10
2-3-94 JSD

SANDIA REPORT

SAND93-1182 • UC-814

Unlimited Release

Printed December 1993

Yucca Mountain Site Characterization Project

Evaluation of the Effects of Underground Water Usage and Spillage in the Exploratory Studies Facility

Ellen Dunn, Steven R. Sobolik

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-94AL85000

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED

"Prepared by Yucca Mountain Site Characterization Project (YMSCP) participants as part of the Civilian Radioactive Waste Management Program (CRWM). The YMSCP is managed by the Yucca Mountain Project Office of the U.S. Department of Energy, DOE Field Office, Nevada (DOE/NV). YMSCP work is sponsored by the Office of Geologic Repositories (OGR) of the DOE Office of Civilian Radioactive Waste Management (OCRWM)."

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831
Prices available from (615) 576-8401, FTS 626-8401

Available to the public from
National Technical Information Service
US Department of Commerce
5285 Port Royal Rd
Springfield, VA 22161

NTIS price codes
Printed copy: A04
Microfiche copy: A01

SAND93-1182
Unlimited Release
December 1993

**Evaluation of the Effects of Underground Water Usage and Spillage
in the Exploratory Studies Facility**

Ellen Dunn
YMP System Performance Assessment Department 6312

Steven R. Sobolik
YMP Performance Assessment Applications Department 6313

Sandia National Laboratories
Albuquerque, New Mexico 87185

ABSTRACT

The Yucca Mountain Site Characterization Project is studying Yucca Mountain in southwestern Nevada as a potential site for a high-level radioactive waste repository. Analyses reported herein were performed to support the design of site characterization activities so that these activities will have a minimal impact on the ability of the site to isolate waste and a minimal impact on underground tests performed as part of the characterization process. These analyses examine the effect of water to be used in the underground construction and testing activities for the Exploratory Studies Facility on in situ conditions. Underground activities and events where water will be used include construction, expected but unplanned spills, and fire protection. The models used predict that, if the current requirements in the Exploratory Studies Facility Design Requirements are observed, water that is imbibed into the tunnel wall rock in the Topopah Springs welded tuff can be removed over the preclosure time period by routine or corrective ventilation, and also that water imbibed into the Paintbrush Tuff nonwelded tuff will not reach the potential waste storage area.

MASTER

ep

The work discussed in this report is covered under the description of work for Task 1.1 of WBS 1.2.5.4.7 (formerly WBS 1.2.1.4.7). The work defined under this task is not applicable for licensing. However, because the work is being performed in support of the ESF design, it will be performed subject to the Quality Assurance Program; therefore, the quality assurance grading used for this work will be the upper-level QAGR S12547A.

Acknowledgments

The authors thank their fellow coworkers who helped in the preparation of this report. Larry Costin, Jack Gauthier, Mert Fewell, and Eric Ryder reviewed the technical content of this document and offered corrections and ideas for improvements. Albin Brandstetter of Intera in Las Vegas, NV, helped us to obtain necessary information and provided the contacts to obtain further necessary information. Robert Saunders of Intera in Las Vegas, NV, and Bruce Stanley of Raytheon Services Nevada in Las Vegas, NV, shared their knowledge of mining engineering and construction and the status of plans for the mining of the Exploratory Studies Facility. Corinne Taylor helped prepare the figures for this report.

Contents

1.0	Introduction.....	1
2.0	Compliance With Title 10, Code of Federal Regulations, Part 60	1
3.0	Description of the Calculations.....	2
3.1	Exploratory Studies Facility Tunnel in Topopah Spring Welded Unit	3
3.1.1	Topopah Spring Welded Unit 2 Flooding Scenario	6
3.1.2	Topopah Spring Welded Unit 2 Wetting Scenario	10
3.2	Exploratory Studies Facility Tunnel in the Paintbrush Tuff Nonwelded Unit	11
3.2.1	Paintbrush Tuff Nonwelded Unit Results	13
4.0	Limitations and Assumptions	17
4.1	Homogeneity of Geologic Units	17
4.2	Composite Porosity Model	18
5.0	Construction Assumptions and Recommendations	20
5.1	Assumptions for the Construction Plans and Processes	21
5.2	Recommendations	22
5.2.1	Recommendation A	23
5.2.2	Justification for recommendation A	23
5.2.3	Recommendation B.....	23
5.2.4	Justification for Recommendation B	23
5.2.5	Recommendation C.....	23
5.2.6	Justification for Recommendation C	23
6.0	Application of the Analyses to the Nine Aspects	24
6.1	Aspect 1: Routine Water Use During the Ramp and Drift Excavation by Tunnel Boring Machines	26
6.1.1	Existing Requirements for Aspect 1	29
6.1.2	Recommendations for Aspect 1	29
6.2	Aspect 2: Water Use for Drilling Purposes	30
6.2.1	Recommendations for Aspect 2	30
6.3	Aspect 3: Water Use for Washing Walls	30
6.3.1	Recommendations for Aspect 3	31
6.4	Aspect 4: Water Use for Fire Fighting	31
6.4.1	Existing Requirements for Aspect 4	33

Contents (concluded)

6.4.2 Recommendations for Aspect 4	34
6.5 Aspect 5: Failure of Sump Pumps to Remove Waste and Mine-Drainage Water	34
6.5.1 Existing Requirements for Aspect 5	35
6.5.2 Recommendations for Aspect 5	35
6.6 Aspect 6: Accidental Breaks in Water Pipes	35
6.6.1 Existing Requirements for Aspect 6	35
6.7 Aspect 7: Water Use for Testing Purposes	36
6.7.1 Existing Requirements for Aspect 7	37
6.7.2 Recommendations for Aspect 7	37
6.8 Aspect 8: Accidental Water Spills by the Tunnel Boring Machines and Other Equipment	37
6.8.1 Existing Requirements for Aspect 8	38
6.9 Aspect 9: Leakage of Water Pipes	38
6.9.1 Existing Requirements for Aspect 9	38
6.9.2 Recommendations for Aspect 9	38
7.0 Conclusion	38
8.0 References	41
9.0 Appendix A: Recommendations for Appendix I of the Exploratory Studies Facility Design Requirements Pertaining to Exploratory Studies Facility Performance Assessment Analysis #13	45
10.0 Appendix B	51

Figures

Figure 1.	Computational grid used in the calculations for the tunnel in the Topopah Spring Welded Unit 2.	6
Figure 2.	Change in saturation in the Topopah Spring Welded Unit 2 tunnel after 1 month of being filled with water.	7
Figure 3.	Change in in situ saturation over time following filling of the tunnel in the Topopah Spring Welded Unit 2 with water for 1 month, removing the water, and applying a no-flux boundary condition at the air/rock interface (no evaporation).	8
Figure 4.	Change in saturation after water has been removed from the tunnel in the Topopah Spring Welded Unit 2 and 1 day of ventilation with 90% relative humidity air has occurred.	9
Figure 5.	Change in total water content in the Topopah Spring Welded Unit 2 tunnel wall rock (per meter of tunnel) after 1 month of being filled with water, then being in contact with air of 90% relative humidity.	9
Figure 6.	Change from in situ saturation in the Topopah Spring Welded Unit 2 resulting from ventilating the tunnel after a 1-month flood.	10
Figure 7.	Loss of water in the Topopah Spring Welded Unit 2 tunnel due to the 90% relative humidity air in contact with the tunnel wall rock.	11
Figure 8.	Water per meter of tunnel imbibed into continuously wetted Topopah Spring Welded Unit 2 wall rock.	11
Figure 9.	Saturation migration in a Topopah Spring Welded Unit 2 as the wall rock is kept continuously wetted for 1 month to 2 years.	12
Figure 10.	Steady-state saturation profile for borehole USW G-4 for Paintbrush Tuff nonwelded properties from project reports.	14
Figure 11.	Mesh used for the Paintbrush Tuff nonwelded calculations.	15

Figures (concluded)

Figure 12. Change in in situ saturation of the Paintbrush Tuff nonwelded after the tunnel is water-filled for 1 month, and then is dewatered and exposed at the rock/air boundary to air with relative humidity of 90%. These calculations used sample IV Yucca Mountain member properties.	16
Figure 13. Saturation change in the Paintbrush Tuff nonwelded at 100 years after the tunnel was filled with water for 1 month.	17
Figure 14. Change in the water content in the tunnel wall rock in the Paintbrush Tuff nonwelded unit in the vicinity of the North Ramp after the 1 month <i>flooding scenario</i> followed by ventilation with 90% relative humidity air.	18
Figure 15. Change in saturation in four hours with the Topopah Spring Welded Unit 2 modeled with high fracture permeability and flooded for 24 hours and 28 hours.	20
Figure 16. Plan view of drifts and main tunnel in relation to the repository boundary.	21
Figure 17. Intersection of the North Ramp and the extrapolated PTn.	32

Tables

Table 1. Definition of Hydrologic Units	3
Table 2. USW G-4 Stratigraphy	3
Table 3. Hydrogeologic Properties at USW G-4	5
Table 4. Alluvium Hydrogeologic Properties	5
Table 5. Yucca Mountain Member Hydrogeologic Properties Used for the PTn	13
Table 6. Existing Requirements from the ESFDR	24
Table 7. Estimates of Water Required for Excavation Using a Tunnel Boring Machine	26
Table 8. Estimated Water Requirements	28
Table 9. USW G-4 Stratigraphy Comparison Between RIB Versions	51

1.0 Introduction

Sandia National Laboratories (SNL) was asked to perform a waste isolation evaluation of underground water use and spills in the planned Exploratory Studies Facility (ESF).¹ The purpose of the evaluation is to provide guidance for the ESF design and, if needed, to define controls on the use of water and combustible fluids. The request stated that this guidance is needed to determine whether restrictions on water use should be imposed, whether the use of combustible materials should be limited, and what measures should be implemented to reduce the probability of accidental spills. It was further requested that the evaluation should consider the following aspects:

1. Routine water use during the ramp and drift excavation by tunnel boring machines (TBMs), principally for dust control.
2. Water use for drilling purposes.
3. Water use for washing walls.
4. Water use for fire fighting.
5. Failure of sump pumps to remove waste and mine drainage water.
6. Accidental breaks in water pipes.
7. Water use for testing purposes.
8. Accidental water spills by the TBMs and other equipment.
9. Water leaks from pipes, including pipes for water supply and for waste water and mine drainage water removal.

Construction and operation of the ESF must be conducted so that these activities do not negatively impact the ability of the site to comply with the performance objectives of Title 10, Code of Federal Regulations, Part 60 (10 CFR 60). The calculations performed in response to the Yucca Mountain Project Office (YMPO) request are based on the infiltration and flow model of NORIA-SP (Hopkins et al., 1991) with a ventilation boundary condition applied. The models used are described in Section 3.0. The evaluation also relies on project planning and requirements documents to assess the completeness of restrictions and requirements already in effect.

Because knowledge of Yucca Mountain will be limited prior to completion of site characterization, the hydrogeological conceptual model, existing conceptual models of the physical processes, and the mathematical models used in these analyses are not yet fully validated. Recommendations based on the analyses results are intended to provide guidance for applying engineering judgement during the design, construction, and operation of the ESF. Refinement of the analyses results is an ongoing and iterative process, which must complement site characterization. The calculations might be refined as better understanding evolves through site characterization and through additional analyses, which will address uncertainties and the sensitivity of the results to alternate conceptual models.

2.0 Compliance With Title 10, Code of Federal Regulations, Part 60

The federal regulation 10 CFR 60 has requirements that pertain specifically to underground radioac-

1. Letter, J. Russell Dyer to Les E. Shephard, FSED:JMB-2266, dated February 1, 1993, Subject: Request for Waste Isolation Evaluation of Underground Water Use and Spills in Exploratory Studies Facility (ESF).

tive waste storage facilities. 10 CFR 60.133a requires that the underground facility shall contribute to the containment and isolation of radionuclides, and that the effects of fires and flooding will not spread through the facility; 10 CFR 60.133c requires control of water intrusion; and 10 CFR 60.133f requires excavation methods that will limit the potential for creating a preferential pathway for groundwater to contact the waste packages or radionuclide migration to the accessible environment.

To meet these requirements, the Exploratory Studies Facility Design Requirements (ESFDR) document (U. S. Department of Energy (DOE), 1992) defines criteria for limits on water use in terms of acceptable but undetermined increases in the saturation level of the repository horizon bedrock,² and criteria for limits on water use underground.³ These criteria could yield a specific quantity of water to budget among the various needs, but they are not verified criteria. Verification is dependent upon the specific repository design, the construction techniques, the hydrologic properties of the rock formations, and the water tolerance of the waste package; all of which are uncertain. This study suggests two criteria:

1. Water used in underground construction and operation of the ESF facility and in the planned testing activities will not interfere with the repository's ability to contain waste if that water or an equal volume of water from the same region is removed during construction or by required or prescribed ventilation during the preclosure phase of the ESF and repository operation.
2. Water used in underground construction and operation of the ESF facility and in the planned testing activities will not interfere with the repository's ability to contain waste if that water does not reach the repository horizon within 10,000 years.

Analyses presented herein that were conducted to provide the requested guidance are based on the models in the computer code NORIA-SP (described in the Section 3.0), current Reference Information Base (RIB) or best estimates for selected rock properties, and assumptions (Section 4.0) illustrating the connection between actual water requirements and the analytical results.

3.0 Description of the Calculations

The analysis described in SNL YMP Work Agreement WA-0062 was conducted to investigate the movement and potential impact on waste isolation of water used or spilled during the construction of the underground tunnels for the ESF. As described in WA-0062, investigators conducting this analysis (referred to as ESF performance assessment (PA) Analysis #13)⁴ were initially concerned with reviewing previous analyses regarding the usage and movement of underground water, and with developing criteria to determine whether that water would have an impact on the ability of the natural

2. To show compliance with 10 CFR 60.133d: The design of the underground facility shall provide for control of water or gas intrusion. ESFDR Sections 1.2.6.4 PC 2h.ii, 1.2.6.5 PC 2i.iii, 1.2.6.6 PC 2j.v, and 1.2.6.8 C E.iii, state the following: *Water use in (shaft construction, ramp construction, the underground facility, or testing) shall be generally consistent with repository design goals to limit the increase in average percent saturation of the repository horizon to [TBD] percent, and limit the increase in the local percent saturation to [TBD] percent in waste emplacement areas.*

3. To show compliance with 10 CFR 60.133d, an earlier version of the ESFDR (Rev. 0, 3/27/91), Sections 1.2.6.4.PC 2g.i, 1.2.6.5.PC 2g.ii, and 1.2.6.6.PC 2h.iv state the following: *The amount of water used in construction and operations shall be limited to that required for dust control and proper equipment operation so as to limit the effects on the containment and isolation capability of the site. The maximum quantity of water (based on use during construction) shall not exceed 15 gallons per ton of rock excavated.* DOE (1992) does not contain this criterion.

4. One of a series of analyses requested by DOE to support the design of the ESF.

barrier system at Yucca Mountain to isolate radioactive waste.

3.1 Exploratory Studies Facility Tunnel in Topopah Spring Welded Unit

Computational analyses were performed to simulate two scenarios for water usage or spillage in the ESF tunnel excavated in the Topopah Spring welded unit (TSw2)(the potential repository unit). The first scenario (referred to as the *flooding scenario*) simulates the complete filling of the tunnel with water, possibly due to a major fire fighting operation or a water line rupture. In this scenario, the tunnel remains filled with water for one month, after which the water is pumped out. The second scenario (referred to as the *wetting scenario*) estimates the water imbibition and movement due to keeping the tunnel walls saturated continuously for varying periods of time. This scenario simulates the original tunnel excavation operations and wall-washing to control dust and to prepare for mapping. For both these scenarios, the finite-element code NORIA-SP, Version 0.10, was used to perform the calculations. NORIA-SP numerically solves the two-dimensional Richards' equation for single-phase flow (liquid water) in porous media using the composite fracture/matrix porosity model (Klavetter and Peters, 1986). The van Genuchten model (van Genuchten, 1980) was used to describe the moisture characteristic curves for the matrix and fractures. Multiphase and nonisothermal effects were not considered. ESF tunnel simulations for both scenarios use the stratigraphy of borehole USW G-4. Table 1 defines the hydrologic units and Table 2 describes the USW G-4 stratigraphy, which was obtained-

Table 1: Definition of Hydrologic Units^a

Unit	Description
CHnz	Zeolitized Calico Hills nonwelded unit (CHn3z, CHn2z, CHn1z)
CHnv	Vitric Calico Hills nonwelded unit (CHn1v)
TSw3	Basal Vitrophyre of the Topopah Spring welded unit
TSw2	Topopah Spring welded unit (The potential repository unit)
TSw1	Topopah Spring welded unit
PTn	Paintbrush nonwelded unit
TCw	Tiva Canyon welded unit
UO	Undifferentiated Overburden (alluvium)

a. Ortiz et al., 1985.

Table 2: USW G-4^a Stratigraphy^b (continued on following page)

Material Designation	Elevation (m)	
	Bottom	Top
Water Table		730.6
CHn3(z)	730.6	735
CHn2(z)	735	752
CHn1z	752	856
CHn1v	856	861
TSw3	861	877
TSw2	877	1066
TSw1	1066	1196

Table 2: USW G-4^a Stratigraphy^b (concluded)

Material Designation	Elevation (m)	
	Bottom	Top
PTn	1196	1234
TC _w	1234	1261
UO (alluvium)	1261	1270

a. Nevada State Plane Coordinates (feet): E5633082, N.765807.

b. Stratigraphy from RIB Version 2.002; water-table level from Robinson et al., 1988.

from the Reference Information Base (RIB), Version 2.002. The material hydrogeologic properties that were used are the current best available data from USW G-4 and USW GU-3 (Peters et al., 1984; Klavetter and Peters, 1986). The selected values for the hydrogeologic properties for both the units of the USW G-4/GU-3 boreholes and the alluvium layer are listed in Tables 3 and 4

The problem is conceptualized as follows. Prior to the construction of the tunnel and the addition of water, the mountain is assumed to be at steady-state saturation conditions that correspond to a uniform infiltration of 0.01 mm/yr through the surface. These steady-state solutions were used as the initial conditions for the transient calculations. A tunnel with a cross section of 10 m × 10 m is excavated through the TSw2 unit with the base of the tunnel at 960-m elevation. A tunnel of this dimension slightly exceeds any proposed dimensions in both surface area per unit length and in cross sectional area making this a conservative model. For the *flooding scenario*, the tunnel is then filled with water for a period of 1 month. After 1 month has passed, the standing water is removed, and two different sets of calculations continue the analyses. One set estimates the movement of the imbibed water given no evaporation of the water from the tunnel walls into the air (i.e., a no-flow boundary condition). The other set estimates the movement of the imbibed water assuming that air at 90% relative humidity is in contact with the tunnel wall rock. These calculations were carried out to 100 years, the proposed active life of the potential repository. For the *wetting scenario*, the walls were maintained at saturation continuously for several time intervals to estimate the amount of imbibed water and its movement from the air/rock boundary.

The problem domain for each case was two-dimensional and cartesian, extending from the water table to the surface for the steady-state calculations, and from the water table to the interface of the TSw2 and the upper Topopah Spring welded unit (TSw1) for the transient calculations. The stratigraphic units were modeled as horizontal and parallel. Symmetry allowed a no-flow boundary to be placed through the tunnel's vertical center line. The other vertical boundary was also defined as a no-flow boundary and placed 31 m from the tunnel's center line. The location for this other no-flow vertical boundary was chosen because it was sufficiently far from the tunnel so as not to affect the resulting lateral flow of the infiltrated water (i.e., to simulate a semi-infinite space). The tunnel walls form additional boundaries at which the water filling, wetting, and ventilation boundary conditions were imposed. For the *flooding scenario*, the entire tunnel was filled with water. A pressure head of 10 m was imposed on the bottom surface of the tunnel, a head of 0 m was imposed on the top surface, and a similar head based on height above the tunnel floor was imposed on the sides of the tunnel. For the

Table 3: Hydrogeologic Properties at USW G-4

Matrix Properties ^a							
Unit	Porosity	Saturated Hydraulic Conductivity (m/s)	Residual Saturation	α (1/m)	β	Bulk-Rock Compressibility (1/m)	Sample
CHnz	0.28	2.00×10^{-11} (2.00×10^{-12} for CHnz2)	0.11	0.00308	1.602	2.60×10^{-6}	G4-11
CHn1v	0.46	2.70×10^{-7}	0.041	0.0160	3.872	3.90×10^{-6}	GU3-14
TSw3	0.07	1.50×10^{-12}	0.08	0.00441	2.058	5.80×10^{-7}	GU3-11
TSw2	0.11	1.90×10^{-11}	0.08	0.00567	1.798	5.80×10^{-7}	G4-6
TSw1	0.11	1.90×10^{-11}	0.08	0.00567	1.798	1.20×10^{-6}	G4-6
PTn	0.40	3.90×10^{-7}	0.10	0.015	6.872	8.20×10^{-6}	GU3-7
TCw	0.08	9.70×10^{-12}	0.002	0.00821	1.558	6.20×10^{-7}	G4-1
Fracture Properties ^b							
Unit	Porosity	Saturated Hydraulic Conductivity (m/s)	Residual Saturation	α (1/m)	β	Fracture Compressibility (1/m)	Sample
CHnz	4.60×10^{-5}	2.00×10^{-4}	0.0395	1.28	4.23	2.80×10^{-8}	G4-4F
CHn1v	4.60×10^{-5}	2.00×10^{-4}	0.0395	1.28	4.23	2.80×10^{-8}	G4-4F
TSw3	4.30×10^{-5}	1.60×10^{-5}	0.0395	1.28	4.23	2.10×10^{-8}	G4-2F
TSw2	1.80×10^{-4}	1.75×10^{-5}	0.0395	1.28	4.23	1.20×10^{-7}	G4-2F
TSw1	4.10×10^{-5}	2.20×10^{-5}	0.0395	1.28	4.23	5.60×10^{-8}	G4-2F
PTn	2.70×10^{-5}	6.10×10^{-4}	0.0395	1.28	4.23	1.90×10^{-7}	G4-3F
TCw	1.40×10^{-4}	3.80×10^{-5}	0.0395	1.28	4.23	1.32×10^{-6}	G4-2F

a. All matrix properties from Peters et al., 1984.

b. All fracture properties from Klavetter and Peters, 1986.

Table 4: Alluvium Hydrogeologic Properties^a

Porosity	Saturated Hydraulic Conductivity (m/s)	Residual Saturation	α (1/m)	β	Bulk-Rock Compressibility (1/m)	Fracture porosity	Fracture compressibility (1/m)
0.32 ^b	5.00×10^{-7} ^b	0.3	0.423	2.06	0	0	0

a. Alluvium matrix properties from van Genuchten(1980), except as cited.

b. Values obtained from personal communication with Alan Flint, U.S. Geological Survey, July 19, 1989.

wetting scenario, a pressure head of 0 m was imposed over the entire surface of the tunnel. A no-flux boundary condition was imposed on the tunnel surface (no evaporation). The model that was used for ventilation is one that has been implemented in previous analyses (Hopkins et al., 1987; Sobolik et al., 1991). The matrix pore potential at the tunnel surface is related to the temperature and relative

humidity of the air by the following equation:

$$\Phi = \frac{-RT}{M} \ln \left(\frac{\phi}{100} \right) \quad \text{where} \quad \begin{array}{l} \Phi \equiv \text{total water potential,} \\ R \equiv \text{universal gas constant,} \\ T \equiv \text{Kelvin temperature,} \\ M \equiv \text{molecular weight of water, and} \\ \phi \equiv \text{relative humidity (percent).} \end{array} \quad (1)$$

The ambient air at Yucca Mountain will be used for ventilation. This air will have a relative humidity usually in the range of 10% to 50%, depending on the time of year and the daily weather patterns. The air will draw moisture from a number of sources in the tunnel, primarily the tunnel walls and the water used for moistening the muck on the conveyor belts. These water sources will add humidity to the air, though perhaps only near the surfaces from which moisture will be absorbed. The moistened air could behave much like a boundary layer, keeping the additional moisture near the tunnel walls. Also, the estimated value for the relative humidity of the air in Equation 1 should not produce results which overestimate the amount of moisture withdrawn from the in situ rock. To satisfy the conditions stated here, an estimate of 90% relative humidity was used in Equation 1 as a boundary condition for ventilating air in the calculations.

3.1.1 Topopah Spring Welded Unit 2 Flooding Scenario

Calculations used for the *flooding scenario* in the TSw2 implemented a mesh with thin elements near the tunnel walls, floor, and ceiling (Figure 1). The extent of water imbibition and movement after the

Figure 1. Computational grid used in the calculations for the tunnel in the Topopah Spring Welded Unit 2.

Figure 2. Change in saturation in the Topopah Spring Welded Unit 2 tunnel after 1 month of being filled with water.

tunnel is filled with water for one month is illustrated in Figure 2 by the contour representing an increase of 0.025 in saturation from steady-state conditions. The maximum extent of water movement is ~ 3 m from the bottom of the side wall of the tunnel, and 3 m below the floor and above the ceiling. The amount of water imbibed through the tunnel walls in one month is ~ 2.6 cubic meters of water per meter of tunnel (m^3/m), or about 209 gallons per foot of tunnel. Assuming that there is no evaporation of water from the tunnel walls into the tunnel air, the imbibed water moves away from the tunnel in a nearly axisymmetric manner. Figure 3 illustrates the movement of the water (as an increase in saturation) after 1, 5, 10, 15, 25, and 100 years, respectively. The region of increased saturation of 0.025 or more extends less than 8 m into the wall rock.

For the case where ventilation is used to evaporate water out of the walls, the suction pressure at the wall is determined by Equation 1. The ventilation boundary condition was implemented in the calculations gradually over a period of 1 day; i.e., Φ was linearly changed from 10 m (on the floor) to the ventilation value from the period beginning at $t = 1$ month and ending at $t = 1$ month + 1 day. This change in saturation after 1 day is illustrated in Figure 4. Figure 5 shows the change in total moisture content in the vicinity of the tunnel as a function of time; the ventilation air has returned the rock to its original moisture content ~ 6 months after the beginning of the filling of the tunnel with water (i.e., after ~ 5 months of ventilation). Ventilation through 100 years continues to dry the rock, until $\sim 6.1 \text{ m}^3$ of water per meter of tunnel has been removed. Figure 6 illustrates the effects of ventilation after 6 months, 5 years, and 100 years.

To compare the effects of ventilating a tunnel that has been filled with water to the effects of the same ventilation in a tunnel at in situ conditions, calculations on the latter case were performed. Figure 7

Figure 3. Change in in situ saturation over time following filling of the tunnel in the Topopah Spring Welded Unit 2 with water for 1 month, removing the water, and applying a no-flux boundary condition at the air/rock interface (no evaporation).

Figure 4. Change in saturation after water has been removed from the tunnel in the Topopah Spring Welded Unit 2 and 1 day of ventilation with 90% relative humidity air has occurred.

Figure 5. Change in total water content in the Topopah Spring Welded Unit 2 tunnel wall rock (per meter of tunnel) after 1 month of being filled with water, then being in contact with air of 90% relative humidity.

Figure 6. Change from in situ saturation in the Topopah Spring Welded Unit 2 resulting from ventilating the tunnel after a 1-month flood.

compares the amount of water removed by ventilation after the one month *flood* scenario and the amount removed immediately after construction with assumed in situ parameters as initial conditions. It can be seen from Figure 7 that, according to the ventilation model used for these analyses, filling a tunnel in TSw2 with water for one month would have a minimal effect on long-term in situ moisture content.

3.1.2 Topopah Spring Welded Unit 2 Wetting Scenario

The effects of many saturating and periodic water application activities were simulated by the calculations performed for the *wetting scenario*. The entire tunnel surface was held at saturation ($\Phi = 0$) for periods of 1 month, 6 months, 1 year, and 5 years. Figure 8 shows the amount of imbibed water as a function of time. The amount of imbibed water after 1 month is $2.1 \text{ m}^3/\text{m}$, similar to that for the *flood* scenario. Figure 9 shows the movement of the water after 1 month of tunnel wetting. The extent of water migration into the rock is approximately the same as that for the *flood* scenario, as summarized in Figure 3. Figure 9 shows the continued movement of water after 6 months, 1 year, and 2 years of tunnel wall rock wetting. Even after 2 years, the vast majority of the imbibed water remains within 7 m of the tunnel walls. As illustrated by Figure 6, the amount of water that might be added to the rock as a result of 1 month of continuous wetting activities can be drawn out of the rock through ventilation with negligible effects on the long-term in situ moisture content. From Figures 3 and 9 it can be seen that this model predicts that in the TSw2 capillary forces dominate over gravity-driven flow.

Figure 7. Loss of water in the Topopah Spring Welded Unit 2 tunnel due to the 90% relative humidity air in contact with the tunnel wall rock.

Figure 8. Water per meter of tunnel imbibed into continuously wetted Topopah Spring Welded Unit 2 wall rock.

3.2 Exploratory Studies Facility Tunnel in the Paintbrush Tuff Nonwelded Unit

Computational analyses were also performed to simulate scenarios for water use or spills in the ESF tunnel excavated in the Paintbrush Tuff nonwelded unit (PTn). The stratigraphic and steady-state

Figure 9. Saturation migration in a Topopah Spring Welded Unit 2 as the wall rock is kept continuously wetted for 1 month to 2 years.

assumptions and the code used for these simulations are the same as for the tunnel in the TSw2, but in this case the tunnel is located in the PTn unit with the base of the tunnel at an elevation of 1209 m. The vertical domain of the simulations is extended in this case to include units above the previous interface to the interface of the PTn and the Tiva Canyon welded unit (TCw)

The material hydrogeologic properties that are used for all units except the PTn are again those listed in Tables 3 and 4. Recent SNL analyses⁵ recognize that the hydrogeologic properties for the PTn derived from Peters et al. (1986) and that have been used in many previous analyses, do not realistically simulate the in situ moisture content of this unit. The PTn is composed in many locations of alternating layers of bedded and nonbedded tuff, and measurements of in situ saturation levels in the PTn vary from 40% to almost 100%. Recent measurements taken from samples from the Pah Canyon and Yucca Mountain members of the PTn (Flint and Flint, 1990) are used to provide values for saturated hydraulic conductivity and moisture retention curves in the matrix to be used for the *flooding scenario* analyses for PTn. Moisture retention and conductivity characteristic curves using the van Genuchten (1990) model were fit to the data visually. Steady-state solutions were calculated for three sets of values for PTn matrix properties: one using the measured and derived properties for the Yucca Mountain member, one using Pah Canyon properties fit only to centrifuge measurements, and one using Pah Canyon properties fit to both centrifuge and pressure-plate measurements. The steady-state profiles for the PTn properties in Table 3, as well as the three sets just described, are shown in Figure 10. For the PTn *flooding scenario* calculations, the Yucca Mountain properties were chosen because they result in the highest prediction of in situ saturation for PTn (~ 50%). The matrix properties of the Yucca Mountain member used for PTn are listed in Table 5. Fracture properties used for the PTn are listed in Table 3.

Table 5: Yucca Mountain Member Hydrogeologic Properties Used for the PTn

Porosity	Saturated Hydraulic Conductivity (m/s)	Residual Saturation	α (1/m)	β
0.436	1.75×10^{-7}	0.39	0.9	1.45

A *flooding scenario* similar to that in the TSw2 but with water confined to the PTn filling the tunnel for 1-month then being removed is simulated, and the no-flow and the ventilation boundary conditions are each applied as before.

3.2.1 Paintbrush Tuff Nonwelded Unit Results

A fine grid similar to that employed for the TSw2 calculations was implemented in the PTn layer (Figure 11). The grid elements in the underlying TSw1 layer are significantly taller than in the PTn layer.

After the tunnel is filled with water for 1 month, 56.3 m^3 of water /m of tunnel has infiltrated through the tunnel surface. As can be seen in Figure 12, which describes the change in saturation from steady-state conditions at six time steps, much of the flow near the tunnel is gravity-driven; at 1 month the leading edge of water movement is ~ 10 m below the tunnel floor, as opposed to ~ 4 m above the tunnel ceiling. The maximum lateral movement after 1 month is ~ 5 m from the tunnel wall. When the

5. Sobolik, S. R., and M. E. Fewell, *Estimations of the Extent of Migration of Surficially Applied Water for Various Surface Conditions Near the Potential Repository Perimeter*, SAND92-2248, Sandia National Laboratories, Albuquerque, NM, in preparation.

Figure 10. Steady-state saturation profile for borehole USW G-4 for Paintbrush Tuff nonwelded properties from project reports.

Figure 11. Mesh used for the Paintbrush Tuff nonwelded calculations.

ventilation boundary condition of Equation 1 with 90% relative humidity air is imposed, water is drawn out from the rock primarily from the ceiling. By 6 months after the beginning of the water-filled period nearly all the additional water from above the tunnel has been removed, whereas the water beneath the tunnel is approaching the TSw1. Notice that the saturation level resulting from ventilation at 90% relative humidity is only 9.8% less than the steady-state saturation level. After 1 year the water has begun to infiltrate the TSw1 unit. The downward water movement continues through 2, 5, 10, and 100 years. Figure 13 shows the lateral extent of water migration at 100 years is ~ 10 m from the tunnel wall in the PTn, and an additional 5 m in the TSw1. During the 100-year period, ventilation withdraws only 32 m³ of the 56.3 m³ of water absorbed per meter of tunnel during the water-filled period. Figure 14 plots the excess water in the wall rock along the tunnel in the PTn as a function of time.

From the scenario described above, it can be observed that the PTn can store a large amount of water. This water will tend to move downward to the TSw1 unit, and not predominantly laterally within the PTn. Because the section of the ESF North Ramp that is in the PTn is 800 m horizontally from the proposed repository boundary, the lateral movement of water from the PTn through the matrix to the repository block is expected to be negligible. Potential impacts on the repository horizon might occur, however, if there is a sufficiently connected network of fractures and faults leading to the repository block. The existence or nonexistence of such a network is currently unknown. Therefore, this uncertainty would indicate that water application in the PTn should be kept to the minimum required.

Figure 12. Change in in situ saturation of the Paintbrush Tuff nonwelded after the tunnel is water-filled for 1 month, and then is dewatered and exposed at the rock/air boundary to air with relative humidity of 90%. These calculations used sample IV Yucca Mountain member properties.

Figure 13. Saturation change in the Paintbrush Tuff nonwelded at 100 years after the tunnel was filled with water for 1 month.

Another observation from the PTn *flooding scenario* is the effect of ventilation assuming 90% relative humidity air near the walls. Because the air used for ventilation will enter the tunnel from the North Portal outside the ventilation ducts, the air used to ventilate the PTn section will be somewhat drier than it will be further downstream in the TSw2 section. The method described here for determining the effects of ventilation might be used to design a remedial ventilation operation should a major influx of water occur in the PTn.

4.0 Limitations and Assumptions

The results of this analysis are dependent upon the validity of the assumptions underlying the conceptual model of flow and its implementation in the numerical model. This Section lists the assumptions and discusses the potential impacts of these assumptions on the conclusions drawn from the calculations. Omitted is the fundamental question of the applicability of Darcy's law and Richards' equation --capillary-bundle theory in general--to the modeling of unsaturated flow through relatively impermeable rock.

Figure 14. Change in the water content in the tunnel wall rock in the Paintbrush Tuff nonwelded unit in the vicinity of the North Ramp after the 1 month *flooding scenario* followed by ventilation with 90% relative humidity air.

4.1 Homogeneity of Geologic Units

Geologic units (e.g., the TCw1) are modeled as a single-matrix material and a single-fracture material. It is known that hydrologic properties from samples within a geologic unit can vary greatly (Peters et al., 1984). It is unknown what effect this variation would have on flow. For this particular analysis, variations in hydrologic properties in highly conductive and porous regions (such as the PTn) might have large effects on the vertical and horizontal dispersion of water. If highly conductive regions are vertically connected, the time for the water to reach the water table could be shortened. If highly conductive regions are horizontally connected, lateral dispersion of flow could be enhanced.

Another simplifying assumption used in these calculations is that of isotropic hydraulic conductivity ($K_{xx} = K_{zz}$) at each point throughout the geologic units. There is much data in professional hydrologic literature that indicates a higher degree of anisotropy for hydraulic conductivity in soils as the saturation level decreases. This anisotropy in soils tends to favor horizontal movement of water ($K_{xx}/K_{zz} > 1$). If this anisotropy exists in the PTn, the estimates given in this report for distances of lateral movement of water from underground activities might be less conservative than stated. However, Flint and Flint (1990) found no evidence of small-scale anisotropy in the nonwelded tuff samples that they tested.

4.2 Composite Porosity Model

The composite porosity model used in these calculations treats the matrix and the fractures as an equivalent porous medium. The pressure heads in the matrix and the fractures at any given location are assumed equal. Different flow models have been proposed for Yucca Mountain; e.g., the weeps-

and-seeps model assumes that flow is confined to limited regions down connected fracture networks (Gauthier et al., 1992). If the weeps-and-seeps model is applicable to flow at Yucca Mountain, the result would be that greater amounts of the water used in the construction of the ESF could flow downward than is indicated by the composite porosity model. Such downward flow implies that underground water usage would not necessarily affect the repository because the matrix would have little time to saturate and the water would be gone before waste was emplaced the repository.

Depending on their orientation to the proposed repository horizon, fast pathways such as fractures, faults, and boreholes might either act as preferential pathways that could negatively affect the repository performance, or prevent adverse effects by routing water away from the potential repository or acting as a barrier to water flow. Fracture apertures used in these calculations were taken from laboratory measurements, and indicate fractures in the Topopah Spring welded tuff with apertures in the range of 4 μm to 6 μm (Peters et al., 1984). The properties used in this TSw2 analysis correspond to a bulk permeability of $3 \times 10^{-16} \text{ m}^2$. Actual fractures within Yucca Mountain could have much different apertures. Smaller apertures would tend to favor more flow through the matrix, increasing saturation. Larger apertures would have the opposite effect of favoring fracture flow and carrying the imbibed water downward, away from the affected region of the tunnel. Other experimental studies report bulk permeabilities for Topopah Spring welded tuff in the range of 10^{-13} m^2 to 10^{-11} m^2 (Montazer et al., 1986; Thordarson, 1983), which probably represents fracture apertures of at least some of the fractures in the range of 100 μm to 1 mm. Larger apertures could also favor a mechanism of flow different from that modeled by the composite-porosity model. Computational studies using both a discrete fracture-matrix model and the composite-porosity model suggest that, particularly for larger fracture apertures, the composite-porosity model artificially smears the water front over the matrix and fractures, resulting in much lower estimates of vertical travel and higher estimates of the lateral spread of the wetting zone in the matrix than predicted by the discrete fracture-matrix model (Buscheck et al., 1991). The Buscheck et al. (1991) studies predict that a water front will flow through a 100- μm fracture through 60 m of Topopah Spring welded tuff after 4.5 hours (an average flux of $3.7 \times 10^{-3} \text{ m/s}$). Preliminary results from combined laboratory and numerical experiments modeling the interaction of flow in a 100 μm fracture in welded tuff measure the flow of a front through 14 cm of welded tuff in about 2 minutes (an average flux of $1.1 \times 10^{-3} \text{ m/s}$) (Foltz et al., 1993). Both studies indicate that the imbibition of water from the fracture to the matrix is proportional to the square root of time.

To evaluate how the conclusions concerning large quantities of water described in this report might be affected by the presence of larger fractures, additional calculations were performed for the water-filled tunnel in TSw2, with a bulk permeability of 10^{-12} m^2 . Using the cubic law and the fracture properties from the original tunnel calculations, the fracture property values selected for the additional calculations are fracture porosity = 2.7×10^{-3} , and fracture saturated hydraulic conductivity = $3.94 \times 10^{-3} \text{ m/s}$.

Figure 15 shows the change in saturation after 24 hours and 28 hours. According to the calculations, over 8 cubic meters of water per meter of tunnel infiltrated the walls during the intervening 4-hour period represented by Figure 15; compared to 2.6 cubic meters for an entire month from the original calculations. Because the fractures are treated as a continuum coexistent with the matrix, the fracture-dominated flow is being smeared over the matrix, resulting in what is probably an overestimate of the volume of infiltrated water. The rate of movement of the saturation front in the fractures is illustrated by the rate of movement of the 0.275 change in saturation contour in Figure 15, $\sim 3 \times 10^{-4} \text{ m/s}$. This rate is similar to those observed in the computational and experimental studies previously cited in this Section.

Figure 15. Change in saturation in four hours with the Topopah Spring Welded Unit 2 modeled with high fracture permeability and flooded for 24 hours and 28 hours.

The capability of larger fractures to drain any ponds in the tunnel will probably result in less water imbibed into the matrix near the tunnel, but that positive impact on waste isolation might be counter-balanced by an impact on the underlying Calico Hills members, which are nearly saturated. These uncertainties make it clear that spills in the tunnel should be cleaned up as soon as possible to preclude impacts on the waste isolation capabilities of the site.

5.0 Construction Assumptions and Recommendations

At the time this analysis was requested final decisions on ESF design, construction techniques, and construction water requirements had not been made. Assumptions, such as the placement of the North and South ramps and the Main Test Level, and the tunnel diameter, the choice of the particular TBM, and the estimates of water usage for various construction activities, must be made in order to create the physical models necessary for a simulation. Information about the current best estimates on construction methods, equipment, design, and water usage was gathered from project personnel and existing documents. The following assumptions are based on the information gathered and on the conceptual

design of the ESF current at the time of this analysis. Details might change as construction plans are finalized. Some of the following assumptions are implicit in the ensuing discussion of the nine aspects; others are not required in the level of detail of the analyses discussed in this report, but might be important in modeling more detailed scenarios stemming from this analysis, and thus are included here for completeness.

5.1 Assumptions for the Construction Plans and Processes

- Tunneling into and associated with the Calico Hills will not occur until after the potential repository horizon excavation is complete.
- The North Ramp will have a 6.8% declining grade from the North Portal to the north end of the Topopah Spring Main Drift, curving with a 1000-foot-radius arc to accommodate the TBM into the low point of the tunnel, which is the north end of the Topopah Spring Main Drift. The Topopah Spring Main Drift traverses the proposed repository level north to southwest with a 5% incline, curving again into the South Ramp which is inclined at a 1.6% grade to the South Portal. Figure 16

Figure 16. Plan view of drifts and main tunnel in relation to the repository boundary.

shows the plan geometry of the pending North and South Ramps and the Main Drift with respect to the potential repository.

- The TBM will make a continuous path from the North Portal to the South Portal before alcoves, sumps, and testing drifts are constructed, and one 42,000-gallon sump will be constructed at the Topopah Spring Main Drift low point after the TBM makes its first pass through the potential repository region.
- Tagged construction water will come from a 200,000-gallon tank located on the surface and this water will be available to fill the workings in the event of a major pipe break, fire, or other cause of unplanned influx of water from the water supply system.
- No large quantity of water will be stored underground.
- The supply lines for water, compressed air, power, and ventilation in the vicinity of the TBM will be made of flexible tubing. More permanent, rigid supply lines will be installed in segments as the TBM progresses and the flexible lines reach their limits. The permanent compressed air line is expected to be 6-inch diameter pipe, the water line will be 4-inch steel or iron pipe, and the main ventilation system will use one 8-foot or two 6-foot diameter ducts. The flexible water pipe will attach to the TBM so that the machine has direct access to the surface water supply.
- The TBM cutting diameter has not yet been determined; 25 feet is assumed. The stroke will be in the range of 4 to 6 feet.
- The boring progress rate for a 25-foot TBM is 8 feet per hour.
- Water might be used at the cutting surface for cooling and consolidating the muck and for suppressing dust.
- The roof-bolt holes will be wet-drilled using a sliding frame attached to the TBM that does not interfere with the TBM's progress. In the ramps and the Main Drift, 10-foot-long roof bolts will be spaced 16 bolts every 4 feet. Drilling roof bolt holes requires 5 gallons of water per foot length of bolt. A small modification will be made to outfit the TBM rig for catching the excess hole-boring water for removal.
- The TBM will have its own conveyor to transport muck from the cutting face to the rear of the machine. From there the muck will be dumped onto an expandable conveyor and carried to the main conveyor. When the expandable conveyor is fully extended, a new section will be added to the main conveyor which will run to the North Portal, and the expandable conveyor will be contracted. The long conveyor system will be fully powered from the surface. Muck will be transported to the surface along another conveyor belt system, which, when the tunnel is complete, will extend throughout the length of the two ramps and the main level drift.
- For the smoothness and continuity of the tunnel surfaces, a high-quality, continuously steerable TBM will be employed, optimally maintained, and manned by skilled operators.
- An underpressure ventilation system will be used that works by exhausting air from the face of the tunnel through a duct to the surface at a rate in compliance with applicable regulations. This will draw outside air from the surface into the tunnel at a similar rate with allowances for leakage. Additional booster fans along the duct will be necessary to move the appropriate amount of air.
- Each piece of machinery will have its own fire suppression system onboard. There are acceptable dry-chemical extinguishers for underground use, but water will be the main fire suppressant. The outflow pumping system will be sized to the inflow water system and this will be sized appropriately for fire suppression requirements.
- The required backup systems will be designed, in place, operable, and maintained during construction and operation of the ESF.

These assumptions influence the discussions in the following Sections.

5.2 Recommendations

The three recommendations described in the remainder of this chapter apply to most of the nine requested aspects of underground water use. These three recommendations are included in part in the ESFDR (DOE, 1992), but each requires expanded application.

5.2.1 Recommendation A

During construction and operation of the ESF, excess water shall be removed to preclude adding unnecessary water to the ESF tunnel wall rock.

5.2.2 Justification for recommendation A

The analyses in this report use a model that shows water would enter the Topopah Spring rock slowly, and would continue to enter the rock as long as the water and rock are in contact. The amount of water imbibed into the rock is important in the containment security of the potential repository, rather than the amount of water used in the construction processes. It is proposed that water not be allowed to puddle, pond, or stand on the floors of the tunnels at any time and that a readily available water pickup system be accessible to immediately remove any standing water which might collect during the construction or operation phase of the ESF. The ESFDR, under 1.2.6.6 PC 1d.iv, specifies underground operations shall not adversely affect site characterization by requiring that excess water shall be removed to preclude interference with tests. It is recommended that this requirement be expanded to include the entire ESF and that the requirement state "During construction and operation of the ESF excess water shall be removed to preclude adding unnecessary water to ESF tunnel wall rock."

5.2.3 Recommendation B

The imbibition rate of water into the wall rock, fractures, and faults shall be monitored in the event of prolonged contact between water and rock.

5.2.4 Justification for Recommendation B

Assumptions have been made about the globally averaged properties of the Topopah Spring unit and further it is assumed those properties control water movement through the rock unit. Connected fracture pathways are not discretely modeled in these analyses, nor are other fast pathways through which radionuclides might travel between the proposed repository horizon and the water table. The exchange rate of water between the sump and the rock wall is one measure to assess the validity of this model with the given set of input parameters; another measure would come from observation of any standing water in the workings. 10 CFR 60.141 (b) requires that subsurface conditions shall be monitored and evaluated against design assumptions. There exist intrusive and nonintrusive methods for tracking infiltration. Seismic, electrical, and radar methods are possibilities for nonintrusive methods. Nelson (1993) describes a method for estimating water-filled porosity that he has applied to data (density and dielectric logs) collected at Yucca Mountain. A radar tracking method was developed under the Stripa project to observe the extent of fracture networks and water penetration into granite (Olsson, 1988; Olsson et al., 1988). Intrusive methods require sampling different depths of rock to estimate infiltration depth and volume. Using intrusive methods, a more accurate estimate of water penetration into the wall rock as a function of the length of contact time between the water and rock can be made if the construction water tracer is changed periodically.

5.2.5 Recommendation C

The quantity of water added to or drawn out of the wall rock shall be estimated over time to determine the effectiveness of ventilation in removing construction water.

5.2.6 Justification for Recommendation C

Assumptions have been made when modeling the effects of ventilation on the moisture content of the rock surrounding the tunnel. To satisfy the 10 CFR 60.133(d) requirement "The design of the underground facility shall provide for control of water or gas intrusion", ESFDR Section 1.2.6.7 C F.iii requires the following: "The design of the ESF underground utility system, including ventilation, shall facilitate monitoring of moisture influx to the ESF from the rock mass and from ventilation, and moisture efflux from mine water removal and ventilation exhaust to limit possible impacts on the capability to adequately characterize the site." This system should be used in conjunction with an estimate of water removed in the muck and on the muck conveyor to monitor the water balance during construction. This will allow an estimate to be made of the water added to the rock matrix during the construction process and will enable an estimate of the capacity of the ventilating air to remove moisture from available sources including muck and water on the conveyor belt and the wall rock.

6.0 Application of the Analyses to the Nine Aspects

Results of the analyses reported in the previous Sections are used in this Section to address the nine requested aspects of underground water use. Several requirements that apply to the nine aspects are already in effect and stated in the ESFDR document. These requirements are listed in Table 6 and are referred to in this Section using the entry numbers as they apply to each aspect.

Table 6: Existing Requirements from the ESFDR (continued on following page)

Entry no.	ESFDR Reference	Requirement
1	1.2.6.5 PC 1d.ii	Water intrusion, if any, into the ramps shall be monitored and controlled by suitable measures such that the effects of expected water inflows (i.e., water heat gasses) will not endanger worker safety and in situ site characterization.
2	1.2.6.5 PC 1d.iii	Appropriate gravity drainage and/or pumping systems shall be incorporated into the ramp for draining water away from testing and other working areas to suitable collection point(s) for further treatment and/or disposal.
3	1.2.6.5 PC 1d.iv	The amount of water used in the construction and operation of the ramp shall be limited to preclude interference with tests.
4	1.2.6.5 PC 1d.v	Methods for dust control and cleaning of walls in the underground portion of the ESF shall be designed to limit adverse effects on the adequacy and reliability of information from site characterization.
5	1.2.6.5 PC 2I.ii	The amount of water used in construction and operation shall be limited to that required for dust control and proper equipment operation so as to limit the effects on the containment and isolation capability of the site.
6	1.2.6.5 PC 2I.iii	Water use in ramp construction shall be consistent with repository design goals to limit the increase in average percent saturation of the repository horizon to less than [TBD] percent, and limit the increase in the local percent saturation to less than [TBD] percent in waste emplacement areas.

Table 6: Existing Requirements from the ESFDR (continued on following page)

Entry no.	ESFDR Reference	Requirement
7	1.2.6.6 PC 1d.i	Appropriate gravity drainage and/or pumping systems shall be incorporated in underground openings for draining water away from testing and other working areas to suitable collection point(s) for further treatment and/or disposal.
8	1.2.6.6 PC 1d.iii	Water intrusion, if any, into the underground openings shall be monitored and controlled by suitable measures such that the effects of expected water inflows (i.e., water heat gasses) will not endanger worker safety and in situ site characterization.
9	1.2.6.6 PC 1d.iv	Appropriate gravity drainage and/or pumping systems shall be incorporated into the underground openings for draining water away from testing and other working areas to suitable collection point(s) for further treatment and/or disposal.
10	1.2.6.6 PC 1d.v	The amount of water used in the construction and operation of the underground openings shall be limited to preclude interference with tests.
11	1.2.6.6 PC 1d.vi	Methods for dust control and cleaning of walls in the underground portion of the ESF shall be designed to limit adverse effects on the adequacy and reliability of information from site characterization.
12	1.2.6.6 PC 2g.iv	The drainage plan for underground work shall be consistent with repository operations and postclosure sealing concerns; be designed to control and limit the impact of a credible flood caused by construction and operations water on testing in the ESF; and not impact the capability to characterize the site.
13	1.2.6.6 PC 2j.iv	The amount of water used in construction and operations shall be limited to that required for dust control and proper equipment operation so as to limit the effects on the containment and isolation capability of the site.
14	1.2.6.6 PC 2j.v	Water used in construction and operations shall not adversely impact the repository design goals to limit the increase in average percent saturation of the repository horizon to less than [TBD] percent and to limit increase in the local percent saturation to less than [TBD] percent in areas of waste emplacement.
15	1.2.6.6 PC 2g.iv	The drainage plan for underground work shall be consistent with repository operations and postclosure sealing concerns; be designed to control and limit the impact of a credible flood caused by construction and operations water on testing in the ESF; and not impact the capability to characterize the site.
16	1.2.6.7 C	All joints in fluid-carrying columns shall be sealed and proof-tested.
17	1.2.6.7 C E.iii	The design of the ESF underground utility system, including ventilation, shall facilitate monitoring of moisture influx to the ESF from the rock mass and from ventilation, and moisture efflux from mine water removal and ventilation exhaust to limit possible impacts on the capability to adequately characterize the site.
18	1.2.6.7 C J	Piping shall be designed to preclude or limit water inflow into the ESF following a pipe rupture.
19	1.2.6.7 PC 1b	The utility services shall include minimal backup units for primary power lines, primary pumps, shaft and ramp conveyances, primary ventilation fans, and primary communications and testing equipment to allow testing continuity.
20	1.2.6.7.6 PC 1b	Gravity drainage, storage and pumping systems, with adequate capacity and control measures, shall be designed and constructed for the control and transfer of underground water to the surface to ensure worker protection and to preclude adverse effects on in situ site characterization testing or the ability of the site to meet performance objectives as stated in 10 CFR 60.112.

Table 6: Existing Requirements from the ESFDR (concluded)

Entry no.	ESFDR Reference	Requirement
21	1.2.6.7.6 PC 1b.i	Water handling and control underground shall be designed for all credible inflows, including inflows from penetration of fault structures or from perched water horizons, use of fire protection sprinklers, and from water line breakage.
22	1.2.6.7.6 PC 1b.ii	Piping shall be provided to carry water from underground pump station(s) to the surface.
23	1.2.6.7.6 PC 1b.iii	Pumping systems with adequate capacity shall be available.
24	1.2.6.7.8 CA	Fire suppression agents shall be selected for their compatibility with their intended use. These agents shall be approved for use based on their impacts on underground safety (i.e., they do not produce adverse geochemical effects), the in situ site characterization testing program, and performance objectives as stated in 10 CFR 60.112.
25	1.2.6.8 C E.ii	The amount of water used in testing and operations shall be limited so as to limit the effects on the containment and isolation capability of the site.
26	1.2.6.8 C E.vi	Excess water shall be removed.
27	1.2.6.8 C E.vii	Any cleaning of ESF walls to facilitate photogrammetry, mapping, or other testing shall be done using compressed air/mist and control procedures to limit water saturation.

6.1 Aspect 1: Routine Water Use During the Ramp and Drift Excavation by Tunnel Boring Machines

Estimates for the amount of water required to operate the TBM and control dust vary (as shown in Table 7) and all are likely correct for some situation. Until they are encountered, the exact circumstances and conditions under which the TBM will be operating will not be known. Table 7 is included to show this variation.

Assumptions relevant to the simple excavation and water use calculations in this Section and to completing Table 7 follow:

- The density of Topopah Spring is 143.33 pounds per cubic foot.
- The density of water is 62.4 pounds per cubic foot.
- The weight of excavated rock is $\pi r^2(\rho_{TS}) = 490.87 \text{ f}^3/\text{ft} (143.33 \text{ lb}/\text{ft}^3)/2000 \text{ lb}/\text{ton} = 35.18 \text{ tons}/\text{ft}$.

Table 7: Estimates of Water Required for Excavation Using a Tunnel Boring Machine

Estimated Water Requirement	Notes	GPT ^a	GPT ^b
2 gallons per linear foot of tunnel	In the original request	5.7×10^{-2}	2
2 to 3 gallons per minute		0.64	22.5
15 gallons per ton of rock excavated	ESFDR, Rev. 0, March 27, 1991, limit for dust control	15	527.7
1% of the weight of excavated rock	In the original request	2.39	84.3
100 to 250 gallons per linear foot of tunnel	Reasonable range	7.1	250
5% of the weight of excavated rock	No restraint on water use	11.98	421.5
60 gallons per minute	For a 7.5-m machine	12.79	450

a. Gallons per ton of rock excavated.

b. Gallons per linear foot of tunnel.

For the following estimate, 450 gallons of water per linear foot of excavation is assumed to be required for operation of the TBM and for dust control. Allowing 16 bolts per 4 linear feet of tunnel, a bolt length of 10 feet, and 5 gallons⁶ of water per foot of bolt, then 200 gallons of water per linear foot of tunnel is needed for drilling water for roof bolts. If 80% of dust control, TBM, and rock bolt water is removed in the mucking operation or through water recovery techniques, then 20% (or 130 gallons per linear foot of tunnel) of this water is available to infiltrate the tunnel walls. If 10 gallons of water per linear foot⁷ of tunnel is used for wall dust removal and mapping (cleaning with compressed air and mist), a total of 140 gallons of water is available to enter the wall rock per linear foot of excavated tunnel.

The saturated wall analysis (*wetting scenario*) discussed in Section 3 showed that 2.1 m³ of water was taken into the wall rock per linear meter of tunnel. This is equivalent to 69 gallons of water per linear foot of tunnel. Section 3 showed that the quantity of water entering the wall rock for the *wetting scenario* was almost equal to that for the *flooding scenario*; thus the ventilation boundary condition was applied only to the water-filled case and the *wetting scenario* results are expected to be approximated by the water-filled case solution. In the Section 3 calculations a volume of 8.52 m³/m (686 gallons per foot), considerably more than 140 gallons of water per foot of tunnel (estimated above), was removed from the wall rock by ventilation during the following 100 years (the nominal preclosure period).

Comparison of the estimated 140 gallons of water per foot of tunnel to the saturated wall analysis (Section 3) shows that NORIA-SP would predict that routine ventilation during the preclosure period of the potential repository could remove this quantity of water and leave a reserve capacity for expected but unplanned water use such as spills, leaks, and fire fighting.

If roof support in addition to the roof bolts is needed, e.g., shotcrete, the wall mapping must be done before the additional support is installed, so the mapping operation must keep up with the tunneling. The U. S. Geological Survey (USGS) plans to clean and map newly bored walls within 24 hours of the boring (Los Alamos National Laboratory [LANL], 1991). This schedule limits the planned wetting period of the walls to some portion of 24 hours. It is questionable that, while operating in the Topopah Spring unit, 140 gallons of water could be taken into each linear foot of tunnel wall rock in the period of time of contact. (If indeed this quantity of water is absorbed into the rock, the model used in this analysis will have been shown invalid for some region.) While the TBM is working on a decline, as assumed along the North Ramp, the excess water would run toward the working face and would be available to be picked up in the normal action of the machine and transported to the conveyor system to be removed with the muck. While the TBM is working at an incline, as assumed along the Topopah Spring Main Drift and the South Ramp, this excess water would run downhill toward the low point of the tunnel (the northeast end of the Main Drift in Figure 16). It is recommended that a system for recovering this water should be considered and be designed for use during uphill excavating.

If the above per-foot calculation is extended to the total excavation, and the same water use on the basis of tons of water per foot excavated is assumed for all excavation methods, and the approximations in Table 8 are assumed, a total of ~ 19 million gallons of water will be needed for dust control and excavation and 8 million gallons will be needed for installing roof bolts (a total of ~ 27 million

6. Five gallons per foot of roof bolt is a more extravagant estimate of drill water required than the 2.5-gallon to 5-gallons per hole suggested for roof-bolt drilling.

7. Ten gallons per linear foot for wall washing water is a greater estimate of the water needed than the 2 gallons per linear foot in the original statement of the analysis request; therefore, it is a conservative estimate.

Table 8: Estimated Water Requirements

Type	Length (ft) ^a	tons/ft	tons	Gallons for Excavation ^b	bolt-ft/ft ^c	bolt-ft	Gallons for Bolts
Total	55,342			19,354,451		1,577,800	7,889,000
25' TBM	27,117	35.17	953,705	12,398,164	40	1,084,680	5,423,400
North Ramp	6,652						
South Ramp	9,820						
Main Drift	10,645						
18' TBM	2,250	18.24	41,040	533,520	16	36,000	180,000
Imbricate Drift	2,250						
Drifts 12x20	14,120	17.2	242,864	3,157,232	16	225,920	1,129,600
Topopah Spring East Drift	3,220						
Topopah Spring West Drift	3,850						
Main Test Area	7,050						
Drift 20x20	1,730	28.67	49,599	644,787	40	69,200	346,000
Main Test Area	1,730						
Alcoves 20x20x40	6,000	28.67	172,020	2,236,260	16	96,000	480,000
Conveyor Drift 10x10	4,125	7.17	29,576	384,488	16	66,000	330,000

a. From Design Analysis ST-MS-500, Rev A WBS 1.2.6.

b. At a rate of 13 gallons of water per ton of rock excavated.

c. An assumption. Roof bolt size depends on rock condition.

gallons of water). Assuming an 80% recovery rate, 5.5 million gallons remain from construction. With 10 gallons per foot (a total of ~ 55,000 feet) for wall-washing water, a total of ~ 6 million gallons of water will be added to the drift wall rock and a total water budget of ~ 28 million gallons will be required.

For an overall order-of-magnitude check, these numbers can be compared to the more detailed analysis performed by Raytheon Services Nevada (RSN), Design Analysis ST-MS-500⁸ which considers different excavation methods for different purposes and appropriate water use for each method. The RSN analysis estimates water needs at 39.5 million gallons. This number includes 4 million gallons for miscellaneous and ~ 2.5 million gallons for concrete; items not included in the estimate shown in the preceding paragraph. If water associated with these items is subtracted from the design analysis total, 33 million gallons for the design analysis can be compared to ~ 28 million gallons. By this comparison, the approximations used in the present "envelope calculation" appears to be credible.

Another comparison could be made with the preliminary allocation of water estimate, which came from a series of meetings and analyses conducted by Participant organizations in 1991 and 1992. This water budget contained ~ 185 million gallons of water for mechanical excavation and dust control, a considerably larger number than the envelope calculation or the RSN estimate. Information from which the 185 million gallons was derived is unknown to the authors of this report.

8. RSN, *ESF Water Consumption Estimate*, Design Analysis ST-MS-500, Rev. A, Raytheon Services Nevada, Las Vegas, Nevada, 1992

In Analysis #8,⁹ Gauthier and Peters conclude that drilling water will not significantly affect the state of saturation of rock if it is applied under low pressure (<30 psig) for a short period of time (<100 minutes) (Peters, 1988). Analysis #8 used TOSPAC (Dudley et al., 1988) with a variety of initial infiltration conditions and lengths of application time of water under pressure. In one case, a 20-m pressure head was applied for 10 minutes. The penetration of saturation was 1 cm, and the model showed the return to approximately initial saturation by 1 month. These results are used to conclude that water used to drill roof-bolt holes will not penetrate great distances as a result of the pressure applied during drilling.

Three previous studies applying ventilation to excavations in the potential repository horizon have been conducted using similar ventilation models. Hopkins et al. (1987) performed calculations to determine how the length of time spent ventilating a repository drift in native rock (with properties expected to exist at Yucca Mountain) would delay advective transport of waste away from containers. This two-dimensional study using the SAGUARO (Eaton et al., 1983) code (a predecessor to NORIA-SP), in one case assumed a 0.1-mm/yr infiltration rate through the Topopah Spring, 90% humidity for ventilating air, and 50 years of continuous ventilation. Results showed that the fluid velocity field took 380 years to return to gravity-dominant flow away from the containers. Waste containers in this study produced no heat.

Sobolik et al. (1991), in an extension of the work by Eaton and Peterson (Peterson et al., 1988), used NORIA-SP to model the time-dependent one-dimensional flow of residual drilling water and in-situ pore water in drift walls. For both these modeling calculations, drift walls were considered to have a zone of high-permeability fractures into which available water flowed uniformly and immediately, later to be imbibed into the rock matrix. Construction water application was 235 gallons per foot., 15% of this water was assumed not to be removed in the mucking operation. The calculations showed that, in the Topopah Spring, significant (≥ 0.005) saturation increase was confined to within 10 m of the drift wall when no water was allowed to flow back to the tunnel as vapor. When a ventilation boundary condition was applied, saturation decreased significantly (≥ 0.005) to a distance of 20 m into the drift wall within 100 years. Heat produced from waste containers was not considered in these analyses.

6.1.1 Existing Requirements for Aspect 1

Existing constraints on water use in the ESFDR that apply to aspect 1 listed in Table 6 include entry numbers 3, 5, 6, 10, 13, and 14.

The analyses presented herein indicate that judicious use of water, with emphasis on recovering a significant portion of the used water, and a policy of no standing water on the floors will be sufficient to meet the required criteria. More costly waterless methods and equipment for excavating and drilling for roof bolts are not required. Conveyor transfer points might be locations of excess water from overflow from belts, spills, misdirected sprays, etc. The excess water at these points should be recovered.

Given the assumptions and limitations listed in Sections 4 and 5, the analyses indicate abiding by the current ESFDR requirements and the following recommendations ensures that routine water use during the ramp and drift excavation by TBMs will have no long-term impact on in-situ hydrological conditions.

9. This is one of a set of numbered analyses not in the series ESF PA analyses.

6.1.2 Recommendations for Aspect 1

These analyses show that all of the estimates for TBM water requirement are acceptable provided excess water is not allowed to pond. Recommendations A, B, and C, as stated in Section 5.2, apply to aspect 1.

6.2 Aspect 2: Water Use for Drilling Purposes

Water will be used for drilling purposes for both alcove and drift excavation and for roof-bolt application. Roof-bolt application is discussed and the water used is accounted for in Section 6.1.

Some portion of the drifting of smaller tunnels and alcoves will likely be excavated using drill-and-blast techniques. If a 50-hole pattern is used and the drilling-water use rate is the assumed 5 gallons per foot, water will be used for this purpose at 250 gallons per linear foot of excavated tunnel. Since this drilling water is applied to rock that will be mined out and removed as muck to be hauled away on the conveyor, it is reasonable to assume 80% recovery of this water is possible. Because the openings that require the use of drill-and-blast technique will be smaller than those mined by the TBM, the roof bolts on average should require shorter holes. Eight-foot bolts spaced 8 to the half tunnel every 4 feet is assumed to be average, making 16 bolt-feet per linear foot of tunnel. Using the 5-gallons of water per foot of bolt assumption as before, the water requirement is 80 gallons per linear foot for the roof bolts. Some system or procedure for recovery of the excess roof bolt drilling water should be instituted so that significant ponding of water for any period of time is prevented.

If 10 gallons of water per linear foot is used for wall misting, the total water budget, not including muck dust control, is 340 gallons of water per linear foot of excavated tunnel. With 80% recovery on the drilling and roof bolt water, the remaining water available for imbibition into the tunnel walls is 76 gallons per linear foot of tunnel. Section 3 analyses predict that at least this quantity of water will be removed by routine ventilation during the preclosure period. The drill-and-blast technique might not produce a smooth continuous floor. Even with an overall slope, local irregularities might block water, causing it to puddle. Water should not be allowed to pond or puddle on the drift floor for reasons discussed earlier.

Analysis #8 (Peters, 1988) was done to address the question of the movement of low-pressure-driven water into rock. An example conclusion was cited under aspect 1 in Section 6.1.

Given the assumptions and limitations listed in Sections 4 and 5, the analyses indicate abiding by the current ESFDR requirements and the following recommendations ensures that water used for drilling purposes will have no long-term impact on in-situ hydrological conditions.

6.2.1 Recommendations for Aspect 2

Some system or procedure for recovery of the excess roof-bolt drilling water shall be instituted so that ponding of water for any period of time is prevented. Recommendations A, B, and C, as stated in Section 5.2, apply to aspect 2.

6.3 Aspect 3: Water Use for Washing Walls

For this study, the instructions were to consider the effect of air misting the walls--at a water delivery rate of 2 gallons per linear foot of tunnel and 100 psig air pressure--to clean and mark the walls for mapping purposes. Section 3 analyses show this to be a relatively small quantity of water that will be

removed promptly by ventilation.

Analysis #8, Gauthier and Peters (Peters, 1988) has some bearing on this problem; however, the original calculation was to investigate roof bolt installation which uses water under a lower pressure (20 m or ~ 28 psig) than the 100 psi requested and the original calculation uses more water per surface area. The effect found by Gauthier and Peters in their investigation was inconsequential compared to the overpowering effect of ventilating.

Given the assumptions and limitations listed in Sections 4 and 5, the analyses indicate abiding by the current ESFDR requirements and the following recommendations ensures that water used for washing walls will have no long-term impact on in-situ hydrological conditions.

6.3.1 Recommendations for Aspect 3

Recommendations A, B, and C, as stated in Section 5.2, apply also to water used for washing walls.

6.4 Aspect 4: Water Use for Fire Fighting

Potential consequences of a large influx of fire fighting water vary dependent upon the status of construction and the location of the fire in the ESF. During excavation of the North Ramp, the workers and machinery located down slope in the ramp should be considered as well as the eventual disposition of fire fighting water. Fire prevention should be a priority to avoid possible consequences of fighting a fire, which include delays, equipment and utility expenses, safety, and additional water added to the wall rock.

Appendix A of West (1988) contains a list of fluids and materials likely to be needed during ESF construction and operation. Those to be used underground are so noted. The flammables of greatest quantity (thereby assumed the greatest impact) are fuels and lubricants for construction machinery and equipment. Lubricants are essential to the maintenance of machinery and equipment. For fire prevention, the following practices are essential; seals intended to contain flammables on all machinery and equipment housed in or entering the underground should be meticulously maintained; lubricants should be stored above ground, with a supply for only a reasonable number of shifts kept underground; during any shift, as fluids are used or replaced, discarded fluids and empty containers should be sealed, handled with care to prevent spills, and removed from the underground by the end of the same shift in which they are collected. If these are not a reasonable or workable requirements, a plan to minimize the fire hazard due to these flammable lubricants, consistent with underground fire safety regulations, should be established.

The conveyor system should be well maintained to avoid excessive friction and heat production during operation. Fire detection and surveillance systems such as heat sensors should be considered, as well as an automatic shutdown and sprinklers to douse conveyor fires.

Fire prevention is more cost effective than fire remediation. Fire hazards should each be carefully considered with major emphasis on prevention. Dry chemicals are appropriate for suppressing some types of fires, but water is considered the most effective method of suppressing most fires. Halon and CO₂ fire suppressants are not used underground.

The North Portal location is shown at the right boundary of Figure 17. A starter tunnel at the North Portal continues along the line marked North Ramp until rock appropriate for excavation with a TBM is encountered. Tunneling with the TBM progresses downhill along the North Ramp to the point

marked, which is the extrapolated intersection of the ramp with the PTn unit (actual data extends as far as the solid lines). The PTn is considered a primary barrier to surface water reaching the proposed repository horizon. The high porosity of the PTn causes it to absorb the gravity-driven water from above.

Figure 17. Extrapolated intersection of the North Ramp and the PTn.

The PTn flood scenario in Section 3.2 simulates water filling the tunnel during ramp construction (possibly as a result of fighting a fire) at the time the TBM is working the PTn. Water is introduced into the ramp to a depth of 10 m and then left for 1 month before being pumped out. The selected model shows that, if a no-flow boundary is imposed after water is removed, within 100 years, the water that entered the rock has influenced a saturation increase of greater than 0.025 in a 20-m radius region. Figure 16 shows a bird's-eye view of the relative positions of the potential repository and the zone of saturation increase in the PTn. The downslope of the PTn/Topopah Spring unit interface at this point is away from the potential repository.

When a ventilation boundary condition (90% humidity air) is used after pumping out the standing water and during the preclosure period of the potential repository, this model predicts that an equivalent volume of water to that absorbed cannot be withdrawn from the PTn. Extra precaution should be taken to avoid fires or large water spills while working the PTn. Dry-chemical fire fighting methods should be considered for use when possible in the case of a fire located in an area of the tunnel where water will pond in this unit. Under current plans, the South Ramp also crosses the PTn but the TBM will be progressing upgrade and most of the water pumped into the tunnel will run downhill. In the

event of a large inflow of water due to dousing a fire or a major spill, large quantities of water will not remain in contact with the PTn for an extended period.

Figure 17 shows that the North Ramp continues downgrade from its intersection with the PTn. Until the TBM passes the beginning of the Topopah Spring Main Drift it will always be located at the low point. Any large inflow of water will collect at the working face. Using the assumption of a single pass through, beyond the northern extreme of the Topopah Spring Main Drift the TBM will head uphill and any large inflow of water will collect at the repository low point at the northern end of the Topopah Spring Main Drift, which is also the planned location of a major sump. During construction, water could at some time pond along the ramp in the Topopah Spring anywhere between the PTn intersection and the Main Drift intersection. The *flooding scenario* simulates an inflow of water to this region to a depth of 10 m. The water is allowed to stand in contact with the wall rock for 1 month before removal. The simulation shows that, if no water is allowed to evaporate out of the rock into the air, the imbibed water will increase the tunnel wall rock saturation by at least 0.025 to a radius of ~ 12 m from the tunnel center. If the 90% humidity boundary condition is imposed, the simulation shows that a quantity of water at least equivalent to the volume of that water taken into the rock can be removed in ~ 6 months.

If a major water-filling event occurs during construction, causing water to stand for a period of time along the North Ramp, the wetted site will be exposed to moving, relatively dry air for the ventilation system assumed. If the site is ventilated during the preclosure period of 100 years, the average incoming air humidity might be less than 90% and the time to remove the equivalent volume of water might be less than the calculations show. If, on the other hand, the sump has been installed and water has been allowed to stand in it for an extended period, additional factors must be considered. A sump might be expected to have some water standing in it at all times, raising the humidity near the surface of the water. Air circulation is likely not considered important for sumps, i.e., ventilation regulations are designed for the health and safety of people working underground. A solution to this particular problem might be installation of a liner in the sump that would be removed before closure.

If severe flooding occurs in a location where normal ventilation is not expected to remove the added water, remedial ventilation could be prescribed and applied to remove the water.

From a total-system perspective, one way that construction water could cause repository failure is by the formation of a direct path of saturation between the repository and the water table at the same time that a source of contaminants is available at the repository horizon. This situation would not necessarily take a lot of water, simply a connected fracture path. This possibility is not included in the NORIA-SP model used for this study, however, a fast pathway model would apply. It is recommended that extra precautions be taken near fracture or fault zones. These precautions might include grouting.

The capacity of the pumps to remove is the same as the capacity of the pumps to bring in water, i.e., these pumps should be able to keep the tunnels dewatered while a fire is being fought.

6.4.1 Existing Requirements for Aspect 4

Current ESHDR (DOE, 1992) requirements pertaining to protection against adding water to the repository horizon in the case of inflow of a large quantity of water are included in Table 6 as entry numbers 12, 17, 19, 20, 21, 22, 23, and 24.

Given the assumptions and limitations listed in Sections 4 and 5, these analyses indicate abiding by

current ESFDR requirements and the following recommendations ensures that water used for fighting fires will have no long-term impact on in-situ hydrologic conditions.

6.4.2 Recommendations for Aspect 4

Recommendations A, B, and C, as stated in Section 5.2, apply to water used for fire fighting. Recommendation C is particularly important in the event of a significant influx of water so that proper determination can be made for the need for remedial ventilation. It is also recommended that, in case of pump failures during an event, the sump water volume shall be monitored to determine whether it drains more rapidly than the NORIA-SP model predicts, and extra precautions regarding water usage shall be taken near fracture or fault zones and throughout the PTn. From a water-imbibition perspective, the use of dry-chemical fire-suppressant methods instead of water in regions where high imbibition rates or fracture flow might occur, such as fault zones and the PTn, will minimize potential impacts on waste isolation.

6.5 Aspect 5: Failure of Sump Pumps to Remove Waste and Mine-Drainage Water

One sump, located at the base of the North Ramp, is designed to service the two ramps and the Topopah Spring Main Drift. Additional sumps will be located in the main test area and the side drifts to the east and west extents of the potential repository. Drifts are sloped so that water will not stand. A requirement is that a sump be located at each low point. The sump is expected to collect excess water from construction, normal underground water, and water from spills, breaks, or fire fighting.

To meet fire regulations, the water out-pumping capacity is the same as the water in-pumping capacity. When a fire is in progress an out pump will be active to prevent water buildup during application to the fire.

Backup systems are required for the sump pump and electrical supply. Maintenance and monitoring of the primary systems and backup systems should be routine. In the case of pump failure during non-emergency conditions, the water supply should be halted until the pumps are operable.

If sump pumps fail and drainage water fills the sump, the analysis of Section 3 applies and the conclusions about the removal of water that enters the sump walls are similar to those for the *flooding scenario*. As noted under Section 6.4 in TSw2 a sump might have some water standing in it at all times, raising the humidity near the surface of the water. Air circulation is likely not considered important for sumps, i.e., ventilation regulations are designed for the health and safety of people and this is not an area where people normally work. A solution to this particular problem might be installation of a liner in the sump that would be removed before closure. If this solution is unacceptable for other reasons, remediation ventilation could be applied to the sump walls. Long-term standing water in a sump might possibly encourage wetting of a fast path to the water table. In this case, a liner is highly recommended.

Fernandez et al. (1989) described three analytical solutions for water flow out of the shaft through a sump. The sump was assumed to be unlined, 4.4 m in diameter, 140 m deep, and filled with material with 30% porosity. Three analytical solutions that were developed to estimate the saturated hydraulic conductivity of soils were used to estimate the movement of water into the rock surrounding and below the sump hole. The ESF design at the time this work was done had the sump as a continuation of one of two shafts. The sump extended into Calico Hills. Water leaked through alluvium into fractured rock in a disturbed zone around the shaft and into the shaft--a different problem from the one

addressed in this analysis. Leakage out of the sump was claimed as a barrier that kept water away from the waste containers after closure. For this reason, any sump liner used to keep water out of the sump lining rock should be considered for removal prior to closure.

6.5.1 Existing Requirements for Aspect 5

Existing requirements from the ESFDR that pertain to aspect 5 are entry numbers 12, 19, 21, and 22 in Table 6.

Given the assumptions and limitations listed in Sections 4 and 5, the analyses indicate abiding by the current ESFDR requirements and the following recommendations ensures that the failure of the pumps to remove sump water immediately will have no long-term impact on in-situ hydrological conditions.

6.5.2 Recommendations for Aspect 5

Recommendations A, B, and C, as stated in Section 5.2, apply to sump failure. Also, in case of pump failures during an event, the sump water volume shall be monitored to determine whether it drains more rapidly than the NORIA-SP model predicts.

6.6 Aspect 6: Accidental Breaks in Water Pipes

In the event of ruptured water pipes, several backup systems are required to be in effect. Line break valves are to be placed at strategic locations to automatically shut in the event of excess flow resulting from damaged or severed water main pipes. Manual shutoff valves are located as required to provide isolation of pipe sections for maintenance or component inspection, outflow pumping capacity sized to handle the inflow capacity is required for fire protection, and a backup system for this outflow capacity is required. If all these systems fail, and water flows from a ruptured pipe emptying the storage tank the water would run downhill to the sump, wetting the base of the tunnel temporarily as it travels. The sump will contain a pump and a backup pump. If both pumps fail, the catastrophic spill described in the analysis of the *flooding scenario* applies. This scenario shows that, according to the models used, the water from this pipe rupture slowly infiltrates the sump wall and floor to an extent dependent upon the time it is allowed to remain in contact with the rock. In the example calculation, the water stands for 1 month, after which time two different assumptions are made and two results are presented. One case assumes all the water that has been imbibed into the rock during the period when the sump is full is trapped within the rock and slowly extends to a plume with a radius of ~ 12 m in 100 years. The other case allows a ventilation boundary condition and predicts removal of the additional water from the wall rock before currently scheduled closure of the potential repository.

6.6.1 Existing Requirements for Aspect 6

The ESF (SDRD) requires of the fire protection system that: "Water controls will be installed to ensure that failure of the distribution system will not be critical". The types of controls that are planned are:

1. Pressure reducing valves utilized to reduce the high pressure head present in the shaft piping.
2. Line break valves placed at strategic locations to automatically shut in the event of excess flow due to damaged or severed water main piping.
3. Pressure relief valves located downstream of pressure regulators for safety. These relief valves will drain to the waste water system if ever used.

4. Manual shutoff valves located as required to provide isolation of piping sections for maintenance or component inspection.
5. Water hammer arrestors used to minimize hydraulic shock caused by sudden reduction of flow in a piping system.

The applicable ESFDR requirements are entry numbers 12, 18, 20, and 22 from Table 6.

Given the assumptions and limitations listed in Sections 4 and 5, the analyses indicate abiding by the current ESFDR requirements and the following recommendations ensures that accidental breaks in water pipes will have no long-term impact on in-situ hydrological conditions.

Recommendations for Aspect 6

Notes, recommendations, and previous analyses under sump pump failure and water used for fire fighting apply here as well. Recommendations A, B, and C, as stated in Section 5.2, apply to ruptured water pipes.

6.7 Aspect 7: Water Use for Testing Purposes

Test activities are intended to investigate the processes and phenomena contributing to the waste isolation performance of the host rock and to characterize undisturbed preexcavation in situ properties and behaviors of the host rock. Some tests require conditions as close to natural preexcavation conditions as possible; water added to drift wall rock will corrupt measurements. Water restrictions for excavations in and near the areas allotted for test activities will likely be more constrained by the need for non-corrupted measurements than by 10 CFR 60 requirements that pertain to waste containment. Some activities require dry drilling of alcoves and drifts, and alcove and drift placement is designed so that activities do not influence each other. In situ testing of seal components is a possible concern because it is the only activity that might create a hydrologic zone of influence. This zone, however, would influence other tests but, analogous to the *flooding scenario* of Section 3, the water could be withdrawn by the ventilation system before closure, thus, it would not reduce the containment ability of the potential repository.

Less water (relative to the volume of rock removed) will likely be used to excavate the test facility than will be used to excavate the ramps and main drift; the current design requirements of the ESFDR should suffice to satisfy the suggested criteria.

Primary responsibility for determining water restrictions for the test activities lies with LANL. Test activities are briefly described in the ESF test planning package, and the water requirements for each activity are listed along with the function of the required water (LANL, 1991).

Activity 8.3.1.15.1.5.3 Sequential drift mining. The small amounts of air and water that may be injected into the rock mass between the drifts for permeability testing are not expected to alter the hydrological conditions more than 1 or 2 m from the boreholes.

Activity: In situ test of seal components (SCP Section 8.3.3.2.3). The method for selecting tests is in 8.3.3.2.2.3. ... Hydrologic considerations may, however, be significant. If testing of sealing systems is needed under simulated flooding scenarios, then a significant amount of water may be required. If this is required, then a hydrologic zone of influence may result. If this

zone of influence were to become unacceptably large or the test were to significantly increase uncertainties related to postclosure performance, an alternative test could be conducted either in the laboratory or in an alternate field location removed from the ESF.

Activity: Overcore stress experiments in the exploratory shaft facility (SCP Section 8.3.1.15.2.1.2).

Tests will be conducted within the approximately 50-ft.-long boreholes extending downward and horizontally from the end of the Demonstration Breakout Room (DBR). Small volumes (approximately 1 to 2 gal) of water may be injected in the vertical test holes at the bottom of the shaft for low-volume hydraulic fracture stress tests. If the quantities of fluid used are carefully limited, the small water volume used is not expected to move beyond the volume of rock that will be mined as the shaft is extended.

Activity: Percolation tests in the exploratory studies facility (SCP Section 8.3.1.2.2.4.2).

Observe and measure fluid flow through a network of fractures under controlled in situ conditions in order to characterize and quantify important flow processes in fractured welded tuff. ...Tracer-tagged water will be introduced from a trickle system/sand bed on the surface of the block.

Activity: Radial borehole tests in the exploratory shaft facility (SCP Section 8.3.1.2.2.4.4).

...at the stratigraphic contacts between the Tiva Canyon welded unit and the Paintbrush non-welded unit and between the Paintbrush non-welded unit and the Topopah Spring welded unit, Crosshole permeability tests will be run with both gas and water. The water injected under low pressure is estimated to influence a zone extending 10 m from the test location (Martinez, 1988). Further, the hydrologic zone of influence is expected to be localized in a vertical sense near the top 10 m of the Topopah Spring welded unit. The calculations of Peters (1988) indicate that the vertical movement of the test water will be very slow and will not be expected to cause significant disturbance at the main ESF test level.

Activity: Hydrological properties of major faults encountered in the main test level of the exploratory shaft facility (Activity 8.3.1.2.2.4.10). ...because the details of this activity are still being planned, the volumes of air or water to be injected in the fault region have not yet been determined. The injected air or water is expected to be confined to the fault and not to permeate the surrounding region of more competent rock because of the greater permeability in the fault zone.

Activity: Repository Horizon Near-field Hydrologic properties (EBSFT) (SCP Section 8.3.4.2.4.4.1). 500 gallons of water are needed per week.

6.7.1 Existing Requirements for Aspect 7

The existing requirements in Table 6 relevant to the Main Test Level activities are entry numbers 1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 25, 26, and 27;

6.7.2 Recommendations for Aspect 7

Recommendations A, B, and C, as stated in Section 5.2, apply to the main test facilities. Recommendation A is satisfied by ESFDR requirements 1.2.6.6.0 PC 1d.iv and 1.2.6.8 C E.vi. If the flooding scenario of Activity 8.3.3.2.2.3 is found necessary to simulate, it is recommended that the test be conducted at a remote analog site.

6.8 Aspect 8: Accidental Water Spills by the Tunnel Boring Machines and Other Equipment

The TBM is assumed to be connected to the main water line and to have the surface supply of water available to it. This is potentially a source of a high volume of water. If the high-flow cutoff valves recommended in the SCP are installed, and if there is frequent and ready access to hand shutoff

valves, TBM spills could be limited to a relatively small quantity of water. Primary and backup systems to pump out high volumes of water are required for the case of a large inflow; however, in the case of a failure of all primary and backup systems the maximum spill could be of the order of the ruptured water pipe, and the discussion will not be repeated here.

6.8.1 Existing Requirements for Aspect 8

Existing requirements pertaining to these water spills include the five types of controls listed in Section 6.6 for the fire protection system and from Table 6 entry numbers 2, 9, 12, 18, 19, 20, 21, and 22.

Given the assumptions and limitations listed in Sections 4 and 5, the analyses indicate abiding by the current ESFDR requirements and the following recommendations ensures that accidental water spills by the TBM or other equipment will have no long-term impact on in-situ hydrological conditions.

Recommendations for Aspect 8

Recommendations and analyses previously discussed under sump pump failure and water used for fire fighting apply here as well. Recommendations A, B, and C, as stated in Section 5.2, apply to accidental water spills by the TBM or other equipment.

6.9 Aspect 9: Leakage of Water Pipes

6.9.1 Existing Requirements for Aspect 9

The water system and waste water collection system are regulated by DOE Order 6430.1A, Division 2 Site and Civil Engineering, and Division 15 Mechanical., NAC Chapter 445, Paragraphs .244 through .420, and NFPA 20, 22, and 24. The effect of a leaking water pipe is not expected to be as severe as a ruptured pipe effect which was discussed earlier as aspect 6. Routine inspection and maintenance and worker awareness of his or her responsibility to report any leak should minimize the effects of a leaking water pipe.

Aspect 5, Section 6.5 lists the required measures to protect water pipes and enable easy shutoff for repairs. These in addition to entry number 16 in Table 6 apply to leakage of water pipes.

Given the assumptions and limitations listed in Section 4 and 5, the analyses indicate abiding by the current ESFDR requirements and the following recommendations ensures that leaks in water pipes will have no long-term impact on in-situ hydrological conditions.

6.9.2 Recommendations for Aspect 9

Recommendations A, B, and C, as stated in Section 5.2, apply to leakage of water pipes. Leaky pipes shall be fixed as soon as they are detected.

7.0 Conclusion

The analyses results indicate that expected water usage during the construction of and operations in the ESF North and South Ramps in the PTn and Topopah Spring welded units, and of the Main Test Level in the TSw2, and water used for testing in these regions of the ESF will not affect the natural ability of the site to isolate waste, provided that the required and recommended precautionary mea-

asures described in Sections 5 and 6 are implemented. In addition, these analyses indicate that measures such as pumping and ventilation might be used to mitigate potential effects resulting from a severe water-filling event in the ESF. Results of these analyses depend on the limits and assumptions previously described in Sections 4 and 5. Of potentially significant impact are those involving the size and spacing of fractures in the welded tuff and the model used for rock drying due to ventilation. The conclusions and recommendations cited in this report were sent previously to the YMPO (Shephard, 1993) to be included in Appendix I of the ESFDR; these recommendations are included as an appendix to this report.

8.0 References

- Buscheck, T. A., J. J. Nitao, and D. A. Chesnut, *The Impact of Episodic Nonequilibrium Fracture-Matrix Flow on Geological Repository Performance*, presented at Focus '91 Conference, Las Vegas, NV, September 29-October 4, 1991, UCRL-JC-106759, Lawrence Livermore National Laboratory, Livermore, CA, 1991. (NNA.911231.0023)
- Case, J. B., and P. C. Kelsall, *Modification of Rock Mass Permeability in the Zone Surrounding a Shaft in Fractured, Welded Tuff*, SAND86-7001, Sandia National Laboratories, Albuquerque, NM, 1987. (NNA.891020.0181)
- DOE (U.S. Department of Energy), *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada*, DOE/RW-0199, Office of Civilian Radioactive Waste Management, Washington, DC, 1988. (HQO.881201.0002)
- DOE (U.S. Department of Energy), *Yucca Mountain Site Characterization Project Exploratory Studies Facility Design Requirements Document, Rev. 7/2/92*, YMP/CM-0019, Yucca Mountain Site Characterization Project (DOE-YMP), Las Vegas, NV, 1992. (NNA.920903.0087)
- DOE (U.S. Department of Energy), *Yucca Mountain Site Characterization Project (DOE-YMP), Reference Information Base (RIB), Rev. 0*, YMP/93-02, Las Vegas, NV, 1993. (NNA.930324.0099)
- Dudley, A. L., R. R. Peters, M. S. Tierney, E. A. Klavetter, J. H. Gauthier, and M. Wilson, *Total System Performance Assessment Code (TOSPAC) Volume 1: Physical and Mathematical Bases*, SAND85-0002, Sandia National Laboratories, Albuquerque, NM, 1988. (NNA.881202.0211)
- Eaton, R. R., D. K. Gartling, and D. E. Larson, *SAGUARO--A Finite Element Computer Program for Partially Saturated Porous Flow Problems*, SAND82-2772, Sandia National Laboratories, Albuquerque, NM, 1983. (NN1.881007.0040)
- Fernandez, J. A., P. C. Kelsall, J. B. Case, and D. Meyer, *Technical Basis for Performance Goals, Design Requirements, and Material Recommendations for the NNWSI Repository Sealing Program*, SAND84-1895, Sandia National Laboratories, Albuquerque, NM, 1987. (NNA.870717.0048)
- Fernandez, J. A., T. E. Hinkbein, and J. B. Case, *Selected Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain*, SAND85-0598, Sandia National Laboratories, Albuquerque, NM, 1989. (NNA.881202.0213)
- Flint, L. E., and A. L. Flint, *Preliminary Permeability and Water-Retention Data for Nonwelded and Bedded Tuff Samples, Yucca Mountain Area, Nye County, Nevada*, USGS/OFR 90-569, U.S. Geological Survey, Denver, CO, 1990. (NNA.920225.0002)
- Foltz, S. D., V. C. Tidwell, R. J. Glass, and S. R. Sobolik, *Investigation of Fracture-Matrix Interaction: Preliminary Experiments in a Simple System*, in High-Level Radioactive Waste Management: Proceedings of the Fourth Annual International Conference, American Nuclear Society, La Grange Park, IL, pp. 328-335, 1993. (NNA.930615.0055)
- Gauthier, J. H., M. L. Wilson, and F. C. Lauffer, *Estimating the Consequences of Significant Fracture Flow at Yucca Mountain*, in High-Level Radioactive Waste Management: Proceedings of the Third Annual International Conference, American Nuclear Society, La Grange Park, IL, pp. 891-898, 1992. (NNA.920505.0068)

Hopkins, P. L., R. R. Eaton, and S. Sinnock, *Effect of Drift Ventilation on Repository Hydrology and Resulting Solute Transport Implications*, SAND86-1571, Sandia National Laboratories, Albuquerque, NM, 1987. (NNA.891019.0244)

Hopkins, P. L., N. E. Bixler, and R. R. Eaton, *NORIA-SP - A Finite Element Computer Program for Analyzing Liquid Water Transport in Porous Media*, SAND90-2542, Sandia National Laboratories, Albuquerque, NM, 1991. (NNA.911202.0031)

Klavetter, E. A., and R. R. Peters, *Estimation of Hydrologic Properties of an Unsaturated, Fractured Rock Mass*, SAND84-2642, Sandia National Laboratories, Albuquerque, NM, 1986. (NNA.870317.0738)

LANL, *Exploratory Studies Facility (ESF), Test Planning Package 91-5, Preliminary ESF Test Planning Package for Support of Pre-Title II ESF Design Studies, First Phase Submittal, Planned ESF Tests, North Ramp Access*, TWS-EES-13-LV-05-91-07, Los Alamos National Laboratory, Los Alamos, NM, 1991. (NNA.920723.0068)

LANL, *Exploratory Studies Facility (ESF), Test Planning Package 91-5, Preliminary ESF Test Planning Package for Support of Pre-Title II ESF Design Studies, Third Phase Submittal, Planned ESF Tests, Topopah Spring Main Test Level and South Ramp Access*, TWS-EES-13-LV-06-91-24, Los Alamos National Laboratory, Los Alamos, NM, 1991. (NNA.920901.0039)

Martinez, M. J., *Capillary-Driven Flow in a Fracture Located in a Porous Medium*, SAND84-1697, Sandia National Laboratories, Albuquerque, NM, 1988. (NNA.891013.0203)

Montazer, P., E. P. Weeks, F. Thamir, S. N. Yard, and P. B. Hofrichter, 1986. *Monitoring the Vadose Zone in Fractured Tuff, Yucca Mountain, Nevada*, in Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone, National Well Water Association, Worthington, OH, pp. 439-469, 1986. (HQS.880517.1797)

Nelson, P. H., *Estimation of Water-filled and Air-filled Porosity in the Unsaturated Zone, Yucca Mountain, Nevada*, in High-Level Radioactive Waste Management: Proceedings of the Fourth Annual International Conference, American Nuclear Society, La Grange Park, IL, pp. 949-954, 1993. (NNA.931102.0062)

Olsson, O., *Description of the RAMAC Borehole Radar System and Interpretation of Data*, ID-No. 88240, Swedish Geological Co., Uppsala, Sweden, 1988. (NNA.931102.0065)

Olsson, O., P. Andersson, S. Carlsten, L. Falk, B. Niva, and E. Sandberg, *Fracture Characterization in Crystalline Rock by Borehole Radar*, ID-No. 88240, Swedish Geological Co., Uppsala, Sweden, 1988. (NNA.931102.0066)

Ortiz, T. S., R. L. Williams, F. B. Nimick, B. C. Whittet, and D. L. South, *A Three-Dimensional Model of Reference Thermal/Mechanical and Hydrological Stratigraphy at Yucca Mountain, Southern Nevada*, SAND84-1076, Sandia National Laboratories, Albuquerque, NM, 1985. (NNA.890315.0013)

Peters, R. R., E. A. Klavetter, I. J. Hall, S. C. Blair, P. R. Heller, and G. W. Gee, *Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials from Yucca Mountain, Nye County, Nevada*, SAND84-1471, Sandia National Laboratories, Albuquerque, NM, 1984. (NNA.870407.0036)

Peters, R. R., *Hydrologic Technical Correspondence in Support of the Site Characterization Plan*, SAND88-2784, Sandia National Laboratories, Albuquerque, NM, 1988. (NNA.881202.0204)

Peterson, A. C., R. R. Eaton, A. J. Russo, and J. A. Lewin, *Technical Correspondence in Support of an Evaluation of the Hydrologic Effects of Exploratory Shaft Facility Construction at Yucca Mountain*, SAND88-2936, Sandia National Laboratories, Albuquerque, NM, 1988. (NNA.881202.0206)

Robinson, J. H., D. M. Stephens, R. R. Luckey, and D. A. Baldwin, *Water Levels in Periodically Measured Wells in the Yucca Mountain Area, Nevada, 1981-87*, USGS/OFR 88-468, U.S. Geological Survey, Denver, CO, 1988. (NNA.891226.0133)

Shephard, L. E., SNL, letter to E. H. Pertie, DOE, Exploratory Studies Facility Branch, Subject: Recommendations for Appendix I of the ESFDR regarding the use of water in the construction and operations of the Exploratory Studies Facility, May 28, 1993. (NNA.930630.0121)

Sobolik, S. R., M. E. Fewell, R. R. Eaton, *Movement of Shaft and Drift Construction Water in Yucca Mountain, Nevada - An Extended Study*, SAND91-0791, Sandia National Laboratories, Albuquerque, NM, 1991. (NNA.911203.0001)

Sobolik, S. R., and M. E. Fewell, *Estimations of the Extent of Migration of Surficially Applied Water for Various Surface Conditions Near the Potential Repository Perimeter*, SAND92-2248, Sandia National Laboratories, Albuquerque, NM, 1993. (NNA.931110.0040)

Thordarson, W., *Geohydrologic Data and Test Results from Well J-13, Nevada Test Site, Nye County, Nevada*, USGS/WRI-83-4171, U.S. Geological Survey, Denver, CO, 1983. (HQS.880517.1849)

van Genuchten, M., *A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils*, Soil Sci. Soc. Am. J., Vol. 44, pp. 892- 898, 1980. (NNA.890522.0287)

WA (Work Agreement), *ESF PA Analysis #13 -- Evaluation of Underground Water Usage and Spillage in the ESF*, WA-0062, Sandia National Laboratories, Albuquerque, NM, 1993 (NNA.930315.0272)

West, K. A., *Nevada Nuclear Waste Storage Investigations Exploratory Shaft Facility Fluids and Materials Evaluation*, LA-11398-MS, Los Alamos National Laboratory, Los Alamos, NM, 1988. (HQS.880517.3218)

Zimmerman, R. M., R. A. Bellman, Jr., K. L. Mann, D. P. Zerga, M. Fowler, and R. L. Johnson, *G-Tunnel Welded Tuff Mining Experiment Evaluations*, SAND87-1433, Sandia National Laboratories, Albuquerque, NM, 1988. (HQS.880517.3224)

9.0 Appendix A: Recommendations for Appendix
I of the Exploratory Studies Facility Design
Requirements Pertaining to Exploratory Studies
Facility Performance Assessment Analysis #13

Recommendations for Appendix I, ESFDR, Pertaining to ESF PA Analysis #13

The following are proposed changes and recommendations to be added to Appendix I of the ESFDR to incorporate the results of ESF PA Analysis #13, which concerns the imbibition and movement of water used in underground construction and testing activities for the ESF. ESF Analysis #13 has been conducted as a quality-affecting analysis, and therefore these recommendations have gone through both a technical and management review in accordance with SNL's Quality Assurance program. The proposed changes to Tables I.1 and I.2 refer to the versions of the tables in the revision of the ESFDR dated July 2, 1992.

Change #1:

Add the following item to the end of Table I.1:

13	Movement of Water Used in Underground Construction Activities in the ESF
----	--

Also, change the first sentence of the paragraph following Table I.1 to indicate that Analysis 13 has been completed for the North and South ramps and the Main Test Level down through the Topopah Spring welded units.

Change #2:

In Table I.2, change the entry in the Analysis No. column for each of the following three requirements as shown below:

Label	ESFDR Requirement	ESFDR or 10 CFR 60 Description	ANALYSIS No.	
			Change from:	To:
186	1.2.6.8 C E.vi.	Excess water shall be removed.		13
193	1.2.6.5 PC 1d.iv	Water use in const./oper. shall not cause interference of tests	2	2,13
194	1.2.6.6 PC 1d.v	Water use in const./oper. shall not cause interference of tests	2	2,13
198	1.2.6.8 C E.vii	Cleaning of ESF walls shall limit water saturation		13
217	1.2.6.8 C E.ii	Limit water use to limit effects on waste containment & isolation		13
361	1.2.6.5 PC 2i.iii	Water use shall be consistent with repository design goals		13
362	1.2.6.6 PC 2j.v	Water use shall be consistent with repository design goals		13
374	1.2.6.5 PC 1d.ii	Water intrusion shall be controlled.		13
375	1.2.6.6 PC 1d.iii	Water intrusion shall be controlled.		13

Change #3:

Add the following section to Appendix I.

I.2.13 Analysis 13. Movement of Water Used in Underground Construction Activities in the ESF

Purpose:

To investigate the movement and potential impact on waste isolation of water used or spilled during the construction of the underground tunnels and testing activities for the Exploratory Studies Facility (ESF).

Summary:

The work conducted for this analysis, which included a review of previous relevant analyses and the performance of additional calculations, was performed in accordance with SNL Work Agreement WA-0062.

The purpose of this evaluation was to provide guidance for the ESF design and to define controls on the use of water and combustible fluids if needed. This guidance was needed to determine whether restrictions on water use should be imposed, whether the use of combustible materials should be limited, and what measures should be implemented to reduce the probability of accidental spills. The evaluation considered the following aspects of underground water usage and spillage:

1. Routine water use during the ramp and drift excavation by tunnel boring machines (TBMs), principally for dust control.
2. Water used for drilling purposes
3. Water used for washing walls
4. Water use for fire fighting.
5. Failure of sump pumps to remove waste and mine drainage water.
6. Accidental breakage of water pipes
7. Water use for testing purposes
8. Accidental water spills by the TBMs and other equipment.
9. Leakage of water pipes, including for water supply and for waste water and mine drainage water removal.

As described in WA-0062, this analysis was conducted in two parts. One part dealt with identifying and reviewing previous analyses regarding the usage and movement of underground water, and with developing criteria that can be used to determine if that water has an impact on the ability of the natural barrier system at Yucca Mountain to isolate radioactive waste. For the other part, computational analyses were performed to simulate various scenarios for water usage or spillage in the ESF tunnels (i.e., the North and South Ramps and the Main Test Level) excavated in the Topopah Spring welded unit (TSw2) and in the Paintbrush Tuff nonwelded unit (PTn). One scenario (referred to as the flooding scenario) simulated the complete flooding of the tunnel possibly due to a major fire fighting operation or a water line rupture. The tunnel was assumed to remain flooded for one month, after which the water was pumped out. The movement of the infiltrated water after all standing water was pumped out was

simulated using two different boundary conditions on the tunnel surface: a no-flux condition, to represent no evaporation of the infiltrated water to the air in the tunnel; and a suction pressure boundary condition corresponding to air at 90% relative humidity used for ventilation. Another scenario (referred to as the wetting scenario) estimated the water infiltration and movement due to keeping the tunnel walls saturated continuously for varying periods of time. This scenario was used to simulate the original tunnel excavation operations and wall washing for dust control and to prepare for mapping. For all these scenarios, the finite element code NORIA-SP (Hopkins et al., 1991), Version 0.10, was used to perform the calculations. Multi-phase and nonisothermal effects were not considered.

This evaluation suggests that the water used in underground construction and operation of the ESF facility and in the planned testing activities will not interfere with the repository's ability to contain waste if that water or an equal volume of water from the same region is removed during construction and by required or prescribed ventilation during the preclosure phase of the ESF and repository operation. To evaluate the ESF construction and testing activities against this criterion, information was gathered regarding estimates of expected applications and volumes of water usage, and potential sources of unplanned water loss in the ESF tunnels. This information is detailed in the documentation for the analysis.

The results of the analysis indicate that expected water usage operations during the construction of the ESF North and South Ramps in Paintbrush Tuff nonwelded and Topopah Spring welded units, and the Main Test Level in the Topopah Spring welded unit, as well as water used for testing in these regions of the ESF, will not affect the natural ability of the site to isolate waste, so long as the recommended precautionary measures described below are implemented. Additionally, this analysis indicates that measures such as pumping and ventilation may be used to mitigate any potential effects resulting from a severe flooding event in the ESF. This analysis is caveated to the limitations and assumptions described in the documentation of this analysis, particularly those involving the size and spacing of fractures in the welded tuff and the model used for rock drying due to ventilation.

These results address concerns expressed in ESFDR requirements 1.2.6.5 PC 1d.ii, 1.2.6.5 PC 1d.iv, 1.2.6.5 PC 2i.iii, 1.2.6.6 PC 1d.iii, 1.2.6.6 PC 1d.v, 1.2.6.6 PC 2j.v, 1.2.6.7 C F.iii, 1.2.6.7 C J, 1.2.6.7 C K, 1.2.6.7.8 C A, 1.2.6.8 C E.ii, 1.2.6.8 C E.vi, and 1.2.6.8 C E.vii.

Recommendations:

Recommendation:

Pooled water on the tunnel floor will continue to infiltrate the rock as long as the two are in contact. Furthermore, fracture systems with apertures of 100 μm or greater could create a preferential pathway for water flow to the Calico Hills units, which could impact waste isolation capabilities. For these reasons, during construction and operation of the ESF excess water should be removed to preclude adding unnecessary water to the ESF tunnel wall rock. Water should not be allowed to puddle, pond or stand on the floors of the tunnels at any time, and it is suggested that a readily available water

pickup system be accessible to immediately pick up any standing water which may collect during the construction or operation phase of the ESF.

Recommendation:

It is possible that an event involving ponded water may occur for which remedial action such as pumping cannot be completed in a short amount of time (e.g., a few days). The imbibition rate of water into the wall rock, fractures and faults should be monitored in the event of prolonged contact between water and rock. Suggested monitoring methods include seismic, dielectric, and radar methods, some of which are referenced in the analysis documentation.

Recommendation:

It is expected that ventilation of the ESF tunnels will help to dry out the walls, and thus could be implemented in the ESF design as a remedial measure to remove infiltrated construction water from the tunnel wall rock. The quantity of water added to or drawn out of the wall rock should be estimated over time to determine the effectiveness of ventilation to remove construction water. ESFDR 1.2.6.7 CF.iii requires the design of the ESF underground utility system, including ventilation, to facilitate monitoring of moisture influx to the ESF from the rock mass and from ventilation, and moisture efflux from mine water removal and ventilation exhaust to limit possible impacts on the capability to adequately characterize the site. This system should be used in conjunction with an estimate of water removed in the muck and on the muck conveyor to monitor the water balance during construction. This will allow an estimate to be made of the water added to the rock matrix during the construction process and will enable an estimate of the capacity of the ventilating air to remove moisture from available sources including muck and water on the conveyor belt and the wall rock. This recommendation is particularly important in the event of a severe flood so that proper determination can be made for the need for remedial ventilation.

Recommendation:

A system or procedure for recovery of excess roof bolt drilling water should be implemented so that significant ponding of water for any period of time is prevented.

Recommendation:

In the case of pump failures during a flooding event, the sump water volume should be monitored to estimate a drainage rate as a function of time.

Recommendation:

From a total system perspective, one way that construction water could impact repository performance is by the formation of a direct path of saturation between the repository and the water table. This would not necessarily take a lot of water, simply a connected fracture path. This possibility is not adequately modeled in this analysis. Also, the Paintbrush Tuff nonwelded unit is highly porous and conductive, and water imbibed there could impact waste isolation if the unit is sufficiently connected to the repository horizon or water table through a fracture network. It is recommended that extra precautions be taken near fracture or fault zones and in the Paintbrush Tuff nonwelded units.

Recommendation:

Leakage of water pipes should not be permitted to persist.

Citations for the data used, lists of assumptions, results, and the rationale for applying the results to address concerns expressed in the requirements can be found in SNL's YMP record center under file code 75/12147/WA-0062/1.0/QA. Additional documentation will be found in the Sandia Report SAND93-1182.

10.0 Appendix B

Information from the Reference Information Base used in this report:

This report contains information in Table 2, pages 3 and 4 from RIB version 2.002 which differs slightly from RIB Rev. 0 (YMP/93-02, December, 1992) as shown in the following table.

Table 9: Stratigraphy Comparison Between RIB Versions at USW G-4

Material Designation	Elevation (m)	
	RIB Rev. 0 Base of Unit	RIB Version 2.002 Base of Unit
CHn3(z)	725	730.6
CHn2(z)	734	735
CHn1z	751	752
CHn1v	855	856
TSw3	860	861
TSw2	876	877
TSw1	1065	1066
PTn	1195	1196
TCw	1234	1234
UO (alluvium)	1260	1261

Candidate information for the Reference Information Base:

This report contains no candidate information for the Reference Information Base.

Candidate information for the Geographic Nodal Information Study and Evaluation System:

This report contains no candidate information for the Geographic Nodal Information Study and Evaluation System.

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

DISTRIBUTION LIST

1	L. H. Barrett (RW-1) Assistant Director OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	L. M. Smith (RW-20) Office of Geologic Disposal OCRWM US Department of Energy 1000 Independence Avenue, SW Washington, DC 20585
1	J. D. Saltzman (RW-2) Acting Deputy Director OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	S. J. Brocoum (RW-22) Analysis and Verification Division OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 2585
1	C. Kouts (RW-4) Office of Strategic Planning and International Programs OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	D. Shelor (RW-30) Office of Systems and Compliance OCRWM US Department of Energy 1000 Independence Avenue, SW Washington, DC 20585
1	A. Benson (RW-5) Office of External Relations OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	J. Roberts (RW-33) Director, Regulatory Compliance Division OCRWM US Department of Energy 1000 Independence Avenue, SW Washington, DC 20585
1	Samuel Rousso (RW-10) Office of Program and Resource Mgt. OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	G. J. Parker (RW-332) OCRWM US Department of Energy 1000 Independence Avenue, SW Washington, DC 20585
1	J. C. Bresee (RW-10) OCRWM US Department of Energy 1000 Independence Avenue SW Washington, DC 20585	1	R. A. Milner (RW-40) Office of Storage and Transporation OCRWM US Department of Energy 1000 Independence Avenue, SW Washington, DC 20585

1	S. Rousso (RW-50) Office of Contract Business Management OCRWM US Department of Energy 1000 Independence Avenue, SW Washington, DC 20585	1	D. R. Elle, Director Environmental Protection and Division DOE Nevada Field Office US Department of Energy P.O. Box 98518 Las Vegas, NV 89193-8518
1	T. Wood (RW-52) Director, M&O Management Division OCRWM US Department of Energy 1000 Independence Avenue, SW Washington, DC 20585	1	Repository Licensing & Quality Assurance Project Directorate Division of Waste Management US NRC Washington, DC 20555
4	Victoria F. Reich, Librarian Nuclear Waste Technical Review Board 1100 Wilson Blvd, Suite 910 Arlington, VA 22209	1	Senior Project Manager for Yucca Mountain Repository Project Branch Division of Waste Management US NRC Washington, DC 20555
5	C. P. Gertz, Project Manager Yucca Mountain Site Characterization Project Office US Department of Energy P.O. Box 98608--MS 523 Las Vegas, NV 89193-8608	1	NRC Document Control Desk Division of Waste Management US NRC Washington, DC 20555
1	C. L. West, Director Office of External Affairs DOE Nevada Field Office US Department of Energy P.O. Box 98518 Las Vegas, NV 89193-8518	1	Philip S. Justus NRC Site Representative 301 E Stewart Avenue, Room 203 Las Vegas, NV 89101
8	Technical Information Officer DOE Nevada Field Office US Department of Energy P.O. Box 98518 Las Vegas, NV 89193-8518	1	E. P. Binnall Field Systems Group Leader Building 50B/4235 Lawrence Berkeley Laboratory Berkeley, CA 94720
1	P. K. Fitzsimmons, Technical Advisor Office of Assistant Manager for Environmental Safety and Health DOE Nevada Field Office US Department of Energy P.O. Box 98518 Las Vegas, NV 89193-8518	1	Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road Drawer 28510 San Antonio, TX 78284
		3	W. L. Clarke Technical Project Officer - YMP Attn: YMP/LRC Lawrence Livermore National Laboratory P.O. Box 5514 Livermore, CA 94551

1	J. A. Blink Deputy Project Leader Lawrence Livermore National Laboratory 101 Convention Center Drive Suite 820, MS 527 Las Vegas, NV 89109	1	V. R. Schnelder Asst. Chief Hydrologist--MS 414 Office of Program Coordination and Technical Support US Geological Survey 12201 Sunrise Valley Drive Reston, VA 22092
4	J. A. Canepa Technical Project Officer - YMP N-5, Mail Stop J521 Los Alamos National Laboratory P.O. Box 1663 Los Alamos, NM 87545	1	J. S. Stuckless Geologic Division Coordinator MS 913 Yucca Mountain Project US Geological Survey P.O. Box 25046 Denver, CO 80225
1	H. N. Kalia Exploratory Shaft Test Manager Los Alamos National Laboratory Mail Stop 527 101 Convention Center Dr., #820 Las Vegas, NV 89101	1	D. H. Appel, Chief Hydrologic Investigations Program MS 421 US Geological Survey P.O. Box 25046 Denver, CO 80225
1	N. Z. Elkins Deputy Technical Project Officer Los Alamos National Laboratory Mail Stop 527 101 Convention Center Dr., #820 Las Vegas, NV 89101	1	E. J. Helley Branch of Western Regional Geology MS 427 US Geological Survey 345 Middlefield Road Menlo Park, CA 94025
5	L. E. Shephard Technical Project Officer - YMP Sandia National Laboratories Organization 6302 P.O. Box 5800 Albuquerque, NM 87185	1	R. W. Craig, Chief Nevada Operations Office US Geological Survey 101 Convention Center Drive Suite 860, MS 509 Las Vegas, NV 89109
1	J. F. Devine Asst Director of Engineering Geology US Geological Survey 106 National Center 12201 Sunrise Valley Drive Reston, VA 22092	1	D. Zesiger US Geological Survey 101 Conventional Center Drive Suite 860, MS 509 Las Vegas, NV 89109
1	L. R. Hayes Technical Project Officer Yucca Mountain Project Branch MS 425 US Geological Survey P.O. Box 25046 Denver, CO 80225	1	G. L. Ducret, Associate Chief Yucca Mountain Project Division US Geological Survey P.O. Box 25046 421 Federal Center Denver, CO 80225

1	A. L. Flint US Geological Survey MS 721 P.O. Box 327 Mercury, NV 89023	2	L. D. Foust Nevada Site Manager TRW Environmental Safety Systems 101 Convention Center Drive Suite 540, MS 423 Las Vegas, NV 89109
1	D. A. Beck Water Resources Division, USGS 6770 S Paradise Road Las Vegas, NV 89119	1	C. E. Ezra YMP Support Office Manager EG&G Energy Measurements Inc MS V-02 P.O. Box 1912 Las Vegas, NV 89125
1	P. A. Glancy US Geological Survey Federal Building, Room 224 Carson City, NV 89701	1	E. L. Snow, Program Manager Roy F. Weston Inc 955 L'Enfant Plaza SW Washington, DC 20024
1	J. H. Sass - USGS Branch of Tectonophysics 2255 N Gemini Drive Flagstaff, AZ 86001	1	Technical Information Center Roy F. Weston Inc 955 L'Enfant Plaza SW Washington, DC 20024
1	DeWayne Campbell Technical Project Officer - YMP US Bureau of Reclamation Code D-3790 P.O. Box 25007 Denver, CO 80225	1	D. Hedges, Vice President, QA Roy F. Weston Inc 4425 Spring Mountain Road Suite 300 Las Vegas, NV 89102
1	J. M. LaMonaca Records Specialist US Geological Survey 421 Federal Center P.O. Box 25046 Denver, CO 80225	1	D. L. Fraser, General Manager Reynolds Electrical & Engineering Co, Inc MS 555 P.O. Box 98521 Las Vegas, NV 89193-8521
1	W. R. Keefer - USGS 913 Federal Center P.O. Box 25046 Denver, CO 80225	1	B. W. Colston, President and General Manager Las Vegas Branch Raytheon Services Nevada MS 416 P.O. Box 95487 Las Vegas, NV 89193-5487
1	M. D. Voegelé Technical Project Officer - YMP SAIC 101 Convention Center Drive Suite 407 Las Vegas, NV 89109	1	R. L. Bullock Technical Project Officer - YMP Raytheon Services Nevada Suite P-250, MS 403 101 Convention Center Drive Las Vegas, NV 89109

1	Paul Eslinger, Manager PASS Program Pacific Northwest Laboratories P.O. Box 999 Richland, WA 99352	1	C. H. Johnson Technical Program Manager Agency for Nuclear Projects State of Nevada Evergreen Center, Suite 252 1802 N. Carson Street Carson City, NV 89710
1	A. T. Tamura Science and Technology Division OSTI US Department of Energy P.O. Box 62 Oak Ridge, TN 37831	1	John Fordham Water Resources Center Desert Research Institute P.O. Box 60220 Reno, NV 89506
1	Carlos G. Bell Jr Professor of Civil Engineering Civil and Mechanical Engineering Dept. University of Nevada, Las Vegas 4505 S Maryland Parkway Las Vegas, NV 89154	1	David Rhode Desert Research Institute P.O. Box 60220 Reno, NV 89506
1	P. J. Weeden, Acting Director Nuclear Radiation Assessment Div. US EPA Environmental Monitoring Systems Lab P.O. Box 93478 Las Vegas, NV 89193-3478	1	Eric Anderson Mountain West Research- Southwest Inc 2901 N Central Avenue #1000 Phoenix, AZ 85012-2730
1	ONWI Library Battelle Columbus Laboratory Office of Nuclear Waste Isolation 505 King Avenue Columbus, OH 43201	1	The Honorable Cyril Schank Chairman Churchill County Board of Commissioners 190 W First Street Fallon, NV 89406
1	T. Hay, Executive Assistant Office of the Governor State of Nevada Capitol Complex Carson City, NV 89710	1	Dennis Bechtel, Coordinator Nuclear Waste Division Clark County Department of Comprehensive Planning 301 E Clark Avenue, Suite 570 Las Vegas, NV 89101
3	R. R. Loux Executive Director Agency for Nuclear Projects State of Nevada Evergreen Center, Suite 252 1802 N. Carson Street Carson City, NV 89710	1	Juanita D. Hoffman Nuclear Waste Repository Oversight Program Esmeralda County P.O. Box 490 Goldfield, NV 89013
		1	Eureka County Board of Commissioners Yucca Mountain Information Office P.O. Box 714 Eureka, NV 89316

1	Brad Mettam Inyo County Yucca Mountain Repository Assessment Office Drawer L Independence, CA 93526	1	Economic Development Dept. City of Las Vegas 400 E. Stewart Avenue Las Vegas, NV 89101
1	Lander County Board of Commissioners 315 South Humbolt Battle Mountain, NV 89820	1	Community Planning and Development City of North Las Vegas P.O. Box 4086 North Las Vegas, NV 89030
1	Vernon E. Poe Office of Nuclear Projects Mineral County P.O. Box 1026 Hawthorne, NV 89415	1	Community Development and Planning City of Boulder City P.O. Box 61350 Boulder City, NV 89006
1	Les W. Bradshaw Program Manager Nye County Nuclear Waste Repository Program P.O. Box 153 Tonopah, NV 89049	1	Commission of the European Communities 200 Rue de la Loi B-1049 Brussels BELGIUM
1	Florindo Mariani White Pine County Nuclear Waste Project Office 457 Fifth Street Ely, NV 89301	6	M. J. Dorsey, Librarian YMP Research and Study Center Reynolds Electrical & Engineering Co Inc MS 407 P.O. Box 98521 Las Vegas, NV 89193-8521
1	Judy Foremaster City of Caliente Nuclear Waste Project Office P.O. Box 158 Caliente, NV 89008	1	Amy Anderson Argonne National Laboratory Building 362 9700 S Cass Avenue Argonne, IL 60439
1	Phillip A. Niedzielski-Eichner Nye County Nuclear Waste Repository Project Office P.O. Box 221274 Chantilly, VA 22022-1274	1	Steve Bradhurst P.O. Box 1510 Reno, NV 89505
1	Jason Pitts Lincoln County Nuclear Waste Project Office Lincoln County Courthouse Pioche, NV 89043	1	Michael L. Baughman 35 Clark Road Fiskdale, MA 01518
		1	Glenn Van Roekel Director of Community Development City of Caliente P.O. Box 158 Caliente, NV 89008

1 Ray Williams, Jr
P.O. Box 10
Austin, NV 89310

1 Nye County District Attorney
P.O. Box 593
Tonopah, NV 89049

1 William Offutt
Nye County Manager
Tonopah, NV 89049

1 R. F. Pritchett
Technical Project Officer - YMP
Reynolds Electrical &
Engineering Company Inc
MS 408
P.O. Box 98521
Las Vegas, NV 89193-8521

1 Dr. Moses Karakouzian
1751 E Reno #125
Las Vegas, NV 89119

1 Dwight Hoxie
USGS - Las Vegas
YMSCP
101 Convention Center Drive
Mail Stop 509
Las Vegas, NV 89109

1 Dierdre Boak
LANL - Las Vegas
YMSCP
101 Convention Center Drive
Mail Stop 527
Las Vegas, NV 89109

1 Albin Brandstetter
M&O/Intera - Las Vegas
YMSCP
101 Convention Center Drive
Mail Stop 423
Las Vegas, NV 89109

1 W.B. Simecka
YMSCP
101 Convention Center Drive
Mail Stop 523
Las Vegas, NV 89109

1 E.H. Petrie
YMSCP
101 Convention Center Drive
Mail Stop 523
Las Vegas, NV 89109

1 W.A. Girdley
YMSCP
101 Convention Center Drive
Mail Stop 523
Las Vegas, NV 89109

1 J. M. Boak
YMSCP
101 Convention Center Drive
Mail Stop 523
Las Vegas, NV 89109

1 J.R. Dyer
YMSCP
101 Convention Center Drive
Mail Stop 523
Las Vegas, NV 89109

1 A.M. Meike
Los Alamos National Laboratory
Yucca Mountain Site Characterization
Project
P.O. Box 1633, EES-13
Los Alamos, NM 87545

1	6300	D.E. Ellis
1	6302	L.E. Shephard
1	6312	H.A. Dockery
1	6313	L.S. Costin
2	6352	G.M. Gerstner-Miller 100/12547/SAND93-1182/QA
2	6352	G.M. Gerstner-Miller DRMS Files
20	6352	WMT Library
1	6319	R.R. Richards
1	6115	P.B. Davies
1	1502	P.J. Hommert
1	6410	D.A. Dahlgren
5	7141	Technical Library
1	7151	Technical Publications
10	7613-2	Document Processing for DOE/OSTI
1	8523-2	Central Technical Files
1	1511	P.L. Hopkins
1	1511	M.J. Martinez
1	1513	R.R. Eaton
1	6115	C.K. Ho
1	6302	F.J. Schelling
1	6312	R.W. Barnard
1	6312	G.E. Barr
1	6312	E. Dunn
1	6312	J.H. Gauthier
1	6312	W.G. Perkins
1	6312	T.H. Robey
1	6312	M.L. Wilson
1	6313	R.E. Finley
1	6313	J.E. Grant
1	6313	J. Pott
1	6313	E.E. Ryder
5	6313	S.R. Sobolik
1	6313	C.F. Taylor

DATE

FILMED

3 / 9 / 94

END