4. CONSEQUENCES OF HUMAN INTRUSION[1]

4.1 Introduction

In Chapter 4, "Human Intrusion and Institutional Control," of its findings and recommendations, the NAS concluded that: "... (i) active institutional controls cannot be relied on to prevent breaching of the repository's engineered or geologic barriers by human activity such as exploratory drilling; and (ii) it is not possible to make scientifically supportable predictions of the probability of such breaches...." The NAS recommended that the repository developer be required to provide a reasonable system of active and passive controls to reduce the risk of inadvertent intrusion (e.g., Tolan, 1993; and Jensen, 1993). The NAS further recommended that a stylized calculation be used to analyze the impact of a hypothetical intrusion scenario on the performance of the repository. Because the probability of such a scenario would be highly speculative, the NAS recommended that the calculation not be included in the TSPA, but be considered separately, using the same critical group assumptions as in the TSPA, to provide insights on the resiliency of the repository to human intrusion.

Human intrusion has been analyzed (determinstically) as a disruptive scenario in prior TSPAs for Yucca Mountain (e.g., Codell *et al.*, 1992; Barnard *et al.*, 1992; Wilson *et al.*, 1994; Wescott *et al.*, 1995), as well as internationally, for other HLW disposal concepts.[2] Each of these analyses relied on certain basic assumptions regarding human behavior and future technology. As noted above, and in Section 1, the NAS concluded that there was no scientific basis for predicting the occurrence of human intrusion subsequent to permanent closure of a geologic repository. Consequently, the staff performed a scoping analysis to better understand the limitations, requirements, and implementation issues associated with a stylized calculation of human intrusion caused by exploratory drilling. As part of its analysis, the staff used its IPA ability to perform some relatively simple calculations of the effect of human intrusion for the purposes of:

- Determining the relationship between the estimated dose and the human intrusion scenario assumptions;
- Determining what intrusion-related parameters (caused by drilling) appeared to be most important to dose; and
- Evaluating the time dependence of the occurrence of the drilling event on the magnitude of dose.

4.2 Specification of Intrusion Scenarios

Consistent with the NAS recommendations, the human intrusion scenario considered for analysis was that of a single borehole, drilled from the surface using conventional rotary drilling technology,[3] on top along the crest of Yucca Mountain. Such an intrusion event could have a number of possible outcomes: (a) passage between repository drifts or outside of emplacement areas (no damage to a waste package or overall repository integrity); (b) passage through a repository emplacement drift (missing a waste package) to the water table; (c) intersecting an emplacement drift, hitting and damaging a waste package, without continuation of drilling below the drift; and (d) intersecting an emplacement drift, hitting and penetrating a waste package, and continuation of drilling to the water table. The ability of a rotary drill bit to damage the waste package will depend on the state (integrity) of the waste package—i.e., a drill bit can only be expected to damage or penetrate an already

[1]The tables shown in this section present the results from the demonstration of the continuing staff capability to review a TSPA. These tables, like the demonstration, are limited by the use of simplifying assumptions and sparse data.

[2]Also see summaries in Nuclear Energy Agency (1995).

[3]Although a number of advanced drilling technologies and methods are under evaluation and/or development (National Research Council, 1994), based on the NAS' concerns about the difficulty in predicting future human activity, no attempt was made by the staff to speculate as to which one of these emerging technologies might become practicable in the future and then integrate this information into the analysis.

(severely) corroded waste package.[4] Thus, the extent of drilling damage to a waste package is related to the time of the intrusion, given that degradation of the waste package is anticipated to occur gradually over hundreds to thousands of years. The effects of these issues are evaluated by considering two different times for the intrusion event itself and two specific intrusion scenarios that are expected to bound the consequences.

The first human intrusion scenario analyzed is specified as a single borehole intersecting the emplacement drift and damaging the waste package. A breach of the waste package is assumed to form in the upper half of the waste package (horizontal emplacement assumed) either through direct penetration by the drill bit or through enhanced corrosion from ground water dripping from the borehole onto the surface of the damaged, but not penetrated, waste package. Once breached, the excavated borehole (annulus) provides a pathway for dripping water to enter the waste package. After the waste package is filled with water, it is assumed any additional water would result in dissolved radionuclides leaving the waste package in the water that leaves the waste package at the same rate as the additional water is entering (i.e., once the waste package is filled with water, it is conservatively assumed that all the subsequent infiltrating water displaces contaminated water from inside the waste package). The second human intrusion scenario analyzed specifies a single borehole intersecting the emplacement drift horizon, intersecting a waste package as well, and then fully penetrating (or perforating) it,[5] followed by a continuation of the drilling down to the water table. In this second scenario, infiltrating water is assumed to enter the waste package, filling the lower half of the waste package up to the lower penetration hole (which would occur somewhere in the bottom half of the waste package), and subsequent release of radionuclides similar to the previous scenario. For the penetration scenario, the consequences of HLW entrained in the drill/borehole cuttings, which could be brought to the surface (e.g., Berglund, 1992), is not evaluated because the effect on doses to any hypothetical receptor group at 20 kilometers is assumed to be insignificant.

4.3 Description of Modeling Approach

Evaluation of annual individual dose requires specification of an exposure scenario that defines the geosphere and biosphere pathways for transport of radionuclides released from a geologic repository to a human receptor in the biosphere. Simulation of radionuclide release, transport in the geosphere, and definition of the biosphere pathways was substantially based on models and parameter ranges recently developed within NRC's performance assessment program (see Mohanty and McCartin, 2000). However, modification of a few parameter ranges was needed to represent the amount of water entering a borehole and transport of radionuclides in the borehole. Important attributes of the analysis of the human intrusion scenario were as follows:

- Conventional rotary drilling technology is assumed. The borehole diameter is 15.24 centimeters (6 inches).[6]
- The intrusion event occurs at either 100 or 1000 years after permanent repository closure.
- Ground-water inflow down the borehole is limited to a 1-square-meter catchment area or a 10-square-meter catchment area. The different catchment areas account for the possibility of borehole degradation at or below the land surface and the existence or formation of a

[4] It could be argued that latest waste package designs may be robust enough to withstand the effects of conventional rotary dril bits using diamond, tungsten, or carbide cutting elements. However, the purpose of this scoping analysis was not to evaluate likely failure modes for the waste package canisters nor speculate on the range of different human intrustion modes. Rather, consistent with the NAS recommendations, this analysis assumes the structural integrity of the waste package canister has been degraded, for whatever reason, and thus can be inadvertently breached by rotary drilling assuming a specific (drilling) scenario.

[5] That is to say the drilling process creates both an entrance (upper half) and exit (lower half) breach or hole within the waste package canister.

[6] This diameter size is consistent with reported information on past drilling practices in the Yucca Mountain area (see Thordarson and Robinson, 1971) as well as what is believed to be current drilling practice overall. See LeRoy *et al.*, (1977), Driscoll (1986), and American Water Works Association (1991).

depression, at the surface, around the borehole, caused by drilling activity.

- Horizontal emplacement of the waste package is assumed. Damage to the waste package results in a breach in the upper half of the waste package (location of the breach is varied between 0.5 and 1.0 of the waste package diameter). Penetration of the waste package results in a breach in both the lower and upper halves of the waste package (the location of the lower breach, which defines the exit location for radionuclides, is varied between 0.0 and 0.5 of the waste package diameter). For both conditions, the location of the lowest breach or hole in the waste package defines what fraction of HLW is contacted by water and thus contributes to release.

- When the waste package is perforated by a drill bit, the borehole extends to the water table and provides a continuous path, for radionuclide transport, from the repository emplacement depth to the water table, which is unaltered by any retardation processes.

- A continuous transport path is assumed to exist from the saturated zone, below the repository footprint, to the receptor location 20 kilometers down-gradient from Yucca Mountain. The saturated zone path is comprised of fractured tuff (approximately two-thirds of the total path length) and porous alluvium (approximately one-third of the total path length).

- All releases from the proposed repository eventually pass the receptor location and are uniformly mixed in the annual volume of water pumped by the receptor group (assumed to be a hypothetical farming community in a semi-arid environment). Water usage is based on the water demands for irrigating 13 to 27 quarter-section plots with 0.94 to 1.33 meters/year (3.1 to 4.38 feet/year)— or 0.016 to 0.049 cubic meters/year (4.4 to 13 million gallons/day).

- The hypothetical receptor group uses untreated ground water for both household purposes and irrigation of agricultural crops. The farmer is assumed to grow alfalfa for feed (for beef and dairy stock, including egg-laying hens), and vegetables, fruits, and grains for personal consumption. For the average member of the hypothetical farming community, the magnitude of personal consumption from local sources is conservatively assumed as follows: 50 percent for food needs; and 100 percent for drinking water and milk. The local sources of food, milk, and potable water are assumed to be contaminated because of the use of contaminated ground water.

4.4 Assumptions and Limitations

As stated above, the analysis was limited to consideration of only a "direct" intrusion scenario—that of a 15.24-centimeter drill bit damaging or penetrating a waste package container. An "indirect" intrusion scenario, in which a borehole misses a waste container, but penetrates contaminated portions of the repository floor and proceeds to the water table, was not considered. To calculate any consequences from the indirect scenario, it would have to be assumed that at least some waste packages, nearby, are degraded and leaking (the number and rate of leakage would either be arbitrary or need to be determined probabilistically) and the contaminated water is diverted to the borehole. The staff considers the second type of intrusion analyzed (i.e., penetration of a waste package and subsequent water inflow leading to radionuclide release down a borehole to the water table) a reasonably conservative approximation for an indirect scenario (i.e., exploratory drilling misses the waste package but provides an alternative pathway for radionuclides). In addition, for the differential in consequences to be significant, the unsaturated zone underlying the repository footprint would have to favor *matrix flow*, such that the borehole represents a significant fast conduit to the water table. If *fracture flow* predominates, the borehole could have limited additional effect on transport of radionuclides to the water table, compared with transport in fractures.

4.5 Results and Conclusions

Estimates of the annual individual dose are uncertain due to variation and uncertainty in the parameters and assumptions associated with the intrusion scenario, as well as other key aspects of the analysis (e.g., infiltration, release rate from the waste form, retardation, etc.). To better understand and quantify the variation in dose estimates caused by uncertainties in the geosphere models (i.e., source-term, hydrologic flow, and radionuclide transport) and the human intrusion scenarios, the staff performed probabilistic analyses. This uncertainty results in a distribution, of the annual individual dose, the estimates for which the staff has elected to represent with a mean value and 95th percentile of the distribution for each of the cases analyzed. Tables 4.1 and 4.2 present the annual individual dose (expressed as TEDE) for the damaged waste package scenario and the perforated waste package scenario, respectively. Additionally, these results represent the dose consequence from only the intrusion event; therefore, the results represent the increase in dose caused by the intrusion event (e.g., this result would be added to the performance results for the remaining waste packages of the repository to determine the total performance).

In regard to the initial review objectives, the staff concludes that the most likely range of doses from a reasonably credible human intrusion drilling event is up to tens of microrems (μ rem).[7] Certain drilling-related parameters (i.e., borehole diameter, catchment area, and timing of the drilling event) have varying degrees of effect on the dose estimates; however, all doses are estimated to be well below 1 millirem (mrem). Although the length of the time of the performance period (e.g., 10,000 versus 50,000 years after repository closure) had the largest impact on the consequences, the doses from the longer period were still well below 1 mrem.

The staff agrees with the NAS finding that it is highly speculative to predict the consequences of future human activity from exploratory drilling for natural resources. However, at this time (and for the foreseeable future), the staff considers exploratory drilling for energy and mineral resources at the Yucca Mountain site to be an extremely unlikely event based on available information.[8] As discussed in Section 2.1, a more likely scenario in the foreseeable future might be exploratory drilling for ground water in one of the intermontane basins (valleys) that lie beyond the site. In the unlikely event that exploratory drilling should take place at or near the repository footprint, the chances are remote that it would intersect a waste

[7]The reader is reminded that the NAS' recommendations apply only to the critical group. Potential doses to the drilling crew, due to inadvertent exploratory drilling, can be expected to be higher than the values reported elsewhere in this NUREG for hypothetical receptor groups. See Charles and McEwen (1991) for an example of this type of calculation.

[8]Because exploratory drilling for natural resources is believed to be the most likely manner in which the geologic repository may be breached, the purpose of this calculation was to assess the resilience of the repository to drilling (using the surrogate of dose), not the likelihood of the drilling event itself taking place. There are many factors that contribute to decisions to explore for energy and mineral resources (see Anderson, 1982; and Harris, 1990). One of these factors certainly would be the existence of known energy, mineral, or ground-water resources at the Yucca Mountain site. In this regard, the staff's review of available natural resource information was intended to provide some simple insights regarding how this information might affect the prospect of future exploratory drilling.

The Yucca Mountain area lies in the southern Great Basin, an area that has been extensively investigated and reported in the literature. DOE provided a preliminary assessment of the potential for natural resources at the site in its 1988 SCP. Although the Yucca Mountain site contains areas of mineralization, these areas don't occur in concentrations or amounts sufficient for exploitation (see DOE, 1988; pp. 1–256 — 1–313). Moreover, experts do not believe that hydrocarbon resources exist in the area (*Op cit.*, pp. 1–313—1–323). Based on recent reports (Raines *et al.*, 1991; Schalla and Johnson, 1994; Sherlock *et al.*, 1996), it is not clear if any mineral resources (including prospects and occurrences) exist beyond those that have been previously identified.

Because a majority of the mineral resources exposed at the surface are believed to have already been discovered, a study was conducted by the USGS, in cooperation with the Nevada Bureau of Mines and Geology (Singer, 1996), to evaluate the metallic mineral resource potential below the cover (within 1 kilometer of the surface). As part of the study, geologic environments that were believed to be permissive for the occurrence of certain types of mineral deposits were identified (i.e., broad resource tracts) where deposits could hypothetically occur (see Cox *et al.*, 1996). No specific mineral deposits, prospects, or occurrences were identified at Yucca Mountain, although some potential (mineral) resource tracts were identified within the boundary of NTS. Thus, based on the information cited, it is not apparent that Yucca Mountain, or the area immediately around it, would represent an attractive candidate for either random or systematic exploratory drilling at this time. The staff believes that a more likely scenario might be drilling for ground water in one of the basins that lie beyond the site.

Table 4–1. Peak Annual Dose Resulting from a Damaged Waste Package.

Time of Intrusion (Years after Repository Closure)	*Mean and (95th percentile) for TEDE over a 10,000-year Performance Period*		*Mean and (95th percentile) for TEDE over a 50,000-year Performance Period*	
	1 m^2 Catchment Area (μ rem)	*10 m^2 Catchment Area (μ rem)*	*1 m^2 Catchment Area (μ rem)*	*10 m^2 Catchment Area (μ rem)*
100 years	1.2 (1.5)	1.9 (1.7)	3.6 (24)	3.8 (33)
1000 years	0.9 (1.1)	1.2 (1.1)	2.8 (20)	2.8 (20)

Table 4–2. Peak Annual Dose Resulting from a Perforated Waste Package.

Time of Intrusion (Years after Repository Closure)	*Mean and (95th percentile) for TEDE over a 10,000-year Performance Period*		*Mean and (95th percentile) for TEDE over a 50,000-year Performance Period*	
	1 m^2 Catchment Area (μ rem)	*10 m^2 Catchment Area (μ rem)*	*1 m^2 Catchment Area (μ rem)*	*10 m^2 Catchment Area (μ rem)*
100 years	0.4 (0.5)	0.4 (0.5)	1.1 (6.8)	1.1 (7.8)
1000 years	0.3 (0.4)	0.3 (0.4)	0.8 (5.2)	0.9 (6.1)

package; rather, exploratory drilling would most likely intersect emplacement tunnels or drifts of the repository or the geologic unit comprising the waste emplacement horizon.

Nonetheless, should a borehole intersect a waste package, the staff believes that it would be a low-consequence event for the types of hypothetical receptor groups considered in this NUREG, when limited to reasonable assumptions. Moreover, the use of active institutional controls, to delay the intrusion event for 1000 years after permanent repository closure, would not significantly affect the resulting, based on the calculations presented in this analysis.

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5. EXAMPLE CALCULATION OF EXPECTED ANNUAL DOSE, AS A FUNCTION OF TIME, FROM EXTRUSIVE VOLCANIC EVENTS AT YUCCA MOUNTAIN[1]

5.1 Introduction

As discussed in previous sections of this NUREG, the 1995 NAS report recommended that future standards for Yucca Mountain limit individual risk (dose) to the average member of a critical group and performance could be assessed over timeframes during which the geologic system is relatively stable (i.e., on the order of 10^6 years). Implementation of this NAS recommendation for an individual risk standard was evaluated earlier, in Section 3.3, by estimating annual doses for the ground-water pathway. Analysis of the risk of an extrusive volcanic (igneous) event is described in this section to gain insight into implementation issues with respect to estimating radiological exposures from low-probability events. Specifically, this (example) scoping analysis was undertaken to provide insights on the ability to estimate exposures for low-probability events and the relationship, if any, between the time period of the analysis and the estimate of dose.

5.2 Approach

Evaluation of the expected annual dose from an extrusive volcanic scenario at the proposed Yucca Mountain repository requires specification of an exposure scenario that defines the transport and fate of radionuclides released in such an event. The exposure scenario modeled in these analyses is depicted in Figure 5−1 and consists of four major components, in the following progression:

Event	*Description*
I	Magma enters the repository and becomes contaminated with only SNF[2] particles.
II	Tephra[3] forms from the contaminated magma and is released from the repository.
III	An eruption column, and plume, form and transport contaminated tephra to locations downwind from the event.
IV	Radionuclide contamination collects on the earth's surface, potentially exposing hypothetical receptor groups.

Each of these four components is discussed in greater detail in the following paragraphs. A more detailed discussion of the models and parameter sampling mechanisms is also provided in Jarzemba *et al.* (1999). The amount of SNF that is incorporated into magma and eventually extruded in the volcanic event is estimated by probabilistically determining the diameter of the volcanic conduit and then determining the amount of SNF overlapped by that area. See Doubik and Hill (1998).

For example, a conduit 50 meters in diameter (1963 square meters in area), occurring within the proposed repository boundary, would extrude 40.8 MTU of SNF assuming an areal mass loading of 85 MTU/acre (0.02079 MTU/square meter)[4] for the current reference repository design (see DOE, 1998; p. 3−23). The range of volcanic conduit diameters used in these analyses is from 24.6 to 77.9 meters.

Once SNF has been incorporated into magma and released from the cone, estimations of the downwind transport and deposition of contaminants must be made. These estimations are performed using the *ASHPLUME* computer code (Jarzemba and LaPlante,

[1]The figures shown in this section present the results from the demonstration of the continuing staff capability to review a TSPA. These figures, like the demonstration, are limited by the use of simplifying assumptions and sparse data.

[2]The principal waste forms to be disposed of at Yucca Mountain will be either SNF or vitrified waste. Other waste forms that may possibly be disposed of include low-level, greater-than-class-C (GTCC), or transuranic wastes. Only SNF was considered for this analysis.

[3]A general term for all pyroclastic rock material ejected from an erupting volcano.

[4]Thermal loading units are expressed in terms of MTU/acre for easy comparison with DOE's recently published 5-volume *Viability Assessment* (DOE, 1999).

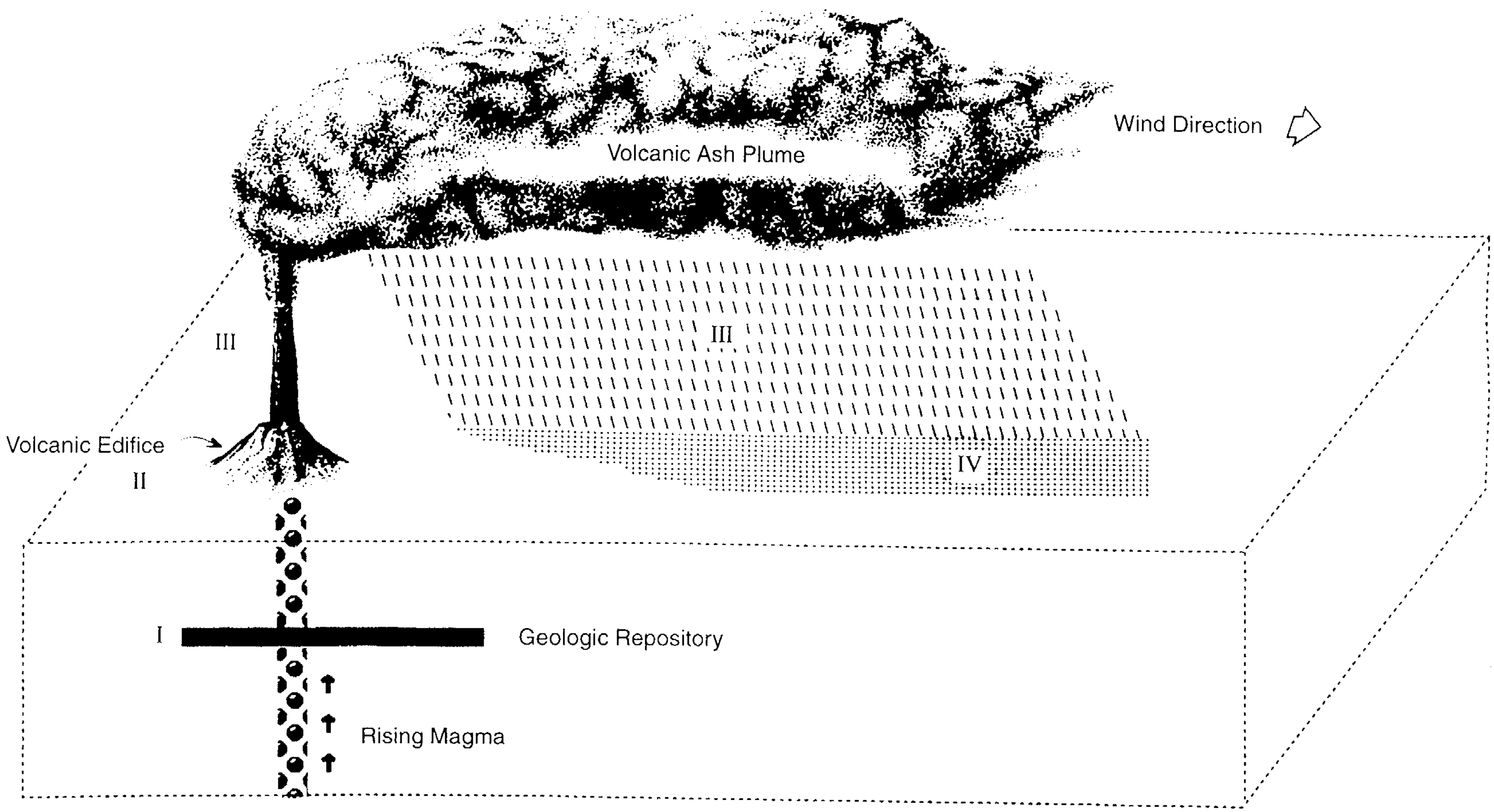

Figure 5–1. Diagram showing the exposure scenario selected for the extrusive volcanic event calculation. Processes depicted by numbers are described in Section 5.2 of the text.

1996; Jarzemba, 1997) which uses probabilistically-determined parameter values to describe the magnitude of the event in order to calculate the downwind deposition of contaminants. Once parameter values have been chosen, the computer code calculates downwind deposition based on a model modified from that of Suzuki (1983). Such parameters include (but are not limited to): wind speed and direction; volcanic event power and duration; eddy diffusivity; and parameters characterizing the fuel and ash particulate size distribution and density after incorporation. For a more complete description of transport and deposition parameters, the reader is referred to Jarzemba and LaPlante (1996). For the most recent information on the parameter sampling mechanisms, the reader is referred to Jarzemba *et al.* (1999).

Since these analyses require the estimation of expected dose as a function of time, and since *ASHPLUME* only determines the radionuclide deposition at the receptor location immediately following the volcanic event, the radionuclide areal concentration at the receptor location as a function of time after the event must be determined. These simulations use a semi-analytical model that accounts for radionuclide ingrowth/decay, leaching of contaminants from the radioactive ash blanket, and bulk erosion of the ash blanket (Jarzemba and Manteufel, 1997). The model uses quantities such as: radionuclide distribution coefficients—K_ds; the relative rate of ash blanket erosion λ^B; amount of water ingress into the ash blanket from irrigation and rainfall; and radioactive decay constants to estimate the radionuclide areal concentration of the ash blanket at times after the event. [For a description of these parameters and their numerical values the reader is referred to Jarzemba and Manteufel (1997).]

Once the radionuclide areal concentrations at times after the event have been estimated, conversion of these contamination levels to dose must be performed. For the purposes of this analysis, there are four possible dose pathways that can cause exposures to members of the hypothetical receptor group (assumed to be located 20 kilometers downwind from the proposed repository):

- Ingestion of crops grown on the contaminated ash blanket;
- Ingestion of contaminated animal products from stock that were raised on agricultural products grown on the contaminated ash blanket;
- Direct exposure from radionuclides in the ash blanket itself; and
- Inhalation from resuspended contamination.

Ingestion of ground water contaminated by radionuclides leaching from the ash blanket is not included in the model. For all pathways except inhalation, biosphere dose conversion factors (DCFs), which are simply multiplicative factors that convert areal contamination levels to dose, are used to estimate radiation doses (LaPlante and Poor, 1997). Because of the large fraction of the total dose from the inhalation pathway, a more mechanistic dose conversion process is used herein. Equation (5–1) describes how doses are estimated for the inhalation pathway:

$$\dot{D}_i = B I_i S \eta_i f_c \frac{T_{B-0} \exp\left[-\lambda^B (t - t_{event})\right]}{T_R} \quad \textbf{(5-1)}$$

where:

$\dot{D}_i$ = Dose rate due to inhalation from radionuclide i of resuspended contamination (rem/year);

B = Breathing rate (1.05×10^4 m^3/year);

I_i = Inhalation-to-dose conversion factor for radionuclide i [rem/Ci; see Eckerman *et al.* (1988)];

S = Airborne mass load (loguniform distribution from 1×10^{-4} to 1×10^{-2} g/m^3);

η_i = contamination level of the ash in radionuclide i (Ci/g); or the areal density of radionuclide i (Ci/cm^2) divided by the areal density of ash (g/cm^2) at the hypothetical receptor location;

f_e = fraction of year receptor individual is exposed to contaminated air (0.24);

$T_{B\text{-}0}$ = thickness of ash blanket immediately after the event;

t_{event} = time of the volcanic event; and

T_R = thickness of the resuspendable layer (0.3 cm).

Important assumptions and conservatisms used to model the four major components of this exposure scenario are described as follows:

- All waste consumed by the conduit is conservatively assumed to be available for incorporation into the magma and subsequent ejection during the extrusive volcanic event.
- The volcanic cone is assumed to form at the center of the hypothetical repository block with an annual probability of 10^{-7}.
- The size distribution of tephra particles is undisturbed by the incorporation of SNF particles.
- The wind duration remains constant throughout the duration of the event.
- Only contamination within the top 15 centimeters of the ash blanket (soil) contributes to dose.
- Contamination of ground water from radionuclides leached out of the ash blanket is not considered.
- The inhalation-to-dose conversion factors found in Eckerman *et al.* (1988) are applicable to the hypothetical receptor (individual) modeled in these analyses.

5.3 Calculation of the Expected Dose to a Hypothetical Receptor Group

The "average risk" or expected annual dose is the product of the consequence (i.e., dose) and the probability that the dose has occurred. Estimates of dose are uncertain because the models and their input parameters are uncertain, as are the times of occurrence of the disruptive events such as volcanic activity. Monte Carlo analysis is used to account for the uncertainty in the parameters used for estimating doses resulting from volcanic events, similar to the approach used in Section 3.3. The Monte Carlo analysis propagates the uncertainty in model inputs through the conceptual models. A Monte Carlo simulation evaluates a model repeatedly using input values that have been randomly selected from the probability distributions for the input variables. The output of the Monte Carlo analysis is a set of results such as dose versus time, for each of the randomly chosen input sets of values. Each dose curve has an associated probability based on the probability of the model inputs selected. Generally, each Monte Carlo output result has equal probability. Thus, each dose curve from the Monte Carlo analysis has a probability of occurring that is the product of the probability associated with the parameter uncertainty (i.e., $1/N$, where N is the number of Monte Carlo samples) and the probability associated with event uncertainty. The overall expected annual dose curve is developed by combining each of the dose curves, with their associated probabilities, into a single dose curve that represents the "average risk" or expected annual dose.

For volcanic activity, dose consequences depend on when the event occurs and the length of time between the occurrence of the event and the exposure. Events that occur soon after repository closure produce larger consequences because the relatively short-lived but high-activity radionuclides like americium-241 (^{241}Am) are still present in significant quantities. Radionuclides can reach the affected population in short times (hours to days), but persist in the environment and also cause lower levels of exposure long after the event (hundreds to thousands of years).

After the event occurs, doses diminish over time because of radioactive decay and erosion of the radioactive ash blanket. The time of occurrence of the event is very important to the dose consequences, and is therefore included in the probabilistic analysis as one of the sampled parameters. The fact that there are short-term variations in the consequences from volcanic events complicates the probabilistic analysis by requiring a large number of Monte Carlo samples to resolve the overall expected dose on both the short- and long-term time scales. For example, if 100 samples are needed to properly represent the parameter uncertainty (e.g., volcanic event power and duration, wind speed, and direction), then theoretically 1 million samples would be required for a 10,000-year simulation [i.e., (100 samples per/year) × (10,000 years)] to ensure that the sampling procedure produced a sufficient number of samples at individual years. Such a large number of Monte Carlo simulations is impractical with the present TPA code.

A more efficient approach to developing the expected annual dose curve is to develop average dose curves for volcanic events at a few and discrete event times. Specific times of occurrence of volcanic activity are selected for the evaluation rather than randomly selecting occurrence times in a Monte Carlo approach. In the present analysis, the event times were 100, 500, and 1000 to 10,000 years in 1000-year time steps. Each specific event time has a distinct probabilistic analysis and associated family of dose curves. The probabilistic analysis is used to develop an average dose curve for each of the distinct times (see Figure 5−2). Linear interpolation, between the times of conditional expected dose curves, was used to consider events at other times. Equation (5−2) describes how the expected annual dose to the receptor individual is estimated in this approach:

$$R(t) = \sum_{n=1}^{E} \Delta T p \, D_n(t) \qquad \mathbf{(5-2)}$$

where:

$R(t)$ = the expected annual dose to the hypothetical receptor as a function of time;

$D_n(t)$ = the average dose rate as a function of time for specific event time n;

p = the annual probability of an event;

ΔT = increment of time associated with the event time n (if events are evaluated on a per-year basis, this would be 1 year); and

E = the number of specific event times used to represent variation in event uncertainty (interpolation between events can be used to generate dose curves for each year).

5.4 Results and Conclusions

The expected annual dose as a function of time is presented in Figure 5−3. The expected dose curve reaches a peak dose of approximately 1 mrem around 1000 years after repository closure. The time of the peak of the expected annual dose curve is a direct result of time-dependent processes (radiation decay and soil erosion) that decrease consequences over time. Figure 5−2 displays this reduction in consequence for volcanic events by showing the variation in consequences for volcanic events over specific occurrence times for the events. The reduction in consequence is largest during the first 1000 years, when short-lived radionuclides have their largest effect. Americium-241, which has a radioactive half-life of 432 years, is the largest contributor to dose over the 10,000-year time period. The direct release of radionuclides occurring in the first 100 years was not considered in this analysis because active institutional controls are assumed to be used to mitigate any potential exposure consequences by restricting human activity in areas with contaminated ash.

Four general conclusions may be drawn from the present analysis:

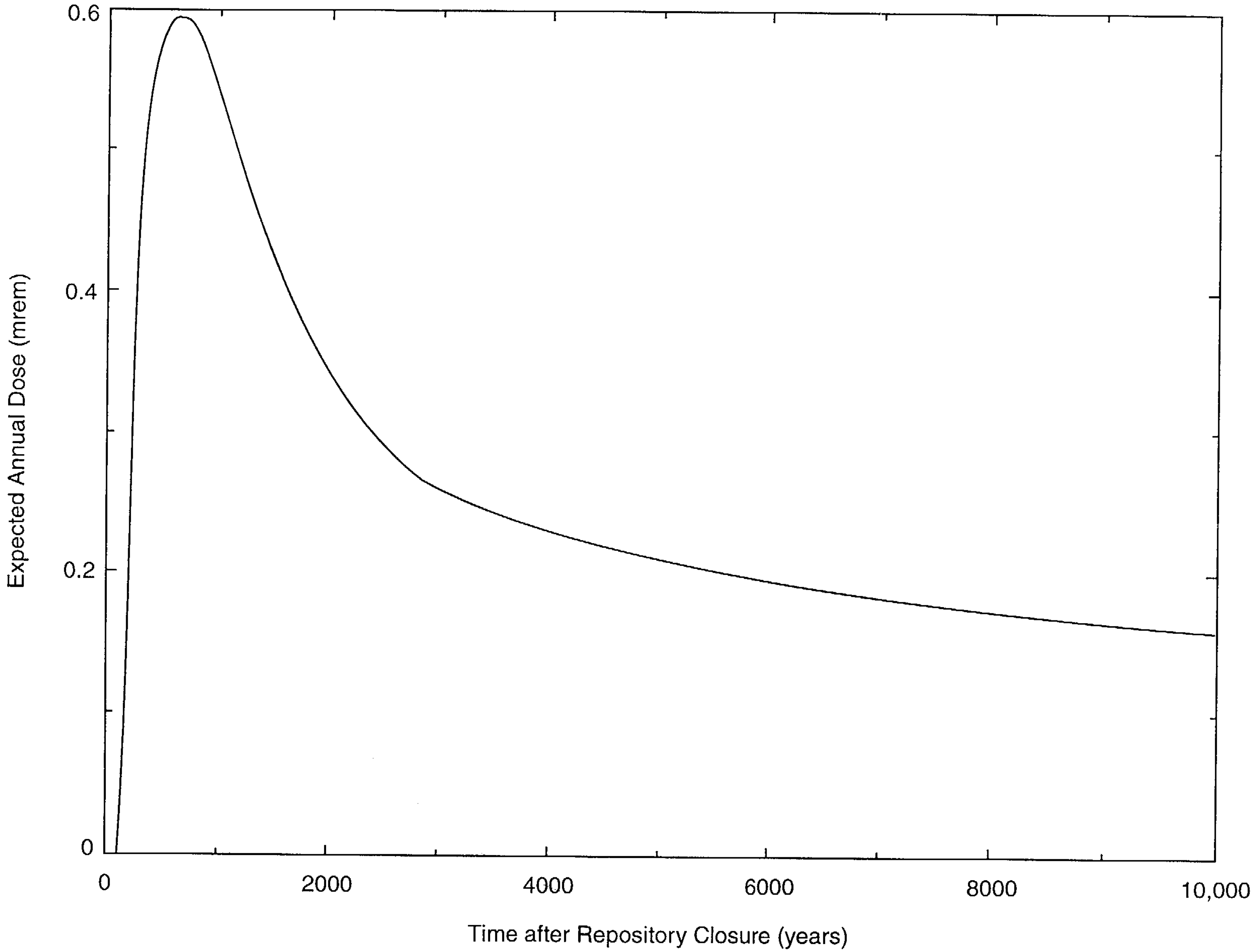

Figure 5–2. Average annual conditional dose resulting from extrusive volcanic events occurring at specific times.
Calculation of conditional dose assumes the event probability is one (1). Initiating times, following repository closure, are as indicated.

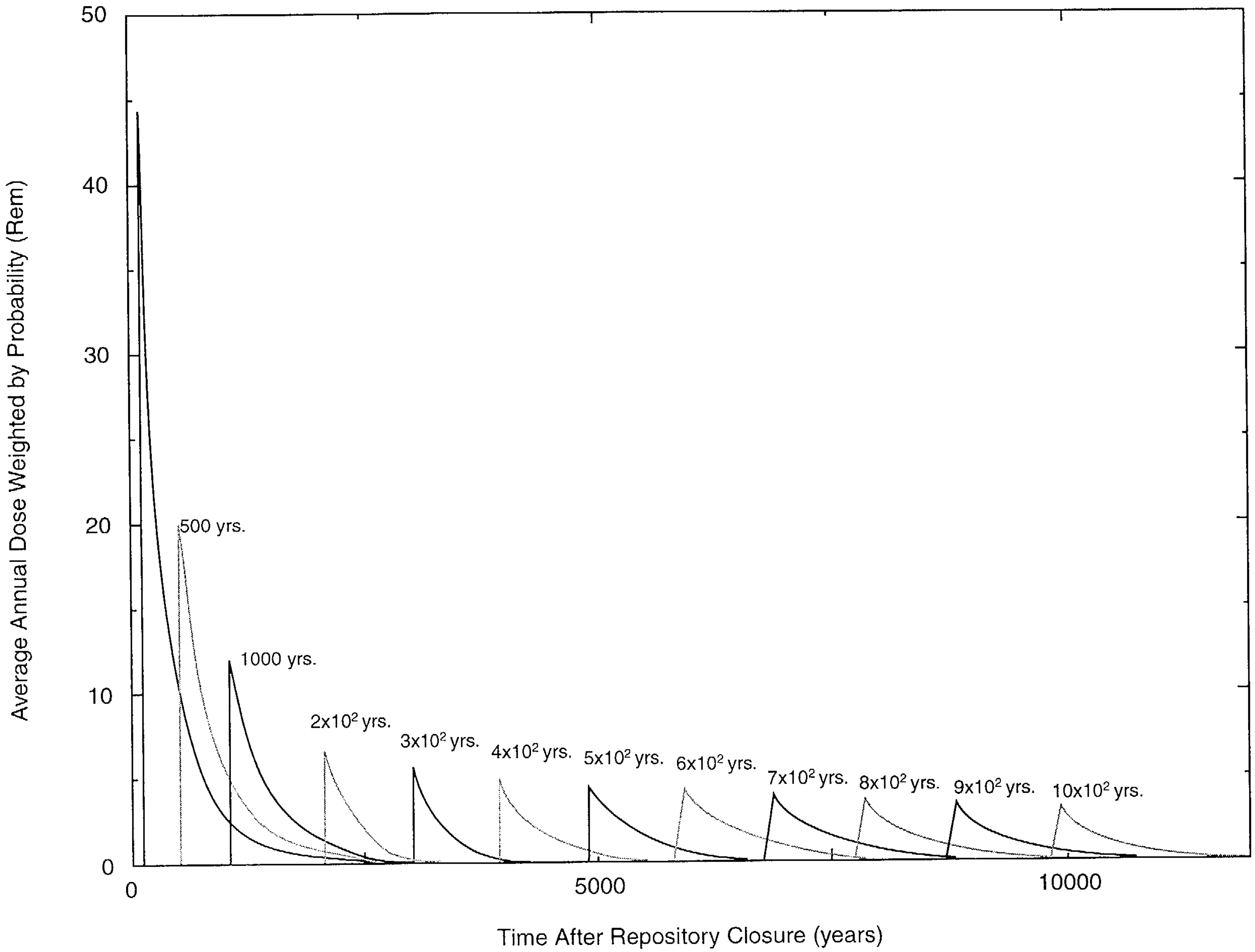

Figure 5–3. Expected annual dose as a function of time from extrusive volcanic events.

- A capability for estimating the annual individual dose, from direct release of radionuclides from an volcanic event, can be incorporated into performance assessments, assuming the concentrations of radionuclides can be estimated in contaminated tephra that collects on the earth's surface;

- The time of occurrence of the volcanic event has a significant effect on the annual individual dose estimate;

- The length of time between when the volcanic event occurs and when the exposure takes place has a significant effect on the annual individual dose estimate; and

- The peak expected annual dose for a direct release of radionuclides occurs during the initial 10,000 years, and is estimated to be on the order of 1 mrem.

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6. ANALYSIS OF RELATIVE HAZARD OF HLW OVER LONG TIME PERIODS[1]

6.1 Introduction

An issue raised by the NAS in its findings and recommendations concerned the time period over which compliance with HLW standards should be of regulatory concern. In its 1995 report, the NAS recommended (National Research Council, 1995; pp. 71–72) that:

> "... [the] calculation of the maximum risks of radiation releases **whenever** they occur as long as the geologic characteristics of the repository environment do not change significantly (emphasis added). The time scale for long-term geologic processes at Yucca Mountain is on the order of approximately one million years."

The purpose of this particular recommendation was to focus on the time at which future populations might be at maximum risk. With time, the radionuclides in a potential geologic repository will decay, and the radiological hazard associated with the waste will decrease (see DOE, 1980; pp. 1.3–1.4). Thus, at some particular point in the future, the hazard associated with the HLW repository will become comparable to the hazard of naturally occurring radioactive sources, such that the disposal facility hazard becomes similar to that of uranium naturally concentrated in an ore body.

6.2 Discussion

The NAS has stated that probably the most significant difference between its findings and recommendations and the existing HLW standards is the time period of regulatory interest (*Op cit.*, p. 119). As noted in Section 1, current regulations at Part 191 recognize a 10,000-year time period of regulatory concern, whereas the NAS has suggested that this time frame be longer—whenever the peak risk occurs (e.g., on the order of up to 1 million years after permanent closure of the repository). Because both EPA and NRC are re-evaluating this time period, the following analysis was conducted to determine when the radioactivity and more importantly, the radiological hazard associated with SNF (the dominant waste constituent in the proposed geologic repository) might become comparable to that of naturally occurring radioactive materials.

The health hazard of radioactive waste depends on two primary factors: (a) the inherent radiotoxicity of the material; and (b) the accessibility of the material to possible human intake or exposure. This scoping analysis compares the hazard associated with a HLW repository with that of a hypothetical ore body at the same location in the unsaturated zone at Yucca Mountain. Specifically, this analysis considers the amount of percolating water that contacts SNF, solubility limits for radionuclides, and radionuclide release rates to account for the accessibility of radionuclides for exposures through the ground-water pathway. Contributions from other characteristics of engineered and geologic barriers will be neglected.

The approach used in this study was to compare the variations in total radioactivity and radiological hazard for a geologic repository containing **only** SNF (hereafter referred to as the "spent fuel repository") and a hypothetical uranium ore body, over a 100-million-year time period. The hypothetical ore body is defined to have the same amount of uranium and occupy the same volume as the proposed geologic repository at Yucca Mountain. The hypothetical ore body is considered to contain only ^{235}U and ^{238}U and their radioactive daughters. The primary difference between a potential geologic repository and the hypothetical ore body referred to in this analysis, is that repository-destined waste has a significant man-made radionuclide inventory (through neutron irradiation and fissioning) as

[1]The figures and table shown in this section present the results from the demonstration of the continuing staff capability to review a TSPA. These figures and table, like the demonstration, are limited by the use of simplifying assumptions and sparse data.

compared with the ore body, which contains naturally occurring nuclides only. The major difference between this analysis and previous work[2] is that the most recently available data and characteristics of the Yucca Mountain site (e.g., solubilities, radionuclide inventories) are used.

6.3 Description of Modeling Approach

6.3.1 Ore Body and Geologic Repository

Uranium is widely distributed throughout the Earth's crust (at about 2 parts per million). It is more abundant than gold, platinum, silver, bismuth, cadmium, and antimony (Krauskopf, 1979). But because it is chemically active, it never occurs as a native element and is usually found in combinations with other minerals (about 100 different ones).[3] Certain geologic conditions (see Finch *et al.*, 1973) permit uraniferous minerals to occur in anomalous concentrations, at about 400 to 2500 times typical crustal abundance, which render these materials exploitable and, therefore, *ore*.

Figure 6–1 shows the major steps in the uranium life-cycle, where ore is extracted from the earth and transformed into SNF (and other radioactive wastes). The first step begins with the extraction of uranium-bearing minerals from an ore-bearing deposit. It takes approximately 50 kilograms of uraniferous ore (containing at least 0.08 percent U_3O_8,[4]) to yield about 1 kilogram of uranium. Uranium, in the form of U_3O_8, is recovered from ore through three primary steps: mining, mill concentration, and chemical processing (see Rahn *et al.*, 1984). Each process step also generates certain byproducts (and wastes). For example, during mining and mill processing, uranium is extracted from ore and separated from gangue materials (the ore aggregate or matrix), thereby creating byproducts (in the form of tailings) that contain radioactive daughters of uranium-234 (^{234}U) and ^{238}U—primarily the isotopes thorium-230 (^{230}Th), radium-226 (^{226}Ra), and lead-210 (^{210}Pb) and ^{235}U—primarily the isotopes protactinium-231 (^{231}Pa) and actinide-227 (^{227}Ac). (Most of the ore's radioactivity is contained in the tailings, in the form of radon gas.) Chemical processing (e.g., refining) of the concentrated ores (now at about 0.5–0.8 percent U_3O_8[5]) and subsequent enriching of the uranium concentrates makes it suitable as nuclear fuel. After enrichment (to about 3.5 percent of fissile ^{235}U, for light-water reactors), the uranium is fabricated into ceramic pellets and sealed into stainless steel or zirconium alloy rods. The rods are subsequently bundled into fuel assemblies, which are then used to power reactors. Over time, the fuel assemblies become inefficient for the purposes of nuclear fission because of neutron irradiation, and thus becomes "spent" (nuclear fuel).

The principal waste forms considered for disposal in a HLW repository at Yucca Mountain will be either SNF from commercial nuclear power reactors and vitrified waste (glass) from both defense and commercial sources, although other waste forms may be disposed.[6] In accordance with Section 114(d)(2) of the Nuclear Waste Policy Act of 1982 (NWPA), as amended (Public Law 97–425), no more than 70,000 metric tons equivalent of waste can be disposed of at any one geologic repository in the U.S.

6.3.2 Radioactivity as a Function of Time

In Figure 6–2, the total radioactivity of SNF is shown, along with the radioactivity of a number of the dominant radionuclides. At early times, the radioactivity is dominated primarily by fission products, whereas at later times, it is dominated by transuranics (and

[2]A number of reports and analyses have addressed the reduction of radioactivity, and radiological hazards of HLW with time, or made comparisons of its hazard relative to uranium ore. For example, see Cohen (1982); Cohen *et al.* (1989); Elayi and Schapira (1987); EPA (1982a, 1982b, 1985); Hamstra (1975); Levi (1980); Liljenzin and Rydberg (1996); Mehta *et al.* (1991); Tacca *et al.* (1991); Wick and Cloninger (1980); and Williams (1980).

[3]Uraninite (UO_2) and carnotite [$U(SiO_4)_{1-x}(OH)_{4x}$] are the chief ores of uranium, although other minerals have also proven to be important sources (e.g., tyuyamunite, torbernite, and autunite). See Hurlbut (1971).

[4]U_3O_8 or triuranium octoxide is a refined oxide of uraniferous ores. Sometimes referred to as *yellow cake*, it is the final product generated during the milling process.

[5]This process step also generates depleted uranium, which is used for kinetic-energy projectiles for the military (Adams, 1995).

[6]Other waste forms that may possibly be disposed of in a geologic repository include low-level, GTCC, or transuranic wastes.

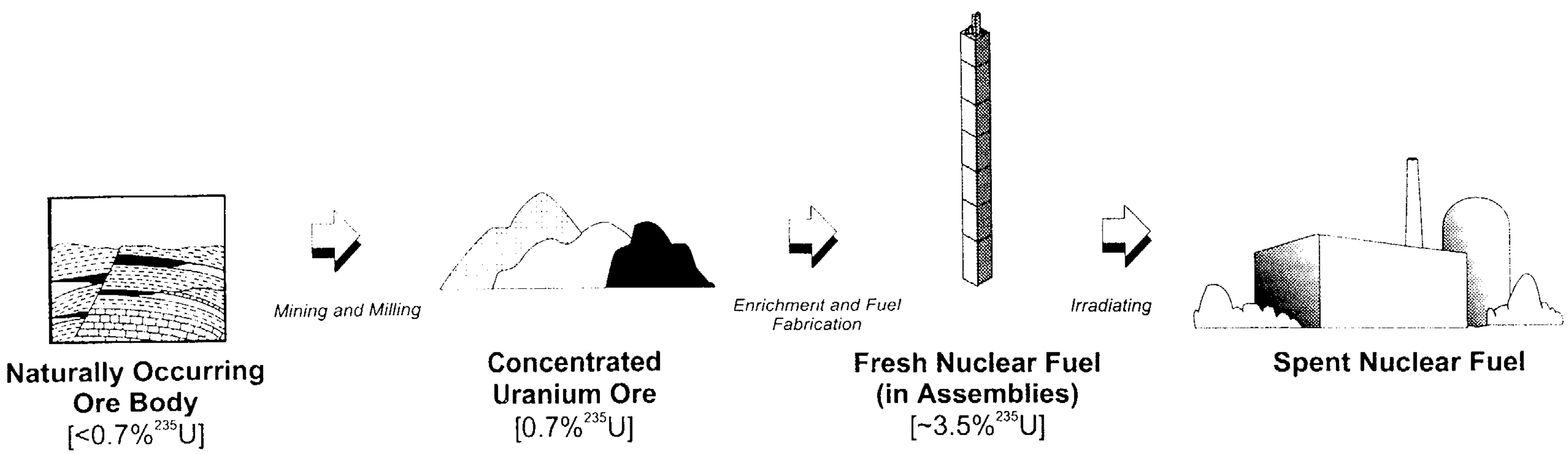

Figure 6–1. Major steps in extraction and use of uranium, along with major byproducts. (Enrichment, fuel fabrication, and irradiation can generate other radioactive waste hazards not addressed in this analysis.)

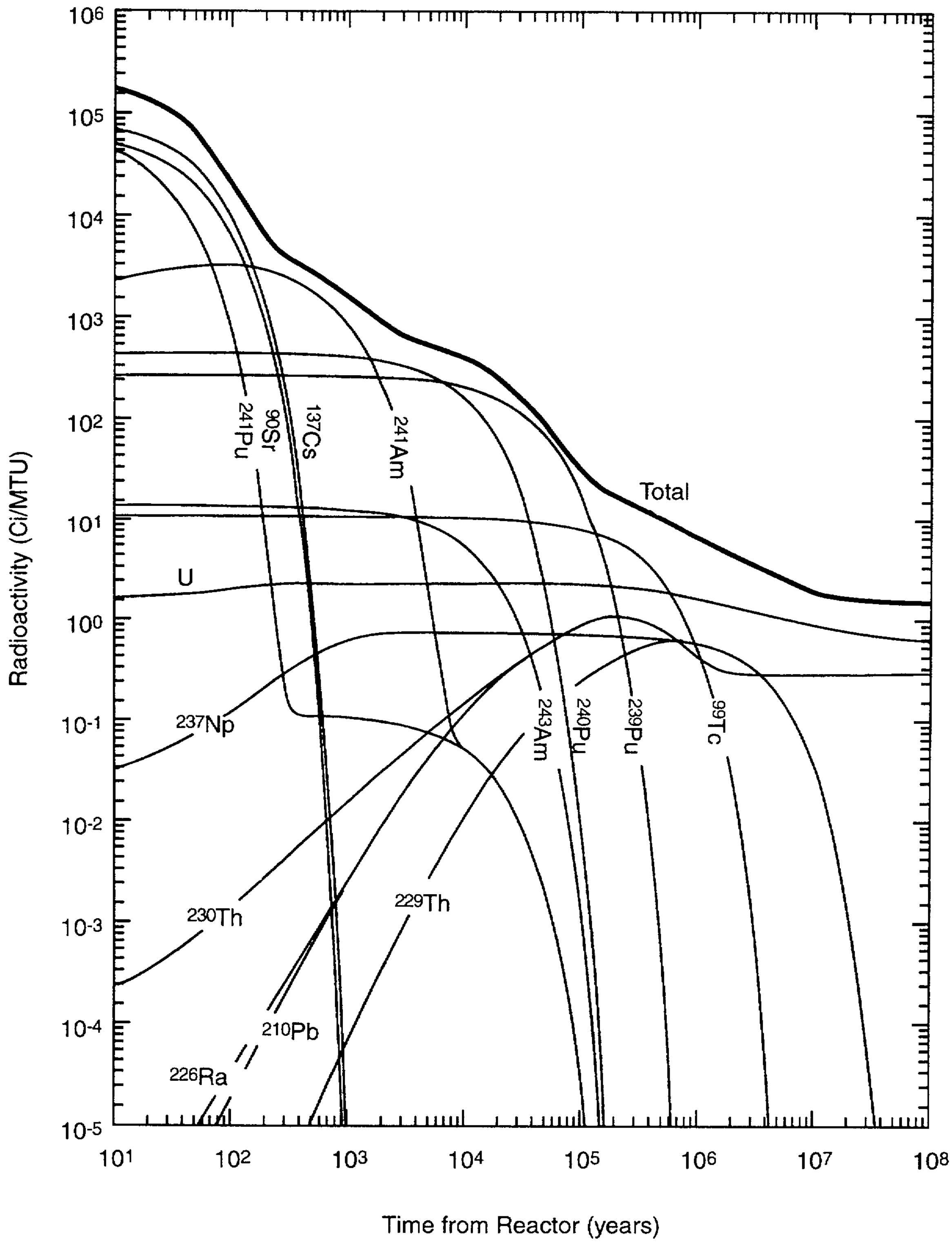

Figure 6–2. Radioactivity of SNF. Inventory based on Lozano *et al.* (1994).

their daughters). Strontium-90 and cesium-137 (^{137}Cs) dominate the activity up to 100–200 years; americium and plutonium up to 100,000 years; and technetium and uranium beyond 100,000 years. At times beyond 10 million years, the activity is dominated by ^{235}U, ^{238}U; and their daughters, which are naturally occurring radionuclides. Figure 6–2 is in agreement with a similar figure shown in a study that was performed to support the rulemaking process for Part 191 in the mid 1980s [see Figures A–4 and A–5 of EPA (1985)].

In Figure 6–3, the inventory of the hypothetical ore body used in this analysis is shown. The ore body is enriched to 3.5 percent ^{235}U to match the pre-irradiation uranium content of SNF. The inventory ranges over 9 orders of magnitude, indicating the ore is predominantly uranium. The daughters are in equilibrium and their activity is 0.318 curies per MTU of uranium (Ci/MTU) for ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, and ^{210}Pb, and is 0.085 Ci/MTU for ^{235}U, ^{231}Pa, and ^{227}Ac. The total radioactivity is 1.85 Ci/MTU for the nuclides tracked in this analysis. Because ^{235}U and ^{238}U have very long half-lives, their inventory and radioactivity remain essentially constant over 100 million years. In Figure 6–4, the total radioactivity of the spent fuel repository and the hypothetical ore body are compared. By 1000 years, the radioactivity of SNF is 1 percent of what it was at 10 years after irradiation. At 10 years from the reactor, the spent fuel radioactivity is about 182,800 Ci/MTU. The ore body radioactivity is about constant at 1.85 Ci/MTU. At approximately 10^4 years, the spent fuel radioactivity will have decreased by 99.9 percent. Beyond 10 million years, the total radioactivity is essentially equal to the hypothetical ore body.

6.3.3 Radiological Hazard as a Function of Time

Although informative, a comparison of total radioactivity of ^{241}Am is approximately 100 times more hazardous than ingesting 1 curie of ^{137}Cs (EPA, 1988; DOE, 1988). For this analysis, the staff compared the radiological hazards associated with drinking ground water, which has been contaminated by either the spent fuel repository or the hypothetical ore body. To make such a comparison, some modeling assumptions and site-specific data are employed. The model, as illustrated in Figure 6–5, consists of steadily percolating ground water that flows through the repository and into the saturated zone. Some of the percolating ground water contacts some of the waste packages. The water that contacts the waste subsequently becomes contaminated with radionuclides. For the analyses, 43 different radionuclides are considered from 10 to 100 million years after irradiation (Lozano *et al.*, 1994). The current geologic repository design[7] is assumed to have a footprint covering an area of about 5 square kilometers (TRW Environmental Safety Systems, Inc., 1994), a 1-millimeter-per-year spatially homogeneous percolation rate [based on Wilson *et al.* (1994) and Wescott *et al.* (1995)]; a cross-sectional area, perpendicular to the infiltration path, of approximately 10 square meters/waste package; a payload of 10 MTU/waste package (TRW Environmental Safety Systems, Inc., 1994); and a package areal density of one waste package per 500 square meters (corresponding to an 80-MTU/acre areal mass loading[8]). Both the spent fuel repository and the hypothetical ore body contain 63,000 MTU, which is consistent with current designs for the proposed repository (*Op cit.*). The percentage of percolating ground water available for contacting the waste is the ratio of the cross-sectional area of all the waste packages compared with the total repository footprint area (approximately 1 percent). The percentage of waste packages contacted is based on the ratio of the area of a single waste package to that surface area necessary to

[7]The geologic repository design described in TRW Environmental Safety Systems, Inc. (1994) and assumed for this NUREG is the reference design found in the 1988 SCP. However, in 1997, DOE announced plans to change both the size and geometry of the repository footprint (see DOE, 1997a; pp. ES–15 – ES–15). These changes were subsequently described in the *Reference Design Description for a Geologic Repository* (DOE, 1997b; p 13). The size of DOE's revised repository footprint is now reported to be 3 square kilometers (300 hectares). This change is not believed to fundamentally change the conclusions of any of the analyses described in this NUREG.

[8]80 MTU/acre are used in this NUREG for easy comparison with DOE's 1988 SCP.

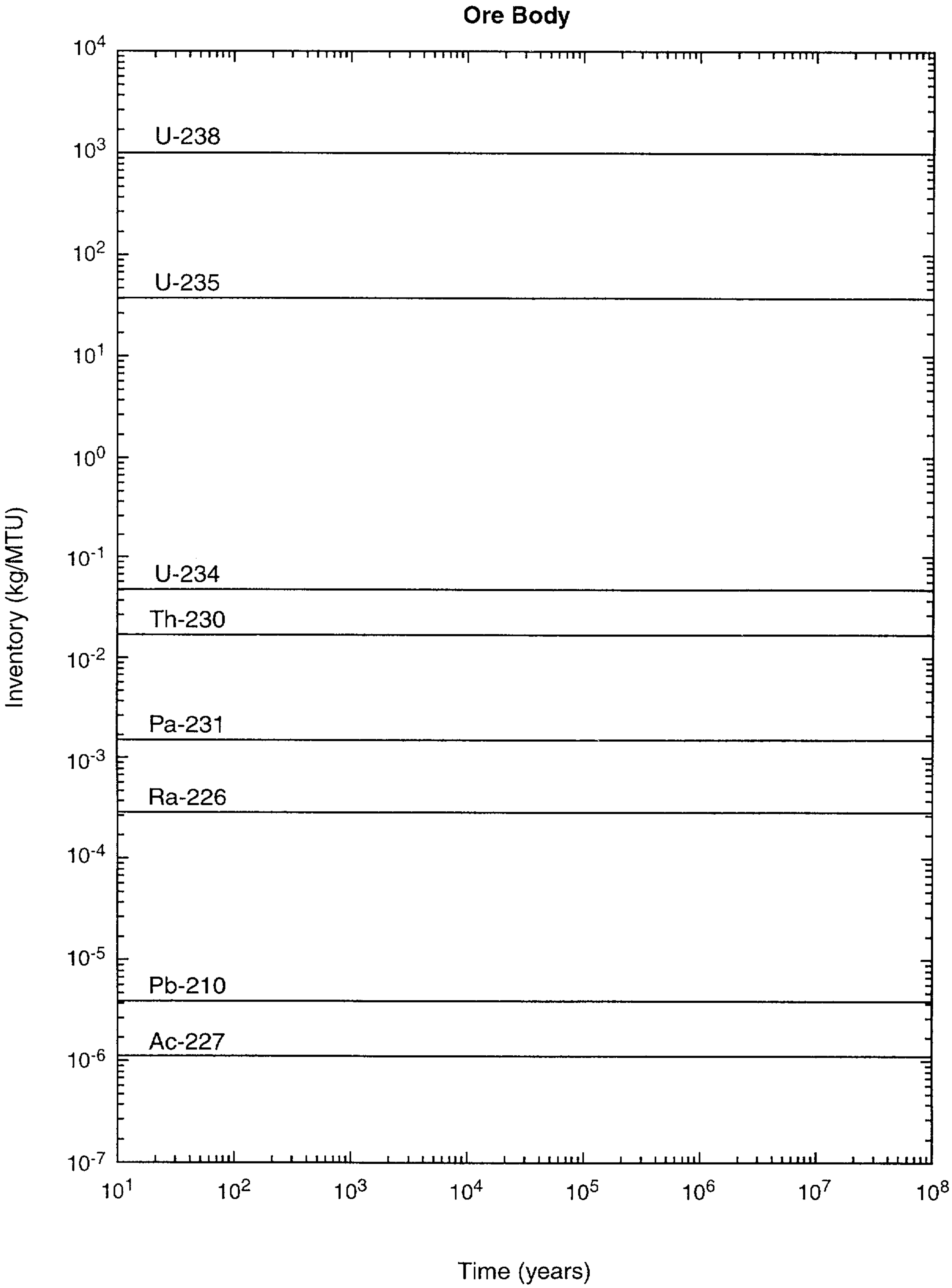

Figure 6–3. Radionuclide inventory of the hypothetical ore body.

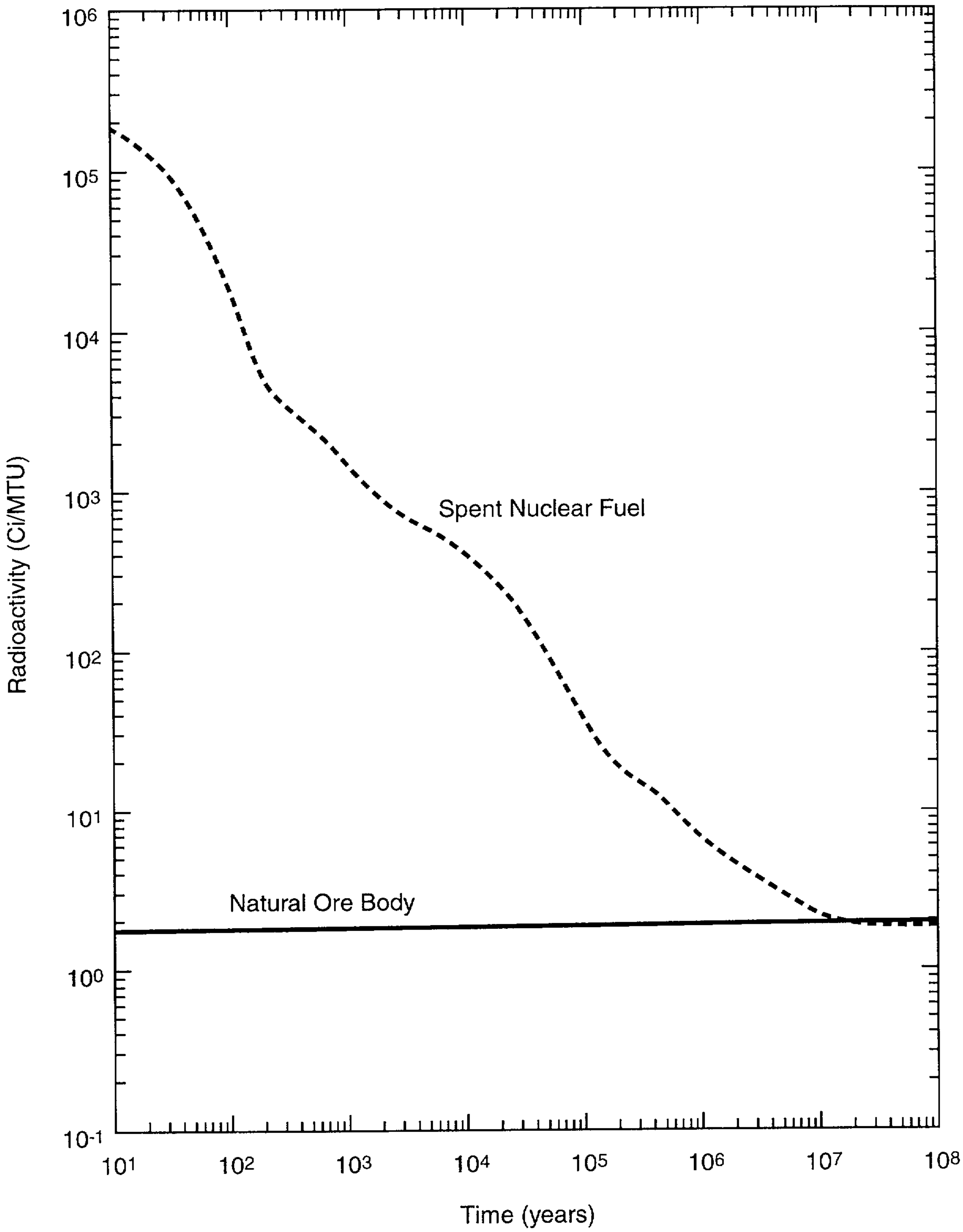

Figure 6–4. Comparison of radioactivity between the spent fuel repository and the hypothetical ore body.

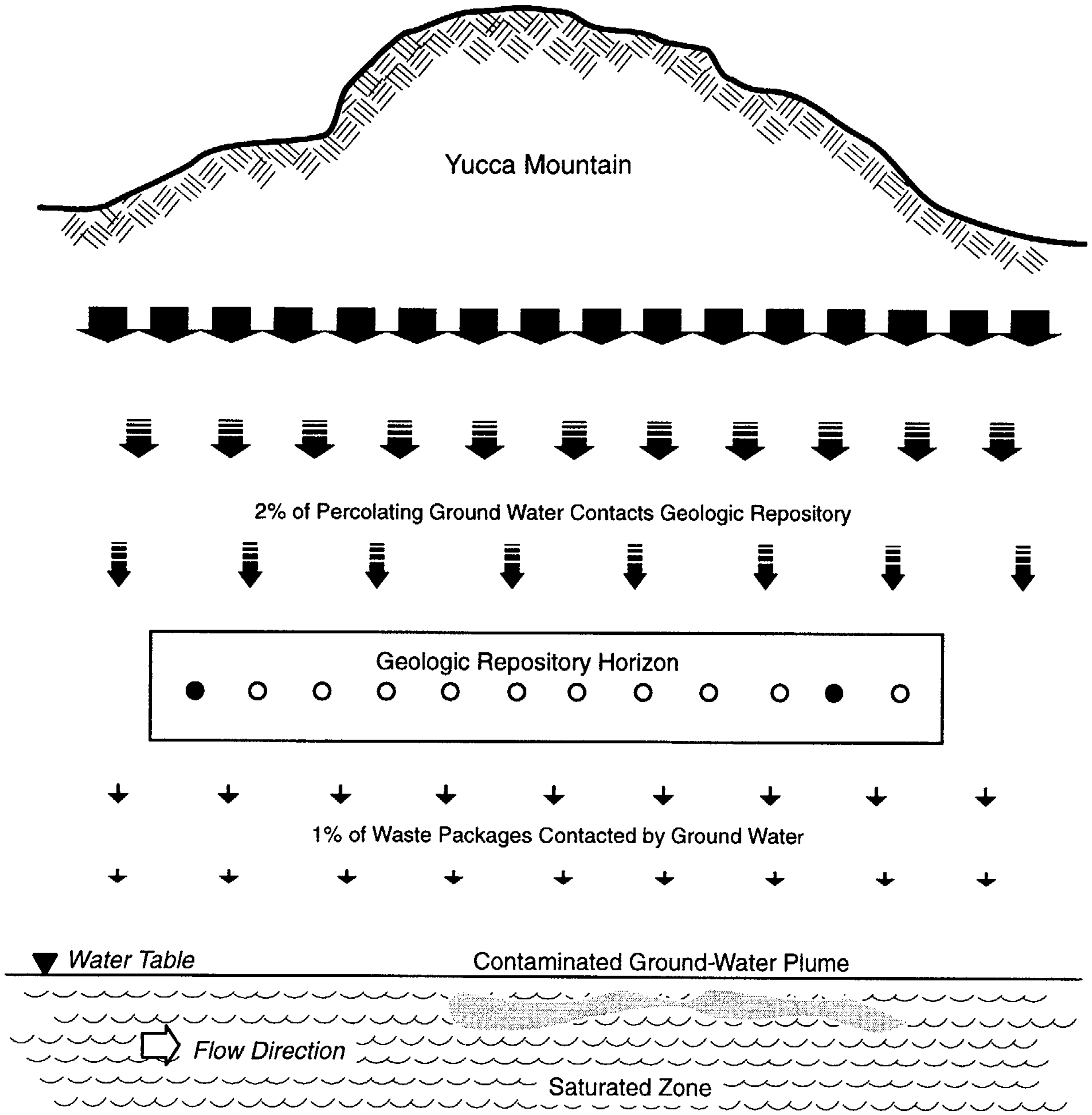

Figure 6–5. Drinking water dose model. Illustration shows ground water percolating through Yucca Mountain, 2 percent of which reaches waste emplacement horizon and contacts 1 percent of the waste package canisters. Subsequently, the radioactive leachate continues to percolate downward until it reaches the water table.

funnel water, to sustain dripping. Sustained dripping is estimated to require a focusing from a 1000-square-meter area above the waste package. Therefore, the ratio of the two areas results in 1 percent of the waste packages experiencing dripping. To be consistent, these same assumptions are used for the hypothetical ore body.

The *drinking water pathway dose conversion factors* (DCF_{dw} s)—assuming a drinking rate of two liters per day—and solubilities of the radionuclides, with associated uncertainties, are summarized in Table 6–1. The DCF_{dw} s are based on a drinking water pathway being the sole means of exposure, and the *ingestion dose conversion factors* (DCFs) used to calculate the DCF_{dw} s are taken from EPA (1988) and DOE (1988). The solubilities are based largely on earlier work contained in Wilson *et al.* (1994) and Wescott *et al.* (1995), and are uncertain because of limited knowledge of the behavior of nuclides (especially actinides) and uncertain geochemical conditions. The same ranges of solubility, which include the associated uncertainties, are used for calculations of both the spent fuel repository and the hypothetical ore body.

Figure 6–6 shows the relative radiological hazard that is the ratio of the doses received by drinking ground water contaminated by the spent fuel repository, and contaminated by a hypothetical ore body. What this figure shows is that a ratio greater than one corresponds to the spent fuel repository being a greater hazard than the hypothetical ore body. The ratio of drinking water doses is not affected by dilution because the dilution volumes are the same for the spent fuel repository and the hypothetical ore body. Sorption of radionuclides is neglected, which may affect the relative hazard. Mean values for radionuclide solubilities and bulk waste dissolution (release) rate were used to generate Figure 6–6. The radiological hazard is dominated by strontium and cesium up to 100–200 years; by plutonium and americium up to 20,000 years; and by neptunium and uranium daughter products beyond 20,000 years. The plateaus in some of the radionuclide dose curves are caused by the solubility-limited release of the radionuclide. Plutonium and americium have relatively low solubilities and hence are solubility-limited. Other radionuclides (technetium, iodine), which are highly soluble, represent a hazard that is controlled by release rate. The maximum release rate that was assumed for generating Figure 6–7 was 1 part in 100,000 of the current inventory per year based on previous staff work (Wescott *et al.*, 1995). The relative hazard is based on a ratio of doses calculated as follows:

$$\frac{D_{dw,rep}}{D_{dw,ob}} = \frac{\sum_i DCF_i \ \min(sol_{i,rep} \times F_g \times A_i,\ R_{i,rep} \times F_w \times \frac{I_{i,rep}}{Q})}{\sum_i DCF_i \ \min(sol_{i,ob} \times F_g \times A_i,\ R_{i,ob} \times F_w \times \frac{I_{i,ob}}{Q})} \tag{6-1}$$

where:

$D_{dw,rep}$ = dose from drinking ground water contaminated by the spent fuel repository–***rep*** (rem/year);

$D_{dw,ob}$ = dose from drinking ground water contaminated by the hypothetical ore body–***ob*** (rem/year);

DCF_i = *DCF* from drinking ground water contaminated by the i^{th} radionuclide [(rem/year)/(Ci/liter)];

sol_i = solubility of the i^{th} radionuclide in the spent fuel repository or the hypothetical ore body (mol/liter);

A_i = activity of the i^{th} radionuclide (Ci/mol);

F_g = fraction of seeping ground water that becomes contaminated (2 percent);

F_w = fraction of inventory contacted by seeping ground water (1 percent);

Table 6-1. Solubilities and Dose Conversion Factors for the 43 Radionuclides Used in the Relative Hazards Scoping Calculation.

Nuclide	*Common Logarithm of Solubility* [a] *(mol/L)*	*Drinking Water Dose Conversion Factors* [b] *(rem/year/Ci/m³)*
^{238}U	-5.3 ± 1	1.68×10^6
^{246}Cm	-5.3 ± 1	3.29×10^7
^{242}Pu	-8.5 ± 2	2.99×10^7
^{242m}Am	-10.0 ± 2	3.07×10^7
^{238}Pu	-10.0 ± 2	2.77×10^7
^{234}U	−5.3 ± 1	1.90×10^6
^{230}Th	−8.0 ± 2	3.87×10^6
^{226}Ra	−7.0 ± 2	8.03×10^6
^{210}Pb	−6.0 ± 1	3.72×10^7
^{243}Cm	−5.3 ± 1	2.12×10^7
^{243}Am	−8.5 ± 2	3.29×10^7
^{239}Pu	−10.0 ± 2	3.14×10^7
^{235}U	−5.3 ± 1	1.83×10^6
^{231}Pa	−7.0 ± 2	8.03×10^7
^{227}Ac	−10.0 ± 2	1.02×10^8
^{245}Cm	−8.5 ± 2	3.29×10^7
^{241}Pu	−10.0 ± 2	6.28×10^5
^{241}Am	−8.5 ± 2	3.29×10^7
^{237}Np	−3.7 ± 1	2.85×10^7
^{233}U	−5.3 ± 1	1.97×10^6
^{229}Th	−8.0 ± 2	2.56×10^7
^{244}Cm	−8.5 ± 2	1.68×10^7
^{240}Pu	−10.0 ± 2	3.14×10^7
^{236}U	−5.3 ± 1	1.83×10^6
^{232}U	−5.3 ± 1	9.49×10^6
^{151}Sm	−10.0 ± 2	2.48×10^3
^{137}Cs	Large [c]	3.65×10^5
^{135}Cs	Large	5.18×10^4
^{129}I	Large	2.04×10^6
^{126}Sn	−7.3 ± 2	1.24×10^5
^{121m}Sn	−7.3 ± 2	9.49×10^3
^{108m}Ag	−10.0 ± 2	5.48×10^4
^{107}Pd	−6.0 ± 1	1.02×10^3
^{99}Tc	Large	9.49×10^3
^{93}Mo	−6.0 ± 1	9.49×10^3
^{94}Nb	−8.0 ± 2	3.72×10^4
^{93}Zr	−9.0 ± 2	1.17×10^4
^{90}Sr	−3.7 ± 1	9.49×10^5
^{79}Se	Large	6.06×10^4
^{63}Ni	−2.7 ± 1	3.94×10^3
^{59}Ni	−2.7 ± 1	1.46×10^3
^{36}Cl	Large	2.19×10^4
^{14}C	Large	1.53×10^4

[a] Based on Wilson *et al.* (1994) and Wescott *et al.* (1995).
[b] Based on EPA (1988); and DOE (1988).
[c] Highly soluble radionuclides are release-rate-constrained.

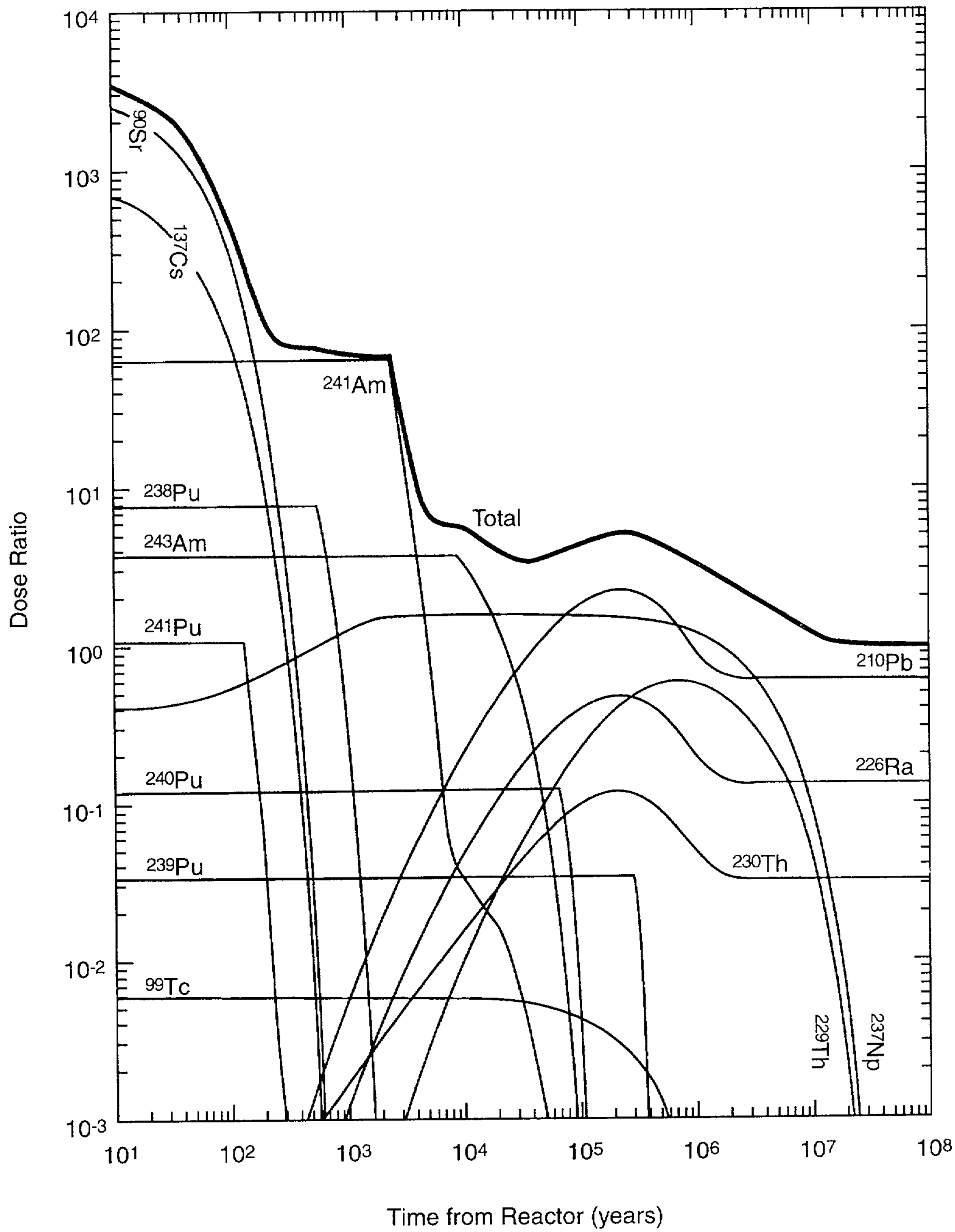

Figure 6–6. Relative radiological hazard of SNF calculated as the ratio of doses from drinking ground water contaminated by the spent fuel repository and by the hypothetical ore body.

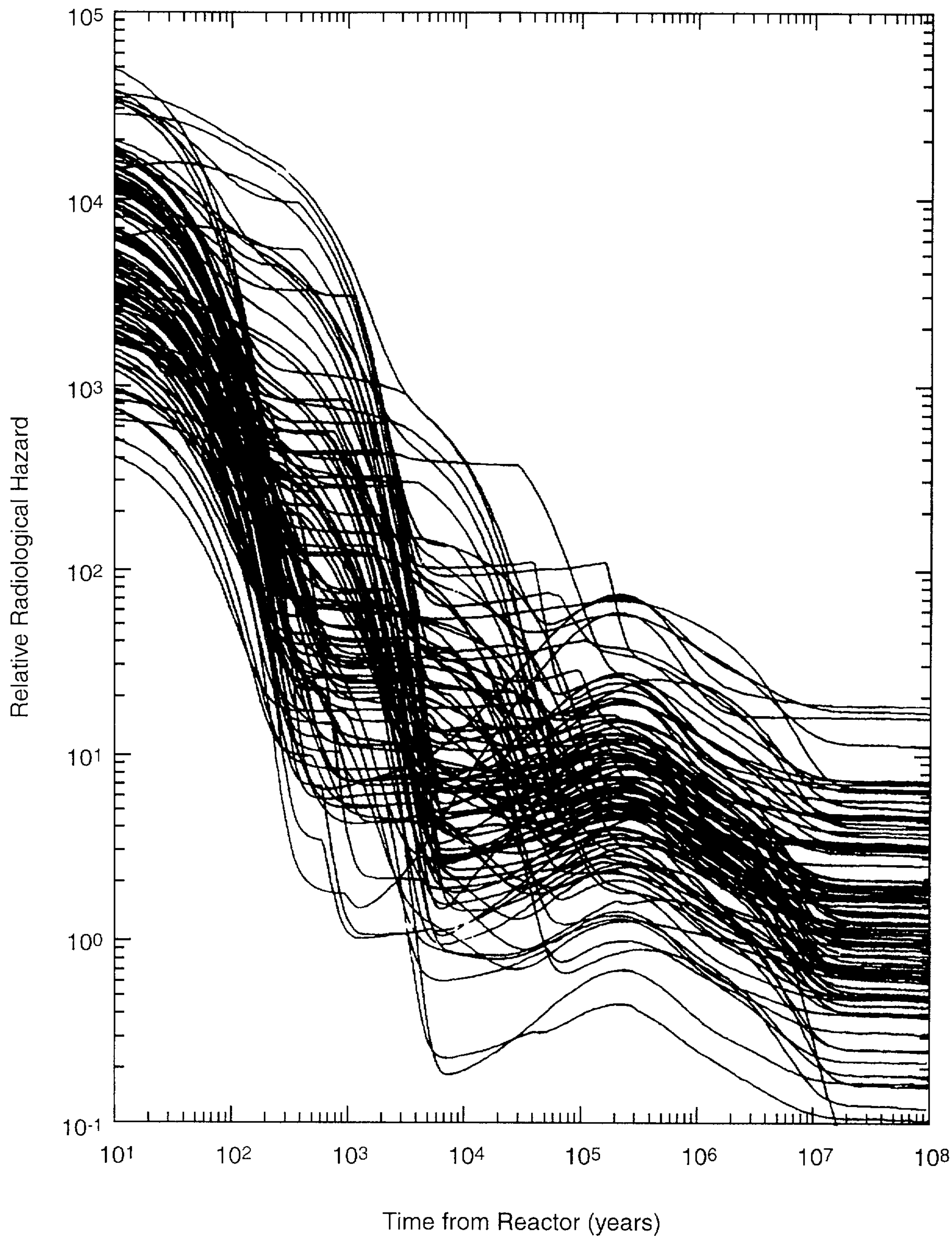

Figure 6-7. Comparison of hazards accounting for uncertainties in radionuclide solubilities and release rates.

R_i = maximum release rate for the i^{th} radionuclide in the spent fuel repository or the hypothetical ore body (1/year);

I_i = total inventory of the i^{th} radionuclide in 63,000 MTU of SNF or a hypothetical uranium ore body (Ci); and

Q = volumetric flow rate of ground water flowing past the repository (liters/year).

By comparing Figures 6–1 and 6–6, one concludes that total radioactivity roughly correlates with radiological hazard. The radiological hazard and total radioactivity are highest during the first 1000 years. In general, the hazard of a radionuclide is significantly diminished if it has a relatively low solubility in water or a low-ingestion DCF.

Figure 6–7 shows the range of relative radiological hazard from uncertainties in radionuclide solubilities and release rates. For both the spent fuel repository and the hypothetical ore body, 100 distinct estimates have been generated by lognormally sampling the radionuclide solubilities and release rate. [The common logarithm of the release rate was assumed to be -5 with a standard error of one-half, based on previous staff work (see Wescott *et al.,* 1995).] If one draws a horizontal line on Figure 6–7 at a relative hazard equal to 1, it can be observed that none of the 100 realizations crosses below the line before 1000 years, and half of the lines cross below, before about 10 million years. Before 1000 years, the spent fuel repository is distinctly more hazardous than the hypothetical ore body. Beyond 10 million years, there is a negligible difference between the spent fuel repository and the hypothetical ore body.

6.4 Assumptions and Limitations

The assumptions and limitations were discussed throughout this work as the analysis was described, but are summarized below for convenience:

- The only radiological hazard considered is drinking contaminated ground water.
- Ground water percolates through a 5-square-kilometer repository area at a rate of 1 millimeter/year such that 2 percent of the ground water contacts 1 percent of the waste, thereby becoming contaminated to the maximum extent reasonable (either solubility-limited or release-rate-limited).
- Radionuclide solubilities and release rates (for highly soluble elements) are assumed to be the same for the spent fuel repository and the hypothetical ore body. The geochemical conditions in and around a naturally occurring uranium ore body could be quite different from the conditions representative of Yucca Mountain assumed in this analysis. Therefore, the hypothetical ore body hazard suggested by this analysis may not be representative of the hazard posed by a naturally occurring ore body.
- The hypothetical ore body contains the same quantity of uranium as the pre-irradiation nuclear fuel, as well as the decay daughters of the uranium in equilibrium.
- The contamination of the ground water by the hypothetical ore body is the same as for the spent fuel repository. The primary difference is that SNF has radioactive fission and activation products that are not present in a naturally occurring ore body.

6.5 Summary and Conclusions

The relative radiological hazard of the spent fuel repository is initially about 4 orders of magnitude greater than that of the hypothetical ore body. The hazard diminishes most rapidly over the first few hundred to a few thousand years. Beyond about 10,000 years, the radiological hazard diminishes less rapidly. The apparent increase in hazard at 100,000 to 500,000 years is from the ingrowth of radionuclides such as ^{230}Th, ^{229}Th, ^{226}Ra, and ^{210}Pb, as observed in Figure 6–2. By 10,000 years the relative hazard will have

decreased by 99.9 percent and be within less than an order of magnitude of the hypothetical ore body. A time period of interest for regulation of a proposed repository of 10,000 years would, therefore, focus attention on the time period when the waste has a significant man-made hazard component that is readily discernable from an equivalent hypothetical ore body, after considering uncertainties associated only with solubilities and release rates.

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APPENDIX A

OVERVIEW OF FARMING AND RANCHING ACTIVITIES IN THE YUCCA MOUNTAIN AREA

A–1 INTRODUCTION

In characterizing the lifestyles and habits of potential receptor groups in the Yucca Mountain area, it will be necessary to consider, among other things, the extent to which agriculture and ranching takes place down-gradient from a geologic repository because of the potential importance of the food-ingestion pathway to dose to humans [see Neel ("Dose-Assessment Module") in Wescott *et al.* (1995)].[1] As noted in Section 2.1 of the main report, the largest population centers down-gradient from the potential repository are the rural communities in the Amargosa Desert, located south of State Highway 95. Most, if not all of these communities rely on private wells for their water supply.

The first two sections of this overview briefly review the types of farming and ranching practices in this portion of the State. The principal sources for this compilation include the State of Nevada/University of Nevada (1974); the U.S. Department of Energy (DOE)(1986); TRW Environmental Safety Systems, Inc. (1995); LaPlante *et al.* (1995); Raines (1996); and Eisenberg (1996). This compilation was also supplemented through an interview and subsequent dialogs with a knowledgeable local resident (Kenneth G. Garey[2]). Because of the exclusive reliance on ground water in these areas, the last section of this overview includes a discussion of some of the issues that affect its availability. It was prepared with the assistance of knowledgeable individuals at both the State and Federal levels.

In reviewing this information, the reader is reminded that the Yucca Mountain area is comprised of several small rural communities, some of them so-called "commuter or bedroom" communities. Most of the activities described below, therefore, do not represent the major industry of southern Nevada.[3] In the past, most farms and ranches were operated on a part-time basis, with the owner working full-time in another occupation (DOE, 1986; p. 3–103); this practice is still believed to be the case in most situations.[4] Nonetheless, farming and ranching are important to the local economy and to the diets of individual households, to varying degrees. Most of these activities rely on alluvial ground water for their water supply. Moreover, some of these activities have other linkages to each other, as discussed below.

A–2 FARMING

There are practical limitations on the types of agriculture that can take place in the Amargosa Desert and Pahrump Valley

[1]As discussed later in this NUREG (see Appendix B), mining played a key role in the early development of southern Nevada, including the Amargosa Desert. Although not discussed in any detail here, it should be noted that the mining of specialty clays (by IMV Floridin), calcium borate (borax—by the American Borate Company), gold (by St. Joe Bullfrog), and fluorspar (fluorite), today, in the southern reaches of the area, continues to make these companies important local employers as well as major consumers of ground water (see Table 2–7).

[2]In addition to being the operator of the *Bar-B-Q Ranch* (Amargosa Valley), Mr. Garey was also the Amargosa Center on-site representative for the Community Radiation Monitoring Program (CRMP), at the time of the first interview. The CRMP, sponsored by DOE, is a cooperative project among DOE, the U.S. Environmental Protection Agency, the Desert Research Institute (Nevada), and the University of Utah (see Black *et al.*, 1995).

[3]Moreover, today, there are a number of other commercial and recreational activities that support the local economies of these two areas. Information on most of these businesses—convenience stores, gas stations, restaurants, and the like—can be obtained from the Chamber of Commerce in the area, as well as from directories published in local newspapers such as *The Amargosa News* or *The Pahrump Valley Gazette*.

Also noteworthy in the Amargosa Desert area is the Longstreet Inn and Casino. Opened in April 1996, this 60-room hotel is located on State Highway 373 at the Nevada-California State line. This hotel has a capacity of 300 guests, as well as having a recreational-vehicle trailer park with hook-ups (spaces) for 120 vehicles. An 18-hole golf course was under construction at the time this *Overview* was being prepared.

[4]Personal communication, K. Garey, *Bar-B-Q Ranch* (Amargosa Valley), May 1996.

because of local soil conditions,[5] the length of the freeze-free season, and other meteorological factors. These factors limit the types and amounts of crops that can be grown in southern Nevada. Under irrigation, only hardy to moderately hardy crops adapted to the region are grown. The growing season is about 200 days [see Bedinger *et al.* (1985; Table 8, p. G32) and Sakamoto *et al.* (1973)]. Late frosts can be a problem. Trees usually bud in February, but there usually is a killing frost every one in four years, in March.

The principal agricultural crop in the Amargosa Desert and Pahrump Valley areas is alfalfa. The long growing season in the area permits about seven cuttings per year. Irrigation rigs are either rotary or wheel lines. However, because of its low nutritional content (e.g., total digestible nutrients or TDNs), most of the crop is destined for markets outside of southern Nevada; no more than 10 percent of the crop is believed to be used locally.[6] Some percentage of the local crop is exported to markets in Japan. Other agricultural products grown in the area include grain; barley; oats; hay (including hayfine); and cotton (about 800 hectares in Pahrump Valley, only). However, these crops are believed to represent a smaller proportion of all total agricultural output for the area. The principal irrigation methods are center-pivot or furrow. Winter temperatures are generally too low for the commercial production of winter vegetables.

Many Amargosa Desert-Pahrump Valley residents maintain "kitchen" gardens. It is estimated that at least 50 percent of the residents in the area maintain some form of garden (or orchard) that provides more than two dozen fruits, nuts, and vegetables—see Table A–1. (Some residents in Pahrump Valley are reported to maintain bee colonies for honey production.) Most of the products grown are shared, sold, or bartered among the local residents, although two households are reported to have commercial operations. Commercial operations are believed to not be more widespread owing to problems in entering the local markets—Las Vegas or Los Angeles (see McCracken, 1990; pp. 82–83). The magnitude of personal home-garden consumption in the area is difficult to estimate—it is generally believed to be about 10 percent[7]—although no resident is understood to subsist solely off of his or her garden. Most residents still purchase the majority of their food stuffs at local grocery stores and use the home-grown produce to supplement their diets.

A third type of agricultural activity reported in the area is the turf farm in the community of Amargosa Valley, adjacent to a dairy. Finally, "Bermuda grass and fescue" are grown for the landscaping market in the greater Las Vegas area.

All of the activities described above rely on some degree of pre-treatment of the soils—with manure, fertilizers, acidifiers, etc.—to allow these crops to grow. What agricultural activities do exist are confined chiefly to the centers of the valley; exposed bedrock along the margin of the basins is generally unsuitable for the practice of agriculture—because of the topography (slope), thin soil veneer, and low moisture-holding capacity. Soils within the alluvial basins are medium- to fine-textured with somewhat higher-moisture holding capacities. However, the high evapotranspiration (ET) rates[8] results in a soil chemistry that is highly alkaline. Moreover, hardpan (pedogenic carbonate or *caliché*) exists extensively throughout the area and presents an additional limitation for agricultural use. As a consequence, based on information prepared by the State Engineers Office/University of Nevada, it is estimated that at least 60 percent of the soils in the

[5]Most of the soils in the Yucca Mountain area are gravelly and coarse textured with low inherent fertility and low waterholding capacity. Consequently, they have been classified as having properties that "...preclude their use for irrigated agriculture..." or "...have severe limitations that reduce [the] choice of crops or require special conservation practices or both...." (State of Nevada, 1974)

[6]Personal communication, K. Garey, *Bar-B-Q Ranch* (Amargosa Valley), May 1996.

[7]Personal consumption could be as high as 30 percent [personal communication, J. Gauthier, DOE Management and Operating Contractor (SPECTRA Research Institute), July 1997].

[8]Due to low humidity (30 to 40 percent), abundant sunshine, and light to moderate winds, ET in this area may exceed 120 inches of pan evaporation (French *et al.*, 1981; p. 32).

Table A–1. Produce Grown in the Amargosa Desert-Pahrump Valley Areas. Compiled from various sources cited in this appendix.		
Fruits and Vegetables		
Beets Broccoli Brussel Sprouts Cabbage Cantaloupes Carrots Cauliflower Corn Garlic	Kohlrabi Lettuce (Head and Loose Leaf) Okra Onions Peppers (Chili, Sweet, Banana, and Bell) Potatoes	Pumpkins Radishes Squash (summer and winter varieties) Tomatoes Turnips Watermelon Zucchini
Fruit Trees		
Apple Apricot Cherry Grapes (Vineyard)*	Fig Nectarines Peach Peanuts	Pear Plum Pomegranate
Nut Trees		
Almond	Pecan	Pistachio
* Including Zinfandel, California Red, Thompson Seedless, and Concord.		

Table A–2. Area Tabulation of Soil Irrigability Class in the Amargosa Desert-Pahrump Valley Areas. Taken from the State of Nevada/University of Nevada (1974; See separate plate in back of report).

Hydrographic Basin	*Soil Irrigability Class (in hectares, described below)*					*TOTAL*
	A	*B*	*C*	*D*	*E*	
Pahrump Valley	6070	1214	4856	3844	188,364	204,348
Amargosa Valley	0	3035	64,326	23,876	140,806	232,043
AREA TOTAL	6070	4249	69,182	27,720	329,170	436,391

EXPLANATION

Class A Soils that have slight or few limitations that restrict their use for irrigated agriculture.

Class B Soils that have moderate limitations that reduce the choice of crops grown or require moderate conservation practices.

Class C Soils that have severe limitations that reduce the choice of crops grown or require moderate conservation practices, or both.

Class D Soils that have very severe limitations that restrict the choice of crops grown or require special practices and management, or both.

Class E Soils that have properties that preclude their use for irrigated agriculture.

Amargosa Desert hydrographic subbasin are not considered irrigable; an additional 28 percent of the soils are classified "severely limited to very severely limited" in their ability to sustain some type of cultivation (see Table A–2).

A–3 RANCHING

In recent years, dairy farms have proven to be the major livestock activity in the area. Two dairy farms operate in Amargosa Desert and Pahrump Valley. The production capacity at the dairy in Pahrump Valley is about 2500 head; in the community of Amargosa Valley, there were about 3300 head in 1996, although the dairy is reported to have a capacity of about 5000 head. All raw dairy products are believed to be destined for processing facilities in southern California. Although the dairies provide local farmers with a dedicated market for a portion of their alfalfa crop, because of the need for livestock feed with a high TDN, most of the feed comes from outside of the County—principally California, Utah, and Lincoln County (Nevada).

Another activity in the area is a commercial catfish farm. Surplus catfish fry are purchased by the State's Department of Conservation and Natural Resources to stock lakes and other waterways throughout the State.

There is some beef cattle ranching in the county but it takes place principally to the north of the Nevada Test Site (NTS), where there is more (and better) natural forage. However, there are a few range cattle in the area (estimated to be less than 100), as well as some lesser numbers of pigs, goats, sheep, chickens, rabbits, and ostriches. The pig, sheep, and ostriches were introduced into the area in the early 1990s; these operations are understood to be commercial. The other stock is raised for local/private consumption. Almost all of these activities rely on the locally produced alfalfa and grains to feed the stock.

A–4 GROUND WATER

Because of the arid climate, there appears to have been an early interest in both the development and conservation of ground water within the State (Maxey and Jamison, 1948; pp. 4–12). The only reliable sources of water historically have been the numerous springs, weeps, and seeps (*Op cit.*) and ground water, to the extent it was accessible. Rapid growth and unregulated use of ground water in the 1920s and 1930s in the greater Las Vegas area resulted in increased withdrawal of water from local aquifers and decreased yields from wells and springs. In 1938, the State Engineer's office became actively involved in the evaluation of ground-water resources (*Op cit.*, pp. 7–8), which resulted in a comprehensive and systematic evaluation of ground water within the State. In an effort to conserve the resource, curtail wasteful practices, and protect legitimate water rights, the Nevada State Legislature approved the *Comprehensive Underground Water Act of 1939* (see Shamberger, 1991; pp. 57–58). This act declares that all underground (ground water) water within the boundaries of the State belongs to the public. To ensure beneficial use of the resource, the Office of the State Engineer was empowered with the authority to regulate ground-water use, through "appropriation" or permitting [see Morros (1982, p. 20545); and State of Nevada (1982, pp. 79–83)]. (Also see French *et al.* (1981) for more discussion of this history.)

Walker and Eakin (1963, pp. 37–38) provide a brief history of the development of ground water in the area. The first reported water well in the area was dug 1852, to support the boundary survey of the California- Nevada State line (Mendenhall, 1909; pp. 36–37). Other wells were subsequently developed around the turn-of-the century to support railroad construction and operation (the *Tonopah and Tidewater,* and *Las Vegas and Tonopah* lines) and mining activities (see Myrick, 1992). The first reported irrigation well in the Amargosa Desert area was reported to have been drilled in 1917 (Walker and Eakin, 1963; p. 37).

Before electrification of the Amargosa Desert area in the early 1960s, the ground-water potential was generally under-developed and as a consequence, there was limited farming and ranching. For example, the number of pre-electrification wells in the Amargosa

Desert area was about 160 (Walker and Eakin, 1963; Table 3). (Before electrification, electric power was typically provided by diesel generators.) Since then, the number of wells has grown by about 25 percent. In DOE's *1986 Environmental Assessment* for NTS, 207 domestic wells were reported, citing State of Nevada data (DOE, 1986; p. 3–85).

The maximum amount of ground water that can be appropriated from a given hydrogeologic basin in Nevada is limited to its perennial or *safe yield*.[9] For each of the hydrologic basins in the State, the State Engineer has estimated the perennial yield, relying on assessments prepared cooperatively by Nevada's Division of Water Resources and the U.S. Geological Survey. When ground-water withdrawals exceed recharge, overdrafting or water-mining can occur. Overdrafting of ground water produces a number of undesirable effects on ranching and farming interests; the most significant is the depletion of the existing ground-water resource because overdrafted water comes from storage. Additional undesirable effects would include deteriorating water quality, well interference, and land subsidence—each of which is problematic from a cost perspective. At present, over-appropriation is prohibited by the State (see Morros, 1982, pp. 20467–20557).

All water use in Nevada is regulated by the Office of the State Engineer in the Division of Water Resources.[10] At present, the maximum permissible water use allowed in southern Nevada, based on the State's perennial yield philosophy, is as follows: residential/domestic use—6.8 cubic meters/day (1800 gallons/day) per single-family unit (State of Nevada, 1982; p. 79) and only one well per household; and agricultural/ranching: 4900 to 6200 cubic meters/year (4 to 5 acre-feet per year).[11] However, it is generally recognized that there is "overdrafting" (e.g., mining or over appropriation) of the aquifers, throughout a large portion of southern Nevada (Harrill, 1986; Plume, 1989; Morgan and Dittinger, 1996), which is believed to have led to some restrictions on development. In instances where it is believed that ground-water withdrawals could exceed ground-water recharge, the State Engineer may designate a ground-water basin (or any portion thereof) as a "designated basin." "Designation" is a means of protecting basins from over-use by restricting the issuance of permits in that area.

Rapid growth in southern Nevada during the last half-century has resulted in an increased demand for potable water. As a result, there have been documented overdrafts throughout the region (Maxey and Jameson, 1948; Malmberg, 1967; Nichols and Akers, 1985; Harrill, 1986; Morgan and Dettinger, 1996). These overdrafts have continued for several decades despite being prohibited by State law. Traditionally, supply-side solutions—such as dams and canals—have been used to meet the growing water needs in the West (Reisner, 1993); today, such solutions may have become prohibitively expensive (Frederick *et al.*, 1996). In a 1992 report prepared for the State of Nevada, it was noted that the greater Las Vegas area would most likely need to adopt a regional solution to its potable water problem (Water Resources Management, Inc., 1992; p. 21). Inasmuch as Nevada already relies on its full allocation from the Colorado River, such solutions may include acquiring unallocated ground water in the valleys of the greater Las Vegas region (Basse, 1990; p 24), which would include Amargosa Desert and Pahrump Valley areas. Such was the case recently in the Amargosa Desert area when a private concern petitioned the State Engineer to initiate forfeiture proceedings to acquire unused water rights (Buqo, 1997; p. 30).

Because there have been overdrafts, both the Amargosa and Pahrump Valley basins are currently listed as "designated basins" (State

[9]The State Engineer applies the "safe-yield" philosophy to the allocation of ground water in Nevada. "Safe yield" is a term of art and is generally regarded as the amount of water that can be pumped from an aquifer, on a sustained annual basis, without depleting the reserve or impacting existing legal rights. Any withdrawal in excess of the safe yield can be considered an "overdraft" (Freeze and Cherry, 1979; p. 364).

[10]Ground water is appropriated by the Nevada State Engineer in the manner described in *Water Supply Report 2* (State of Nevada, 1982; pp. 79–83).

[11]Personal communication, T. Gallagher, Nevada Division of Water Resources(Carson City), July 1997.

of Nevada, 1982; Table 29). One possible explanation for the overdrafts, generally, could be a limitation on the State's 1939 regulatory authority. Ground-water appropriations made before 1913, and used continuously since then, are not covered by the State Engineers 1939 authority. Thus, because there are unregulated ground-water rights in place, it is difficult to evaluate the total amount of ground water available for apportioning throughout the State (*Op cit.*, p. 80). (One of the more well-known examples of the impacts of overdrafting in southern Nevada was the incident involving the now-present Ash Meadows National Wildlife Refuge, in which reduced discharge to some springs in southern Nye County, in the late 1960s-early 1970s, resulted in the extinction of some late-Pleistocene ancestral fish and the endangering of others.[12])

For the Amargosa Desert and Pahrump Valley areas, it is believed that the initial ground-water resource assessments used for water budgeting were performed, respectively, by Walker and Eakin (1963) and Malmberg (1967), using the methodology described by Eakin *et al.* (1951). These initial assessments were limited to the first 30 meters of the aquifer. More recent assessments, relying on a greater thickness of the aquifer, may suggest more extensive ground-water resources than first thought (Harrill 1986; and Pal Consultants, 1995). However, despite years of extensive study, it is believed that there is significant uncertainty associated in estimating the ground-water budgets of basin deposits in Southern Nevada (Harrill, 1986; D'Agnese *et al.*,1997).

[12]Incorporated by Presidential Proclamation into the Death Valley National Monument in 1952, the 8950 hectares of spring-fed wetlands and alkaline desert uplands are located in the southern tip of the Amargosa Desert. Established as a wildlife refuge in 1984 and now managed by the U.S. Fish and Wildlife Service, the location provides a habitat for 24 unique flora and fauna; four kinds of fish; and one plant are currently listed as endangered.

There are about 50 permanent fresh-water springs and seeps that discharge into the refuge. Although this discharge area is geologically and hydrologically complex, it is believed that a series of poorly connected gravel, sand, and terrestrial limestone aquifers, supplied by Paleozoic carbonate rocks to the west, provide water to the refuge (Dudley and Larson, 1976). Development of well fields adjacent to Ash Meadows resulted in water-level declines that threatened the endangered Devil's Hole pupfish (*Cyprinodon diabolis*) and other species of the genus *Cyprinodon* found at the removed Devil's Hole Unit of the Death Valley National Monument. Since a 1976 U.S. Supreme Court decision (*Cappaert v. U.S.*), pumping in the Ash Meadows area has been permanently enjoined to prevent further water-level declines. After the Supreme Court decision, continuous monitoring revealed that the water level in the Devil's Hole sink-hole recovered to pre-pumping levels [Personal communication, T. Mayer, U.S. Fish and Wildlife Service (Portland, Oregon), July 1997].

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APPENDIX B

LIFESTYLES AND WATER-USE PRACTICES IN AND AROUND THE NEVADA TEST SITE BEFORE ITS ESTABLISHMENT: A PRELIMINARY EVALUATION

One of the issues that may have significant weight in defining a potential receptor group for Yucca Mountain performance assessments would be the nature of human activity within the current boundaries of the Nevada Test Site (NTS) before its withdraw from public use. Understanding what took place previously at the site may be valuable inasmuch as it may reflect the lifestyles that would be taking place today had NTS land not been withdrawn. Because of time constraints, the staff was not able to perform an extensive evaluation of the literature or conduct personal interviews to better understand what took place historically within NTS' boundaries. Based on a limited review of some literature, as well as some anecdotal staff knowledge,[1] it appears that limited mining, ranching, and homesteading took place within the current boundaries of NTS before its initial withdraw from public use by the War Department in the early 1940s and later, by the Atomic Energy Commission (AEC), in the 1950s.

As noted earlier in this NUREG, there are no perennial streams in the NTS area. Before development of the ground-water resource, the only reliable sources of water at NTS were the many springs and seeps, as well as a few *tanks*.[2] Cold springs and seeps are located sporadically but frequently throughout the area. Thordarson and Robinson (1971) reported that there were 754 springs within 161 kilometers of NTS. Most of the springs were reported to discharge 0.63 cubic meters/second (10 gallons/minute) or less (*Op cit.*, p. 16). In this portion of the arid southwest, springs are marked by an abundance of foliage (and wildlife—see Ball, 1907; pp. 23–24) when compared with their surroundings. The springs found in the area are typically of the *contact variety*—where a permeable rock overlies a rock of much lower permeability, such as a contact between the more permeable alluvial deposits and less permeable bedrock, or of the *depression variety*—in which ground water seeps into topographic depressions that are covered with a veneer of detrital material (usually gravel). The flow or discharge rate is seasonal, typically corresponding to the amount of precipitation in the previous months (*Op cit.*, p. 21) thereby suggesting that many of the weeps and springs possess juvenile, meteoric water. Tanks also occur in the Yucca Mountain area. They are impermeable, topographic depressions that form natural collection basins for precipitation and snow. The volume and quality of water in tanks typically decrease in the summer months. By August, many tanks in the area are dry and the water in others was scarcely drinkable (*Op cit.*). Playas occur within NTS (Yucca Flat, Frenchman Flat, Gold Flat, and Kawich Valley) and do collect surface-water run-off from periodic storms. Because the storms are infrequent and because the surface water typically evaporates within a few days or weeks, it has never been considered a reliable source of supply.

In historic times, the NTS area was occupied by Native Americans—the Western Shoshone and Southern Paiute. These peoples were nomadic, hunter-foragers and it is generally believed that they relied on the numerous springs for water as well as for the animals and vegetation they attracted and sustained. Ash Meadows, for example, covers approximately 163 square kilometers and contains more than 20 major springs. Ball (1907, pp. 22–23) notes that the placement of many of the early Indian trails in the area was influenced by the locations of the various springs and tanks, and

[1]When at the Lawrence Livermore National Laboratory, H.L. McKague was associated with the NTS from 1972 to 1993. P.T. Prestholt was the U.S. Nuclear Regulatory Commission's on-site licensing representative from 1984–92. Before that, he was stationed at Camp Desert Rock, in the 1950s, while serving in the U.S. Army Signal Corps. Mr. Prestholt later worked as an NTS geophysics contractor in the 1960s.

[2]Naturally occurring cisterns found in impervious rock.

the distance between these sites rarely exceeded 64 kilometers (40 miles—*Op cit.*).

Archeological investigation of the site shows evidence of the Southern Paiute culture in caches of artifacts (beads, pottery, etc.) at camp sites, rock shelters, or stone circles within NTS—but no architecture suggesting that the NTS area was ever permanently inhabited (see Worman, 1969). Close to Yucca Mountain itself, the terraces adjacent to Forty Mile Canyon contain abundant artifacts in the form of projectile points, blanks, and flakes (Worman, 1969; Pippin and Zerga, 1983). In general, most aboriginal groups were believed to reside in Ash Meadows, Indian Springs, Pahrump Springs, or along the Amargosa River (Steward, 1938). Ball's 1906 geologic reconnaissance map identifies an "Indian camp" within Oasis Valley, to the west of NTS. Steward does report that at least nine Shoshone family (or family groups) maintained winter camps within current NTS boundaries between 1875 and 1880 *(Op cit.*, pp. 93–99, 182–185) .

Before the 1800s, European exploration of southern Nevada appears to have been limited to along the Colorado River and to the vicinity of *Las Vegas Meadows* (with its great springs) through which passed the Old Spanish Trail, connecting Santa Fe (New Mexico) and San Gabriel (California). However, the 1849 California gold rush precipitated the great Western migration, and the search for immigration routes and natural resources. These events introduced the NTS area to the first-reported geographical survey and mapping by U.S. Army topographic engineer J.C. Frémont sometime in the mid 1840s (McCracken, 1992; pp. 6–14). Like most explorers in the southwest at that the time, Frémont followed the existing Indian and game trails, with their established sources of water supply, or looked for other recognized natural signs of water (i.e., phreatophytic vegetation and the presence of wildlife—see Ball, 1907; pp. 22–23) to maintain renewable supplies. Again, historical as well as archeological information suggests that the area was regularly traversed in the late 1840s, by emigrants in wagons on their way to California, who took advantage of these springs (see Worman, 1969; pp. 3, 5–8; and Pippin and Zerga, 1983; pp. 51–54, 66–68).

During the first 50 years of Statehood, before the First World War, Nevada's economy depended chiefly on mining (State of Nevada, 1964; p. 273). After the discovery of placer gold at Sutter's Mill (California) in 1848, the lure of mineral wealth opened the West up to exploration. However, it wasn't until 1855, after the discovery of the gold-silver bonanzas, that mining was reported to have begun in Nevada (*Op cit.*, p. 3). The state experienced extensive prospecting and exploration after the 1859 discovery of the Comstock lode, in Virginia City, by the backwash of miners and immigrants in search of new deposits following the playing-out of the California gold fields. Examination of *U.S. Geological Survey 7½ topographic quadrangle maps* for the NTS area shows many "dog holes" in the Calico Hills area, for example. Consequently, as new ore bodies were discovered, mining camps began to spring up. In areas for which there was no artesian water, flumes, tunnels, and pipelines were built (e.g., Shamberger, 1972), or water was hauled to serve the mining communities (see Ransome, 1907).[3]

Despite extensive prospecting within the site, most of the mining activity in the area took place outside of the current NTS boundaries—e.g., the Bare Mountain, Bullfrog (Rhyolite), Goldfield, and Johnnie Districts. However, a modest level of mining took place partially or wholly within NTS boundaries, but never at Yucca Mountain itself (Castor *et al.*, 1989; p. 5).[4] In Area 26, for example, mining was conducted in the Wahmonie District 1928 (see Hewett *et al.*, 1936). The silver-gold deposits there were mined-out in about 3 months. Although the district ultimately attracted a

[3]In 1907, it is reported that water was hauled to the mining community of Rawhide (Mineral County, Nevada), by the *Dead Horse Wells Water Company*, from wells about 13 kilometers (8 miles) outside of town. The haulage cost per barrel was $2.50 (Batchelor and Batchelor, 1998; p. 69) (In this example, a barrel is assumed to hold 31 gallons or 117 liters of water.) Using the 1998 consumer price index to adjust for inflation, that would be about $80.00/barrel, in current dollars (Personal communication, R. Turtil, Division of Waste Management, January 1999).

[4]Between 1987 and 1988, about 30 mining claims were staked at Yucca Mountain. In 1989, DOE purchased the rights to these claims (*Op cit.*).

population of about 1500, the literature suggests that the area was essentially abandoned by 1929. In Area 15, the Oak Spring (Tungsten) District can be found. It was discovered in 1937, followed by development and production in the 1940s (Kral, 1951); significant tungsten production did not begin until the 1950s. After 10 years of co-use during the period of atmospheric bomb testing, the principal mining claims (Climax and Crystal Mines) were acquired through routine condemnation procedures and closed in the early 1960s (see Energy Research and Development Administration, 1977; p. 2–11). Ball (1907, pp. 128–130) reported prospects being developed in the district for precious metals and polymetallics in 1905. Base metals, in the Groom (Lake) District (see Humphrey, 1945), were discovered about 1864; the district was surveyed until about 1915; principal mining was at the Sheahan Groom Mine from 1918–42, with limited mining until the early 1950s (Tschanz and Pampeyan, 1970; p. 148). A mercury mine at Mine Mountain (in Area 6) is also frequently reported to have operated; claim notices indicate exploration in the area in 1928 (Cornwall, 1972; p. 39).

In southern Nevada, there are at least 23 mining districts within 145 kilometers of NTS (see Kral, 1951). The abundant springs and tanks throughout the area influenced the location of thoroughfares between the mining camps and tent towns that developed within these districts—Indian trails evolving to wagon trails and later to finished "carriage" ways (see The Clason Map Company, 1907). As stagecoach and carriage travel became more commonplace, water stops along travel routes became a necessity for both draft animals and people. Before 1900, some relay stations were constructed at several spring locations within the site (see Table B–1) for the stage, freight, and mail lines that operated between southern California and Utah along what is believed to be the so-called "Emigrant Trail" (Long, 1950). Relay station construction frequently included improvements to the spring discharge points (Worman, 1969) but the use of these facilities for their intended purpose to be short-lived (no later than 1910—Pippin and Zerga, 1983; p. 54), probably because of fluctuations in mining activity in the area and the establishment of other more direct thoroughfares to the West. As a consequence, it is likely that some type of homesteading/ranching took place at these sites until the late 1930s, which included wild horse or mule herding, owing to the presence of corrals and barbed wire fence remnants. Mendenhall (1909, p. 21) recommended that travelers passing through the area carry adequate supplies of grain and hay for their horses because of inadequate forage at the lower elevations. It is likely that any ranching that took place occurred only at elevations above 1500 meters.[5] If ranching took place at lower elevations, it is likely that grain and hay were brought in from elsewhere because of the lack of suitable natural forage. Kit fox, mountain lion, bob cat, mule deer, pronghorn and bighorn sheep, and game birds are indigenous to the area, so it is also likely that some of the abandoned homestead sites also may have been used as lodges for hunting excursions.

Despite fluctuations in the U.S. economy through the 1920s and 1930s, the chief employer in southern Nevada continued to be mining. Several mining camps and communities continued to prosper (Beatty, Tonopah) because of the quality of the ores and the size of the deposits. However, as some mining districts became exhausted, new and richer districts were discovered. As a consequence, some mining camps and tent towns ceased to exist (e.g., Rhyolite: 1904–16; Johnnie: 1890s–1920s). These and other such locations are now regarded as ghost towns. In addition, there were a few small unrecorded prospect pits and claims located within current NTS boundaries, some of which have unreported production. They were worked or

[5]It should be noted that there is an extensive variety of vegetation throughout the site. However, the type of vegetation depends on elevation (temperature); slope; slope orientation; precipitation (climate); and soil properties [see Romney *et al.* (1973); and Beatley (1974, 1975).] In general, steep slopes, especially those that face south or west at NTS, generally have little or no vegetation. Desert scrub—mesquite, salt grass, greasewood, and rabbit brush—which makes poor livestock forage, can be found at elevations of less that 1500 meters. At elevations of 1500 meters and above, higher-density cover and better livestock forage—creosote bush, bur-sage, Mormon tea brush, barrel cactus, yucca, and juniper—can generally be found. At elevations of about 1800 meters and above, piñon pines, Joshua trees, and grasses begin to dominate.

staked before acquisition of the site by the government and were not economically viable. To facilitate commerce and trade among the respective mining communities as well as to haul away ore, railroad lines were introduced to the south and west of the site—the *Las Vegas and Tonopah* (Myrick, 1992; pp. 454–503) and the *Tonopah and Tidewater* (*Op cit.*, pp. 545–593); but no lines or spurs were constructed within NTS.[6] With the arrival of railroads, more abundant (and regular) sources of water had to be located and provided for steam locomotive boiler supply. The supply methods took various forms. Usually, railroad companies attempted to use surface water, from either streams or springs. When surface water wasn't available, railroad companies sometimes attempted to create springs by drilling into the sides of mountains, hoping to collect percolating surface water (Kraus, 1969), or dug or drilled wells. [See Baker *et al.* (1973) for descriptions of archetypical examples of early water supplies in several arid states.]

The increase in human activity in the area placed greater demands for water far above that which could be supplied by the natural springs and tanks. In general, water development practices were far from scientific. Overall, the intent was to discover artesian water (under hydraulic pressure or "head"). This is suggested by Mendenhall (1909), where it was noted that the location of early farming/ranching homesteads could be correlated with the occurrence of such springs. Mendenhall (1909, pp. 36–37) reports that the Franklin well was dug in 1852 for parties surveying the California-Nevada boundary line. Ball (1907, p. 21) reports that shallow wells were subsequently sunk in the gravel areas found in flats or gulches adjacent to the main travel routes and railroad alignments, to supplement the springs. Although these shallow wells were sufficient for human consumption and livestock, they were not sufficient for irrigation. The first irrigation well was sunk in the Amargosa Desert area at the *T and T Ranch* (T. 25 S., R. 48 E.) in 1917, to produce crops for the mining communities in Bullfrog and Beatty (Walker and Eakin, 1963; p. 37).[7] Water wells drilled at the ranch ranged in depth from 22 to 25 meters (McCracken, 1990; p. 45).

It is likely that the first wells in the area were hand-dug improvements of springs, followed later by wells sunk using various boring and drilling methods, as improved technologies became available. Before 1900, it is also likely that most water wells in the area were bored by hand-operated or power-driven augers following the drilling techniques practiced in the eastern United States (U.S.—see Carlston, 1943). After 1900, following the successful use of hydraulic rotary methods of drilling in the oil and gas industries, most wells in the area were probably developed using this new technique.[8] However, the water supplies developed using rotary drilling methods were usually only sufficient for a small livestock ranch but never quite adequate for farming or serving large communities because the means for raising the sufficient quantities of water to the surface were believed to not be generally available until the 1910s.[9]

There is no archeological evidence or reports of commercial farming having taken place within the confines of NTS. For the reasons described elsewhere in this NUREG (see Section 2.1 and Appendix A), commercial

[6]In addition to these mining activities, the excavation of industrial minerals/materials also played an important role in the development of the area: clay and peat—Ash Meadows; marble—Carrara; calcium borate (borax)—Death Valley junction area; specialty clays—Clay Camp area and New Discovery mine; and fluorspar—Daisy Mine(Bare Mountain District). See Papke (1979), McCracken (1992), and Myrick (1992).

[7]The *T and T Ranch* was a 4.5-hectare experimental farm and dairy owned and operated by the *Tonopah and Tidewater Railroad*. The goals of the experimental farm were twofold. First, because it was located on the existing right-of-way, it was operated to increase the profitability of this particular railroad line. Second, it was reasoned that if agricultural activity could be established in the area, the products could be transported on the railroad, thereby increasing the line's volume of commercial haulage (see McCracken, 1992; pp. 44–47).

[8]See Bowman (1911) and Tainsh and Churchfield (1978) for a review of drilling technology history.

[9]Before the introduction of electric versions of the centrifugal pump (in the 1910s), a bucket and rope was probably used to lift water to the surface (Wilson, 1896). After their development in the mid-1880s, it was demonstrated that centrifugal pumps were capable of lifting water against high and low head conditions, with good efficiency (Allen, 1958; p. 524). Once such pumps were demonstrated as a practical means for pumping water, designs were soon modified for mobility, driven initially by steam-, coal gas-, or oil-powered machines, and later, by gasoline and electricity (Hood, 1898; Bruce, 1958; p. 560).

farming has been limited to discrete locations outside of the site. Farming (and ranching) was first reported in the Ash Meadows area in the early 1870s, following the example of the Ash Meadows Paiute[10] (see McCracken, 1992; pp. 15–17). As noted earlier, the location of early farming/ranching homesteads can be correlated with the locations of major springs. Before the 1950s, the only reported inhabitants in the Amargosa Desert area were located at the *T and T Ranch*, Ash Meadows, and Lathrop Wells (*Op cit*; p. 51). Wider development of the valley did not take place until amendments were passed to the *Desert Lands Act of 1877*, in the 1950s, which resulted in some additional commercial agricultural activity. However, the introduction of an electric power grid to the Lathrop Wells and Death Valley Junction areas in 1963, by the Rural Electrification Administration, permitted the use of high-capacity pumping equipment and an expansion of irrigated farming (see Walker and Eakin, 1963; pp. 37 38).

Establishment of a national system of parks in the U.S. resulted with the dedication of the Desert National Wildlife Refuge, in 1935, in which the first 6428 square kilometers adjacent to NTS were withdrawn from development and established for public use. However, it wasn't until the early 1940s that land within current NTS boundaries was withdrawn from public use. Originally, 1658 square kilometers were withdrawn to create an aerial bombing and gunnery range for the Army Air Corps (formerly the *Las Vegas Bombing and Gunnery Range*; presently the *Nellis Air Force Range*) at the outbreak of the Second World War. Brady (1975, p. 7) reports that between 300 and 400 cattle ranged at Topopah, Whiterock, and Cane Springs before the war, when the grass was taller and more plentiful. This type of activity would be consistent with the archeological information reported by Worman (1969). After the war, some cattle ranching is reported to have returned, but only at Topopah Spring, Frenchman Flats, and Emigrant Valley (Anonymous, 1969; pp. 7–8). In the 1950s, after testing in the Pacific Ocean, the Nellis Air Force Range was selected as the site of the U.S.' continental nuclear test site because of its closed topographic basins (see Energy Research and Development Administration, 1977; pp. 2–12 – 2–13), and control of the site was assumed by the AEC. Water and grazing rights for the two remaining ranches were acquired by negotiated purchase in 1955 (*Op cit.*, p. 2–12). Subsequent, additional land withdraws by the AEC to the west (in 1954) and the north (in 1964) established the current dimensions of NTS. Today, NTS is approximately 3496 square kilometers and is surrounded by a 10,671-square-kilometer buffer zone.[11]

Over the years, there have been a number of programs and activities at NTS. To support this work, an infrastructure has been created within the site to provide the necessary services. This infrastructure has been described in DOE (1996, pp. 4-10–4-17), including information on water supply (*Op cit.*, pp. 4-22, 4-24). Over the years, about 17 wells supplied the freshwater needs for NTS. Most were located in Yucca Flats, Frenchman Flats, and Mercury Valley and were drilled in the mid-to-late 1950s or early 1960s [see Hood (1961); and Claassen (1973)]. Today, only 11 of these wells still supply water to NTS (see Table 2–4), and these are limited to the southern portion of the site. Construction of NTS facilities to support the weapons testing programs began in 1951. The base camp for nuclear testing operations was Mercury. Located approximately 8 kilometers (5 miles) north of state Highway 95, it served as the main administrative and industrial support center for NTS. The water supply for Mercury is provided principally from Wells 5B and 5C (Frenchman Flats) and Army Well 1 (Mercury Valley), which were drilled in the early 1950s and 1960s. Water from the Frenchman Flats area is lifted vertically about 213 meters over Checkpoint Pass by a series of pumping stations (Corchary and Dinwiddie, 1974; p. 37) and conveyed by an underground aqueduct. Camp Desert Rock, a military installation

10The Ash Meadows Paiute practiced aboriginal agriculture. They grew corn, squash, beans, and sunflowers, supplemented by hunting for deer, mountain sheep, small reptiles, antelope, and rabbit, and foraging for pine nuts, screw beans, Yucca, cactus leaves and fruit, and other types of desert flora.

11That includes the Nellis Air Force and Tonopah Test Ranges.

under the command of the Sixth Army (headquartered at the Presido, in San Francisco, California), was also established to house up to 6000 troops participating in military operations at NTS until 1958. Located between Mercury and the highway, the water supply for Camp Desert Rock was trucked in from a series of pre-existing wells drilled along the former *Las Vegas and Tonopah Railroad* alignment, now abandoned, and replaced by the highway.[12]

Finally, it should be noted that some limited farming and ranching took place at NTS in support of routine radiological surveillance on-site and other health physics studies (see Table B–1). Because these activities were unique forms of government-sponsored (subsidized) research, they should not be viewed as archetypical of the site without further study.

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[12]This railroad line was closest to the present site. It ran from 1906 to 1918, with stations/sidings/watering stops at Indian Springs, Charleston, Point of Rocks, Johnnie siding, and Amargosa. In 1920, Nevada State Highway 5 was constructed along the dismantled rail alignment (Myrick, 1992; p. 503).

Table B-1. Historic and Recent Nevada Test Site (NTS) Locations.
Table summarizes preliminary evaluation by the staff. Approximate locations are shown in brackets [ ].

Location	*Latitude*	*Longitude*	*Water Supply Source*	*Comments*	*Reference*
Pre-NTS Development					
Big Georges's cave	37° 04' 52" N.	116° 21' 08" W.	Unknown	Indian artifacts and prospecting material; occupied no later than 1937. Elevation 1478 meters	Worman (1969, pp. 25-28)
Captain Jack Spring Corral	37° 10' 06" N.	116° 10' 12" W.	Captain Jack Spring	Small corral. Elevation 1737 meters	Worman (1969, p. 40)
Cane Spring Ranch	36° 47' 56" N.	116° 05' 45" W.	Cane Spring	1 stone and 2 frame cabins, corrals; occupied no later than 1922. Elevation 1241 meters	Worman (1969, pp. 12-15)
Las Vegas and Tonopah Railroad	See Figure B-1.		Wells reported to have been dug/drilled at *Rose's Well* and *Amargosa* stations. Also, Pavit's Spring (?) shown on 1906 geologic map [a] close to *Charleston* station.	Concrete tanks known to have been erected at some station stops [b]	The Clason Map Company (1907); Myrick (1992, pp. 454-503); Walker and Eakin (1963, pp. 46, 47)
Fortymile Canyon Relay Stations	Unknown		Not reported: Black Spring (?) and Belted Mountain Spring shown on 1907 map [c]	Site(s) never located along the *Emigrant Trail*	Anonymous (1969); Pippin and Zerga (1983, p. 54)

Location	*Latitude*	*Longitude*	*Water Supply Source*	*Comments*	*Reference*
Groom District	37° 21' N.	115° 46' W.	Cane Spring reported 1.8 kilometers southwest of Groom mine	Polymetallic replacement deposits mined periodically from 1864 to 1955; largest mine is the Groom mine (T. 7 S., R. 55 E.), first acquired by the *Sheahan Family* in 1885	Humphrey (1945, pp. 13, 35-45);Tschanz and Pampeyan (1970, pp. 148-149)
George Lathrop Ranch	Jackass Flats (NTS Area 25)		Concrete water tank at *Lathrop's Well* (located at intersection of State Highway 95 and State Road 373)	Before Second World War, water hauled by wagon from Fairbanks Spring (36°29'20" N., 115°20' 30"W.) to concrete water tank used in earlier construction of *Las Vegas and Tonopah Railroad*	K. Garey (personal comm., Nov. 1998)
Mine Mountain District	[37° 00' N.]	[116° 07' W.]	Not reported.	Mercury retort associated with adits and shafts in T. 11 S., R. 52 E.	Cornwall (1972, p. 39); Worman (1969, p. 8); Brady (1975, p. 10)
Oak Spring District	37° 14' N.	116° 13' W.	Local springs – Oak and Tub Springs – (?) provided sufficient water for domestic use; 107- meter well 11 kilometers east of mine; water lifted 262 meters.	Climax mine worked tungsten skarn deposit until the early 1960s; other polymetallic claims reported to be worked in district before Second World War	Kral (1951); Cornwall (1972, p. 39)
Sheahan (or Sheehan) Ranch	[37° 26' 45" N.]	[116° 53' 24" W.]	Exact supply of water not reported; Cattle Springs closest water supply (?)	Emigrant Valley horse/cattle ranch operated until 1955. Elevation ≈ 1951 meters	Worman (1969, p. 8); Solnit (1994)
Tippipah Spring Ranch	37° 02' 34" N.	116° 12' 13" W.	Tippipah Spring	2 stone cabins, stable, corrals, and barbed-wire pasture fence. Elevation 1583 meters	Worman (1969, pp. 10-11)

Location	*Latitude*	*Longitude*	*Water Supply Source*	*Comments*	*Reference*
Topopah Spring Ranch	36° 59' 19" N.	116° 16' 17" W.	Topopah Spring	Ranch debris from fire (*ca.* 1951) - NaQuinta Ranch (?) Elevation 1737 meters	Anonymous (1969, pp. 7-8); Worman (1969, pp. 15-16); Brady (1975, p. 9)
Sterling Mine	Crater Flat		Water trucked-in from Beatty	240,000 gallons/day	French *et al.* (1981, p. 28)
White Rock Springs Ranch	37° 12' 04" N.	116° 07' 04" W.	White Rock Springs	Cabin and corral occupied no later than the 1930s. Elevation 1530 meters	Worman (1969, pp. 36-40)
Wahmonie District	36° 49' N.	116° 49' W.	Cane Spring	Comstock vein-type of deposits - Horn Silver Mine, ca. 1905 (in T. 5 S., R. 47 E.)	Kral (1951); Brady (1975, pp. 8-9)
Post-NTS Development					
Camp Desert Rock (NTS Area 22)	36° 37' N.	116° 03' W.	Pre-existing *Las Vegas and Tonopah Railroad* wells and/or Army Well 1 (Mercury Valley)	*ca.* 1951-58	Anonymous (1993, pp. 2, 4); DOE (1996, pp. 4-15 – 4-16)
Mercury (NTS Area 23)	36° 39' 30" N.	115° 59' 45" W.	Wells 5B and 5C (Frenchman Flats) and Army Well 1, on a rotating basis	1951- present	French *et al.* (1981, p. 18); DOE (1996, p. 4-16)
Animal Investigation Program in NTS Area 17	Timber Mountain Moat area[d]		Water pond at Test Well 8	Small herds of beef cattle (75 to 100 head) used for on-site radiological surveillance from 1955 through 1970s. Elevation 1736 meters	ERDA (1977, pp. 2-135 – 2-137)
Rock Valley Study Area (NTS Area 25)	36° 40' N.	116° 12' W.	None	Controlled-study area selected in 1960 for desert ecosystem studies	DOE (1996, p. 4-17)

Location	*Latitude*	*Longitude*	*Water Supply Source*	*Comments*	*Reference*
U.S. Environmental Protection Agency experimental farm (NTS Area 15)	37° 12' 30" N.	116° 02' 30" W.	Rehabilitated well UE-15d (and 3800-cubic-meter reservoir)	11-hectare farm and dairy operated from 1964-81. 30 Holstein cows, 100 Hereford beef cattle, and other horses, pigs, goats, and chickens raised on farm-grown forage and vegetables. Site included 6 hectares agricultural plots and 0.8 hectares microplots and greenhouse irrigated. Elevation ≈1372 meters	Anonymous (1993, p. 26); ERDA (1977, pp. 2-17, 2-137); DOE (1996, p. 4-15)

a See Ball (1907).
b Charleston, Point of Rocks, Johnnie siding, and Amargosa.
c See The Clason Map Company (1907).
d And possibly other areas in which there had been nuclear testing activities.

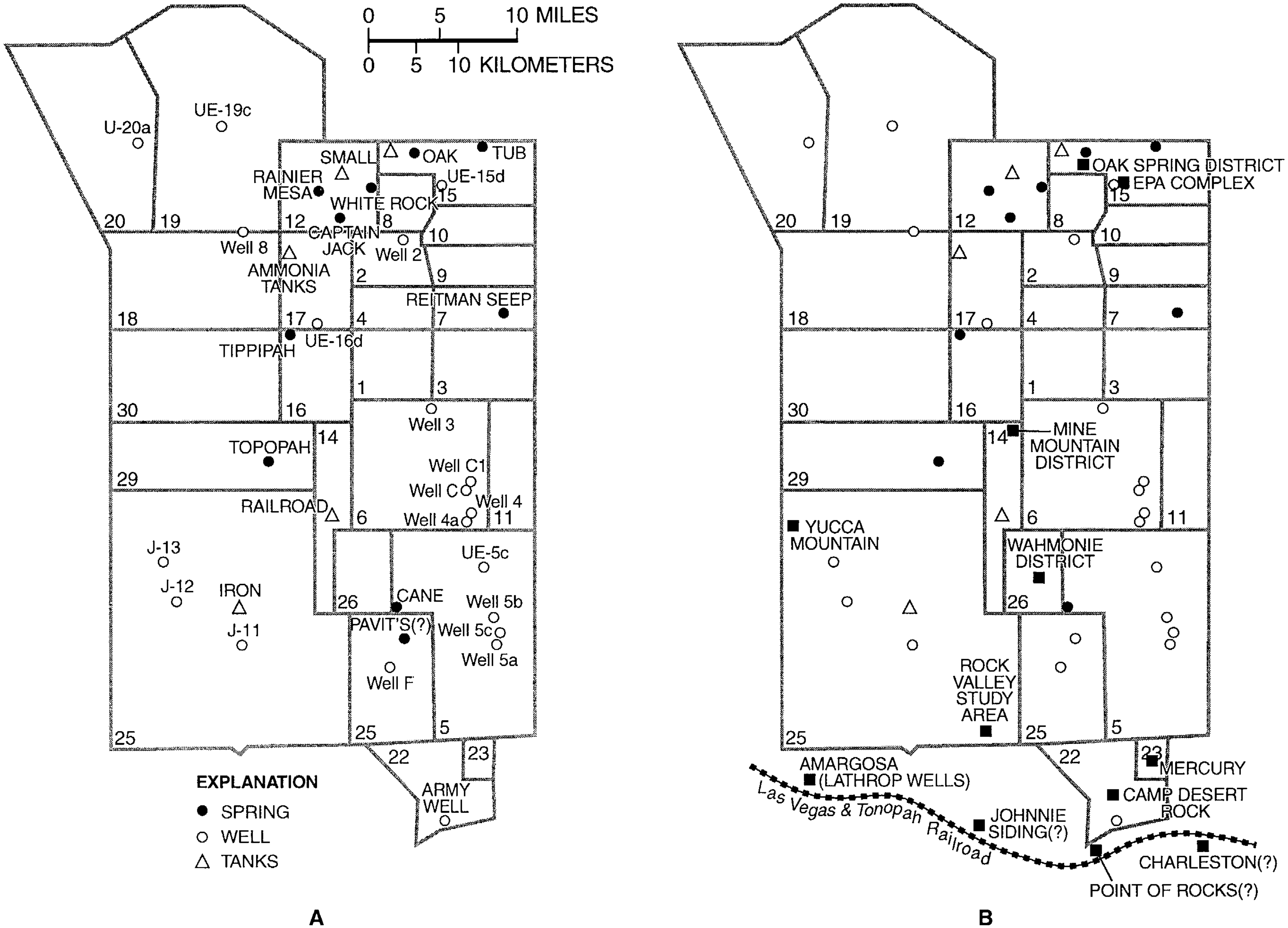
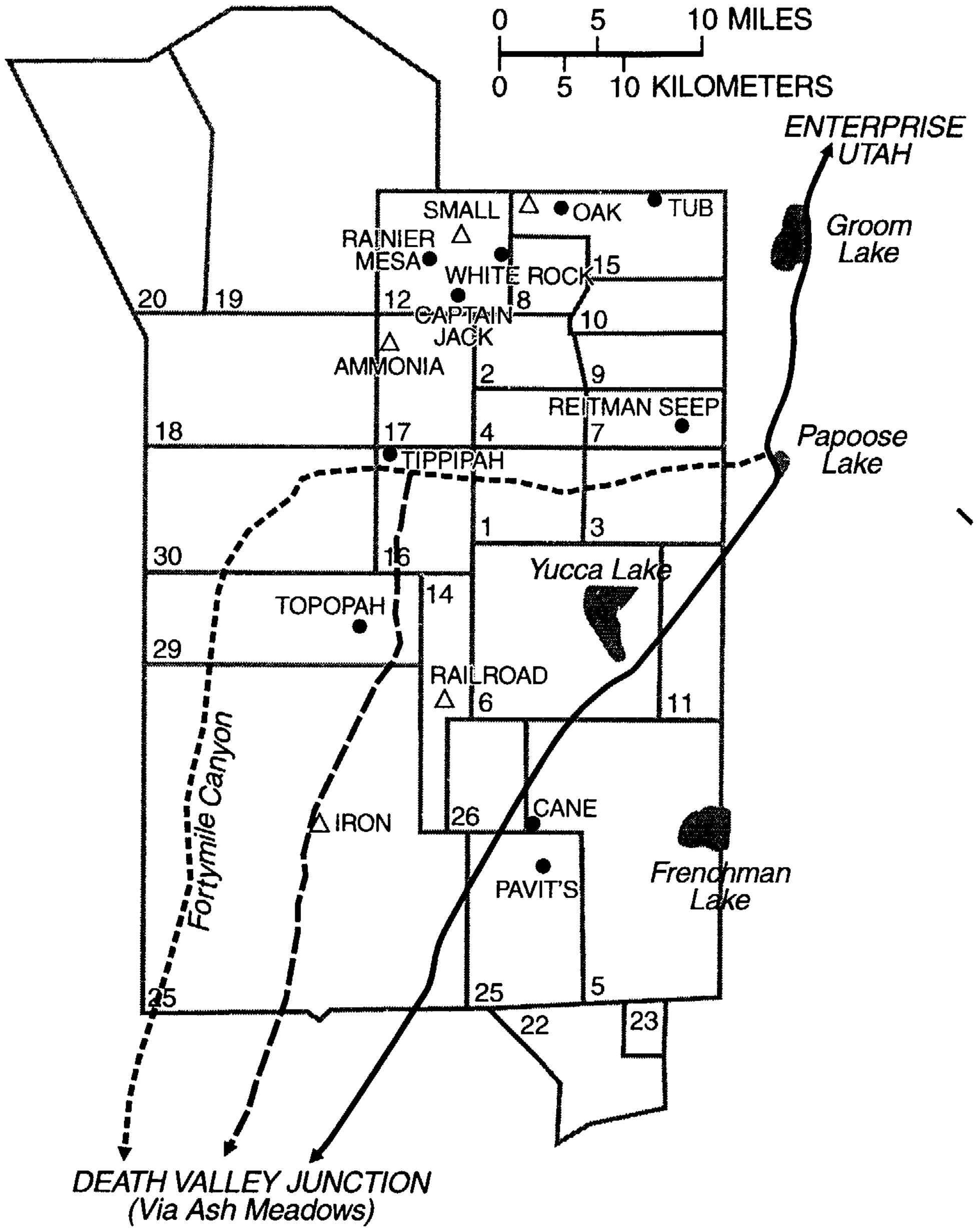


Figure B–1. Location maps for features described in Table B–1.
A. Springs, wells, and tanks within the Nevada Test Site (NTS).
B. Locations for some of the features described in Table B–1 in relation to water supply sources within NTS.



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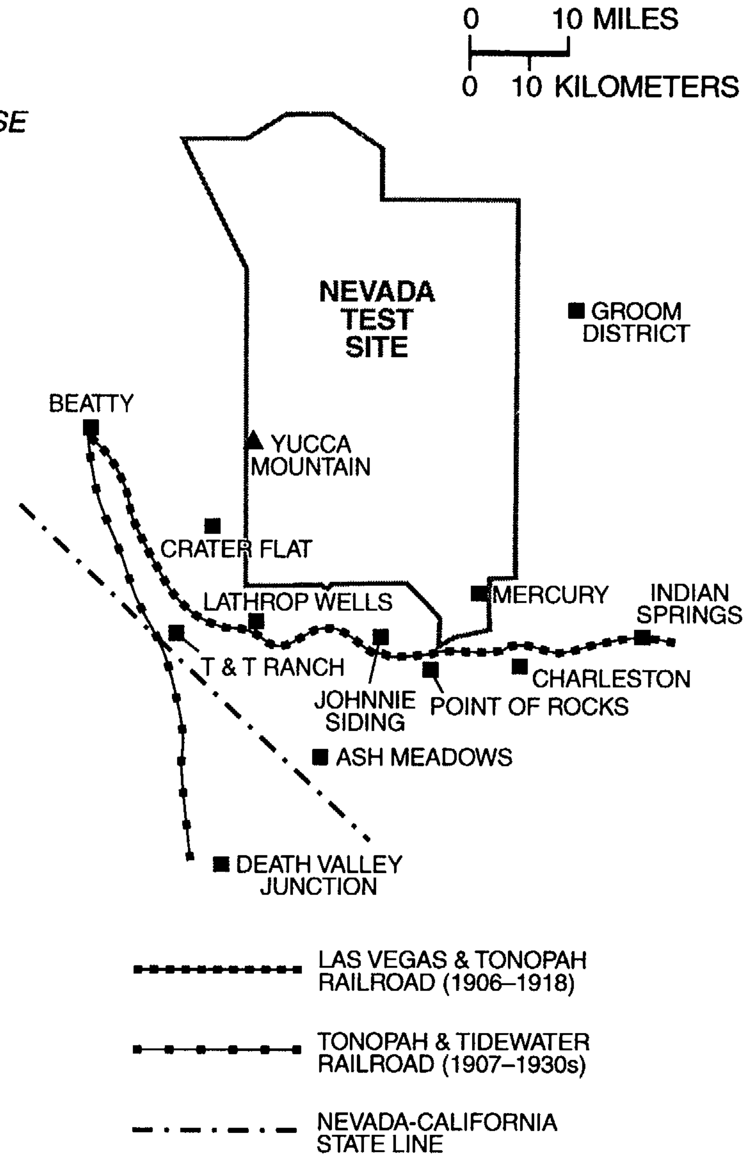

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Figure B–1. continued.
C. Approximate location of "Emigrant Trail" routes (*ca*. mid 1800s) through current NTS boundaries.
D. Locations for some of the features described in Table B–1 to railroad lines operating near current NTS boundaries in the early 1900s.

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APPENDIX C

DETAILED DESCRIPTIONS OF DEEP WELLS

In some portions of the arid U.S., individuals and communities rely on deep wells (i.e., depths to the water table exceed 240 meters) for their fresh water supply. Because this issue could have weight in the definition of a potential receptor group in any Yucca Mountain performance assessment, the staff performed an evaluation to determine the prevalence of deep well drilling practices in areas of the country somewhat comparable to the Yucca Mountain area— specifically in Arizona, Nevada, New Mexico, and the Trans-Pecos region of Texas. The discussion in this appendix documents the results of this evaluation.

C–1 DEEP WELLS IN ARIZONA

The City of Flagstaff in Coconino County has developed two well fields that pump from the Coconino Sandstone aquifer. Five municipal wells in the vicinity of Woody Mountain southwest of Flagstaff have depths to water that range from 337 to 433 meters, whereas a second well field in the vicinity of Lake Mary, southeast of Flagstaff, has depths to water that range from 100 to over 300 meters. Although the Coconino Sandstone can be quite productive where extensively fractured, most of the Flagstaff municipal wells produce 0.006 cubic meters/second or less.[1] Analysis of electronic maps constructed from U.S. Geological Survey (USGS) data indicates two other clusters of wells, northeast of Flagstaff, with depths to water ranging from 388 to 458 meters, which, based on the relatively small diameters of the casings (20 centimeters), appear to be water supply wells for mountain subdivisions.[2] Well head elevations in the Flagstaff area range from 1940 to 2195 meters mean sea level (msl). The average annual precipitation at the Flagstaff meteorological station is 53 centimeters (Sellers *et al.*, 1985). Using the Köppen-Geiger climatological classification system, the climate of Flagstaff is ***Dfa***, or humid temperate. According to Fairbridge (1967), Flagstaff is in the special highland climate category.

Two wells in the vicinity of the towns of Twin Arrows and Angell in Coconino County have depths to water of 280 and 287 meters. One of these wells is used for domestic supply; at the other well, water use is not specified. Well head elevations are 1760 and 1790 meters msl. Twin Arrows lies approximately 35 kilometers east of Flagstaff on Interstate 40. The nearest meteorological stations to Twin Arrows are those at Walnut Canyon National Monument, 20 kilometers to the west, and Meteor Crater, 35 kilometers to the east-southeast, with measured mean annual precipitation of 45 and 21 centimeters, respectively (Sellers *et al.*, 1985). Because of the extreme variation in precipitation between the nearest meteorological stations, it is difficult to classify the local climate; however, it is estimated that the area has a cool to cold semi-arid climate (***BWk*** to ***BWk'***).

In the vicinity of Gray Mountain in Coconino County are two wells, with depths to water of 360 and 377 meters, that are used for domestic and public water supplies. Gray Mountain is located about 65 kilometers north of Flagstaff on U.S. Interstate 89 near the southern boundary of the Navajo Indian Reservation. Well head elevations are approximately 1500 meters msl. Gray Mountain meteorological station recorded mean annual precipitation of 13 centimeters; however, this station only recorded data from August 1956 to April 1962, during which time Arizona experienced two prolonged droughts (*Op cit.*). Wupatki National Monument, approximately 20 kilometers south of Gray Mountain, has a record of 34 years and mean annual precipitation of 20 centimeters, whereas Cameron, lying about 16 kilometers to the north, has a record of 20 years and mean annual precipitation of 14 centimeters (*Op*

[1]Personal communication, R. Wilson, U.S. Geological Survey (Arizona), June 1996.

[2]*Ibid.*

cit.). Gray Mountain probably has a ***BWk*** to ***BWk*** ′climate.

In the northeastern end of the Sacramento Valley, approximately 15 kilometers west of Kingman in Mohave County, there are three public water supply wells with depths to water that range from 309 to 321 meters. Seven other wells in the Sacramento Valley have depths to water ranging from 265 to 406 meters; all lie within three adjacent townships (T. 21 N., R. 18 W.; T. 22 N., R.18 W.; and T. 23 N. 18 W.). Of these seven wells, two are for industrial use, one is for domestic use, and the remaining four are now unused. Well head elevations in this area range from 800 to 1030 meters msl. The average annual precipitation in Kingman is approximately 26 centimeters (*Op cit.*). Köppen-Geiger's climatological classification for Kingman is ***BSh***, or tropical steppe.

Four wells in the eastern part of the Detrital Valley near Dolan Springs in Mohave County have depths to water that range from 215 to 240 meters. Although the depth to water in these wells does not equal or exceed 240 meters, a detailed description was provided because the climate may be similar to that of Yucca Mountain under pluvial conditions. Two of these wells are unused, and the remaining two wells appear to be pumped for domestic use. Elevations of the well heads range from 900 to 920 meters msl. According to a description of the pedology of this region, the soils and climate support native vegetation consisting of blackbrush, creosote bush, Mohave yucca, rayless goldenhead, big galleta, and desert needlegrass.[3] The same source states that the rangeland is suited for wildlife habitat and grazing livestock. Dolan Springs is approximately 40 kilometers northwest of the Kingman meteorological station (elevation 1050 meters).

Within a 1100-square-kilometer area of northwest Yavapai County, including the 12 townships from T. 22. N., R. 10 W. to T. 25 N., R. 8 W., are two clusters of three wells each, and four additional isolated wells that have depths to water which range from 244 to 406 meters. Nine of the 10 wells have depths to water between 244 and 290 meters. One cluster lies within a 14-kilometer radius of the town of Yampai, whereas the second cluster lies within a 5-kilometer radius of the town of Pica—a rail stop on the *Atchison, Topeka, and Santa Fe Railroad*. The three wells near Yampai are currently unused, whereas two of the three wells near Pica are for stock water, and the third for public supply. Elevations of the well heads range from 1570 to 1720 meters msl. Peach Springs meteorological station lies approximately 25 northwest of Yampai and Pica, along Route 66, at an elevation of 1510 meters, and has an average annual precipitation of 28 centimeters (*Op cit.*). Based on the Arizona isohyet map (National Oceanic and Atmospheric Administration, 1974), it seems reasonable to assume that the average annual precipitation in the general area is less than 30 centimeters. Meteorological data from Peach Springs are incomplete so data from nearby Truxton Canyon were used to estimate the region's climate. Using Köppen-Geiger's climatological system, the climate of the region is ***BSh***.

On the Paria Plateau, north of the east end of Grand Canyon National Park, there are four stock wells and one domestic well with depths to water that range from 262 to 457 meters. Well head elevations for these wells range from 1875 to 1950 meters msl. The Paria Plateau appears to have an average elevation of approximately 1850 meters msl, some 300 meters lower than the Kaibab Plateau to the west, where the average annual precipitation at the Jacob Lake meteorological station is 52 centimeters (*Op cit.*). House Rock, Arizona, which lies 16 kilometers west of Jacob Lake at an elevation of 1640 meters msl, has an average annual precipitation of 18 centimeters (*Op cit.*). Based on the magnitude of local orogenic effects, it is estimated that the mean annual precipitation on the Paria Plateau ranges from 30 to 40 centimeters. Because meteorological data for House Rock are incomplete, it is difficult to accurately

[3]Information found on the *World Wide Web* (location, as of August 7, 1996: http://www.statlab.iastate. edu/soils-info/osd) for Nealy series soil. The web page describes the Nealy series soil, type, location about 14 kilometers southwest of Dolan Springs, Mohave County, Arizona. Server located at Iowa State University.

determine the climate of the Paria Plateau. The Paria Plateau is approximately 580 meters lower in elevation than the meteorological station at Jacob Lake, which has a climate similar to Flagstaff. Hence, the plateau probably has a cool semi-arid to highland climate.

At the extreme north central part of the State is a cluster of three wells located in the vicinity of Wahweap and Glen Canyon Dam State Park, with depth to water that ranges from 259 to 268 meters. Two of the wells are pumped for public water supply, whereas the use of the third well is unknown. Well head elevations are approximately 1250 meters msl. Average annual precipitation in Wahweap is only 15 centimeters (*Op cit.*). The Wahweap area has a climate that is similar to that of Las Vegas, which is classified as cool arid or as mid-latitude desert (Fairbridge, 1967).

The city of Williams, Coconino County, Arizona, is considering constructing a municipal supply well that would pump water from the Redwall unit where the depth to water is approximately 600 meters.[4] Williams is located about 45 kilometers west of Flagstaff on Interstate 40, and appears to have a similar highland climate.

C-2 DEEP WELLS IN NEVADA

Of the six wells in Nye and Lincoln Counties with depths to water in excess of 240 meters, five are unused test boreholes, associated with the mobile Inter-Continental Ballistic Missile siting study (the so-called *MX/Peacekeeper Program*), that were constructed by the USGS for the U.S. Department of Defense during the late 1970s and early 1980s. Depths to water in these test boreholes range from 245 to 263 meters. Well head elevations for three of the test boreholes in Coal Valley range from 1550 to 1710 meters msl. Because these boreholes were constructed for national defense, it seems that few inferences can be drawn from their existence regarding water well develop- ment near Yucca Mountain. The use of the sixth deep well (265 meters) is unspecified.

There are seven wells in Clark County, with depths to water that range from 250 to 407 meters. Four of these wells are scattered from west to east across a wide area north of Las Vegas extending from 12 kilometers southeast of Mercury (256 meters) to the southeastern terminus of the Desert Range (407 meters), to a narrow valley between the Dry Lake Range and Muddy Mountains in far eastern Clark County (251 and 251 meters). The well southeast of Mercury has a well head elevation of 1087 meters msl, and pumps water for unspecified use from the Bonanza King formation. The very deep well southeast of the Desert Range has a well head elevation of 1272 meters msl, and is currently unused. The two wells in far eastern Clark County have well head elevations of 789 and 791 meters msl; one well is currently unused, the other supplies stock water. Three other deep wells are located south of Las Vegas. One currently unused well is located in the south end of Hidden Valley directly to the west of the McCullough range at an elevation of 924 meters and has a depth to water of 290 meters msl. South of Boulder City near the northwestern terminus of the Black Hills at an elevation of 707 meters is a domestic well with a depth to water of 250 meters. Approximately 16 kilometers north of Searchlight, along U.S. Interstate 95, there is a stock well, at an elevation of 925 meters, that has a depth to water of 262 meters msl. It is assumed the climate for most of this area is similar to that of Las Vegas or mid-latitude desert.

C-3 DEEP WELLS IN NEW MEXICO

In Bernalillo County, to the west of Albuquerque, there are three wells, that pump at depths to water of 237,[5] 263, and 270 meters, which are located on top of a north-trending mesa some 60 to 70 kilometers in length. Two of the wells are located approximately 10 kilometers west of Albuquerque. Two of the wells on the mesa are currently unused and one is a commercial well. Two other wells with depths to water of

[4]Personal communication, S. Leake, U.S. Geological Survey (Tucson), July 1996.

[5]Included because of association with other wells deeper than 240 meters.

256 and 281 meters are located east of Albuquerque near the town of Sedillo and near Bear Canyon, respectively. The deep well located near Sedillo is also a commercial well; however, Bear Canyon well water use is not specified.

In south central Sandoval County near the county line with Bernalillo County, there are three public supply wells with depths to water of 276, 307, and 342 meters. All three wells are located in or near the town of Alameda, approximately 20 kilometers north-northwest of Albuquerque on a mesa rising about 300 meters above the Rio Grande Valley. Alameda is primarily an upper middle-class residential community. The elevation of Alameda is approximately 1800 meters msl. Alameda probably has a cool semi-arid to arid climate similar to Albuquerque.

Within Santa Fe County (east of Sandoval County) there are three wells with depths to water of 276, 299, and 318 meters. The two deeper wells are located in the Santa Fe National Forest near Pankey Peak, which has an elevation of 2200 meters msl. Both of these wells are powered by windmills and used to supply stock water. The shallowest well is located on Glorieta Mesa approximately 13 kilometers southwest of Pecos, New Mexico. This well also supplies stock water; however, it is pumped by a gasoline-powered pump jack. This region's climate would probably be classified as highland.

Within Taos County, which is north-northeast of Santa Fe County, there are two wells with depths to water of 247 and 329 meters. The deeper of the two wells is located about 10 kilometers south-southeast of Tres Piedras near State Highway 285. This well is used for domestic supply and is pumped by a gasoline-powered pump jack. The shallower well is located about 14 kilometers north of Tres Piedras and appears to be operated by the Johns Mansville Perlite Corporation, for industrial purposes.

West of Albuquerque, in McKinley and Cibola Counties, there are a number of deep wells located on or near Indian reservations. Fourteen kilometers north-northeast of Cebolleta (Seboyeta), Cibola County, near Canon de Marques, in far southeastern McKinley County, there is an unused well with a depth to water of 314 meters. Eight kilometers east-southeast of Cebolleta in Cibola County there are two deep industrial wells located along Meyer Draw, each with a depth to water of 258 meters. Elsewhere in McKinley County there are two unused wells located 21 and 23 kilometers south of the Chaco Culture National Monument, with depths to water of 288 and 314 meters, respectively. A fourth deep well in McKinley County is located 5 kilometers west of Borrego Pass Trading Post, has a depth to water of 240 meters, and is pumped for domestic use. On the Ramah Navajo Indian Reservation located in west central Cibola County approximately 13 kilometers south of the community center, there is a well with depth to water of 298 meters. Orr (1987) designates this as the Ramah-2 well and notes that it pumps from the Glorieta-San Andres aquifer. The Ramah-1 well is located within the same quarter-section as Ramah-2 and pumps from the Glorieta-San Andres aquifer at a depth to water of 291 meters (*Op cit.*). Well head elevations for Ramah-1 and Ramah-2 are 2269 and 2279 meters msl, respectively. The Cheechilgeetho School in Cheechilgeetho, Cibola County, approximately 35 kilometers south-southwest of Gallup, New Mexico, at an altitude of 2076 meters msl, had a well that pumped from the Glorieta-San Andres aquifer with a depth to water of 339 meters, before it was plugged (*Op cit.*).

In southwestern New Mexico near Silver City, Grant County, there are two wells with depths to water of 299 and 594 meters. The shallower well is located about 4 kilometers east of the mining town of Turnerville and is used for public supply. The deep well is located about 3 kilometers south of Turnerville and is used for industrial supply. The extreme depth to water recorded in this latter well may reflect pumpage to dewater underground copper mine adits.

C–4 DEEP WELLS IN TEXAS

In the Trans-Pecos region there are 38 wells with depths to water that equal or exceed 240 meters. Twenty-two of these deep wells are located in Hudspeth County, with 20 being in the general vicinity of the town of Sierra Blanca. Diamondhead Corporation owns seven wells, to the northwest of Sierra Blanca, that have depths to water ranging from 287 to 339. Two of Diamondhead wells are used for public water supply, one for stock, one for industrial supply, one for domestic supply, and one former public supply well is currently unused. All Diamondhead wells pump from the Cretaceous aquifer and produce from 0.00019 cubic meters/second, for stock water, to 0.032 cubic meters/second, for public supply. Well head elevations for the Diamondhead wells range from 1393 to 1522 meters msl. Sierra Blanca Corporation owns two wells near Sierra Blanca with depths to water of 271 and 275 meters. One of Sierra Blanca Corporation deep wells is unused, whereas the other is used for stock water. Nine other wells near Sierra Blanca have depths to water ranging from 240 to 341 meters and are primarily used to supply stock. In northern Hudspeth County, approximately 40 kilometers south of Dell City, there are two wells that pump from a Paleozoic aquifer at depths to water of 244 and 347 meters.

In Culberson County, which lies immediately east of Hudspeth County, there are seven wells with depths to water in excess of 240 meters. Five of these wells are located in a cluster northwest of the town of Kent near the Apache Mountains. Two of these five wells are owned by the Foster Ranch and used to supply domestic and stock water. One of the Foster Ranch wells is a converted oil test well and pumps from a depth to water of 463 meters. The second Foster Ranch well pumps from a depth to water of 276 meters. The other three wells of this cluster are owned by the Apache Ranch and are abandoned industrial wells originally owned by Elcor Chemical Corporation. These three wells have depths to water that range from 307 to 323 meters; two wells are used to provide water for stock tanks, the third is unused. In northern Culberson County south of the city of Pine Springs, which lies at the southern end of the Guadalupe Mountains, the Six-Bar Cattle Company operates a well for stock water that has a depth to water of 244 meters. In the immediate vicinity of Kent, Reynolds Cattle Company pumps stock water from a well with a depth to water of 293 meters. The five wells in the Apache Mountains area and the one well near Kent pump from the Permian Capitan Reef Complex aquifer. The well near Pine Springs pumps from the Paleozoic Bone Spring limestone aquifer. Well head elevations for the Apache Mountains cluster range from 1350 to 1543 meters msl. The Reynolds Cattle Company well head elevation is 1359 meters and the Six-Bar Cattle Company well head elevation is 1391 meters msl.

Scattered along the Rio Grande River in southeastern Brewster County are three wells, used by local ranches for domestic and stock water, that have depths to water ranging from 245 to 328 meters. This area is significantly lower in elevation than most of the Trans-Pecos region, with well head elevations ranging from 745 to 804 meters msl. Two of these wells pump from the Edwards-Trinity Plateau aquifer.

Other deep wells in the Trans-Pecos region include: (i) one in Jeff Davis County near the town of Valentine; (ii) one in Terrell County south of the town of Dryden; and (iii) one in southwestern Val Verde County. The depths to water in these very widely scattered wells range from 241 to 293 meters.

C–5 REFERENCES

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APPENDIX D

WELL CONSTRUCTION COSTS

D–1 DESCRIPTION OF WELLS[1]

Drilling and installation costs for five separate wells were estimated. The completion details for four of the five wells were based on existing wells; the fifth well was a non-specific, low-cost well for supplying a stock pond. Also, not all well completion details were available for the four existing wells; therefore, some standard well installation practices were assumed.

All drilling costs are for air-rotary drilling. All casing costs are for low-carbon steel casing. Replacement wells for the four known wells were completed as gravel packed wells. For consistency, all wells used the same screen—a louvered Johnson Irrigator screen.

The five wells are described in the following paragraphs, below.

Well 1: Well 1 is a 3385-foot-deep well, completed in welded and bedded tuffs. Completion details of Well 1 are described in Table D–1 and shown in Figure D–1, and include the following:

Total borehole depth	*3500 feet*
Well depth	*3385 feet*
Borehole diameter	*26 inches*
Casing diameter	*14 inches*
Total Screen length	*2162 feet*

The well that Well 1 replaced was a telescoped well, with casing diameters of 18, 13 3/8, 11 3/4, and 6 inches. The original Well 1 was completed as a telescoped well because of problems encountered during drilling. Well 1 is simpler to install as a single casing diameter well.

[1]Most drilling engineers in the United States still prefer the use of inch-pound units (the so-called English system), when describing water well characteristics. Therefore, for ease of comparison with engineering existing practice, in this regard, the English system will be used in this appendix. Conversion factors can be found in the front of this NUREG.

Well 1 is outfitted with a submersible pump that was sized to produce 700 gallons/minute against a static head of 1000 feet.

Well 2: Well 2 is an 887-foot-deep well, completed in welded and bedded tuffs. Completion details of Well 2 are described in Table D–2 and shown in Figure D–2, and include the following:

Total borehole depth	*900 feet*
Well depth	*887 feet*
Borehole diameter	*22 inches*
Casing diameter	*12 inches*
Total screen length	*75 feet*

Well 2 is outfitted with a submersible pump that was sized to produce 800 gallons/minute against a static head of 800 feet.

Well 3: Well 3 is a 320-foot-deep well, completed in alluvial deposits consisting of medium to fine-grained sand interbedded with silt. Well 3 is an irrigation well that provides water to a quarter-section center-pivot irrigation system. Completion details of Well 3 are described in Table D–3 and shown in Figure D–3, and include the following:

Total borehole depth	*320 feet*
Well depth	*320 feet*
Borehole diameter	*28 inches*
Casing diameter	*16 inches*
Total screen length	*150 feet*

Pump requirements for Well 3 were estimated based on conversations with a local knowledgeable expert, who noted that most center-pivot irrigation systems in southern and eastern Nevada are fitted with 100-horsepower motors and pump against 150 feet of head.[2] Flow rates from these wells are known. Theoretical calculations for flow rates indicate a 100-horsepower motor produces 2637 gallons/minute against 150 feet of static head. Depending on the size and make of the

[2]Personal communication, B. Wilson, Nevada Agricultural Extension (Ely), July 1996.

discharge pipe, this flow rate will be reduced by friction, but will likely remain above 2400 gallons/minute.

In accordance with irrigation practices in other parts of Nevada, Well 3 is outfitted with a 100-horsepower turbine shaft pump.

Well 4: Well 4 is a 600-foot deep well, completed in alluvial deposits consisting of coarse sand interbedded with gravel and silt. Well 4 is a domestic well, providing water to one or two dwellings. Completion details of Well 4 are described in Table D–4 and shown in Figure D–4, and include the following:

Total borehole depth .... *600 feet*
Well depth .... *600 feet*
Borehole diameter .... *19 inches*
Casing diameter .... *8 inches*
Total screen length .... *200 feet*

Well 4 is outfitted with a 5-horsepower submersible pump, set at 450 feet below the ground surface. The pump was sized to produce at least 10 gallons/minute against a static head of 300 feet.

Well 5: Well 5 is a 1500-foot-deep well, completed in welded and bedded tuff. Well 5 provides water to a stock tank and Well 5 is cased to a depth of 150 feet. Between 150 feet and 1500 feet, Well 5 is completed as an open hole in fractured tuff. This well is designed to be drilled and completed in a single pass with minimal completion details. Completion details of Well 5 are described in Table D–5 and shown in Figure D–5, and include the following:

Total borehole depth .... *1500 feet*
Well depth .... *1500 feet*
Borehole diameter .... *8 inches*
Casing diameter .... *Not Applicable*
Total screen length .... *Not Applicable*

Well 5 is outfitted with a 5-horsepower submersible pump set at 1250 feet below the ground surface. The pump was sized to produce 2 gallons/minute against a static head of 1000 feet.

D–2 WELL COSTS

Estimated capital costs for Wells 1 through 5 are included on Tables D–1 through D–5. These cost estimates are in 1996 dollars.

D–3 OPTIONAL PUMP COSTS

Costs for two optional pumping systems were estimated. The two pumping systems include a windmill and a pump jack. Each optional pumping system was designed to produce 2 to 3 gallons per minute against a static head of 1000 feet.

Windmill: Lifting a column of water 1000 feet requires a 20-foot-diameter windmill. The only available windmills of this size are reconditioned Aermotor windmills. The standard tower for these windmills is 40 feet high. The purchase cost for this tower is unknown. Any other tower over 40 feet high would be custom-built.

Costs for a 20-foot-diameter windmill mounted on a 40-foot tower are included in Table D–6. The total cost is estimated at $25,700.

Pump Jack: A pump jack capable of producing approximately 3 gallons/minute against a head of 1000 feet costs around $5000. This cost does not include the electric motor for powering the pump jack.

Table D–1. Well 1 Estimated Costs				
ITEM	*UNITS*	*QUANTITY*	*UNIT COST ($)*	*COST ($)*
Install 30" Conductor Casing	feet	50	175	8750
Drill Pilot Hole	feet	3450	45	155,250
E-log	line item	1	7000	7000
Ream Pilot Hole to 26"	feet	3450	60	207,000
Caliper Log	line item	1	4000	4000
Install Blank Casing	feet	1223	120	146,760
Install Screen	feet	2162	160	345,920
Install Gravel Pack	feet	2515	45	113,175
Gravel Tube	feet	990	6	5940
Grout Seal	feet	985	55	54,175
Plumbness & Alignment Test	line item	1	5500	5500
Surge/Airlift Development	hours	24	275	6600
Pumping Development	hours	24	150	3600
Step Test	hours	10	150	1500
Constant Q Test	hours	40	150	6000
Pump Cost	line item	1	20,000	20,000
Install Pump	line item	1	6500	6500
Electrical & Wellhead Finish	line item	1	20,000	20,000
TOTAL COST				$ 1,117,670

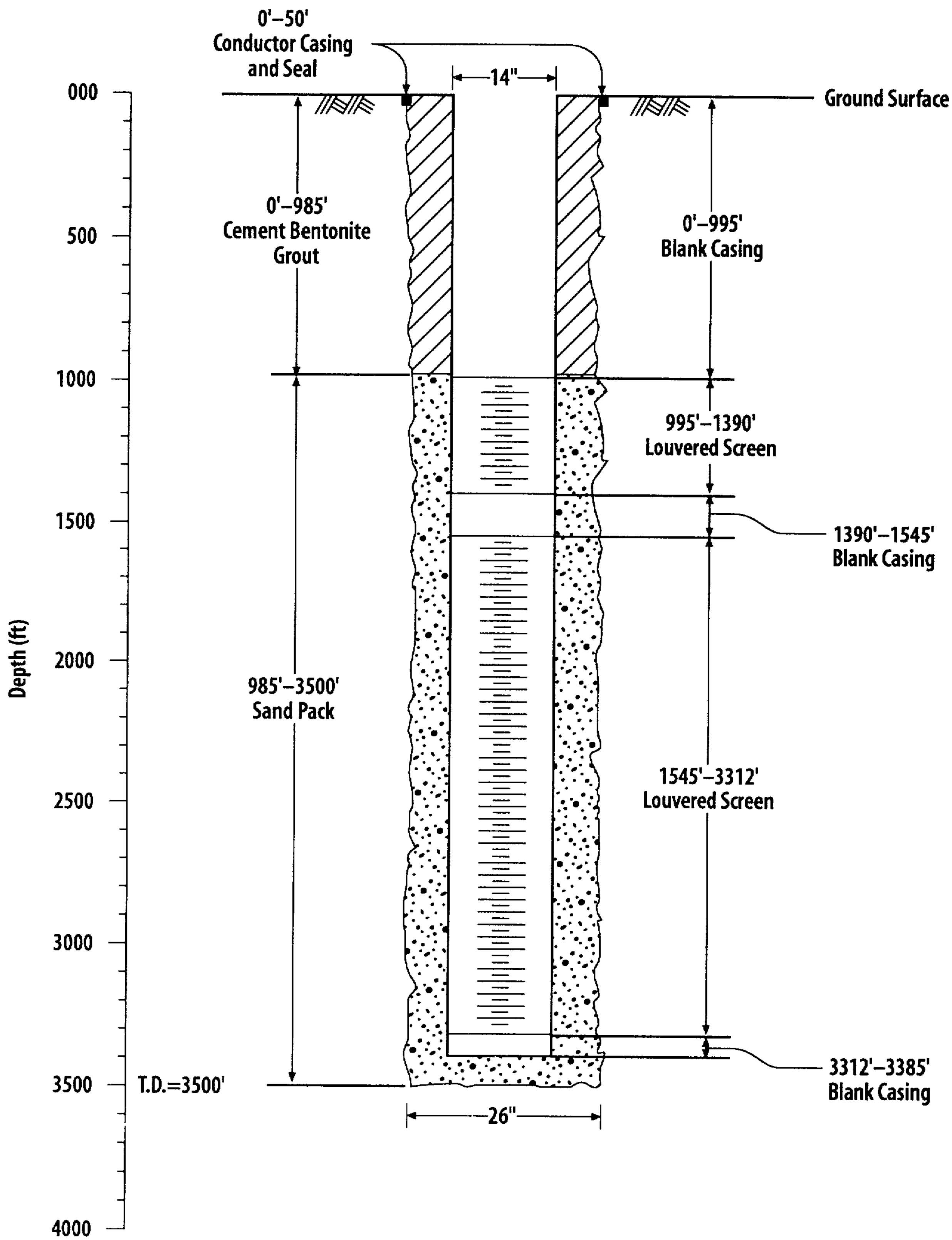

Figure D–1. Completion details for Well 1.

Table D–2. Well 2 Estimated Costs				
ITEM	***UNITS***	***QUANTITY***	***UNIT COST ($)***	***COST ($)***
Install 22" Conductor Casing	feet	50	125	6250
Drill Pilot Hole	feet	400	40	16,000
E-log	line item	1	4000	4000
Ream Pilot Hole to 22"	feet	900	50	45,000
Caliper Log	line item	1	2000	2000
Install Blank Casing	feet	812	55	44,660
Install Screen	feet	75	75	5625
Install Gravel Pack	feet	117	25	2925
Gravel Tube	feet	125	6	750
Grout Seal	feet	783	45	35,235
Plumbness & Alignment Test	line item	1	2500	2500
Surge/Airlift Development	hours	24	275	6600
Pumping Development	hours	24	150	3600
Step Test	hours	10	150	1500
Constant Q Test	hours	40	150	6000
Pump Cost	line item	1	20,000	20,000
Install Pump	line item	1	6500	6500
Electrical & Wellhead Finish	line item	1	20,000	20,000
TOTAL COST				$ 229,145

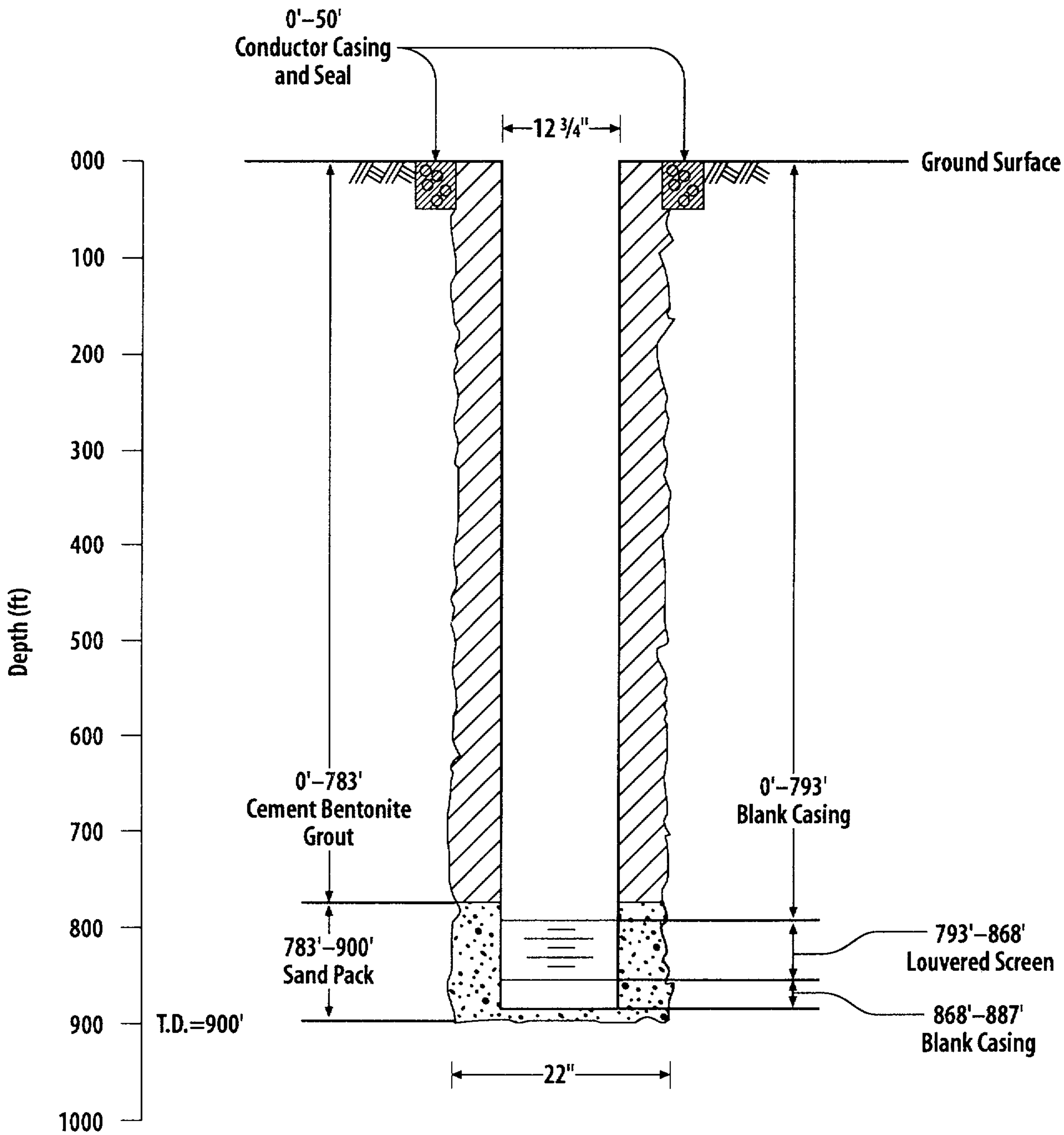

Figure D–2. Completion details for Well 2.

Table D–3. Well 3 Estimated Costs				
ITEM	*UNITS*	*QUANTITY*	*UNIT COST ($)*	*COST ($)*
Install 30" Conductor Casing	feet	50	175	8750
Drill Pilot Hole	feet	320	40	12,800
E-log	line item	1	3000	3000
Ream Pilot Hole to 28"	feet	320	50	16,000
Caliper Log	line item	1	2000	2000
Install Blank Casing	feet	175	65	11,375
Install Screen	feet	150	85	12,750
Install Gravel Pack	feet	180	35	6300
Gravel Tube	feet	145	6	870
Grout Seal	feet	140	55	7700
Plumbness & Alignment Test	line item	1	2500	2500
Surge/Airlift Development	hours	24	275	6600
Pumping Development	hours	24	150	3600
Step Test	hours	10	150	1500
Constant Q Test	hours	40	150	6000
Pump Cost	line item	1	40,000	40,000
Install Pump	line item	1	6000	6000
Electrical & Wellhead Finish	line item	1	20,000	20,000
TOTAL COST				$ 167,745

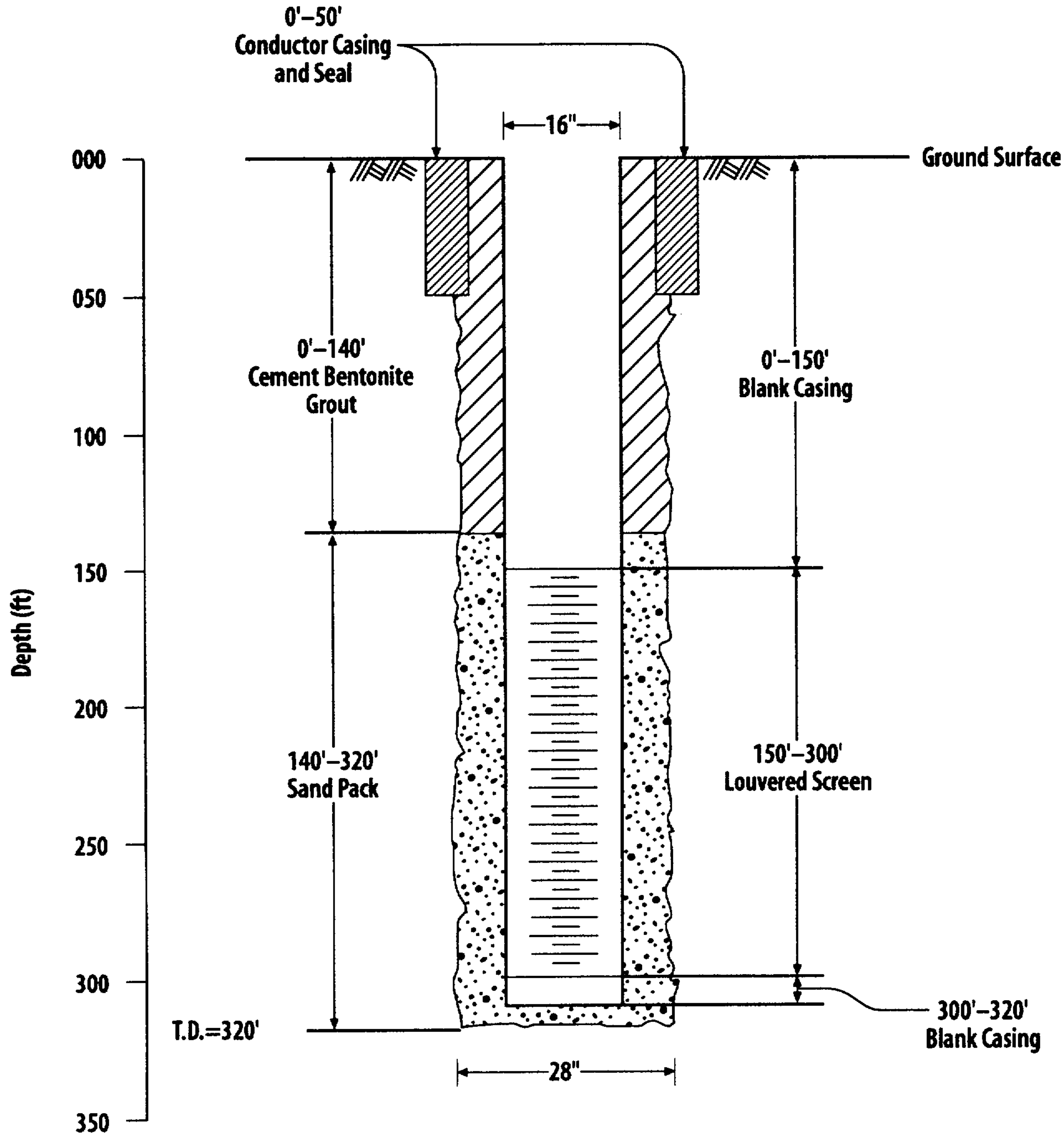

Figure D–3. Completion details for Well 3.

Table D–4. Well 4 Estimated Costs				
ITEM	*UNITS*	*QUANTITY*	*UNIT COST ($)*	*COST ($)*
Install 16" Conductor Casing	feet	50	100	5000
Drill Pilot Hole	feet	600	35	21,000
E-log	line item	1	3000	3000
Ream Pilot Hole to 19"	feet	600	45	27,000
Caliper Log	line item	1	2000	2000
Install Blank Casing	feet	400	41	16,400
Install Screen	feet	200	60	12,000
Install Gravel Pack	feet	260	20	5200
Gravel Tube	feet	345	6	2070
Grout Seal	feet	340	40	13,600
Plumbness & Alignment Test	line item	1	2500	2500
Surge/Airlift Development	hours	24	275	6600
Pumping Development	hours	24	150	3600
Step Test	hours	10	150	1500
Constant Q Test	hours	40	150	6000
Pump Cost	line item	1	8000	8000
Install Pump	line item	1	6000	6000
Electrical & Wellhead Finish	line item	1	20,000	20,000
TOTAL COST				$ 161,470

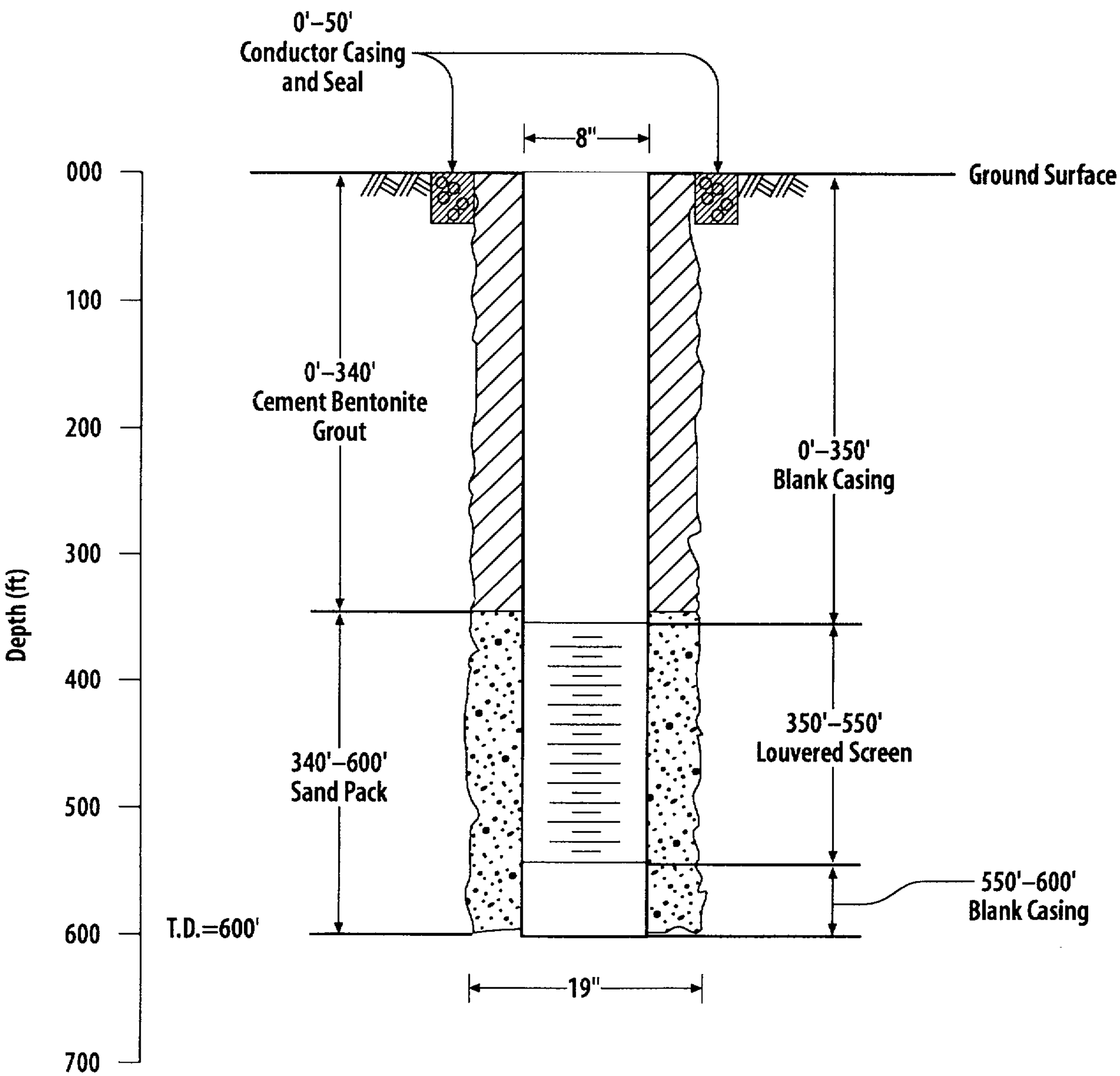

Figure D–4. Completion details for Well 4.

Table D–5. Well 5 Estimated Costs				
ITEM	*UNITS*	*QUANTITY*	*UNIT COST ($)*	*COST ($)*
Install 16" Conductor Casing	feet	50	100	5000
Drill Pilot Hole	feet	1500	45	67,500
E-log	line item	1	5000	5000
Ream Pilot Hole to 26"	feet		N/A	N/A
Caliper Log	line item	1	3000	3000
Install Blank Casing	feet	150	41	6150
Install Screen	feet		N/A	N/A
Install Gravel Pack	feet		N/A	N/A
Gravel Tube	feet		N/A	N/A
Grout Seal	feet		N/A	N/A
Plumbness & Alignment Test	line item	1	N/A	N/A
Surge/Airlift Development	hours	24	275	6600
Pumping Development	hours	24	150	3600
Step Test	hours	10	150	1500
Constant Q Test	hours	40	150	6000
Pump Cost	line item	1	15,000	15,000
Install Pump	line item	1	6000	6000
Electrical & Wellhead Finish	line item	1	20,000	20,000
TOTAL COST				$ 145,350

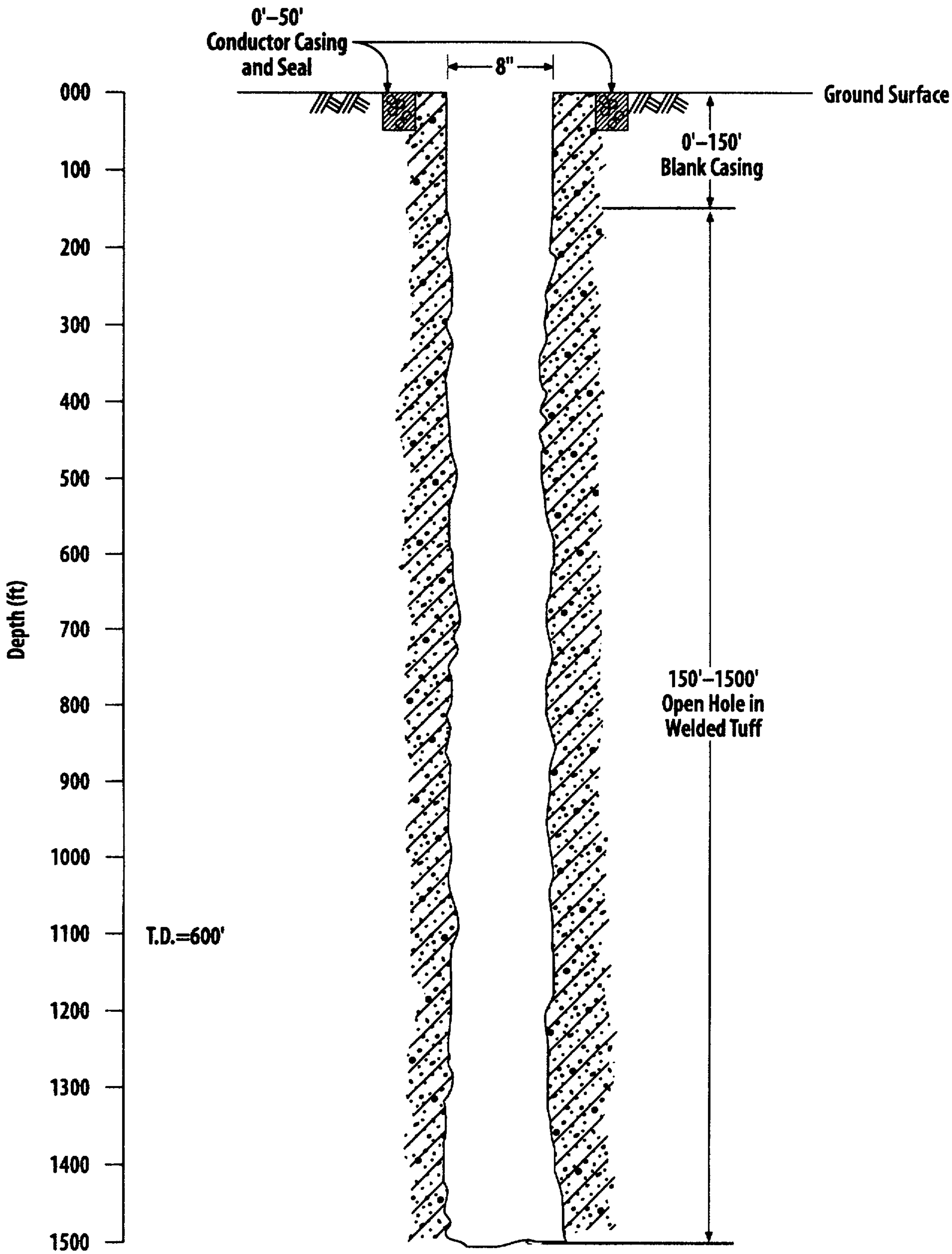

Figure D–5 Completion details for Well 5.

Table D–6. Estimated Windmill Costs				
ITEM	*UNITS*	*QUANTITY*	*UNIT COST ($)*	*COST ($)*
20' Diameter Windmill on a 40' Tower	Lump Sum	1	18,000.00	18,000.00
3/4" Sucker Rod	21' Rod	72	65.94	4747.68
2" Threaded Black Steel Drop Pipe	21' Pipe	72	37.99	2735.28
Pump Cylinder	Lump Sum	1	225.00	225.00
TOTAL COST				$ 25,707.96

APPENDIX E
DETAILED WATER USE TABLE FOR THE YEARS 1983 AND 1985-96

Annual water use estimates (cubic meters) from the U.S. Geological Survey's *Ground-Water Site Inventory* (Mathey, 1989). Location: quarter-quarter section – ***QQ*** ; quarter section – ***QTR*** ; section – ***SEC*** ; township – ***TWN*** ; and range – ***RNG*** . Water use types: commercial – ***COM*** ; mining – ***MM*** ; irrigation – ***IRR*** ; and quasi-municipal – ***QM*** .

Location: [a] *QQ QTR SEC TWN RNG*	*Use*	*Year*												
		1996	*1995*	*1994*	*1993*	*1992*	*1991*	*1990*	*1989*	*1988*	*1987*	*1986*	*1985*	*1983*
SE SE 13 15 49	COM	617	–	–	–	–	–	–	–	–	–	–	–	–
SE NE 16 16 48	COM	2468	–	–	–	–	–	–	–	–	–	–	–	–
NE NE 14 16 49	COM	123.4	–	–	–	–	–	–	–	–	–	–	–	–
NE NW 12 17 48	MM	335648	430666	419560	286288	428815	413390	472622	647850	702146	367732	350456	135740	314670
NE NW 25 18 50	COM	–	–	–	–	–	–	–	–	617	617	740.4	–	–
XX SE 35 16 49	COM	1234	–	–	–	–	–	–	–	–	–	–	–	–
XX SW 36 17 49	COM	921181	531854	465218	631808	377604	141910	620825	1e+06	526918	4936	328244	1e+06	–
NW NE 10 17 49	COM	61700	–	–	–	–	–	–	–	–	–	–	–	–
NE NW 10 16 48	IRR	–	370200	74040	–	–	–	–	–	475090	475090	475090	462750	493600
NE NW 8 16 48	IRR	–	–	–	–	–	–	–	–	–	–	–	–	185100
NE NE 16 16 48	IRR	154250	493600	345520	357860	740400	493600	493600	61700	863800	123400	740400	493600	–
SW NW 7 16 48	IRR	114145	228290	228290	228290	45658	45658	–	–	–	–	–	–	–
XX XX 36 16 48	IRR	986583	1e+06	1443780	1e+06	1e+06	1e+06	30850	–	–	1061240	1e+06	1e+06	771250
NW NW 18 16 48	IRR	493600	493600	592320	246800	–	–	–	–	246800	–	740400	370200	–
NE SE 14 16 48	IRR	215950	215950	215950	215950	–	–	–	–	–	–	–	–	–
NE NE 23 16 48	IRR	771250	771250	771250	825299	771250	987200	–	–	–	–	–	401050	771250

Location: [a] *QQ QTR SEC TWN RNG*	*Use*	*Year*												
		1996	*1995*	*1994*	*1993*	*1992*	*1991*	*1990*	*1989*	*1988*	*1987*	*1986*	*1985*	*1983*
NE SW 25 16 48	IRR	—	—	—	—	771250	—	—	—	—	—	—	771250	771250
NW NE 17 16 48	IRR	—	—	61700	—	—	—	—	—	—	—	—	159063	92550
NE NW 15 16 48	IRR	6170	15425	18510	2468	2468	—	12340	—	—	—	—	—	—
NE NW 15 16 48	IRR	9255	3085	3085	1234	4936	—	—	—	7774.2	—	—	—	—
NE NE 8 16 48	IRR	6170	111060	92550	111060	—	—	—	—	61700	—	240630	—	—
SW NW 20 16 48	IRR	21595	21595	12340	24680	49360	24680	—	—	—	—	—	—	370200
NE NE 24 16 48	IRR	280735	370200	246800	215950	215950	215950	185100	215950	215950	215950	—	—	—
NE SE 24 16 48	IRR	771250	771250	771250	—	246800	246800	—	—	—	—	—	—	—
NE NE 36 16 48	IRR	30850	61700	61700	234460	19744	—	30850	30850	—	—	—	—	—
SE SW 10 16 48	IRR	—	493600	—	246800	—	—	—	—	—	—	—	—	—
SE NW 18 16 48	IRR	811355	842822	667347	405369	—	—	—	—	58245	—	777.25	656.25	—
SE SW 10 16 48	IRR	6170	6170	—	—	—	—	—	—	—	—	—	—	—
NW SW 10 16 48	IRR	21595	21595	21595	21595	21595	—	6170	6170	3085	3085	3085	—	—
NW SW 10 16 48	IRR	13882.5	—	—	—	—	—	—	—	—	—	—	—	—
NW SW 10 16 48	IRR	—	—	—	—	1234	—	27765	—	—	—	—	—	—
SW SE 8 16	IRR	29616	122166	122166	66636	—	—	—	—	6170	—	—	—	74040
NW NW 15 16 48	IRR	15425	12340	12340	2468	7404	—	—	—	—	—	—	—	24680
SE NW 26 16 481	IRR	720039	720039	275602	308500	—	—	308500	—	—	720039	720039	720039	720656
SE NE 26 16 48	IRR	288016	288016	—	—	—	—	720039	—	—	720039	720039	720039	720656
SW SE 8 16 48	IRR	87243.8	92550	74040	37020	—	—	—	—	—	—	—	—	—
SW NW 24 16 48	IRR	720039	720039	720039	719916	—	—	719854	—	—	719854	719854	719854	—
SW NW 15 16 48	IRR	12340	12340	25482.1	7404	7404	—	—	—	42450	—	—	30850	—
NW NW 15 16 48	IRR	15425	—	—	—	—	—	—	—	—	—	—	—	—

Location: [a] QQ QTR SEC TWN RNG	Use	Year												
		1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	1983
NE NW 15 16 48	IRR	6170	—	—	—	—	—	—	—	—	—	—	—	—
NE NW 15 16 48	IRR	1234	—	—	—	—	—	—	—	—	—	—	—	—
NW NW 15 16 48	IRR	6170	—	—	—	—	—	—	—	—	—	—	—	—
NE NW 15 16 48	IRR	1234	—	—	—	—	—	—	—	—	—	—	—	—
NE NE 28 16 49	IRR	226316	226316	226316	226316	226316	—	92550	92550	226316	226316	226316	135617	259140
NE SW 9 16 49	IRR	—	—	—	—	—	—	—	—	—	—	—	—	6170
NE SE 32 16 49	IRR	—	—	—	—	—	—	172143	—	—	—	—	—	—
NE NE 14 16 49	IRR	—	—	—	67870	67870	—	—	—	—	—	—	—	—
NE NW 30 16 49	IRR	820610	820610	820610	820610	—	—	836035	—	—	328244	—	—	—
NE NW 35 16 49	IRR	—	—	—	2468	2468	—	—	—	—	—	—	—	—
NE SE 19 16 49	IRR	771250	771250	771250	771250	771250	771250	493600	308500	—	—	—	—	—
SE SW 9 16 49	IRR	129570	146538	61700	145982	146538	—	146538	146599	92550	92550	92550	61700	146599
NE NE 8 16 49	IRR	33935	111060	18510	12340	12340	—	30850	30850	—	—	—	—	121549
SW SE 5 16 49	IRR	—	—	1234	—	—	—	—	—	—	—	—	—	—
NE SE 8 16 49	IRR	6170	2468	—	4936	4936	—	—	—	—	—	—	—	—
SE NW 35 16 49	IRR	32429.5	32331	22458.8	22459	22508	—	—	—	—	—	—	—	—
SE SW 9 16 49	IRR	30850	30850	30850	30850	30850	30850	30850	30850	30850	30850	30850	30850	30850
NE SE 23 16 49	IRR	771250	771250	771250	771250	771250	771250	—	—	—	—	—	—	771250
NW NE 8 16 49	IRR	—	—	—	16906	—	—	—	—	—	—	—	—	—
SE SW 9 16 49	IRR	30850	30850	30850	30850	30850	30850	30850	—	30850	30850	30850	30850	30850
SE SE 22 16 49	IRR	6170	—	43190	58862	—	—	18510	18510	12340	12340	—	28012	—
SE NE 12 17 48	IRR	—	—	—	—	—	—	—	—	—	—	—	—	30850
SE NW 12 17 48	IRR	80210	80210	80210	80210	80210	80210	80210	80210	55530	55530	55530	92550	—

Location:[a] QQ QTR SEC TWN RNG	Use	Year												
		1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	1983
NE NW 9 17 49	IRR	—	—	—	851460	666360	678700	974860	493600	370200	246800	—	—	—
NE NE 9 17 49	IRR	863800	863800	863800	—	—	—	—	—	—	—	—	—	—
NE NW 15 17 49	IRR	30850	30850	24680	19744	19744	—	14808	14808	14808	14808	—	30850	—
SE SE 8 17 49	IRR	—	146229	—	—	—	—	223477	—	—	—	—	—	—
NE NE 9 17 49	IRR	209780	209780	—	—	—	—	—	—	—	—	—	—	—
NE NE 9 17 49	IRR	774952	774952	385625	774952	—	—	—	—	—	—	—	—	—
XX SW 4 16 48	IRR	—	—	—	—	—	—	—	—	462750	—	—	—	—
XX NW 23 16 48	IRR	—	—	—	—	—	—	—	—	—	—	—	—	771250
XX NW 25 16 48	IRR	—	—	—	—	—	—	—	—	—	—	—	—	771250
NW NW 15 16 48	IRR	9255	—	—	—	—	—	—	—	—	—	—	—	—
XX NW 25 16 48	IRR	771250	771250	771250	—	—	—	—	—	—	—	—	771250	—
XX NW 25 16 48	IRR	771250	771250	—	—	—	—	—	—	—	—	—	—	—
NE NW 17 16 48	IRR	—	74040	74040	—	—	—	—	—	—	—	—	296160	—
SW SE 32 16 49	IRR	—	—	123400	123400	—	215950	215950	215950	—	—	—	—	—
NE NE 28 16 49	IRR	—	—	—	—	—	—	—	—	—	—	—	123400	—
NW SE 1 17 48	IRR	—	—	—	—	—	—	—	—	—	—	—	—	771250
SE NW 12 17 48	IRR	—	—	—	—	—	—	—	—	—	—	—	—	370200
NE SE 12 17 48	IRR	61700	61700	61700	61700	61700	61700	154250	154250	—	—	—	—	—
XX SE 1 17 48	IRR	49360	49360	—	—	—	—	—	—	—	462750	462750	462750	—
SW NE 9 17 49	IRR	49360	49360	—	—	—	—	—	—	—	—	—	—	—
SE NE 9 17 49	IRR	49360	49360	—	—	—	—	—	—	—	—	—	—	—
XX SE 7 17 49	IRR	—	—	—	—	—	—	—	—	—	246800	—	771250	—
XX SW 7 17 49	IRR	771250	771250	—	—	—	—	61700	—	385625	771250	771250	318372	—

Location: [a] QQ QTR SEC TWN RNG	Use	Year												
		1996	*1995*	*1994*	*1993*	*1992*	*1991*	*1990*	*1989*	*1988*	*1987*	*1986*	*1985*	*1983*
NE SW 9 17 49	IRR	246800	246800	–	–	–	–	–	–	–	–	–	–	–
NW SW 9 17 49	IRR	246800	246800	61700	–	–	–	–	–	–	–	–	–	–
NW SE 7 17 49	IRR	–	–	–	–	–	–	–	–	–	–	–	–	771250
NW SW 7 17 49	IRR	–	–	–	–	–	–	–	–	–	–	–	–	385625
NW NE 24 15 49	QM	9872	–	–	–	–	–	–	–	–	–	–	–	–
NE NW 27 16 49	QM	4195.6	–	–	–	–	–	–	–	–	–	–	–	–
SW SE 31 16 49	QM	12957	–	–	–	–	–	–	–	–	–	–	–	–
SE SE 26 16 49	QM	123.4	–	–	–	–	–	–	–	–	–	–	–	–
NW NE 16 16 49	QM	24680	–	–	–	–	–	–	–	–	–	–	–	–
SE SW 1 17 48	QM	9255	–	–	–	–	–	–	–	–	–	–	–	–
SE SW 2 17 49	QM	12340	–	–	–	–	–	–	–	–	–	–	–	–
SE SW 2 18 49	QM	19744	–	–	–	–	–	–	–	–	–	–	–	–
SW SW 2 18 49	QM	61700	–	–	–	–	–	–	–	–	–	–	–	–
SW NE 3 18 50	QM	2468	–	–	–	–	–	–	–	–	–	–	–	–

a Note that *NE* means north-east , *SE* means south-east, *NW* means north-west, *SW* means south-west, and *XX* means that the location was not reported.

Reference

Mathey, S.B. (ed.), "National Water Information System User's Manual: Volume 2, Chapter 4– Ground-Water Site Inventory System," U.S. Geological Survey, Open-File Report 89-587, 1989.

APPENDIX F
TABLE OF BOREHOLE DILUTION FACTORS

Calculated dilution factors for combinations of plume scenarios and capture zones at 25 kilometers used in the analyses described in Section 3.2 of this NUREG. ***Capture identification number,*** in the second column, is in reference to the *Capture Zone Delineation Table* found in Appendix G; pumping rate (m^3/day) – $\boldsymbol{Q}$; transmissivity (m^2/day) – $\boldsymbol{T}$; and regional gradient – ***grad*** . The dilution factors are: volumetric flux-based borehole dilution factor – ***F-BDF***; point dilution factor based on centerline concentration – ***P-DF*** ; and dispersion during transport-based borehole dilution factor – ***T-BDF*** . Additional significant figures are reported to illustrate relative differences, only.

Plume Description	*Capture Zone Description*	*F-BDF*	*P-DF*	*T-BDF*
3-Dimensional (3-D) Plume 1				
20:2:0.2 m	#8, Q = 300	1.4	9.1	34
20:2:0.2 m	#9, Q = 800	2.6	9.1	55
20:2:0.2 m	#10, Q = 1,380	3.5	9.1	57
20:2:0.2 m	#11, Q = 2,000	4.8	9.1	57
Small Irrigation Well, 3-D Plume 1				
20:2:0.2 m	#31, T = 50	2.6	9.1	48
20:2:0.2 m	#32, T = 100	1.8	9.1	34
20:2:0.2 m	#33, T = 200	1.4	9.1	26
20:2:0.2 m	#34, T = 300	1.0	9.1	20
20:2:0.2 m	#35, T = 400	1.0	9.1	18
Large Irrigation Well, 3-D Plume 1				
20:2:0.2 m	#36, T = 200	2.8	9.1	57
20:2:0.2 m	#37, T = 300	3.0	9.1	52
20:2:0.2 m	#38, T = 400	2.4	9.1	45
20:2:0.2 m	#39, grad = 0.001	6.2	9.1	57.5
20:2:0.2 m	#40, grad = 0.002	3.4	9.1	57.5
20:2:0.2 m	#41, grad = 0.003	2.3	9.1	56.6
20:2:0.2 m	#42, grad = 0.005	1.0	9.1	45

Plume Description	*Capture Zone Description*	*F-BDF*	*P-DF*	*T-BDF*
Domestic Wells, 3-D Plume 1				
20:2:0.2m	#21, 940–1,000	9.1	1	9.5
20:2:0.2 m	#22, 930–990	9.1	1	9.7
20:2:0.2 m	#23, 920–980	9.1	1	9.9
20:2:0.2 m	#24, 900–960	9.1	1	10.4
20:2:0.2 m	#1, Q = 1	9.1	1	9.36
20:2:0.2 m	#2, Q = 2	9.1	1	9.44
20:2:0.2 m	#3, Q = 3	9.1	1	9.5
20:2:0.2 m	#4, Q = 4	9.1	1	9.6
20:2:0.2 m	#5, Q = 6.8	9.1	1	9.9
20:2:0.2 m	#6, Q = 37.5	9.1	1	13
20:2:0.2 m	#7, Q = 75	9.1	1	18
20:2:0.2 m	#12, T = 10	9.1	1	12
20:2:0.2 m	#13, T = 50	9.1	1	9.8
20:2:0.2 m	#14, T = 100	9.1	1	9.5
20:2:0.2 m	#15, T = 400	9.1	1	9.3
20:2:0.2 m	#16, grad = 0.001	9.1	1	11
20:2:0.2 m	#17, grad = 0.0025	9.1	1	9.8
20:2:0.2 m	#18, grad = 0.005	9.1	1	9.5
20:2:0.2 m	#19, grad = 0.01	9.1	1	9.4
3-D Plume 2				
100:10:0.1 m	#8, Q = 300	1.9	14	37
100:10:0.1 m	#9, Q = 800	2.7	14	47
100:10:0.1 m	#10, Q = 1,380	3.3	14	60
100:10:0.1 m	#11, Q = 2,000	4.1	14	73

Plume Description	*Capture Zone Description*	*F-BDF*	*P-DF*	*T-BDF*
Small Irrigation Well, 3-D Plume 2				
100:10:0.1 m	#31, T = 50	3.2	14	43
100:10:0.1 m	#32, T = 100	2.4	14	37
100:10:0.1 m	#33, T = 200	1.8	14	34
100:10:0.1 m	#34, T = 300	1.6	14	32
100:10:0.1 m	#35, T = 400	1.5	14	30
Large Irrigation Well, Plume 2				
100:10:0.1 m	#36, T = 200	3.0	14	53
100:10:0.1 m	#37, T = 300	2.6	14	45
100:10:0.1 m	#38, T = 400	2.3	14	41
100:10:0.1 m	#39, grad = 0.001	4.3	14	—
100:10:0.1 m	#40, grad = 0.002	3.3	14	59
100:10:0.1 m	#41, grad = 0.003	2.8	14	49
100:10:0.1 m	#42, grad = 0.005	2.3	14	41
Thin Plumes, Domestic Wells at 25 Kilometers, 20:2 Meter Dispersivity Ratio				
25-m-thick; 20:2 m	#21, 940-1,000	3.3	1.8	1.78
25-m-thick; 20:2 m	#22, 930-990	4.3	1.8	1.77
25-m-thick; 20:2 m	#23, 920-980	5.4	1.8	1.77
25-m-thick; 20:2 m	#24, 900-960	43	1.8	1.76
10-m-thick; 20:2 m	#21, S = 940-1,000	8.2	1.8	1.78
10-m-thick; 20:2 m	#22, S = 930-990	10.3	1.8	1.77
10-m-thick; 20:2 m	#23, S = 920-980	26	1.8	1.70
10-m-thick; 20:2 m	#24, S = 900-960	N/A	1.8	N/A
25-m-thick; 20:2 m	#1, Q = 1	2.8	1.8	1.76
25-m-thick; 20:2 m	#2, Q = 2	3.1	1.8	1.77
25-m-thick; 20:2 m	#3, Q = 3	3.3	1.8	1.78
25-m-thick; 20:2 m	#4, Q = 4	3.5	1.8	1.78

Plume Description	*Capture Zone Description*	*F-BDF*	*P-DF*	*T-BDF*
25-m-thick; 20:2 m	#5, Q = 6.8	4.0	1.8	1.80
25-m-thick; 20:2 m	#6, Q = 37.5	7.6	1.8	1.90
25-m-thick; 20:2 m	#7, Q = 75	10.2	1.8	2.01
10-m-thick; 20:2 m	#1, Q = 1	7.0	1.8	1.76
10-m-thick; 20:2 m	#2, Q = 2	7.7	1.8	1.77
10-m-thick; 20:2 m	#3, Q = 3	8.2	1.8	1.78
10-m-thick; 20:2 m	#4, Q = 4	8.8	1.8	1.78
10-m-thick; 20:2 m	#5, Q = 6.8	10.1	1.8	1.80
10-m-thick; 20:2 m	#6, Q = 37.5	19	1.8	1.90
10-m-thick; 20:2 m	#7, Q = 75	26	1.8	2.01
25-m-thick; 20:2 m	#12, T = 10	6.9	1.8	1.88
25-m-thick; 20:2 m	#13, T = 50	3.9	1.8	1.80
25-m-thick; 20:2 m	#14, T = 100	3.3	1.8	1.78
25-m-thick; 20:2 m	#15, T = 400	2.7	1.8	1.76
25-m-thick; 20:2 m	#16, grad = 0.001	5.3	1.8	1.84
25-m-thick; 20:2 m	#17, grad = 0.0025	3.9	1.8	1.80
25-m-thick; 20:2 m	#18, grad = 0.005	3.3	1.8	1.78
25-m-thick; 20:2 m	#19, grad = 0.01	2.9	1.8	1.77
10-m-thick; 20:2 m	#12, T = 10	17	1.8	1.88
10-m-thick; 20:2 m	#13, T = 50	9.8	1.8	1.80
10-m-thick; 20:2 m	#14, T = 100	8.2	1.8	1.78
10-m-thick; 20:2 m	#15, T = 400	6.8	1.8	1.76
10-m-thick; 20:2 m	#16, grad = 0.001	13.2	1.8	1.84
10-m-thick; 20:2 m	#17, grad = 0.0025	9.8	1.8	1.80
10-m-thick; 20:2 m	#18, grad = 0.005	8.2	1.8	1.78
10-m-thick; 20:2 m	#19, grad = 0.01	7.4	1.8	1.77

Plume Description	***Capture Zone Description***	***F-BDF***	***P-DF***	***T-BDF***
Thin Plumes Irrigation Wells at 25 Kilometers				
25-m-thick; 20:2 m	#8, Q = 300	19	1.8	2.8
25-m-thick; 20:2 m	#9, Q = 800	26	1.8	4.8
25-m-thick; 20:2 m	#10, Q = 1,380	36	1.8	5.9
25-m-thick; 20:2 m	#11, Q = 2,000	49	1.8	5.9
25-m-thick; 50:5 m	#8, Q = 300	19	2.6	3.3
25-m-thick; 50:5 m	#9, Q = 800	26	2.6	4.8
25-m-thick; 50:5 m	#10, Q = 1,380	30	2.6	6.8
25-m-thick; 50:5 m	#11, Q = 2,000	33	2.6	8.8
25-m-thick; 100:10 m	#8, Q = 300	19	3.6	4.1
25-m-thick; 100:10 m	#9, Q = 800	26	3.6	5.2
25-m-thick; 100:10 m	#10, Q = 1,380	30	3.6	6.9
25-m-thick; 100:10 m	#11, Q = 2,000	32	3.6	8.9

APPENDIX G
CAPTURE ZONE DELINEATION TABLE

Calculated capture zone widths and thicknesses used in the analyses described in Section 3.2 of this NUREG. Screen elevation based on 1000-meter-thick aquifer.

Identification Number	*Screen Elevation (m)*	*Pump Rate (m^3/day)*	*Gradient*	*Transmissivity (m^2/day)*	*Width (m)*	*Thickness (m)*	*Not Captured on Top (m)*
1	940 – 1000	1	0.005	100	29	73	—
2	940 – 1000	2	0.005	100	54	82	—
3	940 – 1000	3	0.005	100	76	88	—
4	940 – 1000	4	0.005	100	97	96	—
5	940 – 1000	6.815	0.005	100	146	113	—
6	940 – 1000	37.5	0.005	100	418	224	—
7	940 – 1000	75	0.005	100	607	309	—
8	940 – 1000	300	0.005	100	1292	575	—
9	940 – 1000	800	0.005	100	2330	825	—
10	940 – 1000	1380	0.005	100	3382	941	—
11	940 – 1000	2000	0.005	100	4450	985	—
12	940 – 1000	3	0.005	10	369	203	—
13	940 – 1000	3	0.005	50	133	108	—
14	940 – 1000	3	0.005	100	76	88	—
15	940 – 1000	3	0.005	400	22	70	—
16	940 – 1000	3	0.001	100	248	151	—

Identification Number	*Screen Elevation (m)*	*Pump Rate (m^3/day)*	*Gradient*	*Transmissivity (m^2/day)*	*Width (m)*	*Thickness (m)*	*Not Captured on Top (m)*
17	940 – 1000	3	0.0025	100	133	108	—
18	940 – 1000	3	0.005	100	76	88	—
19	940 – 1000	3	0.05	100	41	78	—
20	940 – 1000	3	0.005	100	76	88	—
21	930-990	3	0.005	100	69	98	0.2
22	920-980	3	0.005	100	67	107	5
23	900-960	3	0.005	100	68	127	21
24	980 – 1000	3	0.005	100	115	65	—
25	940 – 1000	3	0.005	100	76	88	—
26	900 – 1000	3	0.005	100	51	122	—
27	0 – 1000	300	0.005	100	574	1000	—
28	500 – 1000	300	0.005	100	940	752	—
29	810 – 1000	300	0.005	100	1238	601	—
30	940 – 1000	300	0.005	100	1292	575	—
31	940 – 1000	300	0.005	50	1944	751	—
32	940 – 1000	300	0.005	100	1292	575	—
33	940 – 1000	300	0.005	200	876	424	—
34	940 – 1000	300	0.005	300	705	352	—
35	940 – 1000	300	0.005	400	607	309	—
36	940 – 1000	2116	0.005	200	2810	890	—

Identification Number	*Screen Elevation (m)*	*Pump Rate (m^3/day)*	*Gradient*	*Transmissivity (m^2/day)*	*Width (m)*	*Thickness (m)*	*Not Captured on Top (m)*
37	940 - 1000	2116	0.005	300	2146	793	—
38	940 - 1000	2116	0.005	400	1798	719	—
39	940 - 1000	2116	0.001	100	5596	1000	—
40	940 - 1000	2116	0.002	100	3282	934	—
41	940 - 1000	2116	0.003	100	2486	850	—
42	940 - 1000	2116	0.005	100	1798	719	—

APPENDIX H
LATIN HYPERCUBE SAMPLED INPUT PARAMETERS USED IN THE ANALYSIS OF DOSE

The following is a list of important parameters used in the analysis of dose described in Section 3.3 of this NUREG. The reader is referred to Wescott *et al.*(1995) for a description of how these parameters (shown in brackets [ ]) were used in the U.S. Nuclear Regulatory Commission's Iterative Performance Assessment Phase 2 computer code.

Parameter	***Range in Value***		***Distribution***	***Basis for Parameter Assignment***
	High	***Low***		
		Matrix Permeability (m^2) [permm]		
Topopah Spring	3.6×10^{-19}	1.2×10^{-18}	Lognormal	Peters *et al.* (1984) [a]
Calico Hills, vitric	3.9×10^{-15}	2.0×10^{-14}	Lognormal	Peters *et al.* (1984) [a]
Calico Hills, zeolitic	1.3×10^{-20}	6.7×10^{-19}	Lognormal	Peters *et al.* (1984) [a]
Prow Pass	1.9×10^{-16}	9.6×10^{-16}	Lognormal	Peters *et al.* (1984) [a]
Upper Crater Flat	5.1×10^{-18}	1.5×10^{-17}	Lognormal	Peters *et al.* (1984) [a]
Bullfrog	3.5×10^{-16}	4.4×10^{-16}	Lognormal	Peters *et al.* (1984) [a]
Middle Crater Flat	4.1×10^{-18}	1.6×10^{-17}	Lognormal	Assumed same as Upper Crater Flat
alluvium	—	1.6×10^{-12}	Constant	Assumed for this analysis
		Undisturbed Infiltration (m/yr) [infiltration]		
repository footprint	0.0001	0.005	Loguniform	Assumed same as Codell *et al.* (1992) and Wescott *et al.* (1995)

Parameter	*Range in Value*		*Distribution*	*Basis for Parameter Assignment*
	High	*Low*		
Distribution Coefficient (m^3/kg) [kdm]				
Curium				
Topopah Spring	0.045	4.5	Lognormal	Codell *et al.* (1992) [b]
Calico Hills, vitric	0.328	32.0	Lognormal	Codell *et al.* (1992) [b]
Calico Hills, zeolitic	0.166	16.6	Lognormal	Codell *et al.* (1992) [b]
Prow Pass	0.116	11.6	Lognormal	Codell *et al.* (1992) [b]
Upper Crater Flat	0.132	13.2	Lognormal	Codell *et al.* (1992) [b]
Bullfrog	0.12	12.0	Lognormal	Codell *et al.* (1992) [b]
Middle Crater Flat	0.132	13.2	Lognormal	Codell *et al.* (1992) [b]
alluvium	—	32.8	Constant	Assumed for this analysis
Plutonium				
Topopah Spring	0.017	1.7	Lognormal	Meijer (1990) [c]
Calico Hills, vitric	0.017	1.7	Lognormal	Assumed same as Topopah Spring
Calico Hills, zeolitic	0.0066	0.66	Lognormal	Meijer (1990) [c]
Prow Pass	0.013	1.3	Lognormal	Meijer (1990) [c]
Upper Crater Flat	0.0053	0.0053	Lognormal	Derived from Calico Hills, zeolitic [e]
Bullfrog	0.0094	0.94	Lognormal	Derived from Prow Pass [f]
Middle Crater Flat	0.0053	0.53	Lognormal	Same as Upper Crater Flat [e]
alluvium	—	1.7	Constant	Assumed for this analysis

Parameter	*Range in Value*		*Distribution*	*Basis for Parameter Assignment*
	High	*Low*		
Uranium				
Topopah Spring	0.00002	0.002	Lognormal	Meijer (1990) [c]
Calico Hills, vitric	0.002	0.2	Lognormal	Meijer (1990) [c]
Calico Hills, zeolitic	0.0001	0.01	Lognormal	Meijer (1990) [c]
Prow Pass	0.0	0.00001	Uniform	Assumed to be quite small
Upper Crater Flat	0.00008	0.008	Lognormal	Derived from Calico Hills, zeolitic [e]
Bullfrog	0.0002	0.02	Lognormal	Meijer (1990) [i]
Middle Crater Flat	0.00008	0.008	Lognormal	Derived from Calico Hills, zeolitic [e]
alluvium	—	0.2	Constant	Assumed for this analysis
Thorium				
Topopah Spring	0.0048	0.48	Lognormal	Codell *et al.* (1992) [b]
Calico Hills, vitric	0.034	3.4	Lognormal	Codell *et al.* (1992) [b]
Calico Hills, zeolitic	0.017	1.7	Lognormal	Codell *et al.* (1992) [b]
Prow Pass	0.012	1.2	Lognormal	Codell *et al.* (1992) [b]
Upper Crater Flat	0.014	1.4	Lognormal	Codell *et al.* (1992) [b]
Bullfrog	0.013	1.3	Lognormal	Codell *et al.* (1992) [b]
Middle Crater Flat	0.014	1.4	Lognormal	Codell *et al.* (1992) [b]
alluvium	—	3.4	Constant	Assumed for this analysis
Radium				
Topopah Spring	0.15	15.0	Lognormal	Meijer (1990) [j]
Calico Hills, vitric	0.15	15.0	Lognormal	Same as Topopah Spring
Calico Hills, zeolitic	0.15	15.0	Lognormal	Same as Topopah Spring
Prow Pass	0.15	15.0	Lognormal	Same as Topopah Spring
Upper Crater Flat	0.12	12.0	Lognormal	Derived from Calico Hills, zeolitic [e]
Bullfrog	0.5	50.0	Lognormal	Meijer (1990) [j]
Middle Crater Flat	0.12	12.0	Lognormal	Derived from Calico Hills, zeolitic [e]
alluvium	—	50.0	Constant	Assumed for this analysis

Parameter	Range in Value		Distribution	Basis for Parameter Assignment
	High	*Low*		
		Lead		
Topopah Spring	0.00068	0.068	Lognormal	Codell *et al.* (1992) [b]
Calico Hills, vitric	0.0049	0.49	Lognormal	Codell *et al.* (1992) [b]
Calico Hills, zeolitic	0.0025	0.25	Lognormal	Codell *et al.* (1992) [b]
Prow Pass	0.0017	0.17	Lognormal	Codell *et al.* (1992) [b]
Upper Crater Flat	0.0020	0.20	Lognormal	Codell *et al.* (1992) [b]
Bullfrog	0.0018	0.18	Lognormal	Codell *et al.* (1992) [b]
Middle Crater Flat	0.0020	0.20	Lognormal	Codell *et al.* (1992) [b]
alluvium	—	0.49	Constant	Assumed for this analysis
		Americium		
Topopah Spring	0.081	8.1	Loguniform	Meijer (1990) [c]
Calico Hills, vitric	0.081	8.1	Loguniform	Same as Topopah Spring
Calico Hills, zeolitic	0.17	17.0	Loguniform	Meijer (1990) [d]
Prow Pass	0.45	45.0	Loguniform	Meijer (1990) [f]
Upper Crater Flat	0.136	13.6	Loguniform	Derived from Calico Hills, zeolitic [e]
Bullfrog	0.014	1.4	Loguniform	Meijer (1990) [i]
Middle Crater Flat	0.136	13.6	Loguniform	Derived from Calico Hills, zeolitic [e]
alluvium	—	45.0	Constant	Assumed for this analysis
		Neptunium		
Topopah Spring	0.00045	0.045	Loguniform	Meijer (1990) [k]
Calico Hills, vitric	0.00045	0.045	Loguniform	Same as Topopah Spring
Calico Hills, zeolitic	0.00027	0.027	Loguniform	Meijer (1990) [j]
Prow Pass	0.00051	0.051	Loguniform	Meijer (1990) [i]
Upper Crater Flat	0.00022	0.022	Loguniform	Derived from Calico Hills, zeolitic [e]
Bullfrog	0.00051	0.05	Loguniform	Same as Prow Pass
Middle Crater Flat	0.00022	0.022	Loguniform	Derived from Calico Hills, zeolitic [e]
alluvium	—	0.051	Constant	Assumed for this analysis

Parameter	Range in Value		Distribution	Basis for Parameter Assignment
	High	Low		
Cesium				
Topopah Spring	0.036	3.6	Loguniform	Meijer (1990) [i]
Calico Hills, vitric	0.024	2.4	Loguniform	Meijer (1990) [g]
Calico Hills, zeolitic	2.2	220.0	Loguniform	Meijer (1990) [h]
Prow Pass	0.22	22.0	Loguniform	Meijer (1990) [i]
Upper Crater Flat	1.76	176.0	Loguniform	Meijer (1990) [e]
Bullfrog	0.32	32.0	Loguniform	Meijer (1990) [i]
Middle Crater Flat	1.76	176.0	Loguniform	Derived from Calico Hills, zeolitic [e]
alluvium	—	220.0	Constant	Assumed for this analysis
Iodine				
Topopah Spring	0.0	0.0001	Uniform	Assumed to be quite small.
Calico Hills, vitric	0.0	0.0001	Uniform	Assumed to be quite small.
Calico Hills, zeolitic	0.0	0.0001	Uniform	Assumed to be quite small.
Prow Pass	0.0	0.0001	Uniform	Assumed to be quite small.
Upper Crater Flat	0.0	0.0001	Uniform	Assumed to be quite small.
Bullfrog	0.0	0.0001	Uniform	Assumed to be quite small.
Middle Crater Flat	0.0	0.0001	Uniform	Assumed to be quite small.
alluvium	—	0.0	Constant	Assumed for this analysis
Tin				
Topopah Spring	0.0134	1.34	Loguniform	Codell *et al.* (1992) [h]
Calico Hills, vitric	0.097	9.7	Loguniform	Codell *et al.* (1992) [h]
Calico Hills, zeolitic	0.049	4.9	Loguniform	Codell *et al.* (1992) [h]
Prow Pass	0.034	3.4	Loguniform	Codell *et al.* (1992) [h]
Upper Crater Flat	0.039	3.9	Loguniform	Codell *et al.* (1992) [h]
Bullfrog	0.035	3.5	Loguniform	Codell *et al.* (1992) [h]
Middle Crater Flat	0.039	3.9	Loguniform	Codell *et al.* (1992) [h]
alluvium	—	9.7	Constant	Assumed for this analysis

Parameter	Range in Value		Distribution	Basis for Parameter Assignment
	High	Low		
Technetium				
Topopah Spring	0.000001	0.0001	Loguniform	Meijer (1990) [k]
Calico Hills, vitric	0.0	0.0001	Uniform	Assumed to be quite small.
Calico Hills, zeolitic	0.0	0.0001	Uniform	Assumed to be quite small.
Prow Pass	0.000017	0.0017	Loguniform	Meijer (1990) [m]
Upper Crater Flat	0.0	0.0001	Uniform	Derived from Calico Hills, zeolitic
Bullfrog	0.00042	0.042	Loguniform	Meijer (1990) [m]
Middle Crater Flat	0.0	0.0001	Uniform	Derived from Calico Hills, zeolitic
alluvium	—	0.042	Constant	Assumed for this analysis
Zirconium				
Topopah Spring	0.00048	0.048	Loguniform	Codell *et al.* (1992) [b]
Calico Hills, vitric	0.0034	0.34	Loguniform	Codell *et al.* (1992) [b]
Calico Hills, zeolitic	0.0017	0.17	Loguniform	Codell *et al.* (1992) [b]
Prow Pass	0.0012	0.12	Loguniform	Codell *et al.* (1992) [b]
Upper Crater Flat	0.0014	0.14	Loguniform	Codell *et al.* (1992) [b]
Bullfrog	0.0013	0.13	Loguniform	Codell *et al.* (1992) [b]
Middle Crater Flat	0.0014	0.14	Loguniform	Codell *et al.* (1992) [b]
alluvium	—	0.34	Constant	Assumed for this analysis
Strontium				
Topopah Spring	0.008	0.8	Loguniform	Meijer (1990) [i]
Calico Hills, vitric	0.0034	0.34	Loguniform	Meijer (1990) [g]
Calico Hills, zeolitic	0.89	89.0	Loguniform	Meijer (1990) [h]
Prow Pass	0.045	4.5	Loguniform	Meijer (1990) [i]
Upper Crater Flat	0.71	71.0	Loguniform	Derived from Calico Hills, zeolitic [c]
Bullfrog	0.028	2.8	Loguniform	Meijer (1990) [i]
Middle Crater Flat	0.71	71.0	Loguniform	Derived from Calico Hills, zeolitic [c]
alluvium	—	89.0	Constant	Assumed for this analysis

Parameter	Range in Value		Distribution	Basis for Parameter Assignment
	High	Low		
Nickel				
Topopah Spring	0.00037	0.037	Loguniform	Codell *et al.* (1992) [b]
Calico Hills, vitric	0.0027	0.27	Loguniform	Codell *et al.* (1992) [b]
Calico Hills, zeolitic	0.0014	0.14	Loguniform	Codell *et al.* (1992) [b]
Prow Pass	0.0009	0.09	Loguniform	Codell *et al.* (1992) [b]
Upper Crater Flat	0.0011	0.11	Loguniform	Codell *et al.* (1992) [b]
Bullfrog	0.001	0.1	Loguniform	Codell *et al.* (1992) [b]
Middle Crater Flat	0.0011	0.11	Loguniform	Codell *et al.* (1992) [b]
alluvium	—	0.27	Constant	Assumed for this analysis
Carbon				
Topopah Spring	0.0	0.0001	Uniform	Assumed to be quite small.
Calico Hills, vitric	0.0	0.0001	Uniform	Assumed to be quite small.
Calico Hills, zeolitic	0.0	0.0001	Uniform	Assumed to be quite small.
Prow Pass	0.0	0.0001	Uniform	Assumed to be quite small.
Upper Crater Flat	0.0	0.0001	Uniform	Assumed to be quite small.
Bullfrog	0.0	0.0001	Uniform	Assumed to be quite small.
Middle Crater Flat	0.0	0.0001	Uniform	Assumed to be quite small.
alluvium	—	0.0	Constant	Assumed for this analysis
Selenium				
Topopah Spring	0.00026	0.026	Loguniform	Meijer (1990) [g]
Calico Hills, vitric	0.0003	0.03	Loguniform	Meijer (1990) [g]
Calico Hills, zeolitic	0.00045	0.045	Loguniform	Meijer (1990) [h]
Prow Pass	0.00025	0.025	Loguniform	Meijer (1990) [j]
Upper Crater Flat	0.00036	0.036	Loguniform	Derived from Calico Hills, zeolitic [e]
Bullfrog	0.0013	0.13	Loguniform	Meijer (1990) [j]
Middle Crater Flat	0.00036	0.036	Loguniform	Derived from Calico Hills, zeolitic [e]
alluvium	—	0.13	Constant	Assumed for this analysis

Parameter	Range in Value		Distribution	Basis for Parameter Assignment
	High	Low		
Niobium				
Topopah Spring	0.0	0.0001	Uniform	Assumed to be quite small.
Calico Hills, vitric	0.0	0.0001	Uniform	Assumed to be quite small.
Calico Hills, zeolitic	0.0	0.0001	Uniform	Assumed to be quite small.
Prow Pass	0.0	0.0001	Uniform	Assumed to be quite small.
Upper Crater Flat	0.0	0.0001	Uniform	Assumed to be quite small.
Bullfrog	0.0	0.0001	Uniform	Assumed to be quite small.
Middle Crater Flat	0.0	0.0001	Uniform	Assumed to be quite small.
alluvium	—	0.0	Constant	Assumed for this analysis
Fraction of Matrix k_d (percent)				
each of the seven hydrostratigraphic units	0.0	0.1	Uniform	Assumed for this analysis
UO_2 Alteration/Leach Rate (yr^{-1}), by Repository Sub-area [forwar]				
Subarea 1	0.000011	0.001	Loguniform	Estimate based on Grambow (1989)
Subarea 2	0.000021	0.001	Loguniform	Estimate based on Grambow (1989)
Subarea 3	0.000031	0.001	Loguniform	Estimate based on Grambow (1989)
Subarea 4	0.000041	0.001	Loguniform	Estimate based on Grambow (1989)
Subarea 5	0.000051	0.001	Loguniform	Estimate based on Grambow (1989)
Subarea 6	0.000061	0.001	Loguniform	Estimate based on Grambow (1989)
Subarea 7	0.000071	0.001	Loguniform	Estimate based on Grambow (1989)
Fraction of Waste Packages Contacted by Water (percent), by Repository Sub-area [warea]				
Subarea 1	0.0	1.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Subarea 2	0.0	1.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Subarea 3	0.0	1.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Subarea 4	0.0	1.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Subarea 5	0.0	1.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Subarea 6	0.0	1.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Subarea 7	0.0	1.0	Uniform	Assumed [based on Wescott *et al.* (1994)]

Parameter	*Range in Value*		*Distribution*	*Basis for Parameter Assignment*
	High	*Low*		
		Radionclide Solubility (Kg/m³) [sol]		
Curium	2.56×10^{-7}	0.0005	Loguniform	Assumed [based on Wescott *et al.* (1994)]
Plutonium	2.0×10^{-7}	0.0005	Loguniform	Assumed [based on Wescott *et al.* (1994)]
Uranium	4.0×10^{-8}	0.00003	Loguniform	Assumed [based on Wescott *et al.* (1994)]
Thorium	2×10^{-12}	0.0001	Loguniform	Assumed [based on Wescott *et al.* (1994)]
Radium	0.000009	0.00009	Loguniform	Assumed [based on Wescott *et al.* (1994)]
Lead	0.0000021	0.00063	Loguniform	Assumed [based on Wescott *et al.* (1994)]
Americium	0.000001	0.0003	Loguniform	Assumed [based on Wescott *et al.* (1994)]
Neptunium	0.00014	0.0237	Loguniform	Assumed [based on Wescott *et al.* (1994)]
Cesium	1000.0	1001.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Iodine	1000.0	1001.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Tin	5.0×10^{-9}	5.01×10^{-9}	Uniform	Assumed [based on Wescott *et al.* (1994)]
Technectium	1000.0	1001.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Zirconium	4.0×10^{-9}	4.01×10^{-9}	Uniform	Assumed [based on Wescott *et al.* (1994)]
Strontium	0.08	0.0801	Uniform	Assumed [based on Wescott *et al.* (1994)]
Nickel	2.8×10^{-7}	0.0017	Uniform	Assumed [based on Wescott *et al.* (1994)]
Carbon	1000.0	1001.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Selenium	1000.0	1001.0	Uniform	Assumed [based on Wescott *et al.* (1994)]
Niobium	1000.0	1001.0	Uniform	

Parameter	Range in Value		Distribution	Basis for Parameter Assignment
	High	Low		
Fluid Capture Area of Waste Package Canister (m^2) [funnel]				
Subarea 1	0.0	0.4	Uniform	Upper limit based on twice the cross-sectional area of SCP emplacement hole (see DOE, 1988)
Subarea 2	0.0	0.4	Uniform	Upper limit based on twice the cross-sectional area of SCP emplacement hole (see DOE, 1988)
Subarea 3	0.0	0.4	Uniform	Upper limit based on twice the cross-sectional area of SCP emplacement hole (see DOE, 1988)
Subarea 4	0.0	0.4	Uniform	Upper limit based on twice the cross-sectional area of SCP emplacement hole (see DOE, 1988)
Subarea 5	0.0	0.4	Uniform	Upper limit based on twice the cross-sectional area of SCP emplacement hole (see DOE, 1988)
Subarea 6	0.0	0.4	Uniform	Upper limit based on twice the cross-sectional area of SCP emplacement hole (see DOE, 1988)
Subarea 7	0.0	0.4	Uniform	Upper limit based on twice the cross-sectional area of SCP emplacement hole (see DOE, 1988)

Parameter	*Range in Value*		*Distribution*	*Basis for Parameter Assignment*
	High	*Low*		

a Reported range and correlation-length consideration.
b ± one order of magnitude of the mean of the log of retardation factors cited in Codell *et al.* (1992).
c ± one order of magnitude of the mean of the log of the reported values for Wells G3, J13, and UE25a1.
d ± one order of magnitude of the mean of the log of the reported value for Well G2.
e Allowances made for density and porosity.
f ± one order of magnitude of the mean of the log of the reported values for Wells G1and UE25a1.
g ± one order of magnitude of the mean of the log of the reported value for Well G3.
h ± one order of magnitude of the mean of the log of the reported values for Wells G1and G3.
i ± one order of magnitude of the mean of the log of the reported values for Wells G1, J13, and UE25a1.
j ± one order of magnitude of the mean of the log of the reported value for Well G1.
k ± one order of magnitude of the mean of the log of the reported values for Wells G3 and UE25a1.
l ± one order of magnitude of the mean of the log of the reported values for Wells G1, G3, and UE25a1.
m ± one order of magnitude of the mean of the log of the reported value for Well J13.
n ± one order of magnitude of the mean of the log of the reported values for Well UE25a1.

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APPENDIX I
STAFF PARTICIPATING IN THE PRELIMINARY PERFORMANCE-BASED ANALYSES

Staff members from the U.S. Nuclear Regulatory Commission Offices of Nuclear Material Safety and Safeguards (NMSS); and Nuclear Regulatory Research (RES), as well as Center for Nuclear Waste Regulatory Analyses (CNWRA) staff members, have contributed to this NUREG. Each of the eight divisions of technical activity was assigned to a working group with a designated task leader(s). The task leaders proposed plans for the various technical activities and staffing. The staff cited below were responsible for conducting the respective analyses and documenting the results.

Scoping Analysis Topic Area	*Analysis Team[a]/Organization*
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Volcanism	**M. Jarzemba/CNWRA** **T. McCartin/NMSS** R. Codell/NMSS B. Hill/CNWRA C. McKenny/NMSS J. Trapp/NMSS R. Wescott/NMSS
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[a] Bold type designates principal investigators.
[b] Retired.
[c] Independent consultants.

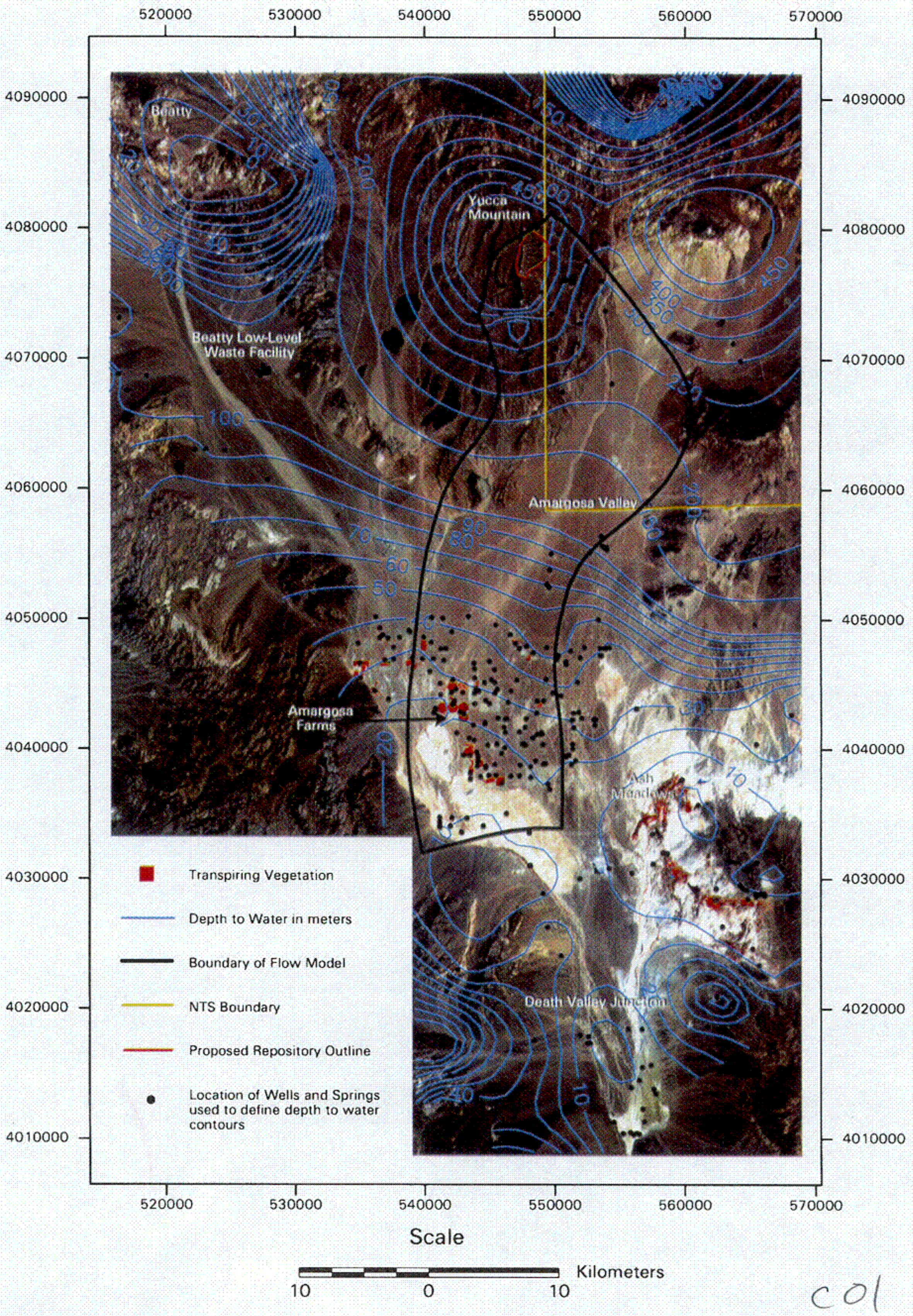

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Figure 2–5. Landsat Image of the Yucca Mountain and the Amargosa Desert Region. In the Amargosa Farms area, red circular forms are quarter-section, center-pivot irrigation plots. These contrast with flood-irrigation plots shown as rectangular-shaped forms. Irregular red patches correspond to areas in Ash Meadows containing wetland/riparian vegetation. Blue contour lines showing the depth to the water table are in the equivalent of meters. Thematic sensor data from the Landsat satellite were used to produce the background image. Satellite altitude was approximately 185 kilometers (115 miles).

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

The NAS recommended that standards for HLW disposal at Yucca Mountain should: (1) set a limit on individual risk; (2) use the ICRP critical group approach; (3) define the critical group using present knowledge and cautious, reasonable assumptions; (4) use a time period for conducting compliance assessment that includes the period of greatest risk; and (5) use a stylized calculation to assess whether the repository's performance would be substantially degraded as a consequence of a postulated intrusion. The staff was able to: (1) tentatively identify characteristics for two potential receptor groups using information for lifestyles and water-use practices presently occurring in the Yucca Mountain area and in other, similar environments; (2) ascertain the potential for reducing radionuclide concentrations in ground water caused by dispersive transport processes and borehole mixing in a pumping water well; (3) describe an approach to implement a dose calculation for the residential and farming receptor groups; (4) describe an approach to implement a dose calculation for direct disruption of the repository from volcanic activity; (5) describe an approach to a stylized calculation for human intrusion; and (6) evaluate the time dependence of radiological hazard of HLW by comparison with naturally concentrated uranium in an ore body.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

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dilution
disruptive events
dose
exploratory drilling
geologic repository
ground water
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human intrusion
Iterative performance assessment
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