8. References

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NCRP (National Council on Radiation Protection and Measurements) 1999. *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies.* NCRP Report No. 129. Bethesda, Maryland: National Council on Radiation Protection and Measurements. TIC: 250396.

8.3 Source Data, Listed by Data Tracking Numbers

GS000508312332.001. Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model. Submittal date: 06/01/2000.

LA0003AM831341.001. Probability Distributions for Sorption Coefficients (Kd's). Submittal date: 03/29/2000.

MO0003SEPSDARS.002. Preliminary Seismic Design Acceleration Response Spectra for the Repository Level (Point B). Submittal date: 03/30/2000. Submit to RPC URN-0203

MO0006SPAPVE03.001. Preliminary Volcanic Eruption Biosphere Dose Conversion Factors. Submittal date: 06/15/2000.

SN9908T0581999.001. Recharge and Lateral Groundwater Flow Boundary Conditions for the Saturated Zone (SZ) Site-Scale Flow and Transport Model. Submittal date: 08/19/1999.

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Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review

1. Model Area	2. AMRs and Other Documents Reviewed [A]	3. Model or Analysis? [B]	4. # Unique Reports [C]
A. Climate	A.1 Future Climate Analysis (ANL-NBS-GS-000008 Rev. 00; USGS 2000)	A	1 Unique AMR
B. Infiltration	B.1 Simulation Net Infiltration for Modern and Potential Future Climates (ANL-NBS-HS-000032 Rev. 00 ICN 1; USGS 2001a)	A+M	2 Unique AMRs
	B.2 Analysis of Infiltration Uncertainty (ANL-NBS-HS-000027 Rev. 00; CRWMS M&O 2000e)	A	
C. UZ Flow	C.1 UZ Flow Models and Submodels (MDL-NBS-HS-000006 Rev. 00; CRWMS M&O 2000bq)	A+M	8 Unique AMRs
	C.2 Calibrated Properties Model (MDL-NBS-HS-000003 Rev. 00; CRWMS M&O 2000i)	A+M	
	C.3 Analysis of Hydrologic Properties Data (ANL-NBS-HS-000002 Rev. 00; CRWMS M&O 2000by)	A	
	C.4 Development of Numerical Grids for UZ Flow and Transport Modeling (ANL-NBS-HS-000015 Rev. 00; CRWMS M&O 2000t)	A+M	
	C.5 Analysis of Geochemical Data for the UZ (ANL-NBS-HS-000017 Rev. 00 ICN 1; BSC 2001o)	A	
	C.6 Conceptual and Numerical Models of UZ Flow and Transport (MDL-NBS-HS-000005 Rev. 00; CRWMS M&O 2000q)	M	
	C.7 Natural Analogs for the UZ (ANL-NBS-HS-000007 Rev. 00; CRWMS M&O 2000bz)	A	
	C.8 Features, Events, and Processes in UZ Flow and Transport (ANL-NBS-MD-000001 Rev. 01; BSC 2001b)	A	
D. Mountain-Scale TH	D.1 Mountain-Scale Coupled Processes (TH) Models (MDL-NBS-HS-000007 Rev. 00; CRWMS M&O 2000av)	A+M	1 Unique AMR (C.8 is tallied in Area C)
	C.8 Features, Events, and Processes in UZ Flow and Transport (ANL-NBS-MD-000001 Rev. 01; BSC 2001b)	*A*	
E. Ambient/ Thermal Drift Seepage	E.1 Seepage Calibration Model and Seepage Testing Data (MDL-NBS-HS-000004 Rev. 01; CRWMS M&O 2001p)	M	4 Unique AMRs (C.8, I.6, and L.1 are tallied in Areas C, I, and L, respectively)
	E.2 Seepage Model for PA Including Drift Collapse (MDL-NBS-HS-000002 Rev. 01; CRWMS M&O 2000be)	M	
	E.3 Abstraction of Drift Seepage (ANL-NBS-MD-000005 Rev. 01; CRWMS M&O 2001b)	A+M	
	E.4 In Situ Field Testing of Processes (ANL-NBS-HS-000005 Rev. 00; CRWMS M&O 2000ca)	A	
	C.8 Features, Events, and Processes in UZ Flow and Transport (ANL-NBS-MD-000001 Rev. 01; BSC 2001b)	*A*	
	I.6 Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux (ANL-EBS-HS-000003 Rev. 00 ICN2; CRWMS M&O 2001c)	*A*	
	L.1 Drift Degradation Analysis (ANL-EBS-MD-000027 Rev. 01; CRWMS M&O 2000x)	*A+M*	
F. Mountain-Scale/Near-Field THC	F.1 Drift-Scale Coupled Processes (DST and THC Seepage) Models (MDL-NBS-HS-000001 Rev. 01 ICN 1; BSC 2001a)	A+M	3 Unique AMRs (I.1 & I.9 are tallied in Area I)
	F.2 Abstraction of Drift-Scale Coupled Processes (ANL-NBS-HS-000029 Rev. 00; CRWMS M&O 2000a)	A	
	F.3 Thermal Tests Thermal/Hydrological Analyses/Model Report (ANL-NBS-TH-000001 Rev. 00 ICN 1; CRWMS M&O 2000bk)	A+M	
	I.1 Multiscale Thermohydrologic Model (ANL-EBS-MD-000049 Rev. 00 ICN 1; CRWMS M&O 2000aw)	*M*	
	I.9 FEPs in Thermal Hydrology and Coupled Processes (ANL-NBS-MD-000004 Rev. 00 ICN 1; CRWMS M&O 2001j)	*A*	

Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review (continued)

1. Model Area	2. AMRs and Other Documents Reviewed [A]	3. Model or Analysis? [B]	4. # Unique Reports [C]
G. Mountain-Scale/ Near-Field THM	G.1 Calculation of Permeability Change Due to Coupled THM Effects (CAL-NBS-MD-000002 Rev. 00; CRWMS M&O 2000g) *I.9 FEPs in Thermal Hydrology and Coupled Processes (ANL-NBS-MD-000004 Rev. 00 ICN 1; CRWMS M&O 2001j)*	(calculation) *A*	No Unique AMRs (G.1 is a Calc. Report; I.9 is tallied in Area I)
H. In-Drift Chemistry	H.1 In-Drift Precipitates/Salts Analysis (ANL-EBS-MD-000045 Rev. 00 ICN 2; CRWMS M&O 2001*l*) H.2 Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier (ANL-EBS-MD-000001 Rev. 00 ICN 1; CRWMS M&O 2000ac) H.3 EBS Physical and Chemical Environment Model (ANL-EBS-MD-000033 Rev. 01; CRWMS M&O 2000ab) H.4 In-Drift Corrosion Products (ANL-EBS-MD-000041 Rev. 00; CRWMS M&O 1999g) H.5 In-Drift Gas Flux and Composition (ANL-EBS-MD-000040 Rev. 00; CRWMS M&O 2000am) H.6 In-Drift Microbial Communities (ANL-EBS-MD-000038 Rev. 00 ICN 1; CRWMS M&O 2000an) H.7 Seepage/Cement Interactions (ANL-EBS-MD-000043 Rev. 00; CRWMS M&O 2000bf) H.8 Physical and Chemical Environmental Abstraction Model (ANL-EBS-MD-000046 Rev. 00 ICN 1; CRWMS M&O 2000az) H.9 Precipitates/Salts Model Results for THC Abstraction (CAL-EBS-PA-000008 Rev. 00 ICN 1; CRWMS M&O 2001w) H.10 Seepage/Backfill Interaction (ANL-EBS-MD-000039 Rev. 00; CRWMS M&O 2000cb) *L.5 EBS Features, Events, and Processes (ANL-WIS-PA-000002 Rev. 01; CRWMS M&O 2001h)*	A+M A M M A A+M A M (calculation) A+M *A*	9 Unique AMRs (H.9 is a Calc. Report; L.5 is tallied in Area L)

Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review (continued)

1. Model Area	2. AMRs and Other Documents Reviewed [A]	3. Model or Analysis? [B]	4. # Unique Reports [C]
I. EBS Moisture Distribution and TH	I.1 Multiscale Thermohydrologic Model (ANL-EBS-MD-000049 Rev. 00 ICN 1; CRWMS M&O 2000aw)	M	8 Unique AMRs (I.8 is a Calc. Report; F.3, L.5, and M.5 are tallied in Areas F, L, and M, respectively.)
	I.2 Water Distribution and Removal Model (ANL-EBS-MD-000032 Rev. 01; CRWMS M&O 2001t)	A+M	
	I.3 Water Diversion Model (ANL-EBS-MD-000028 Rev. 00; CRWMS M&O 2000bu)	M	
	I.4 Water Drainage Model (ANL-EBS-MD-000029 Rev. 00 ICN 1; CRWMS M&O 2000bv)	M	
	I.5 Ventilation Model (ANL-EBS-MD-000030 Rev. 00; CRWMS M&O 2000bx)	M	
	I.6 Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux (ANL-EBS-HS-000003 Rev. 00 ICN2; CRWMS M&O 2001c)	A	
	I.7 In-Drift THC Model (ANL-EBS-MD-000026 Rev. 00 ICN 2; BSC 2001r)	A+M	
	I.8 Effective Thermal Conductivity for Drift-Scale Models Used in TSPA-SR (CAL-EBS-HS-000001 Rev. 00; CRWMS M&O 2001g)	(calculation)	
	I.9 FEPs in Thermal Hydrology and Coupled Processes (ANL-NBS-MD-000004 Rev. 00 ICN 1; CRWMS M&O 2001j)	A	
	F.3 Thermal Tests Thermal/Hydrological Analyses/Model Report (ANL-NBS-TH-000001 Rev. 00 ICN 1; CRWMS M&O 2000bk)	*A*	
	L.5 EBS Features, Events, and Processes (ANL-WIS-PA-000002 Rev. 01; CRWMS M&O 2001h)	*A*	
	M.5 EBS Radionuclide Transport Abstraction (ANL-WIS-PA-000001 Rev. 00 ICN 2; CRWMS M&O 2000z)	*M*	
J. Waste Package/ Drip Shield Degradation: General and Localized Corrosion	J.1 General and Localized Corrosion of the Waste Package Outer Barrier (ANL-EBS-MD-000003 Rev. 00; CRWMS M&O 2000ag)	M	12 Unique AMRs (J.7 and J.13 are Calc. Reports; H.2 is tallied in Area H).
	J.2 Aging and Phase Stability of the Waste Package Outer Barrier (ANL-EBS-MD-000002 Rev. 00; CRWMS M&O 2000d)	M	
	J.3 General and Localized Corrosion of the Drip Shield (ANL-EBS-MD-000004 Rev. 00; CRWMS M&O 2000af)	M	
	J.4 Degradation of Stainless Steel Structural Material (ANL-EBS-MD-000007 Rev. 00; CRWMS M&O 2000s)	M	
	J.5 Abstraction of Models for Pitting and Crevice Corrosion of Drip Shield and Waste Package Outer Barrier (ANL-EBS-PA-000003 Rev. 00; CRWMS M&O 2000b)	A+M	
	J.6 WAPDEG Analysis of Waste Package and Drip Shield Degradation (ANL-EBS-PA-000001 Rev. 00 ICN 1; CRWMS M&O 2000br)	A+M	
	J.7 Calculation of General Corrosion Rate of Drip Shield and Waste Package Outer Barrier to Support WAPDEG Analysis (CAL-EBS-PA-000002 Rev. 01; CRWMS M&O 2000f)	(calculation)	
	J.8 Incorporation of Uncertainty and Variability of Drip Shield and Waste Package Degradation in WAPDEG Analysis (ANL-EBS-MD-000036 Rev. 00; CRWMS M&O 2000ak)	A	
	H.2 Environment on the Surfaces of the Drip Shield and Waste Package Outer Barrier (ANL-EBS-MD-000001 Rev. 00 ICN 1; CRWMS M&O 2000ac)	*A*	

Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review (continued)

1. Model Area	2. AMRs and Other Documents Reviewed [A]	3. Model or Analysis? [B]	4. # Unique Reports [C]
J. Waste Package/ Drip Shield Degradation: Other Corrosion Modes	J.9 Analysis of Mechanisms for Early Waste Package Failure (ANL-EBS-MD-000023 Rev. 02; CRWMS M&O 2000cc)	A	
	J.10 Hydrogen Induced Cracking of Drip Shield (ANL-EBS-MD-000006 Rev. 00 ICN 1; CRWMS M&O 2000ah)	A+M	
	J.11 Stress-Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material (ANL-EBS-MD-000005 Rev. 00 ICN 1; CRWMS M&O 2000bi)	M	
	J.12 Abstraction of Models of Stress-Corrosion Cracking of Drip Shield and Waste Package Outer Barrier, and Hydrogen-Induced Corrosion of the Drip Shield (ANL-EBS-PA-000004 Rev. 00 ICN 1; CRWMS M&O 2000c)	A+M	
	J.13 Calculation of Probability and Size of Defect Flaws in Waste Package Closure Welds to Support WAPDEG Analysis (CAL-EBS-PA-000003 Rev. 00; CRWMS M&O 2000h)	(calculation)	
	J.14 FEPs Screening of Processes and Issues in Drip Shield and Waste Package Degradation (ANL-EBS-PA-000002 Rev. 01; CRWMS M&O 2001x)	A	
K. Waste Form Degradation: General Information	K.1 Inventory Abstraction (ANL-WIS-MD-000006 Rev. 00 ICN 2; BSC 2001i)	A	19 Unique AMRs (K.17, K.18, and K.19 are Calc. Reports)
	K.2 CSNF Waste Form Degradation Summary Abstraction (ANL-EBS-MD-000015 Rev. 00; CRWMS M&O 2000r)	A+M	
	K.3 DHLW Glass Degradation (ANL-EBS-MD-000016 Rev. 00 ICN 1; CRWMS M&O 2001f)	M	
	K.4 DSNF and Other Waste Form Degradation Abstraction (ANL-WIS-MD-000004 Rev. 01 ICN 1; BSC 2001n)	M	
	K.5 In-Package Source Term Abstraction (ANL-WIS-MD-000018 Rev. 00; CRWMS M&O 2000ap)	A+M	
K. Waste Form Degradation: In-Package Chemistry	K.6 Summary of In-Package Chemistry for Waste Forms (ANL-EBS-MD-000050 Rev. 00; CRWMS M&O 2000bj)	A+M	
	K.7 In-Package Chemistry Abstraction (ANL-EBS-MD-000037 Rev. 01; BSC 2001h)	M	
K. Waste Form Degradation: Solubility Constraints	K.8 Pure-Phase Solubility Limits – LANL (ANL-EBS-MD-000017 Rev. 00 ICN 1; CRWMS M&O 2001n)	A	
	K.9 Summary of Dissolved Concentration Limits (ANL-WIS-MD-000010 Rev. 01; CRWMS M&O 2001q)	A+M	
	K.10 Secondary Uranium Phase Paragenesis and Incorporation of Radionuclides Into Secondary Phases (ANL-EBS-MD-000019 Rev. 00; CRWMS M&O 2000bd)	A	

Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review (continued)

1. Model Area	2. AMRs and Other Documents Reviewed[A]	3. Model or Analysis?[B]	4. # Unique Reports[C]
K. Waste Form Degradation: Cladding Degradation	K.11 Initial Cladding Condition (ANL-EBS-MD-000048 Rev. 00 ICN 1; CRWMS M&O 2000ao)	A	
	K.12 Clad Degradation – Localized Corrosion of Zirconium and Its Alloys Under Repository Conditions (ANL-EBS-MD-000012 Rev. 00; CRWMS M&O 2000o)	A+M	
	K.13 Hydride-Related Degradation of SNF Cladding Under Repository Conditions (ANL-EBS-MD-000011 Rev. 00 ICN 1; CRWMS M&O 2001k)	A	
	K.14 Clad Degradation – Wet Unzipping (ANL-EBS-MD-000014 Rev. 00; CRWMS M&O 2000p)	M	
	K.15 Clad Degradation – Dry Unzipping (ANL-EBS-MD-000013 Rev. 00; CRWMS M&O 2000n)	A+M	
	K.16 Clad Degradation – Summary and Abstraction (ANL-WIS-MD-000007 Rev. 00 ICN 1; CRWMS M&O 2001d)	A	
	K.17 Stainless Steel in Waste Packages for TSPA-SR (CAL-WIS-MD-000010 Rev. 00; CRWMS M&O 2000bh)	(calculation)	
	K.18 Thermal Evaluation of Breached 21-PWR Waste Packages (CAL-UDC-ME-000002 Rev. 00; CRWMS M&O 1999f)	(calculation)	
	K.19 Breakage of CSNF Cladding by Mechanical Loading (CAL-EBS-MD-000001 Rev. 00; CRWMS M&O 1999a)	(calculation)	
	K.20 Clad Degradation – FEPs Screening Arguments (ANL-WIS-MD-000008 Rev. 00 ICN 1; CRWMS M&O 2000cd)	A	
K. Waste Form Degradation: Colloid Release	K.21 Colloid-Associated Radionuclide Concentration Limits: ANL (ANL-EBS-MD-000020 Rev. 00 ICN 1; CRWMS M&O 2001e)	A	
	K.22 Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary (ANL-WIS-MD-000012 Rev. 00 ICN 1; CRWMS M&O 2001s)	M	
L. EBS Degradation	L.1 Drift Degradation Analysis (ANL-EBS-MD-000027 Rev. 01; CRWMS M&O 2000x)	A+M	4 Unique AMRs (L.3 and L.4 are Calc. Reports; H.3, H.7, and H.10 are tallied in Area H, and M.5 is tallied in Area M)
	L.2 Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon (ANL-EBS-GE-000006 Rev. 00; CRWMS M&O 2000ae)	A+M	
	L.3 Rockfall on Drip Shield (CAL-EDS-ME-000001 Rev. 00; CRWMS M&O 2000bw)	(calculation)	
	L.4 Committed Materials in Repository Drifts (CAL-GCS-GE-000002 Rev. 00; BSC 2001p)	(calculation)	
	L.5 EBS Features, Events, and Processes (ANL-WIS-PA-000002 Rev. 01; CRWMS M&O 2001h)	A	
	L.6 Flow of Water and Pooling in a Waste Package (ANL-EBS-MD-000055 Rev. 00; BSC 2001c)	A+M	
	H.3 EBS Physical and Chemical Environment Model (ANL-EBS-MD-000033 Rev. 01; CRWMS M&O 2000ab)	*M*	
	H.7 Seepage/Cement Interaction (ANL-EBS-MD-000043 Rev. 00; CRWMS M&O 2000bf)	*A*	
	H.10 Seepage/Backfill Interaction (ANL-EBS-MD-000039 Rev. 00; CRWMS M&O 2000cb)	*A+M*	
	M.5 EBS Radionuclide Transport Abstraction (ANL-WIS-PA-000001 Rev. 00 ICN 2; CRWMS M&O 2000z)	*M*	

Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review (continued)

1. Model Area	2. AMRs and Other Documents Reviewed [A]	3. Model or Analysis? [B]	4. # Unique Reports [C]
M. EBS Radio-nuclide Transport	M.1 Invert Diffusion Properties Model (ANL-EBS-MD-000031 Rev. 01; CRWMS M&O 2000as)	M	5 Unique AMRs (L.5 is tallied in Area L)
	M.2 EBS Radionuclide Transport Model (ANL-EBS-MD-000034 Rev. 00 ICN 1; CRWMS M&O 2000aa)	A+M	
	M.3 In-Drift Colloids and Concentration (ANL-EBS-MD-000042 Rev. 00; CRWMS M&O 2000al)	M	
	M.4 Seepage/Invert Interactions (ANL-EBS-MD-000044 Rev. 00; CRWMS M&O 2000bg)	M	
	M.5 EBS Radionuclide Transport Abstraction (ANL-WIS-PA-000001 Rev. 00 ICN 2; CRWMS M&O 2000z)	M	
	L.5 EBS Features, Events, and Processes (ANL-WIS-PA-000002 Rev. 01; CRWMS M&O 2001h)	*A*	
N. UZ Transport	N.1 UZ and SZ Transport Properties (ANL-NBS-HS-000019 Rev. 00 ICN 1; CRWMS M&O 2001r)	A+M	8 Unique AMRs (C.8 is tallied in Area C)
	N.2 UZ Colloid Transport Model (ANL-NBS-HS-000028 Rev. 00; CRWMS M&O 2000bp)	A+M	
	N.3 Radionuclide Transport Models Under Ambient Conditions (MDL-NBS-HS-000008 Rev. 00; CRWMS M&O 2000ba)	A+M	
	N.4 Particle Tracking Model and Abstraction of Transport Processes (ANL-NBS-HS-000026 Rev. 00; CRWMS M&O 2000ay)	A+M	
	N.5 Analysis of Base-Case Particle Tracking Results of the Base-Case Flow Fields (ID: U0160) (ANL-NBS-HS-000024 Rev. 00; CRWMS M&O 2000ce)	A	
	N.6 Analysis Comparing Advective-Dispersive Transport Solution to Particle Tracking (ANL-NBS-HS-000001 Rev. 00; CRWMS M&O 2000cf)	A	
	N.7 Abstraction of Flow Fields for TSPA (ANL-NBS-HS-000023 Rev. 00 ICN 1; CRWMS M&O 2000cg)	A	
	N.8 Fault Displacement Effects on Transport in the UZ (ANL-NBS-HS-000020 Rev. 01; CRWMS M&O 2000ch)	A	
	C.8 Features, Events, and Processes in UZ Flow and Transport (ANL-NBS-MD-000001 Rev. 01; BSC 2001b)	*A*	
O. SZ Flow	O.1 Hydrogeologic Framework Model for the SZ Site-Scale Flow and Transport Model (ANL-NBS-HS-000033 Rev. 00 ICN 1; CRWMS M&O 2001z)	A+M	6 Unique AMRs
	O.2 Water Level Data Analysis for the SZ Site-Scale Flow and Transport Model (ANL-NBS-HS-000034 Rev. 00 ICN 1; USGS 2001b)	A	
	O.3 Recharge and Lateral Groundwater Flow Boundary Conditions for the SZ Site-Scale Flow and Transport Model (ANL-NBS-MD-000010 Rev. 00; CRWMS M&O 1999h)	A	
	O.4 Geochemical and Isotopic Constraints on Groundwater Flow Directions, Mixing, and Recharge (ANL-NBS-HS-000021 Rev. 00 ICN 1; CRWMS M&O 2001ab)	A	
	O.5 Calibration of the Site-Scale SZ Flow Model (MDL-NBS-HS-000011 Rev. 00; CRWMS M&O 2000j)	A+M	
	O.6 FEPs in Saturated Zone Flow and Transport (ANL-NBS-MD-000002 Rev. 01; CRWMS M&O 2001ac)	A	

Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review (continued)

1. Model Area	2. AMRs and Other Documents Reviewed [A]	3. Model or Analysis? [B]	4. # Unique Reports [C]
P. SZ Transport	P.1 Probability Distribution for Flowing Interval Spacing (ANL-NBS-MD-000003 Rev. 00 ICN 1; CRWMS M&O 2000cj)	A	6 Unique AMRs (N.1 and O.6 are tallied in Areas N and O, respectively)
	P.2 SZ Colloid Facilitated Transport (ANL-NBS-HS-000031 Rev. 00; CRWMS M&O 2000bc)	A+M	
	P.3 Uncertainty Distribution for Stochastic Parameters (ANL-NBS-MD-000011 Rev. 00; CRWMS M&O 2000bo)	A	
	P.4 Input and Results of the Base-Case SZ Flow and Transport Model for TSPA (ANL-NBS-HS-000030 Rev. 00; CRWMS M&O 2000aq)	A+M	
	P.5 SZ Transport Methodology and Transport Component Integration (MDL-NBS-HS-000010 Rev. 00; CRWMS M&O 2000ck)	M	
	P.6 Modeling Sub-Gridblock Scale Dispersion in 3-D Heterogeneous Fractured Media (ANL-NBS-HS-000022 Rev. 00 ICN 1; CRWMS M&O 2000au)	A+M	
	N.1 UZ and SZ Transport Properties (ANL-NBS-HS-000019 Rev. 00 ICN 1; CRWMS M&O 2001r)	*A+M*	
	O.6 FEPs in Saturated Zone Flow and Transport (ANL-NBS-MD-000002 Rev. 01; CRWMS M&O 2001ac)	*A*	
Q. Biosphere	Q.1 Groundwater Usage by the Proposed Farming Community (ANL-NBS-MD-000006 Rev. 00; CRWMS M&O 2000cl)	A	13 Unique AMRs
	Q.2 Identification of Ingestion Exposure Parameters (ANL-MGR-MD-000006 Rev. 00; CRWMS M&O 2000ai)	A	
	Q.3 Input Parameter Values for External and Inhalation Radiation Exposure Analysis (ANL-MGR-MD-000001 Rev. 01; CRWMS M&O 2000ar)	A	
	Q.4 Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods (ANL-MGR-MD-000002 Rev. 00; CRWMS M&O 1999b)	A	
	Q.5 Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water) (ANL-MGR-MD-000005 Rev. 01; CRWMS M&O 2001ad)	A	
	Q.6 Environmental Transport Parameter Analysis (ANL-MGR-MD-000007 Rev. 00 ICN 1; CRWMS M&O 2001ae)	A	
	Q.7 Transfer Coefficient Analysis (ANL-MGR-MD-000008 Rev. 00 ICN 2; CRWMS M&O 2000bn)	A	
	Q.8 Evaluate Soil/Radionuclide Removal by Erosion and Leaching (ANL-NBS-MD-000009 Rev. 00 ICN 1; CRWMS M&O 2001i)	A	
	Q.9 Nominal Performance Biosphere Dose Conversion Factor Analysis (ANL-MGR-MD-000009 Rev. 01; CRWMS M&O 2001m)	A+M	
	Q.10 Non-Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis (ANL-MGR-MD-000010 Rev. 00; CRWMS M&O 2000cm)	A	
	Q.11 Distribution Fitting to the Stochastic BDCF Data (ANL-NBS-MD-000008 Rev. 00 ICN 1; CRWMS M&O 2001af)	A	
	Q 12 Abstraction of BDCF Distributions for Irrigation Periods (ANL-NBS-MD-000007 Rev. 00 ICN 1; CRWMS M&O 2001a)	A	
	Q.13 Evaluation of the Applicability of Biosphere-Related FEPs (ANL-MGR-MD-000011 Rev. 01; BSC 2001q)	A	

Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review (continued)

1. Model Area	2. AMRs and Other Documents Reviewed [A]	3. Model or Analysis? [B]	4. # Unique Reports [C]
R. Disruptive Events: Igneous Disruption Consequences	R.1 Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (ANL-MGR-GS-000001 Rev. 00 ICN 1; CRWMS M&O 2000l)	A	8 Unique AMRs (R.6 is data; R.7 is a Calc. Report)
	R.2 Characterize Eruptive Processes at Yucca Mountain, Nevada (ANL-MGR-GS-000002 Rev. 00; CRWMS M&O 2000k)	A	
	R.3 Igneous Consequence Modeling for the TSPA-SR (ANL-WIS-MD-000017 Rev. 00 ICN 1; CRWMS M&O 2000aj)	M	
	R.4 Dike Propagation Near Drifts (ANL-WIS-MD-000015 Rev. 00 ICN 1; CRWMS M&O 2000u)	A	
	R.5 Disruptive Event Biosphere Dose Conversion Factor Analysis (ANL-MGR-MD-000003 Rev. 01; CRWMS M&O 2001ah)	A+M	
	R.6 Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis (ANL-MGR-MD-000004 Rev. 00; CRWMS M&O 2000cn)	A	
	R.7 DTN: MO0006SPAPVE03.001 (Documentation of BCDF input provided for TSPA-SR)	(data)	
	R.8 Miscellaneous Waste-Form FEPs (ANL-WIS-MD-000009 Rev. 00 ICN 1; CRWMS M&O 2001ai)	A	
	R.9 Number of Waste Packages Hit by Igneous Intrusion (CAL-WIS-PA-000001 Rev. 01; CRWMS M&O 2000ax)	(calculation)	
	R.10 Features, Events, and Processes: Disruptive Events (ANL-WIS-MD-000005 Rev. 00 ICN 1; CRWMS M&O 2000ad)	A	
S. Seismic Hazard	S.1 Characterize Framework for Seismicity and Structural Deformation at YM (ANL-CRW-GS-000003 Rev. 00; CRWMS M&O 2000m)	A	2 Unique AMRs (N.8 is tallied in Area N)
	S.2 Effects of Fault Displacement on Emplacement Drifts (ANL-EBS-GE-000004 Rev. 00 ICN 1; CRWMS M&O 2000co)	A	
	N.8 Fault Displacement Effects on Transport in the UZ (ANL-NBS-HS-000020 Rev. 01; CRWMS M&O 2000ch)	*A*	
T. Integrated Site Model	T.1 Geologic Framework Model (MDL-NBS-GS-000002 Rev. 00 ICN 2; BSC 2001e)	M	3 Unique AMRs
	T.2 Mineralogical Model (MDL-NBS-GS-000003 Rev. 00 ICN 1; CRWMS M&O 2000at)	M	
	T.3 Rock Properties Model (MDL-NBS-GS-000004 Rev. 00 ICN 2; CRWMS M&O 2000bb)	M	
U. PA Modeling	U.1 TSPA Model for SR (MDL-WIS-PA-000002 Rev. 00; CRWMS M&O 2000bl)	M	3 Unique AMRs (U.2 is a Technical Report)
	U.2 Total System Performance for Site Recommendation (TDR-WIS-PA-000001 Rev. 00 ICN 1; CRWMS M&O 2000bm)	(tech. report)	
	U.3 Features, Events, and Processes: System Level and Criticality (ANL-WIS-MD-000019 Rev. 00; CRWMS M&O 2000cq)	A	
	U.4 Performance Assessment and Sensitivity Analysis of Disposal of Plutonium as Can-in-Canister Ceramic (ANL-WIS-PA-000003 Rev. 00; CRWMS M&O 2001u)	A	

Table 1. List of Model Areas and Associated AMRs and Other Reports for Status Review (continued)

1. Model Area	2. AMRs and Other Documents Reviewed [A]	3. Model or Analysis? [B]	4. # Unique Reports [C]
	Number of Unique AMRs Among these Items (as reported in Column 4, not counting italicized items):		125
	Number of Other Calculation Reports, Technical Reports, and Data Assigned for Review (as reported in Column 4, not counting italicized items)		13

NOTES: [A] Italics denote documents which are principally assigned to another model area, and are tallied in that area.

[B] Model, analysis, or both as indicated on the AP-3.10Q cover sheet for the most recent version. Applicable to AMRs only.

[C] Tally for the number of unique AMRs in each model area, not including Calculation Reports, Technical Reports, DTNs, or reports tallied in other model areas.

Table 2. Original Planned Schedule of Tasks Performed for Model Validation Status Review

Task	Date Completed
1. Approve Technical Work Plan	7/11/01
2. Identify technical specialists and model-area leads	6/27/01
3. Conduct training workshops.	6/21/01 6/28/01 7/9-10/01
4. Complete electronic distribution of review materials	7/10/01
5. Receive reviews from lead technical specialists.	8/3/01
6. Conduct final workshop to report findings and formulate recommendations.	8/6-8/01
7. Receive additional input from model-area leads (Science & Analysis Project) on recommendations	8/14/01
8. Draft report sent to review team members for comments.	8/17/01
9. Consolidated draft submitted for checking and review.	8/27/01
10. Final approval	9/20/01
11. Distribute approved report to affected managers.	9/20/01
12. Submit Records Package.	9/30/01
13. Follow-up activities.	TBD

Table 3. List of Supplementary Materials Distributed to the Technical Specialists

Source	Comment
Documents	
Andresen, P.L. 1999. *Interim Report to TRW, "Stress Corrosion Crack Growth Measurements in Environments Relevant to High Level Nuclear Waste Packages", September 1999.*	Obtained from Records Information System
BSC (Bechtel SAIC Company) 2001f. *Ground Control for Emplacement Drifts for SR.* ANL-EBS-GE-000002 REV 00 ICN 01.	Obtained from Records Information System (unavailable from Document Control)
Brekke, T.L.; Cording, E.J.; Daemen, J.; Hart, R.D.; Hudson, J.A.; Kaiser, P.K.; and Pelizza, S. 1999. *Panel Report on the Drift Stability Workshop, Las Vegas. Nevada, December 9-11, 1998.*	Obtained from Records Information System
Budnitz, B.; Ewing, R.C.; Moeller, D.W.; Payer, J.; Whipple, C.; and Witherspoon, P.A. 1999. *Peer Review of the Total System Performance Assessment-Viability Assessment Final Report.*	Obtained from Records Information System
Chandler, N.; Davison, C.C.; Gee, G.; LaPointe, P.; and Neuman, S. 1999. *Yucca Mountain Project, A Consensus Peer Review of Predictions of Seepage into the Drifts of a Proposed Repository at Yucca Mountain.*	Obtained from Records Information System
Crouch, S.L. and Starfield, A.M. 1983. *Boundary Element Methods in Solid Mechanics, with Applications in Rock Mechanics and Geological Engineering.*	Textbook
CRWMS M&O 1999d. *Seismic Ground Motion Hazard Inputs.* Input Transmittal WP-NEP-99309.Ta.	Obtained from Records Information System
CRWMS M&O 1999e. *Seismic Ground Motion Hazard Inputs.* Input Transmittal WP-NEP-99309.T.	Obtained from Records Information System
CRWMS M&O 2000bt. *Waste Package Operations Fabrication Process Report.* TDR-EBS-ND-000003 REV 01.	Obtained from Document Control.
CRWMS M&O 2000w. *Disruptive Events Process Model Report.* TDR-NBS-MD-000002 REV 00 ICN 02.	Obtained from Document Control.
CRWMS M&O 2000bs. *Waste Package Degradation Process Model Report.* TDR-WIS-MD-000002 REV 00 ICN 02.	Obtained from Document Control.
40 CFR 197. 2001. Protection of Environment: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada. 40CFR197.html.	Cited the Electronic Code of Federal Regulations for latest version.
Fabryka-Martin, J.T.; Wolfsberg, A.V.; Dixon, P.R.; Levy, S.S.; Musgrave, J.A.; and Turin, H.J. 1997. *Summary Report of Chlorine-36 Studies: Sampling, Analysis, and Simulation of Chlorine-36 in the Exploratory Studies Facility.*	Obtained from Records Information System
Kelkar, S. and Travis, B. 1999. *Independent Test Case Report for TRACRN Version 1.0*	Obtained from Records Information System

Table 3. List of Supplementary Materials Distributed to the Technical Specialists (continued)

Source	Comment
Reimus, P.W.; Adams, A.; Haga, M.J.; Humphrey, A.; Callahan, T.; Anghel, I.; and Counce, D. 1999. *Results and Interpretation of Hydraulic and Tracer Testing in the Prow Pass Tuff at the C-Holes.*	Obtained from Records Information System
Robinson, B.A.; Wolfsberg, A.V.; Zyvoloski, G.A.; and Gable, C.W. 1995. *An Unsaturated Zone Flow and Transport Model of Yucca Mountain.*	Obtained from Records Information System
Turcotte, D.L. and Schubert, G. 1982. *Geodynamics, Applications of Continuum Physics to Geological Problems.*	Textbook
Data	
GS000508312332.001. Water-Level Data Analysis for the Saturated Zone Site-Scale Flow and Transport Model.	All data in this record were transmitted as supplementary review material.
LA0003AM831341.001. Probability Distributions for Sorption Coefficients (Kd's).	All data in this record were transmitted as supplementary review material.
MO0003SEPSDARS.002. Preliminary Seismic Design Acceleration Response Spectra for the Repository Level (Point B).	All data in this record were transmitted as supplementary review material.
SN9908T0581999.001. Recharge and Lateral Groundwater Flow Boundary Conditions for the Saturated Zone (SZ) Site-Scale Flow and Transport Model.	All data in this record were transmitted as supplementary review material.
Document Input Reference System (DIRS) Reports	
DIRS report listing all documents and data cited by the TSPA-SR Model AMR (CRWMS M&O 2000bl)	Report for DIRS reference 148384.
Edited compilation of DIRS reports listing Project reports cited by various documents assigned to Model Areas J and M in Table 1 (cited by: CRWMS M&O 2000b, 2000c, 2000d, 2000f, 2000h, 2000s, 2000ac, 2000af, 2000ag, 2000ah, 2000ak, 2000bi, 2000z, and 2000cc; and CRWMS M&O 2001x).	Compiled reports for DIRS references: 147648, 151549, 147639, 152542, 144551, 110182, 151568, 144971, 144229, 151559, 146546, 151564, 150792, 152097, and 153937.

Table 4. Assignment of Technical Specialists to Model Areas (X denotes supporting role)

Model Area	Rawlinson	Levitt	Porro	Swenson	Wood	Sayala	DeVries	Palmer	Mizia	Holmes	Osnes	Redden	Magnuson	Attanayake	Johnson	Bogen	Smith	Litehiser	Sholley	Yucel	Pawlowicz	Berkoe	Lee	Varma	Hanrahan	Layton	Callahan	Follin	Bostelman	Payne	Bassett	Anderson
A Climate	Lead																															
B Infiltration		Lead																														
C Unsaturated Zone Flow			Lead										X	X																		
D Mountain-Scale Thermal-Hydrology				Lead																		X										
E Ambient/Thermal Drift Seepage	X	X			Lead																											
F Mountain-Scale/Near-Field Thermal-Hydrologic-				X		Lead																									X	
G Mountain-Scale/Near-Field Thermal-Hydrologic-							Lead																									
H In-Drift Chemistry						X		Lead							X																X	
I EBS Moisture Distribution and Thermal-Hydrology				Lead																		X										
J Waste Package/Drip Shield Degradation									Lead															X	X				X			X
K Waste Form Degradation										Lead														X	X			X				
L Engineered Barrier System Degradation							X	X			Lead																					
M Engineered Barrier System Radionuclide Transport											X	Lead																				
N Unsaturated Zone Transport			X									X	Lead																			
O Saturated Zone Flow														Lead					X		X											
P Saturated Zone Transport					X										Lead						X											
Q Biosphere																Lead										X						
R Disruptive Events - Igneous Disruption																	Lead										X			X		
S Seismic Hazard																		Lead					X									
T Integrated Site Model											X								Lead													
U Performance Assessment Modeling																X				Lead							X					

Table 5. Model Area Leads, Representing Responsible Project Staff

Model Area	Assigned Staff (see note)
A Climate	Ming Zhu/Bo Bodvarsson
B Infiltration	Ming Zhu/Bo Badvarsson
C UZ Flow	Ming Zhu/Bo Bodvarsson
D Mountain-Scale TH	Ming Zhu/Bo Bodvarsson
E Ambient/Thermal Drift Seepage	Ming Zhu/Bo Bodvarsson
F Mountain-Scale/Near-Field THC	Dave Dobson/Yvonne Tsang
G Mountain-Scale/Near-Field THM	Dave Dobson/Yvonne Tsang
H In-Drift Chemistry	Bob MacKinnon
I EBS Moisture Distribution and TH	Bob MacKinnon
J Waste Package/Drip Shield Degradation	Tammy Summers
K Waste Form Degradation	Christine Stockman
L EBS Degradation	Bob MacKinnon
M EBS Radionuclide Transport	Bob MacKinnon
N UZ Transport	Ming Zhu/Bo Bodvarsson
O SZ Flow	Al Eddebbarh
P SZ Transport	Al Eddebbarh
Q Biosphere	Tony Smith
R Disruptive Events - Igneous Disruption	Richard Quittmeyer
S Seismic Hazard	Richard Quittmeyer
T Integrated Site Model	Clinton Lum
U PA Modeling	Jerry McNeish

Note: Selection and participation of Model Area Leads is discussed in Section 5.2.

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
A. Climate	A.1 Future Climate Analysis (ANL-NBS-GS-000008 Rev. 00)	Precession-Based Orbital Clock (A.1)	1
		Bin Subtotals: Bin 1: 1 Bin 2: 0 Bin 3: 0	
B. Infiltration	B.1 Simulation Net Infiltration for Modern and Potential Future Climates (ANL-NBS-HS-000032 Rev. 00 ICN 1) B.2 Analysis of Infiltration Uncertainty (ANL-NBS-HS-000027 Rev. 00)	Net Infiltration Model (B.1)	2
		Bin Subtotals: Bin 1: 0 Bin 2: 1 Bin 3: 0	
C. UZ Flow	C.1 UZ Flow Models and Submodels (MDL-NBS-HS-000006 Rev. 00) C.2 Calibrated Properties Model (MDL-NBS-HS-000003 Rev. 00) C.3 Analysis of Hydrologic Properties Data (ANL-NBS-HS-000002 Rev. 00) C.4 Development of Numerical Grids for UZ Flow and Transport Modeling (ANL-NBS-HS-000015 Rev. 00) C.5 Analysis of Geochemical Data for the UZ (ANL-NBS-HS-000017 Rev. 00 ICN 1) C.6 Conceptual and Numerical Models of UZ Flow and Transport (MDL-NBS-HS-000005 Rev. 00) C.7 Natural Analogs for the UZ (ANL-NBS-HS-000007 Rev. 00) C.8 Features, Events, and Processes in UZ Flow and Transport (ANL-NBS-MD-000001 Rev. 01)	Conceptual Model of UZ Flow (C.6-1) Numerical Grids Model (C.4) Numerical Model of UZ Flow (C.6-2) Active Fracture Model (C.6-3) Calibrated Properties Model (C.2) UZ Flow Model (C.1-1) Geothermal Model (C.1-2) Conceptual Model of Perched Water (C.1-3) 3-D Perched Water Calibration Model (C.1-4)	2 2 2 2 2 1 1 1 1
		Bin Subtotals: Bin 1: 4 Bin 2: 5 Bin 3: 0	
D Mountain-Scale TH	D.1 Mountain-Scale Coupled Processes (TH) Models (MDL-NBS-HS-000007 Rev. 00) *C.8 Features, Events, and Processes in UZ Flow and Transport (ANL-NBS-MD-000001 Rev. 01)*	Mountain-Scale Coupled Processes (TH) Model (D.1)	2
		Bin Subtotals: Bin 1: 0 Bin 2: 1 Bin 3: 0	
E. Ambient/ Thermal Drift Seepage	E.1 Seepage Calibration Model and Seepage Testing Data (MDL-NBS-HS-000004 Rev. 01) E.2 Seepage Model for PA Including Drift Collapse (MDL-NBS-HS-000002 Rev. 01) E.3 Abstraction of Drift Seepage (ANL-NBS-MD-000005 Rev. 01) E.4 In Situ Field Testing of Processes (ANL-NBS-HS-000005 Rev. 00) *C.8 Features, Events, and Processes in UZ Flow and Transport (ANL-NBS-MD-000001 Rev. 01)* *I.6 Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux (ANL-EBS-HS-000003 Rev. 00 ICN2)* *L.1 Drift Degradation Analysis (ANL-EBS-MD-000027 Rev. 01)*	Seepage Calibration Model (E.1) Seepage Model for PA Including Drift Collapse (E.2) Abstraction of Drift Seepage (E.3-1) Abstraction of Thermal Seepage Effects (E.3-2)	2 2 2 2
		Bin Subtotals: Bin 1: 0 Bin 2: 4 Bin 3: 0	

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
F. Mountain-Scale/ Near-Field THC	F.1 Drift-Scale Coupled Processes (DST and THC Seepage) Models (MDL-NBS-HS-000001 Rev. 01 ICN 1) F.2 Abstraction of Drift-Scale Coupled Processes (ANL-NBS-HS-000029 Rev. 00) F.3 Thermal Tests Thermal/Hydrological Analyses/Model Report (ANL-NBS-TH-000001 Rev. 00 ICN 1) *I.1 Multiscale Thermohydrologic Model (ANL-EBS-MD-000049 Rev. 00 ICN 1)* *I.9 FEPs in Thermal Hydrology and Coupled Processes (ANL-NBS-MD-000004 Rev. 00 ICN 1)*	DST THC Calibration Model (F.1-1) THC Seepage Model (F.1-2) **Bin Subtotals: Bin 1: 0 Bin 2: 2 Bin 3: 0**	2 2
G. Mountain-Scale/ Near-Field THM	G.1 Calculation of Permeability Change Due to Coupled THM Effects (CAL-NBS-MD-000002 Rev. 00) *I.9 FEPs in Thermal Hydrology and Coupled Processes (ANL-NBS-MD-000004 Rev. 00 ICN 1)*	THM Model (G.1) **Bin Subtotals: Bin 1: 0 Bin 2: 0 Bin 3: 1**	3
H In-Drift Chemistry	H.1 In-Drift Precipitates/Salts Analysis (ANL-EBS-MD-000045 Rev. 00 ICN 2) H.2 Environment on the Surfaces of the DS and WP Outer Barrier (ANL-EBS-MD-000001 Rev. 00 ICN 1) H.3 EBS Physical and Chemical Environment Model (ANL-EBS-MD-000033 Rev. 01) H.4 In-Drift Corrosion Products (ANL-EBS-MD-000041 Rev. 00) H.5 In-Drift Gas Flux and Composition (ANL-EBS-MD-000040 Rev. 00) H.6 In-Drift Microbial Communities (ANL-EBS-MD-000038 Rev. 00 ICN 1) H.7 Seepage/Cement Interactions (ANL-EBS-MD-000043 Rev. 00) H.8 Physical and Chemical Environmental Abstraction Model (ANL-EBS-MD-000046 Rev. 00 ICN 1) H.9 Precipitates/Salts Model Results for THC Abstraction (CAL-EBS-PA-000008 Rev. 00 ICN 1) H.10 Seepage/Backfill Interaction (ANL-EBS-MD-000039 Rev. 00) *L.5 EBS Features, Events, and Processes (ANL-WIS-PA-000002 Rev. 01)*	High-Relative Humidity Salts Model (H.1) In-Drift Microbial Communities (H.6) Gas Flux and Fugacity Model (H.3-1) In-Drift Gas Flux and Composition Model (H.5) Cement Grout Model (H.3-2) Seepage/Cement Interaction Model (H.7) Corrosion of Steel Used in the Ex-Container EBS (H.3-3) Effect of Evaporation in the Invert (H.3-4) EBS Colloids Model (H.3-5) Normative Precipitates/Salts Model (H.3-6) **Bin Subtotals: Bin 1: 0 Bin 2: 5 Bin 3: 5**	2 2 2 2 3 3 3 3 3 2

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
I. EBS Moisture Distribution and TH	I.1 Multiscale Thermohydrologic Model (ANL-EBS-MD-000049 Rev. 00 ICN 1)	Multiscale TH Model (I.1)	2
	I.2 Water Distribution and Removal Model (ANL-EBS-MD-000032 Rev. 01)	Water Drainage (I.2-1)	2
	I.3 Water Diversion Model (ANL-EBS-MD-000028 Rev. 00)	Water Diversion (I.2-2)	1
	I.4 Water Drainage Model (ANL-EBS-MD-000029 Rev. 00 ICN 1)	Thermohydrologic Model (I.2-3)	2
	I.5 Ventilation Model (ANL-EBS-MD-000030 Rev. 00)	DS Condensation Model (I.2-4)	2
	I.6 Abstraction of NFE Drift Thermodynamic Environment and Percolation Flux (ANL-EBS-HS-000003 Rev. 00 ICN2)	In-Drift THC Model (I.7)	3
	I.7 In-Drift THC Model (ANL-EBS-MD-000026 Rev. 00 ICN 2)	Effective Thermal Conductivity Model (I.8)	3
	I.8 Effective Thermal Conductivity for Drift-Scale Models Used in TSPA-SR (CAL-EBS-HS-000001 Rev. 00)	Ventilation Model (I.5)	3
	I.9 FEPs in Thermal Hydrology and Coupled Processes (ANL-NBS-MD-000004 Rev. 00 ICN 1)		
	F.3 Thermal Tests Thermal/Hydrological Analyses/Model Report (ANL-NBS-TH-000001 Rev. 00 ICN 1)		
	L.5 EBS Features, Events, and Processes (ANL-WIS-PA-000002 Rev. 01)	**Bin Subtotals: Bin 1: 1 Bin 2: 4 Bin 3: 3**	
	M.5 EBS Radionuclide Transport Abstraction (ANL-WIS-PA-000001 Rev. 00 ICN 2)		

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
J. Waste Package/ Drip Shield Degra-dation: General and Localized Corrosion	J.1 General and Localized Corrosion of the WP Outer Barrier (ANL-EBS-MD-000003 Rev. 00) J.2 Aging and Phase Stability of the WP Outer Barrier (ANL-EBS-MD-000002 Rev. 00) J.3 General and Localized Corrosion of the DS (ANL-EBS-MD-000004 Rev. 00) J.4 Degradation of Stainless Steel Structural Material (ANL-EBS-MD-000007 Rev. 00) J.5 Abstraction of Models for Pitting and Crevice Corrosion of DS and WP Outer Barrier (ANL-EBS-PA-000003 Rev. 00) J.6 WAPDEG Analysis of WP and DS Degradation (ANL-EBS-PA-000001 Rev. 00 ICN 1) J.7 Calculation of General Corrosion Rate of DS and WP Outer Barrier to Support WAPDEG Analysis (CAL-EBS-PA-000002 Rev. 01) J.8 Incorporation of Uncertainty and Variability of DS and WP Degradation in WAPDEG Analysis (ANL-EBS-MD-000036 Rev. 00) *H.2* Environment *on the Surfaces of the DS and WP Outer Barrier (ANL-EBS-MD -000001Rev. 00 ICN 1)*	General & Localized Corrosion of the WPOB (J.1)	2
		Aging and Phase Stability: Precipitation Model (J.2-1)	2
		Aging and Phase Stability: Long Range Ordering Model (J.2-2)	2
		General and Localized Corrosion of the Drip Shield (J.3)	2
		Degradation of Stainless Steel Structural Materials (J.4)	2
		Alloy-22 Potential-Based Localized Corrosion Initiation Threshold and Rate Abstraction Model (J.5-1)	1
		Ti Grade 7 Potential-Based Localized Corrosion Initiation Threshold and Rate Abstraction Model (J.5-2)	1
		WAPDEG Analysis of WP and DS Degradation (J.6)	3
		Calculation of General Corrosion Rate of DS and WPOB to Support WAPDEG Analysis (J.7)	2
		Incorporation of Uncertainty and Variability of DS and WP Degradation in WAPDEG (J.8)	3
		Bin Subtotals: Bin 1: 2 Bin 2: 6 Bin 3: 2	

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
J. Waste Package/ Drip Shield Degradation: Other Corrosion Modes	J.9 Analysis of Mechanisms for Early WP Failure (ANL-EBS-MD-000023 Rev. 02) J.10 Hydrogen Induced Cracking of DS (ANL-EBS-MD-000006 Rev. 00 ICN 1) J.11 Stress-Corrosion Cracking of the DS, the WP Outer Barrier, and the Stainless Steel Structural Material (ANL-EBS-MD-000005 Rev. 00 ICN 1) J.12 Abstraction of Models of Stress-Corrosion Cracking of Drip Shield and WP Outer Barrier, and Hydrogen-Induced Corrosion of the DS (ANL-EBS-PA-000004 Rev. 00 ICN 1) J.13 Calculation of Probability and Size of Defect Flaws in WP Closure Welds to Support WAPDEG Analysis (CAL-EBS-PA-000003 Rev. 00) J.14 FEPs Screening of Processes and Issues in DS and WP Degradation (ANL-EBS-PA-000002 Rev. 01)	DS Passive Corrosion (J.10-1)	2
		DS Galvanic Coupling (J.10-2)	2
		SCC Threshold Model (J.11-1)	2
		SCC Slip Dissolution/Film Rupture Model (J.11-2)	2
		Manufacturing Defects Abstraction Model (J.12-1)	2
		Stress and Stress Intensity Factor Profile Abstraction (J.12-2)	2
		Slip Dissolution Abstraction Model (J.12-3)	2
		Threshold Stress Intensity Factor Abstraction Model (J.12-4)	2
		Bin Subtotals: Bin 1: 0 Bin 2: 8 Bin 3: 0	
K. Waste Form Degradation: General Information	K.1 Inventory Abstraction (ANL-WIS-MD-000006 Rev. 00 ICN 2) K.2 CSNF Waste Form Degradation Summary Abstraction (ANL-EBS-MD-000015 Rev. 00) K.3 DHLW Glass Degradation (ANL-EBS-MD-000016 Rev. 00 ICN 1) K.4 DSNF and Other Waste Form Degradation Abstraction (ANL-WIS-MD-000004 Rev. 01 ICN 1) K.5 In-Package Source Term Abstraction (ANL-WIS-MD-000018 Rev. 00)	Inventory Abstraction (K.1)	2
		CSNF Waste Form Summary Degradation Abstraction (K.2)	1
		DHLW Glass Degradation (K.3)	2
		Waste Form Degradation Abstract. - Upper Limit Model (K.4-1)	2
		Waste Form Degradation Abstraction – Conservative Model (K.4-2)	2
		Waste Form Degradation Abstraction – Best Estimate Model (K.4-3)	3
		Waste Form Degradation Abstraction – Immobilized Pu Model (K.4-4)	3
		Bin Subtotals: Bin 1: 1 Bin 2: 4 Bin 3: 2	
K. Waste Form Degradation: In-Package Chemistry	K.6 Summary of In-Package Chemistry for Waste Forms (ANL-EBS-MD-000050 Rev. 00) K.7 In-Package Chemistry Abstraction (ANL-EBS-MD-000037 Rev. 01)	In-Package Source Term Abstraction (K.5)	1
		In-Package Chemistry for Waste Forms (K.6)	2
		In-Package Chemistry Abstraction (K.7)	2
		Bin Subtotals: Bin 1: 1 Bin 2: 2 Bin 3: 0	

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
K Waste Form Degradation: Solubility Constraints	K.8 Pure-Phase Solubility Limits – LANL (ANL-EBS-MD-000017 Rev. 00 ICN 1) K.9 Summary of Dissolved Concentration Limits (ANL-WIS-MD-000010 Rev. 01) K.10 Secondary Uranium Phase Paragenesis and Incorporation of Radionuclides Into Secondary Phases (ANL-EBS-MD-000019 Rev. 00)	Pure-Phase Solubility Limits (K.8) Dissolved Concentration Limits (K.9) Secondary Uranium-Phase Paragenesis and Incorporation of Radionuclides into Secondary Phases (K.10) **Bin Subtotals: Bin 1: 0 Bin 2: 3 Bin 3: 0**	2 2 2
K. Waste Form Degradation: Cladding Degradation	K.11 Initial Cladding Condition (ANL-EBS-MD-000048 Rev. 00 ICN 1) K.12 Clad Degradation – Localized Corrosion of Zirconium and Its Alloys Under Repository Conditions (ANL-EBS-MD-000012 Rev. 00) K.13 Hydride-Related Degradation of SNF Cladding Under Repository Conditions (ANL-EBS-MD-000011 Rev. 00 ICN 1) K.14 Clad Degradation – Wet Unzipping (ANL-EBS-MD-000014 Rev. 00) K.15 Clad Degradation – Dry Unzipping (ANL-EBS-MD-000013 Rev. 00) K.16 Clad Degradation – Summary and Abstraction (ANL-WIS-MD-000007 Rev. 00 ICN 1) K.17 Stainless Steel in WPs for TSPA-SR (CAL-WIS-MD-000010 Rev. 00) K.18 Thermal Evaluation of Breached 21-PWR WPs (CAL-UDC-ME-000002 Rev. 00) K.19 Breakage of CSNF Cladding by Mechanical Loading (CAL-EBS-MD-000001 Rev. 00) K.20 Clad Degradation – FEPs Screening Arguments (ANL-WIS-MD-000008 Rev. 00 ICN 1)	Initial Oxide Thickness (K.11-1) Rod Internal Pressure (K.11-2) Cladding Crack Depth (K.11-3) Overall Cladding Stress (K.11-4) Initial Rod Failure (K.11-5) Zircaloy Corrosion Rate (K.12) Residual Stress in CSNF Cladding Material (K.13) Alternative Wet Clad Unzipping Model (K.14-1) Bounding Model for Clad Unzipping Velocity (K.14-2) Clad Dry Unzipping Model (K.15) Summary and Abstraction - Clad Unzipping and Fuel Dissolution (K.16) Stainless Steel in WPs for TSPA-SR (K.17) Thermal Evaluation of Breached 21-PWR WPs (K.18) Breakage of CSNF Cladding by Seismic Loading (K.19-1) Breakage of CSNF Cladding by Static Loading (K.19-2) **Bin Subtotals: Bin 1: 1 Bin 2: 9 Bin 3: 5**	2 2 2 2 2 2 2 3 1 2 3 2 3 3 3

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
K. Waste Form Degradation: Colloid Release	K.21 Colloid-Associated Radionuclide Concentration Limits: ANL (ANL-EBS-MD-000020 Rev. 00 ICN 1) K.22 Waste Form Colloid-Associated Concentration Limits: Abstraction and Summary (ANL-WIS-MD-000012 Rev. 00 ICN 1)	Colloid-Associated Radionuclide Concentration Limits (K.21) WF Colloid-Associated Concentration Limits: Abstraction and Summary (K.22) **Bin Subtotals: Bin 1: 0 Bin 2: 2 Bin 3: 0**	2 2
L. EBS Degradation	L.1 Drift Degradation Analysis (ANL-EBS-MD-000027 Rev. 01) L.2 Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon (ANL-EBS-GE-000006 Rev. 00;) L.3 Rockfall on DS (CAL-EDS-ME-000001 Rev. 00) L.4 Committed Materials in Repository Drifts (CAL-GCS-GE-000002 Rev. 00) L.5 EBS Features, Events, and Processes (ANL-WIS-PA-000002 Rev. 01) L.6 Flow of Water and Pooling in a WP (ANL-EBS-MD-000055 Rev. 00) *H.3 EBS Physical and Chemical Environment Model (ANL-EBS-MD-000033 Rev. 01)* *H.7 Seepage/Cement Interaction (ANL-EBS-MD-000043 Rev. 00)* *H.10 Seepage/Backfill Interaction (ANL-EBS-MD-000039 Rev. 00)* *M.5 EBS Radionuclide Transport Abstraction (ANL-WIS-PA-000001 Rev. 00 ICN 2)*	DRKBA Rockfall Model (L.1) Rockfall on DS Model (L.3) Flow into WPs Through Small Lid Openings Model (L.6) **Bin Subtotals: Bin 1: 0 Bin 2: 1 Bin 3: 2**	3 2 3
M EBS Radionuclide Transport	M.1 Invert Diffusion Properties Model (ANL-EBS-MD-000031 Rev. 01) M.2 EBS Radionuclide Transport Model (ANL-EBS-MD-000034 Rev. 00 ICN 1) M.3 In-Drift Colloids and Concentration (ANL-EBS-MD-000042 Rev. 00) M.4 Seepage/Invert Interactions (ANL-EBS-MD-000044 Rev. 00) M.5 EBS Radionuclide Transport Abstraction (ANL-WIS-PA-000001 Rev. 00 ICN 2) *L.5 EBS Features, Events, and Processes (ANL-WIS-PA-000002 Rev. 01)*	In-Drift Colloids and Concentrations (M.3) Invert Diffusion Properties Model (M.1) In-Drift Transport of Radionuclides (M.2) EBS Radionuclide Transport Abstraction Model (M.5) Seepage/Invert Interactions Model (M.4) **Bin Subtotals: Bin 1: 0 Bin 2: 1 Bin 3: 4**	3 2 3 3 3
N. UZ Transport	N.1 UZ and SZ Transport Properties (ANL-NBS-HS-000019 Rev. 00 ICN 1) N.2 UZ Colloid Transport Model (ANL-NBS-HS-000028 Rev. 00) N.3 Radionuclide Transport Models Under Ambient Conditions (MDL-NBS-HS-000008 Rev. 00) N.4 Particle Tracking Model and Abstraction of Transport Processes (ANL-NBS-HS-000026 Rev. 00) N.5 Analysis of Base-Case Particle Tracking Results of the Base-Case Flow Fields (ID: U0160) (ANL-NBS-HS-000024 Rev. 00) N.6 Analysis Comparing Advective-Dispersive Transport Solution to Particle Tracking (ANL-NBS-HS-000001 Rev. 00) N.7 Abstraction of Flow Fields for TSPA (ANL-NBS-HS-000023 Rev. 00 ICN 1)	Equilibrium Matrix Sorption Basis (N.1-1) Fracture Sorption (N.1-2) Matrix Diffusion (N.1-3) Colloid Transport (N.2-1) Pu Sorption on Colloids (N.2-2) FRACL Calibration to Borehole Chloride (N.3-1) EOS9nT Calibration to ESF Chloride Profile (N.3-2) Fracture-to-Matrix Colloid Filtration (N.4)	2 2 2 1 2 3 2 2

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
N. UZ Transport (continued)	N.8 Fault Displacement Effects on Transport in the UZ (ANL-NBS-HS-000020 Rev. 01) *C.8 Features, Events, and Processes in UZ Flow and Transport (ANL-NBS-MD-000001 Rev. 01*	**Bin Subtotals: Bin 1: 1 Bin 2: 6 Bin 3: 1**	
O. SZ Flow	O.1 Hydrogeologic Framework Model for the SZ Site-Scale Flow and Transport Model (ANL-NBS-HS-000033 Rev. 00 ICN 1) O.2 Water Level Data Analysis for the SZ Site-Scale Flow and Transport Model (ANL-NBS-HS-000034 Rev. 00 ICN 1) O.3 Recharge and Lateral Groundwater Flow Boundary Conditions for the SZ Site-Scale Flow and Transport Model (ANL-NBS-MD-000010 Rev. 00) O.4 Geochemical and Isotopic Constraints on Groundwater Flow Directions, Mixing, and Recharge (ANL-NBS-HS-000021 Rev. 00 ICN 1) O.5 Calibration of the Site-Scale SZ Flow Model (MDL-NBS-HS-000011 Rev. 00) O.6 FEPs in Saturated Zone Flow and Transport (ANL-NBS-MD-000002 Rev. 01)	Site-Scale Saturated Zone Flow Model (O.5) **Bin Subtotals: Bin 1: 0 Bin 2: 1 Bin 3: 0**	2
P. SZ Transport	P.1 Probability Distribution for Flowing Interval Spacing (ANL-NBS-MD-000003 Rev. 00 ICN 1) P.2 SZ Colloid Facilitated Transport (ANL-NBS-HS-000031 Rev. 00) P.3 Uncertainty Distribution for Stochastic Parameters (ANL-NBS-MD-000011 Rev. 00) P.4 Input and Results of the Base-Case SZ Flow and Transport Model for TSPA (ANL-NBS-HS-000030 Rev. 00) P.5 SZ Transport Methodology and Transport Component Integration (MDL-NBS-HS-000010 Rev. 00) P.6 Modeling Sub-Gridblock Scale Dispersion in 3-D Heterogeneous Fractured Media (ANL-NBS-HS-000022 Rev. 00 ICN 1) *N.1 UZ and SZ Transport Properties (ANL-NBS-HS-000019 Rev. 00 ICN 1)* *O.6 FEPs in* Saturated *Zone Flow and Transport (ANL-NBS-MD-000002 Rev. 01)*	Sub-Gridblock Scale Dispersion in 3-Dimensional Heterogeneous Fractured Media (P.6) Saturated Zone Colloid Facilitated Transport (P.2) Pipe Model for Daughter Radionuclides (P.4-1) Abstraction of FEHM and Coupling with UZ Mass Flux (P.4-2) Transport Parameters from C-Wells and Laboratory Studies (P.4-3) **Bin Subtotals: Bin 1: 1 Bin 2: 2 Bin 3: 2**	1 2 2 3 3
Q. Biosphere	Q.1 Groundwater Usage by the Proposed Farming Community (ANL-NBS-MD-000006 Rev. 00) Q.2 Identification of Ingestion Exposure Parameters (ANL-MGR-MD-000006 Rev. 00) Q.3 Input Parameter Values for External and Inhalation Radiation Exposure Analysis (ANL-MGR-MD-000001 Rev. 01) Q.4 Dose Conversion Factor Analysis: Evaluation of GENII-S Dose Assessment Methods (ANL-MGR-MD-000002 Rev. 00) Q.5 Identification of the Critical Group (Consumption of Locally Produced Food and Tap Water) (ANL-MGR-MD-000005 Rev. 01) Q.6 Environmental Transport Parameter Analysis (ANL-MGR-MD-000007 Rev. 00 ICN 1)	Crop Interception Fraction Submodel (Q.2-1) Irrigation Rate Submodel (Q.2-2) Dose Conversion for Ingestion (Q.4-1) Dose Conversion for Inhalation (Q.4-2) Dose Conversion for External Exposure (Q.4-3) Resuspension Model (Q.9-2) Plant Uptake Model (Q.9-3) Surface Soil Model in GENII-S (Q.9-1) Radionuclide Transfer to Animals (Q.9-4) Radionuclide Transfer to Aquatic Food (Q.9-5)	1 1 1 1 2 2 2 3 3 3

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
Q. Biosphere, continued	Q.7 Transfer Coefficient Analysis (ANL-MGR-MD-000008 Rev. 00 ICN 2) Q.8 Evaluate Soil/Radionuclide Removal by Erosion and Leaching (ANL-NBS-MD-000009 Rev. 00 ICN 1) Q.9 Nominal Performance Biosphere Dose Conversion Factor Analysis (ANL-MGR-MD-000009 Rev. 01) Q.10 Non-Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis (ANL-MGR-MD-000010 Rev. 00) Q.11 Distribution Fitting to the Stochastic BDCF Data (ANL-NBS-MD-000008 Rev. 00 ICN 1) Q.12 Abstraction of BDCF Distributions for Irrigation Periods (ANL-NBS-MD-000007 Rev. 00 ICN 1) Q.13 Evaluation of the Applicability of Biosphere-Related FEPs (ANL-MGR-MD-000011 Rev. 01)	**Bin Subtotals: Bin 1: 4 Bin 2: 3 Bin 3: 3**	
R. Disruptive Events: Igneous Disruption Conse-quences	R.1 Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (ANL-MGR-GS-000001 Rev. 00 ICN 1) R.2 Characterize Eruptive Processes at Yucca Mountain, Nevada (ANL-MGR-GS-000002 Rev. 00) R.3 Igneous Consequence Modeling for the TSPA-SR (ANL-WIS-MD-000017 Rev. 00 ICN 1) R.4 Dike Propagation Near Drifts (ANL-WIS-MD-000015 Rev. 00 ICN 1) R.5 Disruptive Event Biosphere Dose Conversion Factor Analysis (ANL-MGR-MD-000003 Rev. 01) R.6 Disruptive Event Biosphere Dose Conversion Factor Sensitivity Analysis (ANL-MGR-MD-000004 Rev. 00) R.7 DTN: MO0006SPAPVE03.001 (Documentation of BCDF input provided for TSPA-SR) R.8 Miscellaneous Waste-Form FEPs (ANL-WIS-MD-000009 Rev. 00 ICN 1) R.9 Number of WPs Hit by Igneous Intrusion (CAL-WIS-PA-000001 Rev. 01) R.10 Features, Events, and Processes: Disruptive Events (ANL-WIS-MD-000005 Rev. 00 ICN 1)	Conditional Distribution for Number of Eruptive Centers Model (R.1) Geometry of Volcanic Feeder System Model (R.2) Volcanic Eruption Release Model (R.3-1) In-drift Damage Due to Dike Intersection Model (R.3-2) Mass Loading Decay Model Following Deposition of Volcanic Ash (R.5-1) Dose Conversion Factor Model for Inhalation – Igneous Disruption (R.5-2) **Bin Subtotals: Bin 1: 0 Bin 2: 5 Bin 3: 1**	2 3 2 2 2 2

Table 6. Summary of Binning Results from Model Validation Status Review, for Each Model Area (continued)

1. Model Area	2. AMRs and Other Documents (see note)	3. Models Identified	4. Bin
S. Seismic Hazard	S.1 Characterize Framework for Seismicity and Structural Deformation at YM (ANL-CRW-GS-000003 Rev. 00) S.2 Effects of Fault Displacement on Emplacement Drifts (ANL-EBS-GE-000004 Rev. 00 ICN 1) *N.8 Fault Displacement Effects on Transport in the UZ (ANL-NBS-HS-000020 Rev. 01)*	Vibratory Ground Motion Hazard (S.1-1) Fault Rupture Hazard (S.1-2) **Bin Subtotals: Bin 1: 0 Bin 2: 2 Bin 3: 0**	2 2
T. Integrated Site Model	T.1 Geologic Framework Model (MDL-NBS-GS-000002 Rev. 00 ICN 2) T.2 Mineralogical Model (MDL-NBS-GS-000003 Rev. 00 ICN 1) T.3 Rock Properties Model (MDL-NBS-GS-000004 Rev. 00 ICN 2)	Only analyses were identified in this model area. **Bin Subtotals: Bin 1: 0 Bin 2: 0 Bin 3: 0**	N/A
U. PA Modeling	U.1 TSPA Model for SR (MDL-WIS-PA-000002 Rev. 00) U.2 Total System Performance for Site Recommendation (TDR-WIS-PA-000001 Rev. 00 ICN 1) U.3 Features, Events, and Processes: System Level and Criticality (ANL-WIS-MD-000019 Rev. 00) U.4 Performance Assessment and Sensitivity Analysis of Disposal of Plutonium as Can-in-Canister Ceramic (ANL-WIS-PA-000003 Rev. 00)	TSPA-SR Model (U.1-1) Soil Removal Model for Volcanic Disruption (U.1-2) Pu-Ceramic Degradation Model for TSPA-SR (U.4) **Bin Subtotals: Bin 1: 0 Bin 2: 0 Bin 3: 3**	3 3 3
		Bin Grand Totals: **Bin 1: 17 Bin 2: 77 Bin 3: 34** **Total Number of Models Identified: 128**	

NOTE: For bibliographic citations associated with the documents listed in Column 2, please see Column 2 of Table 1. Italics denote documents which are principally assigned to another model area, but were reviewed in multiple model areas for completeness.

Table 7. Summary of Bin-3 Models, Showing How They are Used, and the Model Designation in the Principal Supporting Document

	Model Area	Models Identified	Bin	Used for TSPA?	Used for FEPs?	Called a Model or Other? [A]
1	G. Mountain-Scale/Near-Field THM	THM Model (G.1)	3	N	Y	C
2	H. In-Drift Chemistry	Cement Grout Model (H.3-2)	3	N	Y	M
3		Seepage/Cement Interaction Model (H.7)	3	N	N	A
4		Corrosion of Steel Used in the Ex-Container EBS (H.3-3)	3	N	Y	M
5		Effect of Evaporation in the Invert (H.3-4)	3	N	Y	M
6		EBS Colloids Model (H.3-5)	3	N	N	M
7	I. EBS Moisture Distribution and TH	In-Drift THC Model (I.7)	3	N	N	A+M
8		Effective Thermal Conductivity Model (I.8)	3	Y	N	C
9		Ventilation Model (I.5)	3	N	N	M
10	J. Waste Package/Drip Shield Degradation: General and Localized Corrosion	WAPDEG Analysis of WP and DS Degradation (J.6)	3	Y	N	A+M
11		Incorp. of Uncert. & Variability of DS & WP Degradation in WAPDEG (J.8)	3	N	N	A
12	K. Waste Form Degradation: General Information	Waste Form Degradation Abstract. - Best Estimate Model (K.4-3)	3	N	N	M
13		Waste Form Degradation Abstract. - Immobilized Pu Model (K.4-4)	3	N	Y	M
14	K. Waste Form Degradation: Cladding Degradation	Alternative Wet Clad Unzipping Model (K.14-1)	3	Y	N	M
15		Summary and Abstract. - Clad Unzipping & Fuel Dissolution (K.16)	3	Y	N	A
16		Thermal Evaluation of Breached 21-PWR WPs (K.18)	3	Y	Y	C
17		Breakage of CSNF Clad by Seismic Loading (K.19-1)	3	Y	N	C
18		Breakage of CSNF Clad by Static Loading (K.19-2)	3	N	N	C
19	L. EBS Degradation	DRKBA Rockfall Model (L.1)	3	Y	Y	A+M
20		Flow into WPs Through Small Lid Openings Model (L.6)	3	N	N	A+M
21	M. EBS Radionuclide Transport	In-Drift Colloids and Concentrations (M.3)	3	Y	Y	M
22		In-Drift Transport of Radionuclides (M.2)	3	N	N	A+M
23		EBS Radionuclide Transport Abstraction Model (M.5)	3	Y	N	M
24		Seepage/Invert Interaction Model (M.4)	3	N	Y	M
25	N. UZ Transport	FRACL Calibration to Borehole Chloride (N.3-1)	3	Y	N	A+M
26	P. SZ Transport	Abstraction of FEHM and Coupling with UZ Mass Flux (P.4-2)	3	Y	N	A+M
27		Transport Parameters from C-Wells and Laboratory Studies (P.4-3)	3	Y	Y	A+M
28	Q. Biosphere	Surface Soil Model in GENII-S (Q.9-1)	3	Y	N	A+M
29		Radionuclide Transfer to Animals (Q.9-4)	3	Y	N	A+M
30		Radionuclide Transfer to Aquatic Food (Q.9-5)	3	Y	N	A+M
31	R. Igneous Disruption	Geometry of Volcanic Feeder System Model (R.2)	3	Y	N	A
32	U. PA Modeling	TSPA Model (U.1-1)	3	Y	Y	M
33		Soil Removal Model for Volcanic Disruption (U.1-2)	3	Y	N	M
34		Pu-Ceramic Degradation Model for TSPA-SR (U.4)	3	N	N	A

Notes: A. Based on designation in original document ("M" = model, "A" = analysis, and "C" = calculation). For AMRs that contain model(s) and analysis, "A+M" is used.

Table 8. Models which are Documented as Analyses or Calculations

	Model Area	Models Documented as Analyses or Calculations	Documents Recommended to Become Models
1	A. Climate	Precession-Based Orbital Clock (A.1)	USGS (2000)
2	G. Mountain-Scale/Near-Field THM	THM Model (G.1)	CRWMS M&O (2000g)
3	H. In-Drift Chemistry	In-Drift Gas Flux and Composition Model (H.5)	CRWMS M&O (2000am)
4		Seepage/Cement Interaction Model (H.7)	CRWMS M&O (2000bf)
5	I. EBS Moisture Distribution and TH	Effective Thermal Conductivity Model (I.8)	CRWMS M&O (2001g)
6	J. Waste Package/Drip Shield Degradation: General and Localized Corrosion	Calculation of General Corrosion Rate of DS and WPOB to Support WAPDEG Analysis (J.7)	CRWMS M&O (2000f)
7		Incorporation of Uncertainty and Variability of DS and WP Degradation in WAPDEG (J.8)	CRWMS M&O (2000ak)
8	K. Waste Form Degradation: General Information	Inventory Abstraction (K.1)	BSC (2001i)
9	K. Waste Form Degradation: Solubility Constraints	Pure-Phase Solubility Limits (K.8)	CRWMS M&O (2001n)
10		Secondary Uranium-Phase Paragenesis and Incorporation of Radionuclides into Secondary Phases (K.10)	CRWMS M&O (2000bd)
11	K. Waste Form Degradation: Cladding Degradation	Initial Oxide Thickness (K.11-1)	CRWMS M&O (2000ao)
12		Rod Internal Pressure (K.11-2)	CRWMS M&O (2000ao)
13		Cladding Crack Depth (K.11-3)	CRWMS M&O (2000ao)
14		Overall Cladding Stress (K.11-4)	CRWMS M&O (2000ao)
15		Initial Rod Failure (K.11-5)	CRWMS M&O (2000ao)
16		Residual Stress in CSNF Cladding Material (K.13)	CRWMS M&O (2001k)
17		Summary and Abstract. - Clad Unzipping & Fuel Dissolution (K.16)	CRWMS M&O (2001d)
18		Stainless Steel in WPs for TSPA-SR (K.17)	CRWMS M&O (2000bh)
19		Thermal Evaluation of Breached 21-PWR WPs (K.18)	CRWMS M&O (1999f)
20		Breakage of CSNF Clad by Seismic Loading (K.19-1)	CRWMS M&O (1999a)
21		Breakage of CSNF Clad by Static Loading (K.19-2)	CRWMS M&O (1999a)
22	K. Waste Form Degradation: Colloid Release	Colloid-Associated Radionuclide Concentration Limits (K.21)	CRWMS M&O (2001e)
23	L. EBS Degradation	Rockfall on Drip Shield Model (L.3)	CRWMS M&O (2000bw)
24	Q. Biosphere	Crop Interception Fraction Submodel (Q.2-1)	CRWMS M&O (2000ai)
25		Irrigation Rate Submodel (Q.2-2)	CRWMS M&O (2000ai)
26		Dose Conversion for Ingestion (Q.4-1)	CRWMS M&O (1999b)
27		Dose Conversion for Inhalation (Q.4-2)	CRWMS M&O (1999b)
28		Dose Conversion for External Exposure (Q.4-3)	CRWMS M&O (1999b)

Table 8. Models which are Documented as Analyses or Calculations (continued)

	Model Area	Models Documented as Analyses or Calculations	Documents Recommended to Become Models
29	R. Igneous Disruption	Conditional Distribution for Number of Eruptive Centers Model (R.1)	CRWMS M&O (2000l)
30		Geometry of Volcanic Feeder System Model (R.2)	CRWMS M&O (2000k)
31	S. Seismic Hazard	Vibratory Ground Motion Hazard (S.1-1)	CRWMS M&O (2000m)
32		Fault Rupture Hazard (S.1-2)	CRWMS M&O (2000m)
33	U. PA Modeling	Pu-Ceramic Degradation Model for TSPA-SR (U.4)	CRWMS M&O (2001u)

Table 9. Recommended Analyses Identified in This Review which are Documented as Models

	Model Area	Analyses Which Are Documented as Models
1	F. Mountain-Scale/Near-Field THC	F.3 Thermal Tests Thermal/Hydrological Analyses/Model Report (ANL-NBS-TH-000001 Rev. 00 ICN 1; CRWMS M&O 2000bk)
2	H. In-Drift Chemistry	H.4 In-Drift Corrosion Products (ANL-EBS-MD-000041 Rev. 00; CRWMS M&O 1999g)
3		H.8 Physical and Chemical Environmental Abstraction Model (ANL-EBS-MD-000046 Rev. 00 ICN 1; CRWMS M&O 2000az)
4		H.10 Seepage/Backfill Interaction (ANL-EBS-MD-000039 Rev. 00; CRWMS M&O 2000cb)
5	I. EBS Moisture Distribution and TH	I.3 Water Diversion Model (ANL-EBS-MD-000028 Rev. 00; CRWMS M&O 2000bu)
6		I.4 Water Drainage Model (ANL-EBS-MD-000029 Rev. 00 ICN 1; CRWMS M&O 2000bv)
7	L. EBS Degradation	L.2 Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon
8		(ANL-EBS-GE-000006 Rev. 00; CRWMS M&O 2000ae)
9	O. Saturated Zone Flow	O.1 Hydrogeologic Framework Model for the SZ Site-Scale Flow and Transport Model (ANL-NBS-HS-000033 Rev. 00 ICN 1; CRWMS M&O 2001z)
10	P. Saturated Zone Transport	P.5 SZ Transport Methodology and Transport Component Integration (MDL-NBS-HS-000010 Rev. 00; CRWMS M&O 2000ck)
11	T Integrated Site Model	T.1 Geologic Framework Model (MDL-NBS-GS-000002 Rev. 00 ICN 2; BSC 2001e)
12		T.2 Mineralogical Model (MDL-NBS-GS-000003 Rev. 00 ICN 1; CRWMS M&O 2000at)
13		T.3 Rock Properties Model (MDL-NBS-GS-000004 Rev. 00 ICN 2; CRWMS M&O 2000bb)

Appendix I

(8 pages)

Additional Comments and Recommendations on the

Drift-Scale Test Thermal-Hydrologic-Chemical Calibration Model (F.1-1) and the Thermal-Hydrologic-Chemical Seepage Model (F.1-2)

by Dash Sayala

The following additional recommendations are made concerning the thermal-hydrological-chemical modeling (THC) approach documented in AMR: *Drift-Scale Coupled Processes (DST and THC Seepage) Models* (BSC 2001a):

1. Comments on Input Data

Justify the use of input data that are different than known repository conditions, and assess the impact of those choices on the validation.

Section 4.0 Inputs - Data and Parameters: Input data appropriateness and qualification are not adequately met for parameter calibration, and for reasonableness and consistency. It appears some input data are not consistent between the DST THC and the THC Seepage Models. The choices for input data and references used are not explained in some important ways, depicted by the examples in the following paragraphs.

On p. 31, Section 4.1, it is mentioned that additional thermodynamic data, not specific to Yucca Mountain, are required for all models. The thermodynamic data used are taken from different sources, and some values may be inconsistent. The text should explain what kind of uncertainty the choice of thermodynamic data engenders, and how it could impact the model predictions. The discussion should address whether thermodynamic data can dictate unrealistic dissolution and precipitation reaction trends regardless of other data inputs. Further, the thermodynamic and kinetic data used for calcite is not well developed. From the references, it is not obvious whether the currently used thermodynamic data conform to applicable international ICSU/CODATA and NIST data standards. Conduct comparisons to establish confidence in the data used, especially for calcite.

Molar volumes of alteration minerals are typically greater than for the reactant minerals. Explain whether the selection of minerals, and the chemical data that described their behavior in the model, could significantly impact the porosity reduction predictions.

On p. 31, Section 4.1.1.1, it is stated that the data sets include calibrated and uncalibrated properties (porosity, temperatures and thermal conductivities). What does this say about model validity when more-representative data are mixed with non-representative data? Explain what uncertainty is introduced by this practice.

On p. 34 and Table 3, CO_2 partial pressures and pH are calculated by equilibrating with calculated concentrations of bicarbonate, hematite, and secondary silicate minerals at 17°C and 25°C. These types of data do not represent the expected repository conditions, especially for the pre-closure period with ventilation exhaust and low RH. First, are such data appropriately extrapolated to higher temperatures? Secondly, although this is a validation test, the AMR should

justify how these results apply to expected higher repository temperatures. The measured 400 ppmv CO_2 concentration may be due to equilibration with atmospheric CO_2; explain why this is not so.

Simulations using all data from the revised EQ3/6 V7.2b databases (Section 4.1.4.1) may not yield the same agreement between simulations and field test data, as was obtained using the modifications described in Attachment V. Testing of the sensitivity of model results to thermodynamic input data is needed for confidence in the model predictions.

Under Section 4.1.6 on Transport Parameters (p. 42), diffusion coefficients are apparently used for aqueous and gaseous species. However, the same values are not suitable for both aqueous and gaseous species, and dispersion may be important in either case. As such a classical equation of this form may be appropriate:

$$D = D_o \tau + \alpha V(\theta)$$

where D = Dispersion coefficient (units of length^2/time)

D_o = Free–phase diffusion coefficient (length^2/time)

τ = Tortuosity (length/length, i.e., dimensionless)

α = Dispersivity (length)

V = Solute velocity (length/time), as a function of volumetric water content θ (volume/volume, i.e., dimensionless)

Further, the equation used on p. 42 considers the gas constant, which is indicative of an ideal state function that does not apply to liquids, and temperature and pressure which may not be representative of initial and elevated temperature conditions in the repository. Justify use of these parameters in the model, including all assumptions.

On p. 32, Section 4.1.2 on Mineralogical Data, there are no criteria for selecting the set of primary and secondary minerals, and it is not clear what is the total mineralogical content of the rocks under consideration. For AMR: *In-Drift Microbial Communities* (CRWMS M&O 2000an) biotite was used as one of the important minerals in the analysis, and this mineral is not considered in the THC Seepage Models.

On p. 34, Section 4.1.3 on Water and Gas Chemistry, it is stated that full characterization of Tptpll pore-waters is unavailable because of insufficient data, yet various additional species are included for model input. Concentrations of iron, aluminum and total carbonate were not measured, but are calculated. Justify this approach, and consider the effect on model results and uncertainty.

Applicable codes and standards are not listed under Section 4.3. With regard to thermodynamic data, international and NIST standards should be addressed to establish more confidence in the data and consequential simulations.

2. Comments on Assumptions

Some assumptions are not justified by defensible arguments, and some assumptions are confusing. Examples of these are given in the following:

In the case of the DST THC, Assumption 17 on p. 52 is problematic because it is restrictive; limiting reaction due to ionic strength greater than 2, or liquid saturations less than 10^{-4}, is an artifact and not realistic. If the code cannot be modified to avoid this problem, then additional justification is needed, including sensitivity testing to determine the effect on model results. This problem with the modeling approach does impact reliability of model results and may require impact review.

In the assumptions listed for the DST model (p. 53) there is no discussion of the effect of cement used in the DST on the CO_2 mass-balance. Concrete used in construction will be a significant sink for CO_2.

It is stated that the dual-permeability approach is validated by comparison of measured geochemical data to results of simulations presented, and no further justification is necessary (p. 49, Section 5.A). This statement seems to be without justification. Also, CO_2 partial pressures resulting from heating calcite and gas transport are mentioned. However, the rationale is not given for not using other gases such as Cl, F, HF and water vapor (which are found) in combination with CO_2 for model simulations.

In point A.7 (p. 50), a constant thickness product layer of 10 μm thick on the glass surface was assumed for calculating the rate constant at 25 °C. However, no rationale was given for considering this temperature, which is not representative of postclosure repository conditions. In addition, it is nearly impossible to dissolve silica glass at that temperature unless there are concentrated reactants such as HF in contact with the glass.

Explanation given (see point A.8 on p. 50) for the assumption that pH effects are not important for the THC processes is not justified because the stability of silicate and non-silicate minerals generally depends on Eh and pH, and under conditions of low water activity (i.e. dryout) the given assumption may not be applicable.

In point A.10 on p. 51, mineral dissolution and precipitation are assumed to be uniform over the fracture walls. This is not realistic because, mineral dissolution depends on grain size and degree of grain contact with dissolving solution. Further, dissolution rates of silicate minerals are different from non-silicate minerals. Similarly, precipitation trends for silicate and non-silicate minerals are different and are governed by temperature, pressure and saturation indices at a given area. What are the consequences of these assumptions?

3. Comments on Model Development

Section 6.0 on p. 57 lacks integrating discussion. In some instances the discussion leads to questionable justification or selection of parameters or data. Uncertainty and sensitivity analyses are not treated statistically, and much improvement is needed for model validation. Some examples are given in the following paragraphs:

Explain why the models are run discontinuously, for the pre-closure and postclosure periods, as opposed to running continuously.

Some model simulations are run with the TOUGHREACT V.2.2 and others by TOUGHREACT V2.3 (see p. 59), and the later version of the code was not qualified for the most recent revision. Explain whether this would have any impact on the model predictions.

In a general sense, for a multi-component system, both major and minor mineral constituents may influence the kinetic reactions of mineral dissolution and precipitation that could affect the porosity and permeability. Provide justification for the constituents included, considering those that may be present in the natural system, and the potential reactions that could affect hydrologic properties.

In the THC Seepage Models the dissolution of primary silicates occurs at repository temperatures. To help validate the simulation results, compare and corroborate with observations of dissolution of those minerals as reported in the literature.

In estimating the porosity reduction, consider the possible effects of pore occlusion due to colloids or suspended clays.

4. Comments on Validation Strategy

Clearly define the validation criteria, especially in regard to the aqueous and gas-phase model-data comparisons. Although aqueous and gaseous processes are certainly coupled, the data collection methods, sampling points, and transport phenomena are different and discrete validation requirements are needed. Apply specific observations from natural analogues to provide greater confidence in the validation strategy.

Comparisons between simulations and field data (taken from two boreholes only) are clearly more defensible for the CO_2 behavior than for aqueous chemical transport. Validation criteria are currently liberally defined trends rather than firm, objective confidence-building requirements. Tests of a reactive transport model should include components directly involved in the reactions as well as conservative components, and must have clearly defined spatial and temporal validation criteria. It is assumed that many more data are forthcoming in the near future, and that the authors are awaiting laboratory analysis of samples collected during the DST. With these new data, the validation should focus on key processes. For example, do trends in aqueous concentrations simply represent dilution from condensate coupled with precipitation of calcite, or do they permit a defensible test of the model capability to predict silicate mineral dissolution?

Are the DST data actually sufficient to test the reactive chemical transport (THC) model? Before this question can be answered, the use of the test data for fully testing thermal-hydrologic (TH) models must be demonstrated. This is especially important if the DST is to be the defining experiment for building confidence in simulations of long-term repository near-field processes. Justify whether model-data comparisons using the limited available field data are sufficient for model validation, given the implications of modeling uncertainties for long-term repository predictions. The validation strategy for complex THC simulations cannot have been optimized, so justification of the validation approach actually used requires a demonstration that we understand what improvements to the test and/or the validation strategy could increase confidence.

The CO_2 gas phase composition and isotopic content were monitored. Model validation should address the isotopic signatures of the CO_2–this is important. This type of comparison has the potential to confirm CO_2 sources and transport pathways, and the nature of CO_2 partitioning to the liquid phase. These pathways are simulated in the model and a validation procedure would benefit from approach. Further the ^{14}C data could be used to evaluate CO_2 introduced from the

observation and access drifts. This question is important to a mass balance for CO_2 in the drift-rock-water system.

Much of effort to simulate the DST is focused on calcite dissolution and precipitation kinetics. In this regard, the validation strategy should address the use of pre-test and post-test observations of calcite in the matrix and on fracture surfaces.

The sensitivity studies report modifications of input parameters in order to demonstrate the effects on the simulations. Where these sensitivity changes improve the simulations and are then subsequently used in seepage models, it should be noted that this was a calibration step, not just a sensitivity test. When implementing model-data comparisons, use a statistical approach to quantify improvement in simulation accuracy (and confidence), so that the relative effects of different changes to the model inputs can be compared.

The validation effort should also include minerals. Some discussion is needed concerning what minerals are predicted by the model to be present after the DST, and where they can be found. The value of any post-test coring, borehole video surveys, or other sampling will be enhanced if pre-test model predictions are made. This type of validation is crucial to building confidence in the predictive capabilities. All subsequent seepage models are predictive and their validation depends on the confidence established in this comparison of the DST model with experimental data. If this validation is weak, so will be the validation for the seepage models.

DST THC model simulations of porosity change due to calcite precipitation were on the order of 0.1% (Section 6.2.7.5 on p. 94) but in the THC Seepage Model simulations, using a base-case and extended cases with silicate and non-silicate minerals, it was on the order of 1% to 3% for 20,000 yr and 100,000 yr respectively (Section 6.4.5.2 on p. 168, and Section 6.6.5.2 on p. 207). For validation purposes use the same approach for the DST and the THC Seepage Model simulations, including the same sets of minerals.

To improve the documentation, it would be useful to include tables with all relevant input data, the modeled output data, and the corresponding statistics of model-data agreement. Such presentation should be used for the DST THC Model, the THC Seepage Model, the Plug-Flow test simulations, and natural analogs or any other type of comparison that is included in the model validation strategy.

To test and validate the geochemical models developed for the DST THC, and the Tptpmn and Tptpll THC Seepage Models, kinetic simulations of tuff dissolution rates, under isothermal conditions with initial rock and water compositions, were accomplished using a Crushed-Tuff Experiment and a Plug-Flow Reactor Experiment with conditions that are different from those in the repository. (See pp. 57 and 212, Sections 6 and 6.7). It should be made clear that this is primarily a verification case study for testing the geochemical code, and the conceptual basis, and is not intended as direct validation of the THC Seepage Models. Crushed tuff samples are highly reactive and provide dissolution rates and compositions that may be significantly different from uncrushed samples.

It is suggested that the sensitivity analysis section of the plug-flow test comparison is really a calibration of the model, because the data were not matched to a high degree of confidence using only the base case. Numerous simulations were performed with different inputs such as variable surface area, mineral compositions, and corrections to experimental data before a satisfactory

match was achieved. Validation would require a simulation that met validation criteria using a calibrated model, or using input parameters that were pre-selected and justified. It is not clear that the calibration procedure has improved the predictive capability of the THC modeling methods. In our opinion this is inverse modeling and not predictive. Additional confidence could be provided if pH, and bicarbonate as well as Mg, Fe, SO_4, Al, etc. and other minerals, were predicted as well. Nevertheless, since this work is not extrapolated to the DST, it does not directly impact validation of the field-scale models.

Under Section 6.2.7 on Simulation Results and Model Validation by Comparison to Measured Data, it is mentioned that "There are no experimental data by which the THC Seepage Models can be validated ...validation of the DST model effectively validates them as well" (see paragraph 3, p. 73). Published hydrothermal seepage experimental and natural analog data are available, and by comparing with these, confidence in validation can be augmented. For example, published descriptions of experiments on granite cores, and natural analogs such as the Salton Sea trough hydrothermal system are available in the open literature.

5. Recommendation for Systematic Model Development

Consider a Systems Engineering approach to describing the model inputs and components, and exhibit the following through schematic diagrams:

- Show the model prediction domain in the context of the overall repository system. Establish the relevant regulatory compliance requirements and the corresponding information needs for the drift-system.
- Schematically establish a hierarchy of submodels. Develop a conceptual model, outlining the relevant processes and the scenario-based implications on repository system integrity. Based on the processes, implications and information needs, establish the needs of type of mathematical modeling (including the codes and standards) and Validation/ corroborative studies/experiments needed. Finally, lead into how you would accomplish the model simulations and their validation. Also show, how these simulations are fed to other related studies.

6. Comments on Integration and Documentation

In validating the models, the results of other pertinent models and investigations, such as performed in the areas of UZ Flow (Model Area C, Section 6.3), Mountain-Scale TH (Model Area D, Section 6.4), Ambient/Thermal Drift Seepage (Model Area E, Section 6.5), Mountain-Scale/Near-field THM (Model Area G, Section 6.7), and In Drift Chemistry (Model Area H, Section 6.8), should be integrated to build confidence. Integration with other activities needs to be extensively addressed in the documentation.

Among the THC Seepage Models described, it is not clear which one best represents the actual expected repository conditions and is most appropriate.

It is not clear how the model output is used for predicting the hydrologic flow and chemical transport in the repository environment, and the implications for integrity of engineered barriers.

In many sections, authors refer to previous work without defining the relevant information; thus it is difficult to establish the relevance to model validation. This AMR should be a stand-alone report; therefore, more complete description of previous work is needed.

7. Other Comments and Recommendations

Under the section on Purpose (p. 23) too much unnecessary information is given and the scope was included.

It would be useful to have an introductory section with background, purpose/objective and scope as subheadings. Establish the relevant regulatory compliance requirements and the corresponding information needs for the drift-system.

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Appendix II

(10 pages)

Additional Comments and Recommendations on the Total System Performance Assessment – Site Recommendation Model (U.1): Basis for Assessment of Validation for the TSPA-SR Model

by Ken Bogen

The TSPA-SR analysis/model report (AMR) is intended to "...describe the integration of information that represents different aspects of the repository, into one comprehensive model. ...This AMR provides detail as to how these component models are implemented in the TSPA-SR model" (*Total System Performance Assessment (TSPA) Model for Site Recommendation*, CRWMS M&O 2000bl, p. 25). A corresponding technical report (*Total System Performance Assessment for the Site Recommendation*, CRWMS M&O 2000bm) which describes modeling results obtained using the integrated TSPA-SR model and its application to support SR, contains some background as well as technical material that also is presented in the TSPA-SR model report (CRWMS M&O 2000bl). These two reports should be merged into a single document that presents the basis and validation of an integrated TSPA model, or some material currently in the technical report (CRWMS M&O 2000bm) but not in the model report (CRWMS M&O 2000bl) needs to be reproduced in a revised model report as explained below. In either case, model validation could be improved for the specific reasons listed below.

1. Some Aspects of the Integrated Model Are Not Clearly Described

The integrated TSPA-SR model is described in Section 6 of the AMR (CRWMS M&O 2000bl, p. 80), which dwells primarily on the architecture of the system model in relation to its component (sub)models, and on the mechanics of operating the integrated stochastic model under different assumption, together with a concluding section (Section 6.5, p. 542-559) entitled "Model Validation." However, validation of the integrated TSPA-SR model as a system model, must refer to more than a listing of model components, data-transfer pathways, and model-operation mechanics; it must also refer to the design and operation of the system model as a whole as one that can produce output that is meaningfully related to the intended purpose of the model. The intended purpose of the model is stated in Section 1 of the AMR (CRWMS M&O 2000bl, p. 25) to be "to assist the Performance Assessment Operations (PAO) and its Engineered Barrier Performance Section in analyzing the performance of the repository system in isolating waste for long periods of time." For the purposes of this review, it seems useful to infer that an additional purpose of the model is to support SR in its evaluations of the potential repository with respect to criteria specified in DOE's proposed regulation 10 CFR 963 (64 FR 67054).

As indicated in proposed 10 CFR 963.16, one of the bases for the evaluation of site suitability will be "a total system performance assessment to evaluate the ability of the geologic repository to meet the applicable radiation protection standard...." Applicable radiation protection standards are the NRC's proposed 10 CFR 63 (66 FR 55732) and the EPA's final 40 CFR 197 (2001). Final guidance on the methods for compliance with the NRC and EPA standards is not yet available, and is expected to be provided by the NRC prior to any submittal of a license application. Preliminary comments to the DOE from the NRC on the adequacy of the TSPA-SR

were provided in a technical exchange in August 2001 (Cornell 2001). This technical exchange resulted in a set of agreements between the NRC and DOE regarding additional information about the TSPA that will be needed prior to submittal of any License Application. These agreements, plus any subsequent guidance provided by the NRC, are an appropriate basis for determining the adequacy of the TSPA model for the purpose of evaluating performance with respect to the NRC and EPA regulations.

For the purposes of this review, it is appropriate to note that regulatory criteria in both proposed 10 CFR 63 and final 40 CFR 197 involve consideration of uncertainty in model predictions. With respect to the treatment of uncertainty, the technical documentation should define (1) the underlying approach to uncertainty analysis; and, (2) specific criteria with which output from the model can be used to demonstrate compliance, and what specific model output(s) are intended to address these specified criteria. Each of these topics is discussed below.

1.1 Approach to Uncertainty Analysis

The treatment of uncertainty analysis, and the use of sensitivity analysis, in analyses involving the TSPA-SR model are topics covered explicitly in Sections 2.2.4 through 2.2.5 of the TSPA-SR technical report (CRWMS M&O 2000bm, p. 2-34 through 2-44). It is recommended that this material should also be incorporated within the TSPA-SR model report (CRWMS M&O 2000bl). The incorporation of this information needs to clarify what is meant by the distinction between "uncertainty" and "variability" within the integrated probabilistic TSPA framework (CRWMS M&O 2000bm, Section 2.2.4, p. 2-34 through 2-35):

> "The parameters of the model used to predict the performance of the disposal system are also subject to uncertainty and/or variability. Uncertainty in model parameters arises because of imperfect knowledge or limited data and, in principle, can be reduced with additional measurements. ...Variability refers to the randomness or heterogeneity in physical and/or behavioral characteristics. It is an intrinsic property of the system and cannot be reduced by additional information. ...Often, variability and uncertainty in a parameter are commingled because of imprecise knowledge. ...This leads to a situation where the inputs of the TSPA model (i.e., scenarios, mathematical and conceptual models, and parameters) are uncertain and/or variable, which will therefore result in the output of the model being uncertain as well. As described in the following sections, a probabilistic framework has been adopted in TSPA-SR for translating uncertainties in model inputs to corresponding uncertainties in model predictions."

The definition of "variability," in particular, given above is not quite the same as that for "variability" that generally is used in the context of uncertainty/variability analysis undertaken for the purpose of environmental risk assessment (Bogen and Spear, 1987; National Research Council, 1994; Bogen 1995). Specifically, the distinction being made above for the purpose of TSPA-SR analysis is questioned by this reviewer because: (1) the distinction appears to have no practical impact on the method of analysis undertaken, and (2) it is only "uncertainty" (as correctly defined above, and not "variability" as defined above) that causes and accounts for all "uncertainty" (as defined above) in TSPA-model output. In other words, no TSPA-model variate

that strictly reflects a spatially and/or temporally variable/heterogeneous quantity (as defined above)—by itself—produces any uncertainty in model output. This is expected to be the case if the impact of any and all sources of variability and heterogeneity (independent of the uncertainties) averages out to zero over the relevant spatial and temporal dimensions, as the TSPA is implemented for a substantial duration such as 10,000 yr. On the other hand, if the extent or character of a specific source of variability or heterogeneity is itself uncertain, then this uncertainty may contribute to uncertainty in TSPA model output.

If the conclusion just stated is incorrect, the AMR needs to explain clearly why this is so, using one or more specific examples. If not, then references to modeled "variability" need to be explained to clarify the relevance of this information to model performance and to the interpretation of model output.

1.2 Implementation Criteria for the System Model

As noted above, validation of the integrated TSPA-SR model, as a system model, must refer to more than an enumeration of model components, data-transfer pathways, and mechanics of operating a computerized implementation of the TSPA model. It must also refer to (1) implementation criteria for the integrated system model that meaningfully relate model output to the intended purpose of the model, and (2) other issues bearing on the validation of the integrated model. Topic (1) will be discussed below in this part of the appendix, and topic (2) is discussed in parts 2 through 4 that follow.

As inferred for the purpose of this review, the intended purpose of the TSPA-SR model is to support SR in a way that relates to specific licensing criteria. As discussed in Section 1.3 of the TSPA-SR technical report (CRWMS M&O 2000bm, p. 1-8) key regulatory criteria are contained in proposed NRC regulation 10 CFR 63 (66 FR 55732) and in EPA regulation 40 CFR 197 (2001; proposed at the time the TSPA-SR documents were prepared, but now available in final form). The discussion in Section 1.3 of that report does not appear in the corresponding TSPA-SR model report (CRWMS M&O 2000bl), nor are key regulatory criteria interpreted in either document in an explicit manner.

A key requirement in proposed 10 CFR 63 (66 FR 55732, Part 63 Section 31) is that DOE must provide *reasonable assurance that the expected annual dose* to the average member of the critical group does not exceed the postclosure performance objective (as provided in 40 CFR 197) within 10,000 yr of site closure. This requirement unambiguously refers to reasonable assurance that must be provided concerning the quantitative value of a specific estimator of (i.e., statistic estimating) predicted dose—namely, the *expected value* of predicted dose—to a specified receptor (i.e., the average member of the critical group within 10,000 yr of site closure). In contrast, the corresponding key requirement in 40 CFR 197 (2001) found in §197.13 and §197.14 quoted below, is:

> "**§197.13 How is subpart B implemented?**
> "The NRC implements this subpart B. The **DOE must demonstrate to NRC that there is a reasonable expectation of compliance** with this subpart before NRC may issue a license. In the case of the specific numerical requirements in §197.20 of this subpart, and if performance assessment is used to demonstrate compliance with the specific numerical requirements in §§197.25 and 197.30 of this subpart, **NRC will determine compliance**

based upon the mean of the distribution of projected doses of DOE's performance assessments which project the performance of the Yucca Mountain disposal system for 10,000 years after disposal.

"§197.14 **What is a reasonable expectation?**
Reasonable expectation means that NRC is satisfied that compliance will be achieved based upon the full record before it. Characteristics of reasonable expectation include that it:
"**(a)** Requires **less than absolute proof** because absolute proof is impossible to attain for disposal due to the uncertainty of projecting long-term performance;
"**(b)** Accounts for the inherently greater uncertainties in making long-term projections of the performance of the Yucca Mountain disposal system;
"**(c)** Does not exclude important parameters from assessments and analyses simply because they are difficult to precisely quantify to a high degree of confidence; and
"**(d) Focuses performance assessments and analyses upon the full range of defensible and reasonable parameter distributions** rather than only upon extreme physical situations and parameter values."

The relevant numerical criterion in the EPA regulation cited here (15 mrem/yr) is somewhat less than that specified in the NRC regulation (<25 mrem/yr). Otherwise, the EPA criterion is conceptually similar to that of NRC in that the former requirement (at §197.13) refers to a "reasonable expectation" that must be provided concerning the quantitative value of a specific estimator of (i.e., statistic estimating) predicted dose—namely, in this case, the ***mean value*** of dose predicted using stochastic modeling methods. Because §197.13 clearly states that "NRC will determine compliance based upon the mean of the distribution of projected doses," and because "mean of the distribution of projected [annual] doses" and "expected annual dose" are synonymous phrases in this context, this line of reasoning would assert that the EPA and NRC criteria stated above are operationally identical (§197.14 notwithstanding). Before discussing an alternative reasonable interpretation of 40 CFR 197, implications of the interpretations given above for determining corresponding TSPA model-performance criteria will be described.

The interpretation above implies that the EPA and NRC regulatory criteria discussed can be satisfied jointly ***only*** if DOE demonstrates a reasonable expectation/assurance that the expected value of predicted "critical-target" dose (CTD) will not exceed 15 mrem/yr as maximum annual committed effective groundwater dose equivalent to the specified representative critical person within 10,000 yr after site closure. The "expected value" in the context of a "distribution of projected doses" can only refer to the mathematical expectation of that distribution, which in turn consists of the "true population mean" of an infinite number of hypothetical integrated-TSPA-model realizations. Notationally, the joint regulatory criterion (under the presently assumed interpretation) can thus be expressed as E(CTD) < 15 mrem/yr, where E here denotes the mathematical expectation operator. Notably, under this interpretation, the relevant criterion does not refer directly to uncertainty (e.g., that might be reflected in a shape statistic) *per se* associated with the predicted CTD distribution, but rather refers directly only to the E(CTD) (a location parameter of the predicted distribution). Therefore, this criterion is not very sensitive to the predicted likelihood, e.g., that CTD might exceed 15 mrem/yr. Indeed, in the limiting case in which uncertainty in CTD is modeled approximately as a 2-point probability mass function with one point at CTD = 0 mrem/yr, the criterion implies that a "reasonable expectation" of

compliance means the acceptability of ***any*** likelihood p whatsoever that CTD will ***exceed*** $(15/p)$ mrem/yr, where $0 < p < 1$.

Because only a finite number of TSPA model realizations can be simulated, a "reasonable expectation" concerning the value of E(CTD) can only be made if E(CTD) can be calculated either: 1) exactly (e.g., analytically, conditional on all distributed inputs); or 2) with respect to some "reasonable" upper bound with respect to uncertainty in some feasibly obtained estimator ($\overline{\text{CTD}}$) of E(CTD) (e.g., traditionally, a 2-tailed upper 95% confidence limit, or 97.5th percentile). Conditional on a specified modeling scenario, such as the "base case" considered in the TSPA, the TSPA model described in the TSPA-SR technical report (CRWMS M&O 2000bm) calculates $\overline{\text{CTD}}$ as the arithmetic mean of some number n Monte-Carlo-simulated CTD realizations, i.e., as $\overline{\text{CTD}} = \text{Sum}[\text{CTD}_i]/\,n$, where the value of n used has been 100 to 500—see CRWMS M&O 2000bm, p. 5-9). Nowhere in the TSPA-SR technical report is any reference made to uncertainty in $\overline{\text{CTD}}$, to a reasonable upper bound on that uncertainty (i.e. a suitable definition of $\overline{\text{CTD}}$*), or to a TSPA-implementation procedure intended to demonstrate that $\overline{\text{CTD}}$* < 15 mrem/yr. Such a procedure needs to account for the fact that there is sampling error associated with any Monte Carlo estimate such as $\overline{\text{CTD}}$, which can be addressed approximately by analytic methods (see Ang and Tang, 1984, p. 291-292) or by using the information obtained directly via the Monte Carlo calculation performed (see Bogen et al., 1997). Therefore, under the interpretation stated above and given the reasonable inference that evaluations of compliance with final NRC and EPA regulations will be one of the intended uses of the TSPA, the AMR for the integrated TSPA model needs to include additional discussion to adhere to the YMP QA requirement that "criteria used to evaluate the appropriateness and adequacy of the model for its intended use ... must be justified in the model documentation" (AP-3.10Q §5.3b).

The following paragraphs present an alternative approach to interpreting the requirements for compliance with 40 CFR 197. This interpretation approach has not been reviewed for consistency with available guidance from the NRC regarding the use of the mean for evaluations of compliance (such as the documentation of the recent Technical Exchange meeting on the Total System Performance Assessment Integration Key Technical Issue (Cornell 2001). Insofar as §197.13 requires DOE to provide a "reasonable expectation" that, e.g., CTD < 15 mrem/yr, but the outcome being modeled is the true CTD value that will actually occur within (and hence, can possibly only be known after) a period of 10,000 yr, standard engineering practice used in the context of analogous scenarios involving risk of future failure of durable structures dictates that consideration be given to some "reasonable" upper limit on the estimated likelihood that the specified CTD limit will be exceeded. This alternative interpretation is consistent with established engineering judgment that "consistent levels of safety and reliability may be achieved only if the criteria for design are based on ... probabilistic measures of reliability" (Ang and Tang, 1984, p. 4).

The first approach discussed above based only on E(CTD) collapses all information considered in relation to TSPA modeling for a Yucca Mountain repository to a single output measure of the type most useful for making decisions on the basis of "expected utility." This approach to decision making is reasonably guaranteed to be acceptable "in the long run" (Ang and Tang, 1984, p. 16 and p. 68) for conditions under which similar decisions and corresponding outcome evaluations can be repeated many times. In the case of the Yucca Mountain repository, long-

term outcome can only be determined in the remote future. Consequently, the rational basis of risk acceptability criteria based only on E(CTD) is unclear, in view of which it would be prudent to consider an alternative interpretation described below.

The alternative interpretation would involve showing that some "reasonable" (e.g., 1-tailed $100(1-p)^{th}$ percentile) upper confidence bound (CTD*) on simulated CTD satisfies the required dose limitation, e.g., that CTD* < 15 mrem/yr for p = 0.1, 0.05, or 0.01. Note that such a criterion is not necessarily more conservative than one based solely on E(CTD), because E(CTD) may exceed CTD* if the estimated CTD distribution is sufficiently positively skewed conditional on any value of $p<1$. For example, if CTD is approximately log-normally distributed with a specified geometric standard deviation (GSD), then E(CTD) > CTD* if it is the case that GSD > exp[2 $\Phi(1-p)$], where Φ here denotes the standard normal cumulative distribution function. An alternative CTD-estimator, CTD**, may be defined as the expected value of CTD *conditional* on Prob(dose>CTD) = $1-p$. That is, CTD** is the mean value of the upper tail of the CTD distribution, or the conditional mean value of CTD ignoring all potential CTD realizations less than its unconditional $100(1-p)$ percentile value, for some "reasonable" value(s) of p (such as 0.01, 0.05, 0.1, or even 0.5) consistent with the §197.14(d) requirement that reliance not be made "only upon extreme physical situations and parameter values." Note that CTD** > E(CTD) always unless CTD is a constant (i.e., is not uncertain). Thus defined, the CTD** estimator has the advantage that it satisfies 40 CFR 197 requirements stated both in §197.13 (insofar as it is a "reasonable" conditional expectation) and in §197.14(d) (insofar as it explicitly addresses CTD uncertainty, but does so in a "reasonable" way). CTD** can be estimated via Monte Carlo simulation by Sum[$CTD_{(i)}$]/($p\,n$), where (i) denotes the ordered i^{th}-largest among n simulated CTD-realization values, where $i = (1-p)n$, $1+(1-p)n$, ..., n.

Again, nowhere in the TSPA-SR technical report (CRWMS M&O 2000bm) is any reference made to a suitable definition of CTD* (and/or CTD**) or to a TSPA-implementation procedure (as discussed above) intended to demonstrate that CTD* (and/or CTD**) < 15 mrem/yr.

2. Integrated Treatment of Parameter Uncertainty in the TSPA Model is Defective

Validation of the integrated TSPA model as a system model, means that parameter uncertainty pertaining to each input distribution that is used to characterize uncertainty is characterized using appropriate information. In some cases, this may imply that one or more of the input distributions have the form of a compound distribution (e.g., a normal distribution for which the location and scale parameters are themselves represented by distributions reflecting uncertainty in these parameters). This is especially true for any input distribution that is estimated from a relatively small data set. For example, if uncertainty in a model input X is assumed to be normally distributed with mean M and variance V based on n empirical measures or observations (e.g., for estimated values of a quantity reported in the literature, which a particular TSPA-model parameter is intended to model), and these observations have a corresponding sample mean and variance equal to m and v, respectively, then integrated uncertainty in M should be modeled as t*v/Sqrt[n] where t is Student t-distributed with n-1 degrees of freedom, and *relative* uncertainty in V should also be modeled as c/(n-1) where c is chi-square-distributed with n-1 degrees of freedom and where c and t are independent. Thus, X should in this case be modeled using a dually compound normal distribution. For relatively large n (e.g., n > 500), uncertainties in M and V can reasonably be considered negligible and therefore can be ignored.

Although final determinations of the adequacy of the approach with respect to regulatory requirements will be made by the NRC, this review maintains that the above approach was not adopted, e.g., in the treatment of Biosphere dose-conversion factors (CRWMS M&O 2000bl, p. 438-444). This section of the AMR (p. 439-440) refers to the use of Microsoft Excel-based minimum-chi-square fits of statistical distributions that were obtained to fairly small (n = 130) sets of simulated parameter values. In the case of each TSPA-model-parameter distribution for which an apparently reliable fit was obtained, corresponding uncertainty pertaining to the values of the fitting parameters was not included in the TSPA-SR uncertainty analysis (e.g., a compound distribution). Note that the accuracy of some statistical procedures in Microsoft Excel 97 has recently been called into question (McCullough and Wilson 1999). Furthermore, it is not made clear in the AMR why such distribution-modeling techniques were used, rather than relying directly on original assumptions regarding the underlying plausible distributions of individual TSPA-model parameters. It may expedite subsequent modeling to consolidate several (say, k) stochastic TSPA inputs into a single stochastic input parameter where feasible, so that one input rather than k inputs must be sampled during each Monte Carlo evaluation. But loss in accuracy need not occur by taking this expedited approach, in contrast to the accuracy loss implied by empirical distribution functions that were used in the TSPA model to model inputs for which adequate parametric fits could not be obtained to model corresponding composite distributions (e.g., BDCF values for ^{210}Pb, ^{242}Pu, ^{226}Ra, and ^{230}Th; see CRWMS M&O 2000bl, p. 440-441).

3. Stage-3 Verification of the Integrated TSPA Model is Deficient

Validation of the integrated TSPA-SR model is discussed in Section 6.5 of the AMR (CRWMS M&O 2000bl, p. 542-557). In this section the explanation of Stage-3 model verification (Integrated Model Output Testing, p. 548-550) performed for TSPA-SR states:

> "Integrated model output testing can be accomplished by careful evaluation of the model results, in this case dose, in response to the upstream feeds. For the TSPA model the general measure of performance is dose. ...The total system integrated model is the sum of the subsystem models coupled together using common input data and propagating changes in a logical order through the system, during a simulation. It can be demonstrated through a series of plots...that the integrated total system model is performing as expected. ...The TSPA-SR model has been carefully scrutinized to establish its agreement with the conceptual models developed in the relevant AMRs. This included verifying all of the data fields in the TSPA-SR model. This verification ensures that the input digital model is in accord with the conceptual model... The internal computations performed within the GoldSim code have been verified to be correct when the integrated model is implemented... All the external dynamically linked library routines (DLLs) have been verified under the GoldSim code command. The data transfers to and from the DLLs in the GoldSim code have been verified when the integrated model is implemented... The integrated total system model behaves as expected, and results from each subsystem model component are consistent with the entire total system model."

This summary of criteria for Stage-3 verification does not appear to include any test of whether or not the specific model output of interest (say, the maximum annual dose from the dominant radionuclide over 10,000 yr) actually equals the corresponding value calculated independently

using alternative methods (e.g., analytic methods where feasible) linked to Monte Carlo calculations for remaining model inputs or steps that can only be solved numerically. To perform this test for numerically intensive TSPA model components, it may be sufficient for each component or scenario, to run the numerical model only once. It is likely that the result for a particular radionuclide could be related in a simple manner (e.g., linearly with time t) to the magnitude of the source function used (e.g., the rate of release from a waste package beginning at time t_0). Such simplification and verification have not been done for TSPA-SR.

This exercise could be undertaken using expected values for all stochastic inputs, after solving for predicted dose as some analytic and/or interpolated function G of a linear function $L(\mathbf{x})$ of a reduced set of input model parameters $\mathbf{x}$, where $\mathbf{x}$ is a reduced set of intermediate quantities that reflect the output of previous, simplifying analytic calculations. An independent calculation of the expected values $E(G(L(\mathbf{x})))|(\mathbf{x} = E(\mathbf{x}))$ will be facilitated by the ability to integrate over any (numerically derived, but symbolically specified) arbitrarily nonlinear function G that is interpolated with great accuracy, as might be achieved using the commercially available symbolic software *Mathematica*® (Wolfram 1999). The value of going through this exercise would be to reveal any absolute or relative error that might be introduced by the GoldSim integration of the TSPA-SR system model (CRWMS M&O 2000bl, Sections 6.2 and 6.3), in contrast to the component, dynamically linked submodels contained in the integrated TSPA-SR model. Such absolute or relative error may not be revealed by the analysis of model-output-behavior figures as described above for the current approach to Step-3 model verification.

4. **Validation of Integrated TSPA Model Using AP-3.10Q §5.3.b Requires Comparison of Model Predictions With Best-Available Sets of Relevant Field Data Involving YMP Analogs**

If validation of the TSPA model is to be achieved using the approach described in AP-3.10Q 5.3.b (in lieu of, or in addition to 5.3.c) then at least some completed examples are needed in which TSPA model predictions are compared systematically to relevant field data involving analogs. This approach would require careful consideration of the uncertainty distributions selected for relevant TSPA input parameters. Some comparisons along these lines are included in *Total System Performance Assessment for the Site Recommendation* (CRWMS M&O 2000bm, Appendix C which is entitled: Natural-Analogue Investigations in Support of Performance Assessment of the Potential Yucca Mountain Radioactive-Waste Repository, p. C-13 and C-16). This source states that:

> "...there are no rock-analysis data from beneath the [Nopal I uranium] ore body, and the fate of uranium in downward percolating water, such as modeled by the Repository Integration Program, cannot be corroborated by field data at this time. ... The analysis indicates that a groundwater-sampling program could provide data with which to estimate realistic transport parameters for the Peña Blanca site. By analogy, these parameters may be a useful tool in estimating the performance assessment of the Yucca Mountain site. ... Because of the paucity of well data and other hydrogeologic data for the area, the estimated direction and gradient of groundwater flow is highly uncertain. ... The tentative conclusions developed as a result of the modeling previously described could be enhanced or modified with the implementation of the drilling program described ... [and recommended]. These recommendations were designed to help provide data with which

to more accurately define the magnitude and direction of the groundwater gradient in the vicinity of the Nopal I mine. The proposed additional monitor wells are also needed to provide water-sampling locations that will be used to calibrate future performance-assessment modeling in the Peña Blanca area."

Completion of activities such as the Nopal I study and comparative analysis recommended in the report quoted above, is needed for the TSPA system model to comply with AP-3.10Q §5.3b. Such validation would be helpful in addition to the model verification and peer review approaches that have already been implemented.

5. Monte Carlo Sample Size

The TSPA-SR model (CRWMS M&O 2000bl) is considered by this reviewer to require evaluation of the Monte Carlo sample sizes used in all applications of the system model to explore the parameter hyperspace involved and justify the sample-size. The set of all distributed inputs and their relative contributions to uncertainty in predicted critical dose should be summarized more clearly and concisely (including the use of a single comparative plot to convey this information). The AMR indicates that there are a relatively large number (perhaps more than 100) distributed inputs involved in the TSPA-SR model, and yet only 100 to 300 realizations were generated using Latin-Hypercube sampling. The bases for this sample size should be accompanied by supplementary analyses, and corresponding clear discussion of resulting evidence, demonstrating that nearly all parameters involved have negligible individual effects as well as negligible interactive (e.g., synergistic) effects. Because of the small sample size used, it is possible that interactive effects may not have been fully explored. To see why, suppose, for simplicity, that each of a hypothetical set of 5 independent input parameters (x_i, $i = 1,2,...,5$) is monotonically proportional to predicted dose D as a function $f(x_i)$ of the vector x_i. Again for simplicity, approximate each i^{th} corresponding input probability distribution function (pdf) by a corresponding 2-point approximating probability mass function (apmf), where in each i^{th} case apmf = $\{\{x_{i1}, 1-p\}, \{x_{i2}, p\}\}$ where x_{i2} is the mean of the upper tail (with probability mass p) of the i^{th} pdf and x_{i1} is the corresponding mean of the complementary lower tail (with probability mass 1-p) of this pdf, for some constant $0<p<1$ (e.g., p=25%) (see, e.g., Bogen 1995). Now, unless unexpected synergy can be ruled out a priori, for example based on analysis of model structure, a complete exploration of the potential for substantial (and first order) synergistic interaction among these 5 stochastic variates *requires* that dose be simulated using *all possible* (2^5 or 512) combinations of the apmf-approximated x_i-values, after which a corresponding approximate pdf for dose can be constructed using discrete probability calculus or "DPC" (see Bogen 1995). If 30 variates were involved, this complete exploration would require more than 10^9 realizations. In summary, even if only 5 independent input variates are involved, and if only 100 realizations were used, it is *substantially likely* that the simulations *could fail to reveal the possibility* that a large dose could arise when just two of the inputs are only moderately large (e.g., x_{12} and x_{22}, each with p=0.25 and thus with a joint likelihood >5%). The likelihood of such a large dose may affect the expected dose value, but any such affect will be missed (resulting in a biased underestimate of expected dose) if Monte Carlo simulation fails to identify this likelihood because the number (n_{sim}) of realizations is too low. This argument applies to the estimation of upper-bounds on dose as well as to the estimation of expected dose.

The magnitude of potential bias due to n_{sim} being too low depends of the degree of nonlinearity of the problem and on the variance of the relative contributions from uncertainty in each of the x_i to predicted uncertainty in D. For instance, let $D = A(B^C + D^E)$ involving only five stochastic variates $\{A,B,C,D,E\}$ each distributed as log-normal with a median of 1 and a geometric standard deviation (GSD) of 2. Contrast the mean value of D ($\overline{D}$) estimated using a single simulation of D via Latin-Hypercube sampling with n_{sim}=100, vs. the distribution of $\overline{D}$ estimates obtained when such a simulation is repeated (randomly) 100 times. In this example, this reviewer calculates that the coefficient of variation of $\overline{D}$ (i.e., the standard deviation divided by the expected value of any single estimate of expected dose) is >100%. Therefore, a single estimate of the expected value of D based on n_{sim}=100 is unreliable in this highly non-linear example, even though Latin-Hypercube sampling was used.

In practice, the investigation of potentially substantial synergistic interactions in the YMP simulation problem may be simplified. It is reasonable to focus this investigation only on, e.g., the 5 to 9 input variates that yield the greatest relative univariate contribution (RC) to uncertainty in predicted critical 10,000-yr annual maximum dose D. (Reasonable bases for assuming that substantial synergistic interactions involving the remaining variates would not be expected–e.g., based on arguments involving the TSPA-SR model structure–must be discussed in the AMR.) The apmf-DPC approach described above could then be used for a complete exploration of potential 1st-order synergy among the selected input variates conditional, e.g., on the mean value of all remaining input variates, and to generate a corresponding apmf for predicted dose, using only 512 or fewer simulations. (The AMR must state that the potential for any higher-order synergy among input variates was not investigated systematically, or state how any such investigation was done.) An alternative approach would be to use an RC-based importance-sampling approach rather than Latin-Hypercube sampling for Monte Carlo simulations (or if this approach was in fact used in the TSPA-SR analysis, this fact must be clarified and explained). If neither approach is used, the AMR for the TSPA model must reasonably defend the assumption (which in this case should be stated explicitly in the AMR) that interactions among (or at least between pairs of) uncertain input variates have no substantial synergistic effect on predicted uncertain output. In this case, the Monte Carlo sample size (i.e., number of simulated TSPA model realizations) must always be demonstrated quantitatively to be adequate in relation to specified risk acceptability criteria adopted for a probabilistic risk analysis (Ang and Tang, 1984).

The sample-size issue discussed above is not addressed in the AMR. It is discussed, however in the TSPA-SR technical report (CRWMS M&O 2000bm) in Sections 4.1.4 (for nominal performance) and 4.2.3 (for igneous disruption), where results of analyses using larger numbers of realizations are presented to allow visual confirmation of the adequacy of the sample size. As noted by the NRC in their comments on the TSPA-SR (Cornell 2001, p. 24) additional information regarding sample size and the stability of the model results will be needed to support a potential License Application.

Appendix III

(2 pages)

Additional Comments on Document Content Reorganization for the TSPA Model Report, and the TSPA Technical Report

(by Gary Callahan)

The following reorganization of content is recommended based on the assumption that the purpose of the AMR: *Total System Performance Assessment (TSPA) Model for the Site Recommendation* (CRWMS M&O 2000bl, hereinafter called the U.1 document) is to describe the TSPA model, and the purpose of the technical report: *Total System Performance Assessment for the Site Recommendation* (CRWMS M&O 2000bm, hereinafter called the U.2 document) is to present the TSPA analysis based on the TSPA model presented in the U.1 document. An alternative approach would be to prepare three documents: 1) the philosophy and approach to TSPA, 2) description of the TSPA model (i.e., pretty much what U.1 is presently–a description of the GoldSim (Golder Associates 2000) implementation and its component models, and 3) documentation of the TSPA with results and conclusions.

The following discussion pertains to the organization of the U.2 document (CRWMS M&O 2000bm):

1. Chapter 2, especially Section 2.2 (Methodology) includes model philosophy and details that should be included in the U.1 document. A short summary presenting the methodology of the TSPA model, with reference to the U.1 document, would be better in the U.2 document Chapter 2. The addition of this information to U.1 would be an improvement to the overall presentation of the model development. The U.1 document presently starts out more or less with a bang–presenting software immediately.
2. Portions of Chapter 3 would fit better into the TSPA model report (U.1 document). In particular, discussion of the AMRs supporting the TSPA model and discussion of model conceptualizations are better suited to the U.1 document.
3. Appendix B (Summary of Screening Decision and Basis Information Contained in Revision 00 of the Yucca Mountain Project and Features, Events, and Processes Database) in the U.2 document would be more appropriate for the U.1 document under this recommended reorganization. This would provide the much needed supporting information for those FEPs that are not presently included in the TSPA model.
4. Appendix C (Natural-Analogue Investigations in Support of Performance Assessment of the Potential Yucca Mountain Radioactive-Waste Repository) in the U.2 document provides information on natural analogues that provide confidence in the TSPA model. Thus, Appendix C could be moved to the U.1 document. Comment: The differences between ASHPLUME Version 2.0 and Version 1.4LV are not described in sufficient detail to determine whether or not the simulation results are meaningful. One would expect the two versions of the code to produce similar results. Since the parameters were adjusted (calibrated) to obtain a reasonable fit to the observed data, one would expect the comparison between the calculated and observed data to be reasonable.

5. Appendix F (Synthesis of Major Assumptions and Conservatisms Included in Total System Performance Assessment-Site Recommendation) in the U.2 document summarizes major assumptions used in the individual component models and the degree of conservatism that has been incorporated in these models. Therefore, Appendix F should be included in Chapter 5 of the U.1 document.

6. Process model-area names should be consistent throughout the U.1 and U.2 documents. For example, compare the naming convention used in the U.2 document (p. 3-1, Table 3-1) with terminology used in the U.1 document (Purpose section on p. 25, Figure 6-1 on p. 83, and Section 6-3 on p. 112).

Appendix IV

(72 pages)

Impact Reviews for Bin-3 Models as Submitted by Responsible Project Staff

This appendix contains 34 impact reviews prepared by Project staff (model area leads) responsible for model development. The impact reviews correspond to the Bin-3 models identified in Section 6 and listed in Table 7 of this report.

The impact reviews clearly indicate whether each model was used for TSPA-SR, and whether it was used for FEP screening. Use for TSPA-SR means that quantitative output from the model was used as input to the TSPA-SR system model. This does not necessarily mean that *all* output from the model was used. Use for FEP screening means that the model is cited in a FEP screening analysis AMR, so the use may be qualitative, and may be limited to certain aspects of the model.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Thermal-Hydrologic-Mechanical (THM) Model (G.1)	B. AMR: Calculation of Permeability Change Due to Coupled Thermal-Hydrological-Mechanical Effects. (CAL-NBS-MD-000002 Rev. 00) (CRWMS M&O 2000g)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☒ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: David Dobson [signature] 11-14-01
Type Name/Signature Date:

Continuation of item D (Model G.1):

The reviewer's comments concerning this calculation are acknowledged. These issues of model validation have been recognized for approximately one year, after an audit of the near-field environment program. Steps have already been taken to address them; additional model development and documentation have been completed, and further activities are planned. These findings of the model validation review do not affect the conclusions of the TSPA–SR because the arguments discussed below indicate that "screening-out" of THM effects from the TSPA was reasonable and defensible.

This original calculation report (CRWMS M&O 2000g) has been revised and converted to a new AMR (BSC 2001g) effective in August, 2001. The new AMR includes more extensive information on model validation based primarily on measured field data (including rock displacement measurements) from the Drift Scale Test (DST), Large Block Test, and Single Heater Test (SHT) (Section 4.3.7). This information is also summarized briefly in the SSPA (BSC 2001d; Section 4.3.7).

Alternative modeling approaches have also been compared, to support validation for THM models for Yucca Mountain, as permitted by AP-3.10Q Section 5.3.c.4. A continuum model has been used along with the discrete fracture model in the new AMR (BSC 2001ag). In addition, the THM effects have been independently studied using another continuum model (TOUGH-FLAC) (BSC 2001d, Section 3.2.7). In that effort, the model is calibrated against data from field air permeability measurements in the DST that provide bounds for magnitude of residual apertures as a result of THM processes.

All analyses completed to date indicate that the THM effects on permeability are relatively small (within an order of magnitude change in permeability, based on measurements from both the SHT and DST) compared to the range of permeability (three to four orders of magnitude) arising from natural spatial heterogeneity. Recent results confirm the screening decision not to incorporate THM effects on permeability into the TSPA-SR.THM model validation is the subject of a KTI agreement, for the Repository Design and Thermal-Mechanical Effects (RDTME) Key Technical Issue (Gardner 2001) which is summarized as follows:

- Provide additional validation analysis of field tests related to the thermal-mechanical effects on fracture permeability (RDTME 3.21)

Resolution of this agreement item will fully address the model validation review finding. This will involve alternative representations of fracture geometry and constitutive relationships. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

THM effects on permeability will be further investigated in ongoing and planned underground testing at Yucca Mountain, analyzed using both the discrete fracture modeling approach and continuum modeling, and the results will be documented in revisions to the AMRs that would support a potential License Application.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Cement Grout Model (H.3-2)	B. AMR: Engineered Barrier System: Physical and Chemical Environment Model. (ANL-EBS-MD-000033 Rev. 01) (CRWMS M&O 2000ab)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☒ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheets.

E. Responsible Individual: Robert MacKinnon/ Robert MacKinnon   11/15/01
Type Name/Signature   Date:

Continuation of item D (Model H.3-2):

Model results were used to screen out the effects of cement leachate on the composition of the water in the EBS bulk environment. Cement leachate may affect the concentrations of soluble and colloidal radionuclides and waste package and drip shield degradation. The impact on TSPA-SR is not significant because the predicted cement leachate composition is conservatively alkaline as discussed below, and because current models for waste package and drip shield corrosion rates indicate that water compositions similar to cement leachate will have no significant effect. See CRWMS M&O (2000af; 2000ag) for description of the corrosion models, and Section 3.4 of CRWMS M&O (2000bm) for a summary of the implementation of pH dependence for waste package corrosion, in TSPA-SR. The pH of alkaline cement leachate is expected to be no greater than pH 13 on equilibration with portlandite in a silica-rich environment, and substantially lower than this after reaction with CO_2 in the environment.

It is noted that corrosion data for high-pH conditions that are used in models that support TSPA-SR, are limited to results from cyclic polarization testing of thermally aged Alloy-22 samples in BSW-13 solution at pH 13 (CRWMS M&O 2000ag). As stated in this AMR (Section 6.7.2) more quantitative testing (which would include long-term corrosion testing in strongly alkaline conditions) is needed to support definitive statements on the effects of high-pH (or thermal aging) on corrosion rates.

There are several KTI agreements related to the issue of cement/seepage interactions and their potential effects on performance, for the Evolution of the Near-Field Environment (ENFE) Key Technical Issue (Williams 2001) and the Total System Performance Assessment Integration Issue (Cornell 2001):

- Address the effects of cementitious materials on hydrologic properties of the host rock (ENFE 1.4)
- Evaluate data and model uncertainties for specific in-drift geochemical environment submodels used in TSPA calculations and propagate those uncertainties through the submodels in a systematic approach (ENFE 2.5)
- Evaluate the impact of the range of local chemistry (e.g., dripping of equilibrated evaporated cement leachate and corrosion products) conditions at the drip shield and waste package considering the chemical divide phenomena that may propagate small uncertainties into large effects (ENFE 2.6)
- Provide additional information about the range of composition of waters that could contact the drip shield or waste package, including whether such waters are of the bicarbonate or chloride-sulfate type (ENFE 2.10)
- Evaluate the possibility of preferential dripping from engineered materials including rockbolts, and give appropriate consideration to the uncertainties of the water sources, as well as their potential impact on other models (TSPAI 3.7)
- Provide documentation of the integrated analyses and comprehensive uncertainty analyses related to the EBS physical and chemical environment in documentation associated with TSPA for any potential License Application (TSPAI 3.10)

These agreements will address many of the points raised in the model validation review. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation. The additional consideration of alternative cement phase

minerals, recommended by the model validation reviewer, will provide further confidence in predicted leachate composition. Substitution of more stable phases will tend to decrease the concentrations of key chemical components in cement leachate. Incorporation of multiple invariant points in leachate composition will limit the duration of the most alkaline compositions. Integrated analyses and uncertainty analyses will include evaluation of the effects of cement leachate on other models, i.e. other barriers such as the drip shield and waste package.

The path forward includes revising the cement/seepage model and conducting cement/seepage testing to provide data for model validation. The model revision will revisit the treatment of mineral phases (e.g., ettringite, calcium-silicate-hydrate, and tobermorite) used to represent the cement assemblage (CRWMS M&O 2000ab; Section 6.3), and justify the selections on conservative or other grounds. The current model is conservative in the sense that it assumes highly alkaline portlandite is present, and does not allow for in-place evolution of cement minerals to more stable, less soluble and less alkaline phases with time. Therefore the evolution of cement leachate to less alkaline compositions as cement mineral constituents are exhausted, is not considered with respect to leachate composition. This latter aspect of the cement behavior may be incorporated in future work if it can be adequately validated, otherwise a more conservative approach will be used. It is expected that the Cement Model will be further developed and documented in a new AMR for analysis of introduced materials in the EBS.

Capillary properties of the cement grout will control its water content, and the tendency for flow to converge toward and through the grout. The grout permeability is expected to be small, on the order of 10^{-19} m^2, which limits the amount of leachate that could potentially reach the drift opening. The current model is based on the concept that capillary affinity for water is inversely related to permeability, so that if the grout absorbs water from the rock then its permeability will be low. If the grout cracks or its fabric is altered by mineral evolution, then flow in the grout will become channelized and the extent of interaction with highly alkaline cementitious phases will decrease. This possibility is addressed in the current model by use of flux scaling, i.e. a geometrical argument (rather than based on permeability) for limiting the amount of cement leachate that could reach the drift opening.

In summary, the current model for cement leachate composition is believed to be reasonably conservative, and the possibility for interaction of high-pH waters with the waste package outer barrier has been addressed in the corrosion modeling. The need for improvement of the cement model is acknowledged, and will be addressed by planned work if cementitious materials continue to be used in the design. This topic has been discussed previously with the NRC staff and is the subject of KTI agreement items. While planned work will address the model validation review findings noted in this review, the conclusions of TSPA-SR with respect to the effects of cement on waste package performance are very unlikely to change as a result of new information.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Corrosion of Steel Used in the Ex-Container EBS (H.3-3)	B. AMR: Engineered Barrier System: Physical and Chemical Environment Model. (ANL-EBS-MD-000033 Rev. 01) (CRWMS M&O 2000ab)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☒ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheets.

E. Responsible Individual: Robert MacKinnon / Robert MacKinnon 11/15/01

Type Name/Signature Date:

Continuation of item D (Model H.3-3):

This model is referenced in the screening argument for FEPs related to biological activity in the waste and EBS (CRWMS M&O 2001h, Section 6.4.65).

This model estimates a range of effects from steel corrosion, on the oxygen content of the gas phase in the emplacement drifts. The model is preliminary in that an important assumption is made, that the steel corrosion rate measured for atmospheric conditions decreases in proportion to the oxygen fugacity. This assumption is identified to-be-verified (TBV-4931). Based on this assumption, which is a first-order approximation, a range of oxygen fugacities was calculated (CRWMS M&O 2000ab, Section 6.3 and 6.7) and used to evaluate possible changes in the equilibrium redox chemistry for water and mineral compositions representing the EBS. The effects of microbial activity were included as a multiplier on the steel corrosion rate, based on preliminary data. The result of the model indicated that excursions in oxygen fugacity are possible, but the calculated magnitude is not significant

Apart from the assumption, the approach is conservative in that for purposes of modeling oxygen consumption, the most consumptive reaction (producing Fe_2O_3) is used. Hydrolysis with production of hydrogen would tend to consume less oxygen from the gas phase. Hydrogen species from hydrolysis reactions are known to cause embrittlement in titanium, but this possibility was considered based on direct contact between carbon steel and titanium (CRWMS M&O 2000ah). Also, in the application of the steel corrosion model to gas-phase oxygen calculations, a 2-D approach was used, ignoring mixing of the gas phase along the third axis (parallel to the drift axis).

Other sources of uncertainty with respect to the rate of oxygen consumption were identified by the reviewers, and are acknowledged. These include microbial activity which is represented using preliminary data, represented by a simple multiplication factor. However, the calculated range of oxygen fugacities was shown to be far less (in a logarithmic sense) than that which would be needed to significantly affect the redox potential of the aqueous phase (CRWMS M&O 2000ab; Section 6.7). Consequently, order-of-magnitude changes in the rate of oxygen-consuming processes such as steel corrosion would not affect the calculated result of this model. Accordingly, the use of this model in FEP screening is justified. Further model development, testing, and comparison to natural or man-made analogs may be undertaken if steel remains part of the emplacement-drift design, but would not be expected to change this conclusion.

Some of the concerns raised by the model validation review are similar to previous KTI agreement items for the Evolution of the Near-Field Environment (ENFE) Key Technical Issue (Williams 2001) and the Total System Performance Assessment Integration (TSPAI) Key Technical Issue (Cornell 2001):

- Resolution of preliminary and to-be-verified information, will include TBV-4931 which relates to the form of the predictive expression for reasonable-bound rates of oxygen consumption by steel corrosion (TSPAI 2.1 Item 58)
- Evaluate the impact of the range of local chemistry (e.g., dripping of equilibrated evaporated cement leachate and corrosion products) conditions at the drip shield and waste package considering the chemical divide phenomena that may propagate small uncertainties into large effects (ENFE 2.6)

It is noted that resolution of other agreement items from KTI technical exchange meetings may

also contribute to model validation. It is expected that the Steel Corrosion Model will be further developed and documented in a new AMR for analysis of introduced materials in the EBS.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Effect of Evaporation in the Invert (H.3-4)	B. AMR: Engineered Barrier System: Physical and Chemical Environment Model. (ANL-EBS-MD-000033 Rev. 01) (CRWMS M&O 2000ab)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☒ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Robert MacKinnon / Robert MacKinnon 11/15/01
Type Name/Signature Date:

Continuation of item D (Model H.3-4):

No impact. This model was not used for TSPA-SR and will not be carried forward to License Application (LA).

Physical degradation of the invert and invert materials has been screened out of the TSPA-SR based on low consequence. The screening argument recognizes that the invert is a minor barrier to flow in comparison to the drip shield, waste package, and unsaturated zone beneath the drift. Changes in porosity of the invert would have little effect on radionuclide transport. The typical depth dimension of the invert, about one meter, is much less than the transport distance through the unsaturated zone, and the effect on radionuclide transport is therefore much less.

The path forward includes analyses of coupled processes in the EBS per KTI agreement ENFE 2.7 (Williams 2001). At this time, however, no experiments are planned as the final invert design and material selection has not been made. Tests involving crushed tuff have low priority because the invert offers little waste isolation performance. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

MODEL VALIDATION - IMPACT REVIEW

A. Model: EBS Colloids Model (H.3-5)	B. AMR: Engineered Barrier System: Physical and Chemical Environment Model. (ANL-EBS-MD-000033 Rev. 01) (CRWMS M&O 2000ab)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

No impact. This bounding model was not used for TSPA-SR, and will not be carried forward to LA. This model was used in preliminary process model screening considerations only (see Table I-1, CRWMS M&O, 2001h) and was not used as a basis for screening FEPs for TSPA-SR.

The reviewer's concerns with the need for test data, the use of hematite to represent iron oxide, and the use of constant Kd's, are acknowledged. However, this model is not used, and colloidal transport in the waste package and the ex-container engineered barrier system (EBS) is included in the TSPA-SR based on other models (CRWMS M&O 2000al; 2001s). These other models are reviewed elsewhere in this report (Sections 6.11.29, 6.11.30, and 6.13.1) with findings and recommendations that are not related to the subject model.

The specific details associated with colloids comprised of iron oxides are not addressed by a KTI agreement. However, there are existing KTI agreements for the Evolution of the Near-Field Environment (ENFE) Key Technical Issue (Williams 2001) and the Total System Performance Assessment Integration (TSPAI) Key Technical Issue (Cornell 2001) that pertain to evaluation of colloid properties that control sorption (ENFE 4.6), particles larger than colloids (TSPAI 2.1), and changes in colloid concentrations due to changes in pH and ionic strength (TSPAI 3.42). Resolution of these agreements will help to reduce uncertainty in modeling of colloidal processes. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

E. Responsible Individual: Robert MacKinnon / Robert MacKinnon 11/15/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Seepage/Cement Interaction Model (H.7)	B. AMR: Seepage/Cement Interactions (ANL-EBS-MD-000043 Rev. 00) (CRWMS M&O 2000bf)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Robert MacKinnon / Robert MacKinnon — Date: 11/15/01

Type Name/Signature

Continuation of item D (Model H.7):

No impact. This bounding model was not used for TSPA-SR, and will not be carried forward to LA in its present form. The reviewer's concerns with appropriate boundary conditions and diffusion parameter values, and the need for comparison to test data, are acknowledged for this developmental model.

There are several existing KTI agreements related to the issue of cement/seepage interactions and their potential effects on performance, for the Evolution of the Near-Field Environment (ENFE) Key Technical Issue (Williams 2001).

- Address the effects of cementitious materials on hydrologic properties of the host rock (ENFE 1.4)
- Evaluate data and model uncertainties for specific in-drift geochemical environment submodels used in TSPA calculations and propagate those uncertainties through the submodels in a systematic approach (ENFE 2.5)
- Evaluate the impact of the range of local chemistry (e.g., dripping of equilibrated evaporated cement leachate and corrosion products) conditions at the drip shield and waste package considering the chemical divide phenomena that may propagate small uncertainties into large effects (ENFE 2.6)
- Provide additional information about the range of composition of waters that could contact the drip shield or waste package, including whether such waters are of the bicarbonate or chloride-sulfate type (ENFE 2.10)

It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation. This model overlaps with the Cement Model (H.3-2) which was addressed in a previous impact review. Both models will be consolidated, developed, and documented in a new AMR that evaluates the effects of introduced materials in the EBS.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Ventilation Model (I.5)	B. AMR: Ventilation Model. (ANL-EBS-MD-000030 Rev. 00) (CRWMS M&O 2000bx)

C. Category (Check appropriate case) .

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheets.

E. Responsible Individual: Robert MacKinnon/ Robert MacKinnon 11/21/2001
Type Name/Signature Date:

Continuation of item D (Model I.5):

The model validation findings have no significant impact on the TSPA-SR model (CRWMS M&O 2000bl) primarily because output from the Ventilation Model was not used directly for TSPA-SR. The Ventilation Model was not used for FEP exclusion, because the preclosure ventilation FEP was included in TSPA-SR. (The effects of preclosure ventilation on system performance were represented by models other than the Ventilation Model.)

The Ventilation Model is used to verify that forced ventilation can remove a prescribed fraction (70%) of waste-generated heat during the 50-yr preclosure period. The thermal analyses and thermal-hydrologic models that use this information, do so by decreasing the waste heat output by 70%. All other information produced by the Ventilation Model is not used. Only the feasibility of 70% heat removal resulted from this model, and this result is not questioned in the model validation review. The representation of heat removal by preclosure ventilation in other models may be questioned, but that is not part of the Ventilation Model.

The lumped-parameter averaging approach for temperature and air velocity, the representation of buoyancy, and the representation of drift-wall temperature, are adequate to establish ventilation feasibility as intended. The effects of these model representations on ventilation efficiency are likely to be minor, i.e., readily compensated by minor adjustments in ventilation parameters such as the air flow rate. Evaporation of water from the near-field rock would tend to increase ventilation efficiency if considered in the model. Additional confidence in the predictive model is not needed until detailed design of the ventilation system, which will be done at a later time.

The following actions planned in response to KTI agreement items for the Repository Design and Thermal-Mechanical Effects (RDTME) Key Technical Issue (Gardner 2001) and the Thermal Effects on Flow (TEF) Key Technical Issue (Reamer and Williams 2001) will address some of the findings identified by the model validation review:

- Provide the technical basis for the range of relative humidities, and the possible presence of liquid-phase water, that could affect ground support longevity (RDTME 3.1)
- Provide the results of ventilation testing in an update to the Ventilation Model, which will include the technical basis for discretization, and the basis for application to repository simulation (RDTME 3.14, TEF 2.7)

It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

The following activities have been undertaken, or are ongoing, to further develop confidence in ventilation models:

- A revision to this AMR (revision to CRWMS M&O 2000bx) is in preparation. It compares the original model (considered for the model validation review) to another model that includes more explicit representation of heat and mass transfer.
- The *Supplemental Science and Performance Analyses* (BSC 2001d, Section 5.3.2) investigated the sensitivity of temperatures to ventilation efficiency and to the temporal evolution of ventilation efficiency. For the high-temperature and low-temperature cases considered, the peak waste package temperature changes about 0.7 and 0.35°C for each 1% change in ventilation efficiency. Peak preclosure temperatures were very sensitive to the temporal evolution of the efficiency, which is helpful for guiding future predictive modeling activities.

Based on this discussion it is concluded that the current Ventilation Model adequately establishes the feasibility of preclosure ventilation to remove 70% of waste-generated heat in a 50-yr preclosure period. The need for additional model validation information in the Rev. 00 AMR is acknowledged, and this need is being addressed by additional modeling and testing activities.

MODEL VALIDATION - IMPACT REVIEW

A. Model: In-Drift THC Model (I.7)	B. AMR: In-Drift THC Model. (ANL-EBS-MD-000026 Rev. 01) (BSC 2001r)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

No impact. This model was not used for TSPA-SR, and will not be carried forward to LA. The reviewer's concerns with this model are acknowledged, including model representation of the buoyant flow physics, spatial resolution, and other aspects. This model is preliminary in nature and was developed to represent the original EDA-II backfill design case (Wilkins and Heath 1999). Coupled thermal-hydrologic-chemical processes were to be incorporated in a revision). This backfill case is similar to the current conceptual design, but includes crushed-tuff backfill, slightly different thermal loading, and different thermal management objectives. Although documentation changes to the AMR have been implemented, the original model has not been changed or updated.

E. Responsible Individual: Robert MacKinnon / *Robert MacKinnon* 11/15/01
Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: Effective Thermal Conductivity Model (1.8)	B. AMR: Effective Thermal Conductivity for Drift-Scale Models Used in TSPA-SR. (CAL-EBS-HS-000001 Rev. 00.; a calculation report) (CRWMS M&O 2001g)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Robert MacKinnon/Robert MacKinnon 11/15/01

Type Name/Signature Date:

Continuation of item D (Model I.8):

The effective thermal conductivity parameter is applied directly in two process-level models (Multiscale Thermohydrologic Model and the Thermal-Hydrologic-Chemical Seepage Model) that supply information to TSPA-SR. The effective thermal conductivity parameter controls the rate at which heat is transported from the waste packages to the drift wall during the preclosure period, and from the drip shield to the drift wall in the postclosure period. This influences the calculated temperatures and relative humidity values at the waste package, drip shield, and drift wall.

The impact of validation issues associated with this model, on the conclusions of TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1) is insignificant because: 1) the uncertainty in repository temperature predictions is small, on the order of a few degrees Celsius as shown by predictions from field thermal tests (CRWMS M&O 2000bk); and 2) the sensitivity of system performance to repository temperature is not important to calculated dose (CRWMS M&O 2000bm, Section 5).

The reviewer's concerns are acknowledged; the greatest known potential for error in the model is the suppression of local variations in temperature. Temperatures computed using this approach are spatially smoothed such that local "hot" or "cold" spots along the surfaces of the waste package, drip shield, or drift wall are not predicted although small differences in temperature (for example, comparable in magnitude to the predictive uncertainty discussed above) could occur in the repository. The overall impact of this approximation on the annual dose calculated by TSPA-SR is not important because temperature changes have been shown, in general, not to be important to calculated dose as discussed above. It is noted that the TSPA-SR component models (e.g., WAPDEG; CRWMS M&O 2000br) do not have the spatial resolution that would be needed to simulate corrosion and other processes at "hot" or "cold" spots in the engineered barrier system.

The DOE-NRC agreements concerning the Thermal Effects on Flow (TEF) Key Technical Issue (Reamer and Williams 2001) include items which when resolved, will contribute to validation of this model or alternative approaches that may be used in the future:

- Represent the "cold-trap" effect in thermal-hydrologic simulations, and provide technical justification for inclusion or exclusion of the effect in the various scale models that support TSPA. The analysis will consider thermal effects on flow, and the in-drift geochemical environment (TEF 2.5).

It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

Simulating the "cold-trap" effect is similar to the prediction of small-scale variation of environmental conditions discussed above. It involves the representation of heat and mass transport processes within the emplacement drifts, with sufficient fidelity to predict variations caused by buoyant convection, condensation, and other processes.

MODEL VALIDATION - IMPACT REVIEW

A. Model: WAPDEG Analysis of Waste Package and Drip Shield Degradation (J.6)	B. AMR: WAPDEG Analysis of Waste Package and Drip Shield Degradation (ANL-EBS-PA-000001 Rev. 00 ICN 01) (CRWMS M&O 2000br)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail).

See continuation sheets.

E. Responsible Individual: Tammy Summers / Tammy Summers 11/19/01

Type Name/Signature Date:

Continuation of Item D (Model J.6):

There is no impact from the model validation review findings from Section 6.10.8 of this report, on the conclusions of TSPA-SR (CRWMS M&O 2000bm, Section 6.1). The models used to describe waste package and drip shield performance for TSPA-SR are adequate because they are closely based on the process models (also reviewed for model validation) which in turn are based on Project-generated data relevant to repository conditions.

The technical basis for the process models is the focus of KTI agreement items for the Container Life and Source Term (CLST) Key Technical Issue (Kelmenson 2001) which include:

- Provide data that characterizes passive film stability, including welded and thermally aged specimens (CLST 1.9)
- Provide documentation for Alloy-22 and titanium performance, including the following: measured potentials in the long-term corrosion tests, critical potentials on welded samples, separate effects of water composition on damage/buffering behavior, and critical potentials in environments containing heavy metal concentrations (CLST 1.10)
- Provide documentation for Alloy-22 and titanium performance, including the following: qualify and optimize mitigation processes, generate SCC data over a range of conditions, continue slow strain-rate testing, determine repassivation constants for film rupture model, continue direct current potential drip crack propagation rate measurements extended to additional environments, evaluate SCC resistance of welded/stress mitigated vs. unwelded samples, and evaluate SCC of full-thickness welded material (CLST 1.12)
- Provide documentation for Alloy-22 and titanium performance, including the following: install specimens from mock-up in long-term corrosion tests, evaluate scaling and weld process factors related to actual containers, and provide welded samples for MIC, aging, and localized corrosion testing (CLST 1.15)
- Provide documentation for Alloy-22 performance, including the following: evaluate data input to current models, continue ongoing aging and evaluation of Alloy-22 samples, use theoretical modeling to enhance confidence in kinetic modeling, use welded and nonwelded samples for SCC compact tension tests, expand test program to welded and cold-worked materials, evaluate effects of stress mitigation on phase stability, and expand aging tests to include lower temperatures (CLST 2.5)
- Provide documentation for path-forward items including the following: expand rockfall effect calculations to include weld embrittlement/aging, drip shield thinning, hydrogen embrittlement of drip shield, and effects of multiple rock blocks; and calculate effects from static loading by fallen rock blocks during ground motion events (CLST 2.8)

The data being collected to address the KTI agreement items will be incorporated into the process-model AMRs supporting the WAPDEG AMR and will fully address the model validation review findings identified by the review team. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

The following comments apply to the overall conclusions from the model validation review concerning the WAPDEG model:

- The WAPDEG model is an integration model for waste package degradation analysis and based on the supporting process models and abstraction models. Validation of the process models in the Waste Package/Drip Shield Degradation model area is discussed in Section

6.10 of this report (specifically, Sections 6.10.1 through 6.10.5, and also 6.10.11, 6.10.12, and 6.10.14).

- The WAPDEG model is based on the set of abstraction models identified in the subject AMR (CRWMS M&O 2000br, Section 6.4.18). The validation for each of these contributing abstractions has determined that they are consistent with the parent process-level models.
- The software for WAPDEG has been qualified. The qualification efforts included execution of approximately 100 test cases involving verifying the operation of various segments of the code.

Specific comments from the review team (*in italics*) and responses are provided below.

Review comment: *The WAPDEG Analysis of Waste Package and Drip Shield Degradation Model is assigned to Bin 3 because there is a missing model that should be incorporated. This model will bring together the effects of the weld, weld heat-affected zone, and base plate microstructure/residual stress profile to predict the resistance of the waste package outer barrier (WPOB) to localized corrosion and stress corrosion cracking. The model will incorporate weld process variation within the number of passes needed to fill the joint and the effects of repair welding. The model will also incorporate the effect of chemistry variation in different heats of Alloy 22 weld wire and base plate.*

This model will develop the characterization of the microstructure and residual stress for Alloy 22 under the following conditions:

- *Welds and weld heat affected zone of the WPOB in the as-welded and as-welded/solution annealed condition (aged and un-aged)*
- *The weld and weld heat affected zone of the inner lid of the outer barrier in the WPOB in the as-welded and as-welded/laser peened condition (aged and un-aged)*
- *The weld and weld heat affected zone of the outer lid of the WPOB in the as-welded and as-welded/induction annealed condition (aged and un-aged)*

Analysis: The effects of the weld and weld heat-affected zone on corrosion of WPOB are modeled with a general corrosion enhancement factor due to aging (assumed uniform distribution between 1 and 2.5). The enhancement factor is based on the cyclic polarization data for fully aged and un-aged Alloy 22 base-metal samples in a highly aggressive condition relevant to the potential repository, and this is documented in: *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (CRWMS M&O 2000ag). No localized corrosion initiation was shown for the expected open circuit potential range. The cyclic polarization data are also supported by the various weld samples being tested in the Long-Term Corrosion Testing Facility (LTCTF). The weld samples that have been exposed for up to 2 yr do not show any noticeable differences in the corrosion behaviors (general corrosion, localized corrosion and SCC) and rates from non-welded samples in the LTCTF. The weld process effects on the corrosion resistance are part of the NRC CLST KTI agreements. The lower-tier AMRs (CRWMS M&O 2000ag; 2000bi) supporting the WAPDEG AMR will be updated to incorporate additional data and analyses for the weld process effects, which are being generated to address the NRC agreements.

It is agreed that the effects of potential weld process and materials variations are not addressed in the supporting AMRs (CRWMS M&O 2000ag; 2000bi). These effects are part of the ongoing and planned testing programs in response to NRC CLST KTI agreements. The supporting AMRs will be updated to incorporate additional data and analyses for the weld process and materials variation effects, which are being generated to address the NRC agreements. Updated models and data that will be incorporated into WAPDEG, will resolve the model validation review findings identified by the review team.

Review comment: *The finite element model analysis in the AMR: Stress Corrosion Cracking of the Drip Shield, the Waste Package Outer Barrier, and the Stainless Steel Structural Material (CRWMS M&O 2000bi) is presented but not validated with measurements of residual stress for the as-welded condition before laser peening or induction annealing.*

Analysis: The use of finite element (FEM) analysis (ANSYS analysis; see CRWMS M&O 2000bi) for the stress state in the closure weld regions after the local induction heating treatment is justified. This is based on the fact that the resulting stress state is due to the imposed cool down from annealing temperatures and not related to the as-welded stress state. The ANSYS analysis adequately represents the effect of quenching operations. In addition, preliminary unpublished data from testing by McDermott Technology Inc. of Alloy 22 welds and base metal, show that induction annealing produces compressive residual stresses to a significant depth, thus mitigating the potential for SCC. These measurements represent the combined effects of welding and induction annealing. Although not yet fully documented, it is expected that these data will confirm the FEM analysis.

Review comment: *There are assumptions made for the inner lid induction annealed case but no validating data are presented.*

Analysis: The induction annealing process does not apply to the inner lid, but has been proposed for the outer lid. Validation of the residual stresses in the outer lid closure weld following induction annealing has recently been achieved. Confirmatory data were generated as part of the ongoing production and study of prototypical mockups, and show that the residual stresses are compressive to greater than 5 mm in depth.

Review comment: *The residual stress data presented for the laser-peened WPOB inner lid closure weld are based on other nickel-based materials and weld joint designs that may not reflect accurately the relevant closure weld design.*

Analysis: The stress state for the laser peened WPOB inner lid is based on the measured residual stress before and after peening. While the data are obtained on welded Alloy-22 plate and not on the closure weld configuration, they represent the magnitude (if not the exact configuration) of weld-induced residual stresses and are therefore valid for the intended use, until more representative data become available. The residual stress data for shot-peening of Incoloy 908 were used only to define the stress uncertainty range and were not used for the absolute stress values (CRWMS M&O 2000bi, Section 6.2.2.5).

Review comment: *The residual stress measurement data presented do not account for changes due to the welding process (weld fit-up variations, variations in heat input, travel speed) and possible subsequent repair processes. More data are also required on the equivalence of shot peening and laser peening.*

Analysis: It is agreed that residual stress measurements on mock ups with the closure lid design configurations would provide more reliable supporting data for the model. However, as mentioned in the previous response, the residual stress data are representative of the magnitude of weld-induced stresses (at yield strength or above) and it is the post-mitigated stress state that is important for the model. The shot-peening data are analogous, and are used where more directly relevant are not yet available.

Review comment: *The use of the term "hoop stress" to define residual stress needs clarification.*

Analysis: The term "hoop stress" is used for the z-component (circumferential direction) of the three principal components of the residual stresses in the outer and inner closure lids, as discussed in Sections 6.2.2.1 through 6.2.2.5 of the supporting AMR (CRWMS M&O 2000bi). Accordingly, the same term is used in the subject AMR: *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (CRWMS M&O 2000br) and in the abstraction AMR: *Abstraction of Models of Stress Corrosion Cracking of Drip Shield and Waste Package Outer Barrier and Hydrogen Induced Corrosion of Drip Shield.* (CRWMS M&O 2000c).

Review comment: *The output of the WAPDEG model concludes that localized corrosion is not possible within the 10,000-year evaluation period as represented in the TSPA-SR. However, it is the strongly held opinion of the reviewers that the materials used in the waste package should not be judged on the low rate of general corrosion but localized corrosion or stress corrosion cracking (SCC). This is not adequately expressed in WAPDEG despite the uncertainty that surrounds the technical issues. An example of this is the lack of expression of uncertainty related to the efficacy of the stress mitigation procedures for the WPOB welds. More data are needed (microstructure and residual stress) from representative weld mockups fabricated using the weld process, joint design, and stress mitigation techniques selected for the WPOB.*

Analysis: Localized corrosion is represented in the TSPA. However, it is not triggered because the required threshold environmental conditions do not occur in the system model (CRWMS M&O 2000bm, Section 5.2.3). In addition, thicker welds that are prototypical of the welding process currently planned have been tested for crevice corrosion in a Basic Saturated Water (BSW-12; see CRWMS M&O 2000ac, Table 27). Preliminary, unpublished data from testing by McDermott Technology Inc. show no evidence of localized corrosion in either the weld or heat affected zone, and there was no difference in corrosion behavior observed for the Alloy 22 weld and base metal. Residual stress measurements from samples that were either laser peened or induction annealed have shown that it is possible to produce compressive residual stresses to a significant depth by these stress mitigation techniques, thus mitigating the potential for SCC.

Review Comment: *The multiple mechanisms for localized corrosion and cracking, as described in the abstraction models, should be combined probabilistically and then included in the WAPDEG abstraction model. This is needed to avoid oversimplification and to satisfy stakeholders.*

Analysis: Stochastic models have been developed for the occurrence (initiation and propagation) of crevice corrosion and SCC and implemented in the WAPDEG model for the TSPA-SR (CRWMS M&O 2000br). Localized corrosion of the SCC cracks (or at the SCC crack tips) is not considered in the TSPA-SR WAPDEG analysis because the WPOB is not subject to localized corrosion under expected repository exposure conditions as indicated by the relevant project cyclic polarization data (CRWMS M&O 2000ag).

For the TSPA-SR base case WAPDEG analysis (CRWMS M&O 2000br, Section 6.5.1) the initial breach of waste packages is in fact by SCC in the closure weld regions, and the SCC failure is estimated to begin at about 11,000 yr after the repository closure. Penetration of the waste packages by general corrosion is estimated to begin at about 30,000 yr.

The efficacy of the stress mitigation processes is incorporated in the model as part of the uncertainty bands on the stress profiles used in the model. In addition, more recent analyses have included probabilistic estimates of potential improper heat treatment conditions and the effects on waste package performance. These analyses are documented in the SSPA Volume 1 (BSC 2001d). It is agreed that more data are needed and additional sample testing from the mockups subjected to stress mitigation are planned as part of the ongoing activities to address KTI agreements.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Incorporation of Uncertainty and Variability of Drip Shield and Waste Package Degradation in WAPDEG (J.8)	B. AMR: Incorporation of Uncertainty and Variability of Drip Shield and Waste Package Degradation in WAPDEG (ANL-EBS-MD-000036 Rev. 00) (CRWMS M&O 2000ak)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Tammy Summers/*Tammy Summers* *11/19/01*
Type Name/Signature Date:

Continuation of item D (Model J.8):

The model validation review findings have no impact on the conclusions from TSPA-SR (i.e calculated annual dose; see CRWMS M&O 2000bm, Section 6.1) for the following reasons:

- This AMR was not used in the TSPA–SR, i.e. not referenced by the TSPA-SR reports (CRWMS M&O 2000bl; 2000bm) or the principal supporting WAPDEG report (CRWMS M&O 2000br).
- This AMR was intended to address the effects of uncertainty and variability in various data sets which are used as input to WAPDEG. However, the analysis was not fully developed and so was not used for TSPA-SR.
- The AMR designated as Model J.8 in the model validation review (Table 6 of this report) was originally identified by the author as an analysis and not a model. Further, the AMR was prepared with the intention that it would provide supplemental information only, and would not be used for the TSPA-SR model (CRWMS M&O 2000bl). The subject matter is developmental, and it was originally intended that the AMR would be revised before use in TSPA.
- Representation of uncertainty and variability with respect to waste package and drip shield corrosion processes has been incorporated into the process model and abstraction AMRs that support TSPA-SR (e.g., CRWMS M&O 2000ag; 2000br).
- Revised input from the technical specialist reviewers assigned to this model area indicates that this model should be considered as an analysis instead, in which case there is no need for validation. (This revised input was received recently, after the model-binning and impact reviews were conducted, and could not be incorporated in the findings of the review.)

The analysis may be updated for use for TSPA-LA and if so, will include additional new information generated from ongoing and future testing and model development activities

MODEL VALIDATION - IMPACT REVIEW

A. Model: Waste Form Degradation Abstraction - Best Estimate Model (K.4-3)	B. AMR: DSNF and Other Waste Form Degradation Abstraction (ANL-WIS-MD-000004 Rev. 01 ICN 1) (BSC 2001n)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

This model was not used to represent waste form degradation for TSPA-SR (CRWMS M&O 2000bl) which used the "conservative" representation. The subject AMR (BSC 2001n) was cited in the waste form FEPs screening analysis (CRWMS M&O 2000ai) but the screening arguments do not depend on this model. Therefore the model validation review findings have no impact on the conclusions of the TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1). The model is based at least in part on preliminary or approximate information, and the limitations of the model are discussed in the AMR, including the need for additional validation. In accordance with those limitations, the conservative approach (as defined in the subject AMR) is recommended and used for TSPA.

E. Responsible Individual: Christine Stockman/ Christine Stockman — 11/15/01

Type Name/Signature — Date:

MODEL VALIDATION - IMPACT REVIEW

A. Waste Form Degradation Abstraction – Immobilized Pu Model (K.4-4)	B. AMR: DSNF and Other Waste Form Degradation Abstraction (ANL-WIS-MD-000004 Rev. 01 ICN 1) (BSC 2001n)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☒ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

This model was not used to represent waste form degradation for TSPA-SR (CRWMS M&O 2000bl). The immobilized Pu inventory was averaged into the HLW glass radionuclide inventory, and the immobilized Pu waste form was treated as HLW glass for TSPA-SR. This approach is the "conservative" model developed in the subject AMR (BSC 2001n). The subject AMR was cited in the waste form FEPs screening analysis (CRWMS M&O 2000ai) but the screening arguments do not depend on this model. Accordingly, the model validation review findings have no impact on the conclusions of the TSPA-SR (CRWMS M&O 2000bm, Section 6.1). The model is based at least in part on preliminary or approximate information, and the limitations of the model are discussed in the AMR, including the need for additional validation.

E. Responsible Individual: Christine Stockman/ Christine Stockman 11/15/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: Alternate Wet Clad Unzipping Model (K.14-1)	B. AMR: Clad Degradation - Wet Unzipping (ANL-EBS-MD-000014 Rev. 00) (CRWMS M&O 2000p)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

This model was used in estimating the range of the unzipping multiplier used in TSPA-SR (CRWMS M&O 2000bm, Section 3.5.4.2) and thus influences the time of unzipping and the effectiveness of the cladding in isolating the CSNF inventory. Although the review findings are not specific, the use of limited data support is acknowledged, and future work will address the need for more data to the extent practicable. There is no significant impact of this finding on the conclusions of TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1) because the contribution of cladding, as represented in TSPA-SR, is minor for the 10,000-yr compliance period. It is noted that the unzipping model provides relatively little benefit to system performance, and that future work on this model would be greatly reduced if unzipping models were eliminated from a future TSPA model.

The contribution of cladding to total system performance was evaluated in a sensitivity study, documented in the "robustness analysis" for the TSPA-SR (CRWMS M&O 2000bm, Sections 5.3 and 5.3.4.1). This is a case in which cladding credit is substantially diminished by setting four of the five cladding parameters used in TSPA-SR, at their 95% distribution points signifying greater release rates. The result was a minor increase in the calculated average annual dose over the first 100,000 yr for 100 realizations of the TSPA-SR model (a factor of 1.5), compared to the nominal case in which these parameters were sampled over their full ranges. Thus the cladding model, while based on limited data with attendant model validation questions, does not impact the conclusions of the TSPA-SR (CRWMS M&O 2000bm, Section 6.1).

E. Responsible Individual: Christine Stockman/ Christine Stockman 11/28/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: Summary and Abstraction - Clad Unzipping and Fuel Dissolution (K.16)	B. AMR: Clad Degradation – Summary and Abstraction. (ANL-WIS-MD-000007 Rev. 00 ICN 1) (CRWMS M&O 2001d)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Christine Stockman/ Christine Stockman 11/15/01

Type Name/Signature Date:

Continuation of item D (Model K.16):

This is the cladding degradation summary process model compiled from the submodels documented in the calculation report: *Thermal Evaluation of Breached 21-PWR Waste Packages* (CRWMS M&O 1999f) and in the AMR: *Clad Degradation-Wet Unzipping* (CRWMS M&O 2000p). This model also includes development of the abstraction used for TSPA-SR (CRWMS M&O 2000bl, Section 6.3.4.3). Although the review findings are not specific, the use of limited data support is acknowledged, and future work will address the need for more data to the extent practicable. Some aspects of the review findings are addressed by the KTI agreements discussed below. There is no significant impact of this finding on the conclusions of TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1) because the contribution of cladding, as represented in TSPA-SR, is minor for the 10,000-yr compliance period.

The contribution of cladding to total system performance was evaluated in a sensitivity study, documented in the "robustness analysis" for the TSPA-SR (CRWMS M&O 2000bm, Sections 5.3 and 5.3.4.1). This is a case in which cladding credit is substantially diminished by setting four of the five cladding parameters used in TSPA-SR, at their 95% distribution points signifying greater release rates. The result was a minor increase in the calculated average annual dose over the first 100,000 yr for 100 realizations of the TSPA-SR model (a factor of 1.5), compared to the nominal case in which these parameters were sampled over their full ranges. Thus the cladding model, while based on limited data with attendant model validation questions, does not impact the conclusions of the TSPA-SR (CRWMS M&O 2000bm, Section 6.1).

The following KTI agreements are related to the Cladding Summary and Abstraction Model, for the Container Life and Source Term (CLST) Key Technical Issue (Kelmenson 2001):

- Perform tests for cladding SCC critical stress, under more aggressive conditions (CLST 3.9)
- Update rockfall model and determine if mechanical breakage should be incorporated in the cladding degradation abstraction (CLST 3.10)

Changes resulting form these agreements are expected to provide additional confidence in the cladding abstraction model. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Thermal Evaluation of Breached 21-PWR Waste Packages (K.18)	B. AMR: Thermal Evaluation of Breached 21-PWR Waste Packages. (CAL-UDC-ME-000002 Rev. 00, a calculation report) (CRWMS M&O 1999f)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☒ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

This model provides the difference in temperature between the cladding and the waste package surface. Although this work is documented as a calculation, reviewer comments on the need for validation are acknowledged. The model is used to determine the likelihood of dry oxidation, and as input to the creep model which depends on peak cladding temperature. In the model, 3-D heat transfer, conduction, and convective heat transfer are neglected. The model calculates the peak cladding temperature and the associated uncertainty. The model results are not used for other purposes for which conservatism may not be assured. Accordingly, there is no impact of the model validation review findings on the conclusions of TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1).

In addition, the contribution of cladding to total system performance was evaluated in a sensitivity study, documented in the "robustness analysis" for the TSPA-SR (CRWMS M&O 2000bm, Sections 5.3 and 5.3.4.1). Cladding credit is substantially diminished by setting four of the five cladding parameters used in TSPA-SR at their 95% distribution points signifying greater release rates. The result was a minor increase in the calculated average annual dose over the first 100,000 yr for 100 realizations of the TSPA-SR model (a factor of 1.5 increase), compared to the nominal case in which these parameters were sampled over their full ranges. Thus the contribution of cladding, as represented in TSPA-SR, is minor for the 10,000-yr compliance period. This further supports the position that the validation review findings pertaining to this model do not impact the conclusion of the TSPA-SR (CRWMS M&O 2000bm, Section 6.1).

E. Responsible Individual: Christine Stockman/ Christine Stockman 11/28/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model Breakage of CSNF Clad by Seismic Loading (K.19-1)	B. AMR: Breakage of CSNF Cladding by Mechanical Loading (CAL-EBS-MD-000001 Rev. 00) (CRWMS M&O 1999a)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

This model (documented as a calculation) was used to determine the likelihood of a seismic event causing breakage of the cladding. The reviewer's comments on the robustness of cladding are acknowledged. The model is thus conservative, so there is no impact from the validation review findings on the conclusions of TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1).

The KTI agreements for the Repository Design and Thermal-Mechanical Effects (RDTME) Key Technical Issue (Gardner 2001) include a commitment to further develop and test rockfall models, and to reevaluate the application of rockfall model output to other models including the Model of Breakage of CSNF Clad by Seismic Loading (RDTME 3.19). It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

In addition, the contribution of cladding to total system performance was evaluated in a sensitivity study, documented in the "robustness analysis" for the TSPA-SR (CRWMS M&O 2000bm, Sections 5.3 and 5.3.4.1). Cladding credit is substantially diminished by setting four of the five cladding parameters used in TSPA-SR at their 95% distribution points signifying greater release rates. The result was a minor increase in the calculated average annual dose over the first 100,000 yr for 100 realizations of the TSPA-SR model (a factor of 1.5 increase), compared to the nominal case in which these parameters were sampled over their full ranges. Thus the contribution of cladding, as represented in TSPA-SR, is minor for the 10,000-yr compliance period. This further supports the position that the validation review findings pertaining to this model do not impact the conclusion of the TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1).

E. Responsible Individual: Christine Stockman/ *Christine Stockman* *11/28/01*

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: Breakage of CSNF Clad by Static Loading (K.19-2)	B. AMR: Breakage of CSNF Cladding by Mechanical Loading (CAL-EBS-MD-000001 Rev. 00) (CRWMS M&O 1999a)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

This model (documented as a calculation) was used to evaluate breakage of the cladding caused by loading from backfill or debris from rockfall. The reviewer's comments on the robustness of cladding are acknowledged. The model is conservative, so there is no impact from the validation review findings on the conclusions of TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1).

The KTI agreements for the Repository Design and Thermal-Mechanical Effects (RDTME) Key Technical Issue (Gardner 2001) include a commitment to further develop and test rockfall models, and to reevaluate the application of rockfall model output to other models including the Model of Breakage of CSNF Clad by Static Loading (RDTME 3.19). It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

In addition, the contribution of cladding to total system performance was evaluated in a sensitivity study, documented in the "robustness analysis" for the TSPA-SR (CRWMS M&O 2000bm, Sections 5.3 and 5.3.4.1). Cladding credit is substantially diminished by setting four of the five cladding parameters used in TSPA-SR at their 95% distribution points signifying greater release rates. The result was a minor increase in the calculated average annual dose over the first 100,000 yr for 100 realizations of the TSPA-SR model (a factor of 1.5 increase), compared to the nominal case in which these parameters were sampled over their full ranges. Thus the contribution of cladding, as represented in TSPA-SR, is minor for the 10,000-yr compliance period. This further supports the position that the validation review findings pertaining to this model do not impact the conclusion of the TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1).

E. Responsible Individual: Christine Stockman/ Christine Stockman 11/28/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: DRKBA Rockfall Model (L.1)	B. AMR: Drift Degradation Analysis (ANL-EBS-MD-000027 Rev. 01) (CRWMS M&O 2000x)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☒ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheets.

E. Responsible Individual: Robert MacKinnon / Robert MacKinnon 11/15/01

Type Name/Signature Date:

Continuation of item D (Model L 1):

As stated by DOE in the summary from the Technical Exchange on the Repository Design and Thermal-Mechanical Effects (RDTME) Key Technical Issue (February 6-8, 2001, Las Vegas, NV) "... the Drift Degradation Analysis is consistent with current understanding of the Yucca Mountain site and the present level of detail for the design." Elaborating on this point, the DRKBA model is reasonably conservative for predicting the occurrence of large rockfall blocks, which are then used as the basis for structural analysis of the drip shield design in the calculation report: *Rock Fall on Drip Shield* (CRWMS M&O 2000bw). The DOE has committed to model improvements and alternative modeling approaches as discussed below, but the current model and its supporting and related documentation are considered to provide adequate confidence that the effects of rockfall on integrity of the waste package can be limited for 10,000 yr by the presence of the drip shield, and can therefore be "screened out" for TSPA-SR.

The path forward for model validation is consistent with the KTI agreements for the Repository Design and Thermal-Mechanical Effects (RDTME) Key Technical Issue (Gardner 2001). The relevant agreement items are:

- Provide field data and analysis of rock bridges between rock joints that are treated as cohesion in DRKBA modeling together with a technical basis for how a reduction in cohesion adequately accounts for thermal effects (RDTME 3.15)
- Provide a technical basis for the DOE position that the method used to model joint planes as circular discs does not under-represent the smaller trace-length fractures (RDTME 3.16)
- Provide the technical basis for effective maximum rock size including consideration of the effect of variation of the joint dip angle (RDTME 3.17)
- The acceptability of the process models (Drift Degradation) that determine whether rock fall can be screened out from performance assessment abstractions needs to be substantiated by the DOE (RDTME 3.19)

Considered in more detail, the DOE has committed to: 1) provide revised DRKBA analyses using appropriate ranges of strength properties for rock joints taken from a design parameters analysis report (or other document), accounting for their long-term degradation; 2) provide an analysis of block sizes based on the full distribution of joint trace length data from *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000ae), supplemented by available small joint trace length data, and 3) verify the results of the revised DRKBA analyses using:

- Appropriate boundary conditions for thermal and seismic loading
- Critical fracture patterns from the DRKBA Monte Carlo simulations (at least two patterns for each rock unit)
- Thermal and mechanical properties for rock blocks and joints from a design parameters analysis report (or other document)
- Long-term degradation of joint strength parameters
- Site-specific ground motion time histories appropriate for post-closure period.

This additional verification work will address the performance of the rock fall model for its intended use (i.e., thermal- and seismic-related postclosure drift degradation). It will improve

upon the current UDEC validation results (CRWMS M&O 2000x, Attachment V) by using multiple realizations of fracture patterns modeled in three-dimensional space, with seismic and thermal loads directly applied. This work will extend the validation approach presented in the Drift Degradation Analysis (CRWMS M&O 2000x, Section 6.5) and improve confidence in the methodology.

Based on the results of the analyses above and subsequent revision to drip shield structural calculations, the DOE will reconsider the screening decision for inclusion or exclusion of rockfall in performance assessment analysis. Any changes to screening decisions will be documented in analyses prior to a potential License Application. Note that verification of the results from the revised DRKBA will be developed using a distinct-element modeling approach that can represent both seismic and thermal loads explicitly. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation

MODEL VALIDATION - IMPACT REVIEW

A. Model: Flow into Waste Packages Through Small Lid Openings (FLO) Model (L.6)	B. AMR: Flow of Water and Pooling in a Waste Package (ANL-EBS-MD-000055 Rev. 00) (BSC 2001c)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

No impact. This model was developed after TSPA-SR (CRWMS M&O 2000bl). The purpose of the model was to improve understanding of processes controlling water flow into waste packages.

As currently documented, the model is not planned for direct application in any future TSPA. As stated by the review, this model may find use as an alternative model for comparison to the EBS Radionuclide Transport Model (CRWMS M&O 2000aa).

It is also noted that this model describes water movement through cracks in the drip shield or waste package, which is a topic that is also addressed by an AMR entitled: *Water Diversion Model* (CRWMS M&O 2000bu), and another entitled: *Water Distribution and Removal Model* (CRWMS M&O 2001t), for which model validation was found to be better developed and documented.

E. Responsible Individual: Robert MacKinnon / Robert MacKinnon 11/15/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: In-Drift Transport of Radionuclides Model (M.2)	B. AMR: EBS Radionuclide Transport Model (ANL-EBS-MD-000034 Rev. 00 ICN 1) (CRWMS M&O 2000aa)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Robert MacKinnon/ Robert MacKinnon 11/15/01

Type Name/Signature Date:

Continuation of item D (Model M.2):

This model validation review finding has no impact on the conclusions of TSPA-SR (i.e. calculated annual dose, see CRWMS M&O 2000bm, Section 6.1) because:

- The EBS Radionuclide Transport Model (CRWMS M&O 2000aa) is primarily a sensitivity study that was not used for TSPA-SR.
- The model will not be used directly for the TSPA or other products that support the License Application.

To the extent that the conceptual model is the same as that used in the EBS Radionuclide Transport Abstraction Model (CRWMS M&O 2000z) which was used for TSPA-SR, the following comments apply:

Lateral flux in the invert is not represented in the 1-D model, but if so then the flow path would be longer, because the 1-D flowpath represented by the model is the shortest possible given the invert geometry. The flow in the invert will be unsaturated, so the vertical (shortest path) velocity is controlled by the water content and the gravitational potential.

The use of a continuum approximation to represent pore water velocity (calculated from volumetric water content and liquid flux) may be nonconservative if liquid flow occurs in channels where the velocity is faster than the average. For TSPA-SR (CRWMS M&O 2000bm, Section 5.2.5.1) invert diffusion affects system performance only during early time (diminishing a few thousands years after repository closure) when water content in the invert ballast material, and thus the advective flow velocity, is decreased. Waste package failures are not predicted during early time, so deviation of invert transport behavior from the average response would have no impact on system performance except for waste package early failure scenarios, moreover, the effect of invert transport on dose consequences for such scenarios is small.

The 1-D approach is analogous to column studies, for which abundant experimental data are available. Whereas such analogous data were not included in the AMR, this does not impact the conceptual model for invert transport used for TSPA-SR. Sorption is conservatively ignored in the TSPA-SR, so the treatment of sorption in this AMR has no impact.

MODEL VALIDATION - IMPACT REVIEW

A. Model: In-Drift Colloids and Concentrations Model (M.3)	B. AMR: In-Drift Colloids and Concentration (ANL-EBS-MD-000042 Rev. 00) (CRWMS M&O 2000al)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☒ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

The representation of in-drift colloid-associated radionuclide transport for TSPA-SR, is not significantly impacted by the validation review findings, because the TSPA-SR colloid-abstraction approach documented in the subject AMR uses conservative and/or bounding values for parameters where data are insufficient. Use of the approach to support FEP screening is likewise not impacted. In addition, sensitivity studies have shown that the contribution of colloidal transport in the waste package and the invert is small (CRWMS M&O 2000bm, Section 5.3.4.2). Therefore, the impact of the model validation review findings for this model on the conclusions of TSPA-SR (i.e. calculated annual dose; see CRWMS M&O 2000bm, Section 6.1) is insignificant.

E. Responsible Individual: Robert MacKinnon/ Robert MacK ____ 11/15/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: Seepage/Invert Interactions Model (M.4)	B. AMR: Seepage/Invert Interactions (ANL-EBS-MD-000044 Rev. 00) (CRWMS M&O 2000bg)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☒ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

The model validation review findings have no impact on TSPA-SR because the invert has small benefit to performance (CRWMS M&O 2000bm, Sections 5.2.5.1 and 5.3.4.2). The primary conclusion from this model is that invert materials will not be present in sufficient quantities, relative to the host rock and other EBS materials, to exert significant influence on water composition. For example, the crushed tuff to be used as invert ballast material would be derived from the host rock, so that waters which had already been conditioned to the host rock would exhibit limited changes in composition on contact with the invert. Also, the structural steel that used in the invert would not affect water composition because substantial quantities of similar steel would be located elsewhere in the EBS including inside the waste package, and because the steel corrosion products will be insoluble in the oxidizing environment of the invert.

In addition, potential changes in hydrologic and transport properties of the invert would have little impact on transport of radionuclides in the EBS or elsewhere, because the invert contribution to performance is not significant. The typical depth dimension of the invert, about one meter, is much less than the transport distance through the unsaturated zone, and the effect on radionuclide transport is therefore much less.

The path forward includes analyses of coupled processes in the EBS per KTI agreement ENFE 2.7 (Williams 2001). It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation. At this time, however, no experiments are planned as the final invert design and material selection has not been made. Tests involving crushed tuff have low priority because the invert offers little waste isolation performance.

E. Responsible Individual: Robert MacKinnon / Robert MacKinnon 11/15/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: EBS Radionuclide Transport Abstraction Model (M.5)	B. AMR: EBS Radionuclide Transport Abstraction (ANL-WIS-PA-000001 Rev. 00 ICN 2) (CRWMS M&O 2000z)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

There is no impact from the findings of the model validation review on the conclusions of the TSPA-SR, because this model provides bounding treatment of processes controlling radionuclide transport from the waste package to the drift wall. This position is supported by the part of the review which states that Section 7.2 of the AMR makes a strong case that the model is valid and appropriate for its intended use, to represent fundamental flow and transport processes in a bounding or conservative framework. The review goes on to state that the AMR makes transparent and logical arguments that provide confidence in the model. However, conservatism is not considered grounds for compliant model validation. Hence the Bin-3 designation is justified, although there is no resulting impact on TSPA-SR that would cause calculated dose consequences to increase.

The path forward includes an experiment to validate the model's representation of flow entering and leaving breached waste packages and drip shields. The path forward also includes developing a representation of the performance consequences from drip shield displacement by thermal expansion of the titanium, floor heave, pallet failure, and seismic ground motion. Ongoing process modeling activities will provide additional support. Based on the outcome of model development, the representation of drip shield performance would be included in TSPA rather than screening out these effects. These two items will address what the authors believe to be the major needs for confidence building in the abstraction model.

E. Responsible Individual: Robert MacKinnon / Robert MacK 11/15/01

Type Name/Signature Date:

MODEL VALIDATION - IMPACT REVIEW

A. Model: FRACL Calibration to Borehole Chloride (N.3-1)	B. AMR: Radionuclide Transport Models Under Ambient Conditions (MDL-NBS-HS-000008 Rev. 00) (CRWMS M&O 2000ba)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheets.

E. Responsible Individual: Bo Bodvarsson / [signature] 11/15/01

Type Name/Signature Date:

Continuation of item D (Model N.3-1).

The reviewer has correctly pointed out that there is significant variability in the measured chloride data used to assess the FRACL model, and disputes that the correlation presented represents "reasonable agreement." For several reasons, the AMR authors believe that the FRACL model-chloride data comparison results do support the UZ radionuclide transport model, and are appropriate for use. Also, the results are consistent with other methods used to assess the reasonableness of the UZ radionuclide transport model, and would not significantly affect the overall TSPA-SR results even if they were excluded.

Validation of the model flow field in fractured rock below the repository is the subject of a KTI agreement. for the Radionuclide Transport (RT) Key Technical Issue (Reamer and Williams 2000). DOE has agreed to provide the analysis of geochemical data used for support of the flow field below the repository (RT 3.2). It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

Resolution of this agreement item will partially address the model validation review findings pertaining to the use of chloride data for model-data comparison. The FRACL model-chloride data comparisons are appropriate for use in supporting the radionuclide transport model for the following reasons:

Firstly, concerning the validation of FRACL against measured chloride data from borehole UE-25 UZ#16 described in this AMR, it should be noted that all the measurements in Figure 6.4.4 of the AMR came from the UE-25 UZ#16 well. A better measure of the agreement is also provided by Figure 6-27 in the AMR: *UZ Flow Models and Submodels* (CRWMS M&O 2000bq), which shows the very large deviation of predictions based on uncalibrated infiltration, and supports the claim of reasonable agreement made in this AMR. Regarding the boundary condition, it should be noted that the 0.62 mg/L concentration was not used for consideration of this model in either AMR; the value used was 38 mg/L in both cases. The reviewer is correct that the measured chloride concentrations are widely variable, and there is also some uncertainty associated with the chloride concentration in the infiltrating water. Additional data have since been collected on porewater chloride, and it is anticipated that the FRACL model would be reevaluated using the new data during the next revision of the AMR to support a potential License Application.

Secondly, it should be pointed out that models and results from this AMR are not directly used in the TSPA-SR. The FRACL code was used to simulate the chloride profile for borehole UE-25 UZ#16 in an attempt to gain confidence in its use within the context of the Radionuclide Transport Model described in this AMR, which is then abstracted in the TSPA-SR. The FRACL model itself was not used to simulate radionuclide transport in the TSPA. Instead, UZ radionuclide transport was simulated for TSPA-SR using the FEHM code with the residence time transfer function particle-tracking technique, which is described in the AMR: *Particle Tracking Model and Abstraction of Transport Processes* (CRWMS M&O 2000ay). For this reason the validation status of the FRACL code is not likely to have a significant impact on, or change the conclusions of, the TSPA-SR.

In summary, due to its limited use in the comparison to the chloride data of UE-25 UZ#16, which is used to corroborate the transport calculations in the TSPA-SR, it is appropriate to consider and use the FRACL results. The overall validation of the transport calculations is addressed in other AMRs, and is partially addressed by NRC KTIs related to transport. Also, future revisions of this AMR for the LA will incorporate additional data (such as porewater

chloride concentrations) that will provide further confidence in the calibration and validation of the FRACL model.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Abstraction of FEHM and Coupling with UZ Mass Flux (P.4-2)	B. AMR: Input and Results of the Base-Case SZ Flow and Transport Model for TSPA (ANL-NBS-HS-000030 Rev. 00) (CRWMS M&O 2000aq)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheets.

E. Responsible Individual: Bruce Robinson / [signature] 11/16/01

Type Name/Signature Date:

Continuation of item D (Model P.4-2):

This model uses a convolution integral method implemented as an external routine called by GoldSim (Golder Associates 2000) to couple breakthrough curves generated using the 3-D SZ site-scale flow and transport model (based on the FEHM code), with the breakthrough curves from the "pipe" model used to represent transport of daughter radionuclides, and the radionuclide mass releases from the UZ, in the TSPA calculations. In this way the radionuclide mass flux at the biosphere downgradient of the repository is estimated as a function of the transient mass flux at the water table beneath a repository. The effects of climate change are incorporated into the convolution integral analysis by assuming instantaneous change from one steady-state flow condition to another in the SZ. This is believed to be conservative because climate changes in the TSPA-SR model tend to increase flow in the SZ (i.e., only from drier to wetter conditions) and the associated increases in storage of contaminants in the SZ is neglected in the model. The changes in flow condition are approximated as multiples of the groundwater flux for the base case. Radioactive decay is applied to transport as loss of mass by first-order decay through the interval of travel time. Visual inspection is used to check the breakthrough curves; other techniques are also being considered to check these intermediate results.

The UZ mass coupling is performed using a convolution subroutine that simply executes mathematical manipulations. The approach is based on a conceptual model of the saturated zone as a linear system that can be represented by breakthrough curves calculated from linear sorption behavior, for unit input fluxes of different radionuclides. The linear sorption approach is approximate, but it is mathematically tractable and widely used in groundwater contaminant transport modeling. Essentially, every Performance Assessment analysis performed in the Yucca Mountain and the Waste Isolation Pilot Plant (WIPP) has used the linear sorption "Kd" approach. Although it is recognized that the process of sorption is complex and that Kd values are specific to the chemical conditions and mineralogy, as a practical matter, linear sorption is assumed, and the uncertainties associated with this assumption are incorporated into the parameter uncertainty distribution used in the TSPA analysis. The sorption parameters (Kds) are based on consistent application of laboratory and field data as detailed for the Transport Parameters from C-Wells and Laboratory Studies Model (P.4-3). The flow fields are calculated by the SZ Flow Model (O.5). The implementing software was verified and documented in the subject AMR.

In summary, this model integrates the following component models in a simple computation scheme:

- The SZ flow model is validated elsewhere (see Model O.5)
- The "pipe" model is considered separately (see Model P.4-1)
- Mass flux from the UZ is calculated upstream in the TSPA-SR model

Documentation of the mathematical steps in this integration model, and testing to fully demonstrate appropriate representation of chemical transport, radioactive decay, climate change, and fracture heterogeneity, is not yet complete. The reviewer's comments are acknowledged, and the path forward will include improved documentation, justification for the approach, and verification as discussed below. However, the conceptual model is straightforward, and the implementing calculation has been checked, so future activities are unlikely to change the SZ transport model in a way that would significantly affect the conclusions of TSPA-SR.

The description of this model will be clarified, and more complete explanation of the calculation procedure will be provided, in future revisions of the reports that support a potential License Application. Validation and verification activities will include evaluation of the appropriateness of the FEHM modeling, coupling of FEHM output with UZ mass flux, incorporation of FEHM output with that from the "pipe" model, and the representation of climate change. Confidence will also be improved by review of model input parameters, comparison with testing results where practicable, and verification of model output following the approach begun in *Total System Performance Assessment (TSPA) Model for Site Recommendation* (CRWMS M&O 2000bl; Section 6.3.7).

MODEL VALIDATION - IMPACT REVIEW

A. Model: Transport Parameters from C-Wells and Laboratory Studies (P.4-3)	B. AMR: Input and Results of the Base-Case SZ Flow and Transport Model for TSPA (ANL-NBS-HS-000030 Rev. 00) (CRWMS M&O 2000ag)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☒ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Bruce Robinson / [signature] 11/16/01

Type Name/Signature Date:

Continuation of item D (Model P.4-3):

This model consists of results from laboratory transport tests and field tracer tests, and fitting of field breakthrough curves generated using dual-porosity transport models (RELAP and RETRAN, CRWMS M&O 2001r). Fitting of breakthrough curves for non-sorbing tracers was used to estimate dispersivity, matrix diffusion, and porosity. Fitting of the lithium tracer data was used to estimate sorption parameters. Fitting of colloid tracer data was used to estimate filtration rate constants. Laboratory studies included batch tests to characterize lithium sorption, matrix diffusion measurements, and column tests to evaluate transport in fractured and crushed tuff. Comparison of results from laboratory and field responses was used to show that laboratory-derived sorption parameters could be used defensibly in field-scale predictive calculations. Comparison of laboratory-derived matrix diffusion and mass-transfer coefficients with field responses showed that parameter values estimated from the field tests were smaller (less matrix diffusion) than from the lab results.

The reviewer's comments on lack of validation documentation are acknowledged, but this finding does not impact the conclusions of the TSPA-SR. This is because the model is based on overlapping laboratory and field testing, and complementary analyses of laboratory and field test results, which provide confidence in the parameterization of the dual-porosity model used for TSPA-SR. Evidence for dual-porosity behavior is provided by both field tracer testing, and laboratory diffusion testing. Field testing has been performed in transmissive rock units in the saturated zone downgradient from the Yucca Mountain site, that represent likely transport pathways for radionuclides. The simultaneous use of tracers with distinct transport properties (diffusion coefficients and Kd values) provided very strong evidence that the dual-porosity approach is valid for the fractured volcanic tuffs. Use of dual-porosity models to represent flow and transport in fractured rock has been reported extensively in the technical literature. For example, transport for comparable hydrogeologic conditions was evaluated by Grisak and Pickens (1980), Neretnicks (1980), Sudicky and Frind (1981), Maloszewski and Zuber (1985, 1991) and found to be appropriate for interpreting transport tests in fractured rock. Robinson (1994) documented an approach for validating this model for use in the Yucca Mountain SZ far in advance of the actual C-Wells experiments. Therefore, the validation of matrix diffusion in a dual-porosity system was the fundamental design basis for the test, and results subsequently showed that the model is appropriate for the volcanic tuffs.

Further validation effort will be applied to the selection of the dual-porosity model, and the use of RELAP and RETRAN (CRWMS M&O 2001r) to simulate field test results. In addition, additional documentation is needed to address the validity of the output data (dispersivity and matrix diffusion coefficients) and the use of the lithium tracer tests to justify the use of laboratory-measured Kd values to model SZ transport. Where possible, alternative models will be used for curve fitting to provide additional justification for the approach selected as the basis for SZ parameter estimation. The additional validation will be documented in the revision of this AMR for a future License Application.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Surface Soil Model in GENII-S (Q.9-1)	B. AMRs: Evaluate Soil/Radionuclide Removal by Erosion and Leaching (ANL-NBS-MD-000009 Rev. 00, ICN 01) (CRWMS M&O 2001i) Nominal Performance Biosphere Dose Conversion Factor Analysis (ANL-MGR-MD-000009 Rev. 01) (CRWMS M&O 2001m)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheets.

E. Responsible Individual: A. J. Smith/ [signature] 14Nov01

Type Name/Signature Date:

Continuation of item D (Model Q.9-1):

The reviewer's comment is correct that the current soil model does not explicitly simulate the details of several processes that may affect radionuclide concentrations in soils, and that there are several methods (including those recommended by the reviewer) that could be used to increase the level of detail of the analysis. However, it should also be noted that the relatively simple approach used in this model has several advantages which are appropriate for analysis of long-term performance. The current model is reasonable and technically justifiable, although it produces demonstrably conservative results.

Whether or not the assumption of a uniformly contaminated soil zone to 15 cm is realistic is not specifically addressed by a KTI agreement. However, the KTI agreements for the Total System Performance Assessment Integration Key Technical Issue (Cornell 2001) partially address the model validation reviewer's comments. In particular, the following agreement items address Kd values used for radionuclides in soil and sampling methodology used in GENII-S (CRWMS M&O 2001m):

- Provide justification that the Kd values used for radionuclides in the soil in Amargosa Valley are realistic or conservative for actual conditions at the receptor location (KTS 3.33)
- Provide the technical basis for selection of radionuclide or element specific biosphere parameters (except for Kds which are addressed in KTS 3.33) that are important in the BDCF calculations (e.g., soil to plant transfer factors) (KTS 3.34)
- Provide a quantitative analysis that the sampling method including the correlations between BDCFs utilized by the TSPA code to abstract the GENII-S process model data adequately represent the uncertainty and variability and correlations for the biosphere process model (KTS 3.37)

The current approach is defensible for its intended use, for several reasons, and potential future revisions of the model are unlikely to result in dose assessments that differ significantly from TSPA-SR. Firstly, the current approach (CRWMS M&O 2001m) is the same basic model that is used in other Biosphere models developed both in the USA and by international radiation protection programs (IAEA 2001, Section 5.3).

Secondly, it is true that the current model does not capture details of the variability of radionuclide concentrations in soils due to processes such as non-uniform mixing, erosion or aeolian transport, and also does not explicitly incorporate temporal variation (generally building up over time). However, these simplifications will generally result in the overprediction of radionuclides available for uptake (with some exceptions such as the possible concentration in the upper 5 cm of soil noted by the reviewer). Similarly, the data feed to TSPA-SR (via down-stream AMRs (CRWMS M&O 2001a; 2001af) does not rely upon the predicted time evolution of the radionuclide build-up in soils. The biosphere dose conversion factor (BDCF) data feed to the TSPA-SR model depends only on the asymptotic (i.e., steady state) value of radionuclide build-up in soil, and the simplicity of this approach is considered not only adequate but also a distinct advantage. This approach is believed to be reasonable, since the purpose of the TSPA is to evaluate the long term behavior of the system.

Future revisions of the AMR will consider the uncertainties identified by the reviewer, including the effects of spatially variable radionuclide concentrations and soil salinity on Kds, to determine whether additional data collection, modeling or sensitivity studies are needed. The revised AMR

will address the effects of uncertainties related to each of the model inputs. As the AMR authors continue to evaluate the uncertainties inherent in the process models, they will incorporate additional detail as necessary, or perform sensitivity studies as appropriate, to provide additional information necessary for validation.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Radionuclide Transfer to Animals (Q.9-4)	B. AMRs: Transfer Coefficient Analysis (ANL-MGR-MD-000008 Rev. 00 ICN 2) (CRWMS M&O 2000bn) Nominal Performance Biosphere Dose Conversion Factor Analysis (ANL-MGR-MD-000009 Rev. 01) (CRWMS M&O 2001m)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

The model validation reviewer has noted that several specific pathways are not included in the Radionuclide Transfer to Animals model, and that model-specific validation information has not been provided. The GENII-S based approach used for TSPA-SR dose calculations (CRWMS M&O 2001m) is believed to contain the primary pathways contributing to dose, and the contributions from additional pathways would be small and not significantly affect the conclusions of the TSPA-SR.

In the TSPA-SR dose calculations, the primary pathways for delivering dose to the receptor are drinking water and leafy vegetables. This model as implemented in GENII-S is similar to the equivalent model developed and in use by the International Atomic Energy Agency (see CRWMS M&O 2000bn, Section 4.1 for a list of corroborating literature sources). Consequently, the dose calculated by TSPA-SR is only weakly dependent on the details of the model for transfer of radionuclides to animals, and any impact on dose would be small in comparison to the primary pathways.

The radionuclide transfer to animals model used in GENII-S is in the process of being validated, and will be documented in a revision of the AMR for the potential License Application. If the validation effort indicates that the current model is lacking, a more comprehensive model incorporating additional pathways may be developed.

The omission of incidental ingestion of contaminated soil while grazing, and inhalation of resuspended particles, is not specifically addressed by a KTI agreement.

E. Responsible Individual: A. J. Smith/ [signature] 14Nov01

Type Name/Signature Date:

MODEL VALIDATION – IMPACT REVIEW

A. Model: Radionuclide Transfer to Aquatic Food (Q.9-5)	B. AMRs: Transfer Coefficient Analysis (ANL-MGR-MD-000008 Rev. 00 ICN 2) (CRWMS M&O 2000bn) Nominal Performance Biosphere Dose Conversion Factor Analysis (ANL-MGR-MD-000009 Rev. 01) (CRWMS M&O 2001m)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: A. J. Smith/ [signature] 16 Nov 01

Type Name/Signature Date:

Continuation of item D (Model Q.9-5):

For the reasons summarized below, the issues raised by the model validation review concerning validation of this model do not impact the conclusions of the TSPA-SR (i.e. calculated annual dose; CRWMS M&O 2000bm, Section 6.1). Further, due to a change in the potential pathways available, further assessment of dose consequences from aquatic pathways may be unnecessary.

The aquatic food pathway which uses the radionuclide transfer to aquatic food model is based on an infinite (large) source of water with a uniform concentration of radionuclides. In this large volume, all aquatic life including plants in the food chain are contaminated and the availability of radionuclides not constrained by a finite mass. The need for the aquatic food pathway in Amargosa Valley arose because, when the eating habits survey was conducted (CRWMS M&O 2000bn, Section 4.1.1), there was a small commercial catfish farm in operation. The farm used a limited sized tank to raise the fish, which represents a limited supply of radionuclides. Thus, doses estimated with this model were overly conservative and provided a higher dose than would actually be expected from this pathway. If necessary, a correction to account for the limited water supply, and associated improvement to the model are relatively simple and could be incorporated in the code update.

However, for all radionuclides except ^{14}C, the dose contribution from aquatic foods is insignificant. For ^{14}C in the groundwater (if indeed there should be any present) the dose was overestimated by a factor of about ten. Because the TSPA-SR results are demonstrably conservative, there is no detrimental impact to the conclusions from a compliance perspective. Also, the catfish farm is no longer in operation so there are now no existing aquatic pathways.

The need (or lack thereof) for a model to represent aquaculture as an aquatic pathway for radionuclide uptake by humans in the Amargosa Valley is not specifically addressed by a KTI agreement.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Geometry of Volcanic Feeder System Model (R.2)	B. AMR: Characterize Eruptive Processes at Yucca Mountain, Nevada (ANL-MGR-GS-000002 Rev. 00) (CRWMS M&O 2000k)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Greg Valentine / [signature] 15 Nov 01

Type Name/Signature Date:

Continuation of item D (Model R.2):

This is a conceptual model that is used as a framework to determine how much contaminated volcanic ash could reach a control group. Briefly, the model assumes that magma propagates from depth through dikes. Initially these dikes may intersect the Earth's surface and erupt along a fissure (the trace of the dike). With time, upward flow of magma at shallow depths (within a few hundred meters of the Earth's surface) tends to focus into one or a few vents that are fed by conduits. These conduits represent places where thermal and mechanical erosion of the wall rocks have locally widened the dike. Each of these conduits may feed a growing scoria cone with attendant lava flows. Relatively explosive eruptions that are capable of spreading contamination as far as a control population are generally only fed from conduits (rather than the initial fissure-eruption phases). Therefore for TSPA-SR, only eruptions fed by conduits were considered in the subject AMR. It was also assumed that any waste package that is wholly or partly intersected by a conduit would be disintegrated and available for dispersal in a volcanic plume. Although this conceptual model is used as the basis for calculation of eruptive doses in TSPA-SR, it is not completely and explicitly described by any individual document in the current suite of AMRs.

Because there is no practical way to directly test the conceptual model for the effect of eruptive processes on potential radionuclide releases associated with volcanic activity, there will inherently be significant uncertainty associated with this model. However, the present model is conservative in several respects, so it is considered unlikely that the conclusions of the TSPA-SR would be affected by additional validation activities. In the present model, all waste packages within the cross section of the conduit are considered to be entrained in an eruption, and the entire contents of each package are dispersed in the volcanic plume. If future work to further validate the conceptual model identifies modifications to the existing model, or credible alternative conceptual models, it is possible that more or fewer waste packages would be involved in the volcanic eruption scenario examined as part of the TSPA or that a larger or smaller radionuclide source term may need to be used for groundwater release scenarios.

There are several KTI agreements related to the issue of repository disruption by volcanic, for the Igneous Activity (IA) Key Technical Issue (NRC 2000):

- Document the approach for estimating the number of waste packages incorporated into the volcanic conduit, and the possible consequences of conduit elongation parallel to drifts (IA 2.5)
- Document the calculation of the number of waste packages hit by the intrusion (IA 2.10)

The additional documentation will involve revisions to several AMRs (CRWMS M&O 2000l; 2000u; 2000aj; 2000ax) as well as the subject AMR noted above. These agreement items will address many of the points raised in the model validation review. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to model validation.

The current conceptual model and the basis for numerical estimates of the number of waste packages breached, will be explicitly described in revisions to the referenced AMRs. In addition, further analog investigations, modeling and testing studies are planned that will strengthen the technical bases for the conceptual model. Sensitivity studies will be performed to assess the extent to which uncertainties in eruptive processes could affect total system results.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Total System Performance Assessment-Site Recommendation Model (U.1-1)	B. AMR: Total System Performance Assessment (TSPA) Model for Site Recommendation (MDL-WIS-PA-000002 Rev. 00) (CRWMS M&O 2000bl)

C. Category (Check appropriate case) **N/A, Model is the TSPA Model**

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☒ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheets.

E. Responsible Individual: Jerry McNeish / Jerry A McNeish 11.14.01

Type Name/Signature Date:

Continuation of item D (Model U.1-1).

Background

Development of the TSPA-SR model (CRWMS M&O 2000bl) was based on supporting abstraction and process-level models that represent different aspects of the repository. These abstraction and process-level models were specifically developed for use in the TSPA-SR model for Yucca Mountain.

The hierarchical aspect of total system performance assessment modeling in support of a potential License Application is based on a sequence of modeling activities that starts with the development of process level models that capture the key aspects of the natural and engineered systems. In turn these process models are frequently simplified into abstraction models. These simplified models are compared to the process models on which they are based to build confidence and to ensure that the key aspects of the system are being captured. Once confidence in these processes and abstractions is demonstrated, they become key components in ~~determining the validity of~~establishing confidence in the total system model, where the total system model is probabilistic and stochastic in nature and is intended to capture the behavior of the entire system. These modeling activities are intended to build upon each other sequentially so that when the total system model is finalized, one is confident that the total system is adequately represented.

Currently, model validation is defined as "a process to determine and document the adequacy of the scientific basis (i.e., confidence) for a model and to demonstrate that the model is appropriate and adequate for its intended use" (AP-3.10Q Rev. 2 ICN 4). Thus, model validation of the total system model depends upon the confidence-building activities that are conducted for the key underlying process and abstraction models. The scientific process established on the Yucca Mountain project to accomplish model validation includes comparing analyses or modeling results to data acquired from the laboratory, field experiments, natural and man-made analog studies or other relevant observations such as classical case histories from the literature. In addition to these technical confidence-building activities, the documentation process ensures the traceability, transparency and quality assurance of key modeling inputs such as data, assumptions, and computer software. The component models of the TSPA-SR model undergo verification and validation independently within the source AMRs. Then it is demonstrated that the integrated model is validated, with emphasis on integrated data and results, and the flow of data from each sub-component to the next. Criteria used to demonstrate this integrated model validation consist of: 1) comparison of the final results (in this case dose) to intermediate sub-system results; 2) verification of the implementation of AMR abstractions within the TSPA-SR model, including appropriate use of associated dynamically linked libraries (DLLs); and 3) ensuring correct data are passed between each DLL and the GoldSim code (Golder Associates 2000). When verification of the subsystem models and review of the integrated model are completed, confidence in the model is demonstrated.

For each of the process-level or abstraction analyses or models used as direct inputs to or component models of the TSPA-SR model, a "Results and Verification" subsection is included in Sections 6.3.1 through 6.3.9 of the subject AMR (CRWMS M&O 2000bl). These subsections show the results from a median-value simulation (i.e., median values for all input parameters), and show that the process-level or abstraction models from the supporting AMRs have been implemented appropriately into the TSPA-SR model. Sections 6.5.1 through Sections 6.5.4 of the subject AMR discusses an "integrated testing" approach to the validation of the TSPA-SR model.

There are several KTI agreements related to validation of the TSPA model, for the Total System Performance Assessment Integration (TSPAI) Key Technical Issue (Cornell 2001). In particular, agreements items 3.1 through 3.42 include many actions that will enhance the submodels for TSPA, and their documentation. In addition, the following agreement items pertain more directly to the TSPA system model:

- DOE will document the incorporation of alternative conceptual models into the TSPA model, and document the guidance given to process-level modeling experts, overall ensuring that incorporation of alternative models does not cause risk to be underestimated (TSPAI 4.01).
- DOE will document the methods that will be used to determine that the overall TSPA results are stable, and that the contributing submodels are numerically stable. The method will address the number of realizations, and describe the statistical treatment that will be used to evaluate stability (TSPAI 4.03).
- DOE will conduct appropriate analyses to demonstrate that the results of the TSPA are stable with respect to the effects of temporal and spatial discretization (TSPAI 4.04).
- DOE will document the process, and the implementation of the process, used to develop confidence in the TSPA models. The documentation will demonstrate compliance with model confidence-building criteria in accordance with applicable procedures (TSPAI 4.05 and 4.06).

The additional documentation will be provided in the form of revised procedures, and the analysis/model reports (AMRs) and other technical documents that will support the TSPA for a future License Application. It is noted that resolution of other agreement items from KTI technical exchange meetings may also contribute to validation of the TSPA system model.

Model Validation Review

Two major reasons why the TSPA-SR model was classified as Bin 3 are: 1) sufficiency of the approach used to demonstrate adequacy of the Monte Carlo approach, and 2) the TSPA-SR is of such high importance to the Yucca Mountain Project that additional validation activities such as an independent Peer Review must be conducted. In addition, the review includes findings and recommendations related to the completeness of documentation and testing of the system model, and the approach to validation in compliance with AP-3.10Q. The major points are discussed further in the following paragraphs.

Statistical Analysis

One review finding is that the Monte Carlo sample size used was so low that very little exploration actually was made of the parameter hyperspace involved, coupled with the fact that no discussion and/or justification of this very fundamental aspect of the sample-size issue appears anywhere in the AMR (Appendix II, Part 5). Although the focus on the mean dose is driven by regulatory guidelines (40 CFR 197 [2001] Section 197.13 specifies use of the mean) the 5th, 50th and 95th percentile results are presented to provide an indication of the expected range of model outcomes. The analysis of the sensitivity of these quantities to the number of realizations for the nominal scenario is documented in Section 4.1.4 (Precision of Probabilistic Results) of the TSPA-SR technical report (CRWMS M&O 2000bm). Figure 4.1-22 of that report shows a comparison of mean, median, 5th percentile and 95th percentile dose histories for 100, 300 and 500 realizations. Very little difference can be seen between all three cases over the simulated time period of 100,000 yr. Based on these visual comparisons, 300 realizations have

been selected for analyzing the reference case and carrying out the uncertainty importance analyses (Section 5.1). The 100-realization sample is considered to be adequate for comparing the trends in predictions of mean annual dose for the various sensitivity cases.

Clearly, the stability of the results for all statistical measures shown in Figure 4.1-22 of the TSPA-SR technical report (CRWMS M&O 2000bm) refutes the idea that the sample size used in the Latin-Hypercube sampling scheme produced results which do not fully and reasonably represent the uncertainty on calculated annual dose. Based on these observations, the likelihood that the TSPA systematically missed a combination of parameter values that could have produced extremely high doses appears to be very small for all three sample sizes.

During the ongoing International Peer Review (see following discussion), an issue involving confidence intervals on the expected dose was raised. Further confirmation of the stability of the results was provided in the YMP response on confidence intervals on the 300-sample probabilistic results. The standard error in estimates of the expected dose range from 0.019 (mean=0.112) at 40,000 yr to 7.494 (mean=66.112) at 100,000 yr. The 95% confidence intervals on the 95th percentile values are 0.64-0.76 at 40,000 yr and 274-374 at 100,000 yr.

Peer Reviews

Although the reviewers concluded that the TSPA-SR should be assigned Bin 3 due to the lack of additional validating activities such as a peer review, it should be noted that a peer review was conducted on the previous TSPA model (Budnitz et al. 1999) and an international peer review is currently underway on the TSPA-SR.

The TSPA-SR integrated model (CRWMS M&O 2000bl) is very similar conceptually to the preceding model (DOE 1998) used for performance assessment of a Yucca Mountain repository: the TSPA model for the Viability Assessment (TSPA-VA). The TSPA-VA model underwent extensive peer review and the TSPA-VA Peer Review Panel concluded, in part (Budnitz et al. 1999, p. 43):

> "The Panel believes that the basic framework or architecture of the TSPA-VA is sound, as is the use of abstractions of component models for purposes of computational efficiency. Where the Panel has concerns, it is more often due to the specific methods applied and the details of the component models, rather than with how the models were linked."

Because the TSPA-SR model (CRWMS M&O 2000bl) is quite similar in architecture to the TSPA-VA model, this conclusion adds confidence to the validity of the integrated TSPA-SR model.

In addition, the GoldSim risk-based methodology and software has been used by nuclear waste management programs in other countries. For example, the URL http://www.goldsim.com/software/modules2.asp#problems (GoldSim 2001) provides the following documentation:

> "The GoldSim Contaminant Transport Module has been used to address complex contaminant transport problems in North and South America, Europe, Asia, and Australia. A few of the more high-profile applications of the software (specifically, in the area of radioactive waste management) are listed below:
>
> - "Spanish Radioactive Waste Disposal Research. ENRESA, the Spanish radioactive waste management agency, has been using GoldSim (and RIP) since 1992 to evaluate potential host rocks as

part of a program to select a disposal site for the nation's spent nuclear fuel.

- "Evaluation of Waste Disposal Sites, Los Alamos, New Mexico. Los Alamos National Laboratory is using GoldSim to aid in characterizing risks and to help identify monitoring requirements for low-level radioactive waste disposal areas.
- "Remediation and Closure of Mine Workings and Facilities. GoldSim has been used in Germany to evaluate alternative remediation and closure options for abandoned mine workings and tailings facilities associated with former uranium mining operations."

Additionally, the Yucca Mountain Project has initiated the Joint NEA-IAEA International Peer Review of the TSPA-SR. The objective of this peer review is to provide, consulting the bases of available international standards and guidance as appropriate, an independent assessment of the methodology developed by the DOE Yucca Mountain Site Characterization Project and reported in: *Total System Performance Assessment for the Site Recommendation* (CRWMS M&O 2000bm).

The peer review is a review and critical analysis of the performance assessment methodology and rationale being used in support of the current site recommendation decision process. It is being conducted taking account of the international experience in preparing for and conducting system-level post-closure performance assessments. In addition, the relevant international standards and practices, and specifically the requirements proposed by the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission, are being considered as bases. One aspect of the review is to identify consistencies and inconsistencies between methods being used at YMP and those being considered or developed in international recommendations, standards or practices.

Preliminary findings from the Joint NEA-IAEA International Peer Review (Riotte 2001) with regard to the methodology used for TSPA-SR include the following statements:

- The overall structure of the TSPA-SR methodology, and the approach of building on previous performance assessments, conforms to international best practice.
- The FEP screening methodology used for TSPA-SR also conforms to international best practice.
- The TSPA-SR places far greater emphasis on probabilistic assessment than equivalent programs in other countries. The limitations and strengths of the probabilistic method need to be addressed to ensure a defensible analysis.
- The TSPA-SR does not emphasize natural analogs as much as in some other international studies, and more such effort is recommended.

In response to a request from DOE to provide a statement regarding the adequacy of the overall TSPA-SR approach for supporting the site recommendation decision, the peer review team states:

> "While presenting room for improvement, the TSPA-SR methodology is soundly based and has been implemented in a competent manner. Moreover, the modelling incorporates many conservatisms, including the extent to which water is able to contact the waste packages, the performance of engineered barriers and

retardation provided by the geosphere.

"Overall, the [International Review Team, IRT] considers that the implemented performance assessment approach provides an adequate basis for supporting a statement on likely compliance within the regulatory period of 10,000 years and, accordingly, for the site recommendation decision.

"On the basis of a growing international consensus, the IRT stresses that understanding of the repository system and its performance and how it provides for safety should be emphasised more in future iterations, both during and beyond the regulatory period. Also, further work is required to increase confidence in the robustness of the TSPA."

These statements show that, notwithstanding the findings of the model validation status review, there is consensus among an important part of the international technical community that the TSPA-SR methodology is adequate for its intended use.

Model Testing and Documentation

Planned activities include more complete documentation of submodels that are implemented in the TSPA system model. Also, as recommended, ~~more complete~~ sensitivity and uncertainty analyses will be applied to the system model. For additional confidence building or validation, specific criteria from the applicable implementing procedure (e.g., AP-3.10Q) will be considered. Finally, the documentation for TSPA will be improved to provide additional transparency, consistent at least with the intent of the recommendations in Section 6 and the additional comments in Appendix III.

Conclusion

As stated above, model validation of the total system model depends upon the confidence building activities that are conducted for the key underlying process and abstraction models. Confidence building is an iterative and ongoing process, and the Yucca Mountain Project continues to develop confidence building activities as part of the model validation for process models and abstractions that are used as the underlying bases for the TSPA. In order to provide an appropriate level of confidence in the models used to demonstrate compliance with the draft regulations considered in the site recommendation documents, it is necessary to:

- Confirm that the relevant draft numerical performance standards have been met
- Confirm that the analyses are realistic with reasonable conservatism for uncertainties, that limitations in the analyses are well understood, and appropriate allowances have been made for time period, hazards and uncertainties.

The level of confidence required should be consistent with the importance to performance. With respect to the first bullet, the results of the TSPA-SR indicate that relevant draft numerical performance standards can be met by several orders of magnitude. It should be noted that there are differences between the draft 10 CFR 63 (66 FR 55732) and the final 40 CFR 197 (2001) numerical performance standards and the points of compliance. With respect to the second bullet, sensitivity studies have been documented in the TSPA-SR in the form of uncertainty importance analyses, subsystem sensitivity analyses, and robustness analyses (CRWMS M&O 2000bm; Sections 5.1, 5.2, and 5.3) that indicate the level of uncertainties and conservatisms, the limitations of the models, and the impacts and individual contributions associated with various time periods and likely and unlikely hazards. These sensitivity analyses indicate that the TSPA

model is sufficiently robust that even given the uncertainties that may exist in the confidence of the subsystem models, the relevant draft numerical performance standards will likely be met. Additional sensitivity analyses have been documented in Volumes 1 and 2 of the *FY01 Supplemental Science and Performance Analyses* (BSC 2001d and 2001k, respectively) specifically to provide additional insights into the potential conservatisms and optimisms in the TSPA, to capture a wider range of uncertainties, and to provide updated and more realistic representations of processes. The results of these additional sensitivity analyses also indicate that the relevant draft numerical performance standards can be met for a range of thermal operating modes by several orders of magnitude.

The model validation work performed to date on the TSPA Model including all of the uncertainty and sensitivity analyses coupled with the past and ongoing peer reviews result in a TSPA Model that is sufficiently robust and provides adequate confidence that the model is suitable for its intended use (a site recommendation) and that the relevant draft numerical performance standards will be met in a potential License Application (LA). As model validation exercises continue for subsystem models, confidence will increase in the appropriateness of the models for incorporation into the TSPA iteration required for a potential LA submittal. The TSPA iteration required for a potential LA will be used to confirm that the relevant *final* numerical performance standards have been met.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Soil Removal Model for Volcanic Disruption (U.1-2)	B. AMR: Total System Performance Assessment (TSPA) Model for Site Recommendation (MDL-WIS-PA-000002 Rev. 00) (CRWMS M&O 2000bl)

C. Category (Check appropriate case)

☐ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☒ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

See continuation sheet.

E. Responsible Individual: Jerry McNeish/ Jerry A McNeish 11·14·01

Type Name/Signature Date:

Continuation of item D (Model U.1-2):

As discussed in the *FY01 Supplemental Science and Performance Analyses* (BSC 2001d, Section 3.3.1.2.5) the approach taken in TSPA-SR (CRWMS M&O 2000bm, Sections 3.10.2 through 3.10.4) does not explicitly include the effects of possible surface redistribution of contaminated ash following deposition. Specifically, aeolian and fluvial processes may result in transport of sediment from other regions within the area of the ashfall to the location of the receptor. Instead of explicitly including these processes, TSPA-SR analyses used a conservative approach (CRWMS M&O 2000bm, Section 3.10.4) in which the wind direction was fixed toward the receptor for all eruptive events, overestimating the amount of ash initially deposited at the location receptor. Furthermore, the transition-phase biosphere dose conversion factors (BDCFs) used for calculating eruptive annual dose at all times following ash deposition used high air-mass loading values applicable for fresh, unconsolidated ash, rather than the more appropriate long-term BDCFs calculated for stabilized soils. This overestimate of long-term air-mass loading, combined with the assumption for the purpose of calculating the inhalation dose that all radionuclides would be concentrated in the upper 1 cm of the ash layer regardless of its thickness, form the basis for the assertion in the TSPA-SR technical report that the overall treatment is conservative with respect to ash redistribution processes (CRWMS M&O 2000bm, Section 3.10.4).

Also, as described in the *FY01 Supplemental Science and Performance Analyses* (BSC 2001d, Sections 3.3.1.2.4 and 3.3.1.2.5, and Figure 3.3.1.2.4-3) the no-soil removal case provides an upper bound on conditional annual doses that might result if surficial redistribution processes cause deposition of contaminated sediment at the location of the receptor, as long as concentrations of radionuclides in the redeposited sediments are equal to or less than concentrations in the initial ash layer.

The soil redistribution model will be updated to reflect processes that both add to and remove soil from the receptor site. Rates for soil addition and removal will be based on field studies of soil movement in the Yucca Mountain vicinity. Redistribution of ash from the Lathrop Wells eruption will also be examined. It is planned that these studies will be documented in a revision to the report: *Characterize Eruptive Processes at Yucca Mountain, Nevada* (CRWMS M&O 2000k) and results will be intended for use in TSPA-LA.

MODEL VALIDATION - IMPACT REVIEW

A. Model: Pu-Ceramic Degradation Model for TSPA-SR (U.4)	B. AMR: Performance Assessment and Sensitivity Analysis of Disposal of Pu as Can-in-Canister Ceramic. (ANL-WIS-PA-000003 Rev. 00) (CRWMS M&O 2001u)

C. Category (Check appropriate case)

☒ 1) Model NOT USED in TSPA and DID NOT SERVE as a basis for screening FEPs.

Result: No impact on TSPA-SR

☐ 2) Model NOT USED in TSPA but DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on FEP screening – Complete Section D below

☐ 3) Model IS USED in TSPA but DID NOT SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results – Complete Section D below

☐ 4) Model IS USED in TSPA and DID SERVE as a basis for screening FEPs.

Result: Assess impact of validation findings on TSPA-SR results and FEP screening – Complete Section D below

D. Path Forward and Impact on TSPA (Describe in detail)

The validation review findings on this model do not impact the conclusions of the TSPA-SR, because the model is used only for a sensitivity study, and not for dose calculations that can be compared to regulatory standards. The subject AMR is not cited in the TSPA-SR model or technical report documents (CRWMS M&O 2000bl; 2000bm).

In the subject AMR several models for aqueous dissolution of the ceramic are compared by examining the annual dose results (dose history) for the median value nominal case (median values for distributed inputs). These models include two different ceramic models, plus the HLW glass model, and also an instantaneous dissolution model. The dose results for the LLNL ceramic model, the HLW glass model, and instantaneous dissolution model showed virtually equivalent calculated annual dose on the million-year dose history plot (Figures 6.5-5 and 6.5-6 of the subject AMR). The other ceramic model (Synroc ceramic) showed somewhat lower annual dose at later times (after about 40,000 yr; Figure 6.5-6) and is therefore regarded as less conservative than the other models.

The LLNL ceramic model is selected for use in the sensitivity study because it is mechanistic and thus physically meaningful, but produces results that are equivalent to the bounding instantaneous dissolution model. The fourth model (Synroc ceramic) would require additional justification. The reason that all four models produce such similar results is that release from the failed waste package depends more on actinide solubility than the waste form dissolution rate. The Synroc ceramic model imposes greater kinetic limitation on dissolution, and after 40,000 yr begins to limit the amounts of actinides available for transport out of a failed package, which is why it produces somewhat lower annual dose at later times.

E. Responsible Individual: Jerry McNeish/ Jerry A McNeish   11-14-01

Type Name/Signature   Date:

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