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Conceptual Models for Radionuclide Release from the Yucca Mountain High-Level Radioactive Waste Repository

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1.0 GEOLOGY OF YUCCA MOUNTAIN

1.1 Introduction

This report reviews the preliminary data and assumptions developed by DOE and other organizations concerning the potential for radioactive release to the accessible environment from the proposed Yucca Mountain high level radioactive waste repository. Specific federal requirements define the general parameters to promote waste isolation at such a repository (i.e., 10 CFR 60 and 40 CFR 191). The review and federal requirements form the basis of the analysis defining potential release scenarios.

This report begins with a brief summary of the location and proximate population to the proposed repository and then focuses on the geology, hydrogeology and engineered systems which comprise the primary natural and man-made barriers promoting waste isolation. Release scenarios are developed to summarize the preliminary information and to establish input parameters for modeling Yucca Mountain's performance.

1.2 Regional Geology

The characteristics of the regional geology and specific conditions at the proposed site are important considerations in the performance assessment of Yucca Mountain. Characterization of Yucca Mountain, to date, has produced limited, site-specific data. This report applies currently available data, but acknowledges the large uncertainties and assumptions inherent in these characterizations of Yucca Mountain.

1.2.1 Location and Population

Yucca Mountain, Nevada is currently proposed for detailed characterization as the site of the national high-level radioactive waste repository. It is located in Nye County on federally owned lands controlled by DOE (the Nevada Test Site), Bureau of Land Management (the Department of Interior's holdings) and the Air Force with jurisdiction over flight corridors (Figure 1-1). The nearest state boundary is California which is 50 km (20 miles) to the southwest.

Las Vegas lies approximately 85 miles to the southeast of Yucca Mountain and represents the only major population concentration in proximity to the site. Nye County has a current population density of 0.5 persons/square mile (1984).

1.2.2 Orientation

Yucca Mountain is situated in a complex geological area within the Basin and Range physiographic province. The area exhibits north trending fault ridges which extend from Beatty Wash to the north through the site and continue on a southeastern path. Yucca Mountain rests on subsurface beds dipping 5-10 degrees to the east.

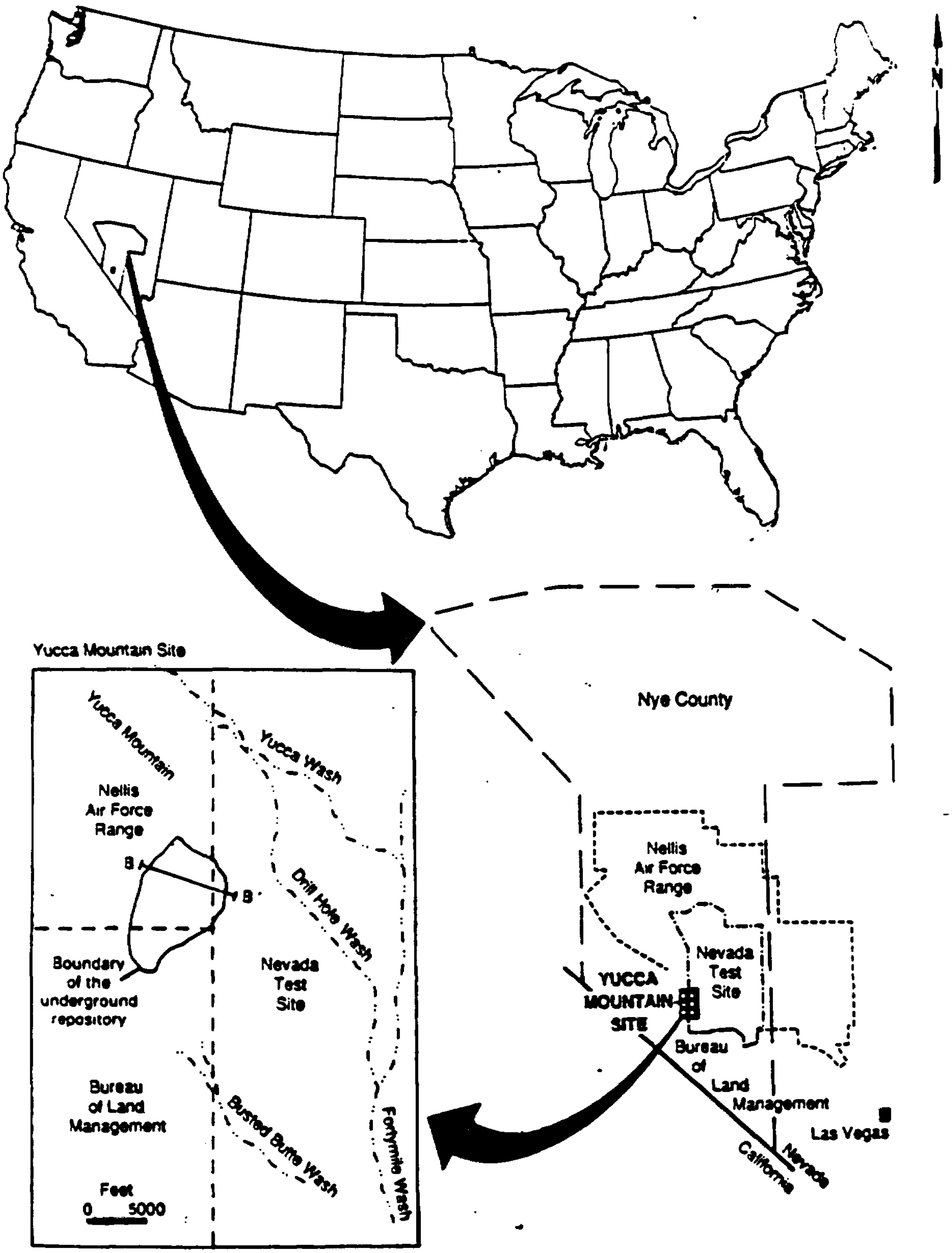


FIGURE 1-1
Location of Proposed Repository
(Source: DOE/RW-0199)

1.2.3 Overview of Site

Yucca Mountain is situated in the southern segment of the Great Basin which was formed by violent, silicic volcanic eruptions. The eruptions deposited volcanic rock called tuff, a rigid, fractured igneous rock exhibiting varying permeabilities and transmissivities. Tuff forms a series of stratigraphic horizons of approximately 915 - 3,000 m (3,000 -10,000) thick under the Great Basin and is at least 1980 m (6500 ft) thick under Yucca Mountain (Figure 1-2). The surrounding relief reaches a height of between 1500 - 1930 m (5000 - 6332 ft) above the floor of Crater Flat, which lies adjacent to Yucca Mountain.

Tuff, which forms the rugged relief at Yucca Mountain, is comprised primarily of welded and non-welded pyroclastic material. Extensive ash flows are layered with lighter non-welded ash fall tuff. Ash flow tuff results from the actual flow of molten material out of a volcano, while ash fall tuff results when pyroclastic material is ejected into the air during an eruption. Additional relief was provided by a series of more recent basaltic eruptions in the Great Basin but these do not represent depositional layers on Yucca Mountain except as thin disturbed layers at or near the surface. It is important to note the role volcanic and companion seismic activities played in the genesis and continuing evolution of the Yucca Mountain area (Figure 1-3).

1.2.4 Choice of a Repository Horizon

NRC and EPA define the general site characteristics necessary to promote waste isolation. DOE assumes the characteristics of the local geology and hydrology support the choice of Yucca Mountain for primary evaluation as the national high level radioactive waste repository. First, an overburden of more than 200 m (650 ft) of unsaturated, vitrified or devitrified tuff offers a potential for mitigating surface disturbances and lessening the potential direct release of radionuclides. Second, the emplacement of waste is in an unsaturated environment which promotes free drainage, lessening the likelihood of water collection or "bath tub" effects which might increase the likelihood of water and waste contact and more rapid waste dissolution. Third, the repository horizon is encased in the unsaturated tuff, a matrix which promotes slow downward movement of water toward the aquifer and extends the travel time of contaminants into the accessible environment. The unsaturated tuff is located at least 200 m (650 ft) above the aquifer. Fourth, the Yucca Mountain repository is not an area with extractible mineral deposits. DOE reports no evidence of oil, natural gas, or additional extractive resources other than water at the site of the proposed repository. Yucca Mountain's volcanic horizons are unlikely to have deposits of extractive resources which would encourage human intrusion such as drilling.

Analysis of these characteristics of Yucca Mountain establishes a basic scenario of downward water movement, a rate of waste dissolution, and subsequent downward

DEPTH (m / ft)	THERMAL/ MECHANICAL UNIT	LITHOLOGIC EQUIVALENT
	UO	ALLUVIUM
	TCw	WELDED, DEVITRIFIED TIVA CANYON
	PTn	VITRIC, NONWELDED TIVA CANYON, YUCCA MOUNTAIN, PAH CANYON, TOPOPAH SPRING
500 ft; 200 m	TSw1	LITHOPHYSAL TOPOPAH SPRING; ALTERNATING LAYERS OF LITHOPHYSAE-RICH AND LITHOPHYSAE-POOR WELDED, DEVITRIFIED TUFF
1,000 ft	TSw2	NONLITHOPHYSAL TOPOPAH SPRING POTENTIAL REPOSITORY HORIZON (CONTAINS SPARSE LITHOPHYSAE)
400 m	TSw3	VITROPHYRE, TOPOPAH SPRING
1,500 ft	CHn1	ASH FLOWS AND BEDDED UNITS, TUFFACEOUS BEDS OF CALICO HILLS; MAY BE VITRIC (v) OR ZEOLITIZED (z)
	CHn2	BASAL BEDDED UNIT OF CALICO HILLS
	CHn3	UPPER PROW PASS
600 m; 2,000 ft	PPw	WELDED, DEVITRIFIED PROW PASS
	CFUn	ZEOLITIZED LOWER PROW PASS AND UPPER BULLFROG
2,500 ft; 800 m	BFw	WELDED, DEVITRIFIED BULLFROG
	CFMn1	ZEOLITIZED LOWER BULLFROG
	CFMn2	ZEOLITIZED BASAL BEDDED UNIT OF BULLFROG
	CFMn3	UPPER ZEOLITIZED TRAM
3,000 ft	TRw	WELDED, DEVITRIFIED TRAM

FIGURE 1-2
Thermal/Mechanical Stratigraphy at Yucca Mountain
(Source: DOE/RW-0199)

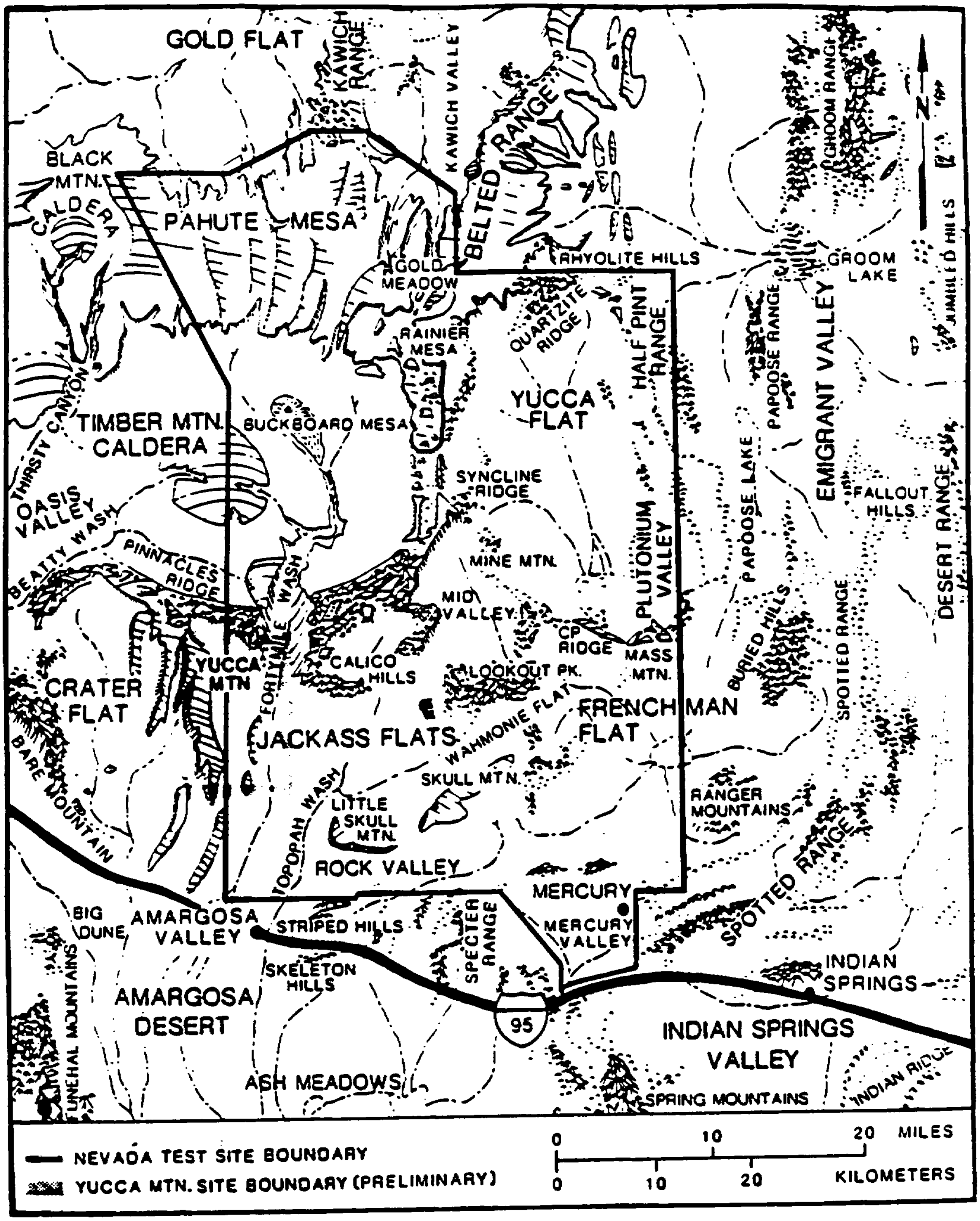


FIGURE 1-3
Physiographic Features of Yucca Mountain and Surrounding Region
(Source: DOE/RW-0073)

flow of contaminated water into the aquifer and then release to the environment. Initial calculations by DOE and SANDIA indicate the travel time through the unsaturated tuff to the aquifer is in excess of 10,000 years except under the most conservative assumptions (Table 1-1 and Table 1-2). The saturated flow of the aquifer is assumed to rapidly transport the radionuclides into the accessible environment.

1.3 Site Stratigraphy

The stratigraphy of the area has a basement of Precambrian crystalline rocks overlain by the Upper Cambrian and Paleozoic sedimentary formations (Figure 1-4). These basement crystalline and sedimentary strata are not likely to conduct radionuclides into the accessible environment and will not be the emphasis of this report. The overlying thick layer of tuff contains the repository and the most proximate underlying aquifer. It is assumed that one of the pathways to the accessible environment results from the downward water movement, the promotion of water-waste dissolution, the continued downward movement of radionuclides into the aquifer and subsequent flow out beyond the perimeter of the site. Little or no radioactive waste release into the underlying Pre-Cenozoic, Upper Cambrian and Precambrian rocks is assumed.

Potential release scenarios suggest movement of radionuclides through the stratigraphy of volcanic tuff. This report details the geologic characteristics of the stratigraphic layers from the surface of Yucca Mountain to the aquifer as the first step to developing release scenarios.

1.3.1 Alluvium

The surficial deposits on Yucca Mountain are sedimentary in nature and represent the Late Tertiary through the Quaternary period. Present relief is rugged with a varied surface of fluvial deposits, debris flows, eolian dunes, sand sheets, basalt flows and cinders. Historically, these layers were deposited by lacustrine or alluvial occurrences, from past pluvial conditions and current processes. Surface soil and underlying beds exhibit the characteristics determined by the mechanism of deposition and the subsequent impacts of wind erosion. The alluvium is approximately 0 - 30 m (0 - 100 ft) thick on Yucca Mountain.

1.3.2 Tiva Canyon Member

The upper layer of the Paintbrush Tuff Formation (which also includes the Yucca Mountain, Pah Canyon, and Topopah Spring Members) is moderately to densely welded ash-flow tuff. The Tiva Canyon Member is a multiple-flow compound cooling unit with two lithophysal subunits. This compound cooling unit contains a devitrified layer, but is overlain by a highly vitrified ash flow and ash fall tuff. This stratigraphic layer of Tiva Canyon tuff typifies the components of a rhyolitic eruption and the resulting complex geology. The Tiva Canyon unit is approximately 90 to 140 m (295 to 459 ft) thick.

TABLE 1-1

Summary of Unsaturated Zone Travel Time for Vertical Flux of 0.5 mm/yr[a]

Travel path[b]	Travel time (yr)
Minimum	9,345
Mean	43,265
Maximum	80,095

[a]Source: Sinnock et al. (1986).
[b]Travel paths are from the repository horizon to the water table and are based on multiple modeling scenarios as discussed in Sinnock et al. (1986).

TABLE 1-2

Estimates for Ground-Water Travel Times Through the Saturated Zone

Parameter	Unit: Tuffaceous beds of Calico Hills	Unit: Topopah Spring Member
Length of path (m)	3,000	2,000
Hydraulic conductivity (m/yr)	69	365
Hydraulic gradient	5.9×10^{-4}	1.1×10^{-4}
Darcy velocity (m/yr)	4.1×10^{-2}	4.0×10^{-2}
Calculated bulk effective fracture porosity[d]	4×10^{-4}	2.8×10^{-3}
Particle velocity (m/yr)	100	14
Travel time (yr)	30	140

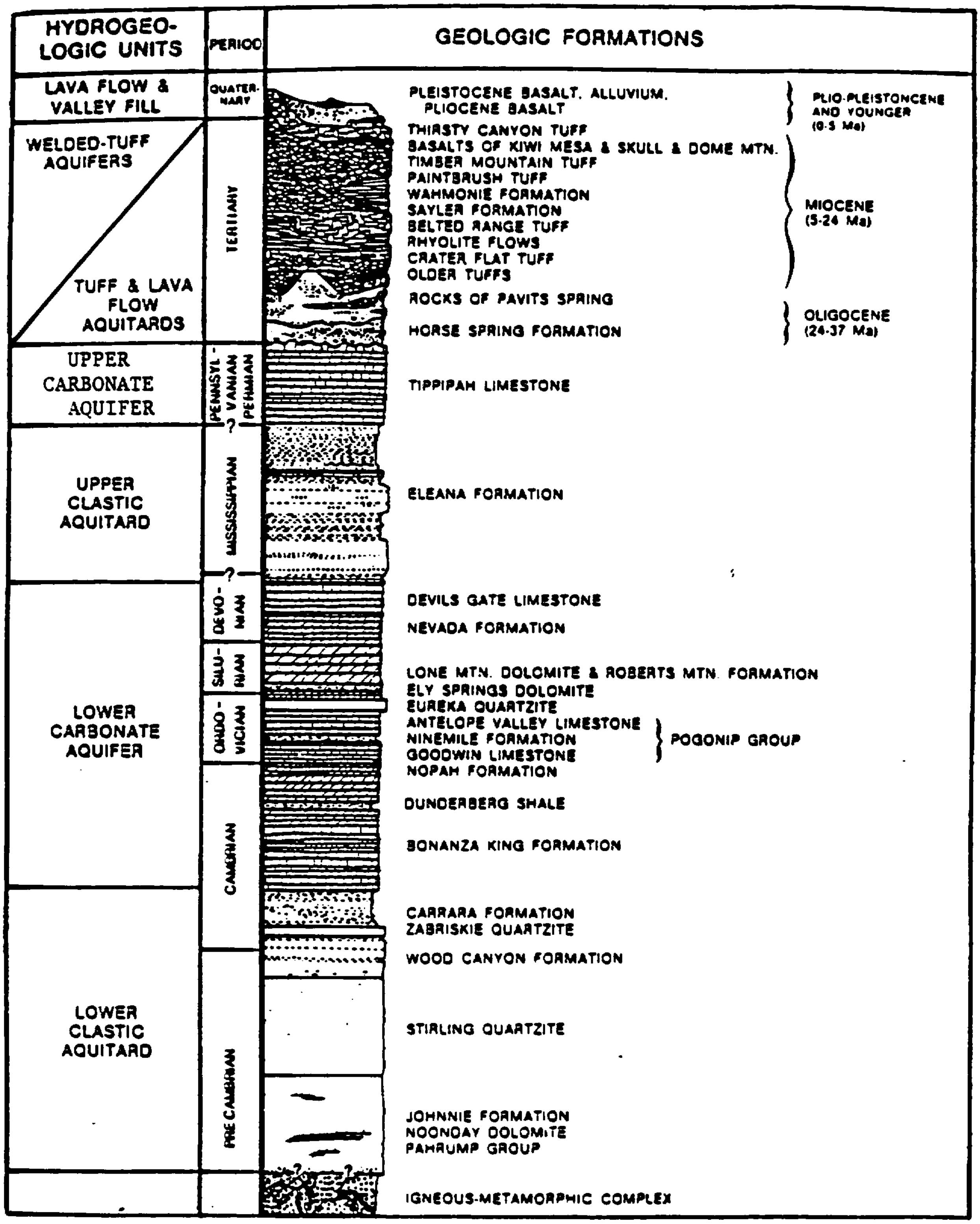


FIGURE 1-4
Generalized Regional Stratigraphic Column Showing geologic Formations and Hydrogeologic Units in the Nevada Site Area Modified from Sinnock (1982)
(Source: DOE/RW-0199 and Carr et. al., 1985)

1.3.3 Pah Canyon and Yucca Mountain Members

These two members are thin layers of partially welded to non-welded, vitric and occasionally devitrified ash flow tuff. They are differentiated by the distinct characteristics of the two parent eruptions. The Yucca Mountain Member is a shard-rich tuff with low levels of pumice, phenocrysts and lithic fragments. It has a maximum thickness of 29 m (95 ft). The Pah Canyon Member has a maximum thickness of 71 m (233 ft) and exhibits a higher percentage of phenocrysts (up to 15% of the total mass).

1.3.4 Topopah Spring Member

Topopah Spring is the thickest tuff stratum underlying Yucca Mountain and represents a highly complex, compound cooling unit created by multiple volcanic flows. Seven distinct zones are defined from the top to the bottom of the member and listed below as:

1) The caprock zone is 39-62 m (128-203 ft) thick and exhibits four distinct zonations with different chemical constituents, degrees of vitrification and percentages of lithophysal openings.

2) The upper lithophysal zone is 54-90 m (177-295 ft) thick and is characterized as rhyolitic, devitrified, moderately to densely welded with differing zonations of lithophysal openings

3) The middle nonlithophysal zone and laterally equivalent subzones are 20-50 m (66-164 ft) thick and are rhyolitic, devitrified, moderately to densely welded but lacking lithophysal zonations.

4) The lower lithophysal zone and laterally equivalent subzones are 43-117 m (41-384 ft) thick and are characteristic rhyolitic, devitrified, moderately to densely welded tuff but exhibit 10-15% lithophysae which are 5-15 cm (2-6 in) in diameter.

5) The lower nonlythophysal (less than 2% lithophysae) zone is 27-56 m (88-184 ft) thick and it is rhyolitic, devitrified and moderately to densely welded. These characteristics were the basis of its choice as the repository horizon.

6) Basal vitrophyre zone is 10-25 m (33-82 ft) thick, rhyolitic, glassy and moderately to densely welded.

7) Lower non-welded to moderately welded zone which is 13-42 m thick (43-138 ft) and is rhyolitic, glassy and non-welded to partially welded.

1.3.5 Calico Hills

An ash-fall tuff, 1-17 m (3.2-56 ft) thick, separates the Paintbrush Tuff from the underlying tuffaceous beds of the Calico Hills Member and is 27-289 m (88-948 ft) thick. It exhibits rhyolitic characteristics and is a homogenous, non-welded ash flow tuff. Significant zeolitized deposits (60-80% of the rock) in the area underlying the northern half of the repository do not exist among the vitric components in the southern section.

1.3.6 Crater Flat

Crater Flat tuff incorporates the following units; the Prow Pass, the Bullfrog and the Tram Members. All three members are rhyolitic ash flows, inter-bedded with air fall tuff. The degree of welding varies from non-welded to moderately welded in the Members. A layer of reworked tuff and ash fall tuff less than 20 m (66 ft) thick separates the Prow Pass Member from the overlying Calico Hills Member. Ash flow tuff of the Prow Pass is 80 - 193 m (262 - 633 ft) thick and exhibits devitrification, slight welding and local deposits of zeolites. A layer of ash fall tuff less than 10 m (33 ft) thick separates the Prow Pass from the Bullfrog member. The Bullfrog member appears to be a single cooling unit with varying degrees of welding and a thickness of 68 - 187 m (223 - 614 ft). A less than 10 m (33 ft) thick layer of reworked tuff separates the Bullfrog from the Tram member. The Tram member is 104 - 370 m (340 - 1214 ft) thick and exhibits three distinct layers with differing characteristics. Localized deposits containing zeolites may be found in areas of reworked tuff or tuffaceous sediments in proximity to the Prow Pass or Tram members. This report assumes the aquifer to be present in the Crater Flat tuff. As the aquifer represents the route horizontally out to the accessible environment, no discussion of volcanic tuff stratigraphy is provided for the layers beneath the Crater Flat.

1.4 Structural Geology and Tectonics

Tectonic processes such as volcanism and faulting are much in evidence at and surrounding Yucca Mountain. The relative motion of two to three crustal plates led to deformation of the area adjacent to and including Yucca Mountain. The rotation northward of the Pacific plate in relationship to the western part of the North American plate produced crustal thinning, upwelling of magma into the mantle and increased geothermal gradients. Subsequent tectonic processes generated first rhyolitic and then basaltic volcanism with companion seismic activity and the production of faults over the past 16-20 million years.

This extensive tectonic activity is documented for the Post-Paleozoic strata above the Pre-Cenozoic stratigraphy. This report will only consider the volcanic strata formed in the past 20 million years (Section 1.3).

1.4.1 Volcanology

Tertiary volcanism produced the extensive tuff deposits characteristic of the Great Basin and Yucca Mountain. Rhyolitic, silicic volcanoes created ash flows which now are under consideration for the repository horizon. Ash flow tuffs resulted in immense clouds or showers of intensely heated but generally minute fragments of volcanic magma. Ash flow functions as a "glowing avalanche" or fluidized system with its solid and liquid components suspended in hot gases. Flows could occur at intervals which allowed individual flows to cool as single units. A compound cooling unit resulted if subsequent flows inundated the individual units, prior to cooling, creating a more complex cooling system.

The complexity of the compound cooling unit depends on the thickness, composition and periodicity of the ash flows. Differential thermal loading throughout a compound cooling unit will produce layers of welded and non-welded tuff, lithophysae and compaction. Porosity of the tuff can vary from unconsolidated porous glass shards to thorough welding with almost zero porosity. Glassy, vitrified layers occur in areas of rapid cooling such as surface or basal locations. Tuff may contain devitrification, vapor phase crystallization and fumarolic alteration layers. Additional layers of ash fall tuff are often incorporated into the compound cooling unit. Ash fall is the glassy, pyroclastic, porous, non-welded ash ejected into the air during rhyolitic eruptions. It cools and falls to the earth's surface, adding an additional porous layer on existing compound cooling units. The Topopah Spring member is one such compound cooling unit which exhibits a number of different cooling layers with distinct properties (Section 1.3.4).

Ash flow and air fall ejecta are part of an interrelated series of events which may culminate in the formation of calderas. Calderas are formed by the rapid draining of magma during an eruption and the subsequent collapse of the cone surface into the drained magma chamber. This collapse is often explosive and leaves a characteristic massive circular depression. Such depressions are found along the western perimeter of the proposed repository area (Figure 1-5).

Yucca Mountain exhibited changing trends of volcanism in the past 16 million years. The rhyolitic eruptions, ash flows and resulting calderas were most active in the Yucca Mountain area from 8 to 16 million years ago. Flows from 7 to 10 million years ago showed the emergence of basaltic volcanism as well as rhyolitic eruptions. All flows in the areas adjacent to Yucca Mountain for the past 7 million years are basaltic. Basalt is a fine grained igneous rock, consisting primarily of calcic plagioclase and clinopyroxene. The flow is extruded at higher temperatures and contains different dissolved gases than the explosive rhyolitic flow.

Basaltic extrusions were not the explosive, caldera forming eruptions characteristic of rhyolitic volcanoes. Three stages of basaltic flow occurred on Yucca Mountain with a lessening of lava volume for each successive stage. These eruptions were located south of the previous rhyolitic activity and Yucca Mountain itself. The Death Valley-Pancake Range is a 50-90 km wide volcanic belt which encompasses

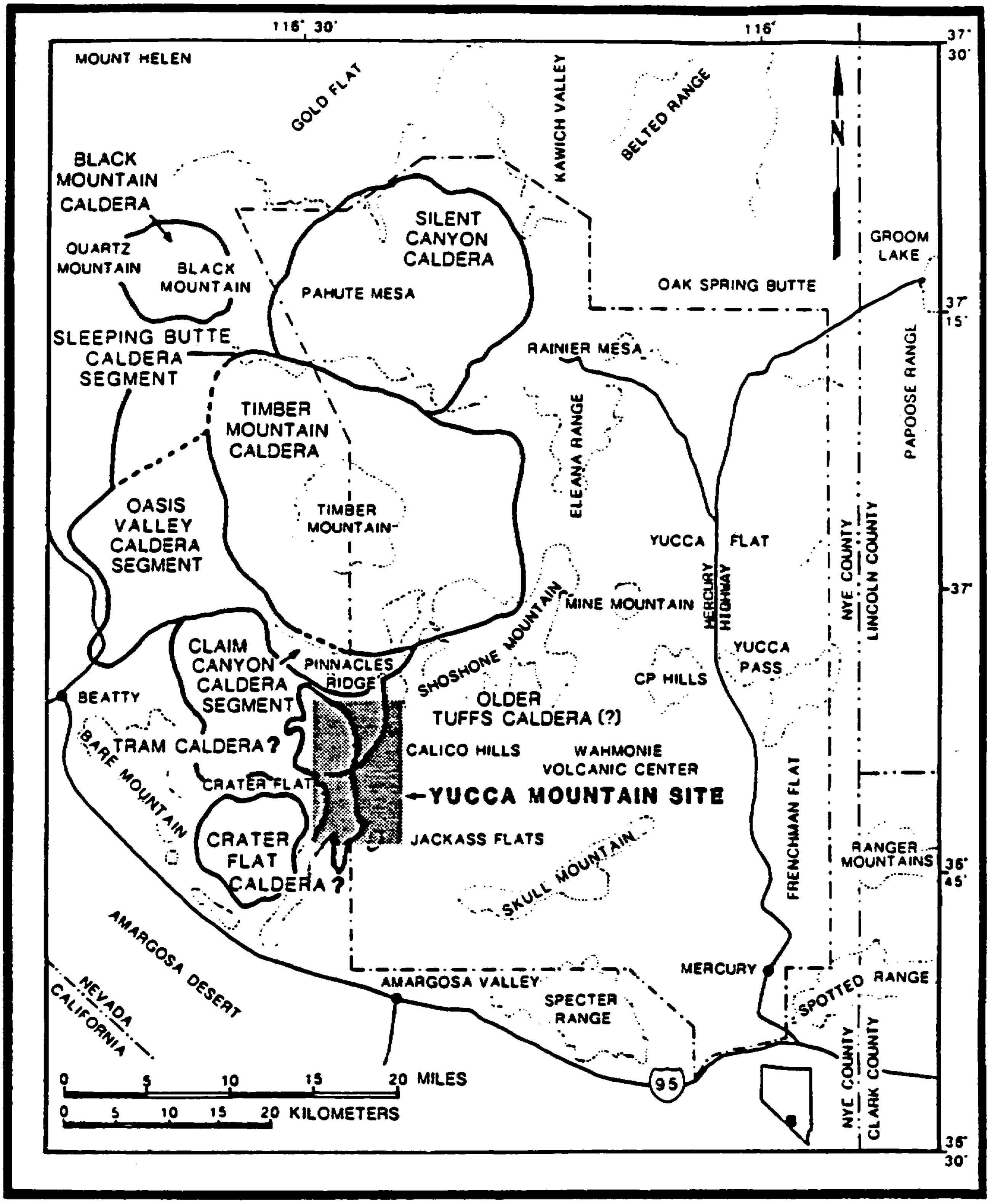


FIGURE 1-5
Southern End of Southern Nevada Volcanic Field Showing Possible Locations of Calderas in the Vicinity of Yucca Mountain
Modified from Malonado and Koether (1983)
(Source: DOE/RW-0199)

the basaltic units (Figure 1-6). The most recent basaltic activity (from 0.1 to 3.7 million years ago) produced basaltic flows and scoria cones which are within 6 km (10 miles) of Yucca Mountain.

No rhyolitic or basaltic eruption has occurred in close proximity to Yucca Mountain in recorded time. However, the entire geologic province, which includes Yucca Mountain, is an area of high heat flow. This heat has the potential to produce geothermal energy and activity. Measurements of heat flow in the crust are often indicative of the potential for future volcanic and tectonic activity. Yucca Mountain itself has lower temperatures than the surrounding area, but DOE proposes the presence of ground water and water vapor at Yucca Mountain may be a factor in the depression of the higher heat flow which is represented over the entire geology province. However the historic evidence of volcanism and the regional high heat flow indicate the potential for tectonic volcanism in proximity to the Yucca Mountain repository.

1.4.2 Seismicity

The Yucca Mountain area has a history of seismic activity which continues to the present. The region is situated among three seismic belts: the Intermountain seismic belt to the east, the Nevada-California seismic belt to the west and the Eastern Mojave seismic zone to the south (Figure 1-7). DOE is employing two methods to catalog the previous seismic activity and characterize future hazard potential related to seismic activity. The first method catalogs the recorded history of activity in the Yucca Mountain area from 1868 to 1978. Beginning in 1978, DOE instituted extensive seismic surveillance as the second method monitoring the Yucca Mountain site and its adjacent areas for both natural phenomena and the impacts of weapons testing at the Nevada Test Site (NTS).

Historic data from 1868 to 1978 indicate a zone of inactivity around Yucca Mountain. Few historic earthquakes produced strong ground motion in the area of the proposed site nor has Yucca Mountain itself been noticeably seismically active. This historic method produces results with great uncertainty due to the low population densities in the observation area, the potential for small, not quantified earthquakes and the short period of observation. Data on Quaternary faulting shows evidence of substantial seismic activity prior to the historic monitoring which began in 1868.

The method of historic monitoring focused on an area in a 400 km (250 mile) radius surrounding the proposed repository. Six major earthquakes with magnitudes of greater than 6.5 originated in the Nevada-California seismic belt. Two equivalent force earthquakes were observed in the San Andreas Fault west of Yucca Mountain. This western trend of seismic activity was underscored by the nearest major earthqûake in Owens Valley in 1872. The epicenter was 150 km (94 miles) west of Yucca Mountain (Figure 1-8).

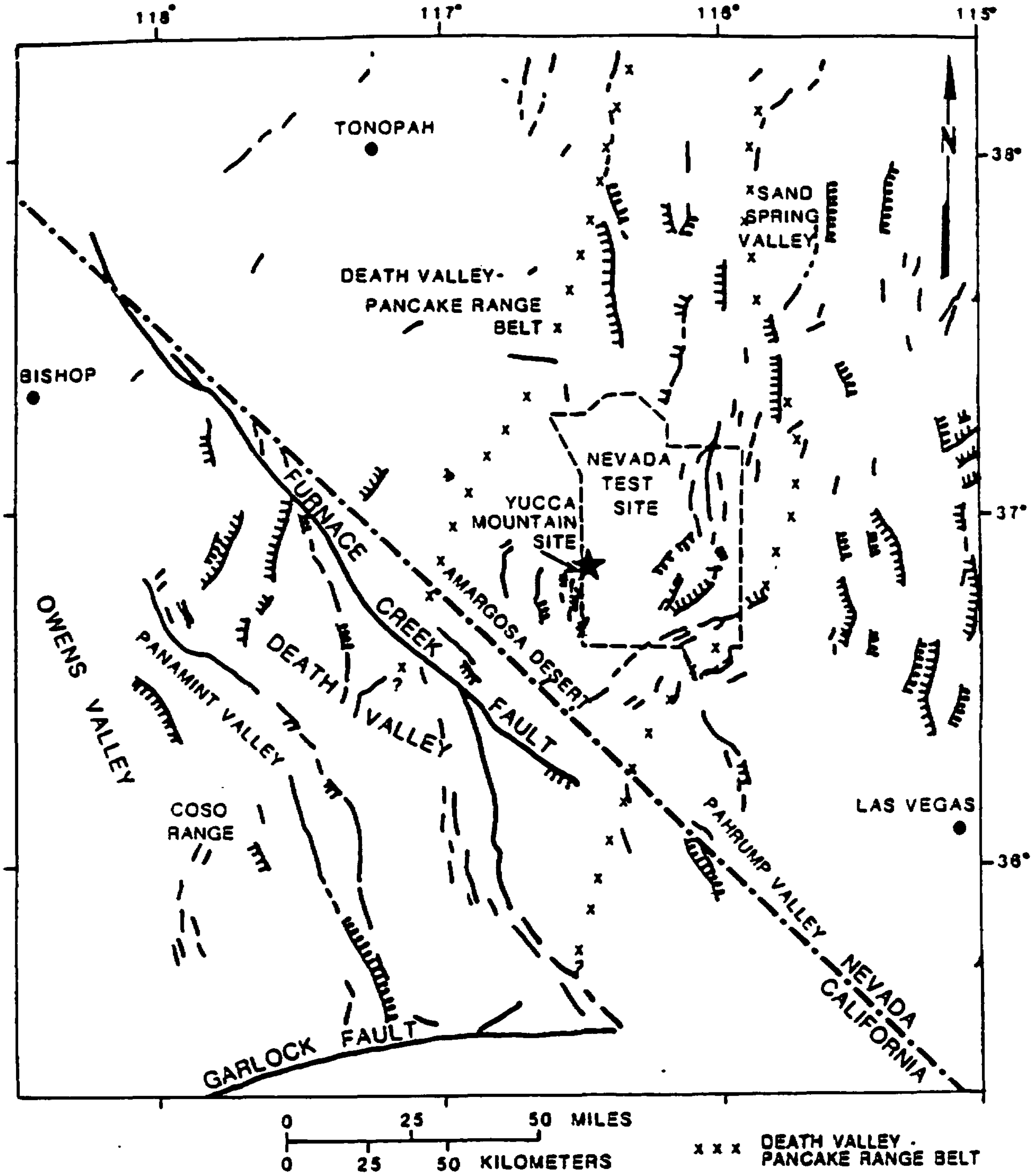


FIGURE 1-6
Late Pliocene and Quaternary Faults in the Nevada Test Site Region and Their Relation to the Death Valley-Pancake Region Belt Modified by Carr (1984)
(Source: DOE/RW-0199)

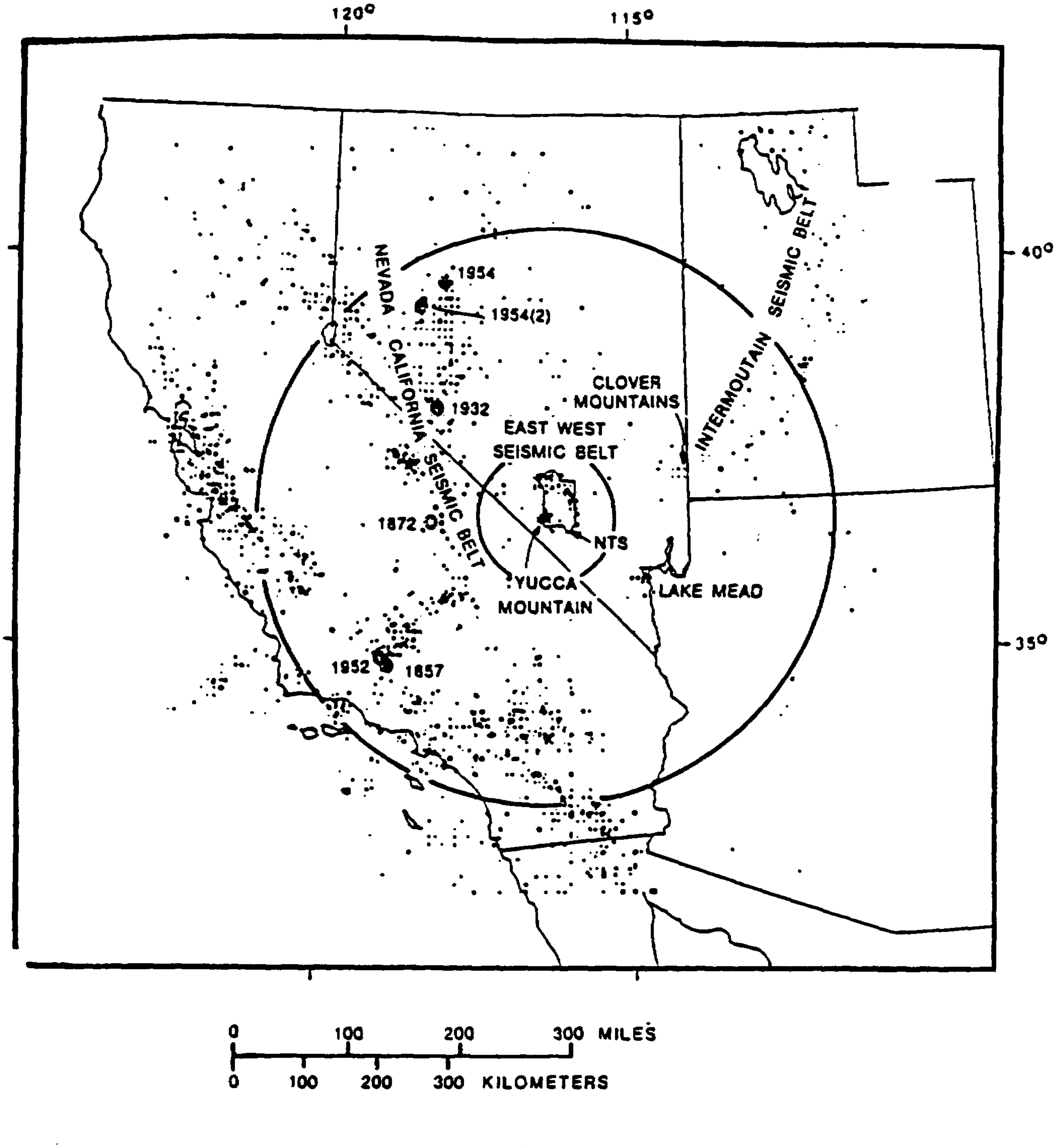


FIGURE 1-7
Seismicity of Southwestern United States Based on Historical and Instrumental Data Through 1978
Compiled from National Earthquake Information Center Files, U.S. Geological Survey
(Source: DOE/RW-0199)

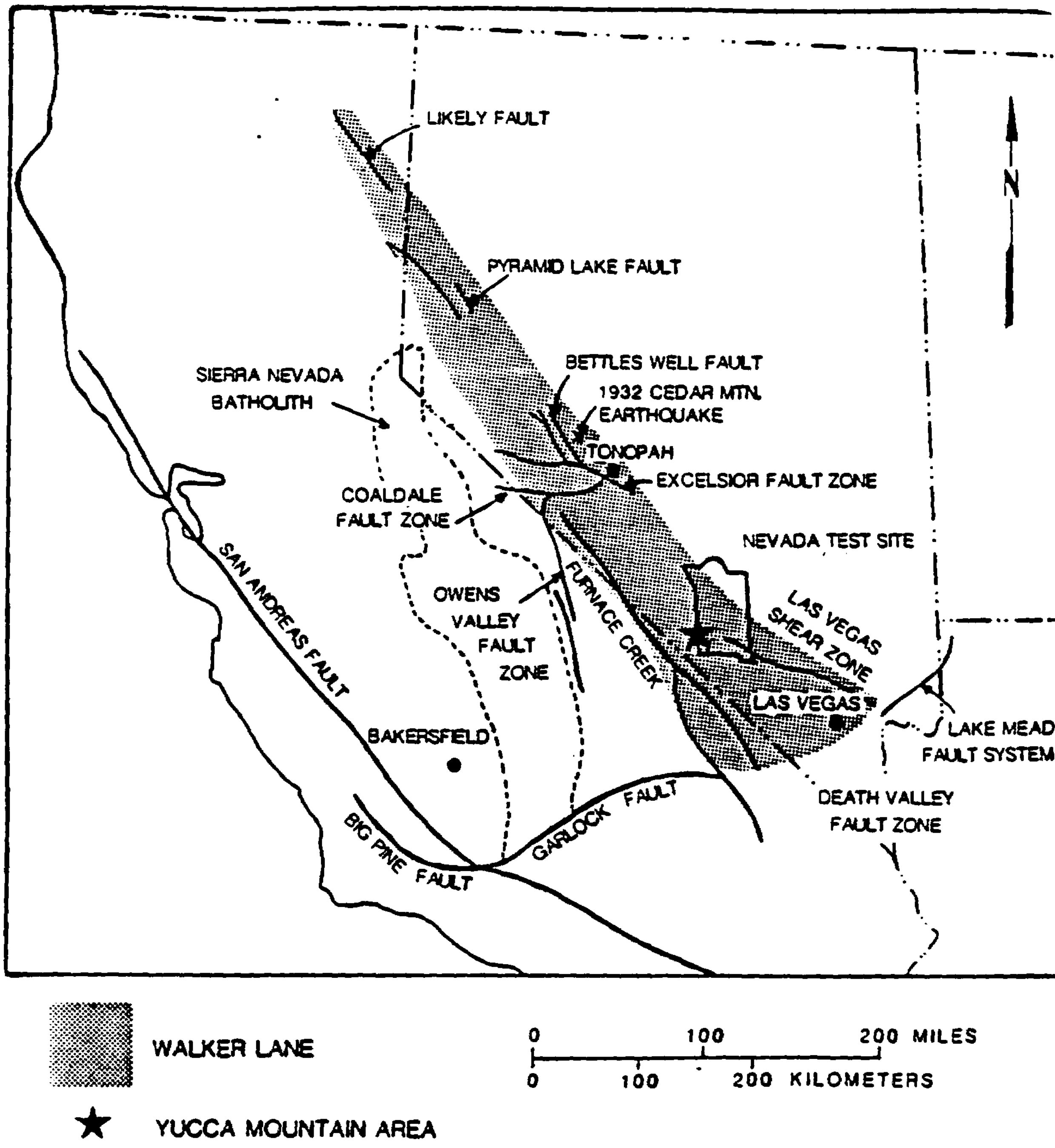


FIGURE 1-8
The Walker Lane and Major Associated Faults
Modified from Stewart (1985)
(Source: DOE/RW-0199)

Seismic studies since 1978 are producing data supporting the historic assumption of low seismic energy density and few epicenters at Yucca Mountain. Yucca Mountain is assumed to be one of the more inactive areas found in the East-West seismic belt. The East-West seismic belt, however, also contains significantly active zones with earthquake epicenters to 10 km (6.25 miles) deep or deeper. Generally, it is an area of high heat flow and seismic potential.

Yucca Mountain itself may serve as a quiescent seismic segment in the West-East seismic area. Current seismic activity to the north and east of Yucca Mountain is primarily related to activities at the NTS. Survey stations are documenting the ongoing weapons testing and detonation which often cause shallow seismic activity. This report will not consider weapons testing to represent a postclosure hazard to the repository. Weapons testing produces shallow seismic movement which is assumed to affect surface facilities but will be assumed to be conducted as to not directly affect the integrity of the underground repository.

Yucca Mountain repository is more at risk from the uncontrolled shocks, deformation and offset from tectonic processes. The West-East seismic belt can generate earthquake impacts to great depth (from ·1 to 17 km or ·1 to 10.6 miles) with significant energy releases.

Historical data has been used to calculate past and future impacts at the Yucca Mountain site. The value of 0.1 g mean peak horizontal acceleration was assumed by DOE to represent the impact of weapons testing at the Nevada Test Site twenty miles west of Yucca Mountain. DOE uses the 0.1 g mean peak horizontal acceleration value for Yucca Mountain due to the proximity and similar conditions to the NTS. The Department acknowledges the uncertainty in this estimate.

1.4.3 Faulting

Yucca Mountain lies in the Basin and Range Province at the center of the North American Crustal Plate. The previous discussion of tectonic processes (Section 1.1.3) described the deformation of the North American Crustal Plate since the Late Cretaceous Period.

Historically, crustal plate movement produced companion tectonic processes. In this report, the period from the extensional tectonism (20 million years ago) through rhyolitic volcanism (7 to 16 million years ago) to basaltic activity (7 million years ago to the present) are reviewed. The extensional tectonics which began 20 million years ago are linked to the subduction and deformation of three crustal plates. Subsequent crustal thinning and increasing heat flow generated the rhyolitic and basaltic volcanism which occurred from the Tertiary period to the present. Tectonic processes in the crust caused seismic activity and faulting. The tectonic factors which cause volcanism and earthquakes also promote faulting in the rock strata. Recent basaltic activity, for example, emerged along large slip strike faults south (Garlock Fault) and west (San Andreas Fault) of Yucca Mountain.

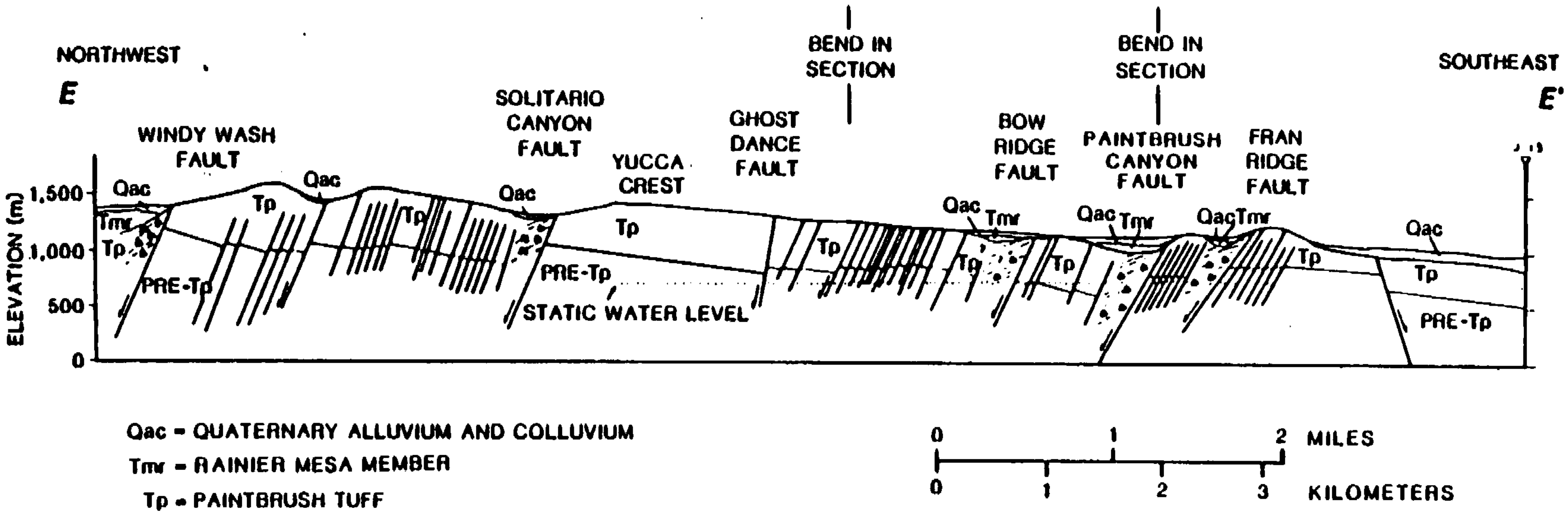
Yucca Mountain exhibits layered north-trending structural blocks which tilt eastward along major west-dipping, high angle normal faults. Most of the fault offset took place between 11.6 and 12.9 million years ago (as noted in the Tiva Canyon member, for example). However, offset continues into the present. Faults, such as the Solitario Canyon Fault, border the proposed repository and exhibit measurable displacement. Individual normal faults in Yucca Mountain generally exhibited lesser Tertiary or Quaternary offsets than other comparable faults found in the southern Great Basin (Figure 1-9).

The Solitario Canyon Fault bounds the repository on the west and a series of imbricate faults border its eastern edge. Solitario Canyon Fault is significant due to its great depth (15 km, 9 miles or more) and proximity to the proposed repository. The Fault's last movement occurred approximately 1.2 million years ago but exhibited multiple episodes of Quaternary movement. DOE considered the presence of additional Quaternary faulting in proximity to Solitario Canyon for this evidence generally serves as the best indicator of future activity. In total, thirty-two faults have documented offset in Quaternary deposits which cover 1100 square miles of Yucca Mountain. The offset was found to be generally 3 m (10 ft) along each fault and at least five have measurable offset dating to within the past 270,000 years. Additional smaller vertical Quaternary offsets of 5 m (16 ft) or less are documented in the boundary of the proposed repository. Data indicates that these smaller faults tend to be north to north-northwest striking faults.

The proposed repository is planned to coincide with a relatively unfaulted segment of the Yucca Mountain structural block. However, the Ghost Dance Fault, bisects the structural block proposed to house the repository (Figure 1-10). Vertical offset along the Ghost Dance is 38 km (125 ft) which is significantly greater than the typical 3-5 m (10-16 ft) Quaternary offset for surrounding faults within the proposed boundary of the repository. The Ghost Dance Fault exhibits a westward downward drop or slope with a steep 80-90° dip westward. It creates breccia zones up to 20 m (66 ft) and offsets the Tiva Canyon member. No current data has been determined by DOE to support or deny the likelihood of recent Quaternary offset.

Relative movement and the existence of additional faults is poorly understood at Yucca Mountain. Present methodologies are utilizing known surficial, Quaternary offsets to predict the patterns of future faulting. The impact of significant, proximate faults such as the Ghost Dance or Solitario Canyon are not well defined and current predictions are weakened by large uncertainties.

This report assumes a general rate of fault movement and probability of faulting events. Preliminary studies by USGS predict the upper bounds of long term slip rates and the related yearly rate of major earthquakes and offsets for the Basin and Range Province which includes Yucca Mountain. This estimate is based on the delineation of faults which are active or have evidence of activity under the present tectonic conditions and the long term rate of movement along these faults. A slip rate of offset is estimated to be 8×10^{-2} mm/yr for the Basin and Range Province. The yearly rate for faulting events is assumed to be 8×10^{-5}. These estimates are



Qac = QUATERNARY ALLUVIUM AND COLLUVIUM
Tmr = RAINIER MESA MEMBER
Tp = PAINTBRUSH TUFF
PRE-Tp = PRE-PAINTBRUSH TUFF
= ABUNDANT BRECCIA
= WEST-DIPPING STRATA IN DRAG ZONE
= INDICATES RELATIVE MOTION

FIGURE 1-9
Schematic Geologic Cross Section E-E at Yucca Mountain
Modified from Scott and Bank (1984)
(Source: DOE/RW-0199)

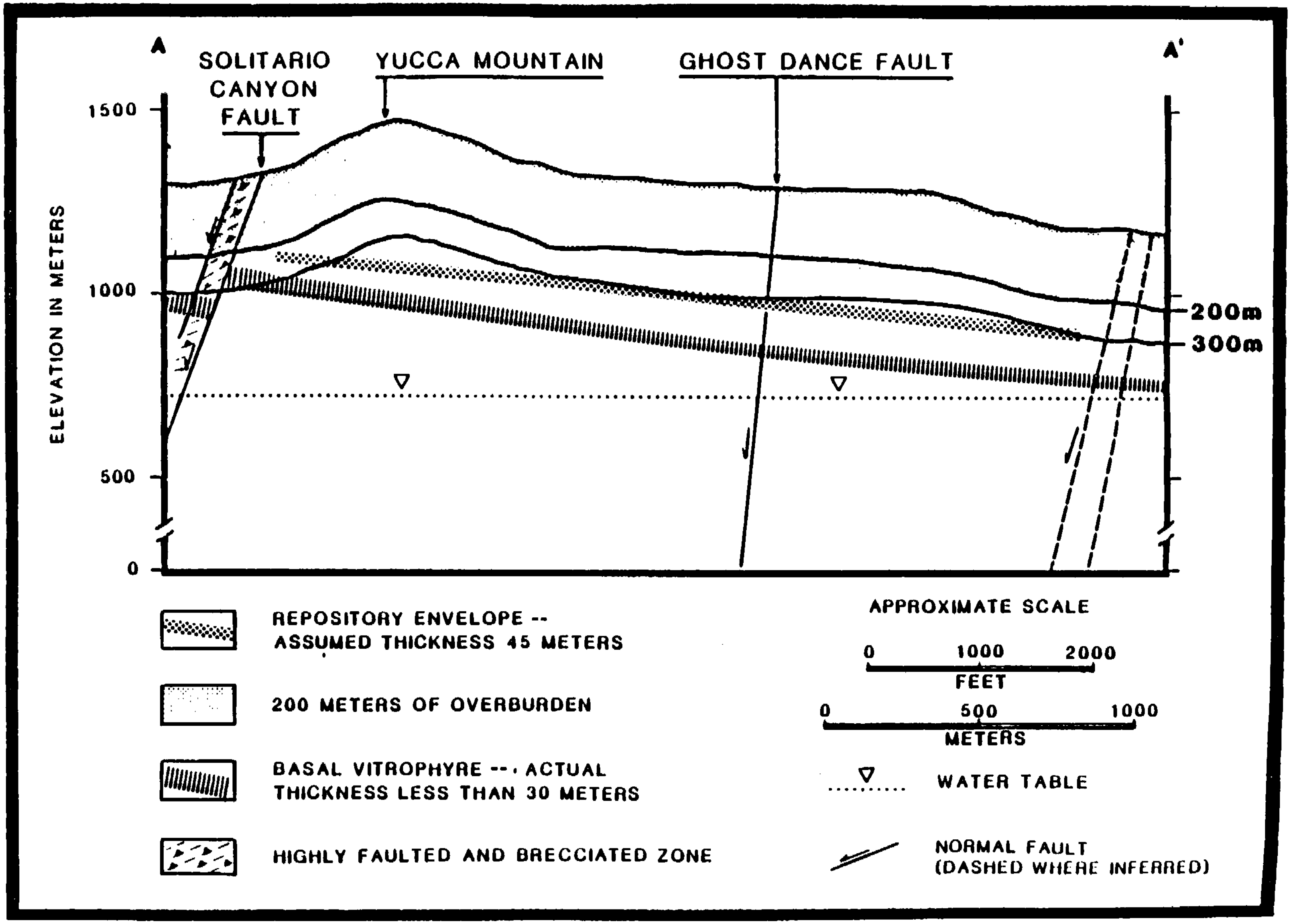


FIGURE 1-10
Profile of Yucca Mountain
(Source: DOE/RW-0073)

based on the following assumptions about the faulting in the Basin and Range Province. First, the location and the prediction of fault offset for existing faults is assumed more indicative of future performance than the rate of new faults. Second, a fault in the Basin and Range Province generally exhibits offset as a distinct event, not a gradual creeping movement. Third, faulting in the region surrounding Yucca Mountain varies substantially so a representative fault is chosen to approximate Yucca Mountain's probability of faulting. The representative fault chosen by the USGS is Yucca Fault in the NTS. Calculation of the fault's probable assume a relation between the slip rate across a major fault, rate of earthquake occurrence and earthquake magnitude based on assumptions of the distribution of fault offsets over time. The rate of faulting events and fault offset are not site specific and offer only an estimate of general trends in the area of Yucca Mountain.

1.4.4 Fractures

Fractures occur in all the strategraphic layers which resulted from volcanic activity over the past 16 million years. Generally, these fractures are strata-bound creating a complex, interconnected network of pathways between fractures and bisecting faults. This network is not well understood but implies the potential to restrict or channel increased groundwater flow, to retard or maximize groundwater recharge and to serve as the mechanism for liquid or gaseous transmission of radionuclides into the accessible environment.

The fractures are divided into three categories with distinct origins. They are:

(1) cooling fractures formed characteristically in 3-5 m (10-16 ft) swarms with consistent spacing of 150-200 m (492-656 ft) apart;

(2) tectonic fractures that occurred after the cooling event and exhibit small strike-slip displacement, but lack the consistent orientation of cooling fractures; and

(3) lateral strike-slip faults which are also tectonic in origin but exhibit a distinct northwest strike orientation

The general categorization of the fractures is the first step to determining local fracture impacts on the repository. Preliminary data indicate specific fracture frequencies which are predicted for several stratigraphic layers which are listed below. Little information is available to define the long term impacts of fractures or faulting on the movement of groundwater, water recharge or the potential for facilitation or retardation of the movement of radionuclides into the accessible environment.

2.0 HYDROGEOLOGY

2.1 General Characteristics

Yucca Mountain is not well characterized as a hydrogeologic system; however, available data supports the following assumptions:

1. Yucca Mountain is within a closed hydrogeologic basin.

2. Host rocks have the geochemical and hydrogeological characteristics which DOE assumes to be favorable to waste isolation.

3. A deep water table at a depth of 600 - 1000 m (1600 - 2500 ft) forms the basis for indirect transport of radionuclides to the accessible environment.

First, DOE assumes the area of the proposed repository is set in the Alkali Flat -- Furnace Creek Ranch groundwater basin (Figure 2-1). Discharge points for the basin were originally assumed to be in Alkali Flat and the springs in Death Valley but these assumptions are now in dispute. Research into the location of the discharge points and the relationship of groundwater movement to specific surface springs is not complete and will not be addressed in this report.

Second, DOE assumes the characteristics of Yucca Mountain repository will promote waste isolation. These characteristics include the geochemical properties of groundwater, the unsaturated nature of the volcanic tuff and the presence of a thick overburden of tuff above the repository.

Repository host rocks in the volcanic tuff at Yucca Mountain determine geochemical properties of the groundwater. Volcanic tuff generally does not readily dissolve in the presence of water. Welded tuff is especially resistant to dissolution in ground water.

The hydrogeologic units underlying Yucca Mountain correspond to the stratigraphic characteristics of the welded and non-welded tuff as defined in Chapter 1 (Figure 2-2). These hydrogeologic units exhibit the varying conductivity and potential for water movement related to the characteristic geologic strata. Welded tuff, such as the Topopah Spring Member, exhibits low permeabilities with a low percentage of continuous pores which impede matrix diffusion of water and encourage free drainage via fracture flow. These conditions promote an unsaturated condition surrounding the emplaced waste and minimize waste-water interaction time (Figure 2-3). Non-welded tuff generally demonstrates higher permeabilities and an increased percentage of continuous pores allowing matrix diffusion of groundwater.

The hydrogeology of Yucca Mountain designates distinct and varying potentials for groundwater infiltration and movement. DOE assumes these layers will allow infiltration to occur slowly through matrix diffusion and will result in long travel times to the accessible environment. Climatic conditions in this arid region lend

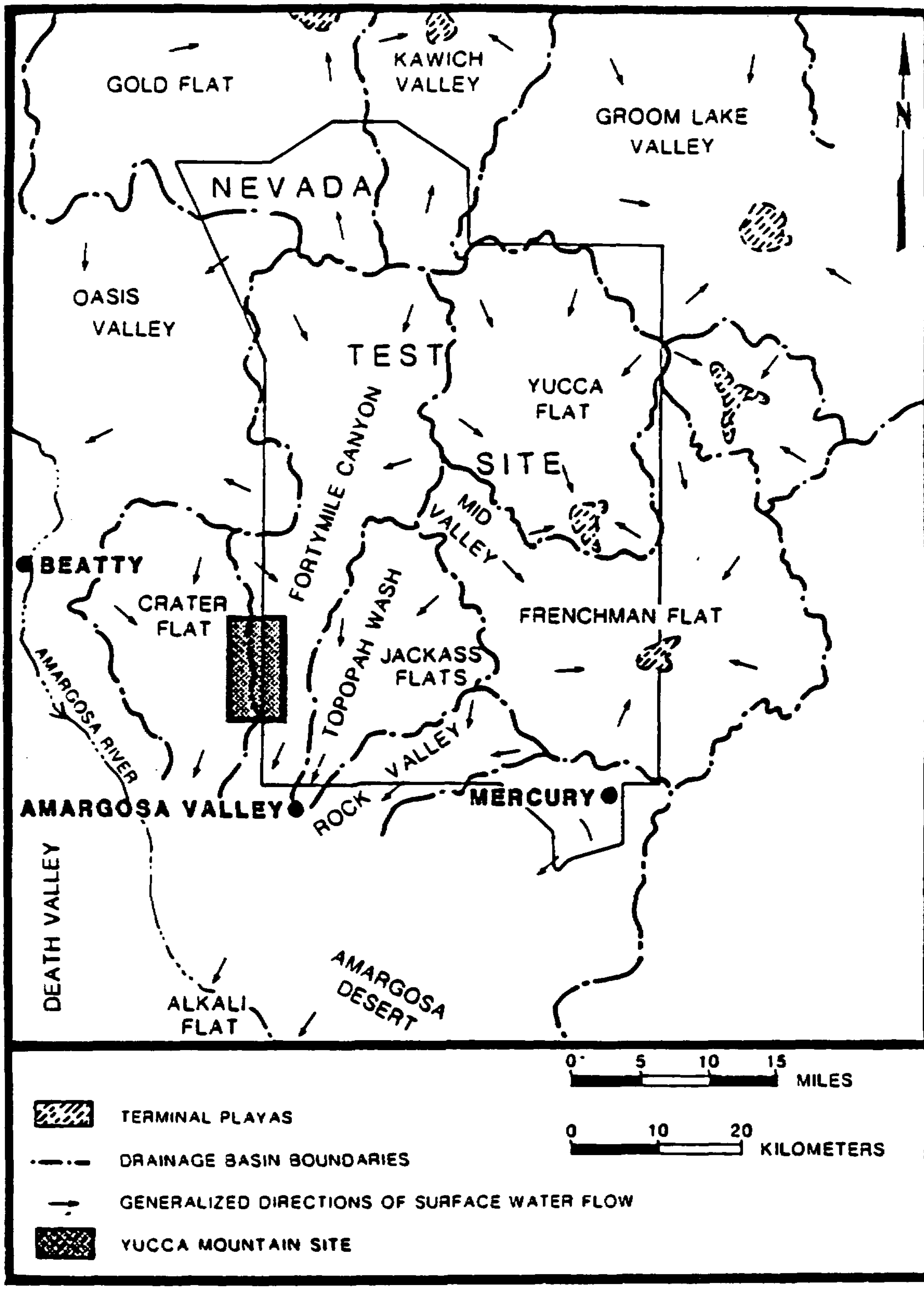


FIGURE 2-1
Drainage Basins in the Yucca Mountain Area Showing Direction of Flow of Surface Water
Modified from ERDA (1977)
(Source: DOE/RW-0073)

	Rock-Stratigraphic Unit	Hydrogeologic Unit [b]	Approximate Range of Thickness (m)	Lithology [c]
	Alluvium	QAL	0-30	Irregularly distributed surficial deposits of alluvium and colluvium
Paintbrush Tuff	Tiva Canyon Member	TCw	0-150	Moderately to densely welded, devitrified ash-flow tuff
Paintbrush Tuff	Yucca Mountain Member	PTn	20-100	Partially welded to nonwelded, vitric and occasionally divitrified tuffs
Paintbrush Tuff	Pah Canyon Member	PTn	20-100	Partially welded to nonwelded, vitric and occasionally divitrified tuffs
Paintbrush Tuff	Topopah Spring Member	TSw	290-360	Moderately to densely welded, devitrified ash-flow tuffs that are locally lithophysae-rich in the upper part, includes basal vitrophyre
	Tuffaceous beds of Calico Hills	CHn: CHnv / CHnz	100-400	Nonwelded to partially welded ash-flow tuffs: Vitric / Zeolitized
Crater Flat Tuff	Prow Pass Member	CHn: CHnv / CHnz	100-400	Nonwelded to partially welded ash-flow tuffs: Vitric / Zeolitized
Crater Flat Tuff	Bullfrog Member	CFu	0-200	Undifferentiated, welded and nonwelded, vitric, devitrified, and zeolitized ash-flow and air-fall tuffs

[a]Sources: Montazer and Wilson (1984) except as noted.

[b]QAL = Quaternary Alluvium, TC_w = Tiva Canyon welded unit, PT_n = Paintbrush nonwelded unit, TS_w = Topopah Spring welded unit, CH_n = Calico Hills nonwelded unit, CH_{nv} = Calico Hills nonwelded vitric unit, CH_{nz} = Calico Hills nonwelded zeolitized unit, CF_u = Crater Flat undifferentiated unit.

[c]Lithology summarized from Ortiz et al. (1985).

FIGURE 2-2
Definition of Unsaturated-Zone Hydrogeologic Units and Correlation with Rock-Stratigraphic Units
(Source: DOE/RW-0073)

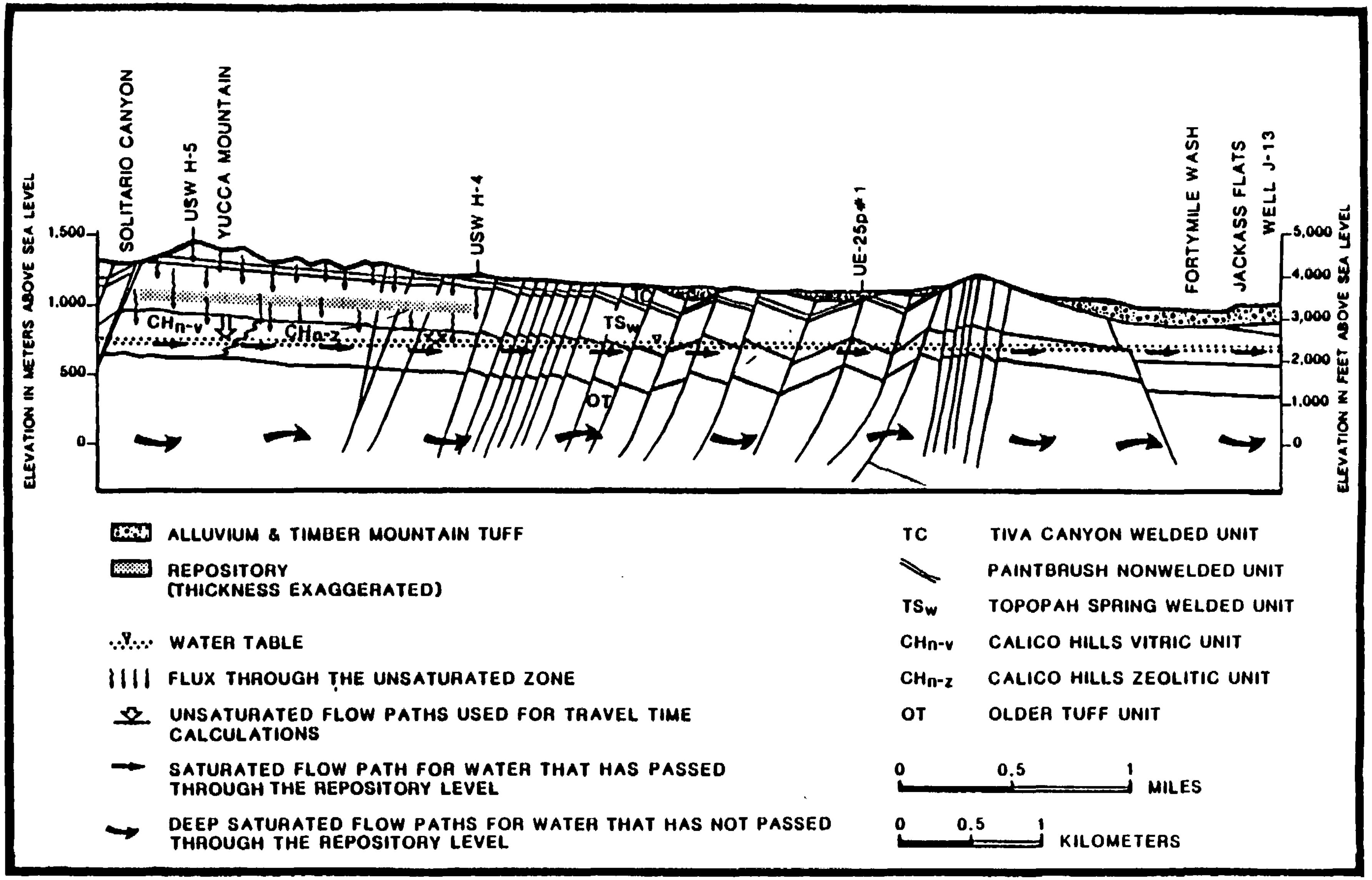


FIGURE 2-3
Conceptual Hydrogeologic Section from Solitario Canyon, Northwest of the Site, to Well J-13 in Jackass Flats
Modified from Scott and Bank (1984)
(Source: DOE/RW-0073)

support to DOE's conclusions that Yucca Mountain's hydrogeology will promote the isolation of radionuclides in an unsaturated environment.

Yucca Mountain is an arid area with minimal recharge of 0.5 mm (0.02 in) per year. Arid conditions allow for very limited infiltration and recharge into the surface alluvium above the repository. Most of the 150 mm (5.9 in) of annual rainfall is subjected to evapotranspiration in the surface alluvium and no surface water bodies exist except occasional flash floods due to seasonal storms. No data presently defines the relationship among flash flooding, infiltration and groundwater recharge. DOE notes the need for further study into the mechanisms of groundwater recharge at Yucca Mountain. The mechanisms will not be discussed in this report. Groundwater is assumed to flow vertically to the aquifer.

A complex stratigraphy of unsaturated layers of welded and non-welded tuff underlies the alluvium. The proposed repository is to be constructed in the welded tuff of the Topopah Spring Member at an approximate depth of 600 m (1988 ft). DOE assumes the welded tuff promotes waste isolation due to its unsaturated state, discontinuous pores and its complex over-burden of tuff. The water table is at a depth of 200-400 m (650-1300 ft) below the repository horizon.

Third, the groundwater flow is predominantly characterized as downward through the unsaturated hydrogeologic units such as the Topopah Spring into the saturated tuffaceous layers below. Release of radionuclides to the accessible environment may follow this indirect path of groundwater movement with the deep water table serving as the most probable conduit for contaminated groundwater flow in the arid area surrounding Yucca Mountain. Radionuclides have few other pathways to the accessible environment due to the depth of the repository, the unsaturated conditions and the presence of potential aquitards in the volcanic tuff.

2.2 Hydrogeologic Units

An overview of the lithology is given to detail the flow path from the ground surface, through the repository and into the aquifer. Individual horizons will be defined in this report from the surface alluvium to the Crater Flat stratigraphic unit (Figure 2-4). The saturated zone of the aquifer is found in the Crater Flat tuff or directly above in the Calico Hills unit tuffaceous beds and represents the mechanism for radionuclide transport beyond the boundary of the repository.

2.2.1 Alluvium

Yucca Mountain alluvium is characterized as a valley fill aquifer. The surface alluvium promotes downward water movement through its coarse, unconsolidated sedimentary horizon. Calcic layers are present and may serve as infiltration barriers, impounding water near the surface and encouraging evaporation.

STRATIGRAPHIC UNIT	TUFF LITHOLOGY[b]	HYDROGEOLOGIC UNIT[c]	SATURATED MATRIX HYDRAULIC CONDUCTIVITY	COMMENTS
Alluvium	- - -	Alluvium	Generally high	Underlies washes: thin layer on flats
Paintbrush Tuff: Tiva Canyon Member	MD	Tiva Canyon welded unit	1 mm/yr	Caprock that dips 5–10° eastward at Yucca Mountain. High fracture density
Paintbrush Tuff: Yucca Mountain Member; Pah Canyon Member	NP, B	Paintbrush nonwelded unit	3300 mm/yr	Vitric, nonwelded, porous, poorly indurated, bedded in part. Low fracture density.
Paintbrush Tuff: Topopah Spring Member	MD	Topopah Spring welded unit	0.7 mm/yr[d]	Densely to moderately welded: several lithophysal cavity zones, intensely fractured. Central and lower part is potential host rock for repository. Bulk hydraulic conductivity in saturated zone east of the site (at well J-13) about 1.0 m/day.
Tuffaceous beds of Calico Hills	NP, B; Vitric / Devitrified (in part zeolitic)	Calico Hills nonwelded unit; Water Table	Vitric: 107 mm/yr[d]; Zeolitic: 0.5 mm/yr[d]	Beneath Yucca Mountain, base of units for unsaturated zone determined by water table. Calico Hills nonwelded unit is vitric in southwest Yucca Mountain, zeolitic in east and north. Zeolitic boundary generally parallels the water table with vitric units above and zeolitic units below a transitional boundary.
Crater Flat Tuff: Prow Pass Member	MD	PP_w; Saturated Zone	88 mm/yr[d]	
	NP, B	PP_n	22 mm/yr[d]	
Crater Flat Tuff: Bullfrog Member	MD	BF_w	118 mm/yr[d]	
	NP, B	BF_n; Crater Flat Member	22 mm/yr[d]	
Crater Flat Tuff: Tram Member			22 mm/yr	None
Lava	Undifferentiated		Very low	Occurs in northwest part of repository block.
Lithic Ridge Tuff			Very low	None
Older volcanics			Very low	In USW H-1 hydraulic head about 50 m higher than water table.
Pre-Tertiary Rocks			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

[a]Data from Montazer and Wilson (1984) except as indicated.
[b]NP = nonwelded to partially welded; MD = moderately to densely welded; B = bedded.
[c]Hydrogeologic unit symbols: PP_w = Prow Pass welded unit; PP_n = Prow Pass nonwelded unit; BF_w = Bullfrog welded unit; BF_n = Bullfrog nonwelded unit.
[d]Data from Sandia National Laboratories Tuff Data Base (SNL, 1985).

FIGURE 2-4
Dual Classification of Tertiary Volcanic Rocks at Yucca Mountain; Stratigraphic Units Reflect Origin and Hydrogeologic Units Reflect Hydrologic Properties
(Source: DOE/RW-0073)

Alluvium in this region exhibits transmissivity ranges from 10 to 400 m^2/per day. Average hydraulic conductivity is defined within the range of 0.21 to 2.9 m per day and is a function of interstitial pore movement.

2.2.2 Tiva Canyon Member

The Tiva Canyon Member underlies the alluvium and functions similarly to a leaky aquitard. The layering of welded and non-welded tuffs promote both downward and lateral water movement. Little data is available to characterize the water movement through complex horizons created by the deposition and cooling of volcanic ash fall and air fall tuff.

Tiva Canyon's hydrogeological characteristics have been estimated by DOE with interstitial porosity ranging from 35 to 50% and a modest hydraulic conductivity of 0.08 m/per day.

2.2.3 Topopah Spring Member

The complex stratigraphy of this compound cooling unit of volcanic tuff has been described earlier in this report (Section 1.3.4). DOE estimates hydrogeologic characteristics of the repository horizon with limited data from proximate wells and laboratory analyses (see Table 2-1). The Topopah Spring retains its unsaturated character in reference to the repository horizon but preliminary data do indicate saturated areas exist under Yucca, Frenchman and Jackass Flats. A layer with lithophysae is present above the repository horizon and provides the potential for a perched aquifer.

2.2.4 Tuffaceous Beds of Calico Hills

The Calico Hills Member underlies the Topopah Spring Member. Zeolitized areas of the Calico Hills are deposited in the horizon underlying the northern half of the repository. The Calico Hills Member exhibits layers of less transmissive, argillized deposits in the area directly under the southern half of the repository. The Calico Hills Member may exhibit aquitard and aquifer characteristics dependent on the matrix composition of the tuff, vitrified tuff and zeolites. The tuffaceous beds may be saturated or unsaturated under Yucca Mountain.

Radionuclides dissolved in groundwater may be selectively sorbed onto zeolite minerals. Vitric, argillized layers do not offer a sorption potential for the radionuclides. The only effect may be the altering of groundwater flow direction or velocity due to the impermeability of the vitric layers.

The Calico Hills has been characterized by DOE through limited in-situ studies and laborafory calculations (see Table 2-1).

Stratigraphic unit	Typical character	In situ (field) analyses: Saturated thickness (m)	Transmissivity[b] (m^2/d)	Average hydraulic conductivity[c] (m/d)	Well or hole tested	Reference[d]	Laboratory analyses (cores): Saturated matrix hydraulic conductivity: m/d	No. of samples	Matrix porosity[e]: %	No. of samples	Well or hole analyzed	Reference[d]
Topopah Spring Member	Moderately to densely welded tuff	167	120	0.7	J-13	7	$3x10^{-7}$ to $2x10^{-4}$	5	4 - 33	5	J-13	7
							$7x10^{-7}$ to $5x10^{-4}$	18	6 - 30	24	UE-25a#1	1
							$8x10^{-7}$	1	12	1	UE-25b#1	4
Tuffaceous beds of Calico Hills	Zeolitized, nonwelded tuff, vitric tuff	148	(82)	0.5	UE-25b#1	4	$4x10^{-6}$ to $3x10^{-4}$	6	20 - 34	7	UE-25a#1	1

[a] Interpretive analyses from in situ testing at some drillholes are not completed yet, including those from drillholes USW G-4, USW H-6, and UE-25c#1,2,3.

[b] Determined from pumping tests, borehole-flow surveys, and slug-injection tests; parentheses indicate approximate value because reported values reflect more than one stratigraphic unit.

[c] Obtained by dividing transmissivity by saturated thickness, which in some cases may not agree with values reported in the cited reference. Productive zones are typically thin, fractured intervals rather than a generally-uniform rock matrix; therefore, the porous-media concept of hydraulic conductivity is not necessarily appropriate.

[d] 1, Anderson (1981); 2, Barr (1985); 3, Craig and Robison (1984); 4, Lahoud et al. (1984); 5, Peters et al. (1984); 6, Rush et al. (1984); 7, Thordarson (1983); 8, Thordarson et al. (1985); 9, Whitfield et al. (1985).

TABLE 2-1
Preliminary Summary of Hydrologic Characteristics of Major Stratigraphic Units in the Vicinity of Yucca Mountain

(Source: DOE/RW-0199)

2.2.5 Crater Flat Tuff

The Prow Pass, Bullfrog Member and Tram Members of the Crater Flat tuff are welded to moderately welded tuffs with intermitted layers of ash fall bedded tuff. A complex matrix of tuff, clays and some deposition of zeolites determine if localized areas function as an aquifer or an aquitard.

Transmissivities have been estimated for the Crater Flat tuff, ranging from less than 0.1 to approximately 300 m^2 per day. DOE estimates the hydraulic conductivity ranges from 8×10^{-4} and 3×10^{-1} m per day. Portions of this area are saturated and contain the water table under Yucca Mountain.

2.3 DOE Estimates

A simple model of ground water movement was developed by DOE. The model assumed a hydraulic gradient of 1.0 and estimated hydraulic properties based on limited data and theoretical calculations (see Table 2-2). These estimates are based on limited representative data with little information about the hydrologic and geologic characteristics specific to the Yucca Mountain site. A complete site characterization is necessary to define the pathways of groundwater flow, the likelihood of waste dissolution and the potential travel times to the aquifer. Current estimates do not consider potential impacts of lateral water movement, capillary barriers between layers of differing permeabilities, fracture flow conditions or the possibility of waste-water interaction.

Uncertainty is inherent in the current estimates and DOE states it has chosen to assume conservative values to minimize the impact of that uncertainty. This report acknowledges the uncertainty inherent in DOE's estimates but applies the currently available information. Until site characterization is completed, conservative estimates are the most useful information available to bound the discussion of release scenarios.

2.4 Role of the Topopah Spring and Calico Hills Members

Due to the location and specific hydrogeologic characteristics of the Topopah Spring and the Calico Hills tuffaceous beds, this report emphasizes these stratigraphic units in the analysis of groundwater dissolution and transport of radionuclides into the underlying aquifer. Yucca Mountain's proposed repository is designed to function in an unsaturated environment. The Topopah Springs and Calico Hills units are the critical areas surrounding the repository and serve as the unsaturated barrier to ground water flow and radionuclide transport.

The retardation of nuclides may result from the presence of natural barriers which retard radionuclide transport and subsequent release in the accessible environment. Zeolitized areas have been discovered in the northern half of the Calico Hills tuffaceous beds strata sandwiched between the repository and the aquifer (Section 1.1.2.5). These tektosilicate minerals are formed as one of the last deposits during

Hydrogeologic unit[a] / Parameter	TS_w	CH_{n-v}	CH_{n-z}	PP_w	PP_n	BF_w	BF_n[b]	Remarks
Hydraulic gradient (i)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	$i = \partial h/\partial \ell = \partial \psi/\partial \ell + \partial z/\partial \ell$ where ℓ = x,y,z, $\partial \psi/\partial \ell << 1.0$ and $\partial z/\partial \ell = \partial z/\partial z = 1.0$, i.e. vertical gravity flow is assumed.
Mean saturated-matrix hydraulic conductivity K_s (mm/yr)[c]	0.7 (31)	107 (8)	0.5 (31)	88 (10)	22 (7)	118 (2)	22 (NA)	$\bar{K}_s = \ln^{-1}$ (mean[$\ln(K_s)$]) Values in parentheses are the number of measurements.
$K_s - 1\sigma$ (mm/yr)	0.1	1.9	0.0	29	3	58	3	$\pm 1\sigma(K_s) = \bar{K}_s + \ln^{-1}(\ln\sigma(K_s))$
$\bar{K}_s + 1\sigma$ (mm/yr)	4.1	6,090	7.6	261	142	240	142	
Mean Effective Porosity $\bar{n}_e \pm 1\sigma$	0.11 ±.05 (138, 12)	0.32 ±.09 (23, 6)	0.27 ±.05 (65, 10)	0.24 ±.06 (27, 4)	0.25 ±.06 (75, 2)	0.22 ±.09 (120, 2)	0.25 ±.06 (NA)	$\bar{n}_e = n_b(1-S_r)$, where n_b is the mean bulk, dry porosity and S_r is residual saturation. Ordered pairs in parentheses are number of measurements of n_b and S_r, respectively.
Range of thicknesses (m)[d]	0-72 (98.5)	0-135 (95.3)	0-135 (94.5)	0-44 (83.2)	0-122 (63.1)	0-91 (25.6)	0-55 (7.5)	Thicknesses between disturbed zone and water table for area within the design repository boundaries. Values in parentheses are percentages of total repository are underlain by the units.
Particle velocity, v (mm/yr): q = 0.5 mm/yr	5.0	5.5	1.9	7.6	4.1	7.3	4.1	$V = (q/n_e)(q/K_s)^{-1/\epsilon}$, where n_e and k_s are mean values and q is flux.
Particle velocity, v (mm/yr): q = 1.0 mm/yr	8.9 (2,780)	9.4	3.4 (4,650)	12.8	7.2	12.5	7.2	Values in parentheses indicate fracture-flow velocity calculated as $(q-K_s)/0.0001$, where 0.0001 is the assumed effective porosity of fractures.
ϵ[e]	5.9	4.2	7.0	4.0	5.2	4.6	5.2	Empirical constant that represents the effects of the relationship between pore-size distribution and saturation on the amount of the effective porosity, n_e, available for flow; the effect of ϵ is to reduce flow area and thus increase particle velocity relative to values calculated using q/n_e.

[a] TS_w = Topopah Spring welded unit; CH_{n-v} = Calico Hills vitric unit; CH_{n-z} = Calico Hills zeolitic unit; PP_w = Prow Pass welded unit; PP_n = Prow Pass nonwelded unit; BF_w = Bullfrog welded unit; BF_n = Bullfrog nonwelded unit.

[b] Assumed to be hydrologically identical to PP_n.

[c] Saturated conductivity and effective-porosity data are from Sandia National Laboratories Tuff Data Base (SNL, 1985).

[d] Range of thickness, Sandia National Laboratories Interactive Graphics Information System (IGIS) (SNL, 1985).

[e] Values calculated from data in Peters et al. (1984).

TABLE 2-2
Parameters Used in Travel-Time Calculations for the Unsaturated Zone
(Source: DOE/RW-0073)

volcanism and result in structures which have an increased capacity for cation exchange and radionuclide absorption. Zeolites do not function as a barrier to groundwater flow similar to a vitric rock layer or capillary barrier between two zones of differing permeabilities. A zeolite area serves as an open, meshed silica framework which promotes replacement of cations in solution. Certain radionuclides dissolved in groundwater would interact with the zeolites and be removed from solution. DOE assumes radionuclide retardation may occur during migration once the dissolved waste flows through the zeolite layers in the Calico Hills tuff.

Normal flow in the area of Yucca Mountain is not well-defined by the available data. Its complex flow patterns, hydrogeological characteristics and potential for capillary barriers, necessitate conservative estimates for normal flow. Simple gravity driven flow models through the unsaturated Topopah Spring and Calico Hills Members provide insight into the generalized normal flow under Yucca Mountain and its potential impact on the radionuclide mobilization and transport.

3.0 ENGINEERED SYSTEMS

3.1 Repository Design

DOE is currently considering design parameters for the Yucca Mountain repository. Design characteristics such as the repository layout, emplacement strategy and plans to promote long term containment are critical to evaluating releases into the accessible environment. This report analyzes current data on the general design parameters, waste emplacement strategies, characteristics of waste canisters and waste profile. Current DOE data has a high rate of uncertainity so this report will apply conservative assumptions to supplement existing data.

3.1.1 General Design Parameters

Current plans are to construct the underground repository in the welded tuff of the eastern flank of Yucca Mountain at a depth of approximately 300 m (1,000 ft.). The repository will encompass an irregularly shaped area with a total of 2,095 acres available for waste disposal (Figure 3-1). Predicted waste volumes now require the utilization of 1,380 acres for the long term disposal of an estimated equivalent of 70,000 MTU (metric tons uranium) waste.

The repository design assumes free drainage in the surrounding strata, no "bathtub" effect of water collecting in proximity to the waste and the dissipation of the thermal loading from decaying spent fuel. The repository must be designed to maintain its integrity in response to seismic events. Federal regulations require DOE's design to address additional natural phenomena, human intervention, in-situ conditions and the likelihood of release of radionuclides to the environment.

3.1.2 Waste Emplacement Strategies

Waste emplacement strategies are a critical component of the design options for the waste repository. Originally, the vertical emplacement of waste was the preferred option but the recent discussion has expanded to include horizontal emplacement of wastes. Either strategy must consider the requirement that the 18 proposed panels will dissipate the thermal loading from spent fuel which peaks within 500 years after closure. The initial maximal thermal loading is estimated to be 57 KW/acre and is based on the potential heat generated by the spent fuel waste components and the heat dissipation properties of welded tuff.

The general repository layout is composed of 18 panels with each panel designed to be approximately rectangular in shape. Current designs assume the panels to be 427 m (1,400 ft.) wide, oriented parallel to the main drifts and within the range of 457 m (1,500 ft.) to 975 m (3,200 ft.) long. Panels are to be excavated with the lengths perpendicular to the main drift. A sump pump system is planned for the lowest point in the repository. The sump pump system will collect any moisture present beneath the repository and pump the water to the surface through the emplacement

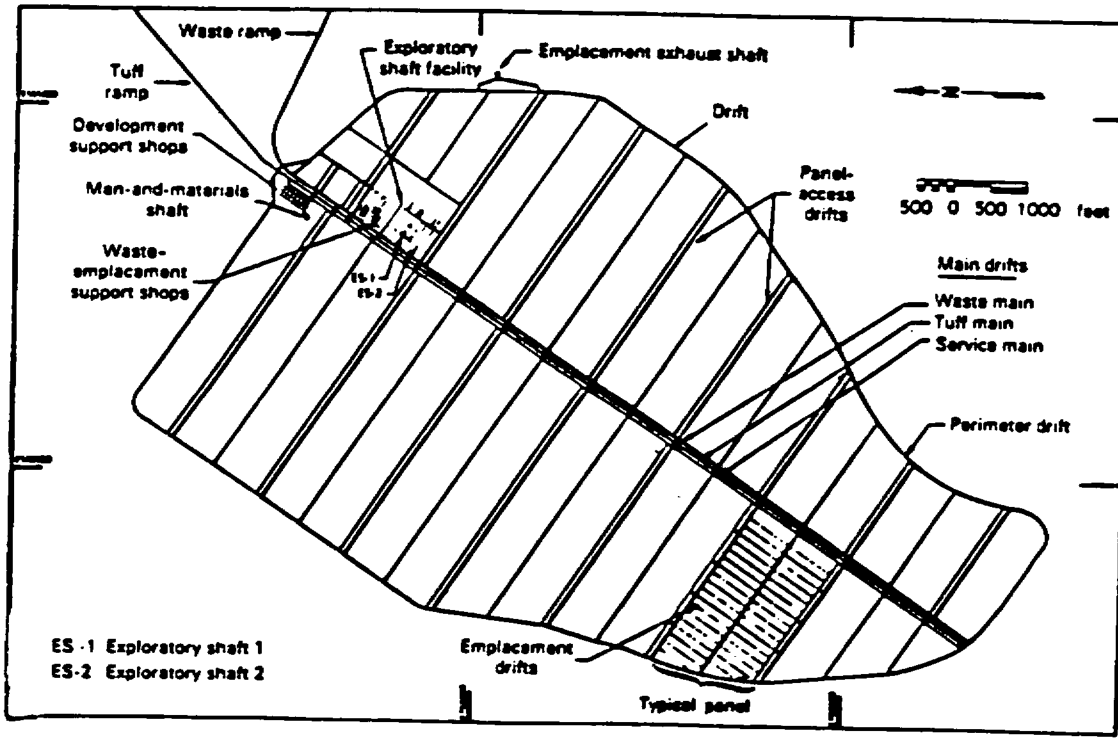


FIGURE 3-1
Underground Repository Layout for Vertical Waste Emplacement
(Source: DOE/RW-0199)

area exhaust shaft. Neither horizontal nor vertical waste emplacement alters these design parameters.

Both vertical and horizontal waste emplacement strategies will be discussed in this report. DOE has developed general and specific design parameters for the two strategies. Definition of the design parameter is preliminary and may yield highly uncertain results until the characterization of the site is complete. As in previous sections, this report will apply relevant DOE data which supports conservative assumptions when limited information is available.

3.1.2.1 Vertical Emplacement

Vertical emplacement involves the drilling of vertical boreholes into the drift floor (Figure 3-2). Panels, defined along a grid, are waste emplacement drifts bisected by access drifts. An additional design feature, the mid-point access panel, is designed to provide access for the entire length of the repository. A roughly perpendicular shape results from emplacement panels being bounded on one side by a parameter access drift and centrally by the midpoint access panel. One canister of wastes will be emplaced in the vertical borehole which is drilled at set intervals called standoffs throughout the drift of each panel. The minimum stand-off distance between individual canisters and a panel access drift is defined as 26 m (85 ft) between boreholes. The design height of the access drift is set at 4 m (14 ft) with the emplacement drift height dependent on the actual equipment used to emplace the waste (Figure 3-3). A borehole must be 25 feet deep and 30 inches in diameter.

The actual vertical emplacement of wastes is defined by a series of design specifications (Figure 3-4). These specifications are assumed to protect the emplaced waste canister and to include the following five design elements. First, a support plate is inserted into the bottom of the vertical borehole. Second, a metal casing is added which rests on the inserted support plate and extends up past the expected length of the waste canister. Third, a waste canister is inserted and capped by a metal plug. This plug is intended to lessen the radioactive release during emplacement therefore serving as a safety feature. Fourth, crushed tuff is packed over the metal shielding. Fifth and finally, the borehole (and the waste canisters) are closed with a metal cover. A final design criterion is to alternate the emplacement of spent fuel and defense high level waste (DHLW) to better dissipate the thermal loading produced by the decay of spent fuel during the initial postclosure period.

3.1.2.2 Horizontal Emplacement

The second strategy under consideration outlines the horizontal emplacement of the wastes, Its design parameters for the repository are similar to the vertical emplacement design (Figure 3-5). One specific change is the modification to remove the midpoint access drift required for vertical emplacement. Additional design changes would establish the emplacement drifts at greater distance than considered for vertical emplacement. Major differences between the two

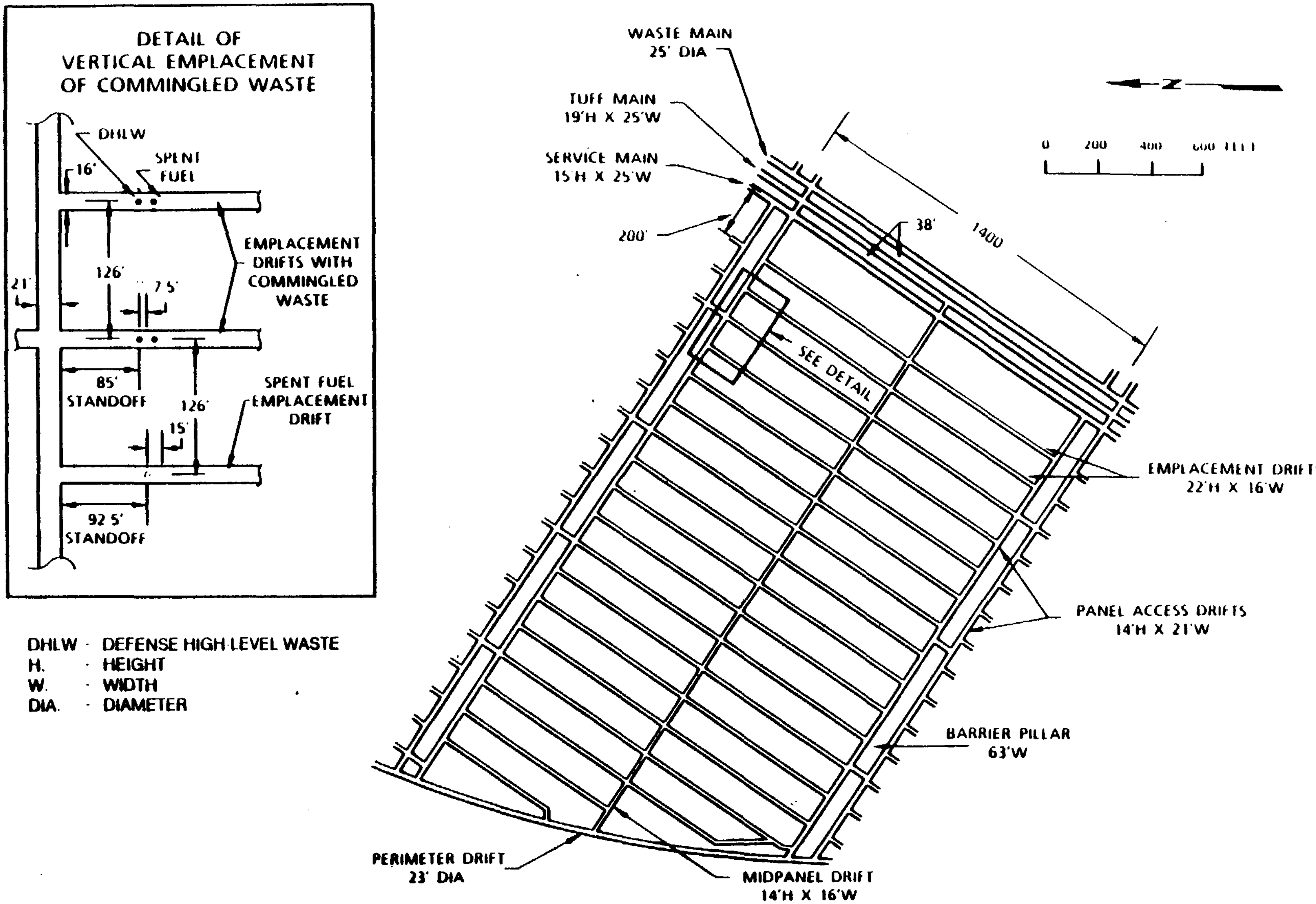


FIGURE 3-2
Typical Panel Layout for Vertical Emplacement
(Source: DOE/RW-0199)

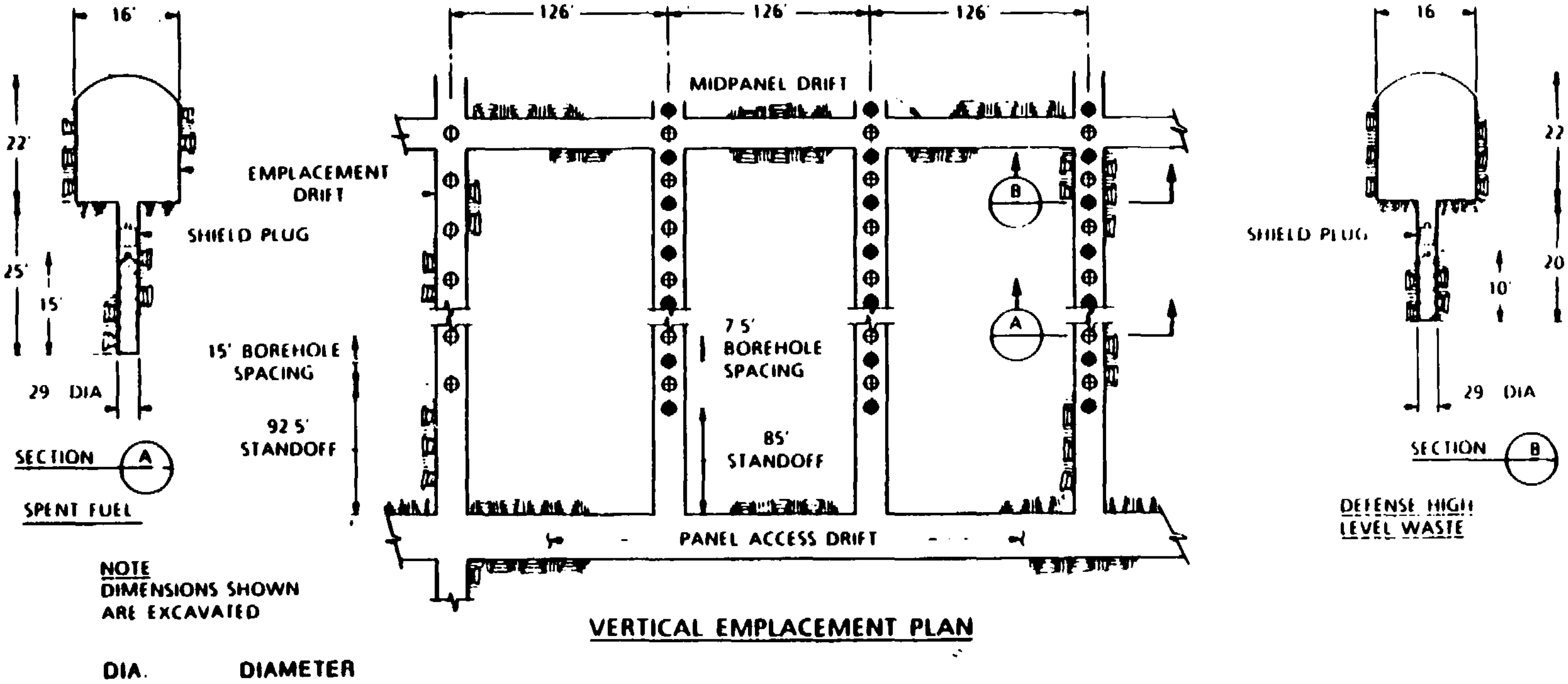


FIGURE 3-3
Panel Details for Vertical Emplacement
(Source: DOE/RW-1099)

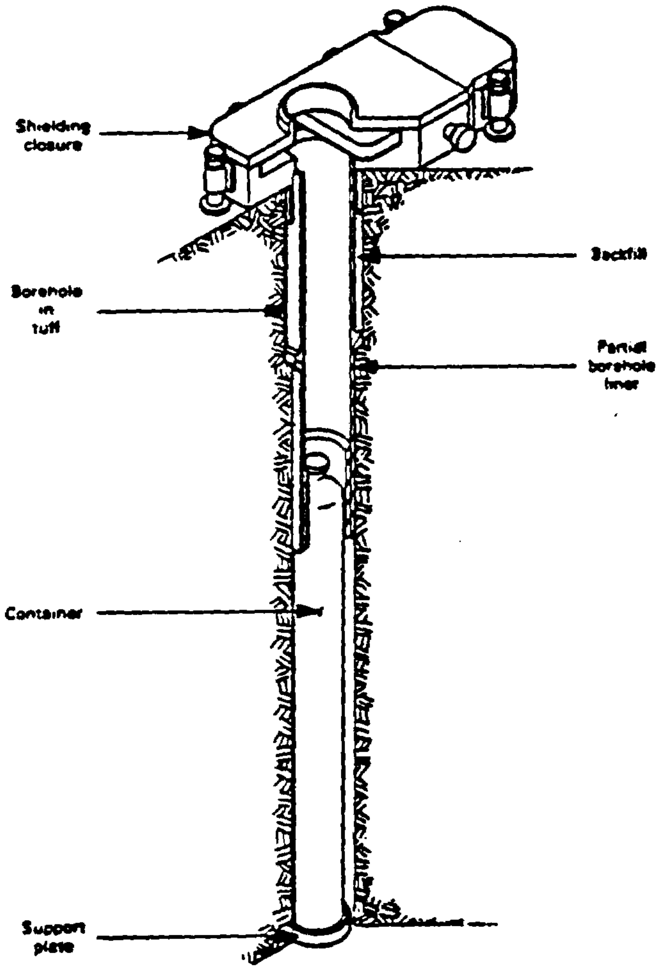


FIGURE 3-4
Vertical Waste-Emplacement Borehole
(Source: DOE/RW-0199)

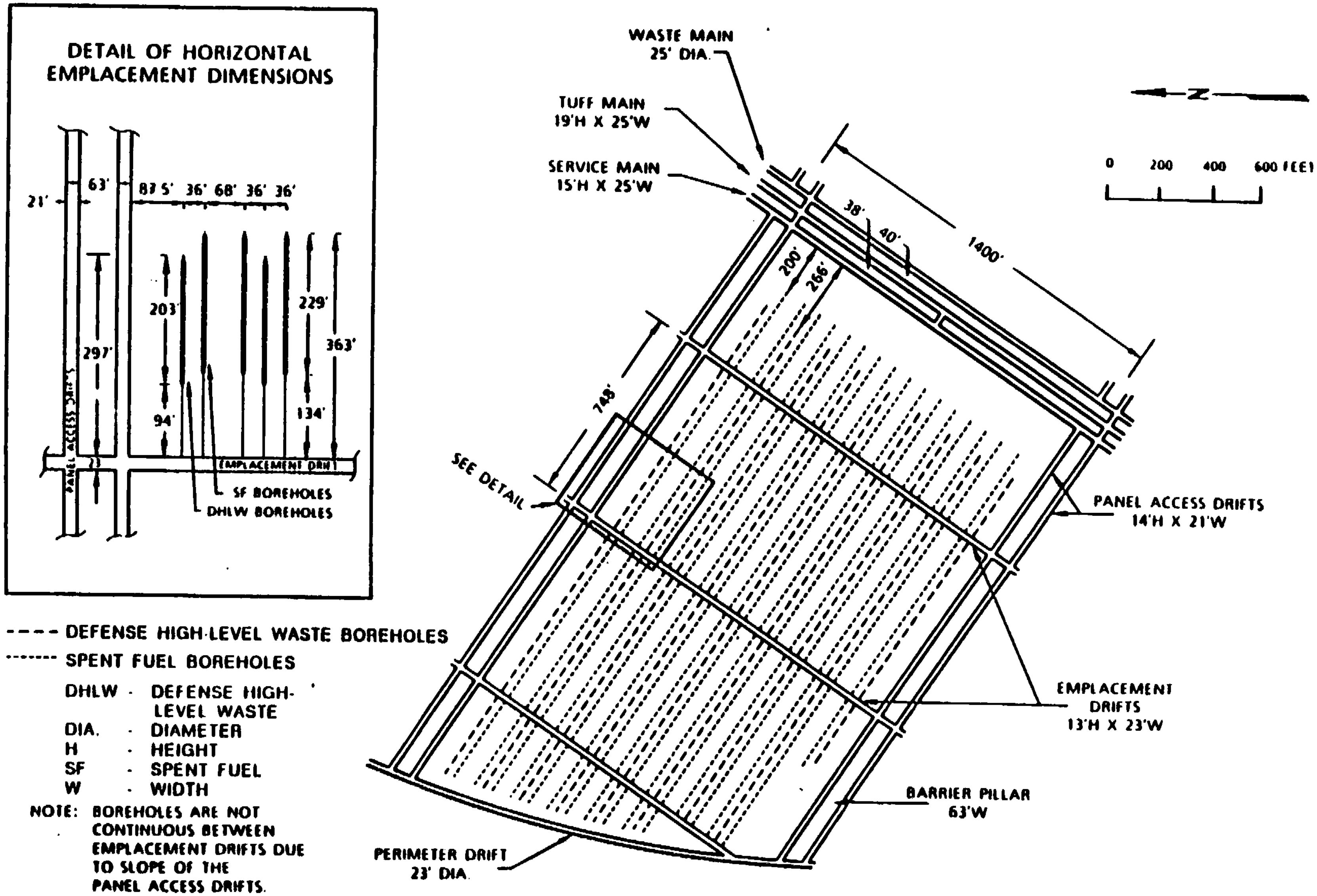


FIGURE 3-5
Typical Panel Layout for Horizontal Emplacement
(Source: DOE/RW-0199)

emplacement strategies include requirements that the panels for horizontal emplacement would be twice the size of vertical emplacement. This design parameter assumes an alternative waste emplacement drift in the shared wall of abutting panels.

Current considerations of the horizontal emplacement strategy have resulted in DOE defining general design parameters for Yucca Mountain. Waste emplacement drifts would be 7 m (23 ft) by 4 m (13 ft) wide lying in the panels assumed to be 427 m (1,400 ft) long. Mid-panel drifts are no longer required and the panel access drifts will be 4 m (14 ft) high by 6 m (21 ft) wide. Unlike the prescribed single waste canister per vertical borehole, horizontal emplacement establishes the maximum load to be 18 containers of DHLW and 14 containers of spent fuel (Figure 3-6). Calculations of the necessary standoff distance are to be determined by the number of waste canisters considered and the underground distances needed to accommodate the resulting thermal load from the spent fuel. Alternating individual spent fuel and DHLW canisters will be applied to dissipate the thermal loading. The need to dissipate thermal loading in the repository will be determined by DOE during the site characterization process. In general, design specifications for the horizontal emplacement of wastes are similar to the requirements for vertical emplacement (Figure 3-7).

3.2 Waste Canisters

A waste canister forms the basis for the engineered system at Yucca Mountain. Research into the most efficient design, meeting the NRC's high integrity criteria, is underway at DOE. This report will discuss available findings and describe the current DOE reference canisters.

3.2.1 General Assumptions

DOE assumes containment of long life isotopes to be held to a stricter standard than past practices used to contain the high-level radioactive waste during storage or transport. The design of the waste container must compensate for the most adverse, limiting conditions and the emplacement in an unsaturated stratigraphic horizon. In the absence of liquid water (or potentially water vapor), few processes can cause a waste container to fail. A saturated system would allow liquid water to readily contact, dissolve and mobilize radionuclides. An unsaturated system would not offer the medium for dissolution and transport and would lessen the likelihood of corrosion of the waste canisters or saturated flow of the radionuclides away from its initial emplacement area.

Requirements for canister integrity are one component of the overall design approach to minimize radionuclide release into the environment. The assumption is to craft a system of multiple engineered designs and natural barriers to predictably contain a large fraction of the radionuclides for 10,000 years. Any radioactivity, once released, would be a very small proportion of the emplaced waste volume.

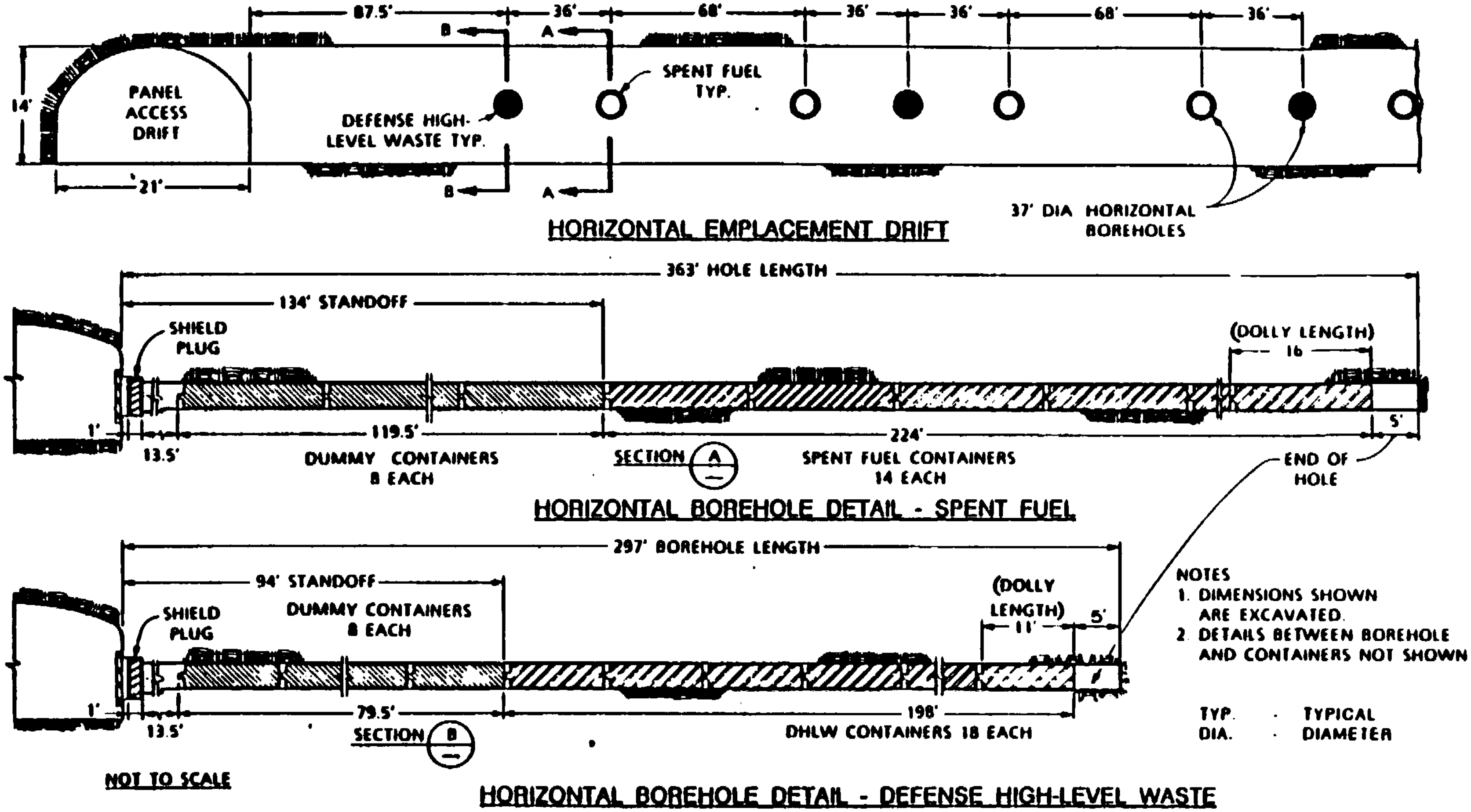


FIGURE 3-6
Panel Details for Horizontal Emplacement
(Source: DOE/RW-0199)

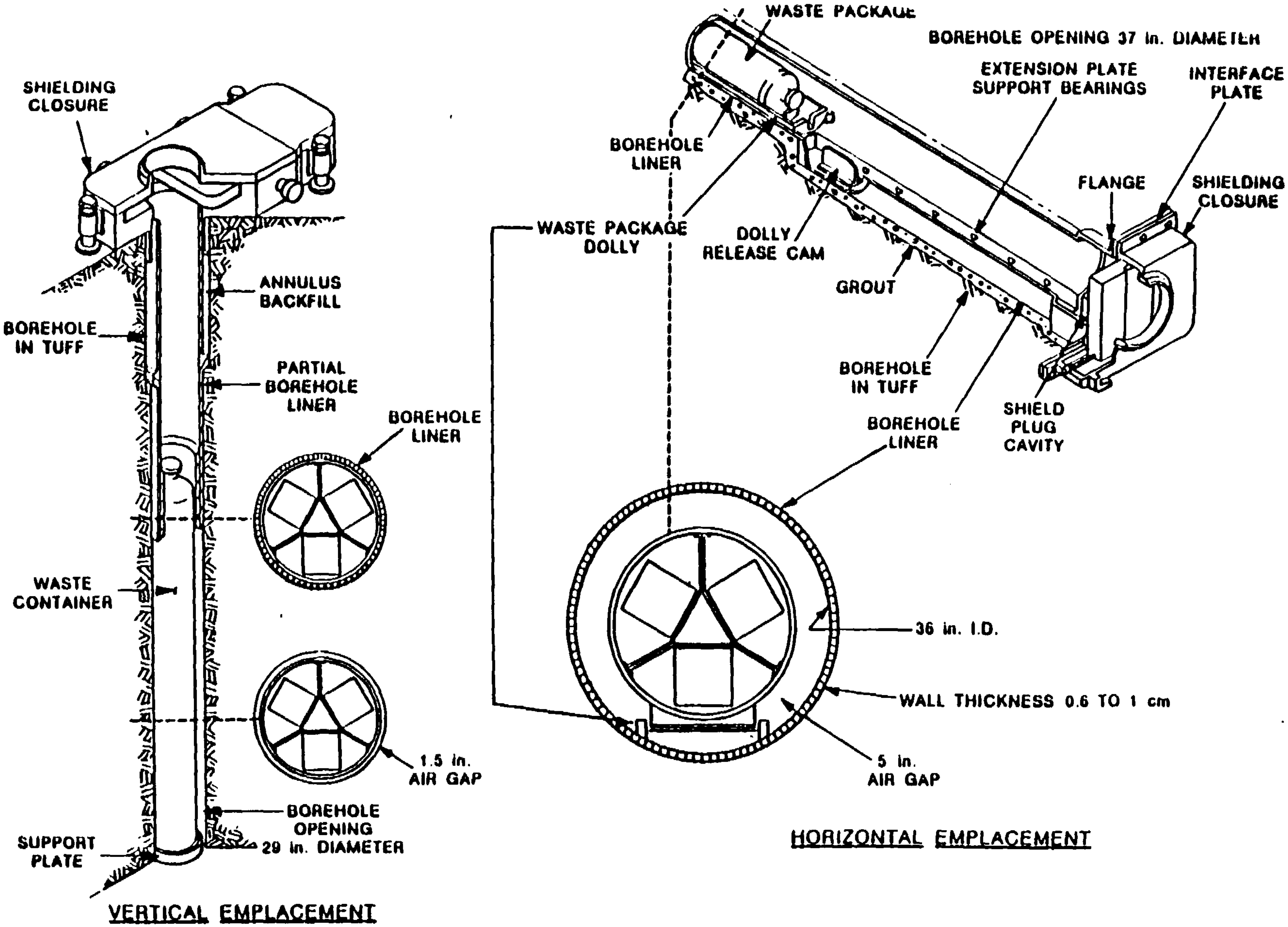


FIGURE 3-7
Design Configuration for Vertical and Horizontal Emplacement
(Source: DOE/RW-0199)

DOE considers this small proportion of actual release to be conservative and appropriate.

3.2.2 Design Features Under Consideration

Currently six types of metal canisters are under review for their individual mechanical, physical and microstructural properties of the welded materials, exposed surfaces and the container base metal. These six canister designs are either austenitic alloys, copper or copper based alloys. Currently accepted reference waste package material is AISI 304L stainless steel (Figure 3-8).

Each is being evaluated against the bounding value of 5 liters of water/year contacting 5% of the waste. This bounding parameter is applied to model the canisters over time and increase to 5 liters of water/year contacting 10% of the waste in the period of 300-1,000 years following closure. The integrity of the waste container is critical to maintaining a separation of the waste from the environment. Corrosion of the waste canister, either in a localized or a general fashion, creates an increased potential for waste-water interaction for radionuclide release to ground water or other pathway to the accessible environment. The final choice of the waste canister design is dependent on data collected during the site characterization.

3.2.3 Design Features of the Reference Canister

The reference waste package provides design criteria for canisters. Each canister is to have a diameter of 66 cm (2.2 ft). A length for the spent fuel or DHLW canister ranges from 3.1 to 4.7m (9-15 ft) which varies given the type of waste to be contained (Figure 3-9). These canisters will weigh between 2.7 and 6.4 metric tons when fully loaded with waste and will average 3.3 KW/canister in decay heat. NRC requires the DOE waste container retain its integrity and prevent substantial radionuclide release for the period of 300-1,000 years postclosure, serving as the most basic component of the engineered system at Yucca Mountain.

3.2.4 Role of Thermal Loading

The generation of excess heat by the spent fuel segment of the waste stream is a critical issue for the repository design and the development of a reliable waste canister. Decay heat will be a significant factor in the early (approximately first 500 years) postclosure period. DOE assumes the thermal pulse for the first 100 years will dry out the surrounding host rock, vaporize water held in the unsaturated rock and force it away from the waste container. This scenario supports current DOE designs to maintain canister integrity in unsaturated host rock.

The decay heat is predicted to establish a heat convection system where the surrounding water is vaporized, the water vapor is driven away, cools and recondenses at some distance from the repository. An engineered air gap and the presence of crushed tuff as a backfill between the host rock and the waste canister

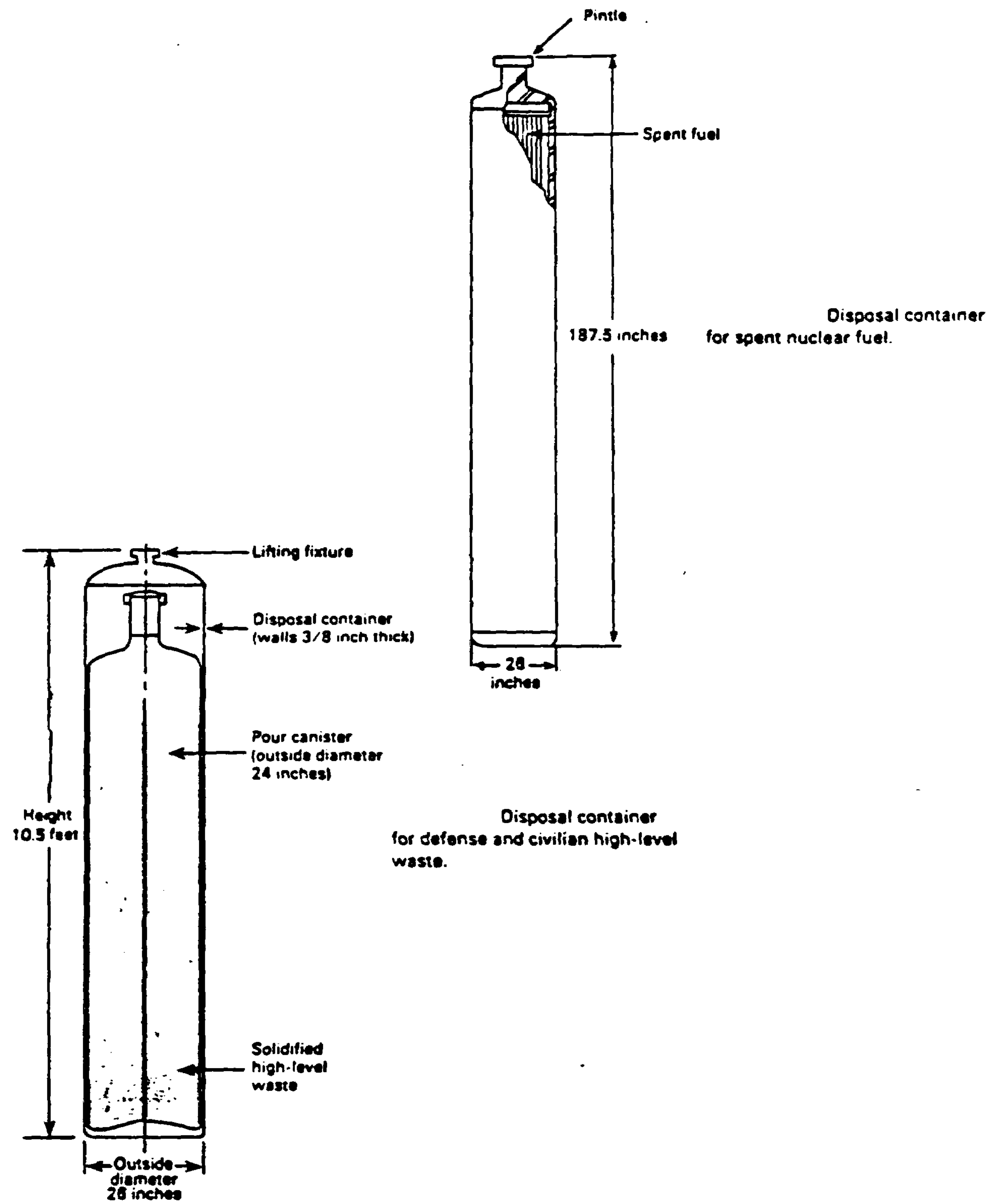


FIGURE 3-8
Disposal Container for Defense and Civilian High-Level Waste
(Source: DOE/RW-0199)

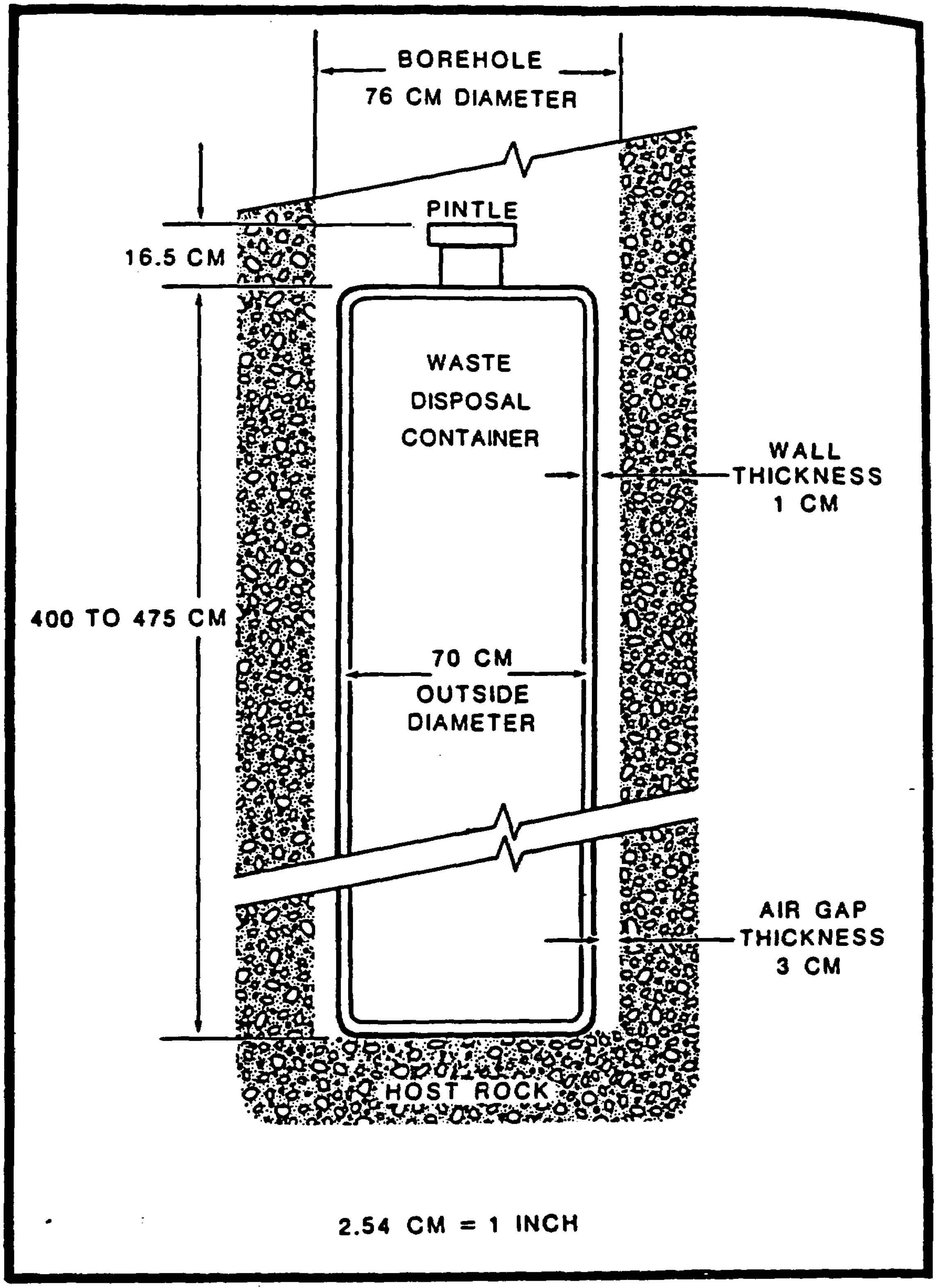


FIGURE 3-9
Reference Conceptual Design for Spent Fuel Waste Disposal Container
(Source: DOE/RW-0073)

are also expected to provide additional capillary barriers to matrix diffusion in welded volcanic tuff. A capillary barrier functions to prevent liquid or gaseous water from diffusing back in contact with the cooling waste canisters due to the inability of water to cross the boudaries of areas with greatly different permeabilities. Thermal loading in the postclosure repository may promote corrosion and not prevent localized release of radionuclides either as a gas or in solution with water. Capillary barriers may, in reality, serve as conduits for liquid or vapor flow into proximity with the waste. Design components such as the thermal loading and engineered capillary barriers are not well enough understood to evaluate their efficacy.

3.3 Waste Profile

The waste profile at Yucca Mountain will consist of two general categories of high level radioactive waste. Unprocessed spent fuel from commercial reactors is one general category of waste. A second general category encompasses high level waste from commercial and defense operations (Figure 3-10).

DOE must take responsibility for spent fuel five years after it is discharged as waste by the commercial reactor. Prior to the five year cutoff, reactors are to store high level waste on site. Present designs at Yucca Mountain are predicated upon the waste to be held in storage for 10 years. DOE acknowledges subsequent waste emplacements may include five year old waste. However, all current emplacement design and volume models are based on spent fuel waste being at least 10 years old (Table 3-1).

3.3.1 Spent Fuel

Spent fuel is an enriched uranium oxide matrix containing transuranic nuclides, fission and activation products from commercial nuclear power reactors. Waste from light water power (LWR) reactors such as boiling water reactors (BWR) and pressurized water reactors (PWR) is expected. The form of these wastes will include components such as:

1. Intact assemblies
2. Metallic components such as tubing or space grids
3. Zirconium alloy or stainless steel cladding which is potentially contaminated with activation products
4. Canisters and consolidated fuel rods

Additional waste forms are predicted to include "failed fuel" and non-fuel hardware. "Failed fuel" is structurally damaged fuel rods and is contained by a protective canister(s) to lessen the release of particulates prior to emplacement. Non-fuel hardware includes the metal fittings and structural components of the intact assemblies.

Arthur D Little

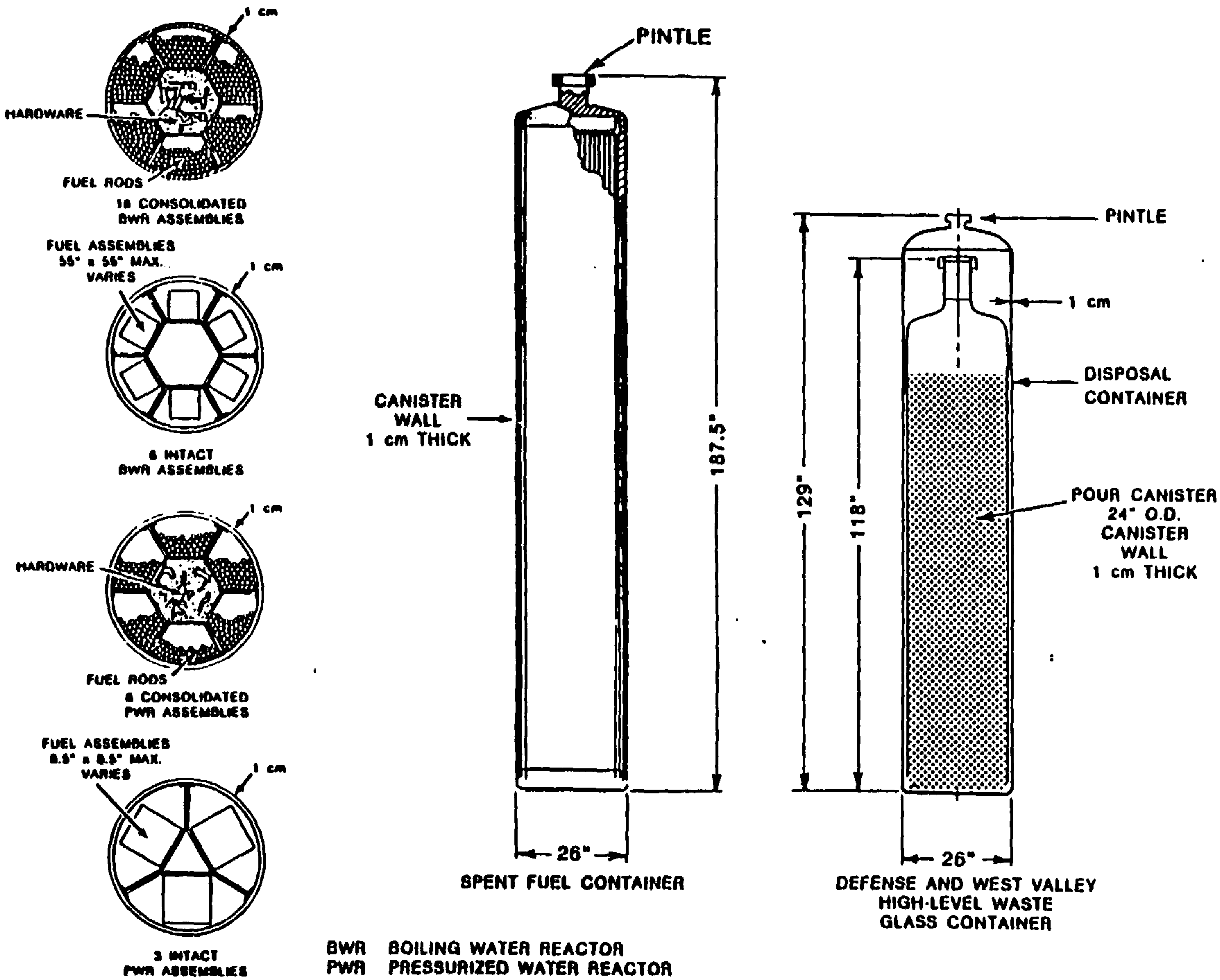


FIGURE 3-10
Spent Fuel and High-Level Waste Glass Containers
(Source: DOE/RW-0073)

TABLE 3-1
Radionuclide Inventory in Repository at 360 and 1,060 Years After Emplacement of a 10 Year Old Spent Fuel
(Source: DOE/RW-0073)

Radionuclide	Half-life (years)	Specific activity (Ci/g)[a]	Radionuclide inventory (Ci/1000 MTU)[a]		
			t = 10 yr[b]	t = 360yr[c]	t = 1,060 yr[c]
Cm-246	5.5×10^{3}	2.64×10^{-1}	3.5×10^{1}	3.4×10^{1}	3.1×10^{1}
Cm-245	9.3×10^{3}	1.57×10^{-1}	1.8×10^{2}	1.8×10^{2}	1.7×10^{2}
Cm-244	1.76×10^{-1}	8.32×10^{1}	9.0×10^{5}	9.3×10^{-1}	0
Cm-242	4.5×10^{-1}	3.32×10^{3}	8.5×10^{3}	2.6×10^{3}	1.1×10^{2}
Am-243	7.95×10^{3}	1.85×10^{-1}	1.4×10^{4}	1.4×10^{4}	1.3×10^{4}
Am-242	1.52×10^{2}	9.72	1.0×10^{4}	2.6×10^{3}	1.1×10^{2}
Am-241	4.58×10^{2}	3.24	1.6×10^{6}	1.0×10^{6}	3.5×10^{5}
Pu-242	3.79×10^{5}	3.90×10^{-3}	1.6×10^{3}	1.6×10^{3}	1.6×10^{3}
Pu-241	1.32×10^{1}	1.12×10^{2}	6.9×10^{7}	1.8×10^{2}	1.7×10^{2}
Pu-240	6.58×10^{3}	2.26×10^{-1}	4.5×10^{5}	4.4×10^{5}	4.1×10^{5}
Pu-239	2.44×10^{4}	6.13×10^{-2}	2.9×10^{5}	2.9×10^{5}	2.8×10^{5}
Pu-238	8.6×10^{1}	1.75×10^{1}	2.0×10^{6}	2.0×10^{5}	9.3×10^{2}
Np-239	6.4×10^{-3}	2.33×10^{5}	1.4×10^{4}	1.4×10^{4}	1.3×10^{4}
Np-237	2.14×10^{6}	7.05×10^{-4}	3.1×10^{2}	4.4×10^{2}	5.8×10^{2}
U-238	4.51×10^{9}	3.33×10^{-7}	3.2×10^{2}	3.2×10^{2}	3.2×10^{2}
U-236	2.39×10^{7}	6.34×10^{-5}	2.2×10^{2}	2.2×10^{2}	2.3×10^{2}
U-235	7.1×10^{8}	2.14×10^{-6}	1.6×10^{1}	1.6×10^{1}	1.6×10^{1}
U-234	2.47×10^{5}	6.18×10^{-3}	7.4×10^{1}	7.2×10^{2}	7.8×10^{2}
U-233	1.62×10^{5}	9.47×10^{-3}	3.8×10^{-2}	5.3×10^{-1}	2.1
Pa-231	3.25×10^{4}	4.51×10^{-2}	5.3×10^{-3}	1.3×10^{-1}	3.7×10^{-1}
Th-232	1.4×10^{10}	1.10×10^{-7}	1.1×10^{-7}	4.1×10^{-6}	1.2×10^{-5}
Th-230	8.0×10^{4}	1.94×10^{-2}	4.1×10^{-3}	2.2	9.0
Th-229	7.34×10^{3}	2.13×10^{-1}	2.8×10^{-5}	8.0×10^{-3}	9.2×10^{-2}
Ra-226	1.60×10^{3}	9.88×10^{-1}	7.4×10^{-6}	1.2×10^{-1}	1.5
Ra-225	4.05×10^{-2}	3.92×10^{4}	8.1×10^{-5}	8.1×10^{-3}	9.4×10^{-2}
Pb-210	2.23×10^{1}	7.63×10^{1}	7.0×10^{-7}	1.5×10^{-1}	1.7
Cs-137	3.0×10^{1}	8.70×10^{1}	7.5×10^{7}	2.3×10^{4}	2.2×10^{-3}
Cs-135	3.0×10^{6}	8.82×10^{-4}	2.7×10^{2}	2.7×10^{2}	2.7×10^{2}
I-129	1.59×10^{7}	1.74×10^{-4}	3.3×10^{1}	3.3×10^{1}	3.3×10^{1}
Sn-126	1.0×10^{5}	2.84×10^{-2}	4.8×10^{2}	4.8×10^{2}	4.8×10^{2}
Tc-99	2.15×10^{5}	1.70×10^{-2}	1.3×10^{4}	1.3×10^{4}	1.3×10^{4}
Zr-93	9.5×10^{5}	4.04×10^{-3}	1.7×10^{3}	1.7×10^{3}	1.7×10^{3}
Sr-90	2.9×10^{1}	1.37×10^{2}	5.2×10^{7}	1.2×10^{4}	6.5×10^{-4}
Ni-59	8.0×10^{4}	7.57×10^{-2}	3.0×10^{1}	3.0×10^{1}	3.0×10^{1}
C-14	5.73×10^{3}	4.45	8.0×10^{2}	7.4×10^{2}	6.9×10^{2}

[a] MTU = metric tons of uranium; Ci/g = curies per gram.

[b] 10 years out of reactor, i.e., the assumed time of emplacement; values taken from tables 3.3.7, 3.3.8, and 3.3.10 of DOE, 1979; once-through-reactor cycle.

[c] 300 or 1,000 years after closure, i.e., 360 or 1,060 years out of reactor, assuming a 50-year operations period before closure; values calculated from 10-year inventories and rounded to 2 significant digits.

TABLE 3-2
Important Radionuclides in Savannah River Plant Waste
(Source: DOE/RW-0199)

Isotope	Half life (yr)	(Assumed) 1990 inventory[b] (Ci)	1,000 yr postclosure inventory[c] (Ci)	NRC release rate limit per year (Ci)	Ratio of release rate to 1 in 100,000 of 1,000 yr inventory[d]
Ni-59[e]	76,000	1.5E+04	1.5E+04	1.52E-01	1.00
Ni-63	100	1.9E+06	1.2E+03	1.23E-02	1.00
Se-79	65,000	8.0E+02	7.9E+02	7.86E-03	1.00
Rb-87	4.89E+10	5.3E-02	5.3E-02	2.47E-03	4,600
Sr-90	29	3.4E+08	3.4E-03	2.47E-03	73,000
Y-90	0.0073	3.4E+08	3.4E-03	2.47E-03	72,000
Zr-93	1.5E+06	8.7E+03	8.7E+03	8.70E-02	1.00
Nb-93m	13.6	8.7E+03	8.7E+03	8.70E-02	1.00
Nb-94m	20,000	7.2E+00	7.0E+00	2.47E-03	35.4
Tc-99	2.13E+05	1.5E+04	1.4E+04	1.45E-01	1.00
Pd-107	6.5E+06	7.2E+01	7.2E+01	2.47E-03	3.4
Cd-113	9.5E+15	6.8E-11	6.8E-11	2.47E-03	**[g]
Sn-121m	55	2.3E+02	3.6E-04	2.47E-03	**
Sn-126	100,000	1.2E+03	1.2E+03	1.15E-02	1.00
Sb-126	0.034	1.2E+03	1.2E+03	1.15E-02	1.00
Sb-126m	0.001	1.2E+03	1.2E+03	1.15E-02	1.00
Cs-135	3.0E+06	6.5E+02	6.5E+02	6.52E-03	1.00
Cs-137	30.17	2.8E+08	7.5E-03	2.47E-03	32,000
Ba-137m	0.001	2.8E+08	7.5E-03	2.47E-03	32,000
Sm-151	90	1.9E+06	5.4E+02	5.37E-03	1.00
Pb-210	22.3	0.0E+00	8.2E+00	2.47E-03	0.63
Ra-226	1600	0.0E+00	1.1E+01	2.47E-03	0.67 ##[h]
Ra-228	5.76	0.0E+00	5.3E-06	2.47E-03	** ##
Ac-227	21.773	0.0E+00	2.0E-01	2.47E-03	98.4 ##
Th-229	7,300	0.0E+00	1.3E-02	2.47E-03	3,000 ##
Th-230	75,400	0.0E+00	6.8E+01	2.47E-03	0.43 ##
Th-232	1.4E+10	0.0E+00	1.4E-05	2.47E-03	** ##
Pa-231	32,800	0.0E+00	2.6E-01	2.47E-03	106.00 ##
U-232	70	1.1E+03	2.8E-02	2.47E-03	8,700
U-233	1.59E+05	1.3E-01	1.3E-01	2.47E-03	1,800
U-234	2.45E+05	3.6E-03	6.4E+03	6.35E-02	1.00
U-235	7.04E+08	1.2E+01	1.2E+01	2.47E-03	20.79
U-236	2.34E+07	2.6E+02	2.6E+02	2.58E-03	0.97 ##
U-238	4.47E+09	6.6E+01	6.6E+01	2.47E-03	3.75
Np-237	2.14E+06	6.8E+01	1.3E+02	2.47E-03	1.71 ##
Pu-238	87.74	7.9E+06	1.7E+03	1.69E-02	1.00
Pu-239	24,110	7.4E+04	7.2E+04	7.20E-01	1.00
Pu-240	6,560	4.7E+04	4.2E+04	4.20E-01	1.00
Pu-241	14.35	8.9E+06	3.3E-02	2.47E-03	7,500
Pu-242	3.76E+05	6.5E+01	6.5E+01	2.47E-03	3.80
Am-241	432	8.3E+04	7.0E+04	7.02E-01	1.00

TABLE 3-2 (Cont.)
Important Radionuclides in Savannah River Plant Waste
(Source: DOE/RW-0199)

Isotope	Half-life (yr)	1,000-yr postclosure inventory (Ci)	NRC release rate limit per year (Ci)	10,000-yr inventory grow-in (Ci)	Ratio of release rate limit to 1 in 10^5 of 10,000-yr total inventory
Pb-210[c]	22.3	8.2E+00[d]	2.47E-03	4.6E+02	0.53
Ra-226	1600	1.1E+01	2.47E-03	4.3E+02	0.57
Ra-228	5.76	5.3E-06	2.47E-03	1.7E-04	***
Ac-227	21.773	2.0E-01	2.47E-03	2.5E+00	98.40
Th-229	7,300	1.3E-02	2.47E-03	8.0E-02	3,064.18
Th-230	75,400	5.8E+01	2.47E-03	5.5E+02	0.45
Th-232	1.400E+10	1.4E-05	2.47E-03	1.3E-04	**
Pa-231	32,800	2.6E-01	2.47E-03	2.3E+00	106.11
U-236	2.34E+07	2.6E+02	2.58E-03	2.7E+02	0.97
Np-237	2.14E+06	1.3E+02	2.47E-03	1.4E+02	1.71
Total		2.47E+05			

[a]Source: Baxter, 1983; Aines, 1986.
[b]Assumed repository closure in year 2050, 0.1 percent of total release rate, 2.47E-03 Ci/yr.
[c]Radionuclides whose release must be controlled at 1 part in 100,000 of their own 1,000-yr-postclosure inventory are underlined.
[d]E indicates exponential notation.
*** = ratio exceeds 100,000.

$$NL_i = \frac{M_i}{(f_i)(SA)} \qquad (7\text{-}1)$$

where

M_i = mass of element i released from the waste form (g)

f_i = mass fraction of element i in the original sample

SA = surface area of the sample (m^2).

TABLE 3-3
Radionuclides Which Grow-in Significantly in Savannah River River Plant Waste Processing Facility Waste Glass
(Source: DOE/RW-0199)

Isotope	Half life (yr)	(Assumed) 1990 inventory[b] (Ci)	1,000 yr postclosure inventory[c] (Ci)	NRC release rate limit per year (Ci)	Ratio of release rate to 1 in 100,000 of 1,000 yr inventory[d]
Am-242m	141	1.1E+02	5.8E-01	2.47E-03	427.71
Am-243	7,370	4.4E+01	4.0E+01	2.47E-03	6.17
Cm-243	28.5	4.3E+01	2.1E-10	2.47E-03	**
Cm-244	18.11	1.3E+03	2.1E-15	2.47E-03	**
Cm-245	8,500	5.1E-02	4.7E-02	2.47E-03	52,62.36
Cm-246	4,780	4.1E-03	3.5E-03	2.47E-03	70,459.20
Totals		1.26E+09	2.47E+05		

[a]Source: Baxter (1983); Aines (1986).
[b]An average age for waste in 1990 assumed.
[c]Assumed repository closure in 2050.
[d]For radionuclides that can be released at 0.1 percent of total release rate limit (2.47×10^{-3} Ci/yr), the column summarizes the extent to which the radionuclides can be released faster than 1 part in 100,000.
[e]Radionuclides with a release that must be controlled at 1 part in 100,000 of their own 1,000-yr-postclosure inventory are underlined.
[f]E indicates exponential notation.
[g]** = Ratio exceeds 100,000. The entire inventory could be released in one year and meet the regulation.
[h]## = Grow-in affects this ratio

The different spent fuel components represent varying values for thermal loading during handling, shipping and emplacement. Radioactive decay of the individual decay chains releases heat. The fission products and activities from neutron capture reactors are the main sources of radioactivity in the spent fuel. Thermal loading in the form of energy is a significant design consideration for the Yucca Mountain repository. Waste canister design parameter(s) will require individualized packaging of wastes to facilitate the optimum heat dissipation while retaining the container integrity.

3.3.2 Defense High Level Waste (DHLW)

This general category consists of high level wastes generated by fuel reprocessing or specific defense related activities. Fuel reprocessing wastes are from the West Valley Demonstration Project in New York. Defense programs also generate volumes of high level waste at facilities at Savannah River, South Carolina, Hanford, Washington and sites in Idaho. The current data which itemizes the DHLW waste and its origin has been projected for Savannah River (Tables 3-2 and 3-3).

The common form of these diverse wastes is an integration of the radioactive component into a borosilicate glass matrix. Generation of heat due to radioactive decay is not an important design characteristic of DHLW in comparison to commercial spent fuel. DHLW will be contained as a solid within the reference stainless steel 403L pour canisters. The canister specifications for the West Valley and the defense related waste are identical. Each pour canister must be 61 cm (2.0 ft) in diameter, 3.0 m (10 ft) long with a thickness of 1 cm. Individual pour canisters will be deformed by the thermal loading stress caused by the adjacent spent fuel component of the waste stream. Therefore, canisters of DHLW waste will be contained in the approved waste canister designed for Yucca Mountain unsaturated conditions and the projected thermal releases from the spent fuel component of the waste cycle (see Section 3.2.3). A staggered emplacement of the DHLW is intended to aid in the dissipation of the heat produced by the spent fuel wastes in the repository.

4.0 SCENARIOS CONSIDERED

4.1 Definition of a Scenario

A scenario outlines a release mechanism of radionuclides into the accessible environment. It must define the causative event, the mechanism for the radionuclide release and the pathway to the accessible environment. A release of radionuclides may result in a direct discharge to the surface above the repository and/or the indirect release by contaminated groundwater flow through the underlying aquifer. Direct and indirect releases follow natural and artificially induced pathways. The discussion will define the event(s), radionuclide release and potential pathways to the accessible environment.

4.2 Underlying Assumptions

Several assumptions define the natural and engineered conditions which will occur regardless of the scenario mechanism. These assumptions frame the general parameters of the repository. Such parameters may affect the impacts of the specific scenarios.

4.2.1 Pluvial Events

The Yucca Mountain area has exhibited distinct pluvial periods. Historical evidence such as pack rat middens and geological data indicate the presence of pluvial events with increased precipitation and cooler temperatures. These conditions will increase the amount of water available for infiltration and downward groundwater flow. Yucca Mountain's repository is designed to function in an unsaturated horizon. The limited data indicate trends of pluvial change over time and the need to consider the impact of increased groundwater flow on the repository. A conservative approach is necessitated by the uncertainty, so pluvial conditions are assumed to return to the estimated maximum levels exhibited during the late Wisconsin glacial period, which represents a doubling of annual precipitation currently recorded. Recharge will exhibit a greater than the twofold increase seen in annual precipitation. DOE developed this recharge estimate to approximate the cooler climate, increased precipitation, and the potential for less evapotranspiration. A representative location at an equivalent altitude was studied by DOE and found to exhibit rainfall 100% greater than current levels at Yucca Mountain.

Pluvial events define a general trend of cooler, wetter weather but often exhibit episodic occurrences. These episodic conditions may contribute elevated levels of precipitation from discrete storm events or trends over periods of days, weeks or years. Pulses of water recharge the underlying soil and rock, promoting increased fracture flow and saturation conditions. A pulse of water which moves through fracture flow and increased matrix diffusion may increase its contact with the emplaced waste and therefore increase waste dissolution.

To simulate both the trends projected by pluvial changes and the impact of episodic events, the following parameters are established. The time period of 10,000 years is divided into 5,000 year increments. Values for the parameters were defined as follows:

	0 - 5,000 years	5,000 - 10,000 years
Average Precipitation	150 mm (5.9 in)	300 mm (11.8 in)
Seasonal Distribution	108 mm (4.2 in) winter	150 mm (5.9 in)
	42 mm (1.65 in) summer	150 mm (5.9 in)

Climatic episodes such as 100 year storms and periods of droughts are accounted for by assuming a steady state system with the average recharge constant for the first 5,000 years and then exhibiting a step increase to a second steady state recharge rate for the second 5,000 year period. The two steady state recharge levels are given as follows:

Average Recharge	0.5 mm (0.02 in)	7.5 mm (0.29 in)

The average recharge estimates were developed by DOE to approximate the current arid conditions and the significant increases during pluvial conditions. The recharge system of Yucca Mountain is poorly understood especially in the understanding of recharge mechanisms and the role of surface water during storm events. No correction for run-off was developed by DOE and the estimated recharge flux of 7.5 x 10^{-3} m was used to calculate preliminary projections of water table rise over time. This report accepts this simplification of the groundwater recharge flow due to the uncertainties inherent in DOE's current data.

4.2.2 Waste Containers

The role of the waste container as a component of the engineered system is defined by the current NRC regulations and is intended to minimize the amount of waste available for dissolution and mobilization in the environment. A 300 year life of an individual container is the minimum acceptable design allowed by the NRC. This report assumes after 300 years that the canisters fail.

The designed canister is expected to retain its integrity during the initial thermal release period produced by spent fuel. DOE assumes the waste canisters and the heat from the decaying spent fuel will provide barriers to waste-water interaction during the period of high activity immediately postclosure. Initial heating by resident radioactive decay chains will be the most extreme within the first 300 years which coincides with the conservative estimate of canister lifetime. Thermal loading will peak at 230°C and will slowly decrease to 190°C within 10 to 20 years.

This thermally induced dry period is predicted to last up to approximately 500 years. Thermal loading of this nature has the potential to alter the host rock but the possible effects will not be discussed in this report. Thermal stress on the waste container will be mitigated by the canister design and the most thermally active period for the spent fuel will be contained for the first 300 years of an approximate 500 year heat cycle.

DOE assumes the thermal loading will serve as a barrier to radionuclide dissolution by vaporizing proximate water and driving the water vapor away from the spent fuel canisters. An unsaturated horizon will develop with water vapor forced away from the canisters. DOE notes the host rock surrounding the canisters will desiccate and may form a capillary barrier to water re-infiltration from more saturated rocks as the thermal loading decreases. The impact of convection cycles and the potential rate of matrix diffusion re-entering the dried strata once the cooling period ensues are not defined and represent a sizeable uncertainty. This report does not analyze DOE's assumptions and does not consider the waste canisters nor the thermal loading to serve as distinct barriers to radionuclide dissolution and transport.

4.2.3 Vertical Emplacement

Design strategies had focused on vertical emplacement of the waste canisters in emplacement drifts. Current discussions have expanded the options to consider the necessary parameters for both vertical and horizontal emplacement strategies (Section 3.1.2). This report assumes one emplacement strategy and applies current DOE design considerations for vertical emplacement of waste.

4.3 Scenarios Considered

A range of scenarios with different causative events, radioactive releases and pathways to the accessible environment are considered including the preliminary analyses by DOE and SANDIA. Six scenarios are developed as potential vehicles for radionuclide release. They are as follows:

1. Normal Flow
2. Borehole/Direct Hit
3. Borehole/Near Miss
4. Fault Movement
5. Rhyolitic Volcanism
6. Basaltic Volcanism

4.3.1 Scenario 1: Normal Flow

The projected normal flow scenario examines the potential for radionuclide release based on current and future patterns of groundwater movement through the area of the repository to the underlying aquifer (Figure 4-1). Current patterns for the first 5,000 years of groundwater flow are based on the existing seasonal pattern of precipitation, recharge and infiltration. Future movement of groundwater flow is assumed to conform to the assumptions for pluvial conditions estimated over the second 5,000 years (Section 4.2.1).

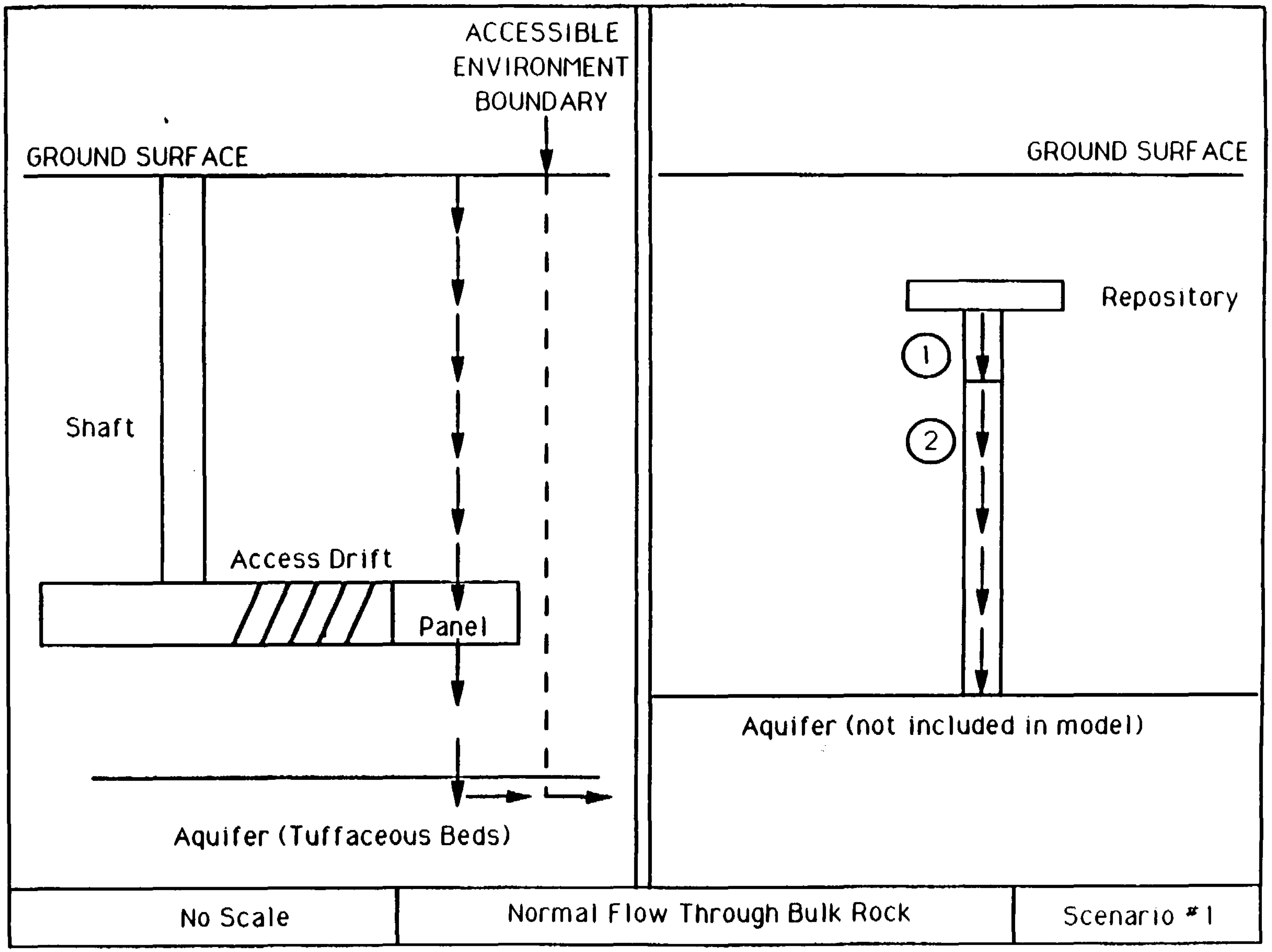

ACCESSIBLE
ENVIRONMENT
BOUNDARY
GROUND SURFACE
Shaft
Access Drift
Panel
Aquifer (Tuffaceous Beds)
GROUND SURFACE
Repository
1
2
Aquifer (not included in model)
No Scale
Normal Flow Through Bulk Rock
Scenario # 1

Figure 4-1

The repository at Yucca Mountain will rely on the concepts of slow matrix diffusion in the unsaturated system, drainage of water, and other barriers to radioactive waste release. First, an unsaturated system will lessen the likelihood of water contacting the waste container. Second, free drainage is assumed to lessen the contact time between groundwater, the waste canister and available waste. The slow matrix diffusion adds a third level of protection as the radioactive waste is in solution in contaminated groundwater and will not move rapidly into the underlying aquifer. Fourth, the presence of zeolites and other cation scavengers in the unsaturated zone will retard radionuclide transport toward the aquifer.

Once in the aquifer, flow in the saturated system may exhibit Darcian properties and radionuclides will be transported at the same rate as the groundwater. Sorption of radionuclides to zeolites or other particulates is possible in the aquifer and could affect the travel time of radionuclides to the accessible environment, defined as outside of a 5 km (3.17 mi) radius beyond the repository. However, the limited data only indicates the localized presence of zeolites and the inherent uncertainty of the data necessitates the assumption that radionuclides flow at the same rate as the groundwater toward the accessible environment. This flow is estimated to range from 2 - 200 m/year under Yucca Flat to 200 m to 20 km/year at Specter Flat. These measurements are based on limited drilling information in the vicinity of Yucca Mountain.

The natural barriers to radionuclide movement are assumed to be in the unsaturated tuff layers between the repository and the aquifer. This assumption is based on the limited site specific data. DOE's current models assume a direct vertical route to the repository and the continuation of vertical flow through the area beneath the repository (Figure 4-2). Travel times are calculated only to the aquifer indicating DOE assumes that the unsaturated zone is the significant pathway to the accessible environment (Section 1.2.4). Limited information suggests movement of radionuclides in the aquifer may be very rapid with the unsaturated zone between the repository and the aquifer representing the more significant determinant of the repository's performance over time.

The lack of detailed, site-specific data and the complex hydrogeology of Yucca Mountain necessitates the development of conservative assumptions and modeling of simplified pathways. This report assumes a direct vertical route through the disturbed zone below the repository and then continued vertical movement through the unsaturated zone to the boundary of the aquifer. Two zones of water movement will be considered, the first is the 25 m (82 ft) disturbed zone beneath the repository and the second is the 175 m (574 ft) zone underlying the disturbed zone and above the aquifer boundary. This 175 m (584 ft) zone exhibits the combined characteristics of the Topopah Spring and the Calico Hill Members to the upper boundary of the aquifer at 200 m (656 ft). The second zone will incorporate the data available for the northern half of the Calico Hills Member indicating a highly zeolitized matrix and the potential for radionuclide sorption.

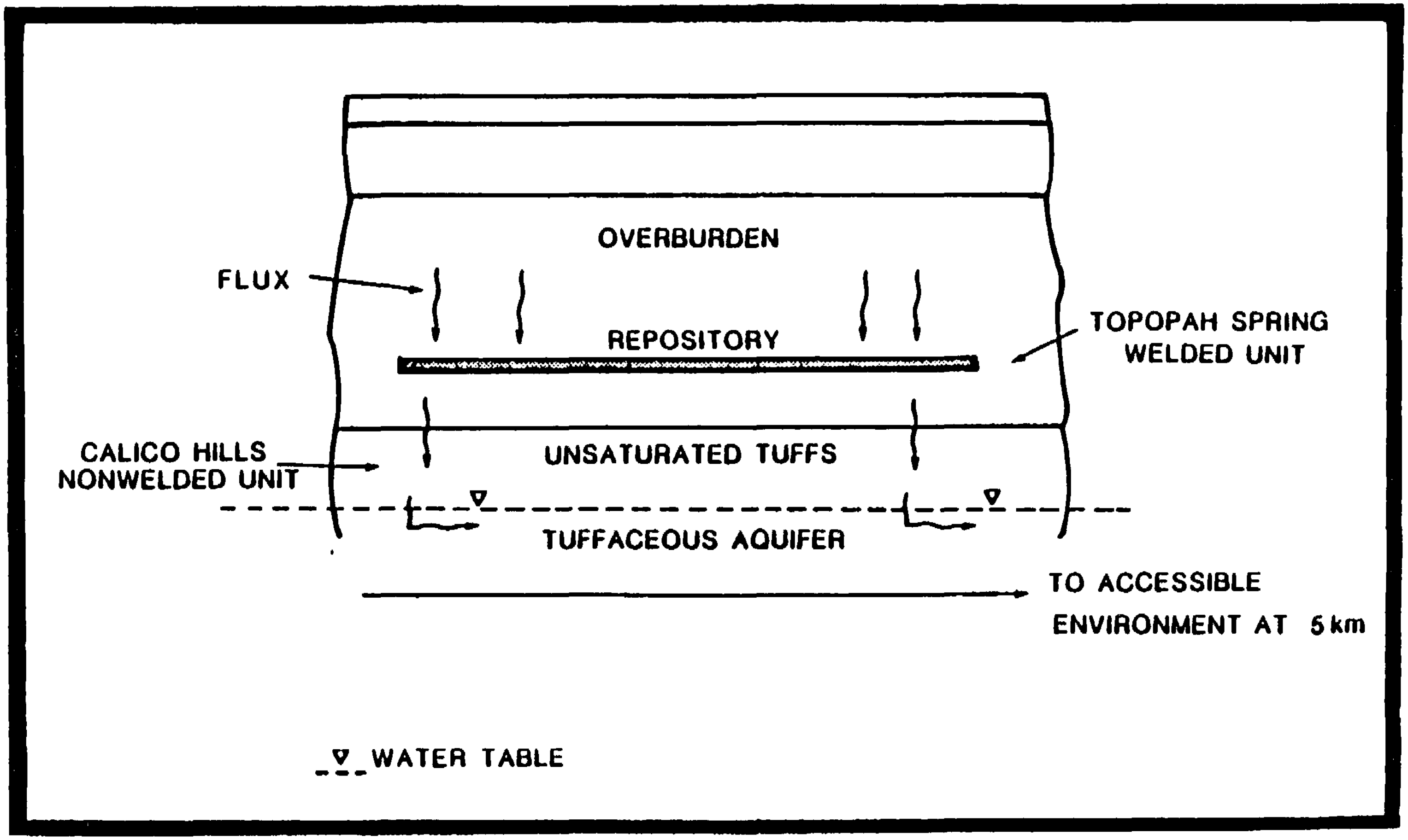


FIGURE 4-2
A Sample Model of Proposed Waste Disposal System
(Source: DOE, Site Characterization Plan, Volume III, 1988)

Choice of a vertical pathway in an unsaturated hydrogeologic unit also requires clarification of the mechanisms for waste dissolution and movement. Data on the leaching rate, solubility of the waste and the retardation factors (Kd) related to spent fuel and DHLW have been developed by DOE. The choice of a leaching rate depends on the conditions of groundwater flow and the potential for waste-water interaction in the repository. DOE reviewed three models to approximate the unsaturated condition of the Topopah Spring unit. The diffusion limited dissolution model is considered by DOE to be the most realistic approach by limiting diffusion only into the water flowing past the emplaced waste. However, DOE noted the lack of available data which necessitated the use of congruent dissolution models for conservatism. Due to the lack of data, this report applies an estimate of a fractional waste dissolution rate of 1×10^{-5} per year predicated by the design requirements of packages set by the NRC.

Solubility of the waste was estimated by DOE through the application of a diffusion limited dissolution model. The solubilities of ten representative waste elements were assumed by DOE to be conservative estimates (Table 4-1). Additional data was generated by in-situ experiments (Table 4-2). Solubilities for radionuclides which are not known have been estimated to be 1 molar. This is a conservative estimate. This report assumes the estimated annual rate of waste dissolution of 1×10^{-5} which will not generate conditions which exceed the projected solubility limits.

DOE developed porous-flow retardation estimates in welded and non-welded tuff units (Table 4-3). The tuff was assumed to be a partially saturated fractured horizon representing the known characteristics of Yucca Mountain welded and the more porous non-welded tuff. Additional assumptions allowed the substitution of predicted moisture contents for the Rf value and the application of standard bulk densities for welded or non-welded tuff. Highly mobile radionuclides such as dissolved carbon, iodine and technetium were assumed to exhibit the same transport-time distributions as the groundwater. This report applied the values for non-welded tuff as they are not significantly different from the values for welded tuff and the non-welded values are more conservative. Current data is based on limited information and therefore is subject to large uncertainties. Retardation values of 1.0 are applied in this report to characterize specific radionuclides which are not listed in current DOE data.

4.3.2 Scenario 2: Borehole/Direct Hit

The likelihood of a direct drilling hit within the Yucca Mountain repository can be estimated based on accepted drilling rates. No historic pattern of drilling or mineral exploration is available as Yucca Mountain is not an area known for its mineral resources, however, limited numbers of boreholes exist on or in proximity to the site. Drilling near Yucca Mountain generally has been in response to the need from information regarding the proposed repository or the activities of the NTS. DOE cites little or no documentation of economically important extractive resources at Yucca Mountain. Oil, natural gas and minerals have not been found in the layer of volcanic tuff, which averages 1,981 m (6,500 ft) thick under the surface of Yucca

Element	Solubility (moles/L)
Americium (Am)	1.0×10^{-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^{-9}

[a]The 10 elements listed here contribute about 99 percent of the spent fuel radioactivity 1,000 years after repository closure.

[b]Solubilities at pH 7, oxidizing conditions (Eh = 700 mV, where Eh is the oxidation-reduction potential), and 25°C (77°F) in water that is characteristic of Yucca Mountain (Kerrisk, 1984).

TABLE 4-1
Selected Radionuclide Solubilities
(Source: DOE, Environmental Assessment, Volume II, 1986, DOE/RW-0073)

Waste element	Solubility (moles/L)	Source of data
Americium	1×10^{-6}	
Plutonium	1×10^{-5}	Nitsche and Edelstein, 1985
Neptunium	1×10^{-3}	Nitsche and Edelstein, 1985
Uranium	4×10^{-3}	Ogard and Kerrisk, 1984
Curium	[b]1×10^{-6}	Apps et al.1983
Thorium	[b]1×10^{-9}	Apps et al. 1983
Strontium	8×10^{-4}	Ogard and Kerrisk, 1984
Radium	3×10^{-7}	Ogard and Kerrisk, 1984
Carbon	High[b,c]	Kerrisk, 1984b
Cesium	High[b,c]	Rai and Serne, 1978
Technetium	High[b,c]	Ogard and Kerrisk, 1984
Iodine	High[b,c]	Apps et al. 1983
Tin	[b]1×10^{-9}	Apps et al. 1983
Zirconium	[b]1×10^{-10}	Rai and Serne, 1978
Samarium	[b]2×10^{-9}	Benson and Teague, 1980
Nickel	[b]1×10^{-2}	Benson and Teague, 1980

[a]At pH of 7, 25°C, and oxidizing conditions.
[b]Estimated data.
[c]Solubility of these waste elements is expected to be high enough so that solubility will not limit concentration at a Yucca Mountain site.

TABLE 4-2
Solubility of Waste Elements in Well J-13 Water[a]
(Source: DOE/RW-0199)

TABLE 4-3
Distribution Coefficients (Sorption Ratios and Calculated Retardation Factors - A Reference Case)
(Source: DOE, Environmental Assessment, Volume II, 1986, DOE/RW-0073)

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[c]	0[c]	1	1
Curium (Cm)	1,200	4,600	28,000	24,000
Cesium (Cs)	290	7,800	6,700	41,000
Iodine (I)	0[c]	0[c]	1	1
Neptunium (Np)	7	11	160	58
Protactinium (Pa)	64	140	1,500	740
Lead (Pb)	5[d]	5[d]	120	27
Plutonium (Pu)	64	140	1,500	740
Radium (Ra)	25,000[e]	25,000[e]	580,000	130,000
Tin (Sn)	100[d]	100[d]	2,300	530
Strontium (Sr)	53	3,900	1,200	21,000
Technetium (Tc)	0.3	0[c]	8	1
Thorium (Th)	500[d]	500[d]	12,000	2,600
Uranium (U)	1.8	5.3	27	45
Zirconium (Zr)	500[d]	500[d]	12,000	2,600

[a]Unless otherwise indicated, distribution coefficients (sorption ratios) were inferred from the sorption ratios quoted by Daniels et al. (1982); ml/g - milliliters per gram.
[b]Calculated using values of moisture content of 10 and 28 percent and bulk densities of 2.33 and 1.48 grams per cubic centimeter for welded and nonwelded tuff.
[c]No data available; assumed to be zero.
[d]Inferred from the mid-range retardation factor for tuffs compiled by National Research Council (1983).
[e]Barium used as a chemical analog.

Mountain. Surveys of the area do not indicate the availability of mineral deposits in the volcanic tuff of any extractible, commercial resources with the exception of potable water. This resource is below the surface in an aquifer at a depth of 488-732 m (1,600-2,400 ft). Water mining is not inconceivable over the course of the 10,000 years. The area has been characterized as arid for the first 5,000 years and exhibiting pluvial episodic events over 10,000 years but potable water may be the limiting factor in future development. This report assumes that areas of relatively high elevation such as Yucca Mountain may be economical to drill in the future.

Yucca Mountain is assumed to have the potential for water mining or other drilling activities over the next 10,000 years. This report applies the EPA's drilling rate and assumes that no record of the repository will be available 100 years after closure. General drilling rates were needed to consider the estimated event of a direct hit on an emplaced waste canister. A direct hit has the potential for short term release of radionuclides into the accessible environment at the surface or to promote long term indirect releases into the groundwater flow.

EPA has previously estimated the annual frequency for drilling and hitting a canister in tuff to be 2.5 x 10^{-6} (based on a generic repository with an area of 8 x 10^{6} m^2). This report assumes Yucca Mountain to have an area of 5.6 x 10^{6} m^2 so the specific annual probability would be 1.75 x 10^{-6}. Two subcases are treated in Scenario 2 to examine the possible effects related to the release of the two categories of emplaced wastes. The waste inventory is assumed to be an equal mix of spent fuel and DHLW and to be emplaced in an alternating configuration in the repository. Subcase 2A assumes a direct hit upon a waste canister containing spent fuel. Subcase 2B assumes similar conditions but the drilling hits a DHLW canister. Flow paths and most parameters are the identical for these subcases. The design strategy assumes vertical emplacement, equal numbers of boreholes and the staggered emplacement of spent fuel and DHLW. Distinct probabilities for contact with each component of the waste profile are an equal annual frequency for either spent fuel or DHLW.

Two flow paths are assumed (Figure 4-3). One is the short term release during drilling when contaminated drilling muds or extracted water, which contain up to approximately 0.15 of a directly hit canister, flow out at the surface. Drilling muds and moved water will be contaminated with spent fuel or DHLW and the specific gases produced by radioactive decay. Contaminated fluids may be forced up the borehole during the drilling or subsequent extraction procedures.

A second flow path consists of the enhancement of the normal flow in Scenario 1. The borehole provides a conduit allowing direct contact of the waste with water flowing downward to the aquifer, promotion of increased waste dissolution and functioning similarly to fracture flow. This report assumes the surface release by a direct canister hit during drilling will overshadow the indirect long term release of radionuclides into the underlying aquifer. Long term releases will not be modeled in this report.

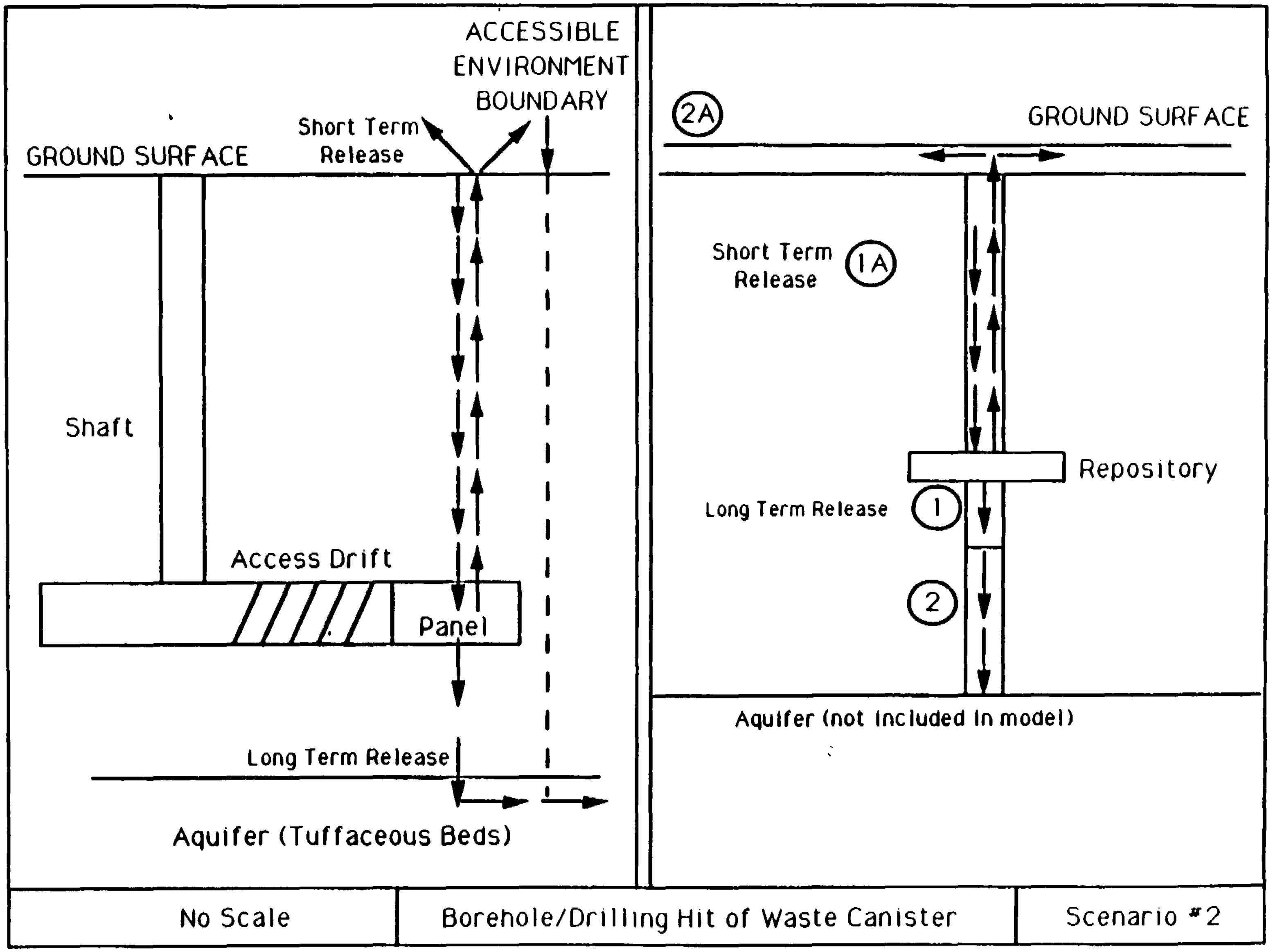

ACCESSIBLE
ENVIRONMENT
BOUNDARY
Short Term
Release
GROUND SURFACE
Shaft
Access Drift
Panel
Long Term Release
Aquifer (Tuffaceous Beds)
2A
GROUND SURFACE
Short Term
Release
1A
Repository
Long Term Release
1
2
Aquifer (not included in model)
No Scale
Borehole/Drilling Hit of Waste Canister
Scenario #2

Figure 4-3

4.3.3 Scenario 3: Borehole/Near Miss

Scenario 3 involves the release of radionuclides through a borehole which is drilled through the repository but does not directly hit a spent fuel or DHLW canister. The probability of such a scenario has has been estimated by EPA to be thousand times greater than the direct hit of an individual waste canister in Scenario 2. This report will apply the adjusted probability developed in Scenario 2 and increase the annual rate by one thousand-fold to 1.75×10^{-5} on a near miss by drilling.

The following is a short narrative of the Scenario 3 events and conditions. Exploration by drilling is conducted under the same assumptions developed for Scenario 2 with drilling commencing after the first 100 years of postclosure institutional control. Drilling operators will not know of the repository's existence and will drill unknowingly through the repository. The borehole will not directly hit a canister but will contact a volume of contaminated tuff or water without the operator's knowledge. This report assumes the size of the contaminated area contacted is equal to the size of the borehole.

After 300 years, waste canisters are assumed to no longer contain the emplaced waste. The potential for thermal loading to dry out the unsaturated repository horizon peaks at 300 years and subsequently diminishes as a protective measure over time. The potential for water/waste contact and subsequent dissolution increases as the thermal load ceases to vaporize free draining water in proximity to the waste. Overall, the dissolution rate is assumed by the NRC requirements for waste canister design. This rate is estimated at 1×10^{-5} annually.

Welded tuff, such as the Topopah Spring Unit housing the repository, has a tendency to fracture. Vertical emplacement of waste requires the drilling of boreholes into the welded tuff creating a high probability of fracturing the proximate tuff. Additional fracturing of the tuff will occur in the area of the borehole during post-closure drilling events. After 300 years, the near miss drilling will introduce drilling muds and increased fracturing into a fractured, cooling strata with uncontained waste. Fracture flow of drilling muds and dissolved waste is an increased likelihood due to the preference for fracture flow in tuff, the likelihood of water being pumped to the surface during drilling and the presence of lateral and horizontal fracturing.

These flow paths to the accessible environment are identical to those defined for Scenario 2 (Figure 4-4). Direct surface releases during the drilling represent a short term release of radionuclides. Indirect, long term release via the groundwater is possible as the uncontained waste is dissolved by subsequent groundwater movement in the borehole, creating an enhancement of Scenario 1 (normal flow). This report assumes that the short term release of radionuclides to the surface will overshadow the long term releases to the aquifer. Short term releases in Scenario 3 are given primary consideration.

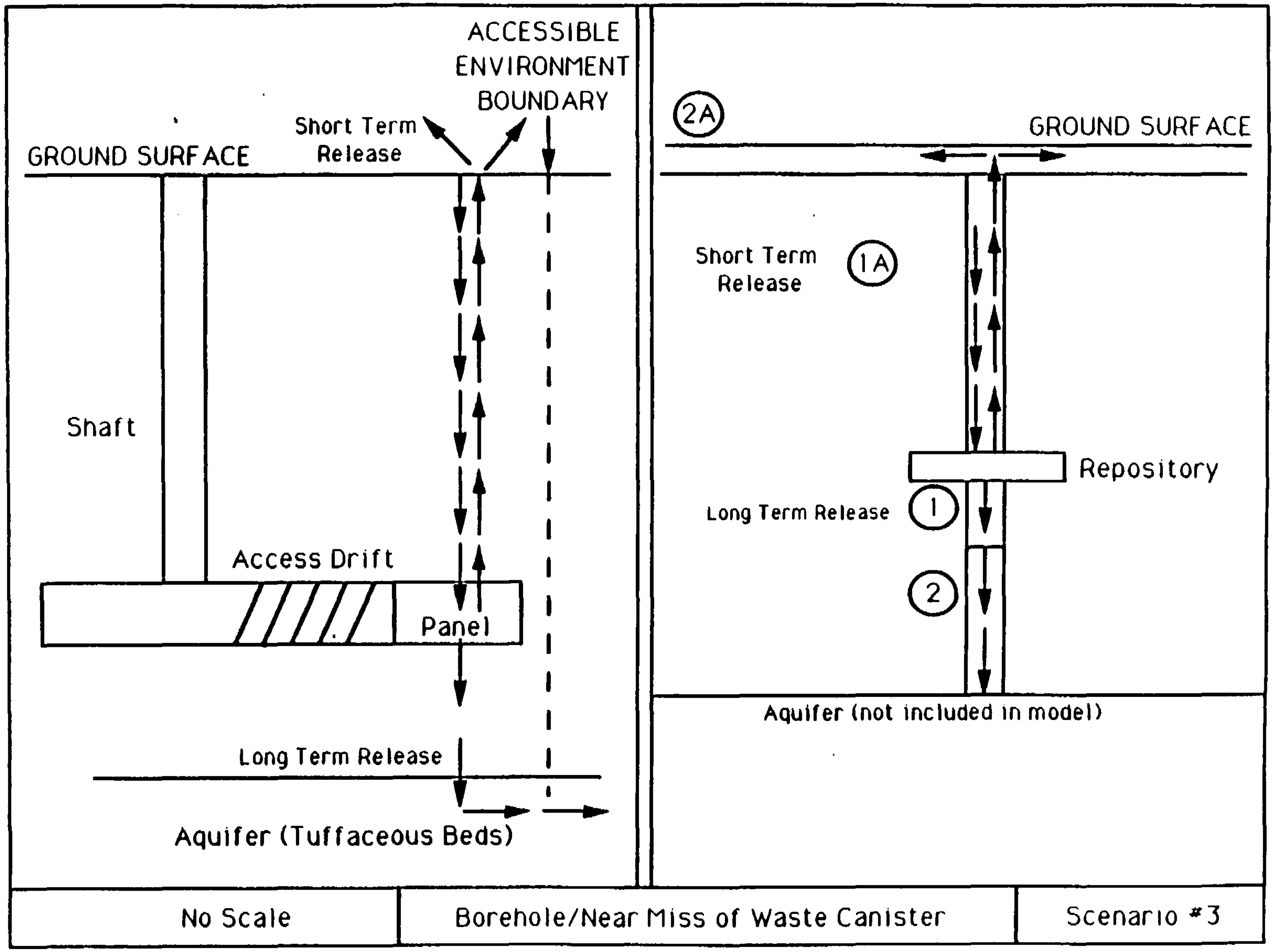

ACCESSIBLE ENVIRONMENT BOUNDARY
Short Term Release
GROUND SURFACE
Shaft
Access Drift
Panel
Long Term Release
Aquifer (Tuffaceous Beds)
2A
GROUND SURFACE
Short Term Release
1A
Repository
Long Term Release
1
2
Aquifer (not included in model)
No Scale
Borehole/Near Miss of Waste Canister
Scenario #3

Figure 4-4

4.3.4 Scenario 4: Fault Movement

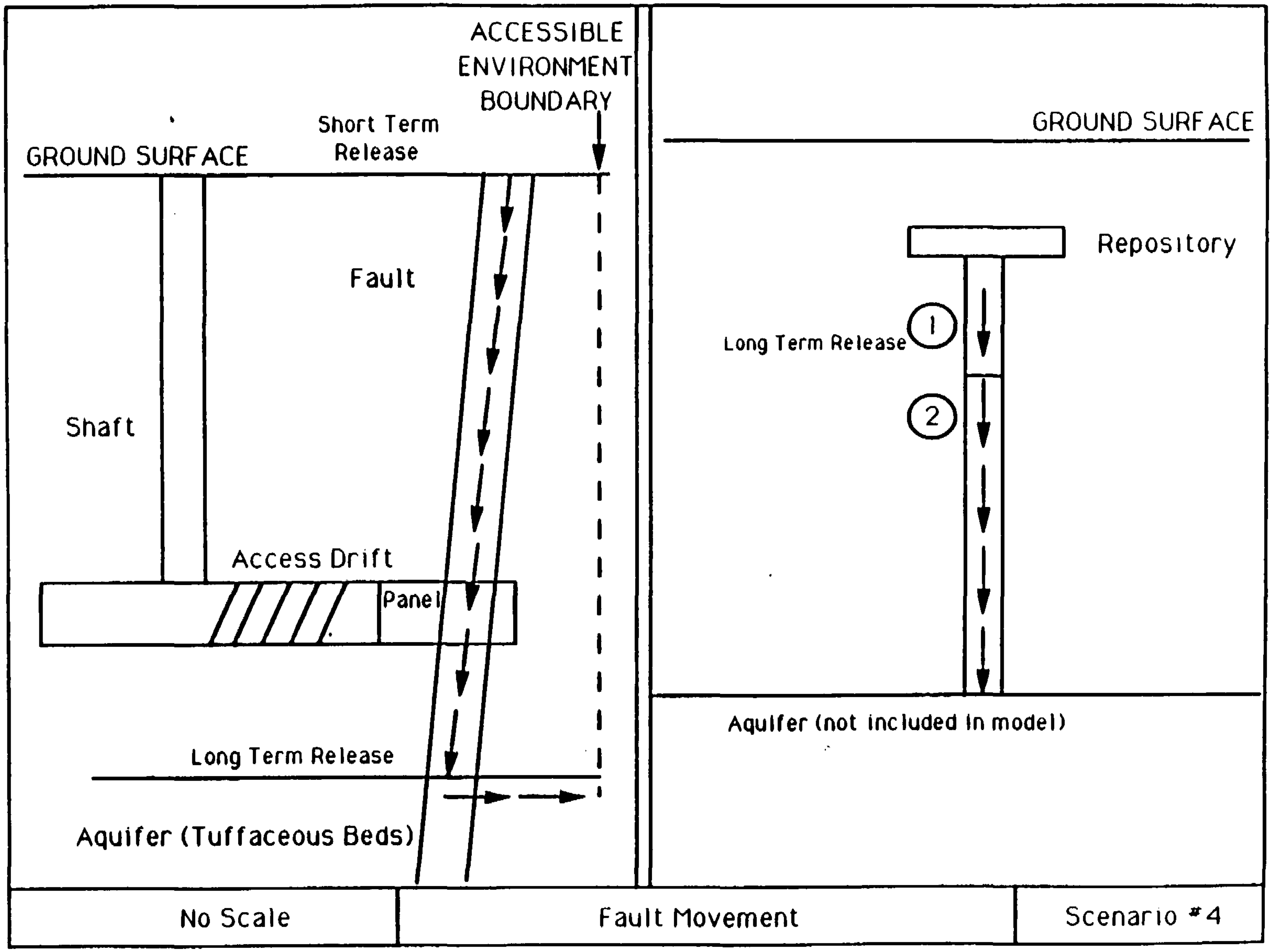
Yucca Mountain has a history of faulting and other tectonic processes. Quaternary movement of 5 proximate faults indicates the potential for movement and offset over the next 10,000 years. Another fault, the Ghost Dance Fault, bisects the tuff stratigraphy and the repository horizon. Its offset cannot be accurately dated at this time but DOE assumes the north-trending faults proximate to Yucca Mountain may be potentially active regardless of the lack of strong evidence of recent (Quaternary) offset. Generally, movement in tuff is more likely to be exhibited by existing weakened areas rather than new faults.

The Ghost Dance Fault may have an active history in Quaternary time indicating a potential for future movement. Movement of the Ghost Dance, other proximate faults or new faults would increase the offset and fracturing potential. Hydraulic conductivity of the Ghost Dance could be increased through physical changes such as brecciation, dilatation of the fracture diameter or increased fracturing. An enhancement of Scenario 1 occurs when faulting promotes a more rapid flow of water from the surface, through the repository and vertically into the aquifer (Figure 4-5). This report assumes the enhanced normal flow would follow the same ground water path delineated in Scenario 1. Vertical groundwater movement would flow through the disturbed area of the Topopah Spring and then continue downward toward the boundary of the aquifer.

Characterization of the repository area would locate such a major existing fault as the Ghost Dance. Design strategies would be expected to avoid the placement of waste canisters in a fault and would develop specific engineering criteria to mitigate the fault's impact on individual waste canisters. However, additional offset could alter the hydraulic conductivity and allow unexpected volumes of free water into the repository. The increased water volume is assumed to increase the probability of waste-water contact and subsequent dissolution. This report will apply the annual probability of faulting developed by the USGS for the southwestern region of the United States. Fault slip movement is estimated to occur at a rate of 1×10^{-5} events per year based on studies of a representative fault in the NTS. The Ghost Dance Fault is currently the only fault known to bisect the area of the repository. This report assumes the Ghost Dance Fault to be the representative fault at Yucca Mountain.

4.3.5 Scenario 5: Rhyolitic Volcanism

The area surrounding Yucca Mountain has an active history of rhyolitic volcanism over a period of 7 million to 15 million years ago. Yucca Mountain itself was formed by extensive ash flow and ash fall tuff extrusions. Exploded calderas and the evidence of other rhyolitic eruptions ring the Yucca Mountain site. A release scenario resulting from rhyolitic volcanism events must be considered for the proposed repository.


ACCESSIBLE
ENVIRONMENT
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Short Term
Release
GROUND SURFACE
Fault
Shaft
Access Drift
Panel
Long Term Release
Aquifer (Tuffaceous Beds)
GROUND SURFACE
Repository
1
Long Term Release
2
Aquifer (not included in model)
No Scale
Fault Movement
Scenario #4

Figure 4-5

The nature and timing of past eruptions may provide data as to the individual patterns of an erupting volcano. Prediction of the potential for future volcanism requires accurate application of such instruments as seismographs, precise leveling instruments and infrared photography. Data are collected to determine the crustal thinning and changes in the heat budget. Additional information is provided by records of seismic shocks in excess of 2.0 on the Richter scale. Nearly 96% of all eruptions are preceded by companion volcanic earthquakes which result from magna intrusion into the upper layers of the crust. In contrast, tectonic earthquakes result from crustal movement not magna intrusion. Little of the necessary instrumental data is currently available for Yucca Mountain to determine the relationship of companion earthquakes to future volcanism.

Ignimbritic, pyroclaslic eruptions which include rhyolitic volcanos pose the most difficult volcanic hazard to evaluate. The timing of individual eruptions appears random and even quiescent areas can exhibit extremely explosive, disruptive eruptions. Calderas around Yucca Mountain indicate the large-scale disruptive power of rhyolitic eruptions.

Two flow paths result in short-term surface release and long-term indirect groundwater release during rhyolitic volcanism (Figure 4-6). Ash flow releases at the surface endanger human life due to increased fire potential, structural collapse, and volcanic gas releases. A surface release of radionuclides could occur if magna intruded into the repository prior to eruption.

A second pathway might release radionuclides indirectly due to the intrusion of magna, corrosive volcanic gases, the dissolution of emplaced waste and the modification of groundwater flow by dike formation. A long term indirect release occurs with the alteration of normal groundwater flow and the availability of uncontained waste for dissolution. These factors suggest the modification of free groundwater drainage, increasing waste dissolution rates and mobility of waste via fracture flow to the underlying aquifer.

This report uses EPA's previous rough estimates of volcanism at Yucca Mountain. EPA's estimate assumes regional vent formation to roughly approximate the magnitude of future volcanism. Volcanic tuff was predicted to exhibit an annual rate of 1×10^{9} volcanic disruption of the repository. This annual probability defines the likelihood of a volcano erupting radioactive waste to the surface. The second pathway of long term indirect release due to magna intrusion is poorly understood and not well documented. EPA estimated the annual probability of igneous intrusion to be 10^{3} times the rate of faulting at the repository emplaced in tuff. This report assumes the magnitude of the release from a short term eruptive event to be so devastating that it will overshadow the long-term indirect release. The indirect releases to the aquifer and the accessible environment will not be discussed further.

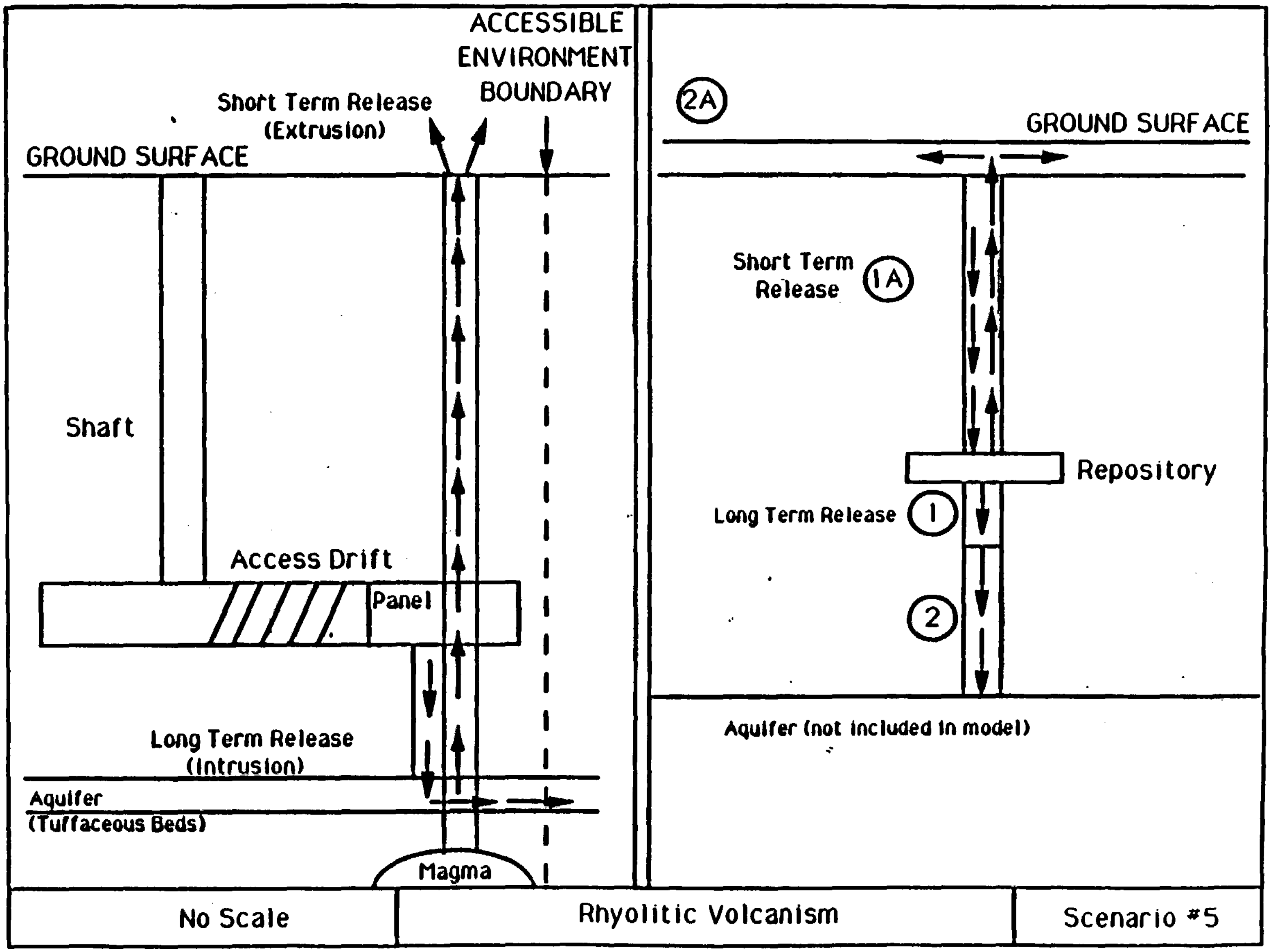

ACCESSIBLE ENVIRONMENT BOUNDARY
Short Term Release (Extrusion)
GROUND SURFACE
Shaft
Access Drift
Panel
Long Term Release (Intrusion)
Aquifer (Tuffaceous Beds)
Magma
2A
GROUND SURFACE
Short Term Release
1A
Repository
Long Term Release
1
2
Aquifer (not included in model)
No Scale
Rhyolitic Volcanism
Scenario #5

Figure 4-6

4.3.6 Scenario 6: Basaltic Volcanism

The probability of rhyolitic volcanism causing direct releases of radionuclides was considered in Scenario 5. Scenario 6 considers the likelihood of radioactive release to the accessible environment from basaltic volcanism. Basaltic volcanism lacks the explosive, destructive characteristics of rhyolitic volcanism and exhibits a less random pattern of eruptions.

The two pathways for direct and indirect release of radionuclides developed for the rhyolitic eruptions in Scenario 5 are applicable to basaltic extrusions (Figure 4-7). Scenario 6 exhibits the potential for direct short lived release of radionuclides during basaltic eruptions. Magma is assumed to intrude into the repository, interact with the radionuclides and propel the waste to the surface during companion eruptions. Basaltic eruptions have the capacity to mobilize radioactive waste and gases to the surface though basaltic volcanism is rarely as explosive as the rhyolitic volcanos in Scenario 5. Long term releases indirectly via magna intrusion and subsequent contaminated groundwater flow are also applicable to either Scenario 5 or Scenario 6 but will not be considered in this report. The short term release will be so devastating as to overshadow magna intrusion and indirect release to groundwater.

DOE estimated various probabilities for basaltic intrusion which relied on sparse data and theoretical calculations. For this analysis, the rate of basaltic eruptions is determined by the number and proximity of volcanic vents. USGS linked the relatively consistent relationship of future basaltic volcanism to the presence of previous eruptions or volcanic events. General calculations of the number of volcanic events provides a realistic approximation of the potential for future basaltic eruptions. This report assumes the annual probability of basaltic eruptions intersecting the repository to be 2.9×10^{-8}.

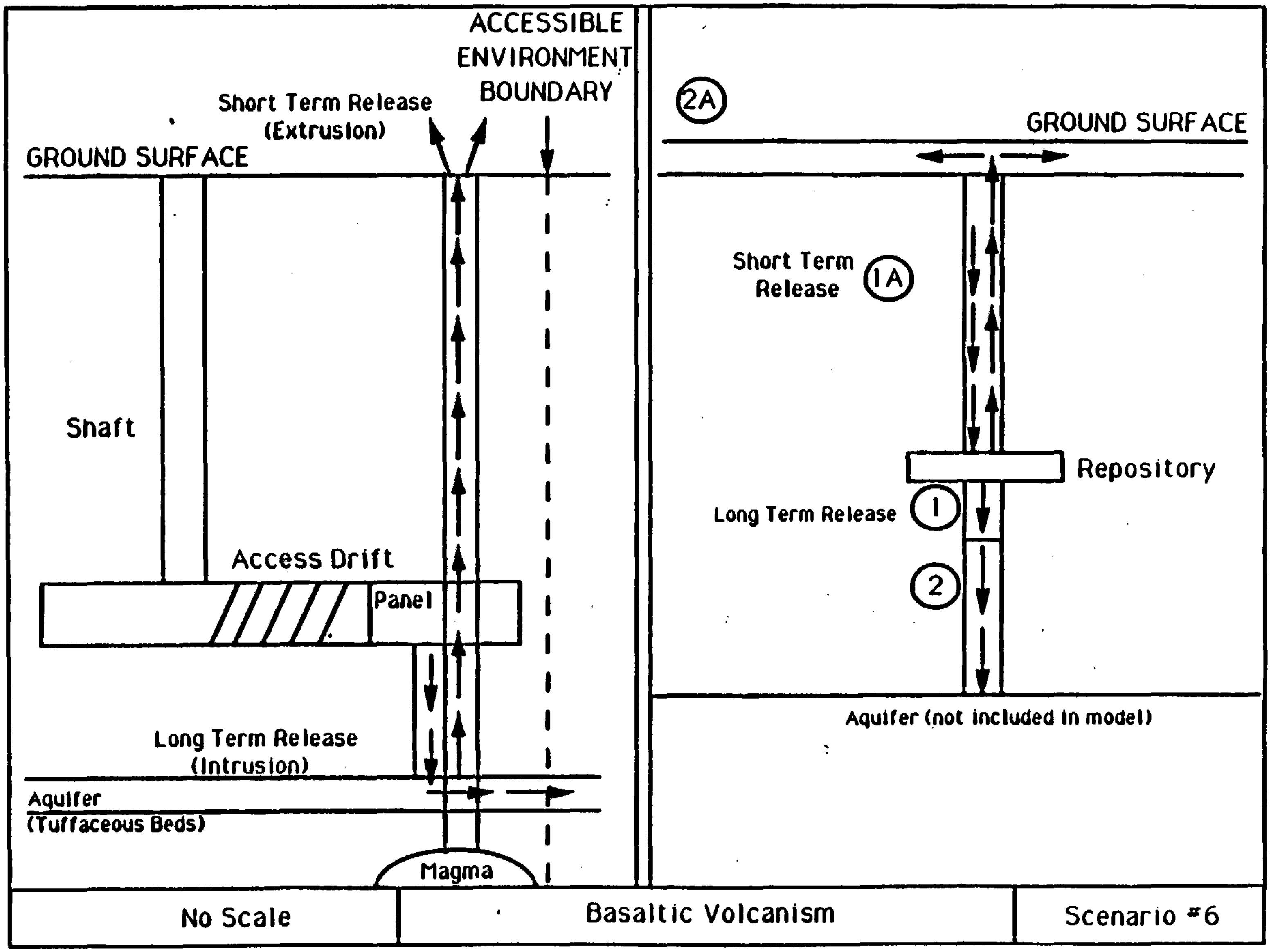
4.4 Summary of Scenarios

This report reviewed existing data, assumptions and predictions related to potential release scenarios for the proposed Yucca Mountain high level radioactive waste repository. Six release scenarios were highlighted to indicate potential mechanisms for release to the accessible environment. The complexity of the hydrogeological environment and lack of comprehensive data required the application of generic data, limited laboratory information or simulated theoretical calculations. Conservative estimates were developed in response to the lack of data on the geology, hydrology and behavior of engineered systems in the environment of Yucca Mountain.

4.5 REPRISK and NEFTRAN

4.5.1 Scenario 1

The annual recharge of .5 mm/yr for the arid first 5,000 years and the 7.5 mm/yr during the second 5,000 years are assumed to provide a steady state rate for


ACCESSIBLE
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Long Term Release
(Intrusion)
Aquifer
(Tuffaceous Beds)
Magma
2A
GROUND SURFACE
Short Term
Release
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Repository
Long Term Release
1
2
Aquifer (not included in model)
No Scale
Basaltic Volcanism
Scenario #6

Figure 4-7

downward groundwater flow. In order to apply REPRISK or NEFTRAN models to the normal flow scenario, several modifications of the inputs are needed.

First, the two-step recharge system over time is calculated at the mid-point of 4×10^{-3} for the entire 10,000 years. This approximation is to incorporate the two separate steady state flow rates assumed at Yucca Mountain. The models currently cannot allow variations of a step function over time for the flow rates or conductivities. Second, the known flux of the recharge is assumed to be the total downward flux. This report applied the assumed flux 4×10^{-3} m/yr to determine a representative conductivity. Interstitial velocity is determined by dividing the flux by the porosity of the hydrogeologic unit. This velocity is also equivalent to the gradient taken times the conductivity divided by the porosity value. Since we are assuming vertical flow, we have a vertical gradient of 1.0, so the effective conductivity for the models will be equivalent to flux. Conductivity is thus assumed to equal 4×10^{-3} for the entire 10,000 years.

A third modification of the data is to create a two-leg sequence of groundwater flow. The dominant importance of the unsaturated zone as a natural barrier focuses the modeling effort on the vertical flow pathway, which is divided into the Topopah Spring and Calico Hills Member. No time delays for downward movement of changing infiltration amounts to the repository are assumed.

A fourth modification is to convert the predicted acreage of the irregularly shaped repository into a more consistent configuration. The 1380 acres predicted by DOE will convert into 5.6×10^{6} m^2 and can be assumed to approximate a square configuration with each side measuring 2.4×10^{3} m. This calculation is necessary to define the input parameter for the thickness of the second leg of the REPRISK model.

Fifth, the radionuclide profile is defined by DOE but will be limited in the application of REPRISK or NEFTRAN. The waste profile for spent fuel focuses on radionuclides exhibiting an activity greater than one curie per 1000 MTU (Appendix C). DHLW radionuclides in REPRISK calculations are assumed to be only those radionuclides which exhibit a 0.1 percent of total release (Appendix D). DOE calculates this value as a designation of important radionuclides in the DHLW waste profile. The limiting of radionculdies will produce a representative profile for the REPRISK and NEFTRAN calculations. This report assumes to apply the same radionuclides for NEFTRAN (Appendix E). The sixth modification is to assume a consistent water flow for both REPRISK and NEFTRAN. This report applies the same conditions to each model due to similar flow conditions.

Porosity volume of the repository (VTANK) for the REPRISK model is assumed to be best approximated by the volume of water passing through the repository yearly. This seventh modification is calculated by multiplying the area of the repository (5.6×10^{6} m^2) by the annual recharge rate of 4×10^{-3} m.

4.5.2 Scenario 2

The direct drilling hit of a canister applies the REPRISK scenario for the direct drill hit (Appendix B). A direct hit impacts the accessible environment due to the removal of radioactive waste from its emplacement and releasing it at the surface.

One should assume the repository holds approximately 70,000 MTU. DOE has not finalized the number of waste canisters so this report assumes 35,000 canisters are emplaced, alternating spent fuel with DHLW waste canisters.

The parameters are given to approximate the percentage of a canister which could be brought up by a direct hit and the annual frequency of a direct hit once a 100 year period for institutional control has lapsed.

4.5.3 Scenario 3

This report applies the same REPRISK model used for Scenario 2 (Direct Hit) to Scenario 3 (Near Miss) (Appendix B). Again the assumptions of 70,000 MTU for total waste volume and the emplacement of 35,000 canisters is used for this scenario. However, calculating the fraction of the waste canister requires a more comprehensive approach than the single area of the borehole in relation to the directly hit canister.

A near miss scenario is assumed to release radionuclides which have dissolved out from the canisters and into the repository. Over time, increasing volumes of waste will be available for contact with a near miss borehole and subsequent removal to the surface. This report calculated the fraction of the canister at the maximum period of dissolution (10,000 years) to approximate the conditions related to the consistent dissolution of waste.

The area of the borehole was considered in relation to the area of the repository which could contain waste. A steady state of dissolution was assumed to produce a uniform concentration of dissolved waste over the entire repository. The assumed annual rate of dissolution is 1×10^{-5} and will result in ten percent of the emplaced waste being dissolved. First, the area of the borehole must be divided by the area of the repository. The resulting value is multiplied by ten percent to determine the fraction of the respository brought to the surface by a near miss borehole.

4.2.4 Scenario 4

Faulting in Yucca Mountain serves to increase groundwater flow. This report models Scenario 4 with the REPRISK model applied to normal flow in Scenario 1 using the values calculated for specific radionuclides (Appendix B). As in Scenario 1, a model of the effects of faulting requires the hydraulic conductivity to be estimated to represent the flow rate. This report assumes the hydraulic conductivity estimated for Scenario 1 must be increased by an order of magnitude to approximate the elevated levels of water flow caused by faulting. No change in porosity is assumed.

The Ghost Dance Fault currently exhibits up to 20 m of brecciation therefore defining the size of the repository affected. An approximate size of the repository has been calculated in Scenario 1 with the square dimensions of 2,400 m per side. A proportion of the repository affected was calculated by modifying the area of brecciation to 24 m and dividing the brecciated area by the side dimension of 2,400 m for the repository.

A total of 1% of the repository is estimated to be affected by the faulting based on current data from the Ghost Dance Fault. The assumption of 70,000 MTU of volume in the repository predicts the potential volume of waste impacted by the fault is 700 MTU.

4.2.5 Scenario 5

The REPRISK model for volcanic disruption is applied to rhyolitic volcanism. In rhyolitic volcanism, the fraction of the repository intersected by the release mechanism is estimated to be 1.0 (Appendix B). A rhyolitic volcano intersecting the repository would likely eject the entire waste volume into the air. The explosive silicic nature and size of previous rhyolitic volcanos in proximity to Yucca Mountain would indicate the potential destruction of the entire repository and ejection of all the waste.

4.2.6 Scenario 6

This scenario also applies the REPRISK model for volcanism but considers basaltic volcanism. In basaltic volcanism, the amount of the repository affected by the eruption is determined by consideration of the average vent size and its relationship to the size of the repository (Appendix B). EPA developed a general estimate for volcanic tuff which assumed the fraction of the repository intersected would equal 4×10^{-4} for an 8×10^{6} m^2 sized repository. Yucca Mountain is smaller so the size of the fraction intersected by the basaltic volcano is proportionally larger. The area of Yucca Mountain is estimated to be 5.6×10^{6} m^2 so the fraction intersected by the basaltic volcano is increased to 5.7×10^{-4}.

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APPENDIX A: REPRISK SITE PARAMETERS

SCENARIO 1: NORMAL FLOW

Site Parameters Considered in Tuff Repository Risk Analysis

Parameter	Value	Source
Distance through disturbed zone to vertical flow path	25 m	DOE
Thickness of vertical flow path	2400 m	DOE
Hydraulic conductivity of vertical flow path	4×10^{-3} m/yr	See Text
Porosity of vertical flow path	.18	DOE
Vertical gradient in vertical flow path	1.0	DOE
Retardation values for individual nuclides in non-welded tuff	Am = 24,000 C = 1 Cm = 24,000 Cs = 41,000 I = 1 Np = 58 Pa = 740 Pb = 27 Pu = 740 Ra = 130,000 Sn = 530 Sr = 21,000 Tc = 1 Th = 2,600 U = 45 Zr = 2,600	DOE

SCENARIO 1: NORMAL FLOW (Cont.)

Site Parameters Considered in Tuff Repository Risk Analysis

Parameter	Value	Source
Natural hydraulic gradient through disturbed zone to vertical flow path	1.0	DOE
Hydraulic conductivity of the rock through disturbed zone to vertical flow path	4×10^{-3} m/yr	(See Text)
Porosity of rock through disturbed zone to vertical flow path	.06	DOE
Vertical distance along the vertical flow path to point regarded as release point to aquifer	175 m	DOE
Hydraulic conductivity of disturbed zone	4×10^{-3} m/yr	(See Text)
Porosity in disturbed zone created by release mechanism	.06	DOE
Cross-sectional area of flow path	5.6×10^{6} m^2	Repository Area (See Text)
Probability or frequency	1.0	EPA 520/3-80-006

SCENARIO 1: NORMAL FLOW

Site Parameters Considered in Tuff Repository Risk Analysis

Parameter	Value	Source
Distance through disturbed zone to vertical flow path	25 m	DOE
Thickness of vertical flow path	2400 m	DOE
Hydraulic conductivity of vertical flow path	4×10^{-3} m/yr	See Text
Porosity of vertical flow path	.18	DOE
Vertical gradient in vertical flow path	1.0	DOE
Retardation values for individual nuclides in welded tuff	Am = 28,000 C = 1 Cm = 28,000 Cs = 6,700 I = 1 Np = 160 Pa = 1,500 Pb = 120 Pu = 1,500 Ra = 580,000 Sn = 2,300 Sr = 1,200 Tc = 8 Th = 12,000 U = 27 Zr = 12,000	DOE

SCENARIO 1: NORMAL FLOW (Cont.)

Site Parameters Considered in Tuff Repository Risk Analysis

Parameter	Value	Source
Natural hydraulic gradient through disturbed zone to vertical flow path	1.0	DOE
Hydraulic conductivity of the rock through disturbed zone to vertical flow path	4×10^{-3} m/yr	(See Text)
Porosity of rock through disturbed zone to vertical flow path	.06	DOE
Vertical distance along the vertical flow path to point regarded as release point to aquifer	175 m	DOE
Hydraulic conductivity of disturbed zone	4 x 10-3 m/yr	Repository Area (See Text)
Porosity in disturbed zone created by release mechanism	.06	DOE
Probability or frequency	1.0	EPA 520/3-80-006

SCENARIO 2: BOREHOLE/DIRECT HIT

Release Mechanism Parameters Considered in Tuff Repository Risk Analysis
Drilling and Hitting a Canister

Parameter	Value	Source
Fraction of canister brought to the surface	0.15	EPA 520/3-80-006
Annual probability or frequency (after control period)	1.75×10^{-6}	EPA 520/3-80-006

SCENARIO 3: BOREHOLE/NEAR MISS

Release Mechanism Parameters Considered in Tuff Repository Risk Analysis
Drilling and Hitting a Canister

Parameter	Value	Source
Fraction of canister brought to the surface	.0002	(See Text)
Annual probability or frequency (after control period)	1.75×10^{-3}	(See Text)

SCENARIO 4: FAULTING

Site Parameters Considered in Tuff Repository Risk Analysis

Parameter	Value	Source
Distance from repository to aquifer	25 m	DOE
Thickness of aquifer	2400 m	DOE
Hydraulic conductivity of aquifer	4×10^{3} m/yr	See Text
Porosity of aquifer	.18	DOE
Vertical gradient in aquifer	1.0	DOE
Retardation values for individual nuclides in welded tuff	Am = 28,000 C = 1 Cm = 28,000 Cs = 6,700 I = 1 Np = 160 Pa = 1,500 Pb = 120 Pu = 1,500 Ra = 580,000 Sn = 2,300 Sr = 1,200 Tc = 8 Th = 12,000 U = 27 Zr = 12,000	DOE

SCENARIO 4: FAULTING (Cont.)

Site Parameters Considered in Tuff Repository Risk Analysis
Routine Releases Due to Faulting

Parameter	Value	Source
	U = 45 Zr = 2,600	
Natural hydraulic gradient through disturbed zone to vertical flow path	1.0	DOE
Hydraulic conductivity of the rock through disturbed zone to vertical flow path	4×10^{-3} m/yr	(See Text)
Porosity of rock through disturbed zone to vertical flow path	.06	DOE
Vertical distance along the vertical flow path to point regarded as release point to aquifer	175 m	DOE
Hydraulic conductivity of disturbed zone	4×10^{-3} m/yr	(See Text)
Porosity in disturbed zone created by release mechanism	.06	DOE
Cross-sectional area of flow path	5.6×10^{6} m^2	Repository Area (See Text)
Annual probability or frequency of faulting	8.0×10^{-5}	USGS Open File Report 82-972

SCENARIO 5: RHYOLITIC VOLCANISM

Release Mechanism Parameters Considered in Tuff Repository Risk Analysis

Parameter	Value	Source
Fraction of the repository intersected by the release mechanism	1.0	(See Text)
Annual probability or frequency	1×10^{-9}	DOE

SCENARIO 6: BASALTIC VOLCANISM

Release Mechanism Parameters Considered in Tuff Repository Risk Analysis

Parameter	Value	Source
Fraction of the repository intersected by the release mechanism	5.7×10^{-4}	EPA 520/3-80-006 (See Text)
Annual probability or frequency	2.9×10^{-8}	USGS Open File Report 80-357

APPENDIX B: TABLES OF REPRISK INPUT CARDS

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EVENT CHARACTERIZATIONS - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
4	23	NVTT(I)	1-5	-	5		Event Type.
5	23	EVNT(I)	-	-	11.0		Event identification number.
6	23	FNIT(I)	0-1	-	0		Fraction of repos. inventory in canisters directly breached by failure event.
7	23	FTANK(I)	0-1	-	1		Fraction of repos. inventory with which groundwater flow can communicate. Default = 1.0, for type 3 and 5 events only.
8	23	VTANK(I)	-	m^3	2.3E4		Porosity volume of repository portion that ground water can communicate with. Default=VR for type 3,4,5 events only.
9	23	VDRILL(I)	-	m^3	0		Volume of water removed from repository during drilling event. Default = VTANK(I); type 3 events only.
10	23	EDES(I,4)	Char	-	NORM FLOW		16 character event identification.

SCENARIO 1

EVENT CHARACTERIZATIONS - 2

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
11	24	EVNT(I)	-	-	11.0		Event identification number = (I).	
12	24	KI(I)	-	m/yr	4E-3		Initial hydraulic conductivity in flow path created by failure event. Type 3,4,5 events only.	
13	24	KPRIM(I)	-	m/yr/yr	0		Rate of change of hydraulic condition in flow path created by failure event. Type 3,5 events only.	
14	24	PORS(I)	-	-	.06		Porosity in flow path created by event. Types 3,4 events only.	
15	24	AREA(I)	-	m^2	5.6E6		Cross-sectional area of flow path created by event.	
16	24	EDES(I,4)	Char	-	NORM FLOW		16 character event identification	

INITIAL EVENT PROBABILITY

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
21	26	EVNT(I)	-	-	11		Event identification number.
22	26	PROB(I,1)	0-1	-	1		Initial probability of event. See manual for further info.
23	26	EDES(I,4)	Char	-	NORM FLOW		16 character event identification.

SCENARIO 1

EVENT CHARACTERIZATIONS - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
4	23	NVTT(I)	1-5	-	2		Event Type.
5	23	EVNT(I)	-	-	40.1		Event identification number.
6	23	FNIT(I)	0-1	-	4.3E-6		Fraction of repos. inventory in canisters directly breached by failure event.
7	23	FTANK(I)	0-1	-			Fraction of repos. inventory with which groundwater flow can communicate. Default = 1.0, for type 3 and 5 events only.
8	23	VTANK(I)	-	m^3			Porosity volume of repository portion that ground water can communicate with. Default=VR for type 3,4,5 events only.
9	23	VDRILL(I)	-	m^3			Volume of water removed from repository during drilling event. Default = VTANK(I); type 3 events only.
10	23	EDES(I,4)	Char	-	DRILL HIT		16 character event identification.

SCENARIO 2

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EVENT CHARACTERIZATIONS - 2

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
11	24	EVNT(I)	-	-	40.1		Event identification number = (I).
12	24	KI(I)	-	m/yr			Initial hydraulic conductivity in flow path created by failure event. Type 3,4,5 events only.
13	24	KPRIM(I)	-	m/yr/yr			Rate of change of hydraulic condition in flow path created by failure event. Type 3,5 events only.
14	24	PORS(I)	-	-			Porosity in flow path created by event. Types 3,4 events only.
15	24	AREA(I)	-	m^2	.05		Cross-sectional area of flow path created by event.
16	24	EDES(I,4)	Char	-	DRILL HIT		16 character event identification

SCENARIO 2

EVENT FAILURE RATE DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
17	25	N2	1-6		2		Sequence number of card.
18	25	EVNT(I)	-		40.1		Event identification number.
19	25	FRATE(I)		events/ yr	1.75E-6		Failure rate of event over extent of time period. See manual for additional information.
20	25	EDES(I,4)	-	-	DRILL HIT		16 character event identification.

EVENT CHARACTERIZATIONS - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
4	23	NVTT(I)	1-5	-	2		Event Type.	
5	23	EVNT(I)	-	-	40.2		Event identification number.	
6	23	FNIT(I)	0-1	-	1E-9		Fraction of repos. inventory in canisters directly breached by failure event.	
7	23	FTANK(I)	0-1	-			Fraction of repos. inventory with which groundwater flow can communicate. Default = 1.0, for type 3 and 5 events only.	
8	23	VTANK(I)	-	m^3			Porosity volume of repository portion that ground water can communicate with. Default=VR for type 3,4,5 events only.	
9	23	VDRILL(I)	-	m^3			Volume of water removed from repository during drilling event. Default = VTANK(I); type 3 events only.	
10	23	EDES(I,4)	Char	-	DRILL/NO	HIT	16 character event identification.	

SCENARIO 3

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EVENT CHARACTERIZATIONS - 2

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
11	24	EVNT(I)	-	-	40.2		Event identification number = (I).
12	24	KI(I)	-	m/yr			Initial hydraulic conductivity in flow path created by failure event. Type 3,4,5 events only.
13	24	KPRIM(I)	-	m/yr/yr			Rate of change of hydraulic condition in flow path created by failure event. Type 3,5 events only.
14	24	PORS(I)	-	-			Porosity in flow path created by event. Types 3,4 events only.
15	24	AREA(I)	-	m^2	.05		Cross-sectional area of flow path created by event.
16	24	EDES(I,4)	Char	-	DRILL/NO HIT		16 character event identification

SCENARIO 3

Arthur D Little

EVENT FAILURE RATE DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
17	25	N2	1-6		3		Sequence number of card.
18	25	EVNT(I)	-		40.2		Event identification number.
19	25	FRATE(I)		events/ yr	1.75E-3		Failure rate of event over extent of time period. See manual for additional information.
20	25	EDES(I,4)	-	-	DRILL/NO	HIT	16 character event identification.

SCENARIO 3

EVENT CHARACTERIZATIONS - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
4	23	NVTT(I)	1-5	-	5		Event Type.	
5	23	EVNT(I)	-	-	71.0		Event identification number.	
6	23	FNIT(I)	0-1	-	.01		Fraction of repos. inventory in canisters directly breached by failure event.	
7	23	FTANK(I)	0-1	-	.01		Fraction of repos. inventory with which groundwater flow can communicate. Default = 1.0, for type 3 and 5 events only.	
8	23	VTANK(I)	-	m^3	2.3E3		Porosity volume of repository portion that ground water can communicate with. Default=VR for type 3,4,5 events only.	
9	23	VDRILL(I)	-	m^3	0		Volume of water removed from repository during drilling event. Default = VTANK(I); type 3 events only.	
10	23	EDES(I,4)	Char	-	FAULT		16 character event identification.	

EVENT CHARACTERIZATIONS - 2

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
11	24	EVNT(I)	-	-	71.0		Event identification number = (I).
12	24	KI(I)	-	m/yr	4E-2		Initial hydraulic conductivity in flow path created by failure event. Type 3,4,5 events only.
13	24	KPRIM(I)	-	m/yr/yr	0		Rate of change of hydraulic condition in flow path created by failure event. Type 3,5 events only.
14	24	PORS(I)	-	-	.06		Porosity in flow path created by event. Types 3,4 events only.
15	24	AREA(I)	-	m^2	5.6E4		Cross-sectional area of flow path created by event.
16	24	EDES(I,4)	Char	-	FAULT		16 character event identification

EVENT FAILURE RATE DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
17	25	N2	1-6		4		Sequence number of card.
18	25	EVNT(I)	-		71.0		Event identification number.
19	25	FRATE(I)		events/yr	1E-5		Failure rate of event over extent of time period. See manual for additional information.
20	25	EDES(I,4)	-	-	FAULT		16 character event identification.

EVENT CHARACTERIZATIONS - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
4	23	NVTT(I)	1-5	-	2		Event Type.
5	23	EVNT(I)	-	-	73.1		Event identification number.
6	23	FNIT(I)	0-1	-	1		Fraction of repos. inventory in canisters directly breached by failure event.
7	23	FTANK(I)	0-1	-			Fraction of repos. inventory with which groundwater flow can communicate. Default = 1.0, for type 3 and 5 events only.
8	23	VTANK(I)	-	m^3			Porosity volume of repository portion that ground water can communicate with. Default=VR for type 3,4,5 events only.
9	23	VDRILL(I)	-	m^3			Volume of water removed from repository during drilling event. Default = VTANK(I); type 3 events only.
10	23	EDES(I,4)	Char	-	RHY VOL		16 character event identification.

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EVENT CHARACTERIZATIONS - 2

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
11	24	EVNT(I)	-	-	73.1		Event identification number = (I).
12	24	KI(I)	-	m/yr			Initial hydraulic conductivity in flow path created by failure event. Type 3,4,5 events only.
13	24	KPRIM(I)	-	m/yr/yr			Rate of change of hydraulic condition in flow path created by failure event. Type 3,5 events only.
14	24	PORS(I)	-	-			Porosity in flow path created by event. Types 3,4 events only.
15	24	AREA(I)	-	m^2			Cross-sectional area of flow path created by event.
16	24	EDES(I,4)	Char	-	RHY VOL		16 character event identification

EVENT FAILURE RATE DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
17	25	N2	1-6		5		Sequence number of card.	
18	25	EVNT(I)	-		73.1		Event identification number.	
19	25	FRATE(I)		events/ yr	1E-9		Failure rate of event over extent of time period. See manual for additional information.	
20	25	EDES(I,4)	-	-	RWY VOL		16 character event identification.	

SCENARIO 5

EVENT CHARACTERIZATIONS - 1

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ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
4	23	NVTT(I)	1-5	-	2		Event Type.
5	23	EVNT(I)	-	-	73.0		Event identification number.
6	23	FNIT(I)	0-1	-	5.7E-4		Fraction of repos. inventory in canisters directly breached by failure event.
7	23	FTANK(I)	0-1	-			Fraction of repos. inventory with which groundwater flow can communicate. Default = 1.0, for type 3 and 5 events only.
8	23	VTANK(I)	-	m^3			Porosity volume of repository portion that ground water can communicate with. Default=VR for type 3,4,5 events only.
9	23	VDRILL(I)	-	m^3			Volume of water removed from repository during drilling event. Default = VTANK(I); type 3 events only.
10	23	EDES(I,4)	Char	-	BAS VOL		16 character event identification.

SCENARIO 6

EVENT CHARACTERIZATIONS - 2

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
11	24	EVNT(I)	-	-	73.0		Event identification number = (I).
12	24	KI(I)	-	m/yr			Initial hydraulic conductivity in flow path created by failure event. Type 3,4,5 events only.
13	24	KPRIM(I)	-	m/yr/yr			Rate of change of hydraulic condition in flow path created by failure event. Type 3,5 events only.
14	24	PORS(I)	-	-			Porosity in flow path created by event. Types 3,4 events only.
15	24	AREA(I)	-	m^2			Cross-sectional area of flow path created by event.
16	24	EDES(I,4)	Char	-	BAS VOL		16 character event identification

SCENARIO 6

EVENT FAILURE RATE DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
17	25	N2	1-6		6		Sequence number of card.	
18	25	EVNT(I)	-		73.0		Event identification number.	
19	25	FRATE(I)		events/ yr	2.9E-8		Failure rate of event over extent of time period. See manual for additional information.	
20	25	EDES(I,4)	-	-	BAS VOL		16 character event identification.	

SCENARIO 6

AQUIFER FLOW SYSTEM DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
45	50	XA	-	m	175		Distance along aquifer to accessible environment outlet.
46	50	XS	-	m	25		Distance from top of repositry to bottom of overlying aquifer.
47	50	XKA	-	m/yr	4E-3		Permeability in aquifer pathway.
48	50	XIA	-	-	1		Gradient in aquifer pathway.
49	50	PORA	0-1	-	.18		Effective porosity in aquifer pathway.
50	50	AQAREA	-	m^2	5.6E6		Cross-sectional area of aquifer overlying the repository (thickness aquifer x widest dimension of rep. floor.)

SCENARIO 1, 2, 3, 5 and 6

AQUIFER FLOW SYSTEM DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
45	50	XA	-	m	175		Distance along aquifer to accessible environment outlet.
46	50	XS	-	m	25		Distance from top of repositry to bottom of overlying aquifer.
47	50	XKA	-	m/yr	4E-2		Permeability in aquifer pathway.
48	50	XIA	-	-	1		Gradient in aquifer pathway.
49	50	PORA	0-1	-	.18		Effective porosity in aquifer pathway.
50	50	AQAREA	-	m^2	5.6E4		Cross-sectional area of aquifer overlying the repository (thickness aquifer x widest dimension of rep. floor.)

SCENARIO 4 ONLY

LEACH RATE, CANISTER LIFETIME, AND OTHER MISCELLANEOUS DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
54	52	WFLR	0-1	yr^{-1}	1E-5		Leach rate of waste form. See manual for additional information.
55	52	CLIFE	-	yrs	300		Canister lifetime.
56	52	VR	-	m^3	2.3E4		Porosity volume of the mined portion of repository. See ID #8.
57	52	TIC	-	yrs	100		Time over which institutional controls are assumed to be effective in preventing intrusion by drilling.
58	52	EXPECT	-	-	.5		Expected value for recurrence of an event. Recommended input is 0.5.

SCENARIO 1-6

HYDRAULIC GRADIENT DATA

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
51	51	ALPH(I)	-	-	0		Exponent.	
52	51	CVA(I)	-	-	0		Coeffient.	
53	51	CVC	-	-	1		Constant. See manual for additional information.	

SCENARIO 1-6

APPENDIX C: SPENT FUEL RADIONUCLIDES CONSIDERED BY REPRISK

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	Am241		Radionuclide Id #. formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	432		Half-life.	
27	30	RNQO(I)	-	Curies	5.6E6		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	24000		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	.82		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Am-241S		Eight character radionuclide identification.	

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Pu240		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	6500		Half-life.
27	30	RNQO(I)	-	Curies	1.5E7		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	750		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	5.5E1		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Pu-240S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Pu238		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	88		Half-life.
27	30	RNOO(I)	-	Curies	7E7		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	740		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	40		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Pu-238S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Pu239		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	24E4		Half-life.
27	30	RNQO(I)	-	Curies	1E7		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	740		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	1.5E-1		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Pu-239S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	CM246		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	5.5E3		Half-life.
27	30	RNOO(I)	-	Curies	1.2E3		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	24000		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	.63-2		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 CM-246S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	CM245		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	9.3E3		Half-life.
27	30	RNQO(I)	-	Curies	6E3		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	24000		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	4E-2		Solubility limit on flow through repository.
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.
		RNDS2(I)	Char	-	CM-245S		

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	CM242		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	80		Half-life.	
27	30	RNQO(I)	-	Curies	3E5		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	24000		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	4.4		Solubility limit on flow through repository.	
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.	
		RNDS2(I)	Char	-	CM-242S			

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Am 243		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	8E3		Half-life.
27	30	RNOO(I)	-	Curies	5E5		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	24000		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	4.4E-2		Solubility limit on flow through repository.
31	30	RNDS1(I)	Char	-			Eight character radionuclide
		RNDS2(I)	Char	-	AM-243S		identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	Am 242		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	152		Half-life.	
27	30	RNOO(I)	-	Curies	3.5E5		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	24000		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	2.3		Solubility limit on flow through repository.	
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.	
		RNDS2(I)	Char	-	AM-242S			

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	Pu242		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	3.8E5		Half-life.	
27	30	RNQO(I)	-	Curies	5.6E4		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	740		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	1E-2		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Pu242S		Eight character radionuclide identification.	

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RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Pu241		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	13.2		Half-life.
27	30	RNOO(I)	-	Curies	2.4E9		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	740		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	2.7E2		Solubility limit on flow through repository.
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.
		RNDS2(I)	Char	-	Pu241S		

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	NP239		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	1E6		Half-life.	
27	30	RNQO(I)	-	Curies	5E5		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	58		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	6E7		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 NP239S		Eight character radionuclide identification.	

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	U238		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	4.5E9		Half-life.	
27	30	RNQO(I)	-	Curies	1E4		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	45		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	3E-4		Solubility limit on flow through repository.	
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.	
		RNDS2(I)	Char	-	U238S			

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	U235		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	7E8		Half-life.
27	30	RNQO(I)	-	Curies	560		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	45		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	2E-3		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 U235S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	1129		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	1.6E7		Half-life.	
27	30	RNQO(I)	-	Curies	1000		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	35		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 I129S		Eight character radionuclide identification.	

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RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	C14		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	5.7E3		Half-life.
27	30	RNQO(I)	-	Curies	2.8E4		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	6E4		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	C145		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	2r93		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	1.5E6		Half-life.
27	30	RNOO(I)	-	Curies	5.9E4		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	2600		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	2E-8		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	2-93S C145		Eight character radionuclide identification.

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RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Tc99		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.13E5		Half-life.
27	30	RNQO(I)	-	Curies	4.5E5		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	1.6E3		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 TC99S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Sn126		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	1.00E5		Half-life.
27	30	RNOO(I)	-	Curies	1.6E4		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	530		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	3.5E-6		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Sn-126S		Eight character radionuclide identification.

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RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Cs135		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	3E6		Half-life.
27	30	RNQO(I)	-	Curies	9.4E3		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	6700		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	1E-2		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Cs-135S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Pb210		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.5E5		Half-life.
27	30	RNQO(I)	-	Curies	59		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	1.6E7		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Pb-210S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	RA226		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.5E5		Half-life.
27	30	RNQO(I)	-	Curies	52		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	130000		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	6.7E-2		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 RA-226S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Th230		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.5E5		Half-life.
27	30	RNOO(I)	-	Curies	315		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	2600		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	4.7E-6		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Th230S		Eight character radionuclide identification.

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RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	U234		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.5E5		Half-life.
27	30	RNQO(I)	-	Curies	2600		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	45		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	5.8		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	U-234S		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	U236		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.3E7		Half-life.
27	30	RNOO(I)	-	Curies	7.7E3		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	45		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	7E-2		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 U-236S		Eight character radionuclide identification.

APPENDIX D: DHLW RADIONUCLIDES CONSIDERED BY REPRISK

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	Ni-63		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	100		Half-life.	
27	30	RNOO(I)	-	Curies	1.9E6		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	3.5E4		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Ni-63		Eight character radionuclide identification.	

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Se-79		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	6.5E4		Half-life.
27	30	RNQO(I)	-	Curies	8E2		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	5.5E3		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Se-79		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Nb-93		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	1.5E6		Half-life.
27	30	RNOO(I)	-	Curies	8.7E3		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	2.4E2		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Nb-93m		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	SB-126		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	1.E5		Half-life.
27	30	RNQO(I)	-	Curies	1.2E3		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	1E10		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	SB126		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	SM151		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	90		Half-life.	
27	30	RNOO(I)	-	Curies	1.9E6		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	8E-3		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Sm-151		Eight character radionuclide identification.	

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Ni59		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	7.6E4		Half-life.
27	30	RNQO(I)	-	Curies	1.5E4		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	40		Solubility limit on flow through repository.
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.
		RNDS2(I)	Char	-	Ni-59		

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Zr93		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	1.5E6		Half-life.
27	30	RNOO(I)	-	Curies	8.7E3		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	2600		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	2E-8		Solubility limit on flow through repository.
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.
		RNDS2(I)	Char	-	Z-93		

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Tc99		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.13E5		Half-life.
27	30	RNQO(I)	-	Curies	1.5E4		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	1.6E3		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Tc-99		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Sn126		Radionuclide Id #. formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	1.00E5		Half-life.
27	30	RNOO(I)	-	Curies	1.2E3		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr $^{-1}$	1E-5		Leach rate.
29	30	RNDA(I)	-	-	530		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m ^{3}	3.5E-6		Solubility limit on flow through repository.
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.
		RNDS2(I)	Char	-	Sn-126		

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	CS135		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	3E6		Half-life.
27	30	RNQO(I)	-	Curies	6.5E2		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	6700		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	1E-2		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Cs-135		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	Pb210		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	2.5E5		Half-life.	
27	30	RNQO(I)	-	Curies	8.2		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	1		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	1.6E7		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Pb-210		Eight character radionuclide identification.	

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Ra226		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.5E5		Half-life.
27	30	RNQO(I)	-	Curies	11		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	130000		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	6.7E-2		Solubility limit on flow through repository.
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.
		RNDS2(I)	Char	-	Ra-226		

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RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Th230		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.5E5		Half-life.
27	30	RNOO(I)	-	Curies	68		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	2600		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	4.7E-6		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Th-230		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	U234		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	2.5E5		Half-life.	
27	30	RNQO(I)	-	Curies	3.6E3		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	45		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	5.8		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 U-234		Eight character radionuclide identification.	

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code	Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.	
25	30	RNID(I)	-	-	U236		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.	
26	30	RNLD(I)	-	-	2.3E7		Half-life.	
27	30	RNQO(I)	-	Curies	26		Initial inventory at respository sealing.	
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.	
29	30	RNDA(I)	-	-	45		Retardation factor in overlying aquifer.	
30	30	RNSOL(I)	-	Ci/m^3	7E-2		Solubility limit on flow through repository.	
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 U-236		Eight character radionuclide identification.	

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Pu238		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	88		Half-life.
27	30	RNQO(I)	-	Curies	7.9E6		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	740		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	40		Solubility limit on flow through repository.
31	30	RNDS1(I)	Char	-			Eight character radionuclide identification.
		RNDS2(I)	Char	-	Pu-238		

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Pu239		Radionuclide Id #. formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	2.4E4		Half-life.
27	30	RNQO(I)	-	Curies	7.4E4		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	740		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	1.5E-1		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Pu-239		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Pu240		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	6500		Half-life.
27	30	RNQO(I)	-	Curies	4.7E4		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	740		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	5.5E-1		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	 Pu-240		Eight character radionuclide identification.

RADIONUCLIDE DATA - 1

ID#	Card Type	Parameter Code	Admissible Values	Units	Input Value	Reference	Comments/Code Description
24	30	NRNTY(I)	1,2	-	1		Radionuclide type 1 = simple decay 2 = daughter product.
25	30	RNID(I)	-	-	Am241		Radionuclide Id #. Formed by atomic # and mass #; C-14 = 6.014.
26	30	RNLD(I)	-	-	432		Half-life.
27	30	RNQO(I)	-	Curies	8.3E4		Initial inventory at respository sealing.
28	30	LR(I)	0-1	yr^{-1}	1E-5		Leach rate.
29	30	RNDA(I)	-	-	24000		Retardation factor in overlying aquifer.
30	30	RNSOL(I)	-	Ci/m^3	.82		Solubility limit on flow through repository.
31	30	RNDS1(I) RNDS2(I)	Char Char	- -	Am-241		Eight character radionuclide identification.

APPENDIX E: NEFTRAN INPUT PARAMETERS

FIXED DATA GROUP --RUN OPTIONS

DVM (0) OR ANALYTICAL (1)	1
SOLVED NETWORK (0) / INPUT VELS (1)	1
LEACH (0)SOLUBIL (1) EITHER(2)	2
FLOTHRU (0)/MIXCELL(1)/EITHER(2)	0
LEACH RATE CONSTANT (0)/EXPONTL (1)	1

FIXED DATA GROUP --CHAIN INCLUSION

CHAIN 1(0/1/2) = (Y/SOURCE/N)	Y
CHAIN 2(0/1/2) = (Y/SOURCE/N)	Y
CHAIN 3(0/1/2) = (Y/SOURCE/N)	Y
CHAIN 4(0/1/2) = (Y/SOURCE/N)	Y
CHAIN 5(0/1/2) = (Y/SOURCE/N)	Y
CHAIN 6(0/1/2) = (Y/SOURCE/N)	Y

FIXED DATA GROUP --SOURCE AND FLOW

INVENTORY ACCESS FRACTION	.1
SOURCE PORE VOLUME (FT^3)	3.4 E3
LENGTH OF SOURCE (FT)	30
LEACH RATE (1/Y)	1E-5
DENSITY (LB/FT^3)	62.43

FIXED DATA GROUP -- TIMES

TOTAL PROBLEM TIME	10,000
INTIAL SOURCE RELEASE TIME	300
TIME TO ONSET OF LEACHING	300

ARRAY LEG PROPERTIES - NETWORK

	LEG INDEX	INLET INDEX	OUTLET INDEX	ROCK-TYPE INDEX	LEG LENGTH (FT)	LEG AREA	BRINE CONC.	TRANSPORT LEG	DISPER.
1	1	1	2	1	82	2.6E4	0	1	0
2	2	2	3	2	570	2.6E4	0	2	0
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									

ARRAY ROCK - TYPE PROPERTIES

	ROCK TYPE INDEX	HYDRAULIC CON (FT/D)	MASS XFER COEFF (1/Y)	MOBILE POROSITY	IMMOBILE POROSITY
1	1	3E-5		.06	
2	2	3E-5		.18	
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					

ARRAY JUNCTION PROPERTIES - NETWORK

	JUNCTION INDEX	JUNCTION ELEV. (FT)	UN/ KNOWN PRES	PRESSURE (PSI)
1	1	656	1	0
2	2	570	0	0
3	3	0	1	0
4				
5				
6				
7				
8				
9				
10				
11				
12				
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14				
15				
16				
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18				
19				
20				
21				
22				
23				
24				
25				

ARRAY INITIAL INVENTORY DATA

DHLW WASTE

	LIBRARY INDEX	CHAIN INDEX	INDEX IN CHAIN	INDEX OF PARENT 1	BRANCH/ PARENT 1	INDEX OF PARENT 2	BRANCH/ PARENT S	INVENTORY (CURIES)	OUTPUT?	WEIGHTING FACTOR
1	30	1	1	0				8E2		
2	32	2	1	0				1.5E4		
3	33	3	1	0				1.2E3		
4	35	4	1	0				6.5E2		
5	28	5	1	0				8.2		
6	26	6	1	0				11		
7	21	7	1	0				68		
8	17	8	1	0				3.6E3		
9	15	9	1	0				260		
10	12	10	1	0				7.9E6		
11	11	11	1	0				7.4E4		
12	10	12	1	0				4.7E4		
13	7	13	1	0				8.3E4		
14										
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ARRAY ELEMENT PROPERTIES

DHL:W WASTE

Array D Title

ELE #	SOLUBILITY (G/G)	SOLUBILITY (G/G)	Rd MOBLE ROCK 1	Rd MOBLE ROCK 2	Rd MOBLE ROCK 3	Rd MOBLE ROCK 4	Rd MOBLE ROCK 5	Rd IMMOB ROCK 1	Rd IMMOB ROCK 2	Rd IMMOB ROCK3	Rd IMMOB ROCK4
	.1		1	1							
	.1		1	1							
	1E-10		530	530							
	.1		6700	6700							
	.2		27	27							
	6E-8		1300000	1300000							
	2E-10		2600	2600							
	8E-4		45	45							
	8E-4		45	45							
10	2E-6		740	740							
11	2E-6		740	740							
12	2E-6		740	740							
13	2E-7		24000	24000							
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											
28											
29											
30											

ARRAY INITIAL INVENTORY DATA

SPENT FUEL

	LIBRARY INDEX	CHAIN INDEX	INDEX IN CHAIN	INDEX OF PARENT 1	BRANCH/ PARENT 1	INDEX OF PARENT 2	BRANCH/ PARENT S	INVENTORY (CURIES)	OUTPUT?	WEIGHTING FACTOR
1	1	1	1	0				1.2E3		
2	2	2	1	0				6E3		
3	4	3	1	0				0		
4	5	4	1	0				3E5		
5	6	5	1	0				5E5		
6	7	6	1	0				5E7		
7	8	7	1	0				5.6E4		
8	9	8	1	0				2.4E9		
9	10	9	1	0				1.5E7		
10	11	10	1	0				1E7		
11	12	11	1	0				7E4		
12	13	12	1	0				1E7		
13	14	13	1	0				1E4		
14	15	14	1	0				8E3		
15	16	15	1	0				5.6E2		
16	17	16	1	0				2.6E3		
17	18	17	1	0				73		
18	21	18	1	0				3E3		
19	26	19	1	0				52		
20	28	20	1	0				59		
21	29	21	1	0				2.8E4		
22	32	22	1	0				4.5E5		
23	33	23	1	0				1.6E4		
24	34	24	1	0				1.1E3		
25	35	25	1	0				9.4E3		
26										
27										
28										
29										
30										

ARRAY ELEMENT PROPERTIES

SPENT FUEL

Arthur D Little

ELE #	SOLUBILITY (G/G)	SOLUBILITY (G/G)	Rd MOBLE ROCK 1	Rd MOBLE ROCK 2	Rd MOBLE ROCK 3	Rd MOBLE ROCK 4	Rd MOBLE ROCK 5	Rd IMMOB ROCK 1	Rd IMMOB ROCK 2	Rd IMMOB ROCK3	Rd IMMOB ROCK4
	.2	24000	24000								
	.2	24000	24000								
	.2	24000	24000								
	.2	24000	24000								
	2E-7	24000	24000								
	2E-7	24000	24000								
	2E-6	740	740								
	2E-6	740	740								
	2E-6	740	740								
10	2E-6	740	740								
11	2E-6	740	740								
12	2E-4	58	58								
13	9E-4	45	45								
14	9E-4	45	45								
15	9E-4	45	45								
16	9E-4	45	45								
17	9E-4	45	45								
18	2E-10	2600	2600								
19	6E-8	130000	130000								
20	.2	27	27								
21	.01	1	1								
22	.1	1	1								
23	1E-10	530	530								
24	.1	1	1								
25	.1	41000	41000								
26											
27											
28											
29											
30											