RAI Volume 3, Chapter 2.2.1.2.1, Fifth Set, Number 5, Supplemental Response:

Provide a technical basis for exclusion of FEP 2.2.07.05.0A that addresses: (1) the observation that temporally varying percolation fluxes may induce time-averaged seepage that is larger than would occur with the same average flux applied at a steady rate; (2) temperature and tritium field observations that suggest episodic flow may be prevalent at Yucca Mountain, at least in scattered locations; and (3) why multi-decadal climate fluctuations necessarily have a negligible effect on performance when percolation fluctuations demonstrably may result in a systematic increase in seepage. This information is needed to evaluate compliance with 10 CFR 63.114.

Basis: Depending on the timing of the fluctuations, temporally varying percolation fluxes may induce time-averaged seepage that is larger than would occur with the same average flux applied at a steady rate. For example, DOE (2009, RAI 3.2.2.1.1-002, Figure 1-1) provides an illustrative example with mean seepage 50 percent larger under variable percolation fluxes than under the equivalent steady percolation flux.

The screening argument for excluding FEP 2.2.07.05.0A relies on numerical modeling to demonstrate that the porous matrix of the PTn imbibes wetting pulses. The screening argument uses a numerical model to explain observations of chlorine-36 in the ESF as a result of fast pathways from approximately 1 percent of infiltration. However, the screening argument does not address temperature and tritium field observations that suggest episodic flow may be prevalent at Yucca Mountain, at least in scattered locations.

1. RESPONSE

This RAI response provides additional information to support exclusion of the feature, event, or process (FEP) described under FEP 2.2.07.05.0A, *Flow in the UZ from Episodic Infiltration*, addressing: (1) temporally varying percolation fluxes; (2) temperature and tritium data relevant to episodic flow; and (3) climate and seepage fluctuations relevant to performance. This response shows that DOE relied on field tests, site data, and modeling to demonstrate that the porous matrix of the Paintbrush nonwelded (PTn) hydrogeologic unit imbibes wetting pulses. Therefore, excluding episodic flow from the performance assessment on the basis of low consequence is justified.

Analyses are provided in Section 1.1 to respond to: (1) the observation that temporally varying percolation fluxes may induce time-averaged seepage that is larger than would occur with the same average flux applied at a steady rate, and (3) why multi-decadal climate fluctuations necessarily have a negligible effect on performance when percolation fluctuations demonstrably may result in a systematic increase in seepage. This is an extension of an existing analysis presented in the response to RAI 3.2.2.1.1-002.

An evaluation of the tritium data and pertinent temperature data are provided in Sections 1.2 and 1.3, respectively, to respond to (2) concerning the consistency of these data relative to the exclusion of episodic flow.

Sections 1.4 and 1.5 present evaluations of field observations of transient flow behavior in the PTn hydrogeologic unit and measurements of ^{14}C in the unsaturated zone. These data provide additional evidence supporting the exclusion of episodic flow.

Throughout this response, reference is made to three different classifications of unsaturated zone stratigraphy, lithostratigraphic nomenclature, unsaturated zone flow model layers, and major hydrogeologic units. A cross-walk between these different classifications is given in Table 1. There is a general correspondence between unsaturated zone flow model layers and major hydrogeologic units.

Table 1. Unsaturated Zone Stratigraphic Cross-Walk

Lithostratigraphic Nomenclature	Unsaturated Zone Flow Model Layer	Major Hydrogeologic Units
Tpcr	tcw11	Tiva Canyon welded
Tpcp	tcw12	(TCw)
TpcLD		
Tpcpv3	tcw13	
Tpcpv2		
Tpcpv1	ptn21	Paintbrush nonwelded
Tpbt4	ptn22	(PTn)
Tpy (Yucca)		
	ptn23	
	ptn24	
Tpbt3		
Tpp (Pah)	ptn25	
Tpbt2	ptn26	
Tptrv3		
Tptrv2		
Tptrv1	tsw31	Topopah Spring Welded
Tptrn		(TSw)
	tsw32	
Tptrl, Tptf	tsw33	
Tptpul, RHHtop		
Tptpmn	tsw34	
Tptpll	tsw35	
Tptpln	tsw36	
	tsw37	
Tptpv3	tsw38	

Table 1. Unsaturated Zone Stratigraphic Cross-Walk (Continued)

Lithostratigraphic Nomenclature	Unsaturated Zone Flow Model Layer	Major Hydrogeologic Units
Tptpv2	tsw39 (vit, zeo)	Calico Hills nonwelded (CHn)
Tptpv1	ch1 (vit, zeo)	
Tpbt1		
Tac (Calico)	ch2 (vit, zeo)	
	ch3 (vit, zeo)	
	ch4 (vit, zeo)	
	ch5 (vit, zeo)	
Tacbt (Calicobt)	ch6 (vit, zeo)	
Tcpuv (Prowuv)	pp4	
Tcpuc (Prowuc)	pp3	
Tcpmd (Prowmd)	pp2	
Tcplc (Prowlc)		
Tcplv (Prowlv)	pp1	
Tcpbt (Prowbt)		
Tcbuv (Bullfroguv)		
Tcbuc (Bullfroguc)	bf3	Crater Flat undifferentiated (CFu)
Tcbmd (Bullfrogmd)		
Tcblc (Bullfroglc)		
Tcblv (Bullfroglv)	bf2	
Tcbbt (Bullfrogbt)		
Tctuv (Tramuv)		
Tctuc (Tramuc)	tr3	
Tctmd (Trammd)		
Tctlc (Tramlc)		
Tctlv (Tramlv)	tr2	
Tctbt (Trambt) and below		

Source: SAR Table 2.3.2-2.

1.1 INFILTRATION VARIABILITY, TRANSIENT FLOW, AND EFFECTS ON SEEPAGE INTO DRIFTS

1.1.1 Exclusion of Episodic Flow

FEP 2.2.07.05.0A, *Flow in the UZ from Episodic Infiltration*, provides information to justify exclusion of episodic flow in the unsaturated zone from the total system performance assessment (TSPA). Infiltration refers to water movement from the ground surface or, if present, unconsolidated surficial materials, into one of the unsaturated zone strata shown in Table 1; percolation refers to water movement within the unsaturated zone domain. The analysis focuses on episodic infiltration events characteristic of desert climates where infiltration occurs over a few days during a typical year (SNL 2008a, Figure 6.5.7.7-6[a]). The unsaturated zone above the repository is divided into three main hydrogeologic units: the Tiva Canyon welded (TCw) hydrogeologic unit, the PTn hydrogeologic unit, and the Topopah Spring welded (TSw)

hydrogeologic unit. The TCw and TSw hydrogeologic units have low rock matrix porosity and permeability along with high fracture permeability that tends to transmit episodic flow with relatively little damping. By contrast, the PTn hydrogeologic unit, which is between the TCw and the TSw hydrogeologic units, has much greater rock matrix porosity and permeability, along with high capillary strength relative to the fractures. These characteristics of the PTn hydrogeologic unit rock matrix lead to strong imbibition from the fracture system and significant damping of episodic flow (SAR Section 2.3.2.2.1).

Simulations of extreme events were performed using an episodic infiltration pattern consisting of a week-long infiltration episode every 50 years (SNL 2007a, Section 6.9). During the week-long episode, the infiltration is raised by a factor of about 360 above the prevailing rate during the remainder of the 50-year cycle. The simulations were conducted for a representative "thin" PTn hydrogeologic unit with a thickness of 21 m and a representative "thick" PTn hydrogeologic unit with a thickness of 81 m. The simulations show that percolation fluxes resulting from episodic infiltration are substantially damped by the PTn hydrogeologic unit. The maximum percolation flux variation below the PTn is about 50% of the mean for the case with a thin PTn and only a few percent for the case with a thick PTn hydrogeologic unit. These variations in flux are small in comparison with other uncertainties in percolation flux included in the TSPA model, and support exclusion of episodic flow below the PTn hydrogeologic unit on the basis of low consequence.

1.1.2 Infiltration Variability and Transient Flow Phenomena

Longer-term changes in climate in the TSPA are represented through discrete climate states that are explicitly included in the infiltration model and downstream models, including drift seepage. Climate states are defined for specific durations into the future and last from hundreds to thousands of years. Uncertainty in climate and infiltration is represented by discrete, temporally uniform scenarios for each climate state. However, as pointed out in the Center for Nuclear Waste Regulatory Analyses (CNWRA) report, "The Nature of Flow in the Faulted and Fractured Paintbrush Nonwelded Hydrogeologic Unit" (Manepally et al. 2007), temporal variations in infiltration can deviate from the longer-term climate state mean, and these deviations may persist for decades to centuries.

The main focus of Manepally et al. (2007) was to evaluate the effects of these longer-term temporal variations in infiltration on flow in and below the PTn hydrogeologic unit. The study found that temporal variations in percolation flux fall within ±20% of the long-term average 80% of the time, and that the range in percolation flux falls within 50% of the long-term average. The effect of longer-term transient flow as presented by CNWRA (Manepally et al. 2007) was discussed in SAR Section 2.3.2.4.2.1.2. Variations in percolation flux induced by longer-term transient flow are similar in magnitude to those found in the investigation of shorter-term transient flow. These are excluded because of larger variations in percolation flux associated with infiltration uncertainty. The range in percolation flux for short- and long-term transient flow processes is used to provide a more specific evaluation of effects of episodic flow on drift seepage.

1.1.3 Effects of Infiltration Variability on Longer-Term Transient Flow and Drift Seepage

The question of barrier performance relative to damping of episodic flow is described in the response to RAI 3.2.2.1.1-002. That RAI response demonstrates drift seepage is smaller for a steady flow process than for an episodic flow process with the same average percolation flux. The question here is similar: what is the impact on drift seepage of an assumed steady flow for each climate state given that some level of transient flow behavior may penetrate the PTn hydrogeologic unit and affect percolation flux at waste emplacement drifts. Therefore, the analysis of mean seepage rate as a function of percolation flux for transient and equivalent steady flow processes is presented in the response to RAI 3.2.2.1.1-002 is also applicable to this question.

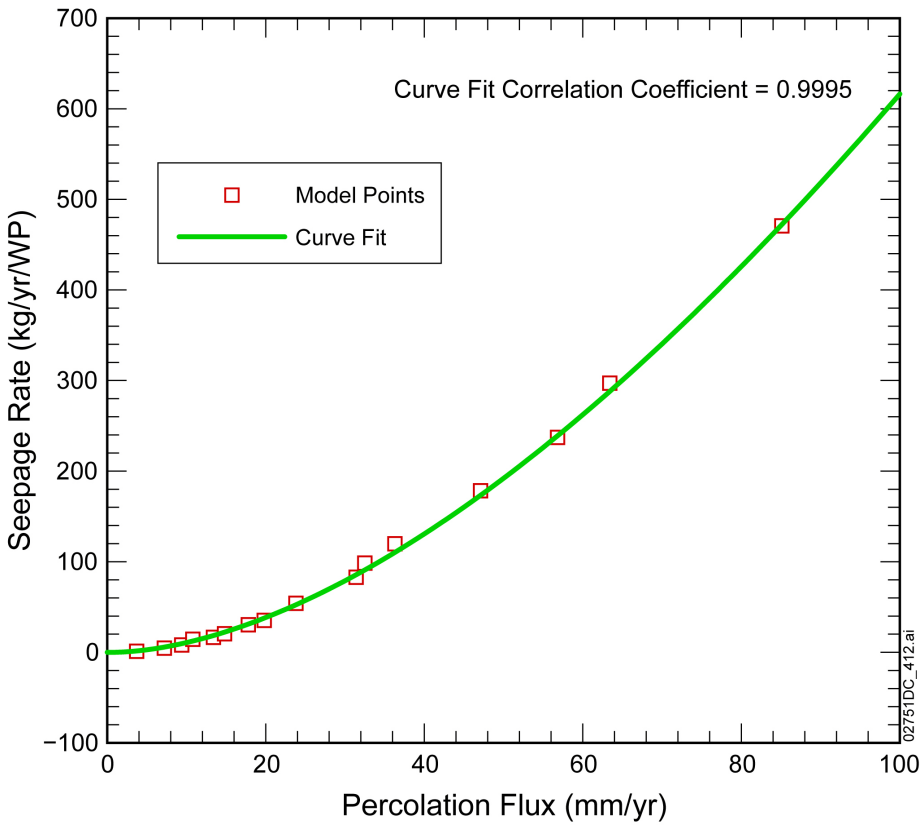
If seepage into drifts is assumed to be a quasi-steady process under transient percolation flux conditions, the variation in seepage behavior for different steady percolation fluxes may be used to evaluate differences in seepage rate into drifts for episodic percolation flux conditions as compared with the equivalent steady percolation flux. "Equivalent steady percolation flux" is defined as the time-weighted average of the series of spatially averaged percolation fluxes defining the episodic flow process. In this response, spatially averaged percolation flux over the repository footprint is referred to as "percolation flux."

The mean seepage rate as computed in the seepage abstraction model is the total amount of water entering drifts divided by the total number of waste packages (SNL 2007b, p. 6-29[a]). In this response, only mean seepage rates will be discussed. (To simplify the description, "mean seepage rate" will be termed "seepage rate.") Because the total number of waste packages is constant, only the seepage rate per waste package needs to be considered as a function of percolation flux. The relationship between seepage rate and percolation flux is shown in Figure 1. The model points (red squares on Figure 1) have been fit using an empirical function (green line on Figure 1) that is constrained to be zero for a percolation flux less than 1 mm/yr and is asymptotically proportional to the percolation flux for large values. The seepage rate curve fit is given by:

$$S_{rm} = H(P_a - 1)\left[0.2\exp(-0.003P_a)(P_a - 1)^{1.69} + 28.05\{1 - \exp(-0.001P_a)\}P_a\right]$$

where S_{rm} is the seepage rate in kg/yr per waste package, P_a is the percolation flux in mm/yr, and H is the step function which equals 1 for $P_a - 1 \geq 0$ and 0 otherwise.

The model points and curve fit show that the seepage rate curve is convex over the range of percolation fluxes displayed in Figure 1. The asymptotic linear behavior of the seepage rate curve occurs at percolation fluxes in excess of 100 mm/yr.



Source: Model points from SNL 2007b, Tables 6-5[a] and 6-6[a].

Figure 1. Seepage Rate as a Function of Percolation Flux

The analysis from CNWRA (Manepally et al. 2007, Section 4.6) suggests two cases to evaluate transient infiltration effects on seepage. Case 1 is a bimodal episodic process defined by end members with percolation fluxes that are ±20% of the average percolation flux. Case 2 is a bimodal episodic process defined by end members with percolation fluxes that are ±50% of the average percolation flux. These two cases for the analysis are evaluated using the 10th, 30th, 50th, and 90th percentile infiltration cases and the glacial-transition climate. This climate was chosen because it has the longest duration of any climate state over the 10,000-year period evaluated for FEP 2.2.07.05.0A. These scenarios are referred to as the 10th, 30th, 50th, and 90th percentile infiltration cases because these cases yield corresponding percentiles of net infiltration in the output from the infiltration model prior to calibration with unsaturated zone temperature and chloride data (SNL 2007a, Section 6.8). Results for these two cases are given in Tables 2 and 3, showing that the mean seepage rate for steady-state processes is less than the equivalent transient process. In addition to the percolation fluxes and mean seepage rates for the steady flow and transient processes, each table displays the weights applied in TSPA after calibration, used here for computing averages and standard deviations. These weights are calibrated probabilities for infiltration uncertainty cases accounting for unsaturated zone temperature and chloride data (SAR Section 2.3.2.4.1.2.4.5). As can be seen in Tables 2 and 3, differences in mean seepage rate between transient and episodic flow processes are approximately 2% to 3% for Case 1, and approximately 13% to 18% for Case 2. By comparison, the uncertainty for mean

seepage rate associated with uncertainty in percolation flux is 137%. Furthermore, the response to RAI 3.2.2.1.3.6-007 has shown that a minor increase in mean percolation flux, and the associated minor increase in mean seepage rate, would have a negligible effect on estimates of repository performance for 10,000 years after closure. Therefore, the effects of temporal fluctuations in percolation flux within a climate state have a negligible effect on the mean seepage rate, supporting the low consequence exclusion of FEP 2.2.07.05.0A.

Table 2. Case 1: Seepage Results for Transient Flow Variations in Percolation Flux of ±20%

Glacial Transition Uncertainty Scenarios	Steady Flow Percolation Rate (mm/yr)	Steady Flow Process Mean Seepage Rate (kg/yr per waste package)	Transient Flow Process Mean Seepage Rate (kg/yr per waste package)	TSPA Weighting Factors	Percent Difference in Mean Seepage Rate
10th percentile	12.2	15.6	16.0	0.6191	2.9
30th percentile	26.3	62.6	64.2	0.1568	2.6
50th percentile	36.2	109.8	112.5	0.1645	2.4
90th percentile	69.7	338.0	345.1	0.0596	2.1
Average	21.8	57.7	59.1		2.4
Standard deviation	15.2	78.9	80.6		2.1
Coefficient of variation	70%	137%	136%		

Table 3. Case 2: Seepage Results for Transient Flow Variations in Percolation Flux of ±50%

Glacial Transition Uncertainty Scenarios	Steady Flow Percolation Rate (mm/yr)	Steady Flow Process Mean Seepage Rate (kg/yr per waste package)	Transient Flow Process Mean Seepage Rate (kg/yr per waste package)	TSPA Weighting Factors	Percent Difference in Mean Seepage Rate
10th percentile	12.2	15.6	18.4	0.6191	18.2
30th percentile	26.3	62.6	72.7	0.1568	16.2
50th percentile	36.2	109.8	126.7	0.1645	15.3
90th percentile	69.7	338.0	382.9	0.0596	13.3
Average	21.8	57.7	66.5		15.2
Standard deviation	15.2	78.9	89.4		13.3
Coefficient of variation	70%	137%	135%		

1.2 TRITIUM DATA AND EPISODIC FLOW

1.2.1 Fast Transport from the Ground Surface and the Conceptual Flow Model in the Unsaturated Zone.

The unsaturated zone flow model has been used to investigate the possibility of rapid transport between the ground surface and the repository level for comparison to observations of ^{36}Cl (SAR 2.3.2.3.4.3). The investigation was based on the steady-flow conceptual model over the entire model domain. In that study, approximately 1% of the tracer released at the ground surface arrived at the level of the repository within a 50-year time period. The study further showed that fast transport was principally facilitated by faults. Thus, a small fraction of water that entered the unsaturated zone during the time of nuclear device testing in the 1950s and 1960s, when atmospheric ^{36}Cl levels rose significantly, can be expected to be present at the repository level, particularly in faults. Therefore, the presence of modern water (water that entered the unsaturated zone since 1952 when nuclear device testing began at the Nevada Test Site) at the repository level can be explained within the framework of the steady-flow approximation.

As a result of heterogeneity in rock properties and stratigraphy, heterogeneity in infiltration, and diffusion and dispersion mechanisms, it is generally expected that some small fraction of water that entered the unsaturated zone within the last 50 years has penetrated to the repository level. This fraction is larger in faults because the hydrogeologic properties of faults result in greater fracture flow through the PTn hydrogeologic unit than in the general fractured rock mass.

1.2.2 Factors That May Lead to the Appearance of Modern Water in the Deep Unsaturated Zone

The main processes and boundary conditions that can lead to the appearance of tritium in the deep unsaturated zone (in the lower PTn hydrogeologic unit and below), consistent with the conceptual model for unsaturated zone flow and transport, are the following:

(1) Transport through faults

(2) Partial penetration of the PTn hydrogeologic unit in the fractured rock mass (other than faults) by episodic fracture flow

(3) Spatially variable infiltration patterns

(4) Heterogeneous hydrologic properties within unsaturated zone flow model layers

(5) Hydrodynamic dispersion.

The conceptual model and model parameterization of the unsaturated zone flow model leads to significant fracture flow through the PTn hydrogeologic unit in some fault locations but not in the fractured rock mass. Therefore, rapid transport through and beneath the PTn hydrogeologic unit is most pervasive in faults. Predominant matrix flow and transport in the fractured rock mass below the repository are limited to the vitric portion of the CHn hydrogeologic unit and to a

lesser degree in some of the devitrified and welded units lower in the CHn (Prow Pass) and Crater Flat undifferentiated (CFu) hydrogeologic units.

Observations at UE-25 UZ#4 in Pagany Wash (see Section 1.3.2) and model calculations (SNL 2007a, Section 6.9) indicate that episodic flow in fractures located in the Tiva Canyon welded hydrogeologic unit (TCw) can transport water into the PTn hydrogeologic unit. Monitoring data indicate that the water entered the Yucca Mountain Tuff lithostratigraphic unit (a component of the PTn hydrogeologic unit), but evidence of episodic flow below the Yucca Mountain Tuff was not observed over two additional years of data collection (LeCain et al. 2002). Therefore, this episodic event appeared to be damped within the PTn hydrogeologic unit.

Additional factors can lead to the appearance of elevated tritium levels in the deep unsaturated zone (i.e., PTn and below). These include spatially variable infiltration and smaller-scale heterogeneity in hydrologic properties within the unsaturated zone, which can lead to spatially variable percolation fluxes and transport velocities. Dispersion can also be important because this mechanism advances low concentrations faster than the average transport velocity.

1.2.3 Source of Tritium

Tritium originates in the atmosphere through natural processes at a natural tritium concentration level of about 6 tritium units (TU) for precipitation at Yucca Mountain (BSC 2006, Section 5). In addition to natural processes, nuclear device testing during the 1950s and 1960s elevated atmospheric tritium levels (bomb-pulse tritium) with peak levels of about 1,900 TU (Figure 2) measured in precipitation at Albuquerque, New Mexico. Local data in the vicinity of Yucca Mountain over this entire time period are not available. Tritium decays with a half-life of about 12.3 years (BSC 2006, Section 5).

Because unsaturated zone tritium measurements at Yucca Mountain were made during the period 1993 through 2002, source term decay must be considered. When corrected for decay to 1995, peak tritium level decreases to about 300 TU. Decay-corrected tritium levels above 100 TU only occur for years 1963 and 1964. Decay-correction to 2002 reduces the maximum tritium concentrations to about 200 TU. The threshold tritium level indicating the presence of modern water (post 1952) was determined to be in the range of 1.4 to 2 TU (BSC 2006, Sections 5.4.1 and 5.4.2), which is approximately the background level of 6 TU decayed over 2 half-lives. For this discussion, the 1.4 TU threshold is used in order to ensure that the potential presence of modern water is not underestimated.

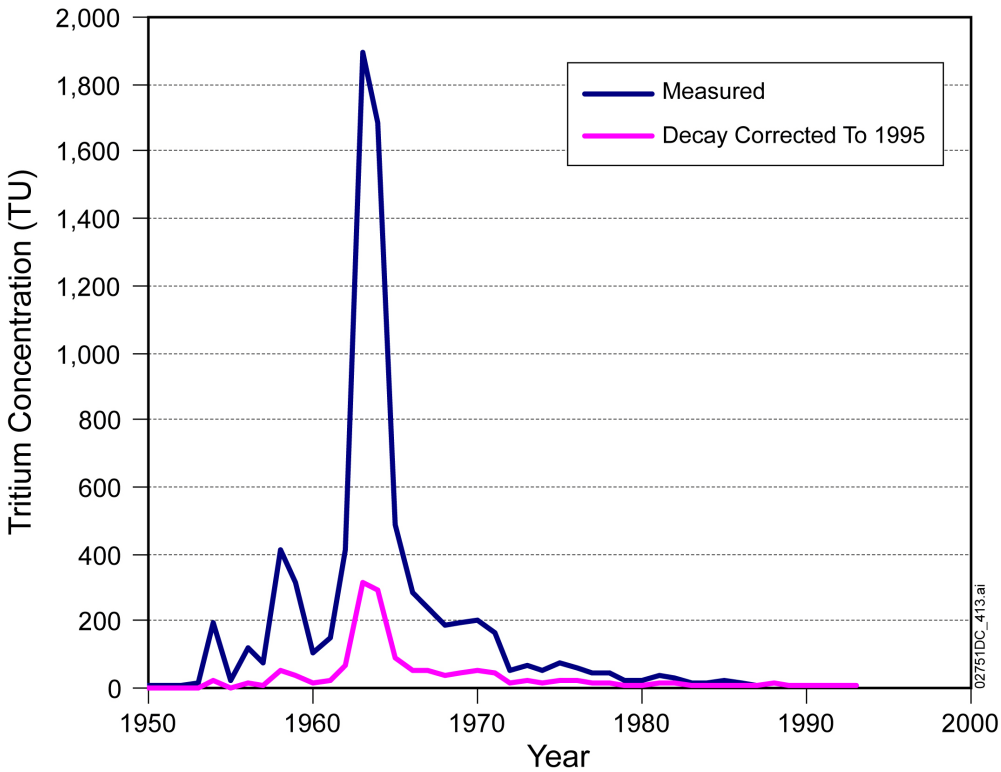


Figure 2. Atmospheric Tritium Levels at Albuquerque, New Mexico

To quantitatively assess the fraction of modern water represented by a tritium concentration above the threshold, it is necessary to know the tritium levels of infiltrating waters over the past 50 years, using the source term curve presented in Figure 2, for Albuquerque, New Mexico. However, a new analysis of existing information presented below indicates that the tritium concentrations in infiltrating water at Yucca Mountain must have been higher than the data derived from the Albuquerque measurements would suggest. If so, the fraction of modern water necessary to achieve a given tritium concentration would be correspondingly reduced.

1.2.4 Tritium Measurements on Unsaturated Zone Samples

Tritium was measured for approximately 860 samples from the unsaturated zone at Yucca Mountain. Measurement techniques changed over time, which generally resulted in improved detection limits (Peterman 2003; BSC 2006). The tritium data are divided into two categories representing samples from surface-based boreholes (Table 4) and samples from the Exploratory Studies Facility (ESF) and Enhanced Characterization of the Repository Block (ECRB) drifts (Table 5). (Because of their length, these tables are located at the end of the response following the summary in Section 1.6.) Because the detection limits of 8.2 to 17.1 TU for this analysis exceeded the threshold for the presence of modern water, measured tritium values that lie below the detection limit are not considered interpretable relative to the presence of modern water and are not included in Table 4.

Data in Table 5 present the tritium measurements from the ESF and the ECRB drifts. The majority of the data from the ESF and all of the ECRB samples were analyzed using a more sensitive technique having a detection limit of 0.4 to 1 TU (BSC 2006, Section 5.4.2). A limited number of measurements from the ESF were analyzed using the less sensitive method. For these data, as for the surface-based borehole data, any ESF samples with measured tritium levels below the detection limits of 8.2 to 17.1 TU are not included in Table 5. Measurements using the more sensitive technique were not screened based on detection limits. With the exception of nine values, the data presented in Table 5 are for samples analyzed using the more sensitive technique. The screening based on detection limits excludes approximately 500 of the 860 total samples from Tables 4 and 5.

Uncertainty in the less sensitive method is a combination of both "internal" and "external" uncertainties. The internal error, based on counting statistics, is estimated to be about ±4 TU (Peterman 2003). The external error was estimated, using 29 duplicate and 6 triplicate analyses, to be 5.7 TU. The internal and external uncertainties are combined to yield the total uncertainty using:

$$\sigma_{total} = (\sigma_{internal}^2 + \sigma_{external}^2)^{0.5}$$

to yield a combined 1σ error of about ±7 TU (2σ = ±14 TU). When estimates of detection limits and analytical uncertainty are combined, only analyses having uncertainties greater than 22 to 31 TU can be considered to contain tritium that is detectable above analytical background at the 95% confidence interval (Table 4). Note that this cutoff eliminates post-bomb pulse waters that have returned to pre-bomb-pulse levels, and hence does not screen directly for modern waters (TU ~ 6TU).

In Table 4, samples with tritium concentrations above the 95th percentile confidence limit from the surface-based boreholes are highlighted in yellow. These measurements are considered interpretable and indicate the presence of bomb-pulse water. In Table 5, samples from the ESF and ECRB with tritium concentrations greater than or equal to 1.4 TU are highlighted in yellow. These measurements indicate the presence of modern water.

Tables 4 and 5 provide additional information for the tritium measurements, including sample identification and location, date, extraction method, stratigraphy, unsaturated zone flow model layer, and qualification status.

1.2.5 Qualitative Assessment of Tritium Information from Surface-Based Boreholes

Table 4 presents the measurements of tritium from the surface-based boreholes that are above detection limits. Tritium values above the 95th percentile confidence limit were found in boreholes UE-25 UZ-16, USW WT-24, USW SD-6, USW NRG-6, USW UZ-14, USW SD-12, and USW NRG-7a. Distances between boreholes and faults are based on Figure 6.1-1 of *UZ Flow Models and Submodels* (SNL 2007a). A large number of measured values from the surface-based boreholes lie below detection limits. To provide information on the coverage of the measurements, Figures 3, 4, and 5 also include non-negative values that are below detection limits.

Borehole UE-25 UZ-16

Thirty-two elevated measurements of tritium were found for borehole UE-25 UZ-16 within the ptn21, tsw31-tsw32, tsw34 through tsw38, ch2-ch5, and pp4 unsaturated zone flow model layers (Figure 3). The borehole lies about 160 m west of the Imbricate Fault, about 300 m east of the Dune Wash Fault, and more than a kilometer east of waste emplacement areas. Geologic maps of the ESF South Ramp, which lies about a kilometer south of the borehole, identified additional (unnamed) faults east of the Dune Wash Fault (BSC 2006, Figure 5-5). The presence of faults in the immediate vicinity of UE-25 UZ-16 is uncertain because of alluvial cover. The highest levels of tritium in the unsaturated zone were found in two samples in the tsw34 at levels of 300 to nearly 500 TU. These samples were collected in 1995. The maximum possible levels based on the source term for tritium is about 300 TU when decay-corrected to 1995. Furthermore, even a value of 300 TU is highly unlikely, because the source was at this level for only two years (1963 and 1964) and the samples are from depths of over 180 meters. The high values of tritium found in UE-25 UZ-16 are concluded to be due to the proximity of Yucca Mountain to the source of atmospheric tritium, the Nevada Test Site. These values would have been greater than those estimated from the regional information collected in Albuquerque, New Mexico.

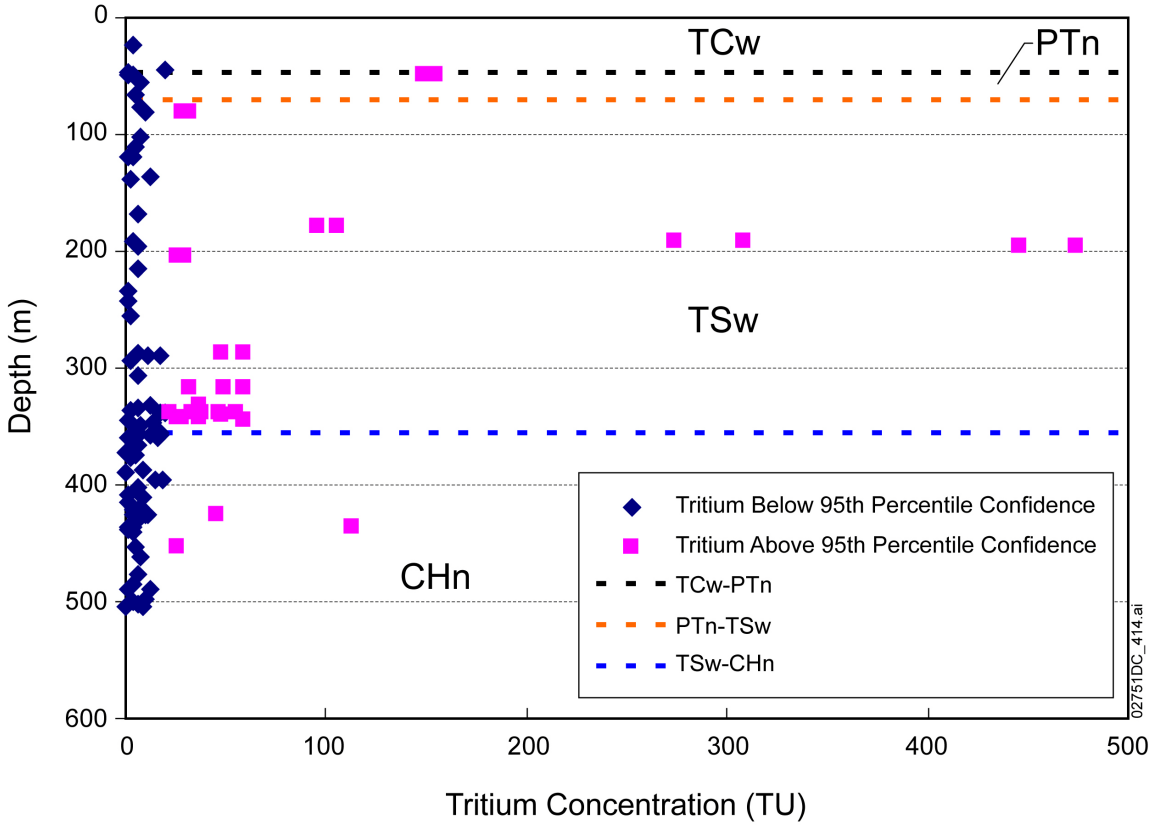


Figure 3. Tritium Measurements in Borehole UE-25 UZ-16

Borehole USW WT-24

Twenty-one elevated measurements of tritium were found for borehole USW WT-24 within the tsw38 and ch2-ch5 unsaturated zone flow model layers (Figure 4). Measurements from this borehole are limited to the lower portion of the Topopah Spring welded (TSw) hydrogeologic unit and the CHn hydrogeologic unit. Most of the values are either at or near perched water levels at the TSw-CHn hydrogeologic unit interface or at or near the water table. The borehole lies about 150 m northeast of Pagany Wash Fault. The high levels of tritium near the TSw-CHn hydrogeologic unit interface suggest that fast transport down the Pagany Wash Fault may have been diverted near USW WT-24 along perched water and along the water table. Strong lateral flow is expected in areas where the CHn hydrogeologic unit is highly zeolitized, as it is at USW WT-24.

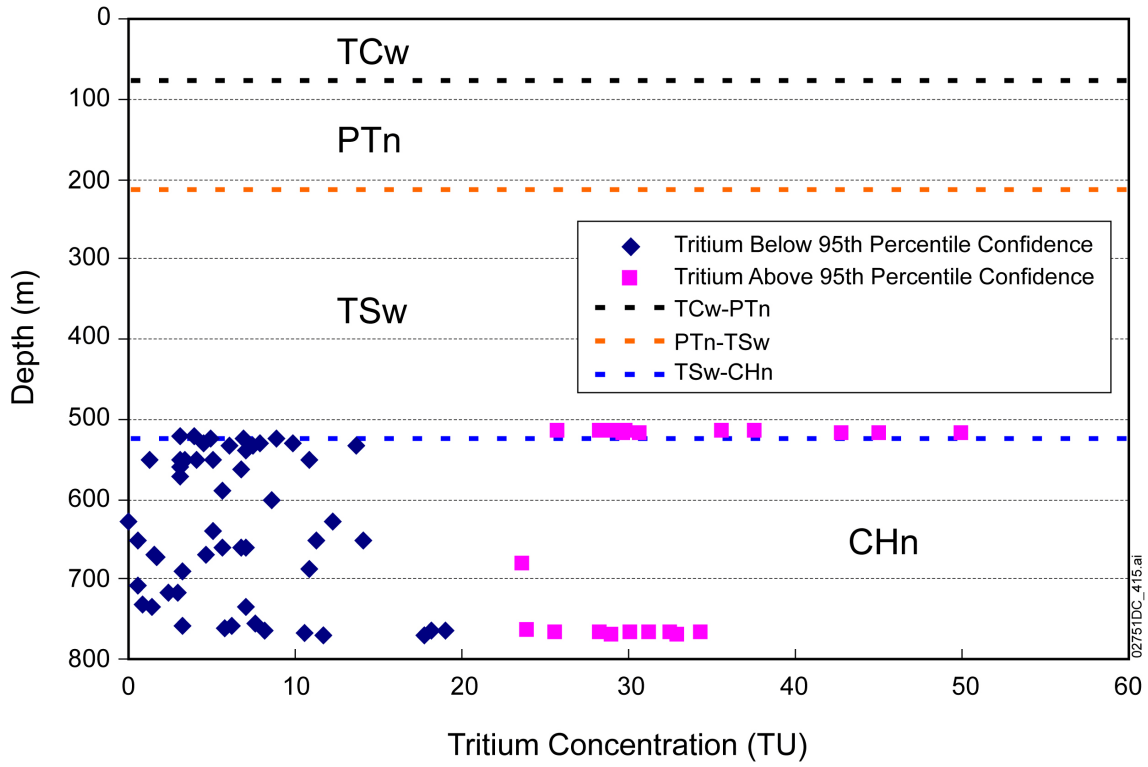


Figure 4. Tritium Measurements in Borehole USW WT-24

Borehole USW SD-6

Ten elevated measurements of tritium were found for borehole USW SD-6 within the tsw37 and pp3 unsaturated zone flow model layers (Figure 5). The borehole lies about 400 m east of the Solitario Canyon Fault. The PTn is relatively thin in this area (about 21 m) and higher tritium levels may be attributed to small-scale lateral diversion within the PTn and partial penetration of episodic flow through the PTn, in addition to fast transport through the fault. Results from the unsaturated zone flow model are consistent with the presence of small amounts of modern water at the repository level near USW SD-6.

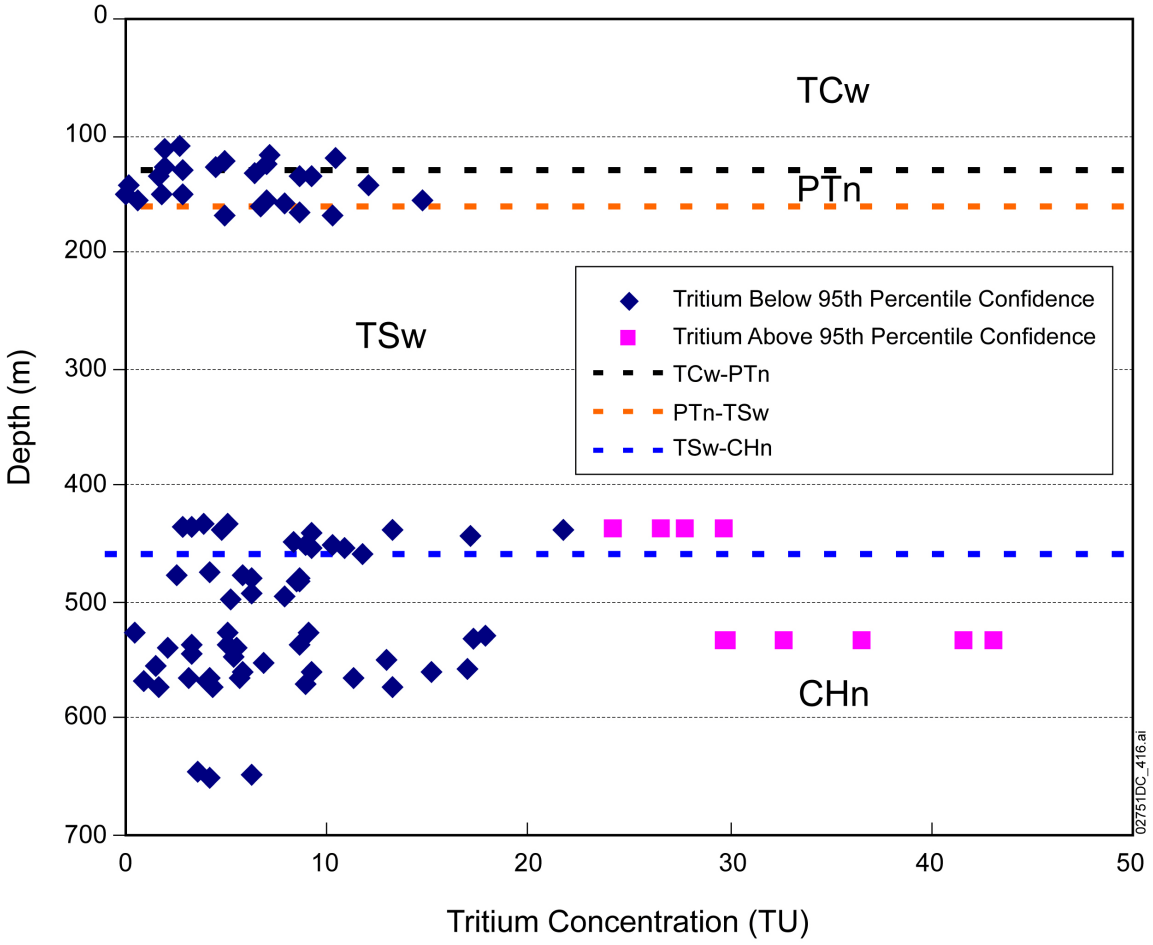


Figure 5. Tritium Measurements in Borehole USW SD-6

Borehole USW NRG-6

Eight elevated measurements of tritium were found for borehole USW NRG-6 within the ptn25 and ptn26 unsaturated zone flow model layers (Table 4). As for USW UZ-14, partial penetration of the PTn hydrogeologic unit by episodic flow as observed in Pagany Wash is the likely explanation for the presence of elevated tritium values in this borehole.

Borehole USW UZ-14

Three elevated measurements of tritium were found for borehole USW UZ-14 within the ptn25 unsaturated zone flow model layer (Table 4). The possibility of partial penetration of the PTn hydrogeologic unit by episodic flow as observed in Pagany Wash is the likely explanation for the presence of elevated tritium values in this borehole.

Borehole USW SD-12

Two elevated measurements of tritium were found for borehole USW SD-12 within the pp3 unsaturated zone flow model layer (Table 4). The borehole lies about 180 m west of the Ghost Dance Fault. The elevated levels of tritium below perched water in USW SD-12 suggest rapid transport along the fault with lateral redistribution within the more permeable pp3.

Borehole USW NRG-7a

One elevated measurement of tritium was found for borehole USW NRG-7a within the tsw31-tsw32 unsaturated zone flow model layers (Table 4). The borehole is about 260 m southwest of Drill Hole Wash Fault.

In summary, elevated levels of tritium indicative of bomb-pulse water have been found in surface based boreholes associated with faults or in samples within the PTn hydrogeologic unit. In some cases, the presence of modern water may be a result of episodic flow and transport through the upper portion of the PTn hydrogeologic unit, combined with dispersive transport through the lower portion. This could allow a small fraction of modern water to enter the TSw, particularly if the region is subject to percolation fluxes that are above average values.

1.2.6 Qualitative Assessment of Tritium Information from the ESF and ECRB

Table 5 presents the measurements of tritium from the ESF and ECRB. Values given in Table 5 that were measured with the less sensitive technique (ESF only, see Section 1.2.4) are restricted to values that lie above detection limits. Samples with tritium levels in excess of both the 95th percentile confidence limit and the 1.4 TU threshold indicating the presence of modern water are assessed in this section in response to the RAI. Information about distances between measurements and fault locations were taken from Figures 5-3, 5-5, and 5-6 of *Chlorine-36 Validation Study at Yucca Mountain, Nevada* (BSC 2006).

ESF

Most of the measurements in the ESF were conducted using the more sensitive technique described in Section 1.2.4. Measurements made using this technique were not screened on detection limit for Table 5. A smaller number of measurements were made using the less sensitive technique. Nine values measured with this technique lie above detection limits and are shown in Table 5. Figure 6 only displays ESF data from Table 5. Thirty-nine samples from the ESF were found to be greater than or equal to 1.4 TU, indicating the presence of modern water (Figure 6).

ESF North Ramp

Eight elevated measurements of tritium are from the Bow Ridge Fault area (Station 1+68) and lie in the tcw12 unsaturated zone flow model layer or other layers above the PTn hydrogeologic unit (Figure 6). One value from the ESF, at Station 7+54, measured with the less sensitive technique (see Section 1.2.4) is above the detection limit but below the 95th percentile confidence level. Two elevated measurements of tritium were found near the intersection of the Drill Hole Wash Fault in the tsw33 unsaturated zone flow model layer at Stations 19+30 and 19+50.

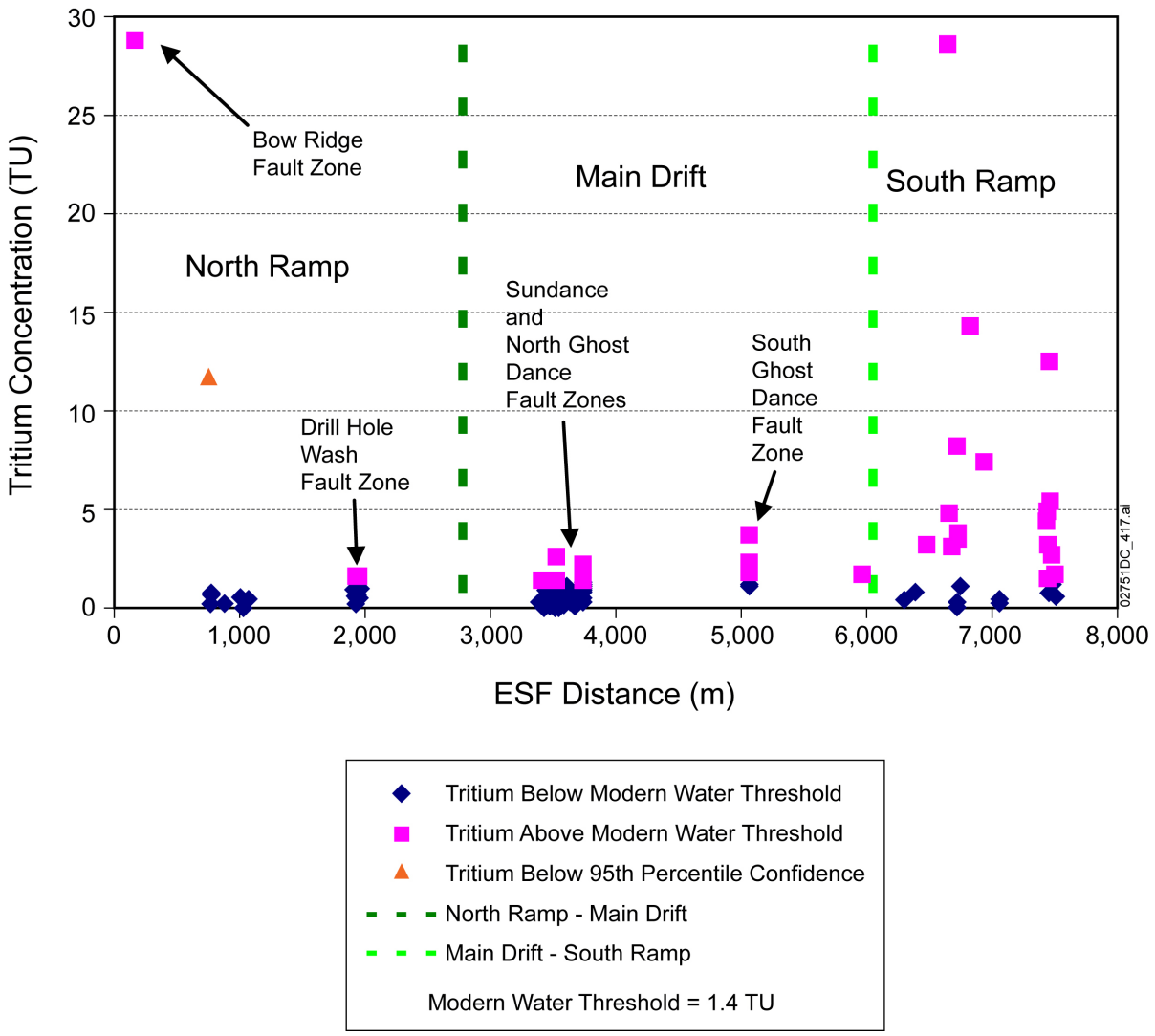
ESF Main Drift

Eight elevated measurements of tritium were found near the Sundance and north Ghost Dance faults in the tsw34 between Stations 34+10 and 37+37. Three elevated tritium values were found near the southern Ghost Dance Fault in the tsw34 at Station 50+64. A single elevated tritium concentration value of 1.7 TU was found at Station 59+65 in the tsw34 (at the corner of the Main Drift and South Ramp), possibly linked to the numerous high values found in the ESF South Ramp.

ESF South Ramp

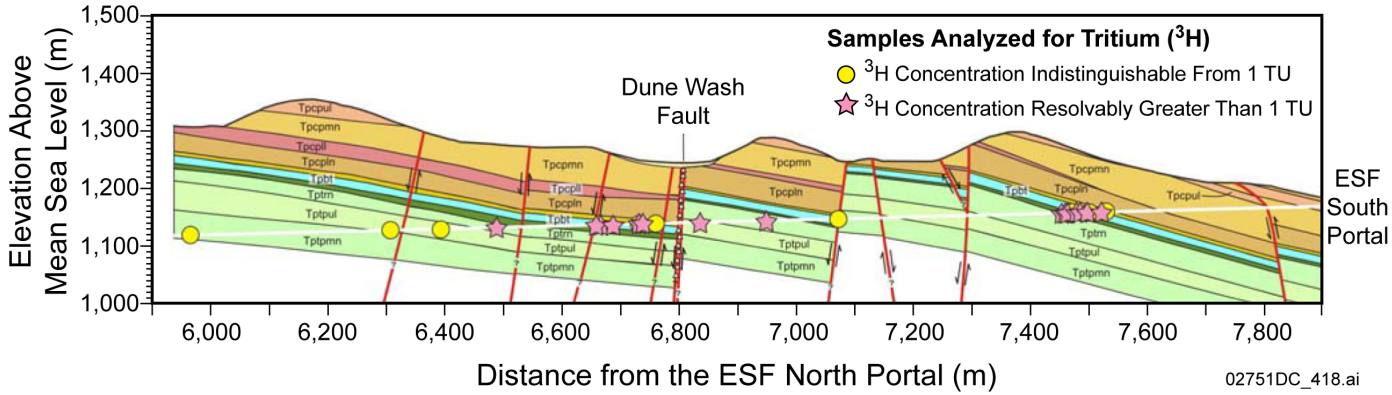
More elevated tritium levels were found in the South Ramp than in either the North Ramp or Main Drift of the ESF. This area is characterized by a greater density of faults and a thin PTn hydrogeologic unit. Notably, a seepage event into the ESF was observed after several months of unusually heavy precipitation in February 2005 (SNL 2007b, Section 7.1[a]). No other locations in the underground tunnels were found to have seepage, which suggests that the region of the South Ramp may be unique and more readily affected by fast transport from the ground surface.

A single elevated tritium concentration value of 3.2 TU was found at Station 64+80 in the tsw33, within 40 m of an unnamed fault (Figure 7). Three elevated tritium concentrations were found at Stations 66+48, 66+58, and 66+80, respectively. These lie within the ptn26 with offsets of approximately 0 to 30 m from an unnamed fault. Three elevated measurements of tritium were found in the tcw12 at Stations 67+21 and 67+30, about 30 to 40 m from an unnamed fault. A single elevated tritium concentration value was found at Station 68+26 in the tsw33, about 30 m from the Dune Wash Fault. A single elevated tritium concentration value of 7.4 TU was found at Station 69+37 in the tsw31-tsw32, about 140 m from an unnamed fault. A tritium concentration value of 4.4 TU was found at Station 74+35 in the tsw31-tsw32, about 200 m from an unnamed fault. Seven elevated measurements of tritium were found at Stations 74+41 to 75+03 in the ptn26, ptn24, and tcw12, about 200 m from an unnamed fault.



NOTE: Seven values at Station 1+68 are not shown in the figure because they are above 30 TU.

Figure 6. Tritium Measurements in the Exploratory Studies Facility



Quaternary

Qac	Alluvial and Colluvial Deposits

Paintbrush Group (Miocene)

Tiva Canyon Tuff

Crystal-poor Member

Tpcpul	Upper Lithophysal Zone
Tpcpum	Upper Lithophysal Zone and Middle Nonlithophysal Zone Undivided
Tpcpmn	Middle Nonlithophysal Zone
Tpcpll	Lower Lithophysal Zone
Tpcpln	Lower Nonlithophysal Zone
Tpcpv	Crystal-poor Vitric Zone

Bedded Tuffs

Tpbt	Includes: pre-Tiva Canyon Tuff Bedded Tuff (Tpbt4), Yucca Mountain Tuff (Tpy), pre-Yucca Mountain Tuff Bedded Tuff (Tpbt3), Pah Canyon Tuff (Tpp), and pre-Pah Canyon Tuff Bedded Tuff (Tpbt2)

Topopah Spring Tuff

Crystal-rich Member

Tptrv	Vitric Zone
Tptrn	Nonlithophysal Zone

Crystal-poor Member

Tptpul	Upper Lithophysal Zone
Tptpmn	Middle Nonlithophysal Zone

NOTE: A limit of 1 TU instead of 1.4 TU was used as a threshold for high and low tritium values in this figure.

Source: BSC 2006, Figure 5-5.

Figure 7. Geologic Section of the ESF South Ramp Showing Locations of Samples Analyzed for Tritium

ECRB

All of the ECRB measurements were made using the more sensitive technique. Therefore, all ECRB measurements are shown in Table 5 and on Figure 8. Eleven samples from the ECRB were found to be greater than or equal to 1.4 TU (Figure 8). Four elevated values of tritium concentration ranging from 1.7 to 6.5 TU at Stations 7+50 to 9+50 were found in the tsw33. Five elevated values of tritium concentration ranging from 1.5 to 10.3 TU at Stations 13+51 and 14+99 (three duplicate samples) were found in the tsw34. Two elevated values of tritium concentration with values of 3.6 and 9.8 TU at Stations 19+50 to 21+49 were found in the tsw35. All of the ECRB samples with elevated tritium concentrations were 200 m or more from mapped major faults. Despite the relatively large distances between the elevated tritium measurements and major faults in the ECRB, lateral movement from faulted areas could occur during transport from the base of the PTn hydrogeologic unit to the ECRB.

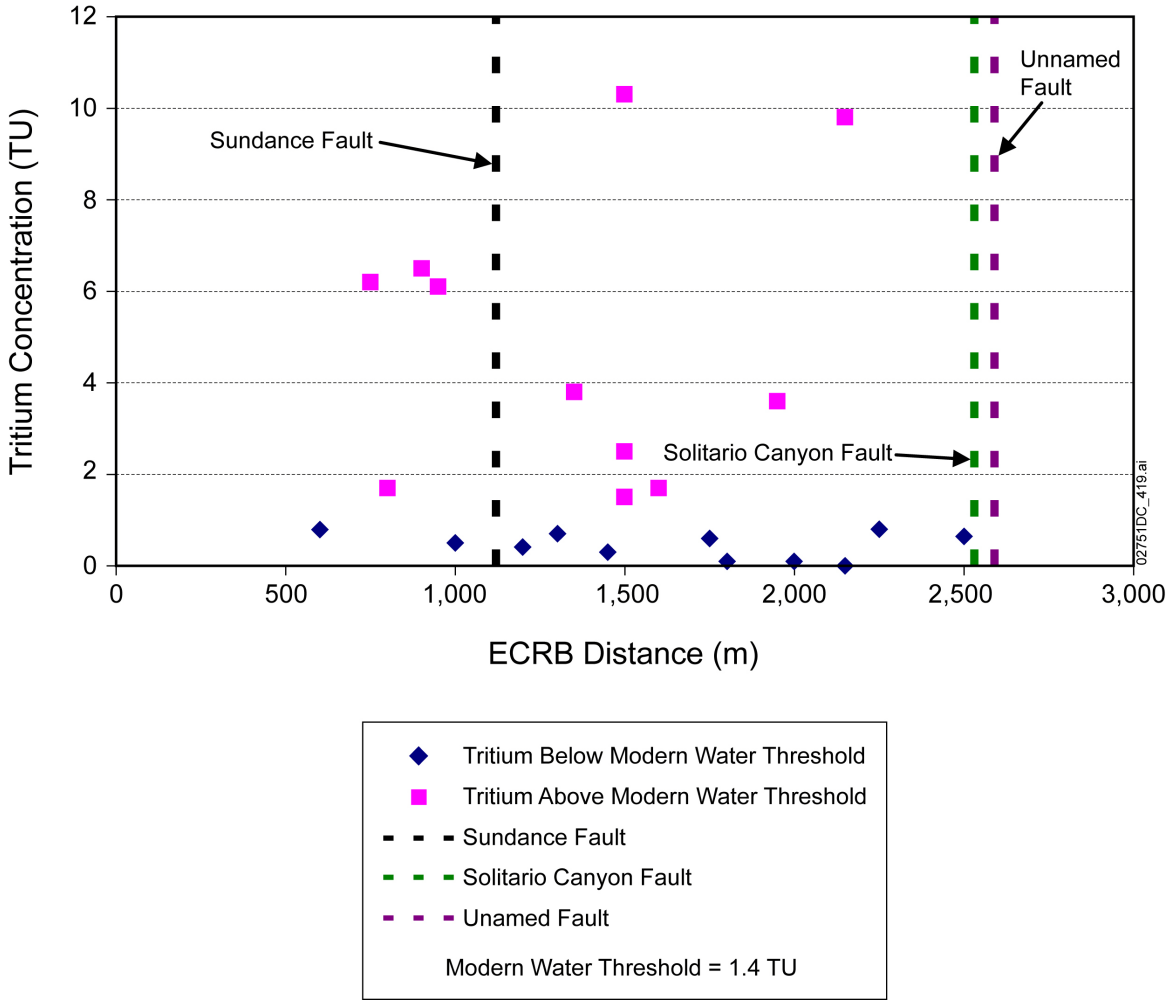


Figure 8. Tritium Measurements in the ECRB

In summary, nearly all of the elevated tritium concentrations found in samples from the ESF were either in close proximity to faults or were taken from TCw or PTn hydrogeologic units. In contrast, the samples with elevated tritium concentration from the ECRB all lie within repository units of the TSw hydrogeologic unit and were not found to be associated with faults. In addition, the highest levels of tritium were found in faulted areas of the ESF North and South Ramps; tritium values found in the ESF Main Drift and the ECRB are 10 TU or less. The PTn hydrogeologic unit above the ECRB is roughly 40 m in thickness (SNL 2008b, Figures D-1 and D-3). Episodic flow and transport through the upper portion of the PTn, combined with dispersive transport through the lower portion could allow a small fraction of modern water to enter the TSw, particularly if the region is subject to percolation fluxes that are above average. Fracture-dominated transport in the TSw hydrogeologic unit would allow for penetration of a small fraction of this water into the repository horizon.

1.2.7 Example of Enhanced Transport through the PTn Hydrogeologic Unit

The data discussed in Sections 1.2.5 and 1.2.6 suggest that in a few cases, water with tritium concentration in excess of 1.4 TU may have moved through the PTn hydrogeologic unit in the general rock mass (i.e., without moving through a fault). This raises the issue as to whether these cases could only be explained by an episodic flow event that penetrates the PTn hydrogeologic unit. It is possible for water with a tritium concentration in excess of 1.4 TU to penetrate the general rock mass of the PTn hydrogeologic unit under steady flow conditions in the lower part of the PTn hydrogeologic unit.

Consider a case where the PTn hydrogeologic unit is 40 m thick, similar to the stratigraphy above the ECRB. The present-day average percolation flux for the 10th percentile scenario is about 3 mm/yr (SNL 2007a, Table 6.1-2), and the water content in the PTn is about 0.2, which gives a transport velocity of about 15 mm/yr. A calculation of tritium transport to the base of the PTn hydrogeologic unit requires a longitudinal dispersivity. A value of 5 m is used, based on reported ranges of field-scale dispersivities for saturated flow conditions (Gelhar et al. 1992) and enhanced disperivities found for unsaturated flow conditions as compared with saturated flow conditions (Toride et al. 2003). Assume that episodic flow can quickly transport tritium through the TCw hydrogeologic unit. Furthermore, based on observations at Pagany Wash and model results showing sustained fracture flow in the ptn21 model layer, assume that transport is fast through the first 10 m of the PTn hydrogeologic unit before fracture water is substantially imbibed into the matrix. Transport through the remainder of the PTn hydrogeologic unit is in the matrix. This is modeled using a one-dimensional, single-continuum, advection-dispersion transport process for a series of instantaneous, annual releases over the 500-year period from 1496 to 1995. Releases prior to this period are not included because they have a negligible effect on the computed tritium concentrations. The concentration for a series of annual, instantaneous point source releases of mass is given by (Bear 1972, p. 629, Equation (10.6.12) and p. 613, Equation (10.4.16)):

$$c(z,t) = \sum_{i=1}^{499} \frac{M(\tau_i)\exp[-\lambda(t-\tau_i)]}{\sqrt{4\pi\alpha\, v(t-\tau_i)}} \exp\left[-\frac{\{z - v(t-\tau_i)\}^2}{4\alpha\, v(t-\tau_i)}\right]$$

where c is the tritium concentration in TU, z is the depth in meters, t is the time of observation in years (which is 1995), τ_i is the time of tracer release at the ground surface, (which ranges from 1496 to 1994), $M(\tau_i)$ is the amount of tritium per square meter (in TU-m) entering the unsaturated zone at time τ_i, v is the transport velocity (equal to the percolation flux divided by the water content) in meters/year, α is the dispersivity in meters, and λ is the decay constant per year. The amount of tritium released per square meter of wetted surface area over one year is:

$$M(\tau_i) = vc_s(\tau_i)$$

where $c_s(\tau_i)$ is the source concentration of tritium (TU) at the ground surface at time τ_i.

The tritium concentration at the base of the PTn is computed using the source profile given in Figure 2 and assuming a 6 TU source concentration for the period prior to 1952. Table 6 gives the results for a hypothetical sample collected in 1995. The results are computed for a range of transport velocities that vary from 15 to 675 mm/yr, considering both infiltration and hydrogeologic property variability that could result in faster transport. A maximum factor of 45 was used for transport velocity variations. This is based on a factor of 9 variation in the average infiltration flux for the present-day 10th and 90th infiltration cases (SNL 2007a, Table 6.1-2) and hydrogeologic property variability, which could lead to another factor of 5 variation in transport velocity.

Table 6. Tritium Concentrations at the Base of the PTn

Transport Velocity Multiplier	Tritium Concentration (TU)	Tritium Concentration (TU) with 10× Source (1954 to 1970)	Tritium Concentration (TU) with 100× Source (1954 to 1970)
1	5.9×10^{-11}	5.9×10^{-11}	5.9×10^{-11}
8	0.0039	0.018	0.16
20	1.7	16	160
45	20	180	1800

The source term is also uncertain, particularly over the period significantly affected by nuclear device testing from 1954 through 1970. As discussed earlier, with respect to the high values of tritium found in borehole UE-25 UZ-16, a source concentration may have been higher than shown in Figure 2. Table 6 shows cases where the source tritium concentration between 1954 and 1970 is increased by factors of 10 and 100. The results show that for certain conditions, tritium concentrations above the threshold for the presence of modern water can penetrate the general rock mass of the PTn hydrogeologic unit. Therefore, the presence of modern water below the PTn hydrogeologic unit does not necessarily imply that episodic flow has penetrated the PTn hydrogeologic unit.

1.2.8 Summary of Tritium Evaluations

Data from the surface-based boreholes indicate that only a small number of the total measurements can be confirmed as representative of bomb-pulse water. Similarly, data from the ESF and ECRB analyzed using more a sensitive technique show that most of the measured concentrations lie below the threshold for the presence of modern water. A few high levels of tritium measured from borehole UE-25 UZ-16 indicate that, during the period of nuclear device testing, the source levels of tritium at Yucca Mountain were higher than available decay-corrected atmospheric measurements at Albuquerque, New Mexico. Because of the uncertainty in the source concentration, the amount of modern water required to raise tritium concentrations in subsurface samples above the threshold is uncertain.

Many of the cases where tritium concentrations indicate the presence of modern water were taken from locations in or near faults. These cases are consistent with transport simulations using the unsaturated zone flow model, which indicate a small fraction of mass arrivals between the ground surface and the repository level can occur through fault pathways within 50 years. In a few cases, such as in the ECRB, the presence of modern water is indicated at locations not associated with faults. An analysis of tritium transport through the PTn hydrogeologic unit show that for certain conditions, tritium concentrations above the threshold for the presence of modern water can penetrate the general rock mass of the PTn hydrogeologic unit. Conditions that lead to this result are higher average percolation flux, localized flow focusing, reduced water content associated with localized areas of higher permeability, and enhanced atmospheric tritium levels. Therefore, the presence of modern water below the PTn hydrogeologic unit does not necessarily imply that episodic flow has penetrated the PTn hydrogeologic unit.

1.3 TEMPERATURE DATA AND EPISODIC FLOW

1.3.1 Discussion of Temperature Logs from Borehole UE-25 a#7

Temperature logs in borehole UE-25 a#7 (referred to here as a#7) suggest movement of water originating as surface runoff from major precipitation events, into the subsurface at depths greater than 100 m, within a few days. Multiple precipitation events were recorded in the vicinity of Yucca Mountain during the period spanned by the logs, and are represented in the temperature variations. This response discusses the temperature transients observed within borehole a#7 and provides the bases for the interpretation that these are artifacts of water moving through the borehole and not deep percolation flux driven by transient infiltration in response to precipitation/streamflow events.

Borehole a#7 was drilled in 1979 and 1980 to a depth of 305.5 m (1,002 ft) and at an angle of nominally 26° from vertical. The hole has steel surface casing, and grouted plastic casing to 40.9 m (134 ft) (Table 7). The borehole was opened to 12-1/4" diameter to a depth of 42.0 m (138 ft), prior to grouting of the plastic casing to 40.9 m (134 ft). Below 42.0 m depth, the hole was drilled in two core sizes, reducing from 5.5" to 3.875" diameter at a depth of 153.0 m (502 ft). At completion of the hole, a string of tubing (2-3/8" diameter, water-filled) was installed from the surface to 291.5 m (956 ft) depth for temperature logging. Depths to stratigraphic contacts for borehole a#7 are shown in Table 8. Note that only part of the alluvium section is

cased, leaving approximately 9.4 m uncased immediately above the reported alluvium–bedrock contact at 50.3 m depth.

Table 7. Construction of Borehole UE25 a#7

Borehole			Casing		
From	**To**	**Size**	**From**	**To**	**Size**
0	3.0 m (10 ft)	15"	0	3.0 m (10 ft)	13-3/8" OD (steel)
3.0 m (10 ft)	42.0 m (138 ft)	12-1/4"	0	40.9 m (134 ft)	7.625" ID (plastic)
42.0 m (138 ft)	152.4 m (500 ft)	5-1/2"(core)	N/A	291.5 m (956 ft)	2-3/8" OD (steel tubing)
152.4 m (500 ft)	153.0 m (502 ft)	4-1/2"	N/A		
153.0 m (502 ft)	305.5 m (1,002 ft)	3.875"(core)	0		

NOTE: Depths are uncorrected for borehole slant. ID = inside diameter; OD = outside diameter.

Table 8. Stratigraphic Picks for Borehole UE25 a#7

Lithology	Lithostratigraphy	Symbol	Contact Depth (m)[a]	Contact Type
Alluvium	Not described	Qa	0.0	Ground surface
Tiva Canyon welded	Tiva Canyon Tuff (Tpc) nondivided	Tpc-un	50.3	Partially eroded
	Tpc, crystal-poor vitric densely welded subzone	Tpcpv3	51.8	Not formed
	Tpc, crystal-poor vitric moderately welded subzone	Tpcpv2	51.8	Crystallization-vitric
	Tpc, crystal-poor vitric nonwelded to partially welded subzones	Tpcpv1	53.6	Welding
Nonwelded	Pre-Tiva Canyon Tuff; bedded tuff	Tpbt4	57.9	Deposition
	Yucca Mountain Tuff; nondivided	Tpy	59.2	Deposition
	Pre-Yucca Mountain Tuff; bedded tuff	Tpbt3	64.6	Deposition
	Pah Canyon Tuff; nondivided	Tpp	69.0	Deposition
	pre-Pah Canyon Tuff; bedded tuff	Tpbt2	81.3	Deposition
Topopah Spring welded	Topopah Spring Tuff (Tpt) crystal-rich vitric nonwelded to partially welded zones	Tplrv3	89.0	Deposition
	Tpt, crystal-rich vitric moderately welded zone	Tplrv2	92.6	Welding
	Tpt, crystal-rich vitric densely welded zone	Tplrv1	92.8	Welding
	Tpt, crystal-rich nonlithophysal zone	Tptrn	94.8	Vitric-crystallization
	Tpt, crystal-rich lithophysal zone	Tptrl	147.3	Crystallization
	Tpt, crystal-poor upper lithophysal zone	Tptpul	154.9	Crystallization
	Tpt, crystal-poor middle nonlithophysal zone	Tptpmn	234.8	Crystallization
	Tpt, crystal-poor lower lithophysal zone	Tptpll	267.9	Crystallization

[a] Depth to upper contact, uncorrected for borehole slant.

The borehole pad for a#7 is located in the lowest portion of Drill Hole Wash (Sass et al. 1988, Figure 3). The elevation of the ground surface and the top of the casing for borehole a#7 were both recorded originally as 4,004.6 ft. Recent observation of the borehole showed that the top of the casing is level with the ground surface, with the access tubing protruding above the casing. The tubing was capped, but the surface casing is open, possibly allowing flow of surface water directly into the hole. The pad was reworked for other uses after the logging study of Sass et al. (1988), and there is no additional information available on the configuration of the wellhead during that study.

The first of the temperature logs was acquired on 3/17/1981 (Sass et al. 1988). Later logs were acquired on 4/29/1981, 12/30/1981, 3/8/1983, and 3/6/1984. The temperature log of 12/30/1981 reflects the highest temperatures because it was acquired more than a year after drilling operations ceased, and precipitation was limited in the latter part of 1981, so there was more time for temperature transients to dissipate. Accordingly, the log of 12/30/1981 was selected as a reference, and it was depth-matched and subtracted from each of the other logs for plotting (Figure 9). In this plot, temperature transients associated with precipitation and possible streamflow in Drill Hole Wash are negative, and converge to zero with depth.

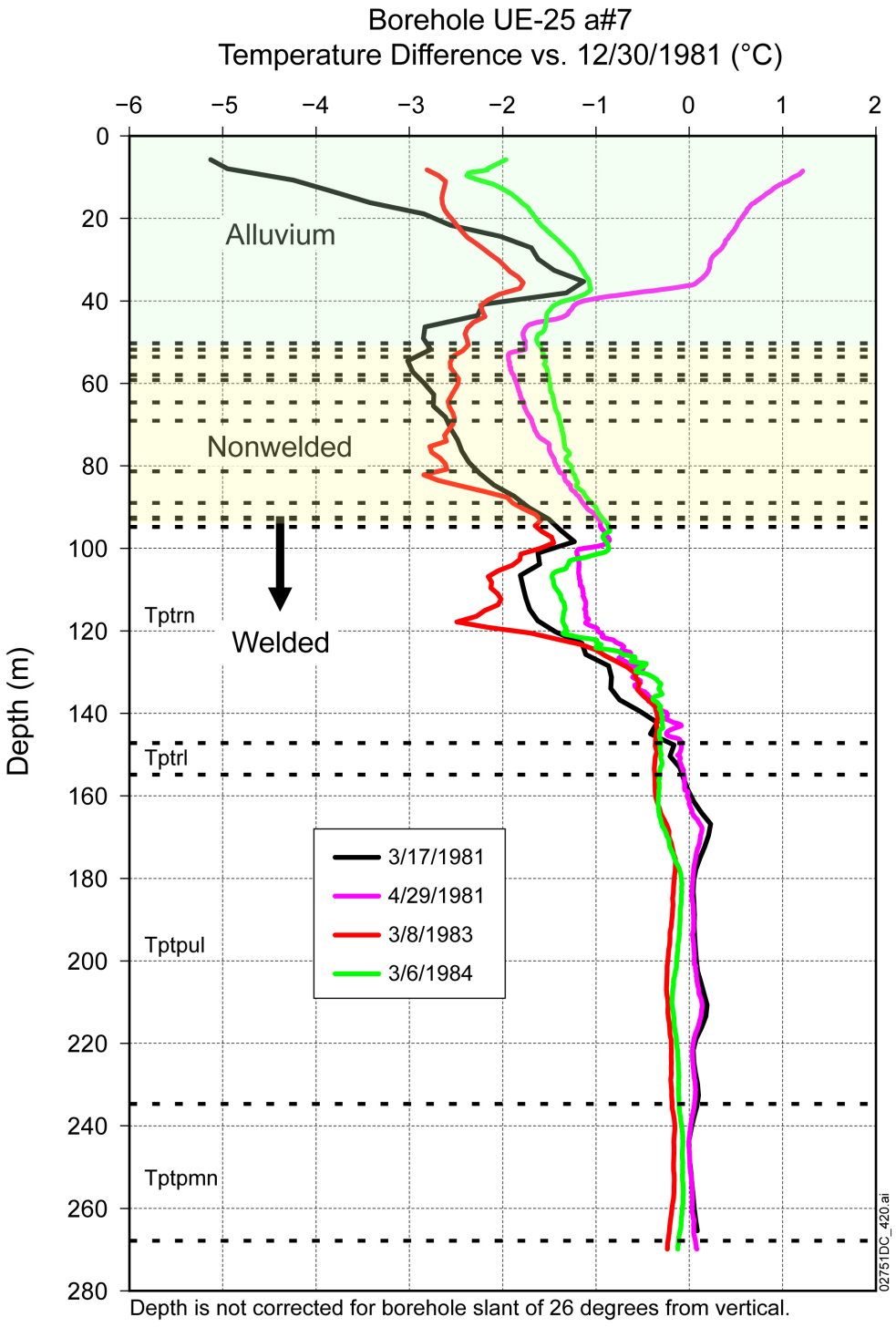
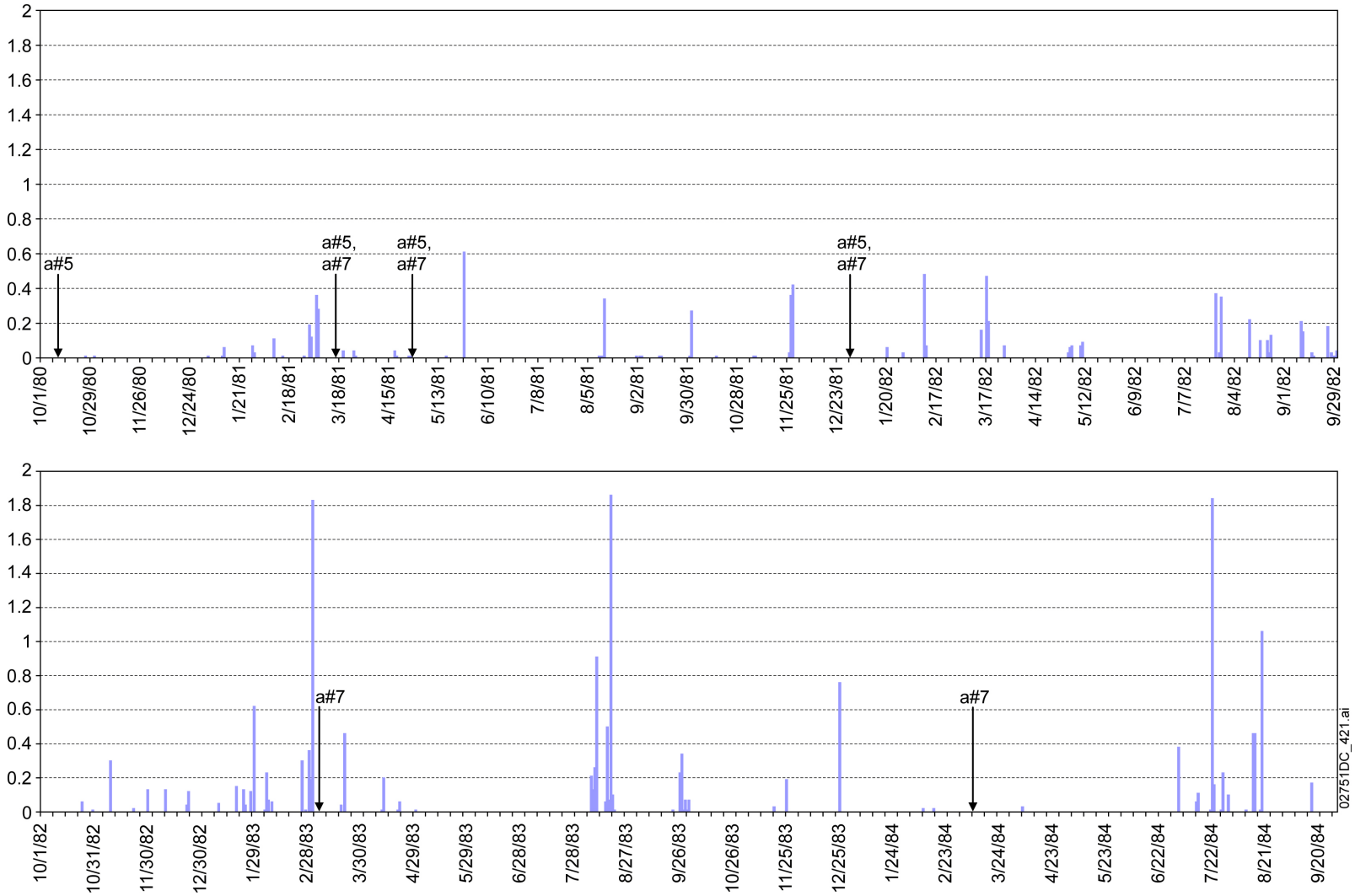


Figure 9. Temperature Logs for UE-25 a#7 Plotted as Differences, Subtracting the Log of 12/30/1981

The dates for some of the temperature logs were timed to follow precipitation events in March 1981 and March 1983 (Figure 10). These events likely produced streamflow in Drill Hole Wash. In particular, for a sequence of precipitation events that occurred during the first three days of March 1983, the effects were seen in the temperature log of March 8th. Another precipitation event occurred in August 1983, which apparently influenced the subsequent temperature log from March 1984. All of these logs exhibit transitions to cooler temperatures in the vicinity of the bottom of the casing at 40.9 m depth. Two alternative interpretations are considered here, that the temperature logs from borehole a#7 represent: (1) capture of flow within the borehole, at the surface or the alluvium–bedrock contact, and drainage back into the tuff sequence below; or (2) vertical percolation of water through the alluvium of Drill Hole Wash, and into the underlying welded and nonwelded tuffs (not involving flow in the borehole).



NOTE: Precipitation at Amargosa Farms (Garey) for Water Years 1981 through 1984. Approximate times where temperature surveys were conducted at UE-25 a#5 and UE-25 a#7 are shown with arrows.

Figure 10. Precipitation Records for Amargosa Farms from 1981 to 1984

Capture of Flow in the Borehole – The first, and most likely, interpretation involves flow of surface water into the borehole, or accumulation of water at the alluvium–bedrock contact at 50.3 m (Table 8), with flow into the open (uncased) borehole at or below the bottom of the casing at 40.9 m depth (Table 7). Water accumulation at the alluvium–bedrock contact has been observed in other, nearby boreholes that were monitored for investigation of infiltration processes.

After precipitation events, the thermal perturbations in borehole a#7 diffused to pre-event temperatures in a few months to a year, which is feasible if the scale of diffusive heat transfer is not more than a few meters (see the scoping calculation below). Specifically, the perturbation recorded on 3/17/1981 was significantly decreased by 4/29/1981. Also, the perturbations associated with precipitation events in August 1983 (if assumed to be similar to the events in early March 1983) were much smaller by the time of the next temperature log on 3/6/1984. As stated by Sass et al. (1988, Appendix 1, p. 24), "The primary conduit may have been the annulus between casing and borehole wall, but the persistence of the disturbance for at least a year indicates that significant lateral infiltration occurred near or in this well." Thus, the borehole served as a conduit for water penetration to depth, and the water infiltrated the formation, altering its temperature in a region of up to a few meters around the borehole.

The role of borehole a#7 as the conduit for water penetration to depth, as opposed to infiltration through the alluvium and tuff, is supported by results from hydrologic studies in Pagany Wash (LeCain et al. 2002). By the time the infiltration pulse in Pagany Wash moved 9.2 m through the alluvium accessed by borehole UZ#4, the water had come into temperature equilibrium with the alluvium (LeCain et al. 2002, Figure 7). Thus, it is unlikely that an infiltration pulse could move through 42 m of alluvium in Drill Hole Wash, plus tens of meters of tuff, and cause a temperature decrease of more than 1°C at depth. The Pagany Wash infiltration study indicated that once the infiltration pulse gets below the first few meters, the downward flow velocity in the alluvium is on the order of 1 m/day (LeCain et al. 2002, Figure 7). Another study in neutron borehole UZN#13 recorded an infiltration pulse associated with the precipitation event of 7/22/84, which penetrated 11.5 m into the Pagany Wash alluvium over a period of 76 days, indicating an average flux rate of 0.15 m/day. The alluvium in Drill Hole Wash is similar, so movement of an infiltration pulse through 42 m of alluvium in 7 days or less (i.e., from 3/1/1983 to 3/8/1983) is unlikely.

Comparing borehole a#7 to temperature profiles for other boreholes from Drill Hole Wash acquired by Sass et al. (1988, Figures 1-2 through 1-5) shows that only borehole UE25 a#5 exhibited a similar response. The deflection in the 3/16/1981 log (Sass et al. 1988, Figure 1-3) corresponds to the bottom of the cemented casing at 36.6 m (120 ft) depth, which is located within the Tiva Canyon welded tuff approximately 9.2 m below the alluvium–bedrock contact. The logs indicate that an infiltration pulse associated with the precipitation events on March 1st through 3rd, 1981, passed through 27.4 m of alluvium and into the upper TCw within approximately 18 days. The larger temperature drop measured on the 4/29/1981 log shows that infiltration continued and additional water reached the upper Tiva Canyon welded tuff over the period March 17, 1981, to April 29, 1981. Thus, percolation through the alluvium was much slower than suggested by the rapid penetration in borehole a#7.

Percolation Through the Alluvium and Bedrock – An alternative interpretation of the temperature logs from borehole a#7 is that the transient infiltration rapidly flowed deeply through the alluvium and bedrock, and cooled the bedrock. This requires that the infiltrating water absorbed enough heat to cool a 100-m thickness of rock by approximately 3°C. Using a bulk density of 2,000 kg/m^3 and specific heat of 10^3 J/kg-K for the alluvium and rock, and assuming the infiltrating water was 10°C cooler than the ground surface, requires infiltration of approximately 14 m^3/m^2 of water for a sequence of precipitation events such as occurred in early March 1983. A smaller temperature difference for infiltrating water would require proportionately greater infiltration. While such recharge is possible, it would effectively saturate the alluvial thickness, and would be limited in lateral extent to the width of the wash, whereas borehole a#7 slants away from the wash at an angle of 26 degrees. Accumulation of such amounts of water at the alluvium–bedrock contact would produce substantial flow into the uncased section of borehole a#7, thus leading to the first alternative interpretation. After initial drainage from the alluvium–tuff sequence, water flow greatly slowed as indicated by the persistent shape of the temperature profiles over several months (Figure 9). Thermal equilibration occurred as heat diffused back into the cooler rock. The time scale (Δt) for thermal diffusion can be estimated from the length scale (L) and the diffusivity (κ) as $\Delta t = L^2 / \kappa$. Using $\kappa = 2 \times 10^{-6}$ m^2/s and choosing L = 30 m as the length scale for thermal dissipation, the time scale Δt = 1.5 years. The temperature transients in borehole a#7 equilibrated faster than this, indicating that they occurred on a smaller length scale than permitted by this second interpretation.

Finally, it is important to note that Drill Hole Wash is fault-controlled, and is represented explicitly as a fault in the unsaturated zone flow model. Core recovery records indicate poor recovery from 24 to 53 m, and therefore the Drill Hole Wash Fault may intercept the upper part of the borehole, directing water from the ground surface (possibly originating as sheet flow from rock slopes) into the borehole at depth. Such behavior would be consistent with the first interpretation, in that downward flow in the borehole is needed to account for thermal effects observed.

In summary, the temperature logs in borehole a#7 indicate movement of water originating as surface runoff from major precipitation events into the subsurface at depths greater than 100 m within a few days. The water cooled the borehole by as much as 3°C which dissipated over time periods from a few months to approximately a year, as shown from repeated logging. Multiple precipitation events were recorded in the vicinity of Yucca Mountain during the period spanned by the logs, and are represented in the temperature variations. The construction of borehole a#7 suggests that water readily flowed from the wash directly into the borehole or it may have infiltrated the alluvium and ponded at the bedrock contact where it entered the borehole through an uncased section. Analogous studies in Pagany Wash, scoping thermal analysis, and comparison with temperature logs in nearby borehole a#5 indicate that the water penetrated within the borehole. Percolation through the alluvium is too slow, and the zone of thermal influence from the water in borehole a#7 was too limited, for rapid flow in the alluvium and the underlying tuffs to have been an important factor.

1.3.2 Subsurface Temperature and Other Evidence for Infiltration at Borehole UE-25 UZ#4

Borehole UE-25 UZ#4 (referred to here as UZ#4) was instrumented in July 1995 to measure temperature, pressure, and humidity as functions of depth as part of a hydrologic monitoring program that determined *in situ* moisture conditions and monitored the progress of transient infiltration after precipitation/streamflow events (LeCain et al. 2002). Sensors were installed at discrete depths (stations) isolated by grouted intervals. Borehole UZ#4 is located in the alluvium of Pagany Wash, close to the active channel, and recorded the effects from infiltration in response to precipitation and streamflow in February 1998. The depths to geologic contacts in UZ#4 are shown in Table 9.

Table 9. Geology of Borehole UZ #4

Lithostratigraphic Unit	Contact Depth (m)
Alluvium (Qa)	0.00
Tiva Canyon Tuff (Tpc) nondivided (Tpc_un)	11.89
Tpc, crystal-poor vitric moderately welded subzone (Tpcpv2)	21.76
Tpc, crystal-poor vitric nonwelded to partially welded subzones (Tpcpv1)	23.77
pre-Tiva Canyon Tuff bedded tuff (Tpbt4)	30.18
Yucca Mountain Tuff nondivided (Tpy)	32.31
pre-Yucca Mountain Tuff bedded tuff (Tpbt3)	46.18
Pah Canyon Tuff nondivided (Tpp)	53.00
pre-Pah Canyon Tuff bedded tuff (Tpbt2)	92.96
Topopah Spring Tuff (Tpt) crystal-rich vitric nonwelded to partially welded zones (Tptrv3)	101.50
Tpt, crystal-rich vitric moderately welded zone (Tptrv2)	104.55
Tpt, crystal-rich vitric densely welded zone (Tptrv1)	105.16
Tpt, crystal-rich nonlithophysal zone (Tptrn)	105.46 (to total depth of 127.7 m)

The active channel of Pagany Wash is approximately 1 to 2 m wide and streamflow has been documented in response to precipitation events that occur every few years, lasting for a day or two with each event. Rain gauges at WT-2 Wash and Jackass Flats recorded precipitation values of 173 mm (6.8 in.) and 135 mm (5.3 in.), respectively, for the 23-day period ending February 25, 1998 (LeCain et al. 2002). The Nevada Test Site precipitation station at Jackass Flats (4JA) recorded monthly precipitation of 159 mm (6.26 in.) for February 1998, with maximum daily precipitation of 43 mm (1.70 in.) on February 23rd.

A sharp temperature drop was observed on February 24, 1998, in alluvium at 3 m depth in borehole UZ#4, in response to infiltration of surface water from the active channel of Pagany Wash. Comparing to the precipitation records, the infiltration water apparently reached this depth in less than a day. A much smaller temperature drop was observed at a depth of 6.1 m (the next instrumented station) approximately six days later. The next two stations in the alluvium (9.2 and

11.1 m depths) exhibited longer term, attenuated temperature responses detected as slight depressions of the annual temperature wave (LeCain et al. 2002).

These observations are similar to neutron logs from borehole UZN#13, which is located in the active channel at the mouth of Pagany Wash, and in which a pulse of water was observed to percolate through 13.4 m of alluvium and contact bedrock, during the winter of 1984 to 1985.

Bedrock stations in UZ#4 also exhibited slight temperature responses (less than 0.05°C) that were interpreted by LeCain et al. (2002) to have been caused by the infiltration pulse and occurred one to two months later. Pressure sensors in borehole UZ #4 also recorded movement of the infiltration pulse by successive isolation of the monitored stations from atmospheric pressure fluctuations. The pressure data indicate that the infiltration pulse remained in the nonwelded Yucca Mountain Tuff (Tpy) between stations at 35.2 m and 45.0 m, for at least two years following the precipitation/streamflow event.

In summary, the investigations in borehole UZ#4 showed that penetration of infiltration pulses from surface streamflow is slow, on the order of 1 m/day, and that temperature differences are substantially attenuated after the pulse has penetrated on the order of 10 m (LeCain et al. 2002). The episodic flow observed to move through the alluvium and Tiva Canyon Tuff appears to have been dampened within the Tpy, which is part of the PTn hydrogeologic unit.

1.4 ALCOVE 4 TESTING AND EPISODIC FLOW

The potential for damping episodic infiltration in the PTn hydrogeologic unit was investigated through liquid release experiments conducted in Alcove 4 of the ESF (BSC 2004a, Section 6.7). These experiments included multiple releases of tracer-laced water into isolated zones located along three horizontal boreholes which accessed either faulted or undisturbed portions of PTn hydrogeologic unit matrix exposed in the Alcove 4 test bed. The zones into which traced water was released were selected based on air-permeability measurements conducted over 0.3-m sections of the boreholes, indicating if the borehole intercepted the fault or undisturbed portions of the rock mass. The plumes that developed following the liquid release were monitored via six separate horizontal boreholes, and the resulting water travel times, lateral dispersion (as seen along the length of the horizontal boreholes), and changes in saturation and water potential were continuously recorded by an automated data acquisition system. Inter-borehole distances were on the order of 1 to 3 meters. A constant-head boundary condition was maintained during injection to determine the maximum rates at which a targeted zone could take in water.

The liquid release rates employed during the tests (up to 138 mL/min) were considerably larger (approximately equal to 10^6 mm/yr) than typical percolation fluxes expected under ambient conditions. Despite the high water release rates, no water was observed to enter the slot excavated immediately below the test bed to record any seepage resulting from gravity drainage of the liquid releases in the horizontal boreholes. Water that imbibed into the matrix was retained for long periods (at least several months for the given test conditions). The observed wetting front migration pattern provides evidence of substantial matrix imbibition from the fault and matrix flow, demonstrating the ability to effectively damp liquid pulses in the PTn hydrogeologic unit. This conclusion is also consistent with field observations from water release

tests for a similar nonwelded unit (the vitric Calico Hills nonwelded hydrogeologic unit) at the Busted Butte test facility (SAR Section 2.3.2.3.2.4).

1.5 CARBON-14 MEASUREMENTS AND EPISODIC FLOW

Measurements of ^{14}C in the unsaturated zone pore water and atmosphere provide information relevant to the residence time (i.e., the age) of the ^{14}C, and in most cases, this age is also considered to be a good approximation of solute and water residence time. Carbon-14 measurements conducted in boreholes USW UZ-1 and USW SD-12 are used to validate the unsaturated zone flow model (SNL 2007a, Figures 7.5-1 and 7.5-2). These data provide evidence of long residence times within the PTn hydrogeologic unit matrix where, due to the large storage capacity, thousands of years are required to traverse the unit (SAR Section 2.3.2.3.4.2). The matrix properties of the PTn hydrogeologic unit (high porosity and low fracture density) have acted to retard the movement of water through the formation, as evidenced by the long ^{14}C residence times observed. These same properties will also act to attenuate any episodic surface infiltration events from rapidly reaching the repository horizon and, as such, these measurements provide additional field evidence of the effectiveness of the PTn hydrogeologic unit as a barrier to the rapid transport of percolating water.

1.6 SUMMARY

Drift seepage for a transient process results in a larger mean seepage rate than the equivalent steady-flow process. Although the PTn hydrogeologic unit is effective at damping episodic flow, longer-term transient flow effects have been shown to penetrate the PTn hydrogeologic unit (Manepally et al. 2007). The increment in the mean seepage rate was found to be relatively small in comparison with other uncertainties included in the model for performance assessment (Section 1.1.3).

Tritium data collected from surface-based boreholes and a small subset of data collected from the ESF (Section 1.2) were analyzed using a technique that has high detection limits and uncertainty levels relative to the threshold for the presence of modern water. Because of this, the only interpretable data from these samples necessarily lie above the threshold for modern water. A more sensitive technique was used for most of the tritium measurements from the ESF and for all data from the ECRB. This data set shows that most of the measured concentrations lie below the threshold for the presence of modern water. A few high levels of tritium measured from borehole UE-25 UZ-16 indicate that, during the period of nuclear device testing, the source levels of tritium at Yucca Mountain were higher than available decay-corrected atmospheric measurements at Albuquerque, New Mexico. Because of the uncertainty in the source concentration, the amount of modern water required to raise tritium concentrations in subsurface samples above the threshold is uncertain.

Many of the cases where tritium concentrations indicate the presence of modern water were taken from locations in or near faults. These cases are consistent with transport simulations using the unsaturated zone flow model, which indicate a small fraction of mass arrivals between the ground surface and the repository level can occur through fault pathways within 50 years. In a few cases, such as in the ECRB, the presence of modern water is indicated at locations not

associated with faults. An analysis of tritium transport through the PTn hydrogeologic unit was conducted for a location with a PTn hydrogeologic unit thickness of 40 m, similar in magnitude to the thickness of the PTn hydrogeologic unit above the ECRB, and for episodic flow damping within the upper 10 m of the PTn hydrogeologic unit. The analysis allows for uncertainty in percolation, hydrogeologic properties, and source concentration. The results show that for certain conditions, tritium concentrations above the threshold for the presence of modern water can penetrate the general rock mass of the PTn hydrogeologic unit. Therefore, the presence of modern water below the PTn hydrogeologic unit does not necessarily imply that episodic flow has penetrated the PTn hydrogeologic unit.

Subsurface temperature measurements from borehole UE-25 a#7, located in Drill Hole Wash, showed penetration of episodic flow below the PTn hydrogeologic unit associated with strong precipitation and runoff events at Yucca Mountain. However, the observations suggest that this penetration was a result of: (1) runoff in Drill Hole Wash flowing directly into the borehole and (2) water rapidly infiltrating the alluvium, ponding at the bedrock contact, and entering the borehole through an uncased section.

Another episodic flow event at borehole UE-25 UZ#4, located in Pagany Wash, was observed using subsurface temperature and pneumatic pressure measurements. These measurements showed penetration of episodic flow through the alluvium, TCw hydrogeologic unit, and into the PTn hydrogeologic unit. However, the episodic flow behavior was not observed below the Yucca Mountain Tuff (Tpy) lithostratigraphic unit, which is a component of the PTn hydrogeologic unit. Therefore, the observations at this borehole are consistent with the conceptual model that episodic flow is damped, leading to steady flow below the PTn hydrogeologic unit.

Observations of episodic flow behavior in the PTn hydrogeologic unit at Alcove 4 and observations of ^{14}C in the unsaturated zone also provide evidence concerning the behavior of episodic flow in the unsaturated zone. Liquid release tests in faulted or undisturbed portions of PTn hydrogeologic unit matrix exposed in the Alcove 4 test bed showed substantial matrix imbibition, demonstrating the ability to effectively damp liquid pulses in the PTn hydrogeologic unit. The ^{14}C data from boreholes USW UZ-1 and USW SD-12 provide evidence of long residence times within the matrix of the PTn hydrogeologic unit requiring thousands of years to traverse the PTn hydrogeologic unit.

Analysis of the subject technical basis information supplied in this RAI response supports the low consequence exclusion justification for FEP 2.2.07.05.0A. The analysis shows that episodic flow in the unsaturated zone is not prevalent in the repository area. Furthermore, any effects of localized episodic flow would not have a significant adverse effect on performance.

Table 4. Surface-Based Borehole Samples

SPC Number	Location	Sampled Depth (m)	Date of Analysis	Extraction Method	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[a]	Uncertainty (+/-)	Tritium Detection Limits (TU)[b]	Level Required for Samples to Be Considered above Background (95% confidence level)[c]	Q Status
SPC00020584	USW UZ-16	43.83 to 43.92	7/12/1993	D	Tpcpv2	tcw13	19.7	6[d]	8.2	22.2	Q
SPC00020609	USW UZ-16	48.28 to 48.37	10/9/1993	D	Tpcpv1	ptn21	154.7	6[d]	8.2	22.2	Q
SPC00020609	USW UZ-16	48.28 to 48.37	1/14/1994	D	Tpcpv1	ptn21	148.2	6[d]	8.2	22.2	Q
SPC00020679	USW UZ-16	80.10 to 80.22	10/9/1993	D	Tptrn	tsw31, tsw32	32.4	6[d]	8.2	22.2	Q
SPC00020679	USW UZ-16	80.10 to 80.22	1/14/1994	D	Tptrn	tsw31, tsw32	28.1	6[d]	8.2	22.2	Q
SPC00020679	USW UZ-16	80.22 to 80.35	2/3/1994	UP/D	Tptrn	tsw31, tsw32	9.3	6[d]	8.2	22.2	Q
SPC00020863	USW UZ-16	136.12 to 136.18	1/26/1994	D	Tptpul	tsw33	12	6[d]	8.2	22.2	Q
SPC00020942	USW UZ-16	177.70 to 177.76	8/15/1995	D	Tptpmn	tsw34	95.8	5.3	10.5	24.5	Q
SPC00020942	USW UZ-16	177.70 to 177.76	7/27/1995	D	Tptpmn	tsw34	105.9	6.1	10.5	24.5	Q
SPC00020991	USW UZ-16	192.12 to 192.21	8/15/1995	D	Tptpmn	tsw34	273.8	7.4	10.5	24.5	Q
SPC00020991	USW UZ-16	192.12 to 192.21	7/27/1995	D	Tptpmn	tsw34	307.8	8.4	10.5	24.5	Q
SPC00021000	USW UZ-16	196.08 to 196.14	8/15/1995	D	Tptpmn	tsw34	445.6	11.4	10.5	24.5	Q
SPC00021000	USW UZ-16	196.08 to 196.14	7/27/1995	D	Tptpmn	tsw34	474.3	10.2	10.5	24.5	Q
SPC00021028	USW UZ-16	203.91 to 204.12	6/17/1993	D	Tptpll	tsw35	29.5	6[d]	8.2	22.2	Q
SPC00021028	USW UZ-16	203.91 to 204.12	6/25/1993	D	Tptpll	tsw35	25.6	6[d]	8.2	22.2	Q
SPC00021550	USW UZ-16	288.04 to 288.16	8/15/1995	D	Tptpln	tsw36	48.2	4.7	10.5	24.5	Q
SPC00021550	USW UZ-16	288.04 to 288.16	7/27/1995	D	Tptpln	tsw36	59.1	5.6	10.5	24.5	Q
SPC00021553	USW UZ-16	288.92 to 289.01	8/15/1995	D	Tptpln	tsw36	10.8	4.1	10.5	24.5	Q
SPC00021553	USW UZ-16	288.92 to 289.01	7/27/1995	D	Tptpln	tsw36	17.6	4.9	10.5	24.5	Q
SPC00021696	USW UZ-16	317.36 to 317.48	9/28/1994	UP/D	Tptpln	tsw36	58.6	6[d]	8.2	22.2	Q
SPC00021696	USW UZ-16	317.36 to 317.48	10/7/1994	UP/D	Tptpln	tsw36	48.8	6[d]	8.2	22.2	Q
SPC00021696	USW UZ-16	317.57 to 317.63	12/10/1994	D	Tptpln	tsw36	31.8	6[d]	8.2	22.2	Q
SPC00021790	USW UZ-16	332.41 to 332.48	11/8/1994	D	Tptpln	tsw37	36.8	6[d]	8.2	22.2	Q
SPC00021790	USW UZ-16	332.41 to 332.48	12/19/1994	D	Tptpln	tsw37	12.2	6[d]	8.2	22.2	Q
SPC00021790	USW UZ-16	332.48 to 332.54	12/27/1994	D	Tptpln	tsw37	11.9	6[d]	8.2	22.2	Q
SPC00021822	USW UZ-16	338.51 to 338.60	9/28/1994	D	Tptpv3	tsw38	22.3	6[d]	8.2	22.2	Q
SPC00021822	USW UZ-16	338.51 to 338.60	10/7/1994	UP/D	Tptpv3	tsw38	33.2	6[d]	8.2	22.2	Q
SPC00021822	USW UZ-16	338.60 to 338.69	8/15/1995	D	Tptpv3	tsw38	20.1	4.3	10.5	24.5	Q
SPC00021822	USW UZ-16	338.60 to 338.69	7/27/1995	D	Tptpv3	tsw38	17.6	4.9	10.5	24.5	Q
SPC00021825	USW UZ-16	339.30 to 339.39	12/10/1994	D	Tptpv3	tsw38	38.2	6[d]	8.2	22.2	Q
SPC00021825	USW UZ-16	339.30 to 339.39	11/8/1994	D	Tptpv3	tsw38	55.2	6[d]	8.2	22.2	Q
SPC00021825	USW UZ-16	339.30 to 339.39	12/19/1994	D	Tptpv3	tsw38	46.8	6[d]	8.2	22.2	Q
SPC00021825	USW UZ-16	339.43 to 339.49	12/10/1994	D	Tptpv3	tsw38	47.4	6[d]	8.2	22.2	Q
SPC00021828	USW UZ-16	341.99 to 342.05	12/27/1994	**NA**	Tptpv3	tsw38	25.6	6[d]	8.2	22.2	Q
SPC00021828	USW UZ-16	342.05 to 342.14	11/8/1994	D	Tptpv3	tsw38	37.4	6[d]	8.2	22.2	Q
SPC00021828	USW UZ-16	342.05 to 342.14	12/10/1994	D	Tptpv3	tsw38	28.3	6[d]	8.2	22.2	Q

Table 4. Surface-Based Borehole Samples (Continued)

SPC Number	Location	Sampled Depth (m)	Date of Analysis	Extraction Method	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[a]	Uncertainty (+/-)	Tritium Detection Limits (TU)[b]	Level Required for Samples to Be Considered above Background (95% confidence level)[c]	Q Status
SPC00021828	USW UZ-16	342.05 to 342.14	12/19/1994	D	Tptpv3	tsw38	28.6	6[d]	8.2	22.2	Q
SPC00021831	USW UZ-16	344.27 to 344.36	7/27/1995	D	Tptpv3	tsw38	58.7	5.5	10.5	24.5	Q
SPC00021842	USW UZ-16	347.41 to 347.53	5/25/1995	D	Tptpv3	tsw38	13.0	3.5	10.5	24.5	Q
SPC00021955	USW UZ-16	355.46 to 355.52	11/8/1994	UP/D	Tptpv2	tsw39 (vit,zeo)	16.7	6[d]	8.2	22.2	Q
SPC00021957	USW UZ-16	356.71 to 356.80	11/8/1994	D	Tptpv2	tsw39 (vit,zeo)	17	6[d]	8.2	22.2	Q
SPC00021957	USW UZ-16	356.80 to 356.83	12/10/1994	D	Tptpv2	tsw39 (vit,zeo)	12.4	6[d]	8.2	22.2	Q
SPC00021958	USW UZ-16	359.45 to 359.54	12/10/1994	D	Tptpv1	ch1 (vit,zeo)	16.4	6[d]	8.2	22.2	Q
SPC00022288	USW UZ-16	386.94 to 387.07	9/13/1993	UP/D	Tac	ch2–ch5(vit,zeo)	8.4	6[d]	8.2	22.2	Q
SPC00022320	USW UZ-16	395.26 to 395.33	1/1/1994	D	Tac	ch2–ch5(vit,zeo)	14.3	6[d]	8.2	22.2	Q
SPC00022320	USW UZ-16	395.26 to 395.33	1/14/1994	D	Tac	ch2–ch5(vit,zeo)	18.5	6[d]	8.2	22.2	Q
SPC00022429	USW UZ-16	409.68 to 409.74	8/2/1994	UP/D	Tac	ch2–ch5(vit,zeo)	8.9	6[d]	8.2	22.2	Q
SPC00023003	USW UZ-16	423.49 to 423.55	6/17/1993	UP/D	Tac	ch2–ch5(vit,zeo)	9.6	6[d]	8.2	22.2	Q
SPC00023008	USW UZ-16	425.35 to 425.47	8/2/1994	UP/D	Tac	ch2–ch5(vit,zeo)	9.4	6[d]	8.2	22.2	Q
SPC00023010	USW UZ-16	426.02 to 426.11	9/13/1993	UP/D	Tac	ch2–ch5(vit,zeo)	45.8	6[d]	8.2	22.2	Q
SPC00023010	USW UZ-16	426.14 to 426.20	3/8/1994	UP/D	Tac	ch2–ch5(vit,zeo)	11.3	6[d]	8.2	22.2	Q
SPC00023145	USW UZ-16	437.17 to 437.27	9/13/1993	UP/D	Tac	ch2–ch5(vit,zeo)	112.6	6[d]	8.2	22.2	Q
SPC00023186	USW UZ-16	453.21 to 453.33	1/1/1994	D	Tcpuv	pp4	25.7	6[d]	8.2	22.2	Q
SPC00023667	USW UZ-16	490.15 to 490.21	3/8/1994	UP/D	Tcpm	pp1	11.8	6[d]	8.2	22.2	Q
SPC00023754	USW UZ-16	498.68 to 498.77	3/8/1994	UP/D	Tcpm	pp1	10.4	6[d]	8.2	22.2	Q
SPC01005475	USW WT-24	514.75 to 514.87	4/12/1999	D	Tptpv3	tsw38	37.6	3.3	8.2	22.2	Q
SPC01005475	USW WT-24	514.90 to 514.99	2/1/1999	D	Tptpv3	tsw38	35.6	3	8.2	22.2	Q
SPC01005478	USW WT-24	515.26 to 515.36	5/15/1999	D	Tptpv3	tsw38	28.3	3	8.2	22.2	Q
SPC01005478	USW WT-24	515.26 to 515.36	5/29/1999	D	Tptpv3	tsw38	29.1	3	8.2	22.2	Q
SPC01005480	USW WT-24	516.45 to 516.88	2/19/1998	PW/D	Tptpv3	tsw38	29.9	3.9	8.2	22.2	Q
SPC01005480	USW WT-24	516.45 to 516.88	4/21/1998	PW/D	Tptpv3	tsw38	25.8	3.2	8.2	22.2	Q
SPC01005483	USW WT-24	517.43 to 517.52	5/15/1999	D	Tptpv3	tsw38	50	3.2	8.2	22.2	Q
SPC01005483	USW WT-24	517.43 to 517.52	5/29/1999	D	Tptpv3	tsw38	42.8	3.2	8.2	22.2	Q
SPC01005487	USW WT-24	518.07 to 518.53	5/14/1998	PW/D	Tptpv3	tsw38	29.7	3.2	8.2	22.2	Q
SPC01005487	USW WT-24	518.07 to 518.53	6/1/1998	PW/D/trap 2	Tptpv3	tsw38	30.7	3.2	8.2	22.2	Q
SPC01005490	USW WT-24	519.04 to 519.14	5/1/1999	D	Tptpv3	tsw38	45.1	3.2	8.2	22.2	Q
SPC01005505	USW WT-24	524.23 to 524.32	5/14/1998	PW/D	Tptpv3	tsw38	8.9	3	8.2	22.2	Q
SPC01005528	USW WT-24	531.82 to 531.88	2/19/1998	UP/D	Tptpv1	ch1 (vit,zeo)	9.8	3.7	8.2	22.2	Q
SPC01005528	USW WT-24	531.88 to 531.94	5/14/1998	UP/D	Tptpv1	ch1 (vit,zeo)	13.6	3	8.2	22.2	Q
SPC01007207	USW WT-24	551.63 to 551.69	9/18/1998	UP/D	Tac	ch2–ch5(vit,zeo)	10.8	3.1	8.2	22.2	Q
SPC01009120	USW WT-24	600.30 to 600.40	2/1/1999	D	Tac	ch2–ch5(vit,zeo)	8.6	2.7	8.2	22.2	Q
SPC01009779	USW WT-24	628.50 to 628.59	5/29/1999	D	Tac	ch2–ch5(vit,zeo)	12.2	2.9	8.2	22.2	Q
SPC01009868	USW WT-24	652.21 to 652.27	8/1/1998	UP/D	Tac	ch2–ch5(vit,zeo)	14.1	3.7	8.2	22.2	Q
SPC01009868	USW WT-24	652.21 to 652.27	8/11/1998	UP/D	Tac	ch2–ch5(vit,zeo)	11.2	3.1	8.2	22.2	Q

Table 4. Surface-Based Borehole Samples (Continued)

SPC Number	Location	Sampled Depth (m)	Date of Analysis	Extraction Method	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[a]	Uncertainty (+/-)	Tritium Detection Limits (TU)[b]	Level Required for Samples to Be Considered above Background (95% confidence level)[c]	Q Status
SPC01010071	USW WT-24	680.28 to 680.37	5/29/1999	D	Tac	ch2–ch5(vit,zeo)	23.6	3	8.2	22.2	Q
SPC01010100	USW WT-24	688.54 to 688.60	9/18/1998	UP/D	Tac	ch2–ch5(vit,zeo)	10.9	3.1	8.2	22.2	Q
SPC01010465	USW WT-24	764.13 to 764.19	1/4/1999	D	Tac	ch2–ch5(vit,zeo)	24	2.8	8.2	22.2	Q
SPC01010465	USW WT-24	764.13 to 764.19	5/1/1999	D	Tac	ch2–ch5(vit,zeo)	18.1	2.9	8.2	22.2	Q
SPC01010468	USW WT-24	765.02 to 765.08	5/15/1999	D	Tac	ch2–ch5(vit,zeo)	19	2.9	8.2	22.2	Q
SPC01010468	USW WT-24	765.02 to 765.08	5/29/1999	D	Tac	ch2–ch5(vit,zeo)	8.2	2.9	8.2	22.2	Q
SPC01010471	USW WT-24	765.96 to 766.02	5/15/1999	D	Tac	ch2–ch5(vit,zeo)	10.6	2.8	8.2	22.2	Q
SPC01010475	USW WT-24	766.85 to 766.94	5/15/1999	D	Tac	ch2–ch5(vit,zeo)	34.3	3	8.2	22.2	Q
SPC01010475	USW WT-24	766.85 to 766.94	5/29/1999	D	Tac	ch2–ch5(vit,zeo)	31.2	3.1	8.2	22.2	Q
SPC01010475	USW WT-24	766.85 to 766.94	6/14/1999	D	Tac	ch2–ch5(vit,zeo)	28.3	3	8.2	22.2	Q
SPC01010478	USW WT-24	767.82 to 767.88	6/14/1999	D	Tac	ch2–ch5(vit,zeo)	30.2	3	8.2	22.2	Q
SPC01010481	USW WT-24	768.77 to 768.83	5/1/1999	UP/D	Tac	ch2–ch5(vit,zeo)	25.7	3	8.2	22.2	Q
SPC01010481	USW WT-24	768.77 to 768.83	5/29/1999	UP/D	Tac	ch2–ch5(vit,zeo)	32.6	3.1	8.2	22.2	Q
SPC01010481	USW WT-24	769.04 to 769.10	4/12/1999	UP/D	Tac	ch2–ch5(vit,zeo)	11.7	2.8	8.2	22.2	Q
SPC01010481	USW WT-24	769.19 to 769.25	2/1/1999	D	Tac	ch2–ch5(vit,zeo)	17.7	2.8	8.2	22.2	Q
SPC01010484	USW WT-24	769.71 to 769.77	10/2/1998	UP/D	Tac	ch2–ch5(vit,zeo)	29	3.3	8.2	22.2	Q
SPC01010484	USW WT-24	769.92 to 769.99	10/2/1998	UP/D	Tac	ch2–ch5(vit,zeo)	33	3.3	8.2	22.2	Q
SPC01006490	USW SD-6	125.43 to 125.52	3/24/1998	D	Tpc_un	tcw11-tcw13	10.4	3.4	8.2	22.2	Q
SPC01006558	USW SD-6	143.56 to 143.65	5/14/1998	UP/D	Tpbt3	ptn24	9.2	3	8.2	22.2	Q
SPC01006558	USW SD-6	143.65 to 143.74	5/14/1998	UP/D	Tpbt3	ptn24	8.7	3	8.2	22.2	Q
SPC01006558	USW SD-6	143.77 to 143.87	5/14/1998	UP/D	Tpbt3	ptn24	12	3	8.2	22.2	Q
SPC01006605	USW SD-6	161.88 to 161.97	3/24/1998	D	Tptrn	tsw31, tsw32	14.7	5.1	8.2	22.2	Q
SPC01006638	USW SD-6	169.68 to 169.80	3/24/1998	D	Tptrn	tsw31, tsw32	8.6	3.4	8.2	22.2	Q
SPC01009309	USW SD-6	433.09 to 433.15	6/15/1998	D	Tptpln	tsw37	10.2	3	8.2	22.2	Q
SPC01009329	USW SD-6	437.78 to 437.88	2/12/1999	D	Tptpln	tsw37	21.7	2.8	8.2	22.2	Q
SPC01009329	USW SD-6	438.15 to 438.24	6/15/1998	D	Tptpln	tsw37	26.7	3.2	8.2	22.2	Q
SPC01009334	USW SD-6	438.82 to 438.91	7/2/1998	D	Tptpln	tsw37	24.3	3.1	8.2	22.2	Q
SPC01009334	USW SD-6	438.91 to 439.00	2/12/1999	D	Tptpln	tsw37	27.9	2.8	8.2	22.2	Q
SPC01009334	USW SD-6	439.13 to 439.25	2/1/1999	D	Tptpln	tsw37	29.7	2.9	8.2	22.2	Q
SPC07009338	USW SD-6	439.67 to 439.77	6/15/1998	D	Tptpln	tsw37	13.3	3.1	8.2	22.2	Q
SPC01009359	USW SD-6	448.82 to 448.94	7/2/1998	D	Tptpv3	tsw38	9.3	3	8.2	22.2	Q
SPC01009374	USW SD-6	451.38 to 451.47	7/2/1998	D	Tptpv3	tsw38	17.1	3.1	8.2	22.2	Q
SPC01009379	USW SD-6	452.17 to 452.29	7/2/1998	D	Tptpv3	tsw38	8.3	3	8.2	22.2	Q
SPC01009383	USW SD-6	453.02 to 453.12	7/2/1998	D	Tptpv3	tsw38	8.9	3.4	8.2	22.2	Q
SPC01009387	USW SD-6	453.88 to 454.00	7/2/1998	D	Tptpv3	tsw38	10.3	3	8.2	22.2	Q
SPC01009420	USW SD-6	460.10 to 460.22	9/18/1998	D	Tptpv2	tsw39 (vit,zeo)	10.8	3.1	8.2	22.2	Q
SPC01009447	USW SD-6	473.78 to 473.87	3/15/1999	D	Tpbt1	ch1 (vit,zeo)	9.3	2.7	8.2	22.2	Q
SPC01009451	USW SD-6	476.34 to 476.43	2/12/1999	D	Tac	ch2–ch5(vit,zeo)	11.7	2.7	8.2	22.2	Q

Table 4. Surface-Based Borehole Samples (Continued)

SPC Number	Location	Sampled Depth (m)	Date of Analysis	Extraction Method	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[a]	Uncertainty (+/-)	Tritium Detection Limits (TU)[b]	Level Required for Samples to Be Considered above Background (95% confidence level)[c]	Q Status
SPC01009480	USW SD-6	483.32 to 483.41	5/1/1999	D	Tac	ch2–ch5(vit,zeo)	8.6	2.8	8.2	22.2	Q
SPC01009486	USW SD-6	491.58 to 491.64	3/1/1999	D	Tac	ch2–ch5(vit,zeo)	8.7	2.7	8.2	22.2	Q
SPC01009491	USW SD-6	494.29 to 494.39	3/1/1999	D	Tac	ch2–ch5(vit,zeo)	8.5	2.7	8.2	22.2	Q
SPC01009517	USW SD-6	529.22 to 529.29	4/12/1999	D	Tcpuv	pp4	9.1	2.7	8.2	22.2	Q
SPC01009533	USW SD-6	533.19 to 533.28	5/15/1999	D	Tcpuc	pp3	29.9	3	8.2	22.2	Q
SPC01009533	USW SD-6	533.19 to 533.28	6/14/1999	D	Tcpuc	pp3	29.7	3	8.2	22.2	Q
SPC01009538	USW SD-6	533.70 to 533.77	4/12/1999	D	Tcpuc	pp3	43.2	3.1	8.2	22.2	Q
SPC01009538	USW SD-6	534.04 to 534.13	2/12/1999	D	Tcpuc	pp3	41.6	2.9	8.2	22.2	Q
SPC01009538	USW SD-6	534.04 to 534.13	5/1/1999	D	Tcpuc	pp3	32.7	3.5	8.2	22.2	Q
SPC01009542	USW SD-6	534.65 to 534.74	12/18/1998	D	Tcpuc	pp3	36.6	3.3	8.2	22.2	Q
SPC01009546	USW SD-6	535.56 to 535.63	2/12/1999	D	Tcpuc	pp3	17.8	2.7	8.2	22.2	Q
SPC01009546	USW SD-6	535.93 to 536.02	12/18/1998	D	Tcpuc	pp3	17.3	3.1	8.2	22.2	Q
SPC10009563	USW SD-6	539.56 to 539.65	6/14/1999	D	Tcpuc	pp3	8.6	2.8	8.2	22.2	Q
SPC01009636	USW SD-6	555.32 to 555.35	6/30/1999	D	Tcpuc	pp3	13	3.1	8.2	22.2	Q
SPC01009653	USW SD-6	559.13 to 559.19	4/12/1999	D	Tcpuc	pp3	16.9	2.8	8.2	22.2	Q
SPC01009669	USW SD-6	563.97 to 564.03	12/18/1998	D	Tcpuc	pp3	15.2	9.5	8.2	22.2	Q
SPC01009669	USW SD-6	564.03 to 564.09	2/12/1999	D	Tcpuc	pp3	9.3	3	8.2	22.2	Q
SPC01009684	USW SD-6	568.15 to 568.21	12/18/1998	D	Tcpuc	pp3	11.3	11.9	8.2	22.2	Q
SPC01009712	USW SD-6	572.99 to 573.08	3/1/1999	D	Tcpm	pp1	8.9	2.7	8.2	22.2	Q
SPC01009716	USW SD-6	573.94 to 574.03	7/2/1998	UP/D	Tcpm	pp1	13.2	3	8.2	22.2	Q
SPC00022087	USW NRG-6	50.47 to 50.51	4/2/1996	D	Tpbt3	ptn24	11.8	4.6	10.5	24.5	Q
SPC00022058	USW NRG-6	52.12 to 52.21	9/22/1994	UP/D	Tpbt3	ptn24	10	6[d]	8.2	22.2	Q
SPC00022058	USW NRG-6	52.12 to 52.21	9/12/1994	UP/D	Tpbt3	ptn24	11.2	6[d]	8.2	22.2	Q
SPC00022058	USW NRG-6	52.24 to 52.36	9/22/1994	UP/D	Tpbt3	ptn24	20.7	6[d]	8.2	22.2	Q
SPC00022058	USW NRG-6	52.24 to 52.36	9/12/1994	UP/D	Tpbt3	ptn24	12.7	6[d]	8.2	22.2	Q
SPC00022063	USW NRG-6	53.52 to 53.64	9/22/1994	UP/D	Tpp	ptn25	42.4	6[d]	8.2	22.2	Q
SPC00022063	USW NRG-6	53.52 to 53.64	9/12/1994	UP/D	Tpp	ptn25	33.6	6[d]	8.2	22.2	Q
SPC00022084	USW NRG-6	64.13 to 64.16	4/2/1996	D	Tpp	ptn25	139.9	5.8	10.5	24.5	Q
SPC00022084	USW NRG-6	64.13 to 64.16	7/23/1996	D	Tpp	ptn25	117.3	5.8	10.5	24.5	Q
SPC00022100	USW NRG-6	67.03 to 67.12	12/27/1994	UP/D	Tpp	ptn25	121.9	6[d]	8.2	22.2	Q
SPC00022100	USW NRG-6	67.15 to 67.24	12/27/1994	UP/D	Tpp	ptn25	171.5	6[d]	8.2	22.2	Q
SPC00022108	USW NRG-6	69.92 to 69.95	4/2/1996	D	Tpbt2	ptn26	30.2	4.7	10.5	24.5	Q
SPC00022108	USW NRG-6	69.92 to 69.95	7/23/1996	D	Tpbt2	ptn26	23.1	4.8	10.5	24.5	Q
SPC00022119	USW NRG-6	74.55 to 74.68	5/15/1995	UP/D	Tpbt2-Tptrv3	ptn26	176	6[d]	10.5	24.5	Q
SPC00024455	USW UZ-14	17.34 to 17.53	8/24/1993	D	Tpy	ptn22, ptn23, ptn24	8.2	6[d]	8.2	22.2	Q
SPC00024493	USW UZ-14	25.97 to 26.09	9/28/1994	UP/D	Tpbt3	ptn24	12.6	6[d]	8.2	22.2	Q
SPC00024494	USW UZ-14	26.15 to 26.24	9/28/1994	UP/D	Tpbt3	ptn24	18.1	6[d]	8.2	22.2	Q
SPC00024504	USW UZ-14	29.32 to 29.44	11/8/1994	UP/D	Tpbt3	ptn24	15.9	6[d]	8.2	22.2	Q

Table 4. Surface-Based Borehole Samples (Continued)

SPC Number	Location	Sampled Depth (m)	Date of Analysis	Extraction Method	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[a]	Uncertainty (+/-)	Tritium Detection Limits (TU)[b]	Level Required for Samples to Be Considered above Background (95% confidence level)[c]	Q Status
SPC00024509	USW UZ-14	30.60 to 30.72	11/8/1994	UP/D	Tpbt3	ptn24	20.1	6[d]	8.2	22.2	Q
SPC00024534	USW UZ-14	38.22 to 38.34	7/14/1994	D	Tpp	ptn25	23	6[d]	8.2	22.2	Q
SPC00024543	USW UZ-14	41.12 to 41.27	7/14/1994	D	Tpp	ptn25	9	6[d]	8.2	22.2	Q
SPC00024544	USW UZ-14	41.30 to 41.39	11/8/1994	UP/D	Tpp	ptn25	31	6[d]	8.2	22.2	Q
SPC00024551	USW UZ-14	43.89 to 44.10	7/14/1994	D	Tpp	ptn25	10.5	6[d]	8.2	22.2	Q
SPC00024552	USW UZ-14	44.14 to 44.26	9/28/1994	UP/D	Tpp	ptn25	13.4	6[d]	8.2	22.2	Q
SPC00024556	USW UZ-14	44.87 to 45.02	7/14/1994	D	Tpp	ptn25	23.8	6[d]	8.2	22.2	Q
SPC00024653	USW UZ-14	68.70 to 68.82	8/24/1993	D	Tpp	ptn25	10.9	6[d]	8.2	22.2	Q
SPC00024654	USW UZ-14	68.85 to 68.95	9/28/1995	UP/D	Tpp	ptn25	13.4	3.7	10.5	24.5	Q
SPC00024676	USW UZ-14	74.62 to 74.77	9/8/1993	D	Tpbt2	ptn26	15.1	6[d]	8.2	22.2	Q
SPC00024677	USW UZ-14	74.83 to 74.92	9/28/1994	UP/D	Tpbt2	ptn26	9.3	6[d]	8.2	22.2	Q
SPC00024731	USW UZ-14	95.19 to 95.34	10/20/1993	D	Tptrn	tsw31, tsw32	12.9	6[d]	8.2	22.2	Q
SPC00024904	USW UZ-14	108.48 to 117.81	7/17/1997	D	Tptrn	tsw31, tsw32	11.6	4.4	8.2	22.2	Q
Multiple[e]	USW UZ-14	108.48 to 117.81	10/1/1997	D	Tptrn	tsw31, tsw32	22	4.8	8.2	22.2	Q
SPC00025294	USW UZ-14	183.46 to 183.64	4/23/1994	D	Tptpul	tsw33	14.7	6[d]	8.2	22.2	Q
SPC00025337	USW UZ-14	197.11 to 197.30	6/17/1994	D	Tptpul	tsw33	8.8	6[d]	8.2	22.2	Q
SPC00026534	USW UZ-14	246.98 to 251.55	7/17/1997	D	Tptpmn	tsw34	17.4	4.4	8.2	22.2	Q
SPC00026534, SPC00026548[f]	USW UZ-14	246.98 to 251.55	10/1/1997	D	Tptpmn	tsw34	12.3	4.7	8.2	22.2	Q
SPC00026586	USW UZ-14	264.90 to 265.08	4/23/1994	D	Tptpll	tsw35	10	6[d]	8.2	22.2	Q
SPC00026685	USW UZ-14	269.60 to 269.75	4/23/1994	D	Tptpll	tsw35	14.2	6[d]	8.2	22.2	Q
SPC00026848	USW UZ-14	293.77 to 293.95	4/23/1994	D	Tptpll	tsw35	8.9	6[d]	8.2	22.2	Q
SPC00027133	USW UZ-14	324.98 to 325.10	12/28/1993	D	Tptpll	tsw35	11.8	6[d]	8.2	22.2	Q
SPC00027266	USW UZ-14	342.60 to 342.72	1/27/1995	D	Tptpll	tsw35	11.6	6[d]	10.5	24.5	Q
SPC00027294	USW UZ-14	352.29 to 352.41	6/17/1994	D	Tptpln	tsw36	9	6[d]	8.2	22.2	Q
SPC00027386	USW UZ-14	366.28 to 366.43	6/17/1994	D	Tptpln	tsw36	10.3	6[d]	8.2	22.2	Q
SPC00028454	USW UZ-14	392.46 to 392.61	1/27/1995	D	Tptpv3	tsw38	19.1	6[d]	10.5	24.5	Q
SPC00028939	USW UZ-14	416.54 to 416.75	4/23/1994	D	Tptpv2	tsw39 (vit,zeo)	14	6[d]	8.2	22.2	Q
SPC00029837	USW UZ-14	424.04 to 424.22	7/14/1994	D	Tptpv1	ch1 (vit,zeo)	11.6	6[d]	8.2	22.2	Q
SPC00029113	USW UZ-14	429.57 to 429.69	5/25/1995	UP/D	Tpbt1	ch1 (vit,zeo)	11.2	3.5	10.5	24.5	Q
SPC00029114	USW UZ-14	429.74 to 429.86	5/25/1995	UP/D	Tpbt1	ch1 (vit,zeo)	14.5	3.5	10.5	24.5	Q
SPC00029844	USW UZ-14	433.55 to 433.73	1/27/1995	D	Tac	ch2–ch5(vit,zeo)	15.5	6[d]	10.5	24.5	Q
SPC00029851	USW UZ-14	435.92 to 436.08	9/2/1994	D	Tac	ch2–ch5(vit,zeo)	13.2	6[d]	8.2	22.2	Q
SPC00033822	USW UZ-14	477.62 to 477.77	11/28/1994	D	Tac	ch2–ch5(vit,zeo)	8.6	6[d]	8.2	22.2	Q
SPC00034258	USW UZ-14	529.32 to 529.47	1/27/1995	D	Tacbt	ch6 (vit,zeo)	12.7	6[d]	10.5	24.5	Q
SPC00035446	USW UZ-14	577.69 to 577.87	1/27/1995	D	Tcplc	pp2	14.1	6[d]	10.5	24.5	Q
SPC00033882	USW SD-12	87.60 to 87.63	9/23/1996	D	Tpp	ptn25	21.2	7	10.5	24.5	Q
SPC00035239	USW SD-12	174.62 to 174.74	6/1/1998	D	Tptpul	tsw33	12.8	3.8	8.2	22.2	Q
SPC00035343	USW SD-12	198.39 to 198.49	2/19/1998	D	Tptpul	tsw33	13.9	4.6	8.2	22.2	Q

Table 4. Surface-Based Borehole Samples (Continued)

SPC Number	Location	Sampled Depth (m)	Date of Analysis	Extraction Method	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[a]	Uncertainty (+/-)	Tritium Detection Limits (TU)[b]	Level Required for Samples to Be Considered above Background (95% confidence level)[c]	Q Status
SPC00035383	USW SD-12	211.53 to 211.62	6/26/1996	NA	Tptpmn	tsw34	11.5	4	10.5	24.5	Q
SPC00035406	USW SD-12	221.47 to 221.56	2/19/1998	D	Tptpmn	tsw34	8.5	4.5	8.2	22.2	Q
SPC00037039, SPC00037041[f]	USW SD-12	329.49 to 330.04	10/20/1997	PW/D	Tptpln	tsw36	9.3	4.4	8.2	22.2	Q
SPC00037198	USW SD-12	348.75 to 348.90	10/20/1997	PW/D	Tptpln	tsw36	9.5	4.4	8.2	22.2	Q
SPC00038005	USW SD-12	430.32 to 430.35	12/21/1995	UP/D	Tac	ch2–ch5(vit,zeo)	14.3	3.7	10.5	24.5	Q
SPC00038015	USW SD-12	433.55 to 433.56	12/21/1995	UP/D	Tac	ch2–ch5(vit,zeo)	13.7	3.8	10.5	24.5	Q
SPC00044335	USW SD-12	444.34 to 444.37	9/28/1995	D	Tac	ch2–ch5(vit,zeo)	13.0	3.5	10.5	24.5	Q
SPC01000104	USW SD-12	476.22 to 476.28	7/16/1998	UP/D	Tac	ch2–ch5(vit,zeo)	10.7	3.9	8.2	22.2	Q
SPC00047432, SPC00047433[f]	USW SD-12	524.62 to 525.02	10/1/1997	PW/D	Tcpuc	pp3	24.5	4.7	8.2	22.2	Q
SPC00047434	USW SD-12	525.02 to 525.17	10/1/1997	PW/D	Tcpuc	pp3	39.2	4.8	8.2	22.2	Q
SPC00047435	USW SD-12	525.44 to 525.51	10/20/1997	D	Tcpuc	pp3	16.8	4.5	8.2	22.2	Q
SPC00029406	USW NRG-7A	83.24 to 83.27	12/21/1995	D	Tpbt2	ptn26	11.4	4	10.5	24.5	Q
SPC00029406	USW NRG-7A	83.27 to 83.33	11/14/1997	D	Tpbt2	ptn26	8.4	4.5	8.2	22.2	Q
SPC00029412	USW NRG-7A	87.54 to 87.63	6/14/1996	D	Tptrv3	ptn26	11.7	4.2	10.5	24.5	Q
SPC00029559	USW NRG-7A	108.72 to 108.75	8/2/1996	D	Tptrn	tsw31, tsw32	46.8	8.6	10.5	24.5	Q
SPC00029643	USW NRG-7A	144.81 to 144.96	10/1/1997	PW/D	Tptrn	tsw31, tsw32	18	4.7	8.2	22.2	Q
SPC00029645	USW NRG-7A	145.18 to 145.33	10/20/1997	PW/D	Tptrn	tsw31, tsw32	9.7	4.4	8.2	22.2	Q
SPC00029983	USW NRG-7A	239.66 to 239.73	9/1/1996	D	Tptpmn	tsw34	13.1	5.2	10.5	24.5	Q
SPC00030174, SPC00030192[f]	USW NRG-7A	320.04 to 341.65	7/17/1997	D	Tptpll	tsw35	9.2	4.3	8.2	22.2	Q
SPC00030205	USW NRG-7A	351.59 to 351.71	7/17/1997	D	Tptpll	tsw35	12.3	4.3	8.2	22.2	Q
SPC00032153	USW NRG-7A	456.62 to 456.71	9/12/1994	UP/D	Tac	ch2–ch5(vit,zeo)	8.6	6[d]	8.2	22.2	Q
SPC00032158	USW NRG-7A	458.82 to 458.85	3/20/1996	D	Tac	ch2–ch5(vit,zeo)	18.1	4.3	10.5	24.5	Q
SPC00503632	USW NRG-7A	460.00	12/10/1994	Pumped/bailed?	Tac	ch2–ch5(vit,zeo)	10.3	6[d]	8.2	22.2	Q
SPC00039979	USW SD-7	49.04 to 49.10	12/1/1997	D	Tpc_un	tcw11-tcw13	8.7	4.2	8.2	22.2	Q
SPC00040707	USW SD-7	82.75 to 82.81	1/16/1998	D	Tpc_un	tcw11-tcw13	10.8	4.1	8.2	22.2	Q
SPC00040707	USW SD-7	82.75 to 82.81	1/7/1998	D	Tpc_un	tcw11-tcw13	10.3	—[g]	8.2	22.2	Q
SPC00041411	USW SD-7	201.05 to 201.11	1/16/1998	D	Tptpul	tsw33	12.5	4.2	8.2	22.2	Q
SPC01000455	USW SD-7	344.58 to 344.67	1/16/1998	PW/D	Tptpln	tsw37	11.8	4.1	8.2	22.2	Q
SPC01000455	USW SD-7	344.58 to 344.67	1/7/1998	PW/D	Tptpln	tsw37	11.4	—[g]	8.2	22.2	Q
SPC00046273	USW SD-7	357.99 to 358.02	9/23/1996	D	Tptpln	tsw37	18.5	6.6	10.5	24.5	Q
SPC00041949	USW SD-7	440.04 to 440.07	9/23/1996	D	Tac	ch2–ch5(vit,zeo)	14.5	6.6	10.5	24.5	Q
SPC00041997	USW SD-7	456.80 to 456.83	9/23/1996	UP/D	Tac	ch2–ch5(vit,zeo)	10.8	6.6	10.5	24.5	Q
SPC00042022	USW SD-7	464.82 to 464.84	4/2/1996	D	Tac	ch2–ch5(vit,zeo)	10.6	4.1	10.5	24.5	Q
SPC00035836	USW SD-9	46.91 to 46.94	6/3/1996	D	Tpbt3	ptn24	19.8	3.8	10.5	24.5	Q
SPC00036308	USW SD-9	213.82 to 213.88	1/16/1998	D	Tptpul	tsw33	14.6	4.3	8.2	22.2	Q
SPC00036335	USW SD-9	222.87 to 222.93	1/16/1998	D	Tptpmn	tsw34	12.7	4.3	8.2	22.2	Q
SPC00036354	USW SD-9	231.89 to 231.95	1/16/1998	D	Tptpmn	tsw34	20.9	4.4	8.2	22.2	Q

Table 4. Surface-Based Borehole Samples (Continued)

SPC Number	Location	Sampled Depth (m)	Date of Analysis	Extraction Method	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[a]	Uncertainty (+/-)	Tritium Detection Limits (TU)[b]	Level Required for Samples to Be Considered above Background (95% confidence level)[c]	Q Status
SPC00036354	USW SD-9	231.89 to 231.95	1/7/1998	D	Tptpmn	tsw34	19.5	—[g]	8.2	22.2	Q
SPC00036417	USW SD-9	259.78 to 259.84	8/2/1996	D	Tptpll	tsw35	14.7	4.2	10.5	24.5	Q
SPC00036479	USW SD-9	301.75 to 301.81	1/16/1998	D	Tptpll	tsw35	19	4.4	8.2	22.2	Q
SPC00037013	USW SD-9	447.60 to 447.69	7/25/1997	PW/D/TR2	Tpbt1	ch1 (vit,zeo)	10.5	4.2	8.2	22.2	Q
SPC00037450	USW SD-9	461.19 to 461.35	8/1/1998	PW/D	Tac	ch2–ch5(vit,zeo)	11.3	4.5	8.2	22.2	Q
SPC00037453	USW SD-9	461.68 to 461.80	8/1/1998	PW/D	Tac	ch2–ch5(vit,zeo)	12	4.5	8.2	22.2	Q
SPC00037453	USW SD-9	461.68 to 461.80	8/11/1998	PW/D	Tac	ch2–ch5(vit,zeo)	17.2	3.8	8.2	22.2	Q
SPC01001161	USW UZ-7a	67.30 to 67.36	6/1/1998	UP/D	Tpbt2	ptn26	13.3	3.6	8.2	22.2	Q
SPC01001173	USW UZ-7a	73.58 to 73.64	3/5/1998	UP/D	Tpbt2	ptn26	9.8	3.5	8.2	22.2	Q
SPC01001236	USW UZ-7a	117.62 to 117.68	11/14/1997	D	Tptpul	tsw33	14.5	3.8	8.2	22.2	Q
SPC01001238	USW UZ-7a	120.27 to 120.40	6/1/1998	D	Tptpul	tsw33	13.5	3.6	8.2	22.2	Q

[a] Values highlighted in yellow are above the 95th percentile confidence limit.
[b] Detection limits prior to 1/27/1995 are assigned the lowest calculated value, for the range between those dates, 8.2 TU.
[c] 95% confidence intervals before 1/27/1995 are assigned the lowest calculated value for the range between those dates, 22.2 TU.
[d] Counting error data not available. DTN provides only estimate of external error, based on replicate analyses, of approximately 6 TU.
[e] Small amounts of water from nine core segments (SPC00024904, SPC00024905, SPC00024916, SPC00024917, SPC00024919, SPC0024920, SPC0024930, SPC00024931, and SPC0024932) were combined to make one sample.
[f] Two adjacent or nearly adjacent core samples were distilled at the same time, yielding one water sample.
[g] Uncertainty information not available.

NOTES: UP = pore water obtained by uniaxial compression.
D = pore water distilled from rock.
PW/D = pore water distilled from rock using ^{14}C distillation system.
PW/CO2 = CO_2 gas (as HCO_3 in pore water) extracted from the pore water using the ^{14}C distillation system; trap 1 and trap 2 are the different cold traps present on the ^{14}C distillation system.
Q = qualified.
NA = not available.

Table 5. ESF and ECRB Drift Samples

SPC Number for Core Sample or Water Sample	Borehole Name	ESF Station[a]	Date of Analysis	Extraction Method	Sampled Interval (ft)	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[b]	Uncertainty 2σ (+/-)	Tritium Detection Limits (TU)	Threshold for Presence of Modern Water (TU)	Q Status
SPC00046014	ESF-AL#2-HPF#1	01+68	10/21/1996	UP/D	34.3 to 34.6[c]	Tpcpmn	tcw12	28.8	8.4	10.5	24.5[d]	Q
SPC00046017	ESF-AL#2-HPF#1	01+68	10/21/1996	UP/D	47.2 to 47.6[c]	Tpcpll	tcw12	30.9	8.4	10.5	24.5[d]	Q
SPC00046018	ESF-AL#2-HPF#1	01+68	10/21/1996	UP/D	50.5 to 50.7	Tpcpll	tcw12	118	19	10.5	24.5[d]	Q
SPC00046019	ESF-AL#2-HPF#1	01+68	10/21/1996	UP/D	55.4 to 55.7	Tpcpll	tcw12	128	10	10.5	24.5[d]	Q
SPC00046022	ESF-AL#2-HPF#1	01+68	10/21/1996	UP/D	58.9 to 59.0[c]	Tmr (pre -Raineer Mesa)	N/A	78.6	9.4	10.5	24.5[d]	Q
SPC00046025	ESF-AL#2-HPF#1	01+68	10/21/1996	UP/D	61.2 to 61.3[c]	Tmr (pre -Raineer Mesa)	N/A	65.3	9.2	10.5	24.5[d]	Q
SPC00046030	ESF-AL#2-HPF#1	01+68	10/21/1996	UP/D	68.6 to 68.9[c]	Tmr (pre -Raineer Mesa)	N/A	155	11	10.5	24.5[d]	Q
SPC00046032	ESF-AL#2-HPF#1	01+68	10/21/1996	UP/D	83.6 to 83.8[c]	Tmr (pre -Raineer Mesa)	N/A	32.9	8.6	10.5	24.5[d]	Q
SPC00045950	ESF-AL#3-RBT#4	07+54	6/3/1996	D	21.6 to 21.8	Tpcpln	tcw12	11.7	7.4	10.5	24.5[d]	Q
SPC01004190	ESF-NR-MOISTSTDY#3	07+68	10/29/1999	D	4.4 to 5.0	Tpcpln	tcw12	0.2	0.8	0.4 to 1	1.4	Q
SPC01004175 SPC01004179	ESF-NR-MOISTSTDY#4	07+73	4/8/1998	D	4.2 to 6.9[e]	Tpcpln	tcw12	0.76	0.24	0.4 to 1	1.4	UQ
SPC01004175 SPC01004179	ESF-NR-MOISTSTDY#4	07+73	4/8/1998	D	4.2 to 6.9[e]	Tpcpln	tcw12	0.66	0.2	0.4 to 1	1.4	UQ
SPC01004240 SPC01004244	ESF-NR-MOISTSTDY#10	08+80	10/29/1999	D	4.0 to 6.5[c,e]	Tpbt3	ptn24	0.22	0.3	0.4 to 1	1.4	Q
SPC01004301	ESF-NR-MOISTSTDY#13	10+07	1/14/1998	D	4.3 to 5.1	Tpp	ptn25	0.55	0.3	0.4 to 1	1.4	UQ
SPC01004381	ESF-LPCA-MOISTSTDY#2	10+28	10/29/1999	D	6.4 to 7.0	Tpbt2	ptn26	<0.1	0.29	0.4 to 1	1.4	Q
SPC01004340	ESF-NR-MOISTSTDY#16	10+70	4/14/1998	D	5.8 to 6.6	Tptrv2	ptn26	0.44	0.3	0.4 to 1	1.4	UQ
SPC03017194	ESF-DHW-CIV#10	19+10	6/28/2000	D	11.2 to 12.4	Tptpul	tsw33	0.94	0.48	0.4 to 1	1.4	Q
SPC03017198	ESF-DHW-CIV#9	19+20	6/28/2000	D	11.5 to 12.5	Tptpul	tsw33	0.6	1.2	0.4 to 1	1.4	Q
SPC03017190	ESF-DHW-CIV#8	19+25	6/28/2000	D	11.7 to 13.1	Tptpul	tsw33	0.2	1.0	0.4 to 1	1.4	Q
SPC03017184	ESF-DHW-CIV#7	19+30	6/28/2000	D	9.6 to 11.0	Tptpul	tsw33	1.6	0.8	0.4 to 1	1.4	Q
SPC03017180	ESF-DHW-CIV#6	19+35	6/28/2000	D	12.2 to 13.9	Tptpul	tsw33	0.48	0.56	0.4 to 1	1.4	Q
SPC03017150 SPC03017151	ESF-DHW-CIV#5	19+40	6/28/2000	D	26.7 to 28.7[f]	Tptpul	tsw33	0.7	0.6	0.4 to 1	1.4	Q
SPC03017159 SPC03017160	ESF-DHW-CIV#4	19+45	6/28/2000	D	12.3 to 13.7[c]	Tptpul	tsw33	0.9	0.6	0.4 to 1	1.4	Q
SPC03017171	ESF-DHW-CIV#3	19+50	6/28/2000	D	12.0 to 13.3	Tptpul	tsw33	1.6	0.8	0.4 to 1	1.4	Q
SPC03017162 SPC03017163	ESF-DHW-CIV#2	19+55	9/7/2000	D	6.5 to 8.2[f]	Tptpul	tsw33	0.5	1.4	0.4 to 1	1.4	Q
SPC03017174 SPC03017175	ESF-DHW-CIV#1	19+65	6/28/2000	D	10.9 to 13.2[f]	Tptpul	tsw33	1	0.8	0.4 to 1	1.4	Q
SPC02015927	ESF-SD-CIV#40	33+89	10/29/1999	D	12.3 to 13.3	Tptpmn	tsw34	0.3	0.32	0.4 to 1	1.4	Q
SPC02015932	ESF-SD-CIV#39	33+99	10/29/1999	D	11.2 to 12.7[c]	Tptpmn	tsw34	0.23	0.28	0.4 to 1	1.4	Q
SPC02015941	ESF-SD-CIV#38	34+10	10/29/1999	D	11.0 to 12.5[c]	Tptpmn	tsw34	1.4	1.6	0.4 to 1	1.4	Q
SPC02015936	ESF-SD-CIV#37	34+20	10/29/1999	D	9.7 to 11.2	Tptpmn	tsw34	0.28	0.26	0.4 to 1	1.4	Q
SPC02015943	ESF-SD-CIV#36	34+25	10/29/1999	D	6.7 to 8.1	Tptpmn	tsw34	<0.1	0.36	0.4 to 1	1.4	Q
SPC02015951	ESF-SD-CIV#35	34+30	10/29/1999	D	10.0 to 11.4[c]	Tptpmn	tsw34	0.29	0.44	0.4 to 1	1.4	Q

Table 5. ESF and ECRB Drift Samples (Continued)

SPC Number for Core Sample or Water Sample	Borehole Name	ESF Station[a]	Date of Analysis	Extraction Method	Sampled Interval (ft)	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[b]	Uncertainty 2σ (+/-)	Tritium Detection Limits (TU)	Threshold for Presence of Modern Water (TU)	Q Status
SPC02016034	ESF-SD-CIV#34	34+35	10/29/1999	D	10.5 to 12.0[c]	Tptpmn	tsw34	0.46	0.42	0.4 to 1	1.4	Q
SPC02016036	ESF-SD-CIV#33	34+40	10/29/1999	D	7.7 to 8.9	Tptpmn	tsw34	0.9	0.6	0.4 to 1	1.4	Q
SPC02016010	ESF-SD-CIV#32	34+45	10/29/1999	D	11.6 to 13.2[c]	Tptpmn	tsw34	0.31	0.46	0.4 to 1	1.4	Q
SPC02016004 SPC02016005	ESF-SD-CIV#31	34+50	7/19/2000	D	11.0 to 12.6[f]	Tptpmn	tsw34	0.3	0.8	0.4 to 1	1.4	Q
SPC02016001	ESF-SD-CIV#30	34+55	3/6/2000	D	12.2 to 13.4[c]	Tptpmn	tsw34	0.2	0.6	0.4 to 1	1.4	Q
SPC02015996	ESF-SD-CIV#29	34+60	10/29/1999	D	10.7 to 12.2[c]	Tptpmn	tsw34	0.28	0.34	0.4 to 1	1.4	Q
SPC02016018 SPC02016019 SPC02016021	ESF-SD-CIV#28	34+65	9/7/2000	D	8.0 to 11.3[e]	Tptpmn	tsw34	1.14	0.52	0.4 to 1	1.4	Q
SPC02016028	ESF-SD-CIV#27	34+70	10/29/1999	D	12.0 to 13.4	Tptpmn	tsw34	0.22	0.34	0.4 to 1	1.4	Q
SPC02016339	ESF-SD-CIV#26	34+73	3/30/2000	D	12.2 to 13.2	Tptpmn	tsw34	0.1	0.8	0.4 to 1	1.4	Q
SPC02016342	ESF-SD-CIV#25	34+90	4/26/2000	D	8.7 to 9.9	Tptpmn	tsw34	0.2	0.8	0.4 to 1	1.4	Q
SPC03017080	ESF-SD-CIV#24	34+95	4/26/2000	D	12.1 to 13.4	Tptpmn	tsw34	0.4	0.6	0.4 to 1	1.4	Q
SPC03017085	ESF-SD-CIV#23	35+00	3/30/2000	D	12.6 to 13.7	Tptpmn	tsw34	0.22	0.58	0.4 to 1	1.4	Q
SPC03017088	ESF-SD-CIV#22	35+05	3/30/2000	D	10.4 to 11.2[e]	Tptpmn	tsw34	0.15	0.54	0.4 to 1	1.4	Q
SPC03017094	ESF-SD-CIV#21	35+10	3/30/2000	D	9.8 to 11.1	Tptpmn	tsw34	0.4	0.56	0.4 to 1	1.4	Q
SPC03017101 SPC03017102	ESF-SD-CIV#20	35+15	4/26/2000	D	10.5 to 13.0[f]	Tptpmn	tsw34	<0.1	0.48	0.4 to 1	1.4	Q
SPC03017119	ESF-SD-CIV#19	35+20	3/30/2000	D	11.7 to 13.1	Tptpmn	tsw34	0.6	0.8	0.4 to 1	1.4	Q
SPC03017113	ESF-SD-CIV#18	35+25	6/28/2000	D	10.9 to 11.8	Tptpmn	tsw34	1.4	1.6	0.4 to 1	1.4	Q
SPC03017114	ESF-SD-CIV#18	35+25	3/30/2000	D	12.3 to 13.5	Tptpmn	tsw34	2.6	1.0	0.4 to 1	1.4	Q
SPC03017107	ESF-SD-CIV#17	35+31	4/26/2000	D	10.5 to 12.0	Tptpmn	tsw34	0.95	0.52	0.4 to 1	1.4	Q
SPC03017108	ESF-SD-CIV#17	35+31	4/26/2000	D	12.0 to 13.2	Tptpmn	tsw34	0.7	0.8	0.4 to 1	1.4	Q
SPC03017124 SPC03017125	ESF-SD-CIV#16	35+35	4/26/2000	D	12.0 to 13.2[c,f]	Tptpmn	tsw34	0.2	0.6	0.4 to 1	1.4	Q
SPC03017132	ESF-SD-CIV#15	35+40	4/26/2000	D	12.0 to 13.5[c]	Tptpmn	tsw34	0.6	1.0	0.4 to 1	1.4	Q
SPC03017136	ESF-SD-CIV#14	35+45	4/26/2000	D	11.6 to 13.4	Tptpmn	tsw34	<0.1	0.3	0.4 to 1	1.4	Q
SPC02016252 SPC02016253	ESF-SD-CIV#13	35+75	2/7/2000	D	30.5 to 32.3[c,f]	Tptpmn	tsw34	0.6	0.8	0.4 to 1	1.4	Q
SPC02016266	ESF-SD-CIV#12	35+80	3/6/2000	D	11.8 to 13.4[c]	Tptpmn	tsw34	0.20	0.54	0.4 to 1	1.4	Q
SPC02016260 SPC02016261	ESF-SD-CIV#11	35+85	3/6/2000	D	11.0 to 12.5[c,f]	Tptpmn	tsw34	0.15	0.56	0.4 to 1	1.4	Q
SPC02016257	ESF-SD-CIV#10	35+90	2/7/2000	D	11.8 to 13.0	Tptpmn	tsw34	0.37	0.58	0.4 to 1	1.4	Q
SPC02016277	ESF-SD-CIV#9	35+95	3/6/2000	D	10.1 to 11.5	Tptpmn	tsw34	0.2	0.6	0.4 to 1	1.4	Q
SPC02016271 SPC02016272	ESF-SD-CIV#8	36+00	2/7/2000	D	7.9 to 9.9[f]	Tptpmn	tsw34	0.6	0.6	0.4 to 1	1.4	Q
SPC02016268	ESF-SD-CIV#7	36+05	2/11/2000	D	8.1 to 9.7	Tptpmn	tsw34	0.3	0.8	0.4 to 1	1.4	Q
SPC02016304	ESF-SD-CIV#6	36+10	2/11/2000	D	9.3 to 10.5	Tptpmn	tsw34	1.1	1.0	0.4 to 1	1.4	Q

Table 5. ESF and ECRB Drift Samples (Continued)

SPC Number for Core Sample or Water Sample	Borehole Name	ESF Station[a]	Date of Analysis	Extraction Method	Sampled Interval (ft)	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[b]	Uncertainty 2σ (+/-)	Tritium Detection Limits (TU)	Threshold for Presence of Modern Water (TU)	Q Status
SPC02016299 SPC02016300	ESF-SD-CIV#5	36+20	2/7/2000	D	7.9 to 9.7[f]	Tptpmn	tsw34	0.71	0.46	0.4 to 1	1.4	Q
SPC02016297 SPC02016298	ESF-SD-CIV#4	36+35	2/11/2000	D	11.8 to 13.4[c]	Tptpmn	tsw34	0.3	0.8	0.4 to 1	1.4	Q
SPC02016289	ESF-SD-CIV#3	36+59	3/6/2000	D	10.7 to 11.4	Tptpmn	tsw34	0.6	0.6	0.4 to 1	1.4	Q
SPC02016281	ESF-SD-CIV#2	36+74	2/7/2000	D	8.0 to 9.9	Tptpmn	tsw34	0.1	0.6	0.4 to 1	1.4	Q
SPC02016331	ESF-SD-CIV#1	36+89	4/26/2000	D	11.5 to 12.6	Tptpmn	tsw34	0.5	0.8	0.4 to 1	1.4	Q
SPC01001916 SPC01001918 SPC01001920	ESF-NAD-GTB#1A	37+37	8/27/1998	D	98.4 to 101.0[e]	Tptpmn	tsw34	1.4	0.8	0.4 to 1	1.4	UQ
SPC01001947	ESF/NAD/GTB#1A	37+37	4/17/2001	D	114.0 to 115.0	Tptpmn	tsw34	0.5	0.6	0.4 to 1	1.4	Q
SPC01001960 SPC01001962	ESF/NAD/GTB#1A	37+37	4/17/2001	D	120.3 to 121.6[c,e]	Tptpmn	tsw34	1	0.8	0.4 to 1	1.4	Q
SPC01001964 SPC01001966	ESF-NAD-GTB#1A	37+37	8/27/1998	D	122.1 to 123.8[e]	Tptpmn	tsw34	1.2	0.8	0.4 to 1	1.4	UQ
SPC01001968 SPC01001970 SPC01001971	ESF-NAD-GTB#1A	37+37	8/27/1998	D	124.4 to 126.0[e]	Tptpmn	tsw34	1.2	0.8	0.4 to 1	1.4	UQ
SPC01001975 SPC01001976	ESF/NAD/GTB#1A	37+37	4/17/2001	D	127.0 to 129.0[e]	Tptpmn	tsw34	1.6	1.2	0.4 to 1	1.4	Q
SPC01001980 SPC01001982	ESF-NAD-GTB#1A	37+37	8/27/1998	D	130.2 to 131.9[e]	Tptpmn	tsw34	0.8	1.4	0.4 to 1	1.4	UQ
SPC01001991 SPC01001993 SPC01001995 SPC01001998	ESF-NAD-GTB#1A	37+37	8/27/1998	D	137.0 to 142.0[e]	Tptpmn	tsw34	0.3	0.8	0.4 to 1	1.4	UQ
SPC01002037 SPC01002038	ESF/NAD/GTB#1A	37+37	4/17/2001	D	165.8 to 166.7[f]	Tptpmn	tsw34	0.8	1.0	0.4 to 1	1.4	Q
SPC01002042 SPC01002045	ESF-NAD-GTB#1A	37+37	8/27/1998	D	168.0 to 169.8[e]	Tptpmn	tsw34	0.8	1.0	0.4 to 1	1.4	UQ
SPC01003284 SPC01003286	ESF-NDR-MF#1	37+37	8/27/1998	D	44.2 to 46.0[c,e]	Tptpmn	tsw34	1.6	1.0	0.4 to 1	1.4	UQ
SPC01003292 SPC01003294 SPC01003296	ESF-NDR-MF#1	37+37	8/27/1998	D	48.9 to 50.9[c,e]	Tptpmn	tsw34	2.2	1.2	0.4 to 1	1.4	UQ
SPC01003300 SPC01003302	ESF-AL6-NDR-MF#1	37+37	7/19/2000	D	53.9 to 55.6[e]	Tptpmn	tsw34	1.3	1.0	0.4 to 1	1.4	Q
SPC01003455 SPC01003457	ESF-AL6-NDR-MF#2	37+37	7/19/2000	D	42.3 to 43.9[e]	Tptpmn	tsw34	1.6	1.4	0.4 to 1	1.4	Q
SPC01003458 SPC01003460	ESF-AL6-NDR-MF#02	37+37	10/29/1999	D	47.3 to 49.0[c,e]	Tptpmn	tsw34	1.2	0.4	0.4 to 1	1.4	Q
SPC01003462 SPC01003464	ESF-AL6-NDR-MF#02	37+37	7/19/2000	D	49.3 to 51.3[e]	Tptpmn	tsw34	1.1	1.0	0.4 to 1	1.4	Q

Table 5. ESF and ECRB Drift Samples (Continued)

SPC Number for Core Sample or Water Sample	Borehole Name	ESF Station[a]	Date of Analysis	Extraction Method	Sampled Interval (ft)	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[b]	Uncertainty 2σ (+/-)	Tritium Detection Limits (TU)	Threshold for Presence of Modern Water (TU)	Q Status
SPC01003468 SPC01003470	ESF-AL6-NDR-MF#02	37+37	7/19/2000	D	55.3 to 57.0[e]	Tptpmn	tsw34	1	1.2	0.4 to 1	1.4	Q
SPC01003478 SPC01003480	ESF-AL6-NDR-MF#02	37+37	7/19/2000	D	61.1 to 62.9[e]	Tptpmn	tsw34	0.9	1.4	0.4 to 1	1.4	Q
SPC01002776	ESF/SAD/GTB#1	50+64	4/17/2001	D	103.4 to 104.1	Tptpmn	tsw34	3.7	1.4	0.4 to 1	1.4	Q
SPC01002800 SPC01002802	ESF/SAD/GTB#1	50+64	4/17/2001	D	124.3 to 125.9[e]	Tptpmn	tsw34	1.1	0.6	0.4 to 1	1.4	Q
SPC01002879 SPC01002897	ESF/SAD/GTB#1	50+64	4/17/2001	D	175.4 to 177.0[e]	Tptpmn	tsw34	1.8	1.4	0.4 to 1	1.4	Q
SPC01002956 SPC01002958	ESF/SAD/GTB#1	50+64	4/17/2001	D	214.5 to 216.9[e]	Tptpmn	tsw34	2.3	0.6	0.4 to 1	1.4	Q
SPC01002754	ESF/SAD/GTB#1	50+64	4/17/2001	D	85.1 to 86.0	Tptpmn	tsw34	1.2	1.0	0.4 to 1	1.4	Q
SPC01004630 SPC01004634	ESF-SR-MOISTSTDY#3	59+65	10/29/1999	D	2.9 to 5.7[e]	Tptpmn	tsw34	1.7	0.8	0.4 to 1	1.4	Q
SPC01004661 SPC01004665	ESF-SR-MOISTSTDY#5	63+00	4/16/1998	D	3.6 to 6.5[c,e]	Tptpmn	tsw34	0.42	0.3	0.4 to 1	1.4	UQ
SPC01004672 SPC01004676	ESF-SR-MOISTSTDY#6	63+89	4/21/1998	D	2.6 to 7.0[e]	Tptpul	tsw33	0.81	0.28	0.4 to 1	1.4	UQ
SPC01004686 SPC01004690	ESF-SR-MOISTSTDY#7	64+80	4/28/1998	D	3.8 to 7.0[e]	Tptrl	tsw33	3.2	0.4	0.4 to 1	1.4	UQ
SPC01004726 SPC01004728	ESF-SR-MOISTSTDY#10	66+48	10/29/1999	D	2.4 to 6.4[e]	Tptrv3	ptn26	28.6	3.6	0.4 to 1	1.4	Q
SPC01004759 SPC01004763	ESF-SR-MOISTSTDY#11	66+58	10/29/1999	D	3.2 to 6.9[e]	Tpbt2	ptn26	4.8	0.8	0.4 to 1	1.4	Q
SPC01004805	ESF-SR-MOISTSTDY#13	66+80	10/29/1999	D	6.0 to 6.8	Tpbt2	ptn26	3.1	0.5	0.4 to 1	1.4	Q
SPC01002421 SPC01002423	ESF-SR-MOISTSTDY#2	67+20	4/2/1998	D	2.2 to 3.9[e]	Tpcpv	tcw12	0.03	0.2	0.4 to 1	1.4	UQ
SPC01004786 SPC01004790	ESF-SR-MOISTSTDY#16	67+21	10/29/1999	D	4.6 to 6.8[c,e]	Tpcpv	tcw12	8.2	1.0	0.4 to 1	1.4	Q
SPC01002407 SPC01002409	ESF-SR-MOISTSTDY#1	67+22	3/31/1998	D	2.1 to 3.6[e]	Tpcpv	tcw12	0.3	0.3	0.4 to 1	1.4	UQ
SPC01004821	ESF-SR-MOISTSTDY#17	67+30	10/29/1999	D	5.8 to 6.7	Tpcpln	tcw12	3.8	0.6	0.4 to 1	1.4	Q
SPC01004821	ESF-SR-MOISTSTDY#17	67+30	10/29/1999	D	5.8 to 6.7	Tpcpln	tcw12	3.5	1.0	0.4 to 1	1.4	Q
SPC01004831 SPC01004835	ESF-SR-MOISTSTDY#18	67+48	10/29/1999	D	4.6 to 6.7[e]	Tpcpln	tcw12	1.1	0.8	0.4 to 1	1.4	Q
SPC01004844 SPC01004848	ESF-SR-MOISTSTDY#19	68+26	10/29/1999	D	4.5 to 6.9[e]	Tptpul	tsw33	14.3	2.0	0.4 to 1	1.4	Q
SPC01004858 SPC01004862	ESF-SR-MOISTSTDY#20	69+37	10/29/1999	D	4.2 to 6.8[e]	Tptrn	tsw31, tsw32	7.4	0.8	0.4 to 1	1.4	Q
SPC01005233	ESF-SR-MOISTSTDY#23	70+59	10/29/1999	D	16.2 to 17.0	Tptpmn	tsw34	0.45	0.30	0.4 to 1	1.4	Q
SPC01005233	ESF-SR-MOISTSTDY#23	70+59	10/29/1999	D	16.2 to 17.0	Tptpmn	tsw34	0.25	0.32	0.4 to 1	1.4	Q

Table 5. ESF and ECRB Drift Samples (Continued)

SPC Number for Core Sample or Water Sample	Borehole Name	ESF Station[a]	Date of Analysis	Extraction Method	Sampled Interval (ft)	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[b]	Uncertainty 2σ (+/-)	Tritium Detection Limits (TU)	Threshold for Presence of Modern Water (TU)	Q Status
SPC01004967 SPC01004970	ESF-SR-MOISTSTDY#25	74+35	10/29/1999	D	5.0 to 6.9[e]	Tptrn	tsw31, tsw32	4.4	0.8	0.4 to 1	1.4	Q
SPC01005175 SPC01005179	ESF-SR-MOISTSTDY#26	74+41	10/29/1999	D	7.4 to 9.6[e]	Tptrv2-Tptrv3	ptn26	4.9	0.5	0.4 to 1	1.4	Q
SPC01004921	ESF-SR-MOISTSTDY#27	74+44	10/29/1999	D	5.9 to 6.8	Tptrv3	ptn26	1.5	0.8	0.4 to 1	1.4	Q
SPC01004930 SPC01004936	ESF-SR-MOISTSTDY#28	74+47	10/29/1999	D	2.5 to 6.8[e]	Tptrv3	ptn26	3.2	0.8	0.4 to 1	1.4	Q
SPC01004949 SPC01004953	ESF-SR-MOISTSTDY#29	74+54	10/29/1999	D	4.5 to 6.8[e]	Tpbt2	ptn26	0.77	0.46	0.4 to 1	1.4	Q
SPC01005033 SPC01005037	ESF-SR-MOISTSTDY#30	74+60	10/29/1999	D	3.8 to 6.7[e]	Tpbt2	ptn26	12.5	1.2	0.4 to 1	1.4	Q
SPC01004981 SPC01004985	ESF-SR-MOISTSTDY#31	74+66	10/29/1999	D	4.7 to 7.0[e]	Tpbt2	ptn26	5.4	0.6	0.4 to 1	1.4	Q
SPC01005054	ESF-SR-MOISTSTDY#33	74+77	9/7/2000	D	5.9 to 6.9	Tpbt2-Tpp	ptn26	2.7	0.6	0.4 to 1	1.4	Q
SPC01005012	ESF-SR-MOISTSTDY#34	74+82	9/7/2000	D	5.9 to 6.8	Tpbt3	ptn24	1.2	0.5	0.4 to 1	1.4	Q
SPC01005099	ESF-SR-MOISTSTDY#38	75+03	9/7/2000	D	5.9 to 6.8	Tpcpv	tcw12	1.7	0.6	0.4 to 1	1.4	Q
SPC01005113	ESF-SR-MOISTSTDY#40	75+10	9/7/2000	D	5.9 to 6.9	Tpcpv	tcw12	0.58	0.32	0.4 to 1	1.4	Q
SPC02013439 SPC02013442	ECRB-SYS-CS0600	06+01	5/10/2002	D	3.2 to 6.0[f]	Tptpul	tsw33	0.79	0.58	0.4 to 1	1.4	Q
SPC02013547 SPC02013543	ECRB-SYS-CS0750	07+50	5/10/2002	D	3.6 to 6.2[f]	Tptpul	tsw33	6.2	1.0	0.4 to 1	1.4	Q
SPC02013530 SPC02013534	ECRB-SYS-CS0800	08+00	5/10/2002	UC/D	2.9 to 5.8[f]	Tptpul	tsw33	1.7	0.6	0.4 to 1	1.4	Q
SPC02013613 SPC02013617	ECRB-SYS-CS0900	09+01	5/10/2002	UC/D	3.5 to 6.4[f]	Tptpul	tsw33	6.5	1.2	0.4 to 1	1.4	Q
SPC02013628 SPC02013624	ECRB-SYS-CS0950	09+50	5/10/2002	UC/D	2.8 to 5.6[f]	Tptpul	tsw33	6.1	0.8	0.4 to 1	1.4	Q
SPC02013695	ECRB-SYS-CS1000	10+00	4/10/2002	D	17.4 to 18.2	Tptpul	tsw33	0.5	0.6	0.4 to 1	1.4	Q
SPC02014326 SPC02014330 SPC02014334	ECRB-SYS-CS1200	11+99	5/10/2002	D	2.9 to 6.9[f]	Tptpmn	tsw34	0.41	0.46	0.4 to 1	1.4	Q
SPC02014285 SPC02014289	ECRB-SYS-CS1300	13+01	8/2/2002	D	3.0 to 5.5[f]	Tptpmn	tsw34	0.7	1.4	0.4 to 1	1.4	Q
SPC02014299 SPC02014303	ECRB-SYS-CS1350	13+51	5/10/2002	UC/D	3.6 to 6.4[f]	Tptpmn	tsw34	3.8	1.0	0.4 to 1	1.4	Q
SPC02014349 SPC02014353	ECRB-SYS-CS1450	14+50	8/2/2002	D	4.0 to 6.5[f]	Tptpmn	tsw34	0.3	1.0	0.4 to 1	1.4	Q
SPC02014381 SPC02014385	ECRB-SYS-CS1500	14+99	4/10/2002	D	14.4 to 17.4[f]	Tptpmn	tsw34	2.5	0.8	0.4 to 1	1.4	Q
SPC02014361 SPC02014365	ECRB-SYS-CS1500	14+99	8/2/2002	D	4.3 to 7.1[f]	Tptpmn	tsw34	10.3	1.8	0.4 to 1	1.4	Q

Table 5. ESF and ECRB Drift Samples (Continued)

SPC Number for Core Sample or Water Sample	Borehole Name	ESF Station[a]	Date of Analysis	Extraction Method	Sampled Interval (ft)	Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer	Tritium Abundance (TU)[b]	Uncertainty 2σ (+/-)	Tritium Detection Limits (TU)	Threshold for Presence of Modern Water (TU)	Q Status
SPC02014371 SPC02014375	ECRB-SYS-CS1500	14+99	8/2/2002	UC/D	9.5 to 12.1[f]	Tptpmn	tsw34	1.5	0.8	0.4 to 1	1.4	Q
SPC02014406	ECRB-SYS-CS1600	16+00	8/2/2002	D	3.4 to 4.3	Tptpmn	tsw34	1.7	1.8	0.4 to 1	1.4	Q
SPC02014436 SPC02014440	ECRB-SYS-CS1750	17+50	4/10/2002	D	3.3 to 5.9[f]	Tptpll	tsw35	0.6	0.8	0.4 to 1	1.4	Q
SPC02014450 SPC02014454	ECRB-SYS-CS1800	18+01	8/2/2002	D	3.6 to 6.1[f]	Tptpll	tsw35	0.1	1.6	0.4 to 1	1.4	Q
SPC02014486 SPC02014490	ECRB-SYS-CS1950	19+50	8/2/2002	D	4.0 to 6.5[f]	Tptpll	tsw35	3.6	1.0	0.4 to 1	1.4	Q
SPC02014623	ECRB-SYS-CS2000	19+99	4/10/2002	D	11.0 to 11.9	Tptpll	tsw35	0.1	1.0	0.4 to 1	1.4	Q
SPC02014661	ECRB-SYS-CS2150	21+49	8/2/2002	D	3.4 to 4.1	Tptpll	tsw35	<0.1	1.8	0.4 to 1	1.4	Q
SPC02014665	ECRB-SYS-CS2150	21+49	5/10/2002	UC/D	5.5 to 6.7	Tptpll	tsw35	9.8	1.0	0.4 to 1	1.4	Q
SPC02014683	ECRB-SYS-CS2250	22+50	5/10/2002	D	2.9 to 3.9	Tptpll	tsw35	0.8	0.8	0.4 to 1	1.4	Q
SPC02014774 SPC02014778	ECRB-SYS-CS2500	25+00	4/10/2002	D	16.7 to 19.8[f]	Tptpln	tsw36, tsw37	0.64	0.6	0.4 to 1	1.4	Q

[a] Sample locations in the main tunnel of the ESF are given in meters relative to the last construction station (CS xx + yy).
[b] highighted values above threshold for presence of modern water.
[c] Interval used for tritium analysis is smaller than the interval traceable to the Sample Management Facility barcode identifier; a portion of the core sample was removed in the laboratory and set aside for other analyses.
[d] 95th percentile confidence level.
[e] Non-adjacent intervals combined to obtain sufficient sample volume.
[f] Adjacent intervals combined to obtain sufficient sample volume.

NOTES: TU = tritium unit.
AL = Alcove.
CS xx+yy = Construction Station, in meters, as surveyed by the Management and Operating Contractor.
ESF = Exploratory Studies Facility – main tunnel.
ECRB = Enhanced Characterization of the Repository Block.
HPF#*n*= Hydrologic properties of faults – Borehole #*n*.
UP = pore water obtained by uniaxial compression.
UC = pore water obtained by ultracentrifugation.
D = pore water distilled from rock.
Q = qualified.
UQ = unqualified.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

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NOTES: [a]Provided as an enclosure to letter from Williams to Sulima, dtd 06/01/09, "Yucca Mountain – Request for Additional Information – Safety Evaluation Report, Volume 3 – Postclosure Chapter 2.2.1.3.6 – Flow Paths in the Unsaturated Zone, Set 1 – (Department of Energy's Safety Analysis Report Sections 2.3.2 and 2.3.3)."

[b]Provided as an enclosure to letter from Williams to Sulima dtd 02/17/2009. "Yucca Mountain – Request for Additional Information Re: License Application (Safety Analysis Report Section 2.1), Safety Evaluation Report Volume 3 – Postclosure Chapters 2.2.1.1 and 2.2.1.3.7 – Submittal of Department of Energy Reference Citations)."