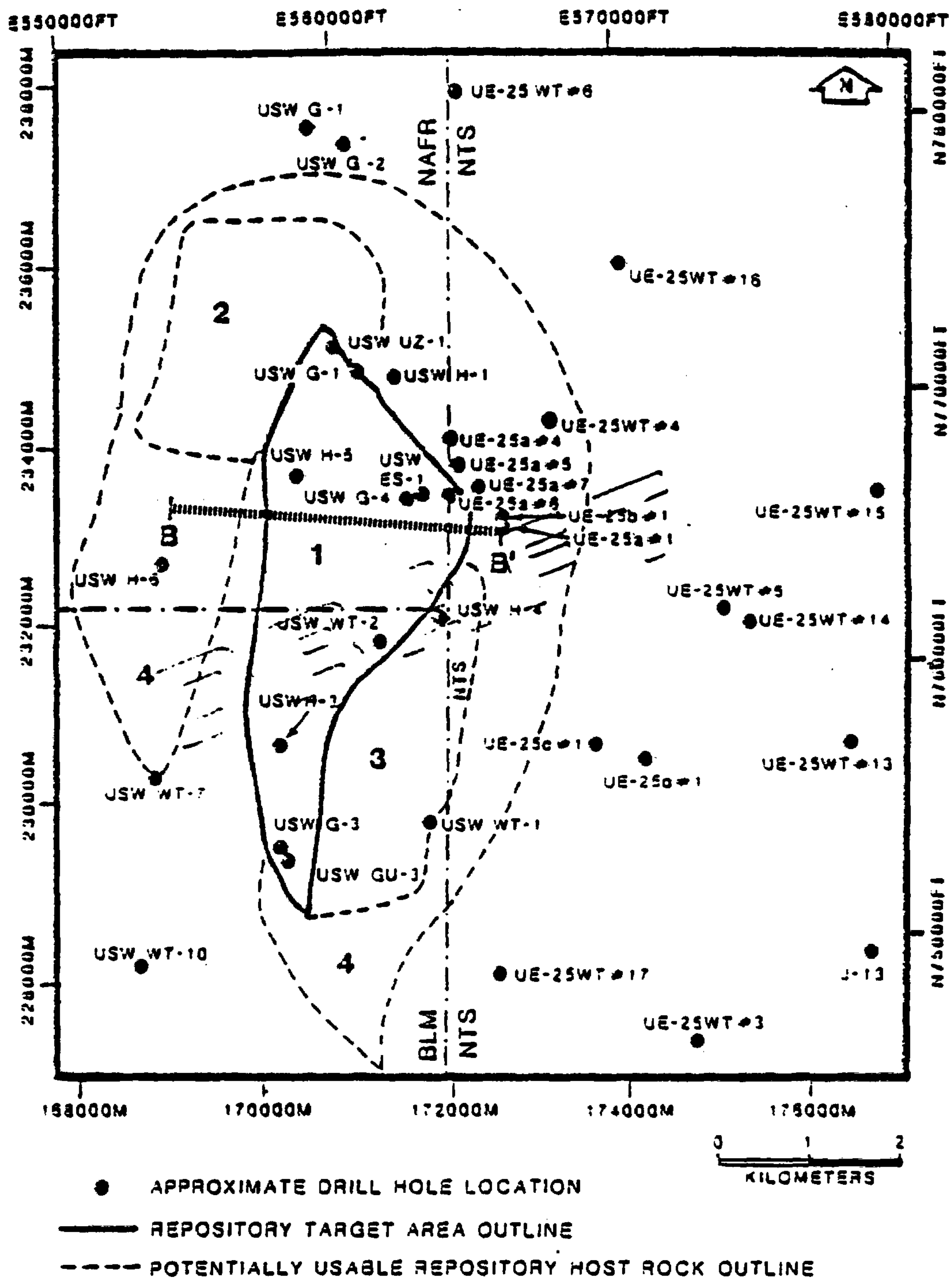

Figure 6.3.3.2-1. Areas 1, 2, 3, and 4 generally correspond to portions of structural blocks near Yucca Mountain. Area 1 is the primary target area for the repository. See Figure 6.3.3.2-2 for cross section B-B'.

approximately 2000 ha (5000 acres) and also may have rock characteristics similar to the other areas, but less data exists for this area, and it is farther from the primary target. Portions of area 4 could also violate the disqualifying condition for 200 m (650-ft) of overburden. Areas 1, 2, 3, and 4 contain over 3800 ha (9500 acres) or about six times the area needed to dispose of 70,000 MTU of waste (Mansure and Ortiz, 1984). However, as noted, not all of the 3800 ha (9500 acres) are considered usable at this time.

Faults in some parts of Yucca Mountain, particularly at the boundaries of structural blocks, have enough offset that they must be considered when selecting the emplacement location. Figure 6.3.3.2-2 shows a cross section of area 1 and the possible location of the underground facility. The figure also indicates that the dip of the beds should be considered in determining the placement of the underground facility. The target emplacement unit is at the base of the unit marked Tpt on Figure 6.3.3.2-2. The basis for choosing this unit and other possible emplacement units are discussed in Section 6.3.1.3 (Postclosure Rock Characteristics). Figure 6.3.3.2-2 indicates that an important feature of area 1 is the relative absence of major faults. The faults that are present are not expected to have enough offset to cause a problem in laying out the repository.

Basic requirements of the geologic section of the site are that there be sufficient overburden and sufficient thickness of suitable host rock for the repository envelope. The thickness of the overburden at Yucca Mountain is discussed in Section 6.3.1.5 (Erosion) and is more than 300 m (7980 ft) over much of area 1. For evaluating the adequacy of the thickness of the host rock for the underground facilities, the repository envelope has been assumed to require 45 m (148 ft) of host rock (Mansure and Ortiz, 1984). In area 1, the relatively lithophysae-free, densely welded Topopah Spring Member averages about four times this thickness, and is more than adequate to provide flexibility in locating a repository.

To date, a value of 15 to 20 percent has been used to differentiate between the lower relatively lithophysae-free section of the Topopah Spring Member and the upper section where lithophysae are more abundant. At low

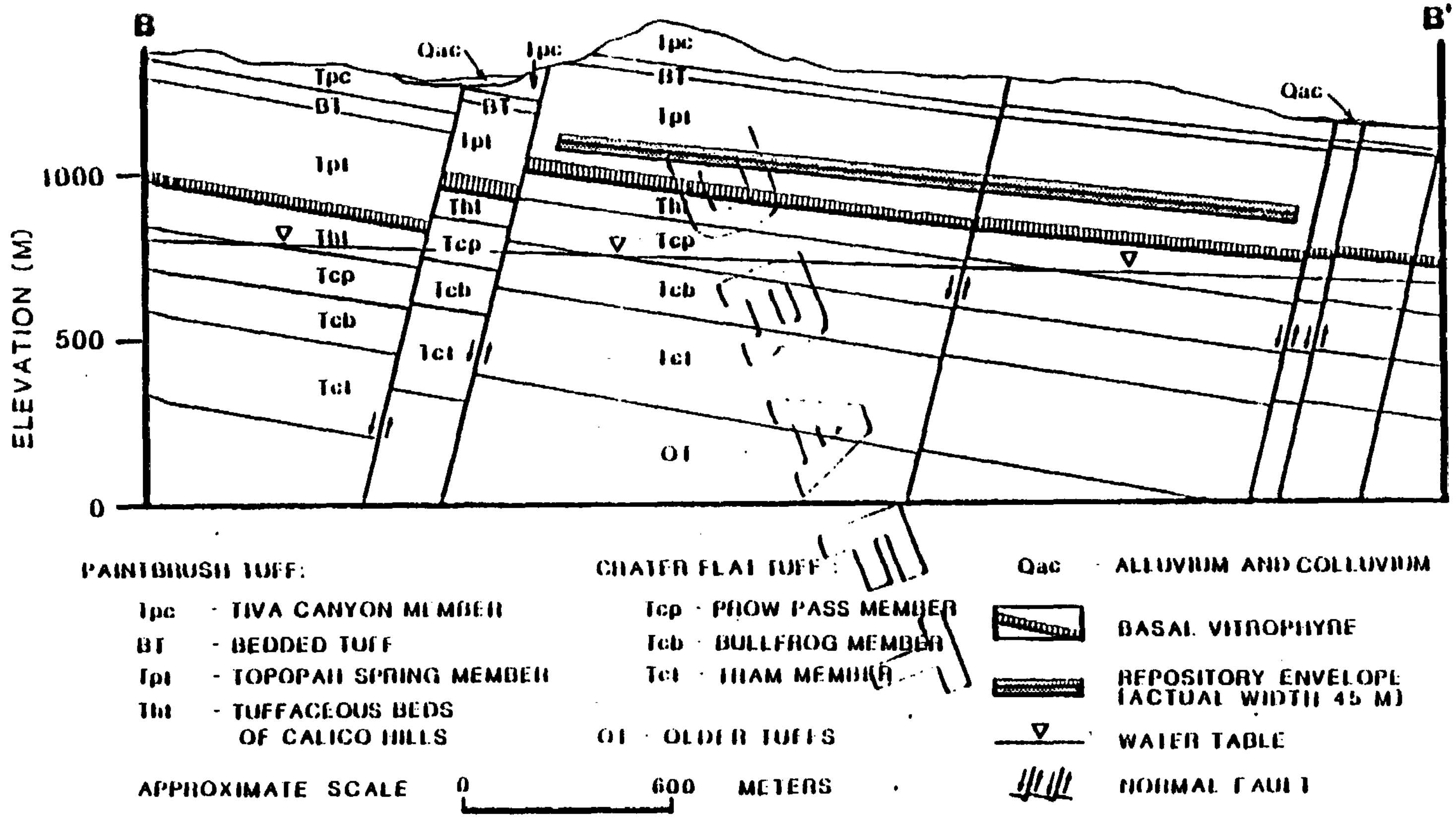

Figure 6.3.3.2-2. Cross section of area 1 showing possible location of underground repository envelope.

percentages, lithophysae have little effect. For high percentages (probably near 30 percent), lithophysae could change the thermomechanical properties of the rock to the point that mineability and ground support requirements are affected. The percentage at which the lithophysae become a concern will be determined during site characterization. For planning purposes, the underground facility has been placed in the lower portion of the Topopah Spring Member, which is expected to have sections less than 15 to 20 percent lithophysae (Mansure and Ortiz, 1984). This does not imply that the underground facility must be in host rock that has less than 15 to 20 percent lithophysae, but only that host rock with lower lithophysae content may be preferable.

A preliminary underground facility plane has been located in area 1 (Mansure and Ortiz, 1984) using the three-dimensional model of Yucca Mountain (Nimick and Williams, 1984). Dip and thickness of the host rock, lithophysae content, and overburden requirements were considered in locating the plane. The position of this preliminary plane, which may change during site characterization, demonstrates that a single plane is available that satisfies all design criteria. The dip of the plane (5°E and 1°N) will not result in grades too steep to be negotiated by waste-handling equipment; therefore, multiple levels will not be required. Although the dip of the preliminary plane is not excessive, data gathered during site characterization will be used to determine whether the underground facility can be positioned more nearly horizontal.

Conclusion: The potential host rock is sufficiently thick to provide significant vertical flexibility in the placement of the repository. The central block, which has to date been the focus of exploration, provides limited lateral flexibility in the placement of the repository. Based on extrapolation of data from the central block, contiguous areas appear suitable for repository placement, but additional exploration will be necessary to claim significant lateral flexibility. At present, considering only the central block, the favorable condition can be claimed only for vertical flexibility in placement, but not for lateral flexibility in placement. Therefore, the Yucca Mountain site does not possess this favorable condition.

(2) <u>A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure</u>.

<u>Evaluation</u>: Estimation of the requirements for artificial supports for subsurface excavations requires much engineering judgment and the use, where possible, of experience gained from excavating rock types with similar characteristics. The preliminary design process uses this data and supplements it with calculations that simulate the expected rock behavior. The analyses and judgments used to support the conclusions of this section were developed from available core property data, extrapolations based upon rock mass classification schemes, finite element analyses of the mined openings, and mineability assessments.

Rock mass classification techniques use compilations of existing underground support practice, categorized according to parameters recognized as important, to determine the required support for underground openings. These techniques are extremely useful in the preliminary design or feasibility stages of a project because they enable designers to make rational and generally conservative judgments about conditions expected. The Topopah Spring Member has been categorized into a range of rock mass quality values based upon available core data. Two compatible, widely used classification techniques were applied (Dravo, 1984a): (1) the Council for Scientific and Industrial Research (CSIR) Classification System (Bieniawski, 1976) and (2) the Norges Geotekniske Institute (NGI) Classification System (Barton et al., 1974).

The rock mass classifications derived from these two systems, cover a range of values. Based on a 6-m (20-ft) span and the given classification values, ground-support requirements can be estimated (Dravo, 1984a) for the full range of rock classifications. The expected support requirements include: (1) 2.5- to 3-m long (8- to 10-ft) fully grouted rock bolts on a 1.5-m (5-ft) grid spacing with chainlink fence for safety; (2) possibly shorter supplemental bolts added on a staggered grid spacing; and (3) 5 to 7 cm (2 to 3 in.) of shotcrete applied to rock surfaces. These anticipated support requirements are the same or more than the support systems presently used on the Nevada Test Site, which are found to provide long-term excavation stability and worker safety. Experience at the Nevada Test Site in excavating weapons test tunnels has shown that the rock conditions encountered in the various tuff members, both welded and nonwelded, do not generally require other than rock bolting with wire mesh for added safety, which is considered to be minimal ground support. In particular, the welded tuff in G-Tunnel and the Topopah Spring Member fall into the same range on the rock mass classification scale. In the G-Tunnel operations, rock bolts with wire mesh have been used successfully as ground support for many years.

The estimated ground-support requirements for ranges of expected conditions are minimal compared with the types of ground-support systems often used in the mining industry. Steel sets, timbers, or reinforced concrete are not expected to be required at Yucca Mountain except in special areas, such as access ramps, shaft openings, and fault zones. The system of using rock bolts, wire mesh and, in some instances, shotcrete sprayed on walls provides the advantage of being easily maintained over an extended time, further ensuring the stability of the mine openings through the closure phase.

Variations in room sizes directly affect the stresses around openings. However, the largest room (required for horizontal emplacement) can be stabilized by rock bolt systems using increased bolt length and density (St. John, 1984). Heat-related stresses caused by waste emplacement are currently viewed as a negative factor in the horizontal emplacement system. These stresses are predicted using numerical analysis techniques. The analyses completed to date indicate that the stresses and displacements that result from the thermal effects of waste emplacement do not lead to significant stability problems in the drifts (Johnstone et al., 1984). A conservative design approach might, however, include an additional row of rock bolts along the drift walls to offset the anticipated lateral thermal expansion of the rock mass.

Conclusion: Excavation experience at the Nevada Test Site and numerical analyses of the stability of repository sized openings suggest that repository development within the Topopah Spring Member at Yucca Mountain will require minimal artificial ground support to ensure safe construction, operation, and closure. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) A host rock that is suitable for repository construction, operation, and closure, but is so thin and laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.

Evaluation: An extensive description of the thickness and lateral extent of the host rock suitable for emplacement of a repository has been given in Favorable Condition (1) of this section and in Favorable Condition (1) of Section 6.3.1.3 (Postclosure Rock Characteristics). Briefly, these discussions noted that most exploration has been limited to the central block at Yucca Mountain (area 1 in Figure 6.3.3.2-1). The analyses (Mansure and Ortiz, 1984) indicate that in area 1, the thickness of the potential host rock averages more than four times the 45 m (148 ft) used as a conservative estimate of the envelope surrounding the underground facility. Such a thickness is judged to provide significant flexibility in selecting the depth and configuration of the repository.

The analyses further indicate that the central block has a usable area of approximately 800 ha (1980 acres). Based on present waste inventories and repository design concepts (Mansure and Ortiz, 1984), approximately 615 ha (1520 acres) are required for a repository. Comparison of these areas shows that the central block contains more usable area than required for a repository, but flexibility in lateral placement of the repository could be shown to be limited during site characterization. Analysis of existing site data and extrapolation of the central block data provides confidence that several contiguous areas (areas 2, 3, and 4 in Figure 6.3.3.2-1) could also contain suitable host rock. Including these areas could increase the usable area by as much as 3000 ha (7350 acres), thereby providing significant flexibility in lateral repository placement. The suitability of these additional areas can only be confirmed by further site characterization. Consequently, more than adequate area exists to configure the repository, and present information indicates some flexibility. There is no information to indicate that lateral flexibility is restricted.

Conclusion: The host rock of Yucca Mountain is sufficiently thick that there is significant flexibility available for selecting the depth and configuration of the underground facility. The central block, which has to date been the focus of exploration, provides some flexibility in the lateral placement of repository. Evaluation of existing data provides confidence that further site characterization could expand the usable area, thereby allowing significant flexibility in lateral placement of the repository. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.

Evaluation: Detailed ground stability studies (St. John, 1984; Hustrulid, 1983) show that the known in situ characteristics of the Topopah Spring Member of the Paintbrush Tuff present no features that cannot be successfully controlled by existing, proven mining methods. The rock characteristics, as well as the design layout and development plan, are such that the underground facility can be developed by conventional mining methods (Dravo, 1984 a, b). The viability of conventional mining techniques in tuff has been demonstrated during the construction of G-Tunnel in Rainier Mesa at the NTS. From the limited work done so far, it appears that a mechanical mining technique may be a viable alternative for repository construction in the Topopah Spring Member.

As stated by Dravo (1984 a, b), the repository access drifts and underground openings can be adequately supported by conventional rock bolts and wire mesh. The rockbolt and wire mesh support is minimal by mining industry standards. Steel, concrete, or both would be used for support only if underground observations make it necessary as in the case of fault zone intersection or possibly at drift intersections. The proposed ground support is within standard established technology (Lucas and Adler, 1973). Shafts would be constructed by standard excavation techniques and lined with concrete (Hustrulid, 1984; Dravo, 1984a).

Most of the repository will be located at more than 200 m (660 ft) above the area water table (Figure 6.3.3.2-3). Experience in tunnels on the Nevada Test Site indicates that if perched water is encountered, then the flow will probably be small and should diminish rapidly. The drill holes that have been placed in and near the proposed repository site have not identified perched water at elevations above the base of the Topopah Spring Member.

<u>Conclusion</u>: There are no indications that the in situ conditions and characteristics would lead to a situation that could not be handled by existing, established engineering and technology measures. The shafts and underground facility can be constructed by using proved, standard methods. Therefore, Yucca Mountain does not possess this potentially adverse condition.

(3) <u>Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure</u>.

<u>Evaluation</u>: The Topopah Spring Member is 250 to 300 m (see Figure 6.3.1.5-1) below the ground surface. At this depth it will not be affected by weathering, surface water, or atmospheric conditions. A rectangular underground opening with an arch-shaped roof will provide a stable opening in the Topopah Spring Member (St. John, 1984). Localized, minor spalling may occur near corners and on walls due to stress relief and the intersection of joints. The spalling can be controlled by using rock bolts and wire mesh (St. John, 1984; Dravo, 1984a). The proposed repository area is relatively free of major faulting. As shown in Figure 6.3.1.3-2, most major

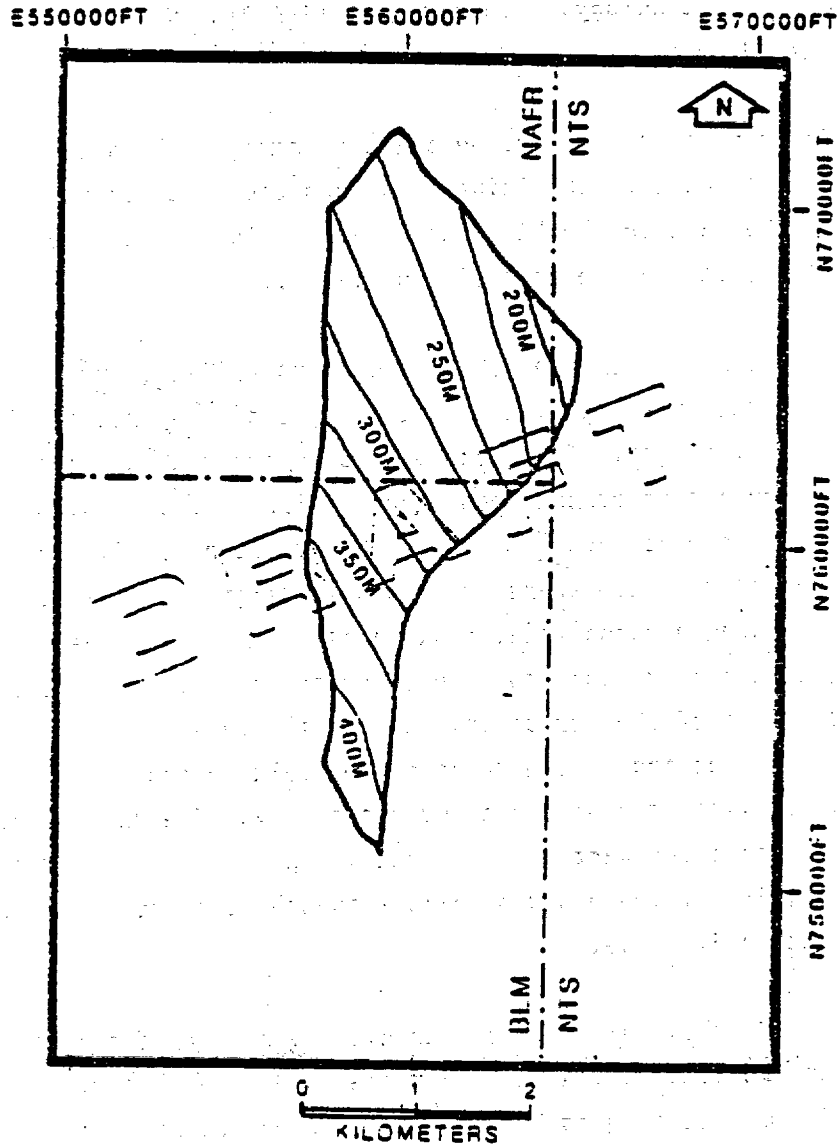

Figure 6.3.3.2-3. Contour map showing depth from the bottom of the repository envelope to the water table.

faults occur outside the anticipated repository boundaries. Based on the very limited data currently available (Dravo, 1984a) it appears that the faults and fault zones at the Yucca Mountain site could be traversed using standard mining and support technology. However, considerable additional site characterization is required to confirm this conclusion.

The repository access, by shaft or ramp, will involve the penetration of the upper members of the Paintbrush Formation (St. John, 1984; Hustrulid, 1984). The CSIR or the NGI Tunnel Quality Index indicate that conventional support systems can be used (Dravo, 1984a).

As shown by St. John (1983) and Dravo (1984a), the in situ stresses are of such magnitude that excavation stability can be maintained by conventional rock bolts and wire mesh. This type of ground support requires limited maintenance and the dry nature of the repository will reduce corrosion problems with the rock bolts or wire mesh. As stated by St. John (1983), the use of an arched roof opening reduces stress and lends stability to the rock mass, further reducing ground support maintenance requirements. Thus, stable conditions should continue through the time of repository closure. Because of the extended life of the repository, there will be some required maintenance of underground openings. The maintenance would be routine, and well within the limits of existing procedures and technology. The thermal stresses resulting from heating after waste emplacement are not expected to significantly impact the stability of the mined opening although some local deformation might occur (see Section 6.3.1.3).

Conclusion: The geomechanical behavior of the rocks at Yucca Mountain provides an inherently stable condition that will not require extensive maintenance to keep the underground openings in serviceable condition for the expected repository life. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(4) Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.

Evaluation: The Topopah Spring Member (the repository host rock in Yucca Mountain) is a highly fractured (Spengler et al., 1981, Scott et al., 1983) unsaturated rock. Johnstone et al. (1984) compared the suitability of the Topopah Spring Member with three other potentially suitable units at Yucca Mountain. They evaluated the stability of underground openings as a result of excavation and thermal effects. The opening stability studies included near field mechanical and thermomechanical finite element code calculations, rock matrix property evaluation, and rock mass classification (Barton et al., 1974; Bieniawski, 1976). These studies considered physical, thermal, and mechanical properties specific to the Topopah Spring Member, the existence of fractures and an estimate of in situ stress. The results also were compared with the behavior of existing underground openings in tuff at the Nevada Test Site. These studies indicate that (a) for periods extending from construction through closure, the mined openings should be expected to remain stable and (b) the impact of thermally induced fracturing is very localized around waste emplacement holes and the periphery of the drifts.

Calculations predict potential rock matrix fracturing in the immediate vicinity of the waste emplacement borehole wall that extends no more than 10 cm (4 in.) into the rock. However, no structural degradation has been observed in two small-diameter heater tests conducted in tuff at G-Tunnel (Zimmerman, 1983). The effect on retrievability of localized sloughing of the borehole walls could be minimized in the repository by incorporating a liner (e.g., steel pipe) in the waste emplacement borehole.

No minerals are present in significant quantities in the repository horizon that are susceptible to thermally induced dehydration or hydration. Bish et al. (1984) summarized the distribution of minerals in the tuffs at Yucca Mountain and stated that greater than 98 percent of the proposed repository host rock is made up of alkali feldspar, cristobalite, and quartz, which are not subject to thermally induced dehydration or hydration. Only minor amounts of smectite and trace amounts of zeolite are present in the repository horizon in the Topopah Spring Member (Bish et al., 1984). Thus, there is little potential for hydration or dehydration of minerals that could affect the safety of repository operation. The transition from alpha to beta cristobalite, occurring at 223 ± 27°C (433 ± 81°F) in confined tests (Lappin, 1982; Daniels et al., 1984), gives rise to a slightly increased thermal expansion. Because of the high transformation temperature, the potential for this transformation to occur is limited to the very near field of the waste package. The thermomechanical studies use thermal expansion coefficients that account for this behavior and predict no additional rock fracture beyond the 10 cm (4 in.) reported earlier.

The only other significant physical or chemical phenomena known to be associated with rock characteristics are related to ventilation system design and worker safety. Temperature increases resulting from the emplaced waste are important in designing ventilation systems and in selecting the standoff distance between the drift and the emplaced waste. Based on excavations at the Nevada Test Site, explosive or other hazardous gases are not anticipated. The ventilation system primarily controls dust. Hazards associated with the dust will be mitigated by supplying adequate flow volumes and filters to meet safety requirements. Similarly, low-level radiation concerns from naturally occuring radon released during rock excavation will be used in establishing ventilation requirements. Techniques already implemented in the uranium mining industry will be considered. Proper design and operation of a ventilation system using current technology should readily mitigate dust and radiation concerns.

Conclusion: The welded tuff host rock at Yucca Mountain is a physically and chemically stable rock that will be little affected by repository conditions. More than 98 percent of the rock is composed of feldspar, cristobalite, and quartz, all of which are nonhydrous minerals. Presently, the rock is fractured and any additional thermally induced fracturing will be minor and will not create a safety hazard or produce difficulty in retrieval operations. Therefore, Yucca Mountain site does not possess this potentially adverse condition.

(5) Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.

Evaluation: The evaluation of this condition is based on currently available geologic and hydrologic data, rock mass classification, ground support estimates, conceptual construction methods, and mined opening analysis using finite-element modeling. The hydrogeology of the region and site vicinity is described in Section 6.3.1.1. Data on water levels in drill holes within and near the site are measured regularly as shown on Figure 6.3.1.1.-1. No perched water has been observed in existing drill holes, and no pressurized water zones have been observed. Only very minor gravity drainage is expected to occur into excavated drifts.

The host rock and rock units above and below the Topopah Spring Member are ash-flow tuffs consisting of 70 percent to 77 percent SiO_2 and phenocrysts of rock forming minerals (Bish et al., 1984; Lipman et al., 1965). The rocks are essentially insoluble and only very small quantities of water exist in the Topopah Spring Member; hence, it is concluded that dissolution effects are insignificant (see Section 6.3.1.6, Dissolution).

The existence of faults and associated shear zones at Yucca Mountain is of concern in the selection of a mining method. The current repository area is in a geologic block which is thought to be free of major faults, and is outlined by bounding fault zones on all sides. This central block has been determined to be mineable using available standard equipment (Dravo, 1984c). The central block can be mined using minimal ground support [see Favorable Condition (2)]. Similar rock has been excavated at the G-tunnel complex using comparable methods of excavation and ground control.

Faults and fault zones, in themselves, do not present insurmountable barriers to mine construction even though it is desirable to avoid them. Dravo (1984b) has evaluated the potential difficulties of mining through the faults and fault zones that bound the central block at Yucca Mountain to determine if expansion of the repository into the contiguous blocks would be possible [see Favorable Condition (1)]. Based on limited data, it appears that the central block boundaries could be traversed using standard mining and support technology. However, considerable additional site characterization is required to confirm this analysis. Fault zones found within the central block can be traversed by drifts using no unusual or unsafe construction practices

(Dravo, 1984a). Increased ground support could be provided in these areas to further reduce any potential safety hazard to repository personnel.

Conclusion: Repository layout, design, and construction will be performed to avoid or minimize contact with portions of the potential host rock where faults and shear zones are identified. There is no indication that pressurized brine pockets, significant accumulations of water, or toxic gases are present within the proposed site. Hence, no other conditions are anticipated that could compromise the safety of repository personnel. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

V. DISQUALIFYING CONDITION

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 reasonably available technology.

Evaluation: The primary emphasis of this disqualifing condition 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 evaluation relies on defining the applicable technical data, and analyses of the anticipated stability of mined openings in the tuff of the Topopah Spring Member.

At present, the data base 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 (Price, 1983; Price et al., 1982; Lappin, 1980a, 1980b; Lappin et al., 1982). 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 decisions related to safe construction and operation of a repository at Yucca Mountain.

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 of up to 3.5 (Healy et al., 1983) with a mean for 12 measurements of 2.1 and a standard deviation of 0.6. This compares with 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 (Tyler and Vollendorf, 1975; Warpinski et al., 1978; Ellis and Ege, 1975; Hooker et al., 1971). G-Tunnel is generally 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 problems in opening stability, even when combined with severe ground accelerations from nearby nuclear tests.

The selection of the Topopah Spring Member as the potential repository host rock was based largely 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 value for thermal and mechanical properties in the Topopah Spring are given in Table 6.3.3.2-1. Johnstone et al., (1984), evaluated opening stability using:

1. Nonlinear, finite element thermomechanical stress analyses.
2. Rock mass classification systems.
3. Linear calculations for mine design and pillar sizing.

These analyses indicate that existing mining technology can be used to develop stable underground openings that will allow repository operations to be safely carried out from construction through decommissioning. Experience gained in

Table 6.3.3.2-1. Average thermal and mechanical properties of the Topopah Spring Member (Tillerson and Nimick, 1984)

Property	Value
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 (to 200°C)
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
Confined 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 of initiation of sliding on joints	0.8

G-Tunnel on the Nevada Test Site supports this conclusion and further indicates that it should be expected that openings can be stabilized using roof bolts and wire mesh. Mineability assessments (Tillerson and Nimick, 1984), also supported by G-Tunnel experience, indicate that controlled blasting can be successfully used to excavate the openings in the densely welded tuff.

Conclusion: Based upon applicable laboratory data and field experience with similar excavation plus thermomechanical stress calculations, activities associated with construction, operation, or closure of a repository at the Yucca Mountain site are not projected to cause significant risk to the health and safety of personnel. Therefore, Yucca Mountain is not disqualified on the basis of the rock characteristics disqualifying condition.

VII. PLANS FOR SITE CHARACTERIZATION

Site characterization activities will supplement the existing data base, both through exploratory borings and access to the proposed host rock and additional laboratory tests. Construction phase tests will provide in situ stress data and shaft convergence data that will be used for design and layout of underground facilities. Large-scale tests performed in the potential repository host rock during the in situ phase of Exploratory Shaft testing will supplement the data base by providing information on the in situ rock conditions as well as effects, such as fracturing caused by stress and temperature. A Canister Scale Heater Test is planned to confirm the behavior of the host rock in the very near field where the highest temperatures and stresses will be induced.

6.3.3.3 Hydrology (10 CFR 960.5-2-10)

I. INTRODUCTION

This preclosure Hydrology Technical Guideline is concerned with surface and subsurface water that could affect repository surface and underground facilities during construction, operation, and closure. Surface waters have the potential for flooding of the underground facilities, including access ramps and shafts, and could affect the ease and cost of construction of the surface facilities, including transportation access routes.

Water will be required for construction, operation, and closure of the proposed repository, including surface and underground facilities. The subsurface hydrologic conditions will have a bearing on cost and safety of construction, operation, and closure of the repository. Subsurface water must not compromise the intended functions of the shaft liners and seals. This guideline relies on technical information similar to that supporting the Geohydrology Technical Guideline (see Section 6.3.1.1); as noted, the application is for different technical reasons.

The Hydrology Technical Guideline consists of one qualifying condition, three favorable conditions, and one potentially adverse condition. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

Water-table elevations at wells near the repository range from about 730 m (2400 ft) along the eastern edge to about 780 m (2600 ft) near the northwestern edge, near the ridgecrest of Yucca Mountain (Robison, 1984). Hydrologic test holes near Yucca Mountain have been tested at yields ranging from about 6×10^{-4} to 4×10^{-2} m^3/s (10 to 600 gpm) (Waddell et al., 1984). Well J-13 has produced more than 0.04 m^3/s (600 gpm) periodically since 1962 (Young, 1972).

<u>Assumptions and Uncertainties</u>: The altitude and configuration of the water table in the Yucca Mountain area are known relatively well because numerous boreholes penetrate the water table, and water levels have been measured precisely (Robison, 1984). Few moisture content values or other hydraulic properties have been measured in the unsaturated zone, the characteristics of which are therefore less certain. Estimates on projected water use in the surrounding region are subject to vagaries associated with human activities; for this reason conservative values have been considered. The effects of increased ground-water withdrawal in the proposed area on regional ground-water supplies have some uncertainty but are considered negligible.

Uncertainty regarding flooding potential is discussed in Section 6.3.3.1 (Surface Characteristics). The analysis regarding surface-water systems [Favorable Condition (2)] is covered in Section 6.3.3.1, Surface Characteristics.

Estimates of water use during repository construction, operation, and closure are conservatively high and are comparable to other estimates used in repository conceptual design efforts that have been made over the past five or more years (KE/PB p 8-66, 1981). Even if the estimates were doubled the impact on available water at Yucca Mountain would be negligible.

Some uncertainty exists about the moisture environment in the unsaturated zone, which could affect sealing concepts. Also, uncertainty exists regarding the possibility of perched water under Yucca Mountain. However, the sealing-concepts study (Fernandez and Freshley, 1984) used a conservative approach and the results would differ little because the moisture environment was considered in the study.

III. QUALIFYING CONDITION

<u>The site shall be located such that the geohydrologic setting of the site will (1) be compatible with those activities required for repository construction, operation, and closure; (2) not compromise the intended functions</u>

Competing requirements for ground-water use have been considered. Surface water has not been considered for repository or domestic use because it is not generally available in this arid region. Well J-13 and the proposed locations of repository surface facilities are on the Nevada Test Site. Should the Federal government develop a repository at Yucca Mountain, a permanent land withdrawal will be necessary, in accordance with the Federal Land Policy and Management Act of 1976 and an Act of Congress. Reservation of water rights is explicit in the withdrawal (see Section 6.2.1.3). The Office of the State Engineer, Nevada, prepared a series of water planning reports (Office of the State Engineer, 1971-1974), and the second report of the series includes estimates of water withdrawals and consumption by counties and hydrographic regions. These estimates provided a basis for projecting future water requirements in Nevada. Water requirements for construction, operation, and decommissioning of the repository have been estimated based on preliminary repository conceptual designs. For a 45-year period of repository activity an average of 400 acre-ft/year of water will be used (McBrien and Jones, 1983).

Squires and Young (1983) have made predictions for 100-yr, 500-yr, and regional maximum floods; these predictions, described in Section 6.3.3.1 (Surface Characteristics), have been used in determinations of flooding potential for surface and underground facilities.

Several studies have been made to determine the impacts of the unsaturated zone environment on shaft liners and seals. Sealing concepts were developed using data and samples obtained from boreholes. Preliminary calculations were based on conceptual understanding of the hydrogeology and supplemented by information from comparable tuff sequences at Rainier Mesa. Fernandez and Freshley (1984) concluded that from a hydrologic point of view, the sealing of repository drifts is unnecessary. Should sealing be required, relatively simple and straightforward solutions are proposed. These include filling drifts and ramps with coarse-grained material, using drains where water seeps are encountered, and using grout if more massive flow occurs. Well USW G-4 (principal borehole for an exploratory shaft) penetrates the proposed repository horizon. Zeolite fill, slurry, or grout seals are proposed for use in this well and in nearby boreholes that penetrate beds of the repository horizon or the underlying tuffaceous beds of Calico Hills.

of the shaft liners and seals; and (3) permit the requirements specified in Section 960.5-1(a)(3) to be met.

Evaluation: Conditions suggest that an essentially ideal hydrologic situation exists at Yucca Mountain: the potential host rock is above the water table and there are no aquifers between it and the land surface; nearby wells will provide adequate water for construction, operation, and closure; and no engineering measures beyond those presently available will be required by ground-water conditions. Flash floods are possible since the proposed site is located in a 500-year floodplain, but existing technology and engineering measures can be used to prevent flooding of surface or underground facilities.

Conclusion: The unsaturated zone at Yucca Mountain appears to provide a favorable hydrologic environment for the placement of underground facilities, offering no currently recognized conditions that would require complex technology or costly engineering. Although a potential for flash-floods exists, reasonable construction measures will be used to prevent potential damage to surface facilities, or flooding of underground facilities. Aquifers capable of producing the required amounts potable water are available to supply projected repository requirements without impacting regional availability in the near or distant future. Therefore, the Yucca Mountain site meets the requirements of the qualifying condition for this guideline.

IV. FAVORABLE CONDITIONS

(1) Absence of aquifers between the host rock and the land surface.

Evaluation: There are no aquifers between the host rock and the land surface because the proposed repository is located in the unsaturated zone. The densely welded portion of the Topopah Spring Member is between 150 and 400 m (500 and 1300 ft) above the water table (See Figure 6.3.1.1-1). Even if the basal vitrophyre of the Topopah Spring Member were to be included in the repository, the water table still would be 100 m (330 ft) below the repository. See Section 6.3.1.1 for additional discussion.

Conclusion: The potential host rock, the densely welded tuff of the Topopah Spring Member, is above the water table at Yucca Mountain and there are no aquifers between it and the overlying land surface. Therefore, the Yucca Mountain site possesses this favorable condition.

(2) Absence of surface-water systems that could potentially cause flooding of the repository.

Evaluation: Candidate locations for surface facilities are located entirely outside of the main-channel flood zones predicted for the 100-year flood (Squires and Young, 1983). In addition, these channels would normally be lined and hydraulically designed in the vicinity of surface facilities to increase flow efficiency and containment. Some areas considered for surface facilities occur within an area affected by the 500-year and regional maximum floods predicted by Squires and Young (1983). These areas can be protected by channel lining and by diversionary measures during construction and operation.

The washes in and emerging from Yucca Mountain have generally steep slopes and are capable of moving large volumes of water and debris including large boulders. Concerted attention to this potential will be given when locating structures or shafts. In most instances, such facilities can be located to avoid adverse conditions or protective measures can be used. For additional information, see Section 6.3.3.1.

Conclusion: The surface-water drainage through arroyo systems feeding Fortymile Wash presents a potential for localized flash flooding during extreme storm events. Some surface facilities would be situated in areas affected by 500-year floods. Existing technology and engineering measures can be used during repository operation, construction, and closure to prevent damage from flooding. Therefore, the Yucca Mountain site possesses this favorable condition.

(3) Availability of the water required for repository construction, operation, and closure.

Evaluation: Well J-13, located east of Fortymile Wash, which supplies some local water needs in the southwestern part of the Nevada Test Site, has yielded as much as 0.04 m^3/s (700 gpm) during pumping tests (Thordarson, 1973, p 22). Pumping has lowered the water level in the well only slightly and so effects on regional potentiometric levels are probably negligible. The static water level was 728.8 m (2391 ft) shortly after the well was drilled in 1962; 18 years later, following substantive periods of intermittent pumping, the water level was essentially the same at 728.9 m (2391.4 ft) (Thordarson, 1983). The excellent production capabilities of well J-13 combined with the equally good productions from the deep regional aquifers under Yucca Mountain (see Section 3.1.3) suggest that sufficient quantities of water can be produced with negligible lowering of the regional ground-water system.

Conclusion: Supplies of ground water are available from nearby wells which will be sufficient to satisfy all requirements during the repository life-cycle. Therefore, the Yucca Mountain site meets this favorable condition.

V. POTENTIALLY ADVERSE CONDITION

Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.

Evaluation: Substantially more severe mine environments than at Yucca Mountain (including saturated conditions) are dealt with routinely (Loofbourow, 1973); therefore, no engineering measures beyond those presently available are likely to be needed. This conclusion is based largely on experience, and it cannot be confirmed until in situ observations and measurements are made during site characterization.

Tunnels in tuffs at Rainier Mesa on the Nevada Test Site are in an area of greater surface recharge and probably of greater moisture flux in the unsaturated zone than at Yucca Mountain. Inasmuch as extraordinary mining techniques have not been required at Rainier Mesa, none are expected to be needed at Yucca Mountain.

Conclusion: Because the proposed repository at Yucca Mountain is entirely within the unsaturated zone and well above the water table, it is most unlikely that any significant amounts of ground water will be encountered in the underground workings. Consequently, ground-water conditions will not require complex engineering measures. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

6.3.3.4 Tectonics (10 CFR 960.5-2-11)

I. INTRODUCTION

This Tectonics Guideline is one of several preclosure guidelines included under the heading ease and cost of construction, operation, and closure. The objective of this guideline is to ensure that a repository site is not likely to be affected by tectonic events that would require unreasonable or unfeasible design features to protect the facilities, repository workers, and the public. The concerns to be addressed under this guideline are ground motion or ground disruption that might cause (1) radioactive material to be accidentally released and (2) damage to repository or transportation facilities resulting in injury to personnel or interuption of repository operations and schedules.

The preclosure Tectonics Guideline consists of one qualifying condition, and one favorable condition, and three potentially adverse conditions. The Yucca Mountain site is evaluated with respect to these conditions in the following sections.

II. RELEVANT DATA

For a summary of relevant data, see Section 6.3.1.7 (Postclosure Tectonics).

<u>Assumptions and Data Uncertainties</u>: The principal assumption made in estimating the future tectonism of the region during the preclosure period of a repository is that the present low rate of tectonic processes will continue into the near future. The major uncertainties arise from the relatively short historical record of earthquakes in Nevada and because a regional instrumented seismic network has been operating for only the last few years at Yucca Mountain.

III. QUALIFYING CONDITION

The site shall be located in a geologic setting in which any projected effects of expected tectonic or igneous activity on repository construction, operation, or closure will be such that the requirements specified in Section 960.5-1(a)(3) can be met.

Evaluation: The following analysis forms the basis for the evaluation of the qualifying condition.

1. During the brief historical record available, no earthquakes have produced damaging ground motions or surface displacement at Yucca Mountain.

2. The predicted maximum ground motion at Yucca Mountain caused by credible maximum earthquakes on any of the largest of the nearby faults considered seismically active is 0.4 g (Rogers et al., 1977). This acceleration is within design limits for a nuclear facility.

3. Ground-surface displacement along faults at the proposed site is unlikely during the preclosure period. This conclusion follows from the work of Swadley et al. (1984), which suggests that no surface displacement has occurred in the Yucca Mountain area for at least the past 35,000 years.

4. The possible effects and probability of basaltic volcanism at Yucca Mountain during the preclosure period has been determined. As evaluated by Crowe et al. (1982), the annual probability of recurring basaltic volcanism disrupting repository activities at Yucca Mountain ranges between 4.7×10^{-8} and 3.3×10^{-10}. Because of the low probabilities and small consequences, the risk posed by basaltic volcanism is judged to be very small during the preclosure period (Link et al., 1982).

Conclusion: The only expected tectonic activity affecting Yucca Mountain during the preclosure period is the occurrence of small magnitude earthquakes in the surrounding region that could produce very limited ground motion at the proposed site. These predicted ground motions are within design limits for a nuclear facility and associated structures, and, therefore, meet the requirements specified in 10 CFR 960.5-1(a)(3). Therefore, the Yucca Mountain site meets this qualifying condition.

IV. FAVORABLE CONDITION

The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.

Evaluation: Preliminary investigations of faults on and near Yucca Mountain suggest they have not had large (>1 m) surface displacements in the last 250,000 years (Swadley and Hoover, 1983). There is no confirmed evidence of surface displacements in deposits considered to be younger than 35,000 years (Swadley et al., 1984).

The peak historical acceleration at a location 20 km (12 mi) east of Yucca Mountain was estimated by Rogers et al. (1977) to be less than 0.1 g. Carr et al. (1984) estimated the seismic hazard for Yucca Mountain using methods like those described in Rogers et al. (1977). The maximum magnitude earthquake expected on the potentially active fault which is thought to present the greatest hazard to the site, was calculated to be a magnitude of 6.8 on the Richter Scale. The resulting peak computed acceleration at Yucca Mountain would be approximately 0.4 g (Carr et al., 1984). This acceleration was calculated to have a return period between 900 and 30,000 years, and the probability of a 0.4 g acceleration being exceeded in a 30-year period is between 0.038 and 0.0019.

Conclusion: No unequivocal evidence of fault displacement of deposits considered to be younger than 35,000 years has been found within a 10-km (6-mi) radius of Yucca Mountain. Within this radius, all instrumentally recorded earthquakes have been smaller than magnitude 2 on the Richter Scale. Predictions of the largest potential earthquake that might affect Yucca Mountain give estimates of a peak surface acceleration of about 0.4 g, a value considered acceptable for nuclear facilities. Therefore, the Yucca Mountain site possesses this favorable condition.

V. POTENTIALLY ADVERSE CONDITIONS

(1) Evidence of active faulting within the geologic setting.

Evaluation: Both geologic and seismological evidence indicate that Quaternary faulting has occurred in the regional geologic setting of Yucca Mountain. Fault scarps, nearly all small and considerably eroded, are present within the region (Carr, 1974; Rogers et al., 1983). The area has been mapped and studied in sufficient detail, however, to indicate that no important fault scarps are undetected. On the basis of presently available data, no confirmed surface displacement younger than 35,000 years has been demonstrated at or near Yucca Mountain (Swadley et al., 1984). The small amount of data available on recurrence intervals of faults within the geologic setting suggest long periods between major earthquakes (Swadley and Hoover, 1983; Szabo et al., 1981), possibly hundreds of thousands of years for individual faults.

Seismological evidence of current fault activity in the regional geologic setting (Rogers et al., 1983) includes (1) occurrence of seismicity throughout most of the region around Yucca Mountain; (2) Quaternary faulting in some of the more seismically active areas, such as the Spotted Range-Mine Mountain structural zone; (3) occasional alignments of epicenters, suggestive of the presence and strike of the associated faults; (4) two historical earthquakes - magnitude 6 on the Richter Scale that occurred in the southern Great Basin, addition to the Owens Valley (probably a magnitude of 8+ on the Richter Scale) earthquake of 1872; (5) faulting of probable Holocene age in Yucca Flat (Carr, 1974) and Death Valley (Hunt and Mabey, 1966); and (6) minor surface displacement of possible Holocene age in Rock Valley (Szabo et al., 1981) and at Bare Mountain.

Seismic monitoring of Yucca Mountain for nearly three years has recorded seven small (less than magnitude 2 on the Richter Scale) earthquakes within 10 km (6 mi) of the site boundaries. The nearest of these events was 1.5 km (0.9 mi) east of the proposed site at a depth of greater than 5 km (3 mi). These events constitute the only evidence that faults at Yucca Mountain are seismically active. Faults at Yucca Mountain, however, are mainly north-northeast trending and are thus favorably oriented for slip in the current stress field (Rogers et al., 1983). Present knowledge concerning seismic cycles and the relation between seismicity and age of faulting does not permit confident judgment about whether faults at Yucca Mountain are storing stress for a future rupture or are mostly de-stressed at present. Either condition might permit the occurrence of small earthquakes. Borehole stress measurements at Yucca Mountain indicate stress conditions that could be interpreted to mean that faults near the site are capable of movement (Healy et al., 1982).

<u>Conclusion</u>: Recurrent faulting occurred in the Quaternary Period within a 10-km (6-mi) radius of Yucca Mountain, but no unequivocal evidence of fault displacements in deposits considered to be younger than 35,000 years has been found within this radius. In the region surrounding Yucca Mountain, however, historic faulting and ground-surface displacement have occurred. Therefore, the Yucca Mountain site possesses this potentially adverse condition.

(2) <u>Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.</u>

<u>Evaluation</u>: As discussed in the evaluation of the favorable condition, the peak historical acceleration for a location in the southern Nevada Test Site area was estimated by Rogers et al. (1977) to be less than 0.1 g. In addition, for Yucca Mountain, the peak acceleration from the maximum

potential earthquake in the area is estimated to be approximately 0.4 g (Carr et al., 1984), which is within reasonable design limits for a nuclear facility. Ground motion from underground nuclear explosions on the Nevada Test Site is expected to be comparable to that produced by the maximum potential natural earthquake (Section 6.2.1.5, Offsite Installation and Operation).

Conclusion: If historic earthquakes or past man-induced seismicity were to recur in the region of Yucca Mountain, the resulting ground motion at the site would be within reasonable design limits. Therefore, the Yucca Mountain site does not possess this potentially adverse condition.

(3) Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.

Evaluation: Rogers et al. (1977) calculated the probabilities of earthquakes of a given size for a location 30 km (19 mi) southeast of Yucca Mountain assuming that nearby major faults may be currently active. Using the same approach, Carr et al. (1984) show that an earthquake occurring on the Bare Mountain fault with a credible maximum magnitude of 6.8 would produce a maximum acceleration at the proposed site of about 0.4 g. This acceleration is the largest expected at the proposed repository site due to credible maximum earthquakes on any of the largest nearby faults thought to be currently active. In this calculation, Yucca Mountain faults are not considered to be active. Under certain conservative assumptions about the distribution of seismicity, activity rates, and attenuation of ground motion, there is as high as a four percent probability that 0.4 g surface acceleration could be exceeded in a 30-year period (Carr et al., 1984).

The probability values for earthquake occurrence near Yucca Mountain are uncertain. Given the present state of earthquake prediction, there is no specific evidence that levels of seismicity higher than those observed in the geologic and historic records are likely at Yucca Mountain. Earthquakes larger than previously known cannot be ruled out, but geologic information shows no confirmed evidence of surface displacement for 35,000 years (Swadley and Hoover, 1983) and no significant (>1 m) surface displacement in the last 500,000 years (Rogers et al., 1983).

Conclusion: The Yucca Mountain site has had no significant surface displacement (>1 m) for the past 500,000 years and shows no evidence of surface displacement for 35,000 years. However, calculations show that the maximum credible magnitude earthquake for the site (6.8 on the Richter Scale) has 4 chances in 100 of being exceeded in a 30-year period. Therefore, the Yucca Mountain site possesses this potentially adverse condition.

VI. PLANS FOR SITE CHARACTERIZATION

During Site Characterization, field investigations will continue to evaluate tectonic activity of the Yucca Mountain site and surrounding region (see Section 6.3.1.7, Postclosure Tectonics, for a complete discussion).

6.3.4 Preclosure system guideline

The preclosure system guideline in this action will be used to evaluate the ease and cost of construction, operation, and closure of a repository at Yucca Mountain.

6.3.4.1 Preclosure system guideline: ease and cost of construction, operation, and closure (10 CFR 996.5-1(3)

INTRODUCTION

The Ease and Cost of Construction, Operation and Closure System Guideline establishes the overall objectives to be met during preclosure (construction, operation, and closure) and ensures that the technical aspects are demonstrated to be feasible on the basis of technology that is readly available at reasonable costs. The preclosure phase relies on engineered systems, equipment, and controls similar to those that are well established and part of standard industrial practice. This guideline would not be met if a large number of special measuras were necessary because of the following conditions: (1) the site had adverse surface features; (2) the host rock characteristics, including thickness and lateral extent, and geomechanical properties, would require technology beyond that available at reasonable cost; (3) hydrologic conditions were present that could limit the effectiveness of sealing or cause flooding of underground workings; or (4) the potential for tectonic activity required unreasonable or infeasible design features to protect the workers or the public.

The Qualifying Condition for this guideline is stated as follows:

The technical aspects of repository construction, operation, and closure shall be demonstrated to be feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options.

Evaluation of the Yucca Mountain site

The evaluations used to compile this system guideline evaluation include those for the Technical Guidelines for Surface Characteristics (Section 6.3.3.1), Rock Characteristics (Section 6.3.3.2), Hydrology (Section 6.3.3.3), and Tectonics (Section 6.3.3.4). This guideline is evaluated assuming the Yucca Mountain site has been selected for repository development and considers the following variables: (1) location of surface features; (2) method of access to the underground facility; (3) depth of emplacement level; (4) size and shape of the facility; and (5) method of waste emplacement. These variables will be evaluated and further refined during repository conceptual design. The conceptual design will be evaluated using additional information obtained during site characterization, and following site characterization, a more precise determination of ease and cost of construction, operation, and closure will be possible.

The system elements pertinent to this guideline must be evaluated according to the anticipated effects of the favorable and potentially adverse conditions contained in the applicable technical guidelines. Surface characteristics that influence location, design, and costs of repository facilities must be evaluated. Likewise, host rock characteristics, hydrology, and tectonic setting of the site that could impact the engineering designs and facility configuration, materials, service requirements and all related costs should also be evaluated.

In the following discussions, activities involved with repository construction, operation, and closure are described and each of the three phases is evaluated on the basis of available technology and relative cost. For evaluation purposes, it has been assumed that 10 percent of the access drifts, emplacement drifts, and holes will be excavated and stabilized during construction and that the remainder will be excavated and stabilized during operation.

Repository Construction. Construction activities include: (1) building surface facilities, including a railroad, a highway, utility systems, waste-handling and treatment buildings, support buildings, and other structures, such as head frames and hoists; (2) constructing underground ventilation filter buildings and underground facilities; and (3) excavating and stabilizing ramps and shafts, drifts, and emplacement holes.

Standard construction and mining techniques and practices can be applied to the majority of these construction activities. The construction of waste-handling and treatment facilities, the construction of ventilation filter buildings serving waste emplacement areas, and the excavation and stabilization of horizontal emplacement holes will require special consideration. Activities requiring nonstandard techniques will be carried out in a manner that provides for safe handling and processing of potentially hazardous radioactive materials under all foreseeable normal and accident conditions. Existing technology is available for drilling long, horizontal, large-diameter tunnels in rock. A development program is under way to transfer this technology to the drilling of small-diameter emplacement holes and lining these holes with a suitable steel liner.

Surface characteristics that impact construction phase activities include topography and surface drainage, and both will be carefully considered in the design and placement of surface facilities. Rock characteristics affecting construction activities include thickness and lateral extent of the host rock, the geomechanical properties of the host rock that impact support requirements, thermomechanical characteristics of the host rock that could impact ease and safety of retrieval, and other rock characteristics that could compromise worker safety. Host rock characteristics will determine the depth selected for the emplacement level, and the exact depth would significantly impact ease and cost of construction of head frames, hoists, and skips, ramps and shafts, drifts, and underground facilities. Size and shape of the emplacement area could also have an impact on the cost of mining the drifts.

Hydrologic factors that impact construction activities are water availability, concerns with potential for flooding, and ground-water conditions that could require complex engineering beyond that reasonably available. Adequate water supplies for repository activities are available locally. Design and locations of surface facilities will include plans for adequate flood protection. Unsaturated host rock and an arid surface climate both provide assurance that hydrologic impacts on construction will be minimal.

Tectonic factors that will affect repository construction, operation, and closure activities include the potential for earthquake-induced ground motion in excess of reasonable design limits for construction and operation of nuclear facilities. Studies to date suggest that the maximum potential ground motion at the site is well within standard earthquake design limits for nuclear facilities.

Repository Operation. Operation activities include waste handling, preparation, and emplacement; administration and management; maintenance; mining; and security. Surface characteristics that may impact repository operation include those that could cause flooding of surface or underground facilities, or characteristics that could lead to the failure of engineered components of the repository. No problems are anticipated with surface facilities, and designs will include flood protection for surface and underground facilities. Rock characteristics could impact repository operation activities. For example, a discovery that the host rock is too thin or laterally restricted would be a major impact. If unexpected in situ rock conditions were encountered that required special engineering measures, or required extensive maintenance of underground openings to guarantee worker safety, then repository operations would be impacted. Rock characteristics related to thermomechanical response are also very important in guaranteeing that retrieval could be accomplished safely and without great cost. All evidence to date suggests that adequate host rock is available, although it is possible that additional lateral extent could be useful to provide added flexibility. In situ host rock conditions and thermomechanical rock properties will allow safe operation and retrieval, should retrieval become necessary.

During operation, the principal hydrologic concerns are that an adequate water supply is available for necessary activities, and that no ground-water conditions are encountered that would require complex technology beyond that which is reasonably available. Adequate water supplies are available locally, and the unsaturated host rock will require no special technology. The tectonics of the site that could impact operation are the potential earthquake and volcanic activities associated with certain geologic settings. Ground motion that is likely to occur as a result of natural seismicity or man-induced seismicity can be estimated and operational procedures can be established to protect workers and facilities. A significant impact on operation would be likely only if earthquakes greatly exceeded design limits of the facilities. Conservative design limits will be used (see Section 6.2.1.5).

Closure of the Repository. The closure of the repository will consist of backfilling drifts, if required, and sealing shafts and ramps. Surface characteristics could only impact shaft and ramp sealing or backfilling if flooding caused disruption of seals or backfill. Rock characteristics that could impact closure activities or potential retrievability include rock instability in boreholes or drifts. The potential for thermally induced fracturing or other changes could lead to safety problems if retrieval were necessary. Flood protection will guarantee that sealing and backfilling are not disrupted, and all evidence to date suggests that retrieval of emplaced wastes should offer no mechanical or safety-related problems.

Hydrology would impact repository closure if flooding occurred, or if water was not available for closure or retrieval operations. Ground-water conditions could impact closure and retrieval if complex engineering measures were required due to unexpected conditions. As previously mentioned, designs will ensure flood protection, and the unsaturated host rock should offer a benign ground-water environment. Tectonic processes could impact the closure activities if the earthquake design limits imposed were not sufficiently conservative to guarantee safety of the workers. This would only be likely if the nature and rates of faulting are changing so that ground motion predictions for Yucca Mountain are low. Evidence presented in Sections 6.3.3.2 and 6.2.1.5, however, indicates that ground-motion predictions are probably reliable. Conservative earthquake design limits will be used for all phases of repository activities.

Conclusions on qualifying condition for Preclosure System Guideline: Ease and Cost of Construction, Operation, and Closure

Repository construction, operation, and closure are not likely to require special technology and are considered feasible on the basis of existing technology. Associated costs are considered reasonable relative to other available and comparable siting options. Site characterization studies will expand the existing information on host rock thickness and lateral extent, host rock mechanical properties, thermomechanical properties, faults, shear zones, and subsurface hydrology. Repository design information currently available at the preconceptual stage and cost estimates and design requirements will be updated during ongoing conceptual design activities. The Yucca Mountain site meets the requirements of this preclosure system guideline.

6.4 ANALYSES SUPPORTING THE COMPARISON WITH SYSTEMS GUIDELINES

Preliminary quantitative analyses of expected systems performance with respect to the requirements of the systems guidelines are summarized in this section. Both preclosure and postclosure system guideline analyses are addressed.

6.4.1 Preclosure system guideline analyses

The preclosure system guidelines establish the overall objectives to be met during the preclosure phase including site characterization, repository construction, operation, decommissioning, and closure. There are three preclosure system guidelines addressing the following categories: (1) radiological safety during repository operation and closure; (2) the environmental, socioeconomic, and transportation impacts associated with repository siting, construction, operation, closure, and decommissioning; and (3) the ease and cost of repository construction, operation, and closure. The preclosure phase relies on engineered systems, equipment, and control, similar to those that are well established in the nclear and other industries.

In the following paragraphs, each Qualifying Condition for this Guideline is first stated, then briefly evaluated, and finally, a general conclusion is given.

1. Preclosure Radiological Safety (10 CFR 960.5-1(1))

<u>Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60 and 40 CFR Part 191, Subpart A.</u>

<u>Evaluation</u>: Technical guidelines used for surrogate evaluation of the System Guideline for Radiological Safety include those for Population Density and Distribution (Section 6.3.1.2); Site Ownership and Control

(Sections 6.2.1.1 and 6.2.1.3); Meteorology (Section 6.2.1.4); and Offsite Installations and Operations (Section 6.2.1.5).

For the summary evaluation, see Section 6.2.2.1; for detailed evaluations of technical guidelines, see the corresponding sections in the text.

2. Environment, Socioeconomics, and Transportation (10 CFR 960.5-1(2))

To the extent practicable, the repository and its support facilities shall be sited, constructed, operated, closed, and decommissioned to (1) protect the quality of the environment in the affected area and mitigate significant adverse environmental impacts considering technical, social, economic, and environmental factors, and (2) protect the socioeconomic welfare of the general public in the affected area. The projected risks, costs, and other impacts of waste transportation operations shall be conducted in compliance with applicable Federal regulations and with those applicable State and local regulations and ordinances that are consistent with Federal regulations.

Evaluation: The technical guidelines used for surrogate evaluation of the System Guideline for Environmental Quality, Socioeconomics, and Transportation include: Environmental Quality (Section 6.2.1.6), Socioeconomic Impacts (Section 6.2.1.7), and Transportation (Section 6.2.1.8).

For the summary evaluation, see Section 6.2.2.2; for detailed evaluations of technical guidelines, see the corresponding sections of the text.

3. Ease and Cost of Construction, Operation, and Closure (10 CFR 960.5-1(3))

The technical aspects of repository construction, operation, and closure shall be demonstrated to be feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options.

Evaluation: The technical guidelines used for surrogate evaluation of the System Guideline for Ease and Cost of Construction, Operation, and Closure are: Surface Characteristics (Section 6.3.3.1), Rock Characteristics (Section 6.3.3.2), Hydrology (Section 6.3.3.3), and Tectonics (Section 6.3.3.4).

For a summary evaluation, see Section 6.3.4.1; for detailed evaluations of technical guidelines, see the corresponding sections of the text.

Conclusion on Preclosure System Guideline: Preliminary calculations for accidents at a repository site show that doses to the general public living within an 80 km (50 mi) radius are below background radiation levels and thus will meet all applicable Federal, State, and local standards (Section 6.2.2.1). Evaluations also show that, from construction through closure of a repository at Yucca Mountain, the environmental quality can be adequately protected, and the socioeconomic welfare of the general public will be preserved. Social and aesthetic values of the region will not be compromised (Section 6.2.2.2).

Existing technology is adequate to construct, operate, and close a repository at the Yucca Mountain site. Costs are considered to be reasonable compared with other available siting options (Section 6.3.4.1). Therefore, preliminary analyses indicate that the Yucca Mountain site meets the three qualifying conditions for the Preclosure System Guidelines.

6.4.2 Postclosure preliminary performance assessment

In this section, a postclosure preliminary performance assessment is made for each of the three major subsystems of the Yucca Mountain waste-disposal system: the waste package, the engineered barrier subsystem, and the geohydrologic subsystem.

6.4.2.1 Scope and objective

The evaluation of the proposed Yucca Mountain site with respect to 10 CFR 960, Subparts C and D, provides part of the basis for site nomination. Anticipated changes to the Guidelines are expected to specify that the evaluation be made using preliminary performance assessments to estimate the likelihood of satisfying regulatory performance criteria contained in the NRC 10 CFR 60 regulation and the EPA 40 CFR 191 working draft 4. A preliminary performance assessment of the Yucca Mountain site is presented in this section; and results of the assessment are used in Section 6.3.2, Postclosure System Guideline, as part of the evaluation of the site.

Because of current limitations on the data base and analytical methodologies, this preliminary assessment is not intended to demonstrate compliance with the Postclosure System Guideline; rather, it is intended to supplement the evidence that will be used to establish whether the Yucca Mountain site merits an investment of further site-characterization efforts. A full performance assessment that will be used to demonstrate compliance with the Postclosure System Guideline is contingent upon and will follow site characterization.

This section is organized into five major sections. Section 6.4.2.2 contains descriptions of the three major subsystems of the proposed Yucca Mountain waste-disposal system: the waste package, the engineered barrier subsystem, and the geohydrologic subsystem. The individual performance of e- of these major subsystems is evaluated in Section 6.4.2.3. The specific objectives of these evaluations are: (1) to satisfy the need for preliminary performance assessments of subsystems as specified in anticipated changes to Subpart B of 10 CFR 960; and (2) to establish the Reference Case system configuration to be used in the analysis of Section 6.4.2.4. Section 6.4.2.4 contains a preliminary assessment of total system performance. In Section 6.4.2.5, subsystem and total system performance discussed in earlier sections are evaluated in terms of the applicable performance objectives of 10 CFR 60 and proposed 40 CFR 191. The objective of these evaluations is to establish a rough measure of undisturbed-system performance that can be used as evidence in the overall site evaluation; a brief discussion of system performance under disturbed conditions is provided in Section 6.4.2.6 on Human Intrusion and disruptive events.

6.4.2.2 Subsystem descriptions

For the purpose of these assessments, it is assumed that a repository at Yucca Mountain would be located entirely within a structurally defined block having an area of roughly 770 ha (1900 acres) that is relatively free of faults and other undesirable structural features. The underground working areas would be located 200 m (650 ft) or more from the surface in the lower portion of the Topopah Spring Member (see Figure 6.3.1.5-1, Erosion). Approximately 615 ha (1500 acres) of the surface would be affected; the present conceptual repository design specifies that mined areas would occupy no more than 25 percent of the total block area. It is assumed that the waste inventory will be 10-year old spent fuel representing 70,000 MTHM (metric tons of heavy metal) at closure time. Inventory composition is listed in Table 6.4.2-1.

Functionally, the waste-disposal system is made up of three major subsystems: (1) the waste package; (2) the mined repository, including any engineered features that are specifically intended to enhance long-term containment or isolation of the waste; and (3) the geohydrologic and geochemical settings of the site. Those parts of each of the three subsystems that are relevant to postclosure systems performance are described below.

<u>The waste package</u>

A reference conceptual design (O'Neal et al., 1984) for a spent fuel waste package is shown in Figure 6.4.2-1. The canister is 65 cm (26 in.) in diameter with lengths that vary from 4.0 to 4.75 m (13 to 15.6 ft) (including pintle) to

Table 6.4.2-1. Radionuclide inventories in repository at various time after closure, 0, 300, and 1000 years (DOE, 1979)

Radionuclide	Half-life (years)	Specific activity (Ci/kg)	70,000 MTHM[a] inventory (kg)		
			0 yr	300 yr	1000 yr
C-14	5.73E+3[b]	4.45E+3	2.24E+1	2.16E+1	1.98E+1
Tc-99	2.15E+5	1.4E+1	5.06E+4	5.06E+4	5.04E+4
I-129	1.59E+7	1.74E-1	1.11E+4	1.11E+4	1.10E+4
Pu-240	6.58E+3	2.26E+2	1.42E+5	1.34E+5	1.29E+5
U-236	2.39E+7	6.34E-2	2.79E+5	2.83E+5	2.94E+5
Th232[c]	1.40E+10	1.1E-1	7.7E-9	7.7E-8	7.7E-7
Cm-245	9.3E+3	1.57E+2	8.53E+1	8.32E+1	7.85E+1
Pu-241	1.32E+1	1.12E+5	2.97E+4	1.72E-1	1.37E-1
Am-241	4.58E+2	3.24E+3	2.57E+4	4.12E+4	1.35E+4
Np-237	2.14E+6	7.05E-1	2.77E+4	5.15E+4	7.88E+4
U-233	1.6E+5	9.47	4.28E-1	4.25	1.92E+1
Th-229	3.34E+3	2.13E+2	2.66E-5	2.70E-3	3.49E-2
Cm-246	5.5E+3	2.64E+2	9.11	8.71	7.86
Am-242	1.52E+2	9.72E+3	6.62E+1	1.69E+1	6.92E-1
Pu-242	3.79E+5	3.9	1.95E+4	1.95E+4	1.95E+4
Pu-238	8.6E+1	1.75E+4	8.58E+3	8.41E+2	4.31
U-238	4.51E+9	3.33E-4	6.64E+7	6.64E+7	6.64E+7
U-234	2.47E+5	6.18	1.02E+4	1.79E+4	1.86E+4
Th-230	8.4E+1	1.94E+1	3.54E-1	1.31	4.86E+1
Ra-226	1.6E+3	9.88E+2	2.0E-5	1.52E-2	1.75E-1
Am-243	7.95E+3	1.85E+2	4.79E+3	4.65E+3	4.38E+3
Pu-239	2.44E+4	6.13E+1	3.65E+5	3.62E+5	3.56E+5
U-235	7.1E+8	2.14E-3	5.97E+5	6.0E+5	6.07E+5
Pa-231*	3.25E+4	4.51E+1	3.71E-4	2.59E-3	2.45E-2
Totals			6.80E+7	6.80E+7	6.80E+7

[a] MTHM = metric tons of heavy metal.

[b] 5.73E+3 = 5.73×10^3.

[c] Note: an asterisk denotes the metable state of a radionuclide.

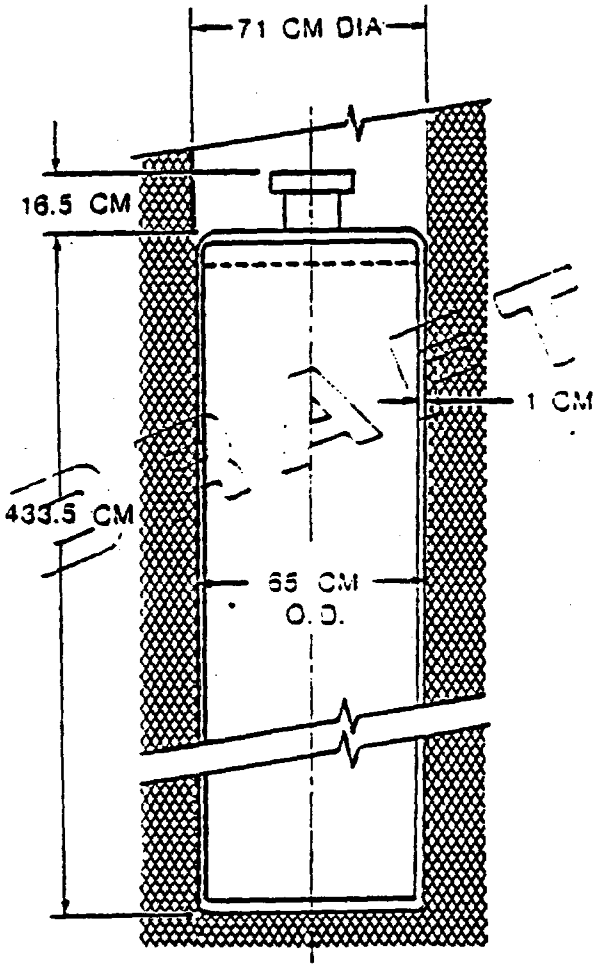

Figure 6.4.2-1. Reference conceptual design for spent fuel waste package.

accommodate various lengths of fuel rods and is fabricated from 304L stainless steel with a wall thickness of 1 cm (0.4 in). This design will accommodate 18 pressurized-water-reactor assemblies (3.42 kW) or 7 boiling-water-reactor assemblies (3.56 kW) of consolidated spent fuel within the same canister diameter. These power loadings are consistent with a 350°C temperature limit imposed to avoid degradation of spent fuel cladding (Hockman and O'Neal, 1984). If it is assumed that the initial thermal loading of the repository is held to 57 kW/acre, then about 21,000 canisters would be distributed over 510 ha (1260 acres); the waste density would thus be about 55.6 MTHM/acre or 3.3 MTHM per canister.

Note that the design shown in Figure 6.4.2-1 is the least complicated of the selected reference and alternative design configurations for this waste form (Gregg and O'Neal, 1983). Each package is placed in a single vertical borehole, and neither an overpack nor packing material is used in this reference design.

The engineered barrier system

By the Nuclear Regulatory Commission definition, the engineered barrier system (EBS) consists of a waste package subsystem and an underground repository facility subsystem. These two subsystems combine to provide long-term containment and to control the release of the radioactive waste to the geologic setting. The waste package subsystem was discussed in previous paragraphs; this section describes the postclosure engineered barrier system.

The outer boundary of the repository subsystem has not yet been clearly defined. The Nuclear Regulatory Commission states in 10 CFR 60 that the repository includes the underground structure, underground openings, and backfill materials, but excludes shafts, exploratory boreholes, and their seals. This implies that the inclusion of some quantity of near-field rock is justified. This position is especially relevant to a repository located in the unsaturated zone because engineered barrier design can be shown to potentially influence containment time and eventual radionuclide release rates. For example, heat from the waste produces a zone surrounding each waste package in which water is eliminated (Pruess and Wang, 1983). The size and duration of this dryout zone will be affected primarily by waste package design and thermal loading. This engineered hydraulic gradient will affect water movement to and from the waste packages during the period following waste emplacement. A second example is that the response of the host rock to construction (mining) and waste emplacement (heat) affects fracture permeability and therefore availability of water in the waste package environment.

For the current calculations, the boundary of the engineered barrier system is defined as the smooth envelope surrounding the outermost waste emplacement drifts and holes by a half pillar width [10 to 20 m (33 to 66 ft)] of host rock. The Nuclear Waste Policy Act and the DOE (10 CFR 960), are both more restrictive in that their engineered barrier systems comprise only man-made components.

The major contributions of the engineered barrier system located outside the waste package include:

1. Control and moderation of water flow characteristics through the host rock and the effects of man-made barriers, such as backfills, drains, and seals (Roseboom, 1983).

2. Retardation of radionuclides released from the waste package by the host rock contained inside the repository subsystem boundary.

Currently, the hydrological information and design data needed to predict the effects of the system of engineered barriers on water availability at the waste package are not known. Therefore, it is not possible at this time to include these barriers in a performance analysis. While the retardation that occurs in the host rock inside the EBS boundary could be included, the release rate at the accessible environment would not be influenced because the major sorptive units underlie the repository horizon in the tuffaceous beds of the Calico Hills. The host rock immediately surrounding the waste packages will eventually be included either as part of the EBS or the natural barrier system. In either case, exclusion of host rock from the present release rate calculations provides confidence that the performance objectives for isolation can be met.

The ground-water subsystem

The ground-water subsystem has two aspects: (1) the flow of water in saturated and unsaturated zones of Yucca Mountain and (2) the geochemical properties of the rocks and waters of Yucca Mountain as they relate to the potential dissolution and transport of nuclear waste in the ground-water flow.

Ground-water flow. The flow of water in saturated and unsaturated zones of Yucca Mountain is reviewed in considerable detail in Section 6.3.1.1, which also provides background and limitations on the relevant data base. Briefly, the flow of water in the geohydrologic subsystem at Yucca Mountain occurs in a thick (about 300-750 m or 980-2460 ft) unsaturated section, and a deep saturated zone. The host rock for the repository is in the unsaturated zone, and is characterized by low water contents; the repository host rock is over 200 m (650 ft) above the water table.

Water enters the unsaturated zone in the form of precipitation that infiltrates the land surface and moves generally vertically downward until it reaches the water table. The flow rate of the percolating water is determined by the rate of infiltration of precipitation and by the hydraulic properties of the rocks in the unsaturated zone. The flux at the repository level is less, perhaps much less, than 1 mm/yr (Section 6.3.1.1), and the flow is confined to the rock matrix. This percolating water provides a minor amount of recharge to the water table beneath Yucca Mountain. On reaching the water table, the ground water then moves generally horizontally to the accessible environment, driven by a hydraulic gradient approximately equal to the slope of the water table and controlled by the hydraulic properties of the intervening rocks. It is probable that the ground-water flow to the accessible environment at Yucca Mountain is mainly through fractures in the welded tuffs.

Geochemical properties. Geochemical properties of the proposed Yucca Mountain site are reviewed in considerable detail in Section 6.3.1.2, which also provides background and limitations on the relevant data base. Between the repository horizon and the water table, there are several zones containing highly sorptive minerals, particularly zeolites and clays. The formations in the saturated zone also contain varying amounts of clays and zeolites. Because of the sorptive properties of these rocks, dissolved radionuclide-bearing compounds may be transported at an effective speed that is generally less than the local pore-water velocity; this is particularly true if flows are confined to the matrix of the rocks. The reduced speed results in a transport time over the same flow path that is larger than the water-flow time by a number known as the retardation factor (R_f). The retardation factor for the jth radionuclide species, $(R_f)j$, is related to the distribution coefficient for the jth species, $K_d(j)$, by the expression (Freeze and Cherry, 1979, p. 404).

$$(R_f)j = 1 + \frac{\text{bulk density} \times K_d(j)}{\text{effective porosity}}$$

DRAFT

Table 6.3.1.2-3 lists estimates of distribution coefficients (called sorption ratios and expressed as R_d) and retardation factors for several waste elements in eight of the tuff units that could be crossed by flow in the unsaturated and saturated zone. These estimates are based on retardation by sorption; other chemical and physical retardation mechanisms, such as precipitation and matrix diffusion, may increase the effective retardation factor, especially for those elements exhibiting low sorption ratios. The waste elements having low or zero sorption ratios, hence small retardation factors, are carbon, iodine, and technetium. These few elements will probably be transported with a speed nearly equal to that of the ground water.

6.4.2.3 Subsystem preliminary performance assessments

The performance of each of the three subsystems described in the previous section is evaluated here. Results will be used in the following section to establish a reference-case system configuration and in Section 6.4.2.5 to make comparisons with regulatory performance objectives.

Some definitions are needed: in the remainder of the present section, and unless otherwise stated, "accessible environment" will be used in conformance with 10 CFR 60 and will mean those parts of the saturated zone that lie at distances of 10 km (6.25 mi) or more downgradient from the projected repository boundary; the "disturbed zone" will mean the volume of host rock contained within a distance of about 22 m (72 ft) from any waste canister or mined opening.

The waste package lifetime

Estimates of the lifetime of the reference waste package design (Section 6.4.2.2) are based on short-term exposure tests that attempt to simulate the Yucca Mountain environment. The quantity measured is the corrosion rate for 304L stainless steel immersed in water and subjected to various temperature, geochemical, and radiation conditions. In low-salinity nearly neutral pH, aerated water, the uniform corrosion rate for 304L stainless steel appears to be less than 0.1 mil per year or about 2.54×10^{-4} cm/yr (LaQue and Copson, 1963). If uniform corrosion is the only mechanism that acts to breach the waste package, the lifetime of the canister would be about 3000 years. In contrast to these results, McCright et al. (1983) have observed a maximum value of 3.7×10^{-5} cm/yr for the uniform corrosion rate of 304L stainless steel in 2-month exposure tests. In their tests the sample was immersed, under pressure, in 105°C water from well J-13 at Yucca Mountain and simultaneously subjected to a 3×10^{5} rads/hr radiation field. The canister lifetime under these conditions would be about 30,000 years. However, McCright et al. (1983) conclude that a conservative upper limit of 1×10^{-4} cm/yr is reasonable for the uniform corrosion of 304L stainless steel in the Yucca Mountain environment, and that expected canister lifetimes are accordingly of the order of 10,000 years. In summary, waste package lifetime (which is assumed to be the same thing as canister lifetime for purposes of these assessments) could range from 3,000 to 30,000 years, with an expected value of 10,000 years. The 10,000-year value is adopted for the analysis of the reference case in Section 6.4.2.4. None of these values, however, take into account failure by localized corrosion mechanisms.

Release rate from the engineered barrier subsystem

As stated in Section 6.4.2.2, the elements of the repository that make up the engineered barrier system at the proposed Yucca Mountain repository are controversial. To facilitate the present assessments, the boundaries of the engineered barrier system are assumed to coincide with the boundaries of the waste packages, and the release from the engineered barrier system will be calculated as the release from the geometrical envelope containing the waste packages.

As long as the waste package remains substantially intact, there would be little or no release of radionuclide-bearing compounds. The expected low-flux conditions at Yucca Mountain (Section 6.4.2.2) would be unlikely to produce sufficient water to enter the small cracks in the surface of the corroding canister. But at some point in time (3000 to 30,000 years), the canister would no longer protect the waste form from contact with water and, neglecting any containment provided by the Zircaloy cladding on spent fuel, dissolution of the spent-fuel pellets could begin. Presently, the question of release rate must focus on the waste-form release rate.

Release rates from spent fuel can be expected to vary from essentially zero (for intact Zircaloy-clad fuel rods) to values in excess of one part in 100,000 per year for bare fuel elements. The latter rates are, however, extremely unlikely under Yucca Mountain conditions. Wilson and Oversby (1984) reported the initial results from spent fuel cladding-containment tests. Solution concentrations indicate a uranium release rate of 5×10^{-6} per yr from bare fuel [pellets from a 13 cm (5 in.) long rod segment] submerged in 250 ml of deionized water, and a release rate of 2×10^{-5} per yr for plutonium. Similar studies by these investigators suggest that release rates from spent fuel samples with relatively large artificially induced cladding defects are still 10 to 100 times less than the bare fuel release rates. Another study (Woodley, 1983), examined the characteristics of spent fuel from light water reactors, and estimated the cladding failure rate for General Electric boiling water reactor fuel designs to be between 1.0 percent and a value approaching zero. These failure levels appear reasonably typical of all light water reactor fuel, although the lower bound will probably remain near 0.01 to 0.02 percent failures (Locke, 1975; Garzarolli et al., 1979).

A straightforward calculation shows that even bare fuel could have release rates considerably less than 1×10^{-5} per yr in the expected environment of the Yucca Mountain repository after closure. Taking a single canister in Section 6.4.2.2) as the unit of inventory, the rate of mass loss by dissolution in flowing water, $\dot{M}$, is given by the expression

$$\dot{M} = FAS$$

where F is the flux of water (m^3/m^2 yr), A is the canister area normal to the flux (m^2), and S is the solubility limit of the waste matrix (kg/m^3). Available evidence suggests that the flux is less than 1 mm/yr, and could be as low as .01 mm/yr (Montazer et al., 1984); the midpoint value of this range (0.5 mm/yr) is taken as the reference flux. Taking $F = 5 \times 10^{-4}$ m/yr, $A = 0.33\ m^2$ (a vertically placed reference canister), and a site-specific value for the solubility limit of uranium (the major component of spent fuel), $S = 5 \times 10^{-2}\ kg/m^3$ (Kerrisk, 1984), one finds $\dot{M} = 8.3 \times 10^{-6}$ kg/yr. For a canister containing 3.3 MTHM, the fractional mass release rate is 2.5×10^{-9} per yr. For a horizontally placed canister (A = 2.8 m^2) the fractional release rate is 2.1×10^{-8} per yr. Provided that the dissolution of the radionuclide-bearing compounds imbedded in the spent fuel matrix is controlled by the dissolution of the UO_2 matrix itself (congruent leaching), the fractional release rate for each radionuclide-bearing compound would exactly equal the fractional mass release rate.

Thus, even though release rates from the engineered barrier system may range from zero up to 2×10^{-5} per yr, a conservative but realistic value would be about 1×10^{-8} per yr. This value will be adopted as the reference-case value.

<u>Validity of congruent leaching assumption</u>: The congruent leaching assumption may lead to both overestimates and underestimates of the release rate from the waste form. Fuel pellets of UO_2 undergo physical and chemical changes during the irradiation process. High temperatures that occur in the fuel during reactor operation allow segregation of fission products and the formation of a complex heterogeneous assemblage of phases in the irradiated fuel (Ewart and Taylor, 1976; and Davies and Ewart, 1971). These phases are generally segregations of oxide compounds that have low solubility in UO_2 or elements that are metallic under the redox conditions in the fuel. Because of the presence of these phases, the release of some radionuclide species from

spent fuel may be greater than the rate of dissolution of the UO_2 matrix. On the other hand, the congruent leaching assumption ignores the frequently low solubility limits for the majority of the compounds in the waste forms. The solubilities of several waste elements are listed in Table 6.3.1.2-4; with the exception of carbon, cesium, and technetium (and iodine, not shown), all values are less than or comparable to the value for UO_2.

The use of a saturation-limited dissolution model is probably valid in the expected low flux conditions of the Yucca Mountain unsaturated zone. Even in the saturated spent fuel release-rate studies (Wilson and Oversby, 1984) with high ratios of water volume to waste form area, solution concentrations appear to reach steady state in less than 30 days. For large flux values which would be typical of fracture flow considered unlikely at Yucca Mountain, solubility kinetics may control the release rate and a saturation-limited dissolution model would overestimate the rates.

Ground-water travel times

Ground-water travel times associated with the Yucca Mountain geohydrologic system were analyzed in Section 6.3.1.1. There it was shown that with an expected flux of less than 1 mm/yr through the unsaturated zone below the repository, flow would be predominantly in the matrices of the Topopah Spring welded unit and the Calico Hills nonwelded unit (see Table 6.3.1.1-1). Assuming minimum thicknesses, respectively, of 50 and 100 m for these units, expected travel time from the base of the Topopah Spring welded unit to the water table was conservatively estimated to be greater than 20,000 years if the flow passed through the zeolitic part of the Calico Hills, and greater than 50,000 years if the flow passed through the vitric part of the Calico Hills. Travel times through the saturated zone along a 10 km path to the accessible environment were conservatively estimated to be between 500 and 1,200 years.

The method used to obtain estimates of ground-water travel times in the unsaturated zone is an application of the expression

$$V_u = \frac{F}{\theta}$$

where V_u is the linear water-particle velocity in the unsaturated rock, F is the flux of percolating water (typical units: $m^3/m^2/yr$), and θ is the moisture content expressed as a decimal fraction (Freeze and Cherry, 1979, p. 71). This expression applies to one-dimensional, steady-state flows in porous rock with values of saturated hydraulic conductivity not less than the flux, F.

The method used in Section 6.3.1.1, to obtain estimates of ground-water travel time is an application of the expression

$$V_s = \frac{K_s\, i}{n_e}$$

where V_s is the linear water-particle velocity, i is the hydraulic gradient, K_s is hydraulic conductivity, and n_e is the effective porosity. The two expressions for linear water-particle velocity are equivalent if $F = K_s i$ by d'Arcy's law and n_e is taken to be the moisture content, θ, in unsaturated rock. Travel times through the units are estimated by dividing the appropriate linear water-particle velocity for each unit into the thickness of the unit; the total travel time is the sum of the unit travel times. The major limitations of these simple methods are that they ignore the three-dimensional spatial variation in hydrologic properties of the actual rock units, and they do not include the phenomena of hydrodynamic dispersion (Freeze and Cherry, 1979, p. 389). Inclusion of these effects would lead to wider bounds on the water travel time between two points located in the rock units. These simple approaches provide an average or expected travel time.

<u>Reference case travel time</u>: A point estimate of water travel time will be needed for the discussion of the reference case in Section 6.4.2.4. A conservative estimate of flux in the unsaturated zone is 0.5 mm/yr. Available evidence (Montazer et al., 1984) suggests that the flux at Yucca Mountain is

less than 1 mm/yr, and could be as low as 0.01 mm/yr; the midpoint value of this range (0.5 mm/yr) is taken as the reference flux. It is also assumed that, after flowing through the disturbed zone, the percolating water crosses an average of 50 m of the Topopah Spring welded unit and 150 m of zeolitized Calico Hills nonwelded unit before reaching the saturated zone. If the Topopah Spring unit has a moisture content of 10 percent, the pore-water velocity will be

$$\frac{0.5 \text{ mm/yr}}{0.10} = 5 \times 10^{-3} \text{ m/yr}$$

and the expected travel time through the unit will be 10,000 years. If the zeolitized Calico Hills has a moisture content of 28 percent, the pore-water velocity will be

$$\frac{0.5 \text{ mm/yr}}{0.28} = 1.8 \times 10^{-3} \text{ m/yr}$$

and the expected travel time through the unit will be 83,000 years. This estimate of travel time is considerably greater than the conservative estimate developed in Section 6.3.1.1, Disqualifying Condition. The travel times through the saturated zone to the accessible environment (500 to 1,200 years) can be neglected in view of the long, unsaturated-zone travel times. Thus, a 0.5 mm/yr flux at the repository level implies an expected water travel time between the disturbed zone and accessible environment of about 93,000 years.

<u>Reference case retardation factors</u>: Point estimates of porous-flow retardation factors in the welded and nonwelded tuff units will also be needed for the discussion of the reference case in Section 6.4.2.4. These estimates are shown in Table 6.4.2-2; they are consistent with the geochemical properties of the Yucca Mountain tuffs described in Section 6.3.1.2, although the retardation factors were calculated using different hydrologic parameters.

Table 6.4.2-2. Distribution coefficients and calculated retardation factors used in preliminary system performance assessment - reference case

Element	Distribution coefficient[a], K_d (mL/g)		Retardation factor[b], $(R_f)j$	
	Welded	Nonwelded	Welded	Nonwelded
Americium (Am)	1,200	4,600	28,000	24,000
Carbon (C)	0	0	1	1
Curium (Cm)	1,200	4,600	28,000	24,000
Cesium (Cs)	290	7,800	6,700	41,000
Iodine (I)	0	0	1	1
Neptunium (Np)	7	11	160	58
Protoactinium (Pa)	64	140	1,500	740
Lead (Pb)	5[c]	5[c]	120	27
Plutonium (Pu)	64	140	1,500	740
Radium (Ra)	25,000[d]	25,000[d]	580,000	130,000
Tin (Sn)	100[c]	100[c]	2,300	530
Strontium (Sr)	53	3,900	1,200	21,000
Technetium (Tc)	0.3	0[e]	8	1
Thorium (Th)	500[c]	500[c]	12,000	2,600
Uranium (U)	1.8	5.3	27	45
Zirconium (Zr)	500[c]	500[c]	12,000	2,600

[a] Unless otherwise indicated, distribution coefficients were taken from Table 6.3.1.2-3 or were inferred from sorption ratios quoted in Daniels et al. (1982).

[b] Calculated using values of moisture content of 10 percent, 28 percent and bulk densities of 2.33 grams per cubic centimeter, 1.48 grams per cubic centimeter, respectively, for welded and nonwelded tuff.

[c] Inferred from mid-range retardation factor for tuffs in compilation by Krauskopf, Table 7-1, National Research Council, 1983.

[d] Barium used as chemical analogue (Kerrisk, 1984).

[e] No data available; assumed to be small.

6.4.2.4 Preliminary system performance assessment

The purpose of this section is to provide information that will help evaluate the capability of the proposed site to qualify under the Postclosure System Guideline (Section 6.3.2). The purpose is accomplished by estimating the performance of the total system using simple methods, available information, and the results of the subsystem preliminary performance assessments in Section 6.4.2.3. The measure of total system performance will be the Environmental Protection Agency performance measure defined in Table 1 and Note 1 of Appendix A, 40 CFR 191, Working Draft 4. For purposes of these assessments, the Environmental Protection Agency performance measure will be expressed as a function of time:

$$R(t) = \sum_j \frac{C_j(t)}{L_j}$$

where $C_j(t)$ is the cumulative curies released to the accessible environment in the form of the jth radionuclide up to time t after repository closure, and L_j is the 10,000 year release limit for the jth radionuclide, as specified in Table 1, Appendix A, 40 CFR 191. The sum is taken over all radionuclides having nonzero cumulative curies releases by time t. Times greater than 100,000 years are not considered in these assessments.

System description

A highly idealized conceptual model of the proposed waste-disposal system at Yucca Mountain is shown in Figure 6.4.2-2. The level of detail in this conceptual model is consistent with present knowledge of the three major subsystems: waste package, engineered-barrier, and the geohydrologic subsystem of the unsaturated zone. The mathematical relationships used to quantify the conceptual model in these preliminary assessments are consistent with the level of detail of the conceptual model.

The waste packages and the engineered-barrier subsystems described in Section 6.4.2.2 are contained in the feature shown as "repository" in the figure. The waste canisters are assumed to be uniformly distributed throughout the repository. The curie release rate from each waste package is given by

$$\dot{C}_j = a_j f_j (t) \dot{M} \qquad \text{(Ci/yr)}$$

where a_j is the specific activity for the jth radionuclide and $f_j(t)$ is the fraction of the inventory mass that remains at time t in the form of the jth radionuclide. $\dot{M}$ is the mass release rate described in Section 6.4.2.3. The total curie release rate from the engineered-barrier system to percolating ground water is simply the curie release rate from a single waste canister times the number of waste canisters. In effect, the repository is treated as a planar source term for solutes injected into the unsaturated-zone flux; the assumption of congruent leaching (see Section 6.4.2.3) is made and possible effects of precipitation of solutes are ignored.

Water flow through the overburden and unsaturated tuffs below the repository is assumed to be uniform and downward; the percolation flux is, however, treated as a model parameter that applies only at or below the level of the repository. Flow in the unsaturated zone is described in the Section 6.4.2.3. Because the flow time in the saturated zone is short, adding the time of transport in the saturated zone makes little difference in the total transport time, and consequently has been ignored.

A computer model is used to calculate the transport of radionuclide-bearing compounds from the disturbed zone through the unsaturated tuffs and to the water table. The model and the code that implements the model are undocumented, but some details are provided by Sinnock et al. (1984). The code contains a numerical solution of the one-dimensional dispersionless transport equations for radionuclide decay chains (see, for example, Harada et al., 1980, p. 4-21).

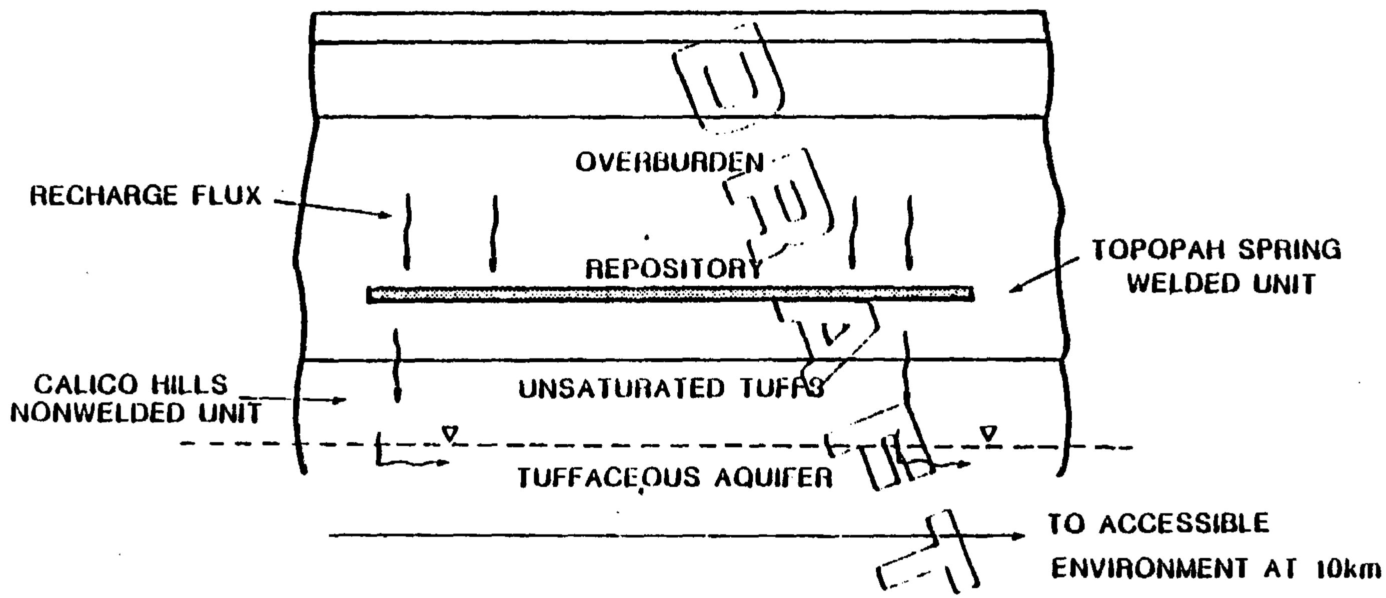

Figure 6.4.2-2. Idealized conceptual model of proposed waste-disposal system at Yucca Mountain.

In the remainder of this section, the performance of the system will be calculated with the simple conceptual model just described in three configurations. These three configurations are as follows:

1. Reference-case configuration: The reference-case configuration for the total system is intended to represent conservative estimates of values and conditions that can be supported and that are expected on the basis of subsystem assessments in Section 6.4.2.3. The reference-case values and conditions developed in Section 6.4.2.3 are collected and summarized in Table 6.4.2-3.

2. Performance-limits case configuration: The performance-limits case is the same as the reference case except that the waste package lifetime is limited to 300 years and the fractional release rate from the engineered-barrier subsystem is defined to be 1×10^{-5} per yr, the upper limit on fractional release rates defined in 10 CFR 60.113.

3. Low-retardation case configuration: The low retardation-case is the same as the reference case except that the waste package lifetime is limited to 300 years and the distribution coefficients listed in Table 6.4.2-2 are uniformly reduced 100 times.

System Analysis

Qualitative analysis shows that, in the reference case configuration,there could be no release to the accessible environment for at least 100,000 years after closure. With a 10,000-year waste package lifetime and 93,000-year water flow time, release of radioactivity would begin at about 103,000 years if effects of hydrodynamic dispersion are ignored. The major radionuclide in the release would have to be iodine-129, which is not retarded, has a half-life of about 10 million years, and represents 10,000 kg of the initial inventory. Other nonretarded nuclides, carbon-14 and technetium-99, would not appear in the release in significant amounts because carbon-14 has too short a half-life, 5,700 years, and too small an initial mass, 22 kg, to contribute much to releases at 100,000 years and technetium-99 is slightly retarded in the flow through the welded tuff (see Table 6.4.2-2).

Table 6.4.2-3. Summary of values and conditions used in preliminary system performance assessment - referance case

Item	Reference case value	Range
Waste package lifetime	10,000 yr	3,000 to 30,000 yr
Fractional release rate from Engineered Barrier Subsystem	1×10^{-8} yr[a]	0 to 2×10^{-5}/yr
Flux through repository level	0.5 mm/yr[b]	0 to 1 mm/yr[c]
Water flow times between disturbed zone and accessible environment	93,000 yr	>25,000 yr at 1 mm/yr flux[c]
Retardation factors for unsaturated tuffs	(see Table 6.4.2-2)	Consistent with 100 times more or less than Table 6.4.2-2 values for distribution coefficients

[a] See Section 6.4.2.3.

[b] Montazer and Wilson (1984) report flux <1 mm/yr, perhaps as low as 0.01 mm/yr; midpoint of this range (0.5 mm/yr) is used as reference flux.

[c] See Section 6.3.1.1.

Performance of the system in the performance-limits and low-retardation configurations are shown in Table 6.4.2-4 and in Figure 6.4.2-3 which is a plot of the Environmental Protection Agency performance measure, R(t), defined in the introduction to this section. Because of the 93,000-year water travel time, substantial releases occur for only the nonretarded species.

6.4.2.5 Comparisons with regulatory performance objectives

In this section, the results of the Subsystem Preliminary Performance Assessments, Section 6.4.2.3, and the Preliminary System Performance Assessment, Section 6.4.2.4, are informally compared with applicable regulatory performance objectives. The comparisons are not intended to show that the subsystems and total-system performance will presently meet applicable regulations. Rather, the regulatory criteria are used to detect areas that require increased study or emphasis. The comparisons may also increase or decrease levels of confidence in the ability of the subsystems and total system to eventually meet the regulatory performance objectives.

Comparisons are made in Table 6.4.2-5, which lists some of the applicable regulatory criteria, briefly summarizes their content, and presents relevant findings of Sections 6.4.2.3 and 6.4.2.4. Several cautions are warranted: with respect to 40 CFR 191.13 Working Draft 4 (item 1), the likelihood of exceeding stated release limits is not addressed by the analyses of Section 6.4.2.4; and both the conceptual and mathematical models used in the analyses are oversimplified. With respect to 40 CFR 191.15, Groundwater Protection Requirements, (item 2), the present calculations are based upon matrix flow. If flux conditions changed drastically, the rock could become saturated and fracture flow could become dominant. In such a case, travel time to the accessible environment would be decreased and some radionuclides could be released to an aquifer during the first 1000 years. Whether such fracture flow is now present at Yucca Mountain, or could occur in the future will be investigated during site characterization. The likelihood of such release is also decreased by the fact that it would require that the waste packages rupture instantaneously. In addition, decrease in travel time of this

Table 6.4.2-4. Cumulative curies released to accessible environment in preliminary system performance assessment - three configurations

Configuration	Cumulative curies released to accessible environment by: 10,000 years	100,000 years
Reference case	0	0
Performance-limits case	0	26 Ci of I-129 1×10^{-6} Ci of C-14
Low-retardation case	0	4.4 Ci of Tc-99 0.02 Ci of I-129 1×10^{-8} Ci of C-14

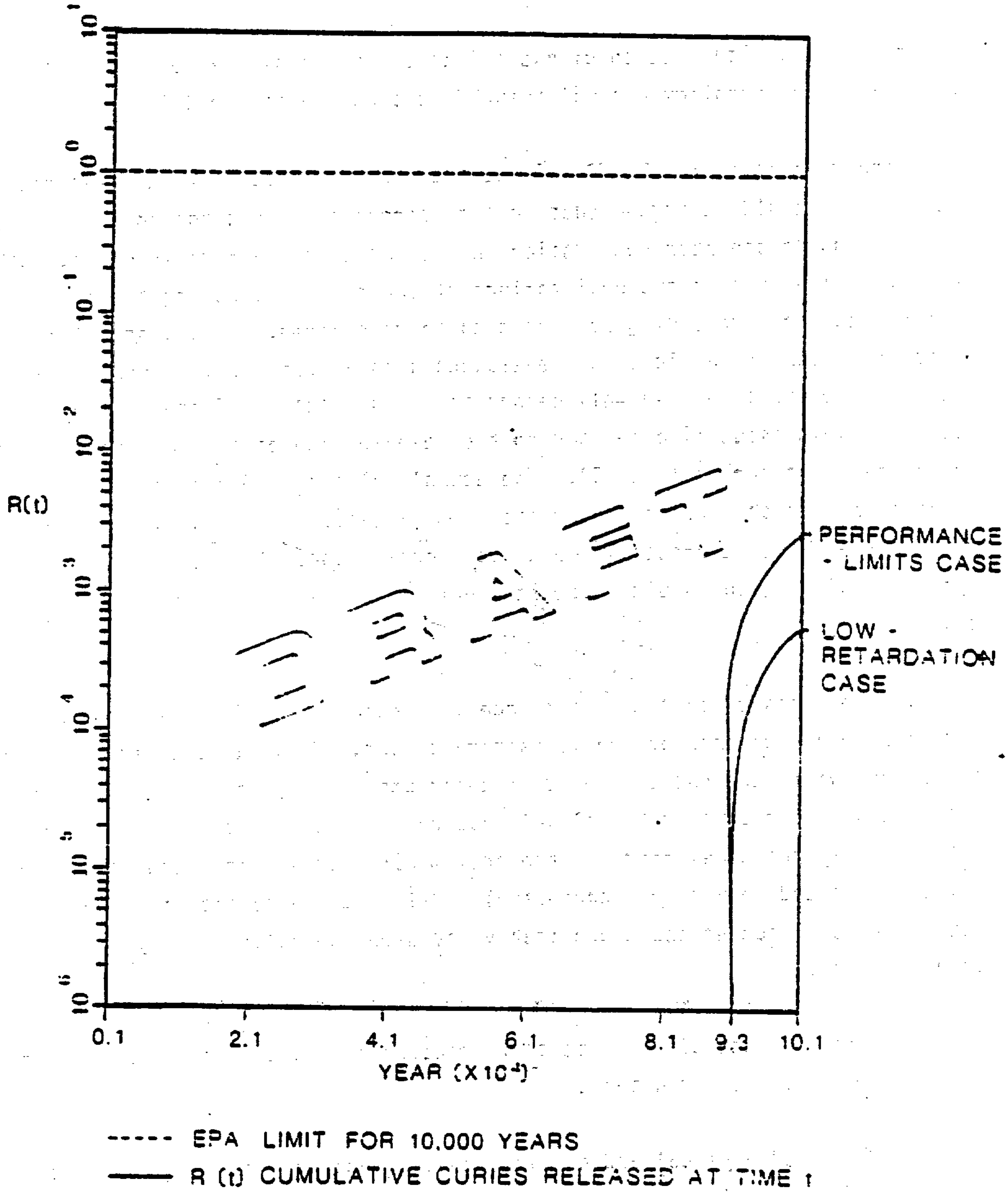

Figure 6.4.2-3. Performance of the system in the performance-limits and low-retardation configurations.

magnitude could also lead to disqualification of the site according to the 10 CFR 960, Geohydrology Disqualifying Condition (Section 6.3.1.1).

With respect to 10 CFR 60.113 requirements on waste-package lifetimes (item 4), it could be argued that uniform corrosion is not the only mechanism contributing to canister degradation in the Yucca Mountain environment. Other mechanisms involving structural failure of the canisters during their interaction with the surrounding rock need to be considered. A statistical model of canister breaching should to be developed; such a model would necessarily predict some small release well before the mean lifetime of the canister has elapsed. This issue also relates to the release rate of radionuclides after the containment period (item 5). The actual release rate appears to be proportional to the area of the waste form exposed to flowing water. The wetted area of waste probably would not increase abruptly, as postulated in the systems analyses, but would increase slowly and in a random fashion as time elapsed.

The analysis of system performance in Section 6.4.2.4 represents the undisturbed performance of the repository system. Uncertainties in predicted system behavior were not evaluated, and the possibility that the repository system could be disrupted by unlikely natural events or intentional human intrusion was not considered. These preliminary assessments were done with limited data and very simple conceptual models. Site-characterization activities and studies could profitably focus on the following key uncertainties:

1. The presence of and extent of fracture flow within the unsaturated zone at Yucca Mountain.

2. Expected physical and chemical environment in the mined repository following closure.

3. Expected waste package lifetime distributions in the postclosure repository environment.

Table 6.4.2-5. Comparison of regulatory criteria and results of preliminary system performance assessments for a repository at Yucca Mountain

Regulatory criteria	Relevant stipulations	Predicted repository system performance
1. 40 CFR 191, Working Draft 4 191. 13 Containment Requirements	"...cumulative releases of waste to accessible environment for 10,000 years after disposal (shall not exceed) quantities calculated according to Table 1 (Appendix A)."	Cumulative releases to accessible environment are zero for 10,000 years (Table 6.4.2-4).
2. 40 CFR 191, Working Draft 4 191.15 Ground Water Protection Requirements	"...for 1000 years after disposal, undisturbed performance (of the system) shall not increase the radionuclide concentrations in any major source of groundwater...by more than (a)15 picocuries per liter of alpha-emitting radionuclides; or..."	Releases to saturated zones are expected to be zero for the first 1000 years or more (Section 6.4.2.4).
3. 10 CFR 60.113	1000-year pre-waste-emplacement ground-water travel time requirement.	Ground-water travel time to accessible environment is expected to exceed 80,000 years (Section 6.4.2.3).
4. 10 CFR 60.113	Containment of radioactive waste within the waste packages will be substantially complete for a period to be determined by the NRC, (but) such a period shall not be less than 300 years nor more than 1000 years after permanent closure of the geologic repository.	Expected waste-package lifetime is 10,000 years in the Yucca Mountain environment (Section 6.4.2.3).
5. 10 CFR 60.113	The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year (of the) inventory present 1000 years after closure.	Fractional release rates are expected to be much less than 10^{-5}/yr in the Yucca Mountain environment (Section 6.4.2.3).

In addition, these and other assessments (e.g., Sinnock et al., 1984; Thompson et al., 1984) suggest that refinements in the theory of flow and transport in fractured, porous unsaturated rock will be needed before adequate post-characterization assessments can be made. In particular, methods for treating the stochastic aspects of flow and transport in fractured, porous media need to be developed in order to estimate the effects of hydrodynamic dispersion and chemical retardation on potential radionuclide releases to the accessible environment. A data base containing estimates of the mean values and upper and lower bounds for key rock properties is also essential.

6.4.2.6 Preliminary evaluation of disruptive events

The evaluations of Postclosure Technical Guidelines (Section 6.3.1) contain assessments of the effects of many potentially disruptive natural processes on a repository system located at Yucca Mountain. Summaries of some of the relevant assessments in that section are collected in the following discussion, followed by a discussion of the likelihood and consequences of human intrusion at the site after closure.

Disruptive natural processes

Fracture flows. Section 6.3.1.1, Geohydrology, noted that if the percolation flux in the Topopah Spring welded unit and Calico Hills nonwelded zeolitized tuffs exceeded about 1 mm/yr, the matrix of these rocks would eventually saturate, and flow through fracture networks would begin. Such fracture flow could drastically reduce water travel times. The initiation of fracture flow in the near future is believed to be highly unlikely because evidence from paleoclimatology suggests recharge and water table positions were relatively stable throughout the Quaternary.

Somewhat related to the problem of fracture flow is the problem of shaft-seal failures and potential increases in flux near the repository because of construction, or thermally induced increases in fracture permeability. These effects are believed to be insignificant (Section 6.3.1.3, Rock Characteristics) because under current conditions at Yucca Mountain, water moving through fractures above and around the repository could travel only a few tens of meters before being drawn into the matrix by the high matric potential (Section 6.3.1.1, Geohydrology).

Climatic changes. Under the climatic changes expected at Yucca Mountain during the next 10,000 years, increases in precipitation could increase percolation and recharge fluxes by as much as 50 percent above today's values (Section 6.3.1.4, Climatic Changes). Such an increase is expected to have no significant effect in view of the current flux values of less than 1 mm/yr. Rises in the water table below the repository are expected to be insignificant during the next 10,000 years and little change in the travel time to the accessible environment would be expected as a consequence of a slight water table rise (Section 6.3.1.4, Climatic Changes).

Extreme Erosion. Erosion (Section 6.3.1.5) has proceeded at Yucca Mountain at less than 10^{-4} m/yr for the past 10 million years. Using this rate gives 2.3 million years for the time required for removal of the minimum repository overburden thickness of 230 m. Consequently, erosion without major vertical tectonic movement is not a credible disruptive process at Yucca Mountain.

Dissolution. Section 6.3.1.6 (Dissolution) shows that dissolution of the host rock is not a credible disruptive process at Yucca Mountain. The silica-rich tuffaceous rocks are insoluble under present physical and chemical conditions at Yucca Mountain.

Effects of Tectonism. Tectonic effects are the most problematic of the potentially disruptive natural processes at Yucca Mountain. Several consequences of tectonism were considered in Section 6.3.1.7 (Tectonics): faulting might create new ground-water pathways to the accessible environment; uplift or subsidence might increase erosion rates; and the occurrence of basaltic eruptions at the site could radically change the expected geologic, hydrologic, and geochemical settings of the site. Evidence and analyses that could demonstrate the likelihood and magnitude of these consequences are generally lacking. The likelihood that any that these scenarios will occur at Yucca Mountain within the next 10,000 years is judged to be small, according to current knowledge and the limited data available. Although the region surrounding Yucca Mountain has been tectonically active during the Quaternary, there is no evidence of extreme and recent activity at the Yucca Mountain site. Carr (1984) estimates displacement rates of less than 0.04 m/1000 years. Available geologic data suggest that faults at and near Yucca Mountain have not had large (>1 m) surface displacements in the last 250,000 years (Swadley and Hoover, 1983), and have had no unequivocally demonstrated surface displacements in the last 35,000 years (Swadley et al., 1984). Regarding basaltic eruptions at the site, Crowe et al. (1982) estimate that the cumulative probability of such events disrupting the site within the next 10,000 years is between 4.7×10^{-4} and 3.3×10^{-6}. All these estimates lie near the probability limits beyond which disruptive events can be classified as not credible.

Human Intrusion. In Section 6.3.1.8, Human Interference and Natural Resources, it was concluded that there would be little incentive for resource exploration of the Yucca Mountain site in the near future. There are no known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource; limited water resources are present but are not amenable to exploitation under current economic standards and needs. Thus, as long as some records of resource distribution are available, it is highly unlikely that people will mine or drill at Yucca Mountain. However, if all records were lost to society, and a program of exploration were initiated to recover the lost information, a waste-disposal repository at Yucca Mountain could be inadvertently penetrated during exploratory drilling. The likelihood of this is small, but not insignificant when cumulated over a 10,000-yr period. In Appendix B of 40 CFR 191, Working Draft 4, a drilling rate of 3×10^{-4} boreholes per square kilometer per year is suggested as an upper limit on the rate of penetrations of nonsedimentary rocks; using this upper limit, a 1260-acre repository would be expected to be drilled about 15 times in 10,000 years. The consequences of drilling would be insignificant, however, unless the drill bit actually penetrated a waste package and material was brought to the surface in a core. The probability of contact with a 0.7 m (2.3 ft) diameter canister in a single try is 1.6×10^{-3} (the ratio of canister areas to total repository area) and the probability of one contact in 15 tries is about 8×10^{-3}. Thus, the upper likelihood of serious consequences from human intrusion over a 10,000-year-period is less than one chance in one hundred.

6.4.2.7 Conclusions

The foregoing preliminary performance assessments uncovered no information that suggests that the Yucca Mountain site is unsuitable for further characterization or that it would likely be disqualified under the Postclosure System Guideline (Section 6.3.2) following further site studies and more-refined analyses of system performance. Based on the analyses in Sections 6.4.2.3 through 6.4.2.6 and other analyses discussed in Section 6.3.2, the conclusion can be drawn that the site is suitable to be nominated for site characterization.

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LIST OF ACRONYMS

ANSI	American National Standard Institute
BLM	Bureau of Land Management
BMI	Batelle Memorial Institute
BP	Before present
BWR	Boiling water reactor
CCRPC	Clark County Regional Planning Council
CHLW	Commercial high-level waste
CHTRU	Contact-handled transuranics
CSIR	Council for Scientific and Industrial Research (South African)
DBR	Demonstration breakout room
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOE/NV	DOE, Nevada Operations Office
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DRI	Desert Research Institute
EA	Environmental Assessment
E-MAD	Engine Maintenance Assembly and Disassembly
EPA	U.S. Environmental Protection Agency
ERC	Environmental Research Corporation
ERDA	U.S. Energy Research and Development Administration
ES	Exploratory Shaft
HLW	High-level waste
H&N	Holmes & Narver, Inc.
LANL	Los Alamos National Laboratory
LATA	Los Alamos Technical Associates, Inc.
LBL	Lawrence Berkeley Laboratory
LET	Linear energy transfer
LLNL	Lawrence Livermore National Laboratory
LVCVA	Las Vegas Convention and Visitors Authority
LVMPD	Las Vegas Metropolitan Police Department
MSHA	Mine Safety and Health Administration
MTHM	Metric tons of heavy metal
MTU	Metric tons of uranium
NAAQS	Nevada Ambient Air Quality Standard
NAFB	Nellis Air Force Base
NAFR	Nellis Air Force Range
NAS	National Academy of Sciences
NDCNR	Nevada Department of Conservation and Natural Resources
NDRH	Nevada Division of Radiologic Health
NEPA	National Environmental Policy Act
NGI	Norges Geotekniske Institute (Norwegian Geotechnical Institute)
NNWSI	Nevada Nuclear Waste Storage Investigations
NOAA	National Oceanic and Atmospheric Administration

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NOCS	Nevada Office of Community Services
NRC	Nuclear Regulatory Commission
NRDA	Nevada Research and Development Area
NSHCC	Nevada State Health Coordinating Council
NSL	Nevada State Library
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act
NWTS	Nuclear Waste Terminal Storage
OBERS	Office of Business and Economic Research Service
PSD	Prevention of significant deterioration
PWR	Pressurized water reactor
REECo	Reynolds Electrical and Engineering Company, Inc.
RHTRU	Remote-handled transuranics
SAI	Science Applications, Inc.
SF	Spent reactor fuel
SMSA	Standard Metropolitan Statistic Area
SNL	Sandia National Laboratories
SWP	State Water Plan
TLDs	Thermoluminescent dosimeters
TSP	Total suspended particulates
UNLV	University of Nevada, Las Vegas
UNR	University of Nevada, Reno
USAF	United States Air Force
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WESTPO	Western Governor's Policy Office
WSA	Wilderness Study Area

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GLOSSARY

ablation	All processes by which snow and ice are lost from a glacier; also, the amount lost.
absorbed radiation dose	A measure of the amount of ionizing radiation deposited in a given mass of absorbing medium. The unit of absorbed radiation is the rad.
accessible environment	The atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that is outside the controlled area.
actinides	Radioactive elements with atomic number larger than 88.
active fault	A fault along which there is recurrent movement which is usually indicated by small, periodic displacements or seismic activity.
adsorption	The adherence of gas molecules or of ions or molecules in solutions to the surface of solids with which they are in contact.
aeromagnetic survey	A magnetic survey made with an airborne magnetometer from a moving airplane.
affected area	The area in which environmental impacts are expected.
air-fall tuff	A tuff deposited showerlike from a volcanic eruption cloud.
albite	A white or colorless triclinic mineral of the feldspar group: $NaAlSi_3O_8$. It occurs commonly in igneous and metamorphic rocks.
alkaline	Having a pH greater than 7. Also referred to as being basic (see also pH).
alluvial fan	An outspread, gently sloping mass of alluvium deposited [illegible] stream.
alluvial piedmont	Lying or formed at the base of a mountain or mountain range (see also bajada).
alluvium	A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material deposited during comparatively recent geologic time by a stream or other body of running water.

alpha radiation	Ionizing radiation composed of alpha particles, which are emitted from the nuclei of certain heavy radioisotopes as they decay. Alpha particles consist of two protons and two neutrons, have a very short range of emission (a few centimeters in air) and cannot penetrate the outer layer of human skin. Thus, they are only an internal radiation hazard.
alunite	A mineral with chemical formula, $KAl_3(SO_4)_2(OH)_6$. It usually occurs in white, gray or pink masses in hydrothermally altered feldspathic rocks. (see also feldspathic)
amorphous silica	Silica that lacks any ordered internal structure.
amphibole	A mineral group including common rock-forming minerals characterized by good prismatic cleavage.
analcime	A mineral with chemical formula: $NaAlSi_2O_6 \cdot H_2O$. It is an isometric zeolite, commonly found in alkali-rich basalts.
andesite	A dark colored, fine grained extrusive igneous rock.
angle of internal friction	The angle between a resultant force and the perpendicular line to the plane of friction.
anion	A negatively charged ion.
apatite	A group of hexagonal minerals consisting of calcium phosphate together with fluorine, chlorine, hydroxyl or carbonate in varying amounts. They occur as accessory minerals in igneous rocks, metamorphic rocks and ore-deposits.
APPLICON	A computer-aided total graphics design system that generates contour maps, etc. from data input (CAD-CAM).
aquiclude	A formation or body of relatively impermeable rock that does not transmit water rapidly enough to serve as a supply.
aquifer	A formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
aquitard	A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water (see also aquiclude).

arqillaceous	Applied to all rocks or substances composed of clay minerals or having a notable proportion of clay in their composition such as shale, slate, etc.
argillite	A compact rock, derived either from mudstone (claystone or siltstone) or shale, that has undergone a somewhat higher degree of induration than is present in mudstone or shale.
arroyo	A term applied in the arid and semiarid southwestern U.S. to a small deep flat-floored channel or gully of an ephemeral or intermittent stream.
ash-flow tuff	A tuff deposited by an ash flow or gaseous cloud.
avifauna	Birds or kinds of birds of a region, period or environment.
background radiation	The level of radiation in an area which is produced by sources other than the one of specific interest, such as naturally occurring radioactive materials in the biosphere, cosmic radiations, fallout from nuclear weapons tests, and naturally occurring radioisotopes in living organisms.
bajada	A broad, gently inclined detrital surface extending from the base of mountain ranges out into an inland basin, formed by the lateral coalescence of a series of alluvial fans, and having an undulating character.
barrier	Any material or structure that prevents or substantially delays the movement of water or radionuclides.
basalt	A dark to medium-dark-colored, commonly extrusive, mafic igneous rock composed chiefly of calcic plagioclase and clinopyroxene in a glassy or fine-grained groundmass.
base-metal	Any of the more common and more chemically active metals, e.g., lead, copper.
Basin and Range Province	Physiographic province in the SW U.S. characterized by a series of tilted fault blocks forming longitudinal, asymmetric ridges or mountains and broad, intervening basins.
bentonite	A soft, plastic light-colored clay formed by chemical alteration of volcanic ash.
beta radiation	Ionizing radiation composed of beta particles, which are essentially electrons originating from the nuclei of certain radiosotopes as they decay. High energy beta particles can be both an internal and external radiation hazard, while low energy beta particles are only an internal hazard. Beta particles can be either positively ("positron") or negatively ("negatron") charged.
biota	The flora and fauna of a region.

biotite — A common rock-forming mineral of the mica group. It is black in hand specimen, brown or green in thin section, and has perfect basal cleavage (see also mica).

boiling water reactor (BWR) — A reactor system that uses a boiling water primary cooling system. Primary cooling system steam turns turbines to generate electricity.

borehole — A hole made with a drill, auger, or other tools for exploring strata in search of minerals, for water supply, for blasting or emplacement purposes, for proving the position of old workings or faults, or for releasing accumulations of gas or water. Boreholes include core holes, dry-well monitoring holes, and waste-storage holes or test holes for geophysical or ground-water characterization.

borehole log — A log obtained from a borehole; especially a lithologic record of the rocks penetrated.

borosilicate glass — A silicate glass containing at least five percent boric acid and used to vitrify calcined waste.

breccia — A coarse-grained clastic rock composed of large (>2mm in diameter), angular, and broken rock fragments that are cemented together in a finer-grained matrix.

cairn — A heap of stones piled up as a memorial or as a landmark.

calcine — Material heated to a temperature below its melting point to bring about loss of moisture and oxidation.

calcite — A common rock-forming mineral, $CaCO_3$. Commonly white or gray, it has perfect rhombohedral cleavage. It is the chief constituent of limestone and most marble.

caldera — A large, basin-shaped volcanic depression, more or less circular or cirquelike in form.

caliche — Gravel, sand, or desert debris cemented by porous calcium carbonate; also the calcium carbonate itself.

candidate site — An area, within a geohydrologic setting, that is recommended by the Secretary of Energy under Section 112 of the Act for site characterization, approved by the President under Section 112 of the Act for characterization, or undergoing site characterization under Section 113 of the Act.

capillary fringe — The zone immediately above the water table in which all or some of the interstices are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table.

caprock	A comparatively impervious layer of rock immediately overlying a fluid-bearing reservoir.
carbonate	A mineral compound characterized by a fundamental anionic structure of $CO_3^{=}$.
catchment area	As applied to an aquifer, the recharge area and all areas that contribute water to it.
cation	A positively charged ion.
chromatographic	Of or relating to several processes of separating components of a sample by moving the sample in a mixture or solution over or through a medium using adsorption, partition, ion exchange, or other property in such a way that different components become separated.
cinder cone	A conical hill formed by the accumulation of cinders and other pyroclasts around a volcanic vent.
cistern	An artificial reservoir for storing liquids and especially water.
cladding hull	A metal or ceramic covering that contains the radioactive fuel material.
clastic	Pertaining to a rock or sediment composed principally of fragments derived from preexisting rocks or minerals and transported some distance from their places of origin; also said of the texture of such a rock.
clinoptilolite	A relatively common zeolite mineral associated with other zeolites; is also a widespread alteration product of intermediate to acid volcanic glass and occurs as a mineral in sedimentary rocks, especially tuffaceous sandstones. It is a potassium-rich variety of the mineral heulandite and commonly white in color.
clinopyroxene	Any of the group of pyroxenes crystallizing in the monoclinic system and sometimes containing considerable calcium with or without aluminum and the alkalies.
closure	Final backfilling of the remaining open operational areas of the underground facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts.
coefficient of friction	An experimental constant dealing with forces when two solid bodies which are in contact slide or tend to slide on each other. The constant depends largely on the roughness of the mating surfaces.
cohesion	Shear strength of a rock not related to interparticle friction.

colloid — In reference to a substance that contains particles of greater size than ordinary molecules. Colloidal particles cannot diffuse through membranes which allow ordinary molecules and ions to pass freely.

compressive strength — The maximum compressive stress that can be applied to a material, under given conditions, before failure occurs.

confining unit — A body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

coniferous — Said of a tree having needlelike or scalelike leaves and naked seeds borne in cones.

containment — The confinement of radioactive waste within a designated boundary.

controlled area — A surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be prohibited before and after permanent closure.

core (geologic) — A cylindrical section of rock, usually 5-10 cm in diameter and up to several meters in length, taken by a core bit and brought to the surface for examination and/or analysis.

craton — A generally large part of the earth's crust which has attained stability, and which is relatively immobile.

cristobalite — A mineral: SiO_2. It is a high-temperature form of quartz and tridymite, and occurs as white octahedrons in acidic volcanic rocks.

crystalline — Of or pertaining to the nature of crystal, having regular molecular structure as contrasted with amorphous.

cryptocrystalline — Said of a texture of a rock consisting of crystals that are too small to be recognized and distinguished under the ordinary microscope.

cumulative releases of radionuclides — The total number of curies of radionuclides entering the accessible environment in any 10,000-year period, normalized on the basis of radiotoxicity in accordance with 40 CFR Part 191. The peak cumulative release of radionuclides refers to the 10,000-year period during which any such release attains its maximum projected value.

curie — A unit of radioactivity used to describe the number of atoms undergoing radioactive decay as a function of time.

dacitic	Characteristic of a fine-grained extrusive rock with the same general composition as andesite but having a less calcic feldspar (dacite).
debris-flow (geologic)	A moving mass of rock fragments, soil, and mud, with more than half of the particles being larger than sand size.
decay products (radioactive)	Remaining materials after radioactive products undergo a change from one isotope or state to another, releasing radiation in the process.
decommissioning	The permanent removal from service of surface facilities and components necessary for preclosure operations only, after repository closure, in accordance with regulatory requirements and environmental policies.
denudation	The sum of the processes that result in the wearing-away or the progressive lowering of the earth's surface by weathering, mass wasting, and transportation; also the combined destructive effects of such processes (see also erosion).
deposition	The laying down of rock-forming material by any natural agent, e.g., the mechanical settling of sediment from suspension in water.
detrital	See detritus.
detritus	Loose rock or mineral material removed directly by mechanical means and deposited at another site.
devitrification	Conversion of the glassy texture of rock to a crystalline texture after its solidification.
diagenetic alteration	All the changes undergone by a sediment after its initial deposition, exclusive of weathering and metamorphism. Also known simply as diagenesis.
diapir	A dome or fold, the overlying rocks of which have been ruptured by the squeezing-up of the plastic core material.
dike (geologic)	A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks.
dip-slip fault	A fault in which the earth's displacement is parallel to the dip of the fault, and there is no horizontal component parallel to the strike.
disposal	The emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste, and the isolation of such waste from the accessible environment.

disqualifying condition	A condition that, if present at a site, would eliminate that site from further consideration.
dissolution front	A planar feature which provides evidence that rocks have been or are presently being dissolved in the presence of fluids.
disturbed zone	That portion of the controlled area, excluding shafts, whose physical or chemical properties are projected to change permanently as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of the geologic repository.
dose equivalent (radiation)	A concept used to describe the effectiveness of a given unit of absorbed radiation dose. The unit of dose equivalent is the rem.
dosimetry	The measurement and evaluation of absorbed radiation dose or dose equivalent.
downfaulted	Said of rocks on the downthrown side of a fault.
drag fold	A minor fold, usually one of a series, formed in an incompetent bed lying between more competent beds, produced by movement of the competent beds in opposite directions relative to one another.
drift	Horizontal, or nearly horizontal, mined passageway.
ductility	Property of solid material that undergoes more or less plastic deformation before it ruptures.
earthquake	A sudden motion or trembling in the earth caused by the abrupt release of slowly accumulated strain.
ecosystem	An ecologic system, composed of organisms and their environment.
ecotone	A transition zone that exists between two ecologic communities.
effective porosity	The amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as the ratio of the volume of interconnected pores and openings to the volume of rock.
electrical resistivity	The electrical resistance per unit length of a unit cross-sectional area of a material.
endemic plant	A plant that is restricted or peculiar to a locality or region.

engineered barrier system	The manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. Such term includes the radioactive-waste form, radioactive-waste canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility.
environmental assessment	The document required by Section 112(b)(1)(E) of the Nuclear Policy Act of 1982.
eolian	Pertaining to the wind; especially said of deposition of sediments by the wind or of structures such as wind-formed ripple marks, or of erosion accomplished by the wind.
ephemeral drainage	Drainage of a stream or portion of a stream which flows briefly in direct response to precipitation in the immediate vicinity, and whose channel is at all times above the water table.
epicenter (earthquake)	The point on the earth's surface directly above the exact subsurface location of an earthquake.
equilibrium	A state of adjustment between opposing or divergent influences or elements.
erosion	The wearing-away of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, wind and underground water (see also denudation).
evaporation	To dissipate or draw off in fumes; to convert into vapor.
evapotranspiration	That portion of the precipitation returned to the air through evaporation and transpiration.
expected	Assumed to be probable or certain on the basis of existing evidence and in the absence of significant evidence to the contrary.
expected repository performance	The manner in which the repository is projected to function, considering those conditions, processes, and events that are most likely to prevail or occur during the time period of interest.
extrusive	Said of igneous rock that has been erupted onto the surface of the earth.
facility	Any structure, system, or system component, including engineered barriers, created by the DOE to meet repository performance or functional objectives.

fallout (radioactive) — Radioactive fallout consists of fission and activation products produced by the above-ground detonation of a nuclear device. These fission and activation products are carried upward by the energy of the resulting cloud and then "fallout" or precipitate either locally or distantly depending on factors such as particle size, initial elevation, atmospheric transport conditions, etc.

fault — A fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture or zone of fractures.

fault block — A crustal unit formed by block faulting; it is bounded by faults, either completely or in part.

fault escarpment — See fault scarp.

fault scarp — The cliff or escarpment formed by a fault that reaches the earth's surface.

faulting — The process of fracturing and displacement that produces a fault.

favorable condition — A condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular guideline can be met.

feldspar — A group of abundant rock-forming minerals of general formula: MAl $(Al,Si)_3O_8$, where M=K, Na, Ca, Ba, Rb, Sr, and Fe. Feldspars are the most widespread of any mineral group and constitute 60 percent of the earth's crust.

feldspathic — Containing feldspar as a principal ingredient.

ferromagnesian — Containing iron and magnesium; applied to mafic minerals (see also mafic).

fission (nuclear) — The division of the nucleus into nuclides of lower mass, accompanied by emission of gamma rays, neutrons, and significant energy.

fluorite — A clear to translucent mineral with chemical formula, CaF_2 belonging to the isometric crystal class. It is commonly blue or purple, but occurs in many other colors.

fluvial — Of or pertaining to rivers; growing or living in a stream or river; produced by the action of a stream or river.

fold (geologic) — A bend or flexure in bedding, foliation, cleavage, or other planar features in rock. A fold is usually a product of deformation.

fracture permeability — The capacity of a fracture for transmitting a fluid; it is the measure of the relative ease of fluid flow under unequal pressure.

fugitive emissions — Emissions of any pollutant, including fugitive dust, which do not pass through a stack, chimney, vent, or a functionally equivalent opening and are generated by activities necessary for continued operation of the source.

fumarole — A vent, usually volcanic, from which gases and vapors are emitted; it is characteristic of a late stage of volcanic activity.

fumarolic — See fumarole.

gamma radiation — Electromagnetic ionizing radiation which is emitted during some types of radioactive decay processes. Gamma radiation can penetrate various thicknesses of absorbed material depending primarily on the energy of the gamma ray and the composition of the material. Gamma radiation is primarily an external radiation hazard.

geochemistry — The study of the distribution and amounts of the chemical elements in minerals, ores, rocks, soils, water and the atmosphere.

geochronology — Study of time in relationship to the history of the earth.

geodetic survey — Survey in which account is taken of the figure and size of the earth and corrections are made for earth curvature.

geohydrologic setting — The system of geohydrologic units that is located within a given geologic setting.

geohydrologic system — The geohydrologic units within a geologic setting, including any recharge, discharge, interconnections between units, and any natural or man-induced processes or events that could affect ground-water flow within or among those units.

geohydrologic unit — An aquifer, a confining unit, or a combination of aquifers and confining units comprising a framework for a reasonably distinct geohydrologic system.

geomechanics — That branch of geology dealing with the response of earth materials to the application of deforming forces and embracing the fundamentals of structural geology.

geomorphology — The branch of geology that deals with the general configuration of the earth's surface; specifically the study of the classification, description, nature, origin, and development of landforms.

geologic repository	A system, requiring licensing by the NRC, that is intended to be used, or may be used, for the disposal of radioactive waste in excavated geologic media. A geologic repository includes (1) the geologic-repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.
geologic-repository operations area	A radioactive-waste facility that is part of the geologic repository, including both surface and subsurface areas and facilities where waste-handling activities are conducted.
geologic setting	The geologic, hydrologic, and geochemical systems of the region in which a geologic-repository operations area is or may be located.
geomorphic processes	Geologic processes that are responsible for the general configuration of the earth's surface, including the development of present landforms and their relationships to underlying structures, and are responsible for the geologic changes recorded by these surface features.
geophone	See seismometer.
geophysical	Applies to the study of the earth with respect to its structure, composition, and development.
geosyncline	Large, generally linear trough that subsided deeply throughout a long period of time in which a thick sequence of stratified sediments accumulated.
geotechnical	Pertaining to the application of scientific methods and engineering principals to the acquisition, interpretation, and use of knowledge of materials of the earth's crust.
geothermal gradient	The rate of increase of temperature of the earth with depth.
gneiss	A foliated rock formed by regional metamorphism, in which bands of granular minerals alternate with bands of minerals with flaky or elongate prismatic habit.
granite	A plutonic rock in which quartz makes up 10 to 50 percent and the alkali feldspar ratio is 65 to 90 percent.
gravity survey	Measurements of the gravitational field at a series of different locations. The object is to associate variations with differences in the distribution of densities and hence rock types.
Great Basin	A subdivision of the Basin and Range Province; located in southern Nevada within a broad desert region.

ground motion (earthquake)	The displacement of the ground due to the passage of elastic waves arising from earthquakes, explosions, seismic shots, and the like.
ground water	Subsurface water as distinct from surface water.
ground-water basin	A subsurface structure having the character of a basin with respect to the collection, retention and outflow of water.
ground-water flux	The rate of ground-water flow per unit area of porous or fractured media measured perpendicular to the direction of flow.
ground-water sources	Aquifers that have been or could be economically and technologically developed as sources of water in the foreseeable future.
ground-water travel time	The time required for a unit volume of ground water to travel between two locations. The travel time is the length of the flow path divided by the velocity, where velocity is the average ground-water flux passing through the cross-sectional area of the geologic medium through which flow occurs, perpendicular to the flow direction, divided by the effective porosity along the flow path. If discrete segments of the flow path have different hydrologic properties, the total travel time will be the sum of the travel times for each discrete segment.
guideline	A statement of policy or procedure that may include, when appropriate, qualifying, disqualifying, favorable, or potentially adverse conditions as specified in the "guidelines."
guidelines	Part 960 of Title 10 of the Code of Federal Regulations (CFR) - General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories.
half-life (radioactive)	The time it takes for one-half of the radioactive atoms initially present to decay.
herbaceous	Having little or no woody tissue and persisting usually for a single growing season.
high-level radioactive waste	The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; other highly radioactive material that the NRC, consistent with existing law, determines by rule requires permanent isolation.

highly populated area — Any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2500 or more persons, or any census designated place (as defined and delineated by the Bureau) of 2500 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.

Hooke's law — A statement of elastic deformation, that the strain is linearly proportional to the applied stress.

host rock — The geologic medium in which the waste is emplaced, specifically the geologic materials that directly encompass and are in close proximity to the underground facility.

hot cell — A facility that allows remote viewing and manipulation of radioactive substances.

hydraulic conductivity — The volume of water that will move through a medium in a unit time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

hydraulic gradient — A change in the static pressure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction.

hydraulics — An engineering discipline dealing with the statics and dynamics of fluids (see also hydrology).

hydrogeologic unit — Any soil or rock unit or subsurface zone that has a distinct influence on the storage or movement of ground-water by virtue of its porosity or permeability.

hydrograph — A graph showing stage, flow, velocity, or other characteristics of water with respect to time.

hydrologic process — Any hydrologic phenomenon that exhibits a continuous change in time, whether slow or rapid.

hydrologic properties — Those properties of a rock that govern the entrance of wat- and the capacity to hold, transmit, and deliver water, such as porosity, effective porosity, specific retention, permeability, and the directions of maximum and minimum permeabilities.

hydrology — Hydrology deals with global water and its properties, circulation, and distribution, from the time it falls as rainwater until it is returned to the atmosphere through evapotransoiration or flows into the ocean (see also hydraulics).

hydrothermal alteration	Alteration of rocks or minerals by the reaction of heated water with pre-existing solid phases.
igneous activity	The emplacement (intrusion) of molten rock material (magma) into material in the earth's crust or the expulsion (extrusion) of such material onto the earth's surface or into its atmosphere or surface water.
igneous rock	A rock or mineral that solidified from molten or partly molten material, i.e., from a magma.
ilmenite	An iron-black opaque rhombohedral mineral with formula, $FeTiO_3$. It is a common accessory mineral in basic igneous rocks and is also concentrated in mineral sands.
impoundment	The process of forming a lake or pond by a dam, dike, or other barrier; also, the body of water so formed.
induration	The hardening of rock material by heat, pressure, or the introduction of some cementing material.
in situ testing	Various surveys and tests run on materials in their natural position; specifically of a rock, soil, or fossil when in the situation in which it was originally formed or deposited.
intensity (earthquake)	Measure of the effects of an earthquake on man, on man-built structures, and on the earth's surface at a particular location. Quantified by a numerical value on the Modified Mercalli Scale [see also magnitude (earthquake), Modified Mercalli Scale, and Richter Scale].
interstice	An opening or space in a rock or soil.
interstitial	A term referring to the space between particles.
intrusive	Of or pertaining to the emplacement of magma in pre-existing rock; magmatic activity.
ion	An atom or group of atoms that is not electrically neutral but instead carries a positive or negative electric charge (see also anion and cation).
isolation	Inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.
isopleth	A general term for a line on a map or chart that connects points of equal value.

isotope	One of two or more species of the same chemical element, i.e., having the same number of protons in the nucleus, but differing from one another by having a different number of neutrons.
joint (geologic)	A surface of fracture or parting in a rock, without displacement; the surface is often a plane and may occur with parallel joints to form a joint set.
kinetics	A branch of science that deals with the effects of forces upon the motions of material bodies or with changes in a physical or chemical system.
lacustrine	Pertaining to, produced by, or inhabiting a lake or lakes. Said of a region characterized by lakes.
latite	A porphyritic extrusive rock having plagioclase and potassium feldspar present in nearly equal amounts as phenocryts, little or no quartz, and a finely crystalline groundmass.
lava flow	A lateral surficial outpouring of molten magma from a volcanic vent or fissure.
leachate	A solution obtained by leaching; e.g., water that has percolated through soil containing soluble substances and that contains certain amounts of these substances in solution.
leaching	The dissolution of soluble constituents from a rock or ore body by the action of percolating water or chemicals.
ligand	A group, ion, or molecule coordinated to a central atom in a complex.
likely	Possessing or displaying the qualities, characteristics, or attributes that provide a reasonable basis for confidence that what is expeceted indeed exists or will occur.
lineament	A linear topographic feature of regional extent that is believed to reflect crustal structure. Examples are fault lines, aligned volcanoes, and straight stream courses.
linear energy transfer (LET)	A measure of the energy deposited per unit of path length.
linear expansion	The change in length of a solid due to the change in temperature. The coefficient of linear expansion is the change in a solid's unit length per 1 degree change in temperature.
lithology	The description of rocks, especially in hand specimen and in outcrop. The physical character of a rock.

lithophysae	Hollow, bubblelike structures composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials.
lithosphere	The solid part of the earth, including any ground water contained within it.
low-level waste (radioactive)	Radioactive material that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material as defined in Section 11a(2) of the Atomic Energy Act of 1954.
mafic	Said of an igneous rock composed chiefly of dark, ferromagnesian minerals.
magma	Naturally occurring mobile rock material, generated within the earth and capable of extrusion and intrusion, from which igneous rocks are thought to have been derived through solidification and related processes.
magnetic survey	A type of survey made with a magnetometer, on the ground or in the air, that yields local variations, or anomalies, in magnetic field intensity.
magnetite	A black, isometric, strongly magnetic, opaque mineral. It constitutes an important ore of iron and is very common and widely distributed in rocks of all kinds.
magnitude (earthquake)	The measure of the strength of an earthquake; related to the energy released in the form of seismic waves, as determined by seismographic observation. Magnitude is quantified c.. numerical value on the Richter Scale (see also intensity, Modified Mercalli Scale, and Richter Scale).
member of the public	Any individual who is not engaged in operations involving the management, storage, and disposal of radioactive waste. A worker so engaged is a member of the public except when on duty at the geologic repository operations area.
metamorphism (geologic)	The mineralogical, chemical, and structural adjustment of solid rocks to physical and chemical conditions imposed at depth below the surface zones of weathering and cementation, which differ from the conditions under which the rocks originated.
metastable (chemistry)	Said of a phase that is stable with respect to small disturbances but that is capable of reaction with evolution of energy if sufficiently disturbed.
metastable (radionuclide)	A state of temporary nuclear stability which occurs in some types of radioactive decays. During these decays (called "isomeric transition"), an intermediate product is formed by the first stage of decay. This product has a half-life long enough to be considered a separate isotope.

mica	A group of minerals consisting of complex silicates with perfect basal cleavage, which split into thin elastic laminae and range from colorless to black (see also biotite).
midden	Manure pile (see also scat).
mineral	A naturally occurring inorganic element or compound having an orderly internal structure and a characteristic chemical composition, crystal form, and physical properties.
mineralogy	The study of minerals: formation, occurrence, properties, composition, and classification.
mitigation	A term meaning (1) avoiding the impact altogether by not taking a certain action or parts of an action; (2) minimizing impacts by limiting the degree or magnitude of the action and its implementation; (3) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (4) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; or (5) compensating for the impact by replacing or providing substitute resources or environments.
model	A conceptual description and the associated mathematical representation of a system, subsystem, component, or condition that is used to predict changes from a baseline state as a function of internal and/or external stimuli and as a function of time and space.
Modified Mercalli Scale	An earthquake intensity scale having 12 divisions ranging from I (not felt by people) to XII (damage nearly total), commonly abbreviated M.M. [see also magnitude (earthquake)]
modulus of deformation	A term used for materials that deform other than according to Hooke's law. Also called modulus of elasticity. (see Hooke's law)
mordenite	One of the zeolite minerals which generally has a sodium-rich composition and is frequently associated with clinoptilolite, having essentially the same occurrence.
muck	Broken rock or ore that results from excavation during mining operations.
multivalent	An element is said to be multivalent when one atom of that element can hold more than one atom of hydrogen in chemical combination if negative, or can displace in a reaction if positive.

neutron probe	A probe that measures the intensity of radiation (neutrons or gamma rays) artificially produced when rocks around a borehole are bombarded by neutrons from a synthetic source.
noble gases	A group of rare gases that includes helium, neon, argon, krypton, xenon, and sometimes radon and that exhibit great stability and extremely low reaction rates. Also known as inert gases.
normal fault	A fault in which one side (the hanging wall) appears to have moved downward relative to the other (footwall). The angle of the fault is usually 45 to 90°.
NO_x	Oxides of nitrogen, specifically NO and NO_2.
outcrop (geologic)	That part of a geologic formation or structure that appears at the surface of the earth.
overburden (geologic)	1. Loose or consolidated rock material that overlies a mineral deposit and must be removed prior to mining. 2. The upper part of a sedimentary deposit, compressing and consolidating the material below.
overcoring	A process for determining stress components in a rock mass. The process consists of drilling a small diameter borehole and inserting deformation sensing devices. Subsequently, a larger diameter hole is drilled concentrically with the first hole and in doing so, relieves the stress in the rock cylinder. The measured deformations are related to stresses through elastic relationships.
overpack	Any receptacle, wrapper, box, or other structure that becomes an integral part of a radioactive waste package and is used to enclose a waste container for purposes of providing additional protection or meeting the requirements of an acceptance or isolation criterion for a specific site.
oxidation (chemical)	The process of combining with oxygen; e.g., the oxidation o Zn given ZnO.
packer-injection tests	A variety of tests whereby a liquid (usually water) or gas is injected into a "sealed off" or isolated portion of a borehole or well to obtain data on such things as formation permeability and fracture flow parameters of rocks.
paleoclimate	The climate of the geologic past.
paleoecology	The study of the relationship between ancient organisms and their environment.
paleohydrology	The study of ancient hydrologic features preserved in rock.
paleosol	A buried soil; a soil of the past.

pedology	The study of the morphology, origin, and classification of soils.
perched ground water	Unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a perched water table. Perched ground water is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.
perennial	Present at all seasons of the year.
performance assessment	Any analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions.
permeability	A rock's capacity for transmitting fluid which is measured by the rate at which a fluid can move a given distance through a given time interval. The customary unit of measurement is the millidarcy.
permanent closure	Synonymous with closure.
petrofabric	The actual rock fabric as analyzed on the thin-section or micro scale, including grain shapes and relationships.
petroglyph	A rock carving; it usually excludes writing and therefore is of prehistoric or protohistoric age.
petrography	That branch of geology dealing with the description and systematic classification of rocks especially by means of miroscopic examination of thin sections.
petrology	That branch of geology dealing with the origin, occurrence, structure, and history of rocks.
pH	The negative $\log_{10}$ of the hydrogen-ion activity in solution; a measure of the acidity or basicity of a solution.
phenocryst	A textural term applied to any relatively large conspicuous crystal in an igneous rock.
phosphatic rock	Any rock that contains one or more phosphatic minerals, especially apatite.
photogrammetry	The science and art of obtaining reliable measurements from photographs.
piezometer	An instrument for measuring the change of pressure of a material subjected to hydrostatic pressure.
pillar	A solid mass of rock left standing to support a mine roof.

playa	The lowest, central portion of arid basins, which is dry and totally barren most of the time, but occasionally flooded to shallow depths. Clay and silt are the principal constituents, resulting often from former lakes during the Pleistocene.
pluvial	Pertaining to rain, or to precipitation. Also said of a climate characterized by relatively high precipitation.
Poisson's ratio	The ratio of the lateral unit strain to the longitudinal unit strain in a body that has been stressed longitudinally within its elastic limit.
porphyritic	An igneous texture in which larger crystals (phenocrysts) are set in a finer groundmass which may be crystalline or glassy or both.
postclosure	The period of time after the closure of the geologic repository.
potable water	Water that is suitable for drinking.
potentially acceptable site	Any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the DOE undertakes preliminary drilling and geophysical testing for the definition of site location.
potentially adverse condition	A condition that is presumed to detract from expected system performance unless further evaluation, additional data, or the identification of compensating or mitigating factors indicates that its effect on the expected system performance is acceptable.
potentially disruptive processes and events	Those natural processes and events, or processes and events initiated by human activities, affecting the geologic setting that are judged to be reasonably unlikely to occur during the period over which the intended performance objective must be achieved, but that are nevertheless sufficiently credible to warrant consideration.
potentiometric	Said of, or relating to electromotive forces.
precipitation (geochemical)	The process of separating mineral constituents from a solution by evaporation, or from magma to form igneous rocks.
preclosure	The period of time before and during the closure of the geologic repository.
pressurized water reactor (PWR)	A reactor system that uses a pressurized water primary cooling system. Steam formed in a secondary cooling system is used to turn turbines to generate electricity.

pre-waste-emplacement	The period of time before the authorization of repository construction by the NRC.
pumice	A light-colored, cellular, glassy rock commonly having the composition of rhyolite.
pyroclast	An individual particle ejected during a volcanic eruption.
quadrangle (geographic)	A tract of country represented by one of a series of map sheets (as published by the U.S. Geological Survey).
qualifying condition	A condition that must be satisfied for a site to be considered acceptable with respect to a specific guideline.
quality factor (radiation)	A measure of the relative biological effectiveness of a given type of radiation.
quartz	Crystalline silica, an important rock-forming mineral, SiO_2. It is, next to feldspar, the most common mineral, occurring either in transparent hexagonal crystals or in crystalline or cryptocrystalline masses.
quartzite	A metamorphic rock consisting mainly of quartz grains of equal size formed by recrystallization of sandstone by regional or thermal metamorphism.
quaternary period	The second period of the Cenozoic Era, following the Tertiary, beginning 2 to 3 million years ago and extending to the present.
radiation (ionizing)	Particles and electromagnetic energy emitted by nuclear transformations that are capable of producing ions when interacting with matter; gamma rays and alpha and beta particles are primary examples.
radioactive waste	High-level radioactive waste and other radioactive materials, including spent nuclear fuel, that are received for emplacement in a geologic repository.
radioactive-waste facility	A facility subject to the licensing and related regulatory authority of the NRC pursuant to Sections 202(3) and 202(4) of the Energy Reorganization Act of 1974 (88 Stat. 1244).
radioisotope	A radioactive isotope of an element.
radionuclide	An unstable radioactive isotope that decays toward a stable state at a characteristic rate by the emission of ionizing radiation(s).

radionuclide retardation	The process or processes that cause the time required for a given radionuclide to move between two locations to be greater than the ground-water travel time, because of physical and chemical interactions between the radionuclide and the geohydroogic unit through which the radionuclide travels.
rain shadow	A very dry region on the lee side of a topographic obstacle, usually a mountain range, where the rainfall is noticeably less than on the windward side.
raptorial	Of, relating to, or being a bird of prey.
reasonably available technology	Technology that exists and has been demonstrated, or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods.
recharge (hydrologic)	The processes involved in the addition of water to the zone of saturation; also, the amount of water added.
reduction (chemical)	The removal of oxygen from a compound.
relative porosity	The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.
repository	Synonymous with geologic repository.
repository closure	Synonymous with closure.
repository construction	All excavation and mining activities associated with the construction of shafts, shaft stations, rooms and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site characterization activities.
repository operation	All of the functions at the site leading to and involving radioactive-waste emplacement in the underground facility, including receiving, transportation, handling, emplacement, and, if necessary retrieval.
repository support facilities	All permanent facilities constructed in support of site characterization activities and repository construction, operation, and closure activities, including surface structures, utility lines, roads, railroads, and similar facilities, but excluding the underground facility.
residual saturation	The minimum saturation that occurs due to gravitational forces alone in the absence of recharge.

restricted area — Any area to which access is controlled by the DOE for purposes of protection of individuals from exposure to radiation and radioactive materials before repository closure, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

retrieval — The act of intentionally removing radioactive waste before repository closure from the underground location at which the waste had been previously emplaced for disposal.

rhyolitic — Characteristic of a group of extrusive igneous rocks, generally porphyritic and exhibiting flow texture with phenocrysts of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass (rhyolite).

Richter magnitude — See Richter Scale.

Richter Scale — A logarithmic scale of energy released that characterizes earthquake magnitude, as measured on an instrument such as a seismometer, which transforms the mechanical effects of earth shocks into electrical signals. It was devised in 1935 by the seismologist C. R. Richter. Very small earthquakes, or microearthquakes, can have negative magnitude values (see also intensity, magnitude, earthquakes, and Modified Mercalli Scale).

rift (geologic) — A long, narrow trough bounded by normal faults; of regional extent, often associated with volcanism.

right-lateral fault — A fault, the displacement of which is right-lateral separation. In plan view, the apparent movement of the side opposite the observer is to the right.

riparian — Relating to or living or located on the bank of a natural water course, e.g., a river.

rock — An aggregate of one or more minerals, e.g., granite, shale marble, or a body of undifferentiated mineral matter, e.g., obsidian, or of solid organic material, e.g., coal.

rock bolt — An apparatus used to secure or strengthen rocks in mine workings, tunnels, or rock abutments by drilling and then inserting and firmly anchoring the bolt.

saturated zone — That part of the earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

scarification — The process of breaking up and loosening the surface of a material.

scat — An animal fecal dropping (see also midden).

Secretary — The Secretary of Energy.

seismic — Pertaining to an earthquake or earth vibration, including those that are artificially induced.

seismicity — The tendency for the occurrence of earthquakes or the spatial distribution of earthquake activity. Also the phenomenon of earth movement.

seismic reflection survey — A type of seismic survey based on measurement of the travel times of waves that originate from an artificially produced disturbance and are reflected back to the surface at near-vertical incidence from subsurface boundaries separating media of different elastic-wave velocities.

seismic refraction survey — A type of seismic survey based on the measurement of the travel times of seismic waves that have moved nearly parallel to the bedding in high-velocity layers, in order to map such layers.

seismic survey — Gathered seismic data from an area; the initial phase of seismic prospecting.

seismometer — An instrument that receives seismic impulses and converts them into electrical voltage or otherwise makes them evident. Also known as a geophone.

shale — A fine-grained detrital sedimentary rock, formed by the compaction of clay, silt or mud.

shear resistance — The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called cohesion. Also called shear strengtn.

shear zone — A tabular zone of rock that has been crushed and brecciated by many parallel fractures due to snear strain.

shield rocks — Areas of exposed-basement rocks in a craton commonly with a very gently convex surface, surrounded by sediment-covered platforms. (see also craton)

silicification — The introduction of, or replacement by, silica, generally resulting in the formation of fine-grained quartz, chalcedony, or opal, which may fill pores and replace existing minerals.

silicified — See silicification.

sill (geologic) — A tabular igneous intrusion that parallels the planar structure of the surrounding rock.

site	A potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.
site characterization	Activities, whether in the laboratory or in the field, undertaken to establish the geologic condition and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.
siting	The collection of exploration, testing, evaluation, and decision-making activities associated with the process of site screening, site nomination, site recommendation, and site approval for characterization or repository development.
slurry	A highly fluid mixture of water and finely divided material, e.g., pulverized coal and water.
smectite	A group of expanding-lattice clay minerals. These minerals are common in soils, sedimentary rocks and some mineral deposits and are characterized by swelling in water and extreme colloidal behavior.
sonic velocity	Continuous recording of travel time of sound from surface to an instrument lowered down a borehole.
sorptive	The ability to take up and hold by either adsorption or absorption.
specific activity	The measure of radioactivity as a function of mass. The unit of specific activity is curie/g.
spent nuclear fuel	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.
spherulitic	Texture of a rock composed of numerous rounded or spherical masses of needlelike crystals, radiating from a central point.
strain	Change in the shape or volume of a body as a result of stress; a change in relative configuration of the particles of a substance.

stratigraphy	The branch of geology that deals with rock strata. It is concerned with all characters and attributes of rocks as strata; and their interpretation in terms of mode of origin and geologic history.
stress	In a solid, the force per unit area acting on any surface within it and variously expressed as pounds or tons per square inch, or dynes or kilograms per square centimeter; also, by extension, the external pressure which creates the internal force.
strike (geologic)	The direction or trend of a structural surface, e.g., a bedding or fault plane, as it intersects the horizontal.
strike-slip fault	A fault in which the net slip is horizontal or parallel to the strike of the fault (see also dip-slip fault).
subsidence	Sinking or downward settling of the earth's surface, not restricted in rate, magnitude, or area involved.
surface facilities	Repository support facilities within the restricted area.
surface water	Any waters on the surface of the earth, including fresh and salt water, ice, and snow.
system	The site, engineered components, and associated processes and events that affect expected repository performance, considered as an integrated entity.
system performance	The total, integrated result of all acting processes and events caused by or affecting a repository.
tailings	Those portions of washed or milled ore that are regarded as too poor to be treated further.
tectonic	Of, or pertaining to, the forces involved in, or the resulting structures or features of, tectonics.
tectonics	A branch of geology dealing with the broad architecture of the outer part of the earth; that is, the regional assembling of structural or deformational features, a study of their mutual relations, their origin, and their historical evolution.
tensile strength	The ability of a material to resist a stress tending to stretch it or to pull it apart.
thermal conductivity	1. The time rate of transfer of heat by conduction, througn unit thickness, across unit area for unit difference of temperature. 2. A measure of the ability of a material to conduct heat.

thermal expansion	An increase in the linear dimensions of a solid or in the volume of a fluid as a result of an increase in temperature.
thermodynamic	The relation of heat to mechanical and other forms of energy.
thermoluminescent dosimeter (TLD)	A type of dosimetric (or radiation measurement device) containing a "chip" of thermoluminescent material which emits light when subjected to heat. The amount of light emitted is directly proportional to the radiation dose absorbed by the chip, enabling the quantification of this dose.
thermomechanical	Temperature impact on physical properties of rock.
thrust fault	A fault with a dip of 45° or less over much of its extent, on which the top block (hanging wall) appears to have moved upward over the lower block (footwall).
topography	The general configuration of a land surface or any part of the earth's surface, including its relief and the position of its natural and man-made features.
tortuosity	The inverse ratio of the length of a rock specimen to the length of the equivalent path of water within it.
to the extent practicable	The degree to which an intended course of action is capable of being effected in a manner that is reasonable and feasible within a framework of constraints.
transmissivity	The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient.
transpiration	The process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface.
transuranics	Those elements which have an atomic number higher than 92. They do not normally occur in nature and have to be produced artificially from uranium, either directly or indirectly by successive steps of transmutations.
tridymite	A mineral, SiO_2. It is a high-temperature form of quartz, and usually occurs as minute tabular white or colorless crystals or scales, in cavities in acidic volcanic rocks.
tritium	A radioactive isotope of hydrogen having two neutrons and one proton in the nucleus.
tufa	A chemical sedimentary rock composed of calcium carbonate, formed by evaporation as an incrustation around the mouth of a spring, along a stream, or around a lake.

tuff	A rock formed of compacted volcanic ash and dust.
tuffaceous	Said of sediments containing up to 50 percent tuff.
unconformity (geologic)	A break or gap in the geologic record, such as an interuption in the normal sequence of deposition of sedimentary rocks, or a break between eroded metamorphic rocks and younger sedimentary strata.
underground facility	The underground structure and the rock required for support, including mined openings and backfill materials, but excluding shafts, boreholes, and their seals.
unsaturated zone	The zone between the land surface and the water table. It includes the "capillary fringe". Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.
uplift (geologic)	A structurally high area in the earth's crust produced by movements that raise the rocks, as in a broad dome or arch.
vadose water	Water of the zone of aeration (unsaturated zone). Also known as suspended water.
vitric	See vitrophyre.
vitrophyre	Any porphyritic igneous rock having a glassy groundmass.
volcanic glass	Natural glass produced by the cooling of molten lava or some liquid fraction of molten lava to rapidly too permit crystallization.
volcanism	The processes by which magma and its associated gases rise into the crust and are extruded onto the earth's surface and into the atmosphere.
waste form	The radioactive waste materials and any encapsulating or stabilizing matrix.
waste package	The waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container.

water flux	A stream of flowing water; flood or outflow of water.
watershed	A drainage basin.
water table	The water surface in a body of ground water at which the water pressure is atmospheric.
welded tuff	Indurated volcanic ash in which the constituent glassy shards and other fragments have become welded together, apparently while still hot and plastic after deposition. Where the distinction between nonwelded and partly welded tuff is necessary, the boundary should be placed at or close to that point where deformation of glassy fragments becomes visible. The transition from partly to densely welded is one of progressive loss of pore space accompanied by an increase in deformation of the shards and pumiceous fragments.
xenolith	An inclusion in an igneous rock to which it is not genetically related.
Young's modulus	A modulus of elasticity in tension or compression, involving a change of length.
zeolites	Any of the various silicates analogous in composition to the feldspars, which occur as secondary minerals in cavities, along fractures, and on joint planes in basaltic lavas. Occur also as authigenic minerals in sedimentary rocks.

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GENERALIZED GEOLOGIC TIME SCALE

ERA	PERIOD	EPOCH	MILLIONS OF YEARS BEFORE PRESENT
CENOZOIC	QUATERNARY	HOLOCENE (RECENT) PLEISTOCENE	0.1
	TERTIARY	PLIOCENE MIOCENE OLIGOCENE EOCENE PALEOCENE	1.8 6 24 38 54 65
MESOZOIC	CRETACEOUS		140
	JURASSIC		190
	TRIASSIC		230
PALEOZOIC	PERMIAN		280
	PENNSYLVANIAN		310
	MISSISSIPPIAN		345
	DEVONIAN		405
	SILURIAN		425
	ORDOVICIAN		500
	CAMBRIAN		570

PRECAMBRIAN

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LIST OF ELEMENTS

Element	Symbol	Atomic number	Element	Symbol	Atomic number
Actinium	Ac	89	Mendelevium	Md	101
Aluminum	Al	13	Mercury	Hg	80
Americium	Am	95	Molybdenum	Mo	42
Antimony	Sb	51	Neodymium	Nd	60
Argon	Ar	18	Neon	Ne	10
Arsenic	As	33	Neptunium	Np	93
Astatine	At	85	Nickel	Ni	28
Barium	Ba	56	Niobium	Nb	41
Berkelium	Bk	97	Nitrogen	N	7
Beryllium	Be	4	Nobelium	No	102
Bismuth	Bi	83	Osmium	Os	76
Boron	B	5	Oxygen	O	8
Bromine	Br	35	Palladium	Pd	46
Cadmium	Cd	48	Phosphorus	P	15
Calcium	Ca	20	Platinum	Pt	78
Californium	Cf	98	Plutonium	Pu	94
Carbon	C	6	Polonium	Po	84
Cerium	Ce	58	Potassium	K	19
Cesium	Cs	55	Praseodymium	Pr	59
Chlorine	Cl	17	Promethium	Pm	61
Chromium	Cr	24	Protactinium	Pa	91
Cobalt	Co	27	Radium	Ra	88
Copper	Cu	29	Radon	Rn	86
Curium	Cm	96	Rhenium	Re	75
Dysprosium	Dy	66	Rhodium	Rh	45
Einsteinium	Es	99	Rubidium	Rb	37
Erbium	Er	68	Ruthenium	Ru	44
Europium	Eu	63	Samarium	Sm	62
Fermium	Fm	100	Scandium	Sc	21
Fluorine	F	9	Selenium	Se	34
Francium	Fr	87	Silicon	Si	14
Gadolinium	Gd	64	Silver	Ag	47
Gallium	Ga	31	Sodium	Na	11
Germanium	Ge	32	Strontium	Sr	38
Gold	Au	79	Sulfur	S	16
Hafnium	Hf	72	Tantalum	Ta	73
Helium	He	2	Technetium	Tc	43
Holmium	Ho	67	Tellurium	Te	52
Hydrogen	H	1	Terbium	Tb	65
Indium	In	49	Thallium	Tl	81
Iodine	I	53	Thorium	Th	90
Iridium	Ir	77	Thulium	Tm	69
Iron	Fe	26	Tin	Sn	50
Krypton	Kr	36	Titanium	Ti	22
Kurchatovium[a]	Ku	104	Uranium	U	92
Lanthanum	La	57	Vanadium	V	23
Lawrencium	Lr	103	Wolfram[b]	W	74
Lead	Pb	82	Xenon	Xe	54
Lithium	Li	3	Ytterbium	Yb	70
Lutecium	Lu	71	Yttrium	Y	39
Magnesium	Mg	12	Zinc	Zn	30
Manganese	Mn	25	Zirconium	Zr	40

[a] Suggested name.
[b] Also called tungsten.

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