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Probability Distribution for Flowing Interval Spacing

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12. Revision No.	13. Description of Change
REV 00	Initial Issue.
REV 00 ICN 01	Description of the changes for ICN 01 includes listing qualified source data DTNs in Section 4., revised Criteria in Section 4.2, made editorial correction in Section 5., updated Section 6.0 – 6.4 as needed, updated the table of contents, updated the list of Figures, updated the references to include the new DTNs in Section 8, made editorial corrections to figure captions. Note: that none of input values changed, therefore none of the figures, tables, or results changed. While minor in nature, these changes were extensive enough that Section 5.9d)2 of AP-3.10Q was followed. Therefore, vertical lines were not used in the margins to indicate changes.
REV 00 ICN 02	Update the Data in Table 1, Section 4, and References, Section 8, to include Q DTN. Minor editorial changes made in body text.
REV 01	This revision documents activities including regulatory, technical integration and data compliance issues in order to address Regulatory Integration Team (RIT) Phase 1 comments. The entire analysis documentation was revised because the changes were too extensive to use step 5.6e)1) of AP-SIII.9Q REV 01 ICN 01 BWA 9/22/04

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ACRONYMS AND ABBREVIATIONS

CDF	cumulative distribution function
FEP	feature, event, and process
LA	licensing application
LHS	latin hypercube sampling
SZ	saturated zone
TSPA	Total System Performance Assessment
TWP	technical work plan
USGS	U.S. Geological Survey
UZ	unsaturated zone
YMRP	Yucca Mountain Review Plan

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1. PURPOSE

Fracture spacing is a key hydrologic parameter in analyses of matrix diffusion. Although the individual fractures that transmit flow in the saturated zone (SZ) cannot be identified directly, it is possible to determine the fractured zones that transmit flow from flow meter survey observations. The fractured zones that transmit flow as identified through borehole flow meter surveys have been defined in this report as flowing intervals. The flowing interval spacing is measured between the midpoints of each flowing interval. The determination of flowing interval spacing is important because the flowing interval spacing parameter is a key hydrologic parameter in SZ transport modeling, which impacts the extent of matrix diffusion in the SZ volcanic matrix.

The output of this report is input to the *Saturated Zone Flow and Transport Model Abstraction* (BSC 2004 [DIRS 170042]). Specifically, the analysis of data and development of a data distribution reported herein is used to develop the uncertainty distribution for the flowing interval spacing parameter for the SZ transport abstraction model. Figure 1-1 shows the relationship of this report to other model reports that also pertain to flow and transport in the SZ. Figure 1-1 also shows the flow of key information among the SZ reports. It should be noted that Figure 1-1 does not contain a complete representation of the data and parameter inputs and outputs of all SZ reports, nor does it show inputs external to this suite of SZ reports.

Use of the developed flowing interval spacing probability distribution is subject to the limitations of the assumptions discussed in Sections 5 and 6 of this analysis report. The number of fractures in a flowing interval is not known. Therefore, the flowing intervals are assumed to be composed of one flowing zone in the transport simulations. This analysis may overestimate the flowing interval spacing because the number of fractures that contribute to a flowing interval cannot be determined from the data. In terms of repository performance, the results of this analysis may underestimate the effect of matrix diffusion processes in SZ transport models. Underestimation of matrix diffusion in the transport modeling would result in more rapid simulated migration of radionuclide mass to the accessible environment and correspondingly higher simulated dose to the reasonably maximally exposed individual in the Total System Performance Assessment-License Application (TSPA-LA) analyses.

The flowing interval spacing is appropriate for use in the SZ site-scale transport abstraction model because the 500 m grid block size in the numerical transport model is more than an order of magnitude larger than the expected flowing interval spacing (BSC 2004 [DIRS 170042], Section 6.3.1). Therefore, the use of the developed flowing interval spacing parameter is limited to a numerical grid spacing that is at least an order of magnitude greater than the average flowing interval spacing to ensure a reasonable description of transport behavior in a grid.

This analysis report supports several features, events, and processes (FEPs) and contributes to the characterization of the SZ as a natural barrier, which provides evidence related to the capability of the SZ to delay movement of radionuclides through the SZ to the accessible environment.

This scientific analysis is governed by the *Technical Work Plan for: Natural System - Saturated Zone Analysis Model Report Integration* (BSC 2004 [DIRS 171421]). This report documents the

NOTE: This figure is a simplified representation of the flow of information among SZ reports. See the DIRS of each report for a complete listing of data and parameter inputs. This figure does not show inputs external to this suite of SZ reports.

Figure 1-1. Generalized Flow of Information among Reports Pertaining to Flow and Transport in the SZ

2. QUALITY ASSURANCE

The scientific analysis documented in this report was evaluated in accordance with AP-2.27Q, *Planning for Science Activities* and AP-SIII.9Q, *Scientific Analyses*, and was determined to be quality-affecting and subject to the Office of Civilian Radioactive Waste Management (*Quality Assurance Requirements and Description* (QARD) (DOE 2004 [DIRS 171539])). Accordingly, efforts to develop this report have been conducted in accordance with the Office of Repository Development (ORD) quality assurance program using approved procedures identified in the *Technical Work Plan for: Natural System - Saturated Zone Analysis Model Report Integration* (BSC 2004 [DIRS 171421])). The technical work plan also identifies the methods used to control the electronic management of data (BSC 2004 [DIRS 171421], Section 8).

This analysis report provides a hydrologic property of a natural barrier that is important to the demonstration of compliance with the postclosure performance objectives prescribed in 10 CFR 63.113. Therefore, it is classified on the *Q-List* (BSC 2004 [DIRS 168361]) as “SC” (Safety Category), reflecting its importance to waste isolation, as defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q-List*. The report contributes to the analysis data used to support postclosure performance assessment; the conclusions do not directly impact preclosure engineered features important to safety, as defined in AP-2.22Q.

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3. USE OF SOFTWARE

See Figure 3-1 for a flowchart of the software used for this analysis. The software cited below is appropriate for use in this application. The computer used for this analysis was a DELL OptiPlex GX1, Sandia serial number R429068, Windows 97 Operating System. The range of validation for the Latin Hypercube Sampling (LHS) portion of RIP, Excel, Statistica, and PV Wave is the set of real numbers, within the format limitations of data entry (e.g., -1.0E99 to 1.0E99). All calculations were performed within the range of permissible values with these software codes.

Repository Integrated Program (RIP) Version 5.19.01. Note: This software has been “retired” since the use of this software in REV. 00 of this report. The “retired” software is controlled through the software configuration management “retired” baseline and is associated with the following identifiers:

CSCI: 30055 V5.19.01
DI: 30047-2003, REV2

The RIP 5.19.01 code (Golder Associates 1999 [DIRS 151395]) was obtained from SCM and installed by means of DI 30047-2003, Rev 2 and MI 30047-MO4-001, Rev. 2.

Only the LHS module of RIP was used to run the 1000 realizations of fracture spacing dip, flowing interval spacing dip, flowing interval spacing and fracture spacing.

Commercially available software used in the analyses documented in this report:

Statistica REV 5 1997

Used for the statistical analysis and graphing of flowing interval spacing, fracture spacing and dip data (Sections 6.4 and 6.5). Note that only standard functions of this software were used in the analyses.

Excel 97-SR-1

Used for spreadsheet calculations for flowing interval spacing, fracture spacing and dip data (Sections 6.4 and 6.5). Note that only standard functions of this software were used in the analyses.

PV-Wave 6.21

Used to create Figure 15, comparison of the flow meter survey borehole information used in this analysis. Note that this software was used only for the purposes of visualization and graphical rendering.

Figure 3-1. Flowchart of Software Used in This Analysis

4. INPUTS

4.1 DIRECT INPUTS

All data inputs documented in Section 4 are used as direct inputs to the analyses. These input data are considered appropriate for the development of the probability distribution for flowing interval spacing. The data, used as direct input in this report, include all of the relevant information from wells for which flow meter surveys have been conducted in tuffs near Yucca Mountain.

Table 4-1. Borehole Input Data Table

Data Name	Originating Report	Data Tracking Number
Borehole H-3, Flowing Interval Depth Data and Dip Data	USGS OFR-84-149 (Thordarson et al. 1984 [DIRS 103200], FMS Fig. 3, Dip Table 4)	MO0007FLWINTH3.000 [DIRS 151135]
Borehole H-1, Flowing Interval Depth Data and Dip Data	USGS OFR-83-141 (Rush et al. 1983 [DIRS 107944], FMS Fig. 4 and 5, Dip Table 6)	MO0007FLWINTH1.000 [DIRS 151137]
Borehole H-4, Flowing Interval Depth Data and Dip Data	WRIR 85-4066 (Erickson et al 1985 [DIRS 105279], FMS Fig. 3, Dip Fig. 3)	MO0007FLWINTH4.000 [DIRS 151134]
Borehole UE-25c#3 Flowing Interval Depth Data	BAA000000-01717-5000-002 REV 00 1997 (CRWMS M&O 1997 [DIRS 107898], FMS Table B-3)	MO0012FLOW25C3.001 [DIRS 154765]
Borehole UE-25c#3 Dip Data	USGS WRIR 94-4177 (Geldon 1996 [DIRS 100396], Dips Table 12)	MO0007FDIP25C3.000 [DIRS 151130]
Borehole UE-25c#2 Flowing Interval Depth Data and Dip Data	WRIR 94-4177 (Geldon 1996 [DIRS 100396], FMS Table 5, Dip Table 11)	MO0007FLWINTC2.000 [DIRS 151158]
Borehole UE-25c#1 Flowing Interval Depth Data and Dip Data	WRIR 94-4177 (Geldon 1996 [DIRS 100396], FMS Table 4, Dip Table 10)	MO0007FLWINTC1.000 [DIRS 151159]
Borehole G-4 Flowing Interval Depth Data	OFR-84-063 (Bentley 1984 [DIRS 101192], FMS Figure 8)	MO0007FLWDEPG4.000 [DIRS 151132]
Borehole UE-25P#-1 Flowing Interval Depth Data and Dip Data	USGS WRIR 84-4248 (Craig et al 1984 [DIRS 101040], FMS Figure 5, Dip Plate1)	MO0007FLWINTP1.000 [DIRS 151131]

NOTE: The originating reports contain the flow meter survey information from which the flowing interval depths are determined. The associated DTNs only contain the interpreted flowing interval depth and dip information used in this analysis.

FMS=Flow Meter Survey Data; USGS=U.S. Geological Survey; WRIR=Water Resources Investigative Report

4.2 CRITERIA

The general requirements to be satisfied by the TSPA are stated in 10 CFR 63.114 [DIRS 156605]. Technical requirements to be satisfied by the TSPA are identified in the Yucca Mountain *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275]). The acceptance criteria that will be used by the Nuclear Regulatory Commission to determine whether the technical requirements have been met are identified in the *Yucca Mountain Review Plan, Final Report (YMRP)* (NRC 2003 [DIRS 163274]). The pertinent requirements and criteria for this report are summarized in Table 4-2.

Table 4-2. Project Requirements and Acceptance Criteria Applicable to this Analysis Report

Requirement Number ^a	Requirement Title ^a	10 CFR 63 Link	YMRP Acceptance Criteria ^b
PRD -002/T-015	Requirements for Performance Assessment	10 CFR 63.114 (a)-(c) and (e)-(g)	2.2.1.3.9.3, criteria 1 through 3

^a from Canori and Leitner (2003 [DIRS 166275]).

^b from NRC (2003 [DIRS 163274]).

YMRP=Yucca Mountain Review Plan

In cases where subsidiary criteria are listed in the YMRP for a given criterion, only the subsidiary criteria addressed by this scientific analysis are listed below. The acceptance criteria identified in Section 2.2.1.3.9.3 of the YMRP (NRC 2003 [DIRS 163274]) are included below. Note that the acceptance criteria listed below are different from those identified in the TWP (BSC 2004 [DIRS 171421], Section 3.2) to be associated with this report. Further assessment of which Sections of the YMRP and which acceptance criteria are relevant to this report has been conducted since the completion of the TWP. Differences from the TWP reflect these further assessments.

Acceptance Criteria from Section 2.2.1.3.9.3 Radionuclide Transport in the Saturated Zone

Acceptance Criterion 1: System Description and Model Integration Are Adequate.

- (1) Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the radionuclide transport in the saturated zone abstraction process.
- (2) The description of the aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings, that may affect radionuclide transport in the saturated zone, is adequate. For example, the description includes changes in transport properties in the saturated zone, from water-rock interaction. Conditions and assumptions in the abstraction of radionuclide transport in the saturated zone are readily identified, and consistent with the body of data presented in the description.
- (3) The abstraction of radionuclide transport in the saturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For

example, assumptions used for radionuclide transport in the saturated zone are consistent with the total system performance assessment abstractions of radionuclide release rates and solubility limits, and flow paths in the saturated zone (Sections 2.2.1.3.4 and 2.2.1.3.8 of the Yucca Mountain Review Plan, respectively). The descriptions and technical bases provide transparent and traceable support for the abstraction of radionuclide transport in the saturated zone.

- (5) Sufficient data and technical bases for the inclusion of features, events, and processes related to radionuclide transport in the saturated zone in the total system performance assessment abstraction are provided; and
- (6) This document has been developed under the QARD (DOE 2004 [DIRS 171539]), which commits to using the guidance in NUREG-1298 (Altman 1988 [DIRS 103750]) and NUREG-1297 (Altman 1988 [DIRS 103597]), which is incorporated in AP-SIII.9Q. Compliance with these procedures has been determined by quality assurance audits and other over-site activities.

Acceptance Criterion 2: Data Are Sufficient for Model Justification.

- (1) Geological, hydrological, and geochemical values used in the license application are adequately justified (e.g., flow path lengths, sorption coefficients, retardation factors, colloid concentrations, etc.). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.
- (3) Data on the geology, hydrology, and geochemistry of the saturated zone, including the influence of structural features, fracture distributions, fracture properties, and stratigraphy, used in the total system performance assessment abstraction, are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses used to support the U.S. Department of Energy total system performance assessment abstraction are adequate to determine the possible need for additional data.

Acceptance Criterion 3: Data Uncertainty Is Characterized and Propagated through the Model Abstraction.

- (1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate.
- (4) Parameter values for processes, such as matrix diffusion, dispersion, and groundwater mixing, are based on reasonable assumptions about climate,

aquifer properties, and ground-water volumetric fluxes (Section 2.2.1.3.8 of the Yucca Mountain Review Plan).

4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulations other than those identified in the *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275], Table 2-3) and determined to be applicable (Table 4-2) were used in this analysis.

5. ASSUMPTIONS

There are several types of assumptions related to this analysis. The assumptions listed in this section of the report are restricted to those that meet the definition given in the quality assurance procedure AP-SIII.9Q, *Scientific Analysis*, Section 3.2. This definition states that an assumption is “a statement or proposition that is taken to be true or representative in the absence of direct confirming data or evidence.” There are additional technical assumptions related to the analysis that are documented in Section 6 of this report (primarily in Section 6.3). The technical assumptions documented in Section 6 of this report are simplifications of the analysis, not related to the absence of direct confirming data or evidence.

1. Only one fracture is assumed to transmit fluid in a flowing interval. Justification: Solutes diffuse from fractures to the matrix at the fracture matrix interface. Consequently, matrix diffusion is enhanced when there are multiple ‘fluid transmitting’ fractures embedded in the rock matrix. In this analysis, the flowing interval spacing is determined as the midpoint between flowing zones. It is assumed a single flowing interval is the result of a single fracture transmitting fluid. However, each flowing interval probably has more than one fracture contributing to flow, equating to more fracture-matrix interfacial surface area and diffusive transport, compared to a single fracture in a flowing interval. Impact: The results of this analysis of flowing interval spacing underestimates the effect of incorporating matrix diffusion and diffusive transport processes, resulting in shorter transport times and correspondingly higher simulated dose to the reasonably maximally exposed individual in the TSPA-LA analyses.
2. No correlation between the flowing interval spacing and the dips is assumed. Justification: This is a reasonable assumption in the absence of information suggesting such a correlation and given the fact that uncertainty in flowing interval spacing is greater from the analysis using uncorrelated input parameters. Impact: Greater uncertainty in the flowing interval parameter underestimates the effect of matrix diffusion in the transport modeling resulting in a more rapid simulated migration of radionuclide mass to the accessible environment.

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6. SCIENTIFIC ANALYSIS DISCUSSION

6.1 OBJECTIVES

The primary objective of this analysis is to develop a probability distribution for flowing interval spacing for the *Saturated Zone Flow and Transport Model Abstraction* (BSC 2004 [DIRS 170042]) using borehole flow meter survey data. The general approach used to meet this objective is a statistical analysis of the flowing interval data. For comparison purposes, a probability distribution was also developed for fracture spacing in the saturated zone.

The flowing interval spacing is measured between the midpoints of two neighboring intervals as shown in Figure 6-1. Fracture spacing has been shown to be a key hydrologic parameter in analytical solutions for matrix diffusion [“Contaminant Transport in Fractured Porous Media: Analytical Solutions for a System of Parallel Fractures” (Sudicky and Frind 1982 [DIRS 105043])]. Matrix diffusion of radionuclides could serve as an important retardation mechanism at Yucca Mountain. The site-scale SZ transport conceptual model of matrix diffusion in the fractured volcanic rocks assumes groundwater flow in evenly spaced, parallel-walled fractures separated by impermeable matrix. The flowing interval spacing parameter developed in this analysis has implications for the minimum grid spacing in the SZ site-scale transport model for which the conceptual model of radionuclide transport would be appropriate. The grid spacing in the dual-porosity transport model should exceed the expected value of the flowing interval spacing to ensure that both fractures and matrix are present within each grid cell.

Figure 6-1. Example of Flowing Interval Spacing and Fracture Spacing as Identified from Borehole Flow Meter Survey Data

6.2 FEPS SUPPORTED BY THIS SCIENTIFIC ANALYSIS

As stipulated in *Technical Work Plan For: Natural System - Saturated Zone Analysis Model Report Integration* (BSC 2004 [DIRS 171421]) this analysis report addresses the SZ FEPs pertaining to flowing interval spacing that are screened in (i.e., Included FEPs) for TSPA-LA (Table 6-1). Saturated Zone FEPs that were screened out (i.e., Excluded FEPs) for TSPA-LA are described in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]). Table 6-1 provides a list of FEPs that are relevant to this analysis in accordance with their assignment in the LA FEP list (DTN: MO0407SEPFEPPLA.000 [DIRS 170760]). Specific reference to the various sections within this document where issues related to each FEP are addressed is provided in the table. The detailed discussion of these FEPs and their implementation in TSPA-LA are documented in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]).

Table 6-1. Saturated Zone Included FEPs for which this Analysis Report Provides Support

FEPs No.	FEPs Subject	Location in Document Where Supporting Text is Found	Discussed in Supporting Reports
1.2.02.01.0A	Fractures	Section 6.5	Upstream Feeds ^a -N/A Corroborating ^b – <i>Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model</i> (BSC 2004 [DIRS 170008]), <i>Saturated Zone In-Situ Testing</i> (BSC 2004 [DIRS 170010])
2.2.03.01.0A	Stratigraphy	Section 6.3, Table 6-2	Upstream Feeds ^a -N/A Corroborating ^b – <i>Saturated Zone In-Situ Testing</i> (BSC 2004 [DIRS 170010]), <i>Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model</i> (BSC 2004 [DIRS 170008])
2.2.03.02.0A	Rock properties of host rock and other units	Sections 6.3 and 6.4	Upstream Feeds ^a -N/A Corroborating ^b – <i>Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model</i> (BSC 2004 [DIRS 170008]), <i>Saturated Zone In-Situ Testing</i> (BSC 2004 [DIRS 170010])
2.2.07.12.0A	Saturated groundwater flow in the geosphere	Sections 6.3 and 6.4	Upstream Feeds ^a -N/A Corroborating ^b – <i>Recharge and Lateral Groundwater Flow Boundary Conditions for the Saturated Zone Site-Scale Flow and Transport Model</i> (BSC 2004 [DIRS 170015]), <i>Saturated Zone In-Situ Testing</i> (BSC 2004 [DIRS 170010])
2.2.07.13.0A	Water-conducting features the SZ	Sections 6.3 and 6.4	Upstream Feeds ^a -N/A Corroborating ^b – <i>Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model</i> (BSC 2004 [DIRS 170008]), <i>Saturated Zone In-Situ Testing</i> (BSC 2004 [DIRS 170010])
2.2.07.17.0A	Diffusion in the SZ	Sections 5.1, 6.5, and 7.1	Upstream Feeds ^a -N/A Corroborating ^b – <i>Saturated Zone In-Situ Testing</i> (BSC 2004 [DIRS 170010])
2.2.08.08.0A	Matrix diffusion in the SZ	Sections 5.1, 6.1, 6.5, and 7.1	Upstream Feeds ^a -N/A Corroborating ^b – <i>Saturated Zone In-Situ Testing</i> (BSC 2004 [DIRS 170010])
2.2.12.00.0B	Undetected features in the SZ	Section 6.4	Upstream Feeds ^a -N/A Corroborating ^b – <i>Hydrogeologic Framework Model for the Saturated-Zone Site-Scale Flow and Transport Model</i> (BSC 2004 [DIRS 170008]), <i>Saturated Zone In-Situ Testing</i> (BSC 2004 [DIRS 170010])

^a Upstream Feeds – Aspects of the SZ FEP screening position adopted in this report are a result of SZ analyses performed in a directly upstream SZ model or analyses.

^b Corroborating –SZ analysis or model report that indirectly supports the FEP topic.

FEP=feature, event, and process; SZ=saturated zone

6.3 GENERAL APPROACH

The general approach for this analysis consists of a statistical analysis using LHS to generate a data set of flowing interval spacing and fracture orientation data (dip), based upon a Cumulative Distribution Function (CDF) of the raw data (flowing interval spacing or fracture orientation data). Fracture orientation data were required to make a correction to the flowing interval spacing measured in the borehole, which will be explained further below. The corrected flowing interval spacing values are then used to develop a probability distribution for flowing interval spacing. The same process, for comparison purposes, is repeated to develop a probability distribution for fracture spacing in the SZ.

The number of fractures that contribute to a flowing interval cannot be determined from the flowing interval surveys. As a result, the term fracture spacing, which implies such knowledge, was not used in this analysis. The fact that only a portion of the fractures in the SZ contribute to the total flow in a borehole is well documented in the borehole flow meter survey reports [*Identification and Characterization of Hydrologic Properties of Fractured Tuff Using Hydraulic and Tracer Tests – Test Well USW H-4, Yucca Mountain, Nye County, Nevada* (Erickson and Waddell 1985 [DIRS 105279], p. 1); *Geohydrologic and Drill-Hole Data for Test Well USW H-1, Adjacent to Nevada Test Site, Nye County, Nevada* (Rush et al. 1983 [DIRS 107944], p. 12); and *Geohydrology of Rocks Penetrated by Test Well UE-25p#1, Yucca Mountain Area, Nye County, Nevada* (Craig and Robison 1984 [DIRS 101040], p. 6)] cited in this analysis. In this analysis, a single fracture is assumed to transmit fluid at the center of the flowing interval, thus minimizing physical retardation of contaminants to the accessible environment. Consequently, the overall effect in adopting this assumption is to decrease transport times to the accessible environment.

The flowing interval spacing approach is used in the SZ transport analyses because direct observations with flow meter surveys indicate that numerous fractures between flowing intervals do not transmit significant quantities of groundwater. Consequently, fracture spacing is not representative of the matrix block size appropriate for the matrix diffusion process in the SZ transport simulations. Measurements analogous to the SZ flow meter surveys are not possible in the unsaturated zone (UZ) because of very low groundwater flow rates in the fractures under unsaturated conditions. In addition, liquid flow in the UZ is dominated by vertical flow in a portion of connected fractures (BSC 2004 [DIRS 170035], Section 6.1). Unsaturated flow is also controlled by other factors (e.g., liquid saturation) than the permeability within individual fractures (Domenico and Schwartz 1990 [DIRS 100569], Section 3.5). Therefore, the flowing interval spacing approach is not appropriate for use in UZ transport simulations. Instead, a similar approach involving the active fracture concept is used in the UZ flow and transport studies (BSC 2004 [DIRS 170035], Section 6.3.7).

Figure 6-2 shows all of the boreholes and the flowing interval depth data used in this analysis. The shaded area indicates the flowing intervals, including the percentage of flow within the indicated interval. This figure also shows the limited number of data points within each interval and how the flowing interval spacings span adjoining hydrogeological units. Note that two separate flow surveys were conducted in well H-1 and that the percentage of flow shown from individual flowing intervals is the percentage from the upper or lower survey only. The permeability is much higher for the portion of well H-1 corresponding to the upper survey than for the portion of the lower survey, as indicated by the relative magnitudes of drawdown in pumping tests (Rush et al. 1983 [DIRS 107944], Figures 7 and 11).

* Top of second survey. Two surveys were conducted in this borehole

** Note 28% of flow moved past lowest measurable station

Output DTN: SN9907T0571599.001.

NOTE: The shaded areas indicate flowing intervals and the number within the flowing interval represents the percentage of total flow within that interval.

Figure 6-2. Comparison of the Flow Meter Survey Borehole Information Used in This Analysis

Examination of Figure 6-2 does not reveal any clearly discernible correlation between flowing interval spacing and hydrogeologic unit. The flowing interval spacing is assumed to be not correlated with the hydrogeologic units in the analysis documented in this report. To justify this assumption, a statistical test for significant differences between the hydrogeologic units based on the percentage of flow within each flowing interval was conducted. Although the percentage of flow for each flowing interval is not an exact proxy for flowing interval spacing, it is an approximate measure of the distribution of groundwater flow among the hydrogeologic units in the wells. This analysis was done using a nonparametric rank test called the Kruskal-Wallis test, which assesses the hypothesis that different samples in the comparison were drawn from the same distribution [*Statistica. Volume 1, General Conventions and Statistics I* (StatSoft, Inc. 1995 [DIRS 101158], pg. non-1601)]. The software STATISTICA was used to run this test. The Kruskal-Wallis test results show the difference in the flow is not significant at 95% level of confidence. The p-level, or statistical significance level, of the result was found to be 0.52, indicating based on the percentage of flow in each hydrogeologic unit, that the hydrogeologic units were not significantly different from each other; see Table 6-2. If the results from this test had been significant, this would indicate that the units were significantly different from one another based on the percentage of flow in each hydrogeologic unit. In other words, based on this data set, the statistical test does not show a significant difference between the percentages of flow among hydrogeologic units. Figure 6-3 shows the percentage of flow within a flowing interval per hydrogeologic unit. This figure also supports the assumption that the percentage of flow does not correlate with any particular hydrogeologic unit.

Table 6-2. Statistical Test Results from Kruskal-Wallis Rank Test

Hydrogeologic Units	Kruskal-Wallis Anova by Ranks	Kruskal-Wallis test: H (4, N=41) = 3.23 p=0.5185	
Dependant:newvar17	Code	Valid N	Sum of Ranks
Lithic	100	3	69.5
Tram	101	14	268.0
Bullfrog	102	14	330.5
Bull-Prow-Pass	103	1	3.5
Prow-Pass	104	9	189.5

Output DTN: SN9907T0571599.001.

6.4 FLOWING INTERVAL SPACING DATA ANALYSIS

The boreholes selected for this study had orientation data as well as flow meter survey data. The flowing interval depths were determined from the flow meter survey graphs that indicate the percentage of flow within an interval. The flowing interval depth data was interpreted from flow meter survey graphs contained in the source reports outlined in Table 4-1. Flowing intervals were identified at the location where the slope of the flow meter survey graph changed. The spacing between the midpoint of each identified flowing interval was then considered the spacing between the flowing intervals as shown in spreadsheet, *fracture_dips2.xls*, sheet Flowing Interval Spacing (FIS) (DTN: SN9907T0571599.001). Histograms of flowing interval spacing raw data and dip data can be seen in Figure 6-4.

Output DTN: SN9907T0571599.001.

Figure 6-3. Percentage of Flow in each Flowing Interval per Hydrogeologic Unit

Source: DTNs: MO0007FLWINTH4.000 [DIRS 151134], MO0012FLOW25C3.001 [DIRS 154765], MO0007FDIP25C3.000 [DIRS 151130], MO0007FLWINTC2.000 [DIRS 151158], MO0007FLWDEPG4.000 [DIRS 151132], MO0007FLWINTC1.000 [DIRS 151159], MO0007FLWINTP1.000 [DIRS 151131].

Figure 6-4. Histogram of the Flowing Interval Spacing and Dip Raw Data

Note that a limitation to the borehole data used for this analysis is the number of possible missed vertical fractures using a vertical borehole. With the available data, if the intersection of more vertical fractures would result in a significant change in the flowing interval spacing it is difficult to discern. Additionally, the data is limited because of the inability to determine the packer spacing used for each borehole. Different packer spacing may create inconsistencies in comparing flowing interval spacing data from different boreholes. The borehole flow meter survey data used in the analysis reflects the potential occurrence of undetected features in the SZ such as fracture zones, inhomogeneities and faults.

Another limitation of the use of borehole flow meter survey data is the differences in the types of flow meter tests. The data used in this analysis include flow meter survey tests such as radioactive-tracer tests (while water is pumped into or out of the borehole), spinner tests, and heat pulse flowmeter tests. The various tests may introduce biases that may add additional uncertainties to the results. An additional limitation in the data is related to testing methods that measured flow in arbitrarily set borehole intervals, as in well H-1 (Rush et al. 1983 [DIRS 107944]). This testing method effectively limits the resolution of the determination of flowing interval spacing to the distance between adjacent packer intervals in the testing of the well.

A cumulative distribution function (CDF) was generated from the flowing interval spacing data (Figure 6-5). The data set of flowing interval spacing that was used to develop the CDF reflects the various limitations and uncertainties discussed in the previous paragraphs. To input the CDF in the LHS module of RIP, ten data points from the raw data were selected to generate 1000 realizations of flowing interval spacing. The ten data points were selected to represent the measured data set as shown in Figure 6-5. In Figure 6-5, the curve labeled “data input to LHS,” is the data that was input to the LHS module of RIP and is shown in Table 6-3.

Source: DTNs: MO0007FLWINTH3.000 [DIRS 151135], MO0007FLWINTH1.000 [DIRS 151137], MO0007FLWINTH4.000 [DIRS 151134], MO0012FLOW25C3.001 [DIRS 154765], MO0007FLWINTC2.000 [DIRS 151158], MO0007FLWDEPG4.000 [DIRS 151132], MO0007FLWINTC1.000 [DIRS 151159], MO0007FLWINTP1.000 [DIRS 151131].

Figure 6-5. CDF for Flowing Interval Spacing Used as Input to LHS Module in RIP

Table 6-3. Input to LHS in RIP for Flowing Interval Spacing

Probability (Number of raw data points = 32)	Flowing Interval Spacing (m)
0	11.5
0.13	21.34
0.34	30.48
0.44	39.01
0.56	47.5

Dip data were recorded for fractures within flowing intervals from USGS reports as shown in spreadsheet, *fracture_dips2.xls* (DTN: SN9907T0571599.001), and a CDF was generated (Figure 6-6). The only borehole dip data not used as part of the data set was for G-4. The dip data for G-4 did not distinguish between the dips in the entire saturated zone and the dips that were within the flowing intervals, therefore the dip data for G-4 could not be used. No correlation between the flowing interval spacing and the dips is assumed. This is a reasonable assumption in the absence of information suggesting such a correlation and given the fact that uncertainty in flowing interval spacing is greater from the analysis using uncorrelated input parameters.

Source: DTNs: MO0007FLWINTH3.000 [DIRS 151135], MO0007FLWINTH1.000 [DIRS 151137], MO0007FLWINTH4.000 [DIRS 151134], MO0007FDIP25C3.000 [DIRS 151130], MO0007FLWINTC2.000 [DIRS 151158], MO0007FLWINTC1.000 [DIRS 151159], MO0007FLWINTP1.000 [DIRS 151131].

Figure 6-6. CDF for Flowing Interval Spacing Dip Data Used as Input to LHS Module in the RIP Code

Similar to the procedure described for the flowing interval spacing, ten data points from the CDF were used as input to the LHS module of RIP for 1000 realizations, as shown in spreadsheet, *fracture_dips2.xls* (DTN: SN9907T0571599.001), Figure 6-6, and Table 6-4. The resulting 1000 output data points for dip and flowing interval spacing were then used to correct for flowing intervals measured along the borehole using an equation from Terzaghi [“Sources of Error in Joint Surveys” (1966 [DIRS 105805], p. 295)]:

$$F_{\text{snc}} = F_{\text{sm}} \cos (D_f) \quad (\text{Eq. 6-1})$$

where F_{smc} is the corrected flowing interval spacing (normal to the dip of the fracturing), F_{sm} is the uncorrected flowing interval spacing from the LHS realizations, and D_f is the flowing interval spacing dip from the LHS realizations. Boreholes are assumed to be vertical in order to apply the Terzaghi correction. This assumption was necessary to apply the correction used to ensure that the distance measured between flowing intervals was normal to the fracturing.

A potential concern exists with regard to the LHS module of RIP. An error in the GoldSim software code has been identified in the sampling algorithm, as documented in Condition Report 2222. Although this error was not explicitly identified in the RIP software code used in this analysis, the version of the GoldSim software code in which the error was identified was developed from RIP. This error in the sampling algorithm can result in an unintended correlation between sampled parameters. Flowing interval spacing and dip were sampled simultaneously with the RIP code in this analysis and they were intended to be sampled independently. The coefficient of determination (R^2) for the 1000 values of flowing interval spacing and dip sampled by RIP is 0.000166. A value of 0 for the coefficient of determination indicates complete lack of correlation between the parameters and a value of 1 would indicate perfect correlation. The value of R^2 for the 1000 realizations in this analysis is very close to 0, indicating that there is essentially no correlation between flowing interval spacing and dip, as intended. This result shows that there is no impact of any sampling error in the RIP software code, related to Condition Report 2222.

Table 6-4. Input to LHS in RIP for Flowing Interval Spacing Dips

Probability (Number of raw data points = 165)	Flowing Interval Spacing Dips (Degrees)
0	0
0.036	23
0.127	29
0.19	38
0.31	55
0.678	72
0.848	78
0.93	81
0.99	85
1	87

Output DTN: SN9907T0571599.001.

The results of this calculation are shown in the spreadsheet, *resul_fis2.xls* (DTN: SN9907T0571599.001). A probability distribution of the corrected flowing interval spacing data was then developed using the industry standard software STATISTICA (Statsoft 1995 [DIRS 101158]). A normal distribution of the log-transformed corrected flowing interval spacing data was developed as shown in Figure 6-7. The log-transformed values result in a nearly normal distribution as shown in Figure 6-7, which qualitatively indicates a lognormal distribution (Davis 1986 [DIRS 123714], p. 87). The mean of the log-transformed data (in units of meters) was found to be 1.29 (corresponding to a geometric mean of 19.5 m) compared to the uncorrected flowing interval spacing mean of 1.68. The standard deviation of the log-transformed data was determined as 0.43.

Output DTN: SN9907T0571599.001.

Figure 6-7. Probability Distribution of Corrected Flowing Interval Spacing

6.5 FRACTURE SPACING DATA ANALYSIS

For comparison purposes, a second probability distribution was developed for the fracture spacing within the SZ. This includes all fracture spacing in the SZ, not just the flowing intervals. The same procedure was followed for this second distribution as outlined above for dips and flowing interval spacing including the correction using equation 1. Fracture spacing data and fracture dip data are shown in spreadsheet, *fracture_dips2.xls* (DTN: SN9907T0571599.001). The data used to identify fracture spacing and dip data consisted of graphical data and tabular data. An explanation of how the data was extracted for each borehole are discussed below:

C-wells (C#-1, C#-2 and C#-3): Tables 10, 11 and 12 in USGS WRIR 94-4177 [*Results and Interpretation of Preliminary Aquifer Tests in Boreholes UE-25c #1, and UE-25c #3, Yucca Mountain, Nye County, Nevada* (Geldon 1996 [DIRS 100396])], were used to determine spacing between fractures and the dip angle. The spacing was determined as an average for a 10-foot interval. When the interval exceeded 10-foot, the spacing was averaged over this larger interval. Spacing that exceeded ten feet was used directly because it was felt that a measurement greater than ten feet would be an accurate measurement.

G-4: Figure 13 in USGS OFR 84-789 [*Stratigraphic and Structural Characteristics of Volcanic Rocks in Core Hole USW G-4, Yucca Mountain, Nye County, Nevada with a Section on Geophysical Logs* by D.C. Miller and J.E. Kibler (Spengler et al. 1984 [DIRS 101357], p. 36)] was used to determine the dips. Figure 13 gives the percentage of fractures for each 10° dip interval. A total number of 300 fractures and associated dip angles were recorded for the saturated zone interval. The number of dips for a 10° average dip was calculated as shown on spreadsheet, *fracture_dips2.xls*. The fracture spacing for the saturated zone was determined from Plate 1 (Spengler et al. 1984 [DIRS 101357]). Fracture frequency was given for 10-foot

intervals. Fracture spacing was determined from the reciprocal of the fracture frequency given for 10-foot intervals.

H-4: Figure 3 in USGS WRIR 85-4066 (Erickson and Waddell 1985 [DIRS 105279]) was used to determine the dips and the fracture spacing. Data points for dip angles were extracted from Figure 3 directly. Fracture spacing was measured between the data points when possible. When the data points were clustered together, an average spacing was calculated based on the length of the cluster divided by the number of data points.

UE25P#-1: Plate 1 in USGS OFR-86-175 [*Geology of Drill Hole UE25p#1: A Test Hole Into Pre-Tertiary Rocks Near Yucca Mountain, Southern Nevada* (Carr et al. 1986 [DIRS 102046])], was used to determine fracture spacing and dip angles. Data points for dip angles were extracted from Plate 1 directly. Fracture spacing was measured between the data points.

H-1: Table 6 in USGS OFR-83-141 (Rush et al. 1983 [DIRS 107944]) was used to determine dip angles directly. Only three data points were available for dip angle. Fracture spacing in the saturated zone was not available for this borehole.

H-3: Table 4 in USGS OFR-84-149 (Thordarson et al. 1984 [DIRS 103200]) was used to determine dip angles directly. Fracture spacing in the saturated zone was not available for this borehole.

The procedure outlined for flowing interval spacing regarding the data input to the LHS module of RIP, was also followed for the fracture spacing and dip data. The corresponding histograms of fracture spacing and associated dips raw data can be seen in Figure 6-8. The CDFs of the fracture spacing and the dips are shown in Figures 6-9 and 6-10 respectively. Tables 6-5 and 6-6 list the data input to the LHS module of RIP.

A normal distribution of the log transformed data of the corrected fracture spacing was developed resulting in a mean of -0.59 compared to the uncorrected fracture spacing mean of -0.25 and the standard deviation was calculated to be 0.63 . The lognormal probability distribution for the corrected flowing interval spacing and fracture spacing are compared and shown in Figure 6-11. Table 6-7 shows a comparison of the descriptive statistics (based on the logs) for the flowing interval spacing and the fracture spacing distributions. Note that approximately an order of magnitude difference in log space exists, between the flowing interval spacing and the fracture spacing distribution. The use of fracture spacing in SZ transport modeling would result in greater matrix diffusion and diffusive transport compared to the use of the flowing interval spacing parameter.

Source data: Thordarson et al. 1984 [DIRS 103200]; Rush et al. 1983 [DIRS 107944]; Carr et al. 1986 [DIRS 102046]; Erickson and Waddell 1985 [DIRS 105279]; Spengler et al. 1984 [DIRS 101357]; Geldon 1996 [DIRS 100396].

Figure 6-8. Histogram of the Raw Fracture Spacing and Dip Data

Source: Carr et al. 1986 [DIRS 102046]; Erickson and Waddell 1985 [DIRS 105279]; Spengler et al. 1984 [DIRS 101357]; Geldon 1996 [DIRS 100396].

Figure 6-9. CDF for Fracture Spacing Used as Input to RIP for LHS

Table 6-5. Input to LHS in RIP for Fracture Spacing in SZ

Probability (Number of raw data points = 1119)	Fracture Spacing in SZ (m)
0	0.1
0.0598	0.16
0.227	0.19
0.3955	0.28
0.659	0.52
0.9205	3.08
0.95	7.09
0.979	18.5
0.99	34.5
1.0	77.1

Output DTN: SN9907T0571599.001.

Output DTN: SN9907T0571599.001.

Source: Thordarson et al. 1984 [DIRS 103200]; Rush et al. 1983 [DIRS 107944]; Carr et al. 1986 [DIRS 102046]; Erickson and Waddell 1985 [DIRS 105279]; Spengler et al. 1984 [DIRS 101357]; Geldon 1996 [DIRS 100396].

Figure 6-10. CDF for Fracture Spacing Dips Used as Input to RIP for LHS

Table 6-6. Input to LHS in RIP for Fracture Spacing Dips

Probability (Number of raw data points = 943)	Fracture Spacing Dips (Degrees)
0	0.001
0.13	25
0.27	41
0.33	45
0.49	56
0.58	64
0.73	72
0.79	75
0.87	77
1	87

Output DTN: SN9907T0571599.001.

Output DTN: SN9907T0571599.001.

Figure 6-11. Comparison of the Probability Distributions of the Log of Corrected Flowing Interval Spacing and Corrected Fracture Spacing

Table 6-7. Comparison of Statistics of the Logs of the Corrected Flowing Interval Spacing and the Logs of the Corrected Fracture Spacing

Variable	Valid N	Mean	Min.	Max	Std. Dev.
Log of corrected flowing interval spacing	1000	1.29385	0.25428	2.571806	0.433811
Log of corrected fracture spacing in the SZ	1000	-0.59449	-1.94979	1.728895	0.628003

Output DTN: SN9907T0571599.001.

NOTE: Output from STATISTICA.

Min.=Minimum; Std. Dev.=Standard Deviation; SZ=Saturated Zone

7. CONCLUSIONS

7.1 SUMMARY

This analysis developed a probability distribution for flowing interval spacing and fracture spacing in the SZ. The probability distribution for flowing intervals will be used to develop the associated uncertainty distribution for the *Saturated Zone Flow and Transport Model Abstraction* (BSC 2004 [DIRS 170042]). This analysis applies to all scenario classes in the TSPA analysis. The output data from this report is contained in the DTN: SN9907T0571599.001. The flowing interval spacing distribution was derived from flowing interval depth and dip data.

This analysis did not correlate flowing interval spacing with the hydrogeologic units. This approach was justified through a statistical analysis of differences between the hydrogeological units based on the percentage of flow in each interval. The analysis confirms that for this data set, no correlation exists between percentage of flow within an interval and hydrogeological unit.

The corrected flowing interval spacing and fracture spacing in SZ resulted in a lognormal probability distribution function for both variables and displayed in Figure 6-11. The mean of the log transformed corrected flowing interval and fracture spacing data (in units of meters) is 1.29 and -0.59, respectively. This analysis indicates a difference between the flowing interval spacing and fracture spacing of about one order of magnitude. This comparison is made to show the significant difference between flowing interval spacing and fracture spacing.

The flowing interval spacing is appropriate for use in the SZ site-scale transport models because the grid block size in the numerical transport model are more than an order of magnitude larger than the expected flowing interval spacing. Therefore, the use of the results from this analysis should be evaluated prior to use in other transport models, particularly those at smaller scales.

A restriction of this analysis is that the probability distribution of flowing interval spacing may underestimate the effect of incorporating matrix diffusion processes in the SZ transport model because of the possible overestimation of the flowing interval spacing. Larger flowing interval spacing results in a decrease in the matrix diffusion processes. As mentioned earlier, this analysis may overestimate the flowing interval spacing because the number of fractures that contribute to a flowing interval cannot be determined from the data. Because each flowing interval probably has more than one fracture contributing to a flowing interval, the true flowing interval spacing could be less than the spacing determined in this analysis. Therefore, in terms of repository performance, the results of this analysis may underestimate the effect of matrix diffusion and diffusive transport processes in SZ transport models. Underestimation of matrix diffusion in the transport modeling would result in a more rapid simulated migration of radionuclide mass to the accessible environment and correspondingly higher simulated dose to the reasonably maximally exposed individual in the TSPA-LA analyses.

7.2 HOW THE APPLICABLE ACCEPTANCE CRITERIA ARE ADDRESSED

The following information describes how this analysis addresses the acceptance criteria in the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1.3.9.3). Only those acceptance criteria that are applicable to this report (see Section 4.2) are discussed. In most cases, the applicable acceptance criteria are not addressed solely by this report; rather, the acceptance criteria are fully addressed when this report is considered in conjunction with other analysis and model reports that describe transport in the saturated zone.

Acceptance Criteria from Section 2.2.1.3.9.3, Radionuclide Transport in the Saturated Zone

Acceptance Criterion 1: System Description and Model Integration Are Adequate.

Subcriterion (1): The aspects of this report that support the TSPA incorporate Yucca Mountain physical phenomena and couplings from the borehole analyses and tests (Section 4.1 and 6.3). This information supports the description of and assumptions made (Sections 5 and 6.3) about characteristics of radionuclide transport in the saturated zone relative to matrix diffusion. These assumptions are consistently incorporated in other SZ transport related reports and reflected in the abstraction process.

Subcriterion (2): The description of how fractures may affect transport in the saturated zone is adequate for the following reasons. Qualified borehole input data including flow meter survey data and fracture orientation data discussed in Section 4, Table 4-1, Borehole Input Data Table, were analyzed to develop the probability distribution for flowing interval spacing which is a key input parameter to the matrix diffusion approach used to analyze the Yucca Mountain Project radionuclide transport in the saturated zone TSPA and abstraction process. The output of this report (Sections 6.4 and 7) describes, in a conservative manner, the hydrology, geology, and physical phenomena of flowing intervals that affect radionuclide transport in the saturated zone. Assumptions made in this report (Sections 5, 6.3, 6.4, and 6.5) are consistent with assumptions concerning matrix diffusion in the abstraction process.

Subcriterion (3): Parameters developed in this report (Sections 6.4 and 7) for matrix diffusion are appropriate to describe the flowing interval characteristics in the SZ and are consistently applied throughout other related reports and abstractions. Assumptions made (Section 5) are consistent with the observed data and tests and other models used to describe radionuclide transport in the SZ. The descriptions and technical bases provide transparent and traceable support as noted in Sections 4, 6.3, 6.4, and 6.5 and the data and input files and reports referenced therein.

Subcriterion (5): Features, events and processes appearing in this report that are related to radionuclide transport in the saturated zone are listed in Section 6.2. Table 6-1 lists the FEPs included in the TSPA-LA that are supported by the results of the analyses described in this document. The technical basis for FEPs incorporated in the TSPA-LA model, which are implemented through specific process models or input parameters, are presented in the SZ FEPs report, *Features, Events, and Processes in SZ Flow and Transport* (BSC 2004 [DIRS 170013]).

Subcriterion (6): This report was developed using processes and procedures consistent with the QARD (DOE 2004 [DIRS 171539]).

Acceptance Criterion 2: Data Are Sufficient for Model Justification

Subcriterion (1): The flowing interval spacing probability distribution used to support the TSPA abstraction is adequately justified because adequate descriptions of how the data were used and appropriately synthesized are described in Sections 6.3 and 6.4. This report provides adequate justifications for the methodology (Section 6.3) and assumptions (Section 5 and 6.3) employed in the development of these parameters. Adequate descriptions of data use and interpretations are provided throughout Section 6.3.

Subcriterion (3): Data employed in this report on the geology, hydrology, and geochemistry of the SZ are based on appropriate techniques that include the influence of fracture distributions, fracture properties, and stratigraphy based on borehole flow meter surveys, orientations, borings properties, and dip data as described in Sections 6.1 through 6.5.

Acceptance Criterion 3: Data Uncertainty is Characterized and Propagated Through the Model Abstraction

Subcriterion (1): Section 5 describes the main assumptions made for this analysis that only one fracture transmits fluid in a flowing interval and no correlation exists between the flowing interval spacing and the dips (Sections 6.4 and 5). Other assumptions important to the analysis are: (1) Boreholes are vertical (Section 6.4); (2) and No correlation exists between flowing intervals and hydrogeological units (Section 6.3). Sections 5 and 6.3 through 6.5 provide the technical justifications for those assumptions. As noted in Sections 1 and 7.1, adopting this analytical approach (versus use of fracture spacing as in the UZ) underestimates matrix diffusion, which results in a conservative performance analysis determination of radionuclide transport in the saturated zone.

Subcriterion (4): Section 6.4 develops key parameters from aquifer properties influencing borehole flow meter survey and orientation data at Yucca Mountain. These parameters are used as input for the matrix diffusion approach used to analyze radionuclide transport in the saturated zone abstraction process.

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MO0007FLWINTC1.000. Fracture Dip Data and Flowing Interval Depth Data from Borehole UE-25 c #1 Flow Meter Survey. Submittal date: 07/20/2000.	151159
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MO0007FLWINTH1.000. Fracture Dip and Flowing Interval Depth Data from Borehole USW H-1 Flow Meter Survey. Submittal date: 07/20/2000.	151137
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MO0007FLWINTH4.000. Fracture Dip Data and Flowing Interval Depth Data from Borehole USW H-4 Flow Meter Survey. Submittal date: 07/20/2000.	151134
MO0007FLWINTP1.000. Fracture Dip and Flowing Interval Depth Data from Borehole UE-25P#1 Flow Meter Survey. Submittal date: 07/20/2000.	151131
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8.5 SOFTWARE CODES

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