SEEPAGE WORKSHOP REPORT

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: All CNWRA-generated original data contained in this report meet quality assurance requirements described in the Geosciences and Engineering Division Quality Assurance Manual. Sources of other data should be consulted for determining the level of quality of those data. The work presented in this report is documented in Scientific Notebooks 282E, 355, 382, 432, 478E, 814E, 822E, and 843E.

1 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) is responsible for evaluating a license application for a potential geologic repository for high-level waste at Yucca Mountain, Nevada. In support of the regulatory review activities, staff conducts detailed technical analyses for improving the understanding of seepage processes in a fractured and unsaturated flow domain and in the engineered barrier system (EBS)[1] that affect the long-term performance and safety of the potential repository. Seepage of deep percolating water into emplacement drifts may affect the fraction of waste packages contacted by water; waste package integrity; the onset of aqueous corrosion of waste packages; and dissolution, mobilization, and transport of radionuclides from failed waste packages. These are key factors for the assessment of long-term performance of the potential repository.

The Total-system Performance Assessment (TPA)[2] Version 5.1 is a review tool to assist staff in pre-licensing activities and the review of a license application for a potential repository at Yucca Mountain. TPA Version 5.1 is designed to simulate the potential behavior of the repository system, taking into account the essential characteristics of the natural barriers and EBS. In TPA Version 5.1, some previous factors were modified and several new seepage factors were introduced to account for the possibility of (i) mountain-scale flow convergence/divergence in a fractured unsaturated medium above the emplacement drifts, (ii) flow divergence at the outer and inner walls of the emplacement drifts; (iii) flow convergence/divergence in the rubble, (iv) the potential that a fraction of waste packages may be affected when a particular failure mode occurs and the fact that not all failed waste packages may breach, and (v) the effects of thermal load on the percolation rate near the drift.

In TPA Version 5.1, the seepage factors provide a simplified representation of the complex unsaturated flow processes. They are empirical factors that may be constant values, time-series data, or internally computed time-variant parameters. This report documents recent updates to the technical basis for the seepage factors used in abstractions in TPA Version 5.1. Discussions include conceptualizations related to seepage including ambient and thermal seepage, seepage-related parameters, and technical basis for fluid and heat flow parameters used in TPA Version 5.1.

Section 2 briefly introduces the seepage factors used in TPA Version 5.1 that estimate the changes in flow rates in the unsaturated fractured host rock above the drift crown, at the drift/rock interface for intact drifts, and in the EBS until deep percolating water leaves the rubble zone in degraded drifts. Section 3 explains the technical basis for the seepage factors, elaborates underlying assumptions and analyses, and reports correlations between the seepage factors. This section also explains concisely the implementation of seepage factors in TPA Version 5.1. Section 4 discusses the representation of thermal seepage across a dryout zone above the drift crown and its implementation in TPA Version 5.1. Section 5 discusses preliminary results from a set of exploratory analyses that focus on the significance of the

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[1]Engineered barrier system is referenced frequently throughout this report, consequently, the acronym EBS will be used.

[2]Total Performance Assessment is referenced frequently throughout this report, consequently, the acronym TPA will be used.

convective-diffusive flow cycle in the rubble zone during the thermal period, the effect of axial and radial transport of vapor inside the drift and in the rubble, and flow and condensation of evaporated water above the dryout zone. Section 6 discusses the technical basis for the changes in the thermal conductivity of the host rock based on process-level simulations. Section 7 summarizes this report.

2 SEEPAGE FACTORS IN TPA VERSION 5.1—OVERVIEW

At the potential repository site at Yucca Mountain, infiltrating water from the ground surface is believed to flow downward under gravity through a thick, partially saturated fractured flow domain and potentially contacts the engineered barrier system (EBS) as part of thermal seepage during the thermal period or as ambient seepage after the thermal period. The percolation paths of the infiltrating water are affected by the distribution of capillary barriers imposed by small- and large-scale structural features (e.g., fault and fractures), permeability contrasts across the flow paths, temporal and spatial variations in climate features and infiltration rates, the extent of the vaporization barrier during the thermal period, and alterations in the flow domain due to possible mechanical failures of the EBS components (e.g., drift degradation). Because of the various effects of heterogeneity in unsaturated fracture networks, capillary effects at the interface of large openings, and diversion by intact or degraded EBS components, only a fraction of the total infiltrated water from the ground surface may potentially seep into emplacement drifts and contact the waste through breaches in the EBS.

There is uncertainty in the flow field because of heterogeneity, perturbation during the thermal period, and multiple processes acting at the drift boundary and in the rubble. Ambient seepage (not driven by thermal disturbances) from a fractured domain at the potential repository site through *in-situ* mesoscale infiltration and seepage tests was reported by Salve, et al. (2004, 2002); Salve (2005); and Zhou, et al. (2006). Additionally, there are a number of relevant observations of preferential flow paths in unsaturated fractured flow domains and thermal seepage into underground openings or cavities from fractures (See Section 4).

U.S. Nuclear Regulatory Commission (NRC) uses Total Performance Assessment (TPA) Version 5.1 to perform independent analyses and identify features, events, and processes that are important to long-term safety of the potential repository. In TPA Version 5.1, seepage factors have been introduced to account for the effects of mountain and drift-scale processes on the deep percolation rate in both ambient and thermal conditions.

2.1 Ambient Seepage

Ambient seepage factors discussed in this report involve (i) mountain-scale flow convergence/divergence across the fractured unsaturated flow domain above the emplacement drifts, (ii) drift-scale flow divergence in the close vicinity of the inner and outer walls of the emplacement drifts, and (iii) flow convergence/divergence across the rubble zone in degraded drifts (Figure 2-1). The last seepage factor is not applicable to intact drifts. As the deep percolating water approaches the drift wall, the flow is expected to either converge (focused flow) or diverge (dispersed flow) based on mountain-scale characteristics of structural features (e.g., fractures, faults) and temporal variations in the infiltration rate. The flow convergence in TPA Version 5.1 refers to an increase in water volume (and rate) approaching the emplacement drifts. It is conceptualized that each seep point on the drift ceiling has its own capture zone above it, which is analogous to an outlet of a drainage basin (watershed).

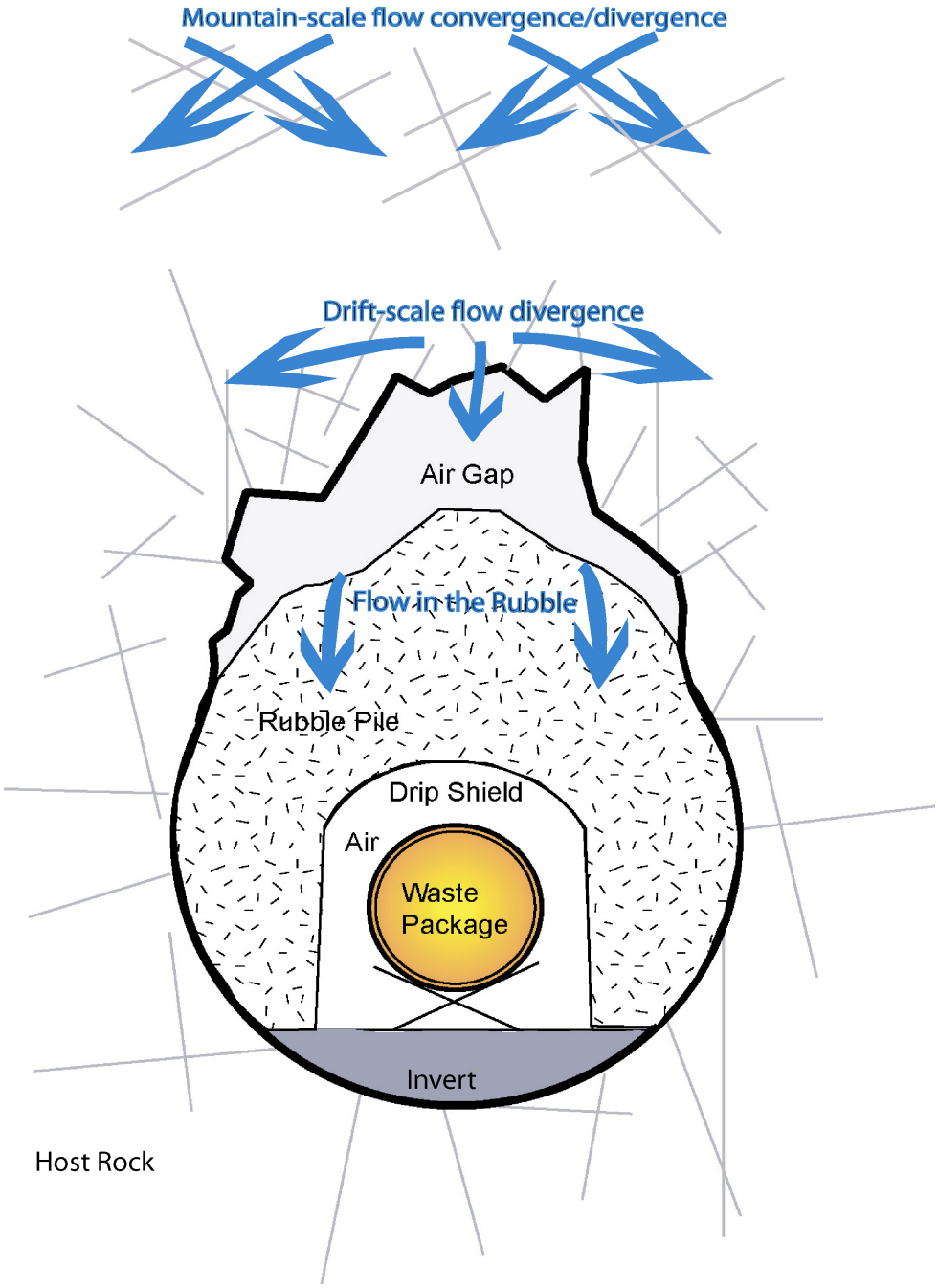

Figure 2-1. A Schematic Representation of Ambient Seepage Processes Abstracted in TPA Version 5.1

The flow convergence implies that water is gained from other capture zones outside the footprint of the drift opening, which would increase the deep percolation rate approaching the drift crown. As the flow reaches the drift crown, it can either be diverted away above the outer surface of the drift crown or can enter the drift and form drops at the drift ceiling based on the relative strengths of the capillary barrier imposed by the drift opening and gravity. Similarly, the water (in drops) can seep from the ceiling if the gravitational force overcomes capillary retention; otherwise, it flows in films along the inner walls of the drift and bypasses the EBS below.

In the case of a degraded drift, rubble would gradually accumulate on the drip shield. Water that seeps from the drift wall would have to pass through the rubble zone before contacting the drip shield.

2.2 Thermal Seepage

During the thermal period, the deep percolation rate approaching the drift is still controlled by the mountain-scale flow convergence/divergence and drift-scale flow convergence factors, as for the ambient flow case. However, due to the heat emitted from waste forms in the thermal period, a dryout zone forms around the drift as pore water near the drift wall vaporizes, migrates, and condenses in cooler regions away from drift walls (Figure 2-2). The dryout zone extends from the drift wall to the boiling isotherm, and its thickness is different for intact drifts than for degraded drifts. During the thermal period, the percolating water has to breach both capillary and vaporization barriers before it can potentially seep into the drift.

The condensate water above the boiling isotherm can locally breach the dryout zone and seep into emplacement drifts if the potential penetration depth of the condensate water exceeds the dryout zone thickness. Hence, the water flux rate leaving the dryout zone in the thermal period varies with the dryout zone thickness and the deep percolation rate. Following the thermal period, the dryout zone and the vaporization barrier will have dissipated and need not be considered.

2.3 Parameters in TPA Version 5.1 Representing Seepage Factors

2.3.1 Seepage Factors in TPA Version 5.1 Related to the Ambient Seepage

The ambient seepage factors are discussed in depth in Section 3. Briefly, the mountain-scale flow convergence is a product of two ambient seepage factors: an auxiliary input parameter F_{OW} (read from wpflow.def) and a tpa.inp parameter WastePackageFlowMultiplicationFactor in TPA Version 5.1. The former is reserved for introducing the effects of detailed fracture characteristics and climate factors to the mountain-scale flow convergence factor when such detailed data are available. The latter accounts for flow convergence at the drift wall–fractured domain interface in terms of a number of seeps on the drift ceiling correlated to fracture spacing. As the deep percolation flow approaches the drift wall, the seepage reduction at the drift wall is quantified by a seepage factor called F_{mult} which accounts for reductions due to water diversion at the outer surface of the drift wall and film flows on inner surfaces of the drift wall. F_{mult} is either read from an auxiliary input file (wpflow.def) or computed by TPA Version 5.1 based on other tpa.inp parameters. As the seepage water flows through the rubble zone in degraded drifts, the effects of the rubble on the flow rate are represented by an auxiliary input parameter F_r (read from wpflow.def).

2.3.2 Seepage Factors in TPA Version 5.1 Related to the Thermal Seepage

The thermal seepage calculations are discussed in Section 4. Unlike the ambient seepage factors, the thermal seepage across the dryout zone is computed by TPA Version 5.1 using the modified O.M. Phillips equation (Phillips, 1996) as a function of dryout thickness, thermal, and physical properties of the host rock and water. The condition for the thermal seepage to breach through the dryout zone is controlled by a threshold temperature called SeepageThresholdT[C], which is a tpa.inp parameter.

2.3.3 Seepage Factors Affecting the Inventory

The seepage factors affecting the inventory are discussed in Section 3. The product of a tpa.inp paramater SubAreaWetFraction and an auxiliary input parameter F_{wet} (read from wpflow.def) is used to introduce the temporal variations in the fraction of waste packages contacted by seepage. In TPA Version 5.1 SubAreaWetFraction is correlated to WastePackageFlowMultiplicationFactor.

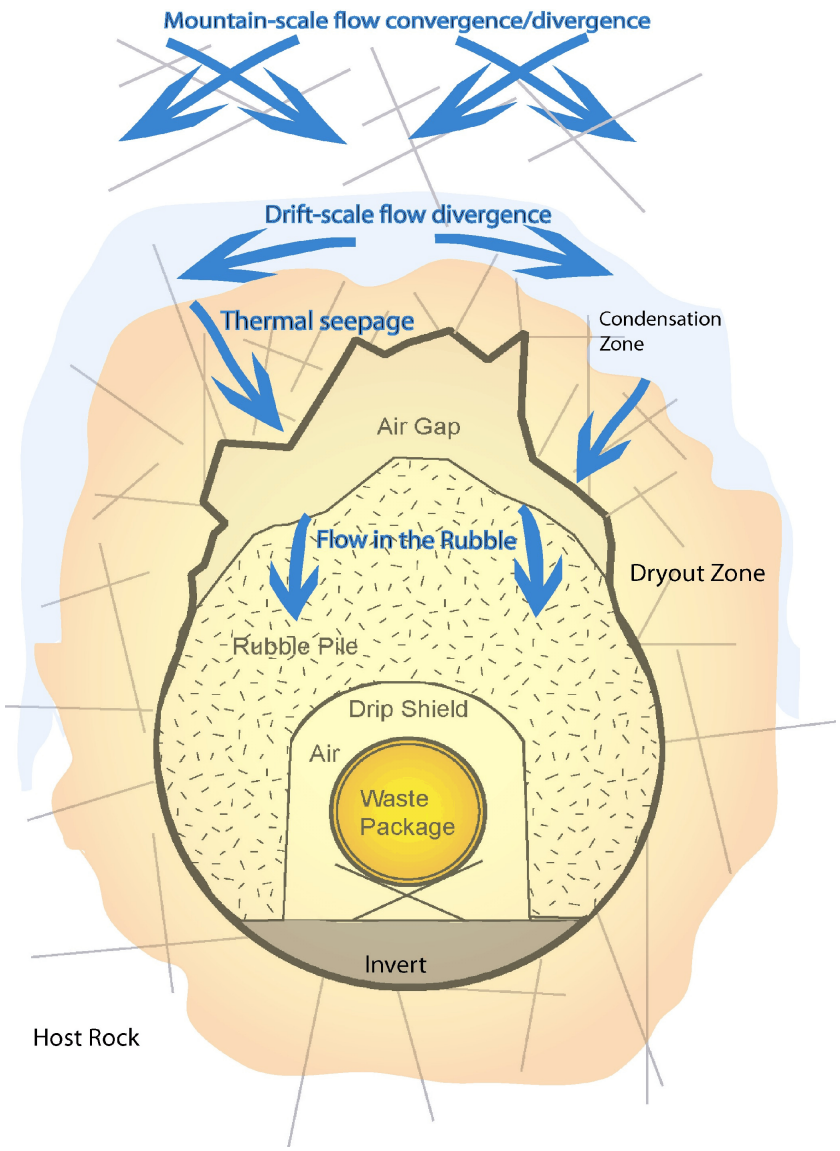

Figure 2-2. A Schematic Representation of Thermal and Ambient Seepage Processes Abstracted in TPA Version 5.1