SAND2010-3465P

Sandia National Laboratories

Representation of THMC Coupling in Seismic Consequences Models:

An Example from the Yucca Mountain Performance Assessment

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IAEA Regional Training Course

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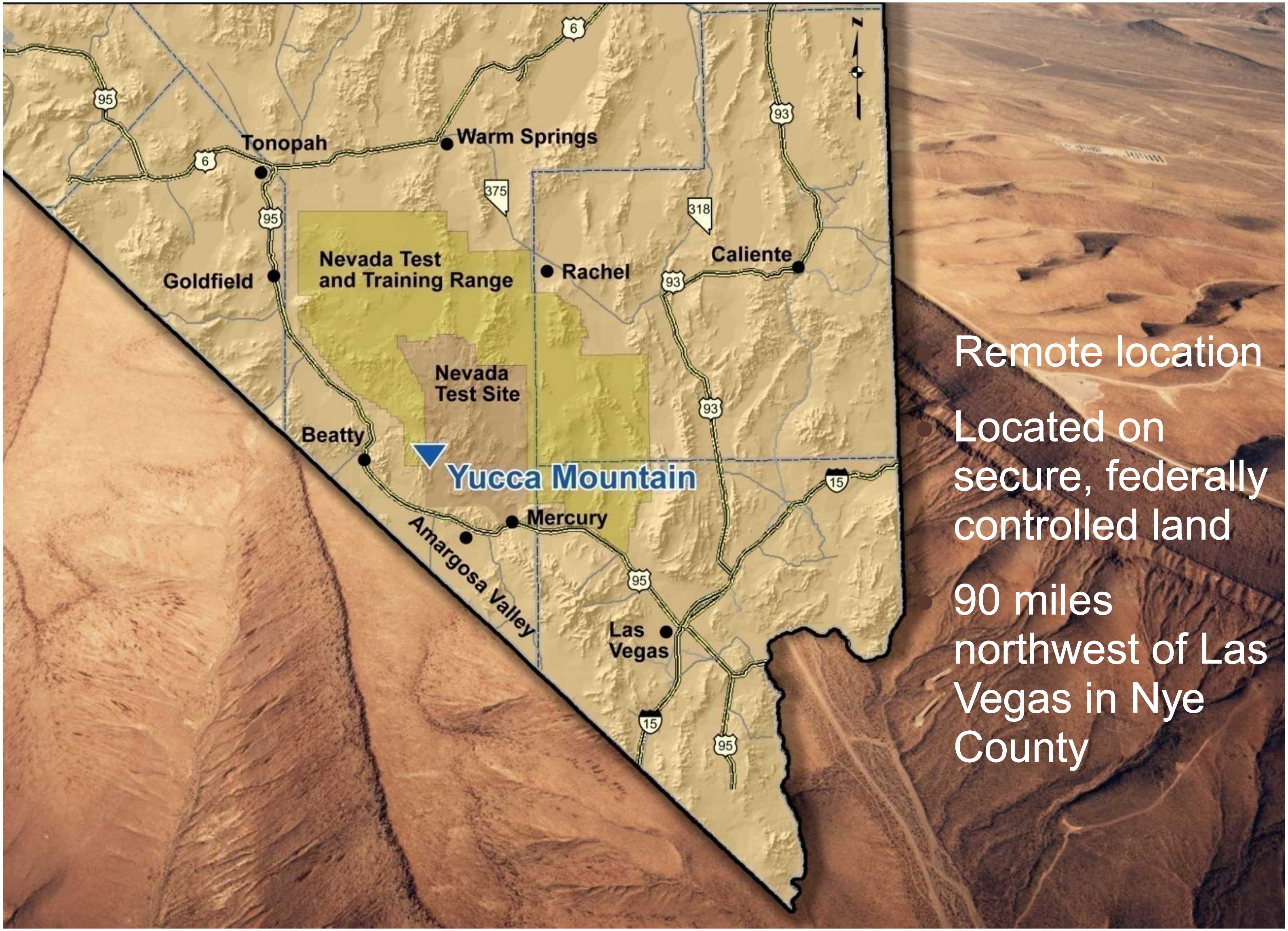
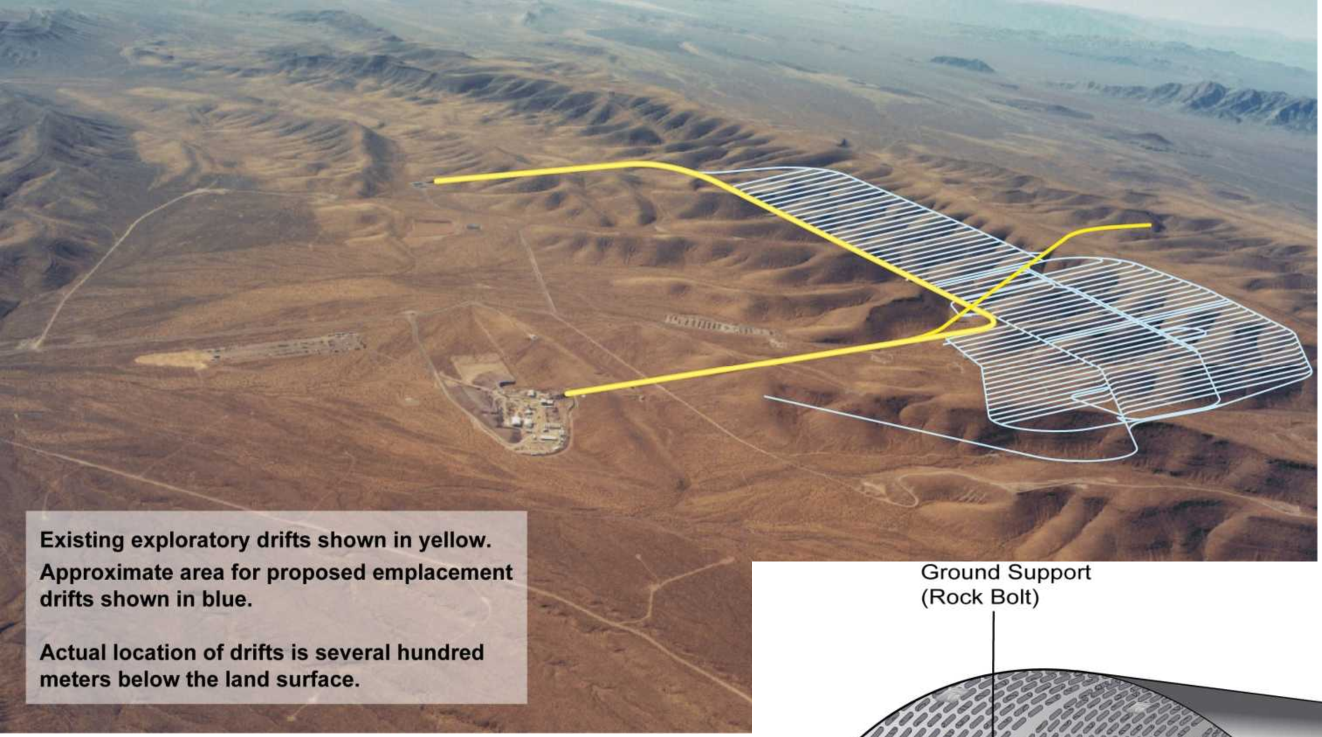
Yucca Mountain, Nevada



- Remote location
- Located on secure, federally controlled land
- 90 miles northwest of Las Vegas in Nye County

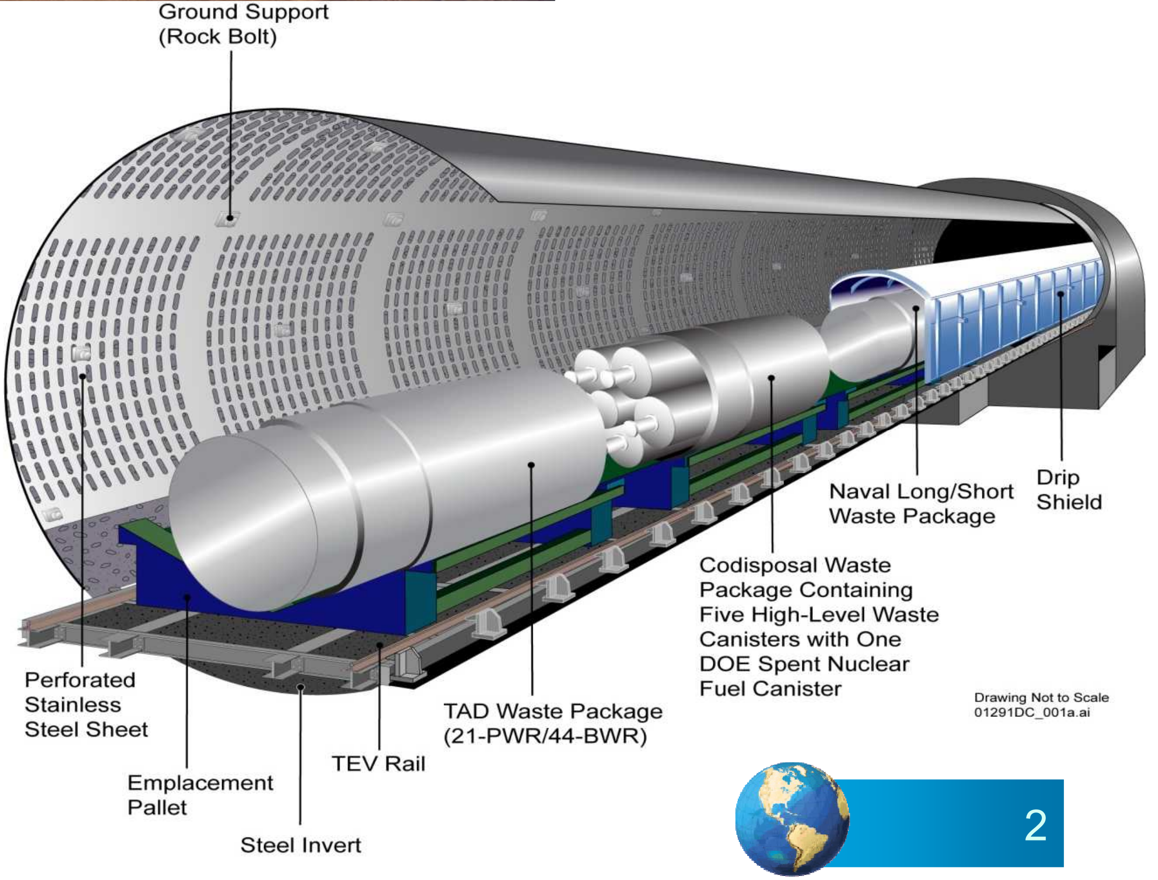
Subsurface Design



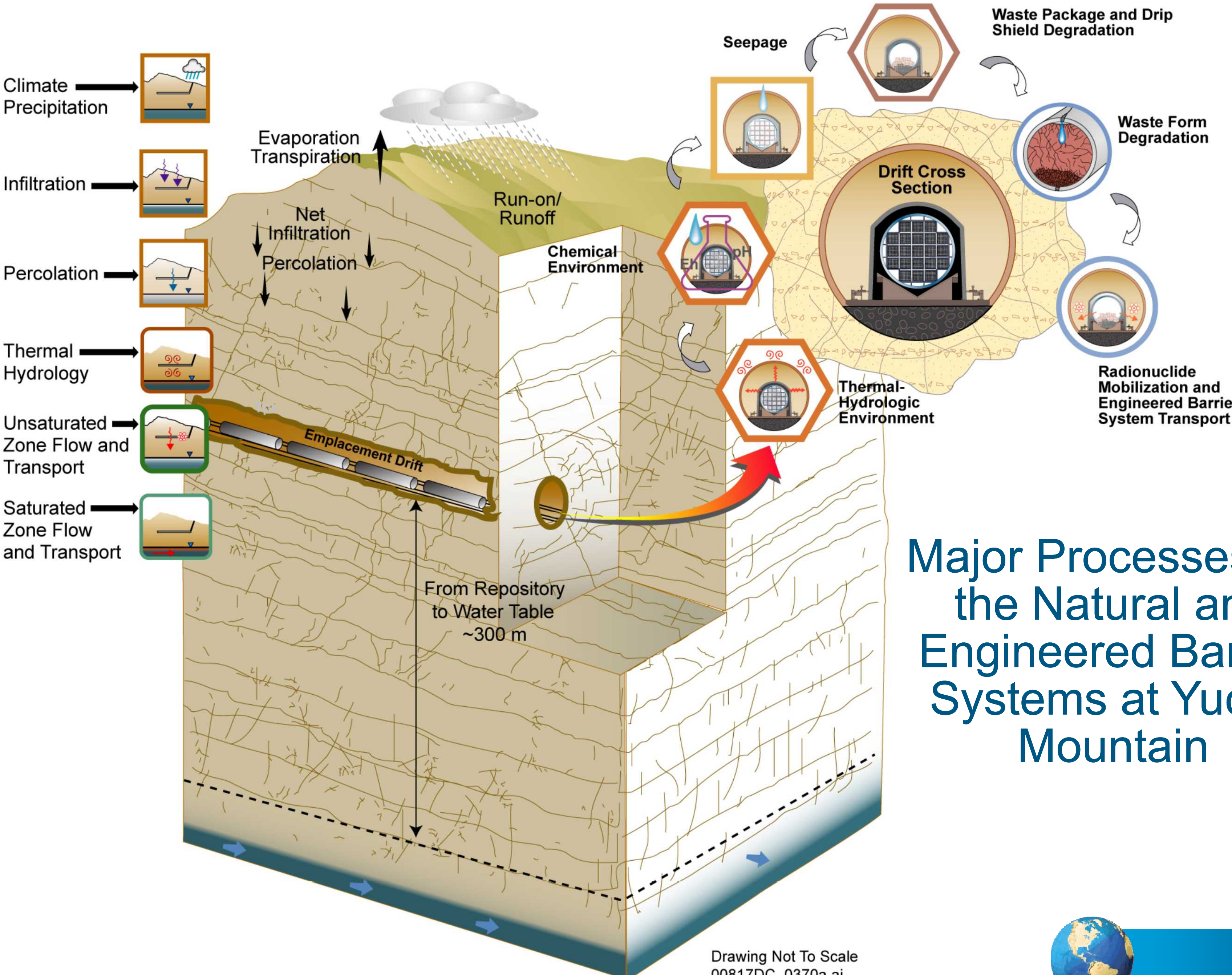
Emplacement drifts
- 5.5 m diameter
- approx. 100 drifts, 600-800 m long

Waste packages
- ~11,000 packages
- ~ 5 m long, 2 m diameter
- outer layer 2.5 cm Alloy 22 (Ni-Cr-Mo-V)
- inner layer 5 cm stainless steel

Drip shields
- free-standing 1.5 cm Ti shell

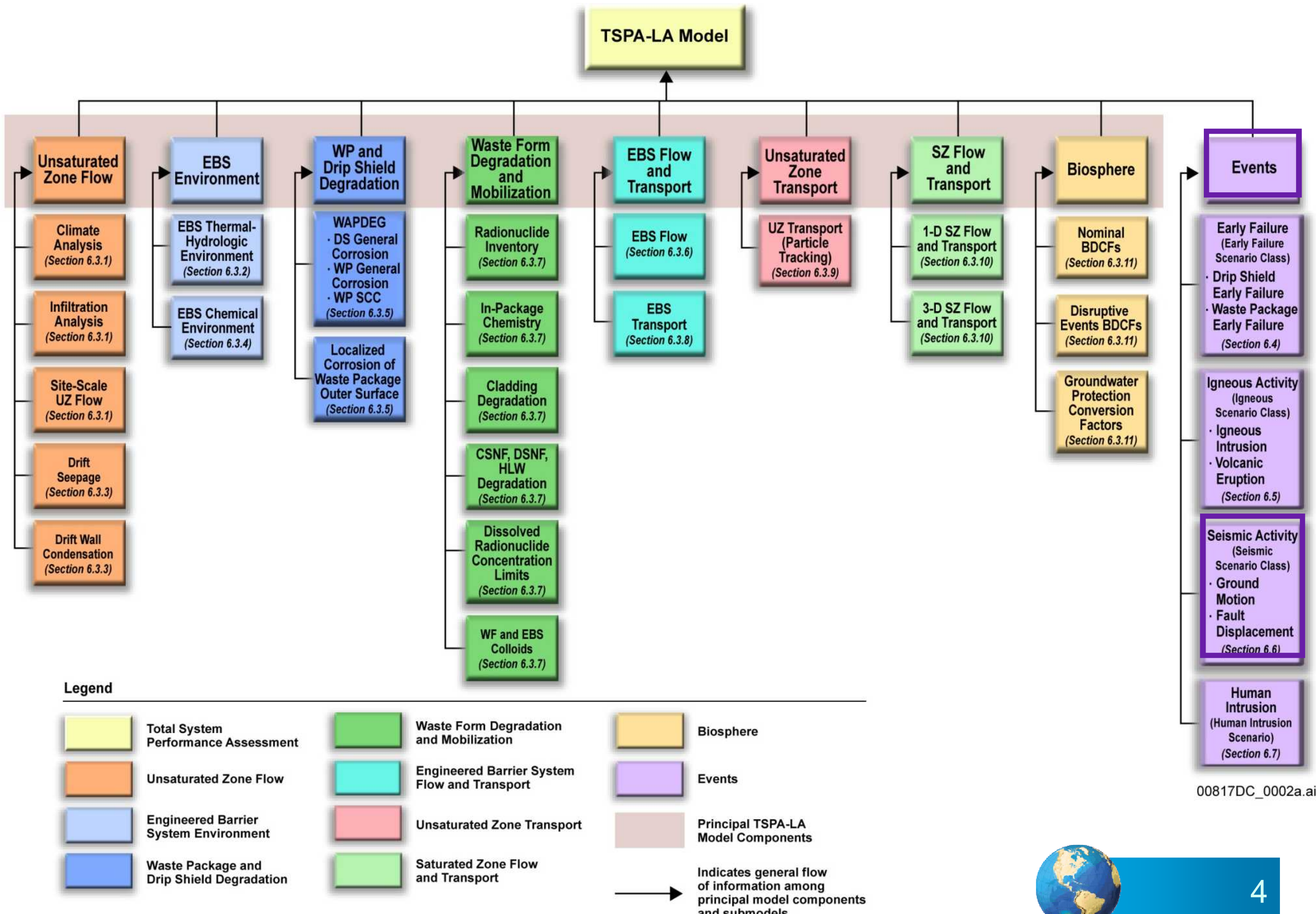


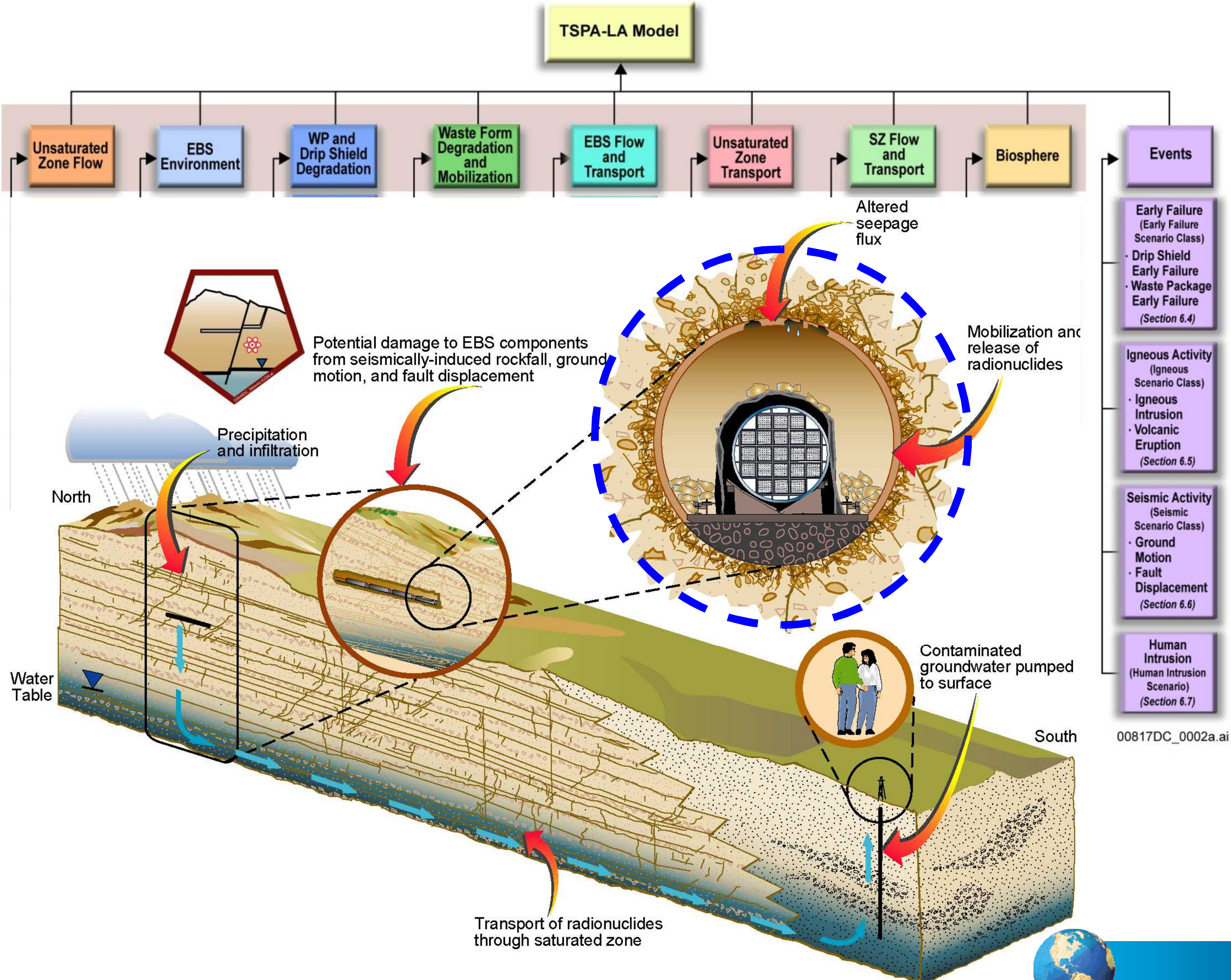
Major Processes for the Natural and Engineered Barrier Systems at Yucca Mountain



Performance Assessment System Model

(with component models and submodels)

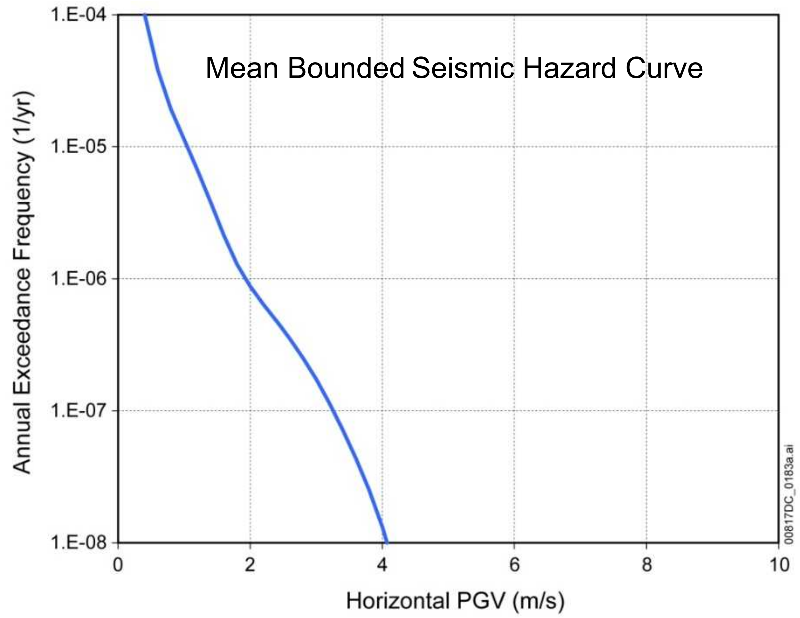


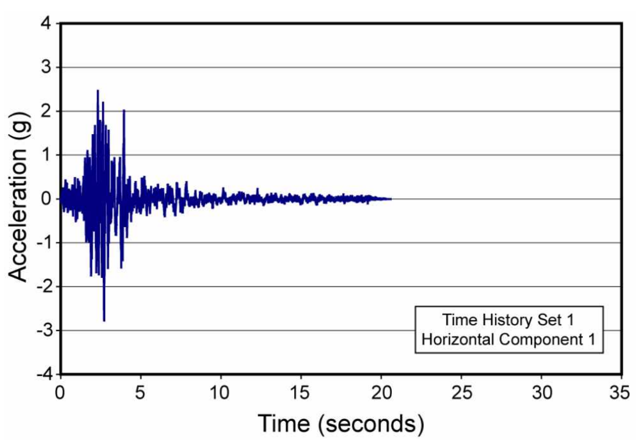


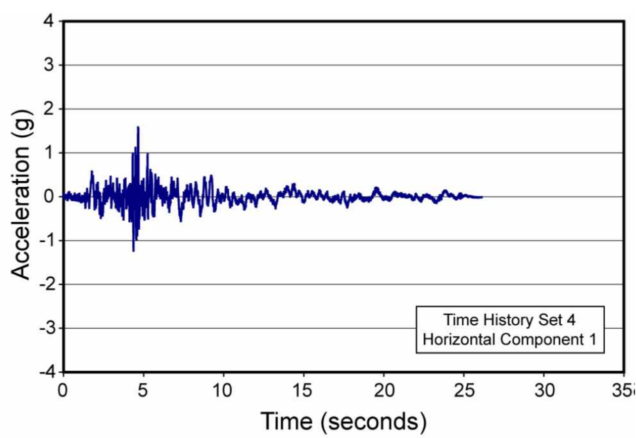
TSPA-LA Model
Unsaturated Zone Flow
EBS Environment
WP and Drip Shield Degradation
Waste Form Degradation and Mobilization
EBS Flow and Transport
Unsaturated Zone Transport
SZ Flow and Transport
Biosphere
Events
Early Failure (Early Failure Scenario Class) · Drip Shield Early Failure · Waste Package Early Failure (Section 6.4)
Igneous Activity (Igneous Scenario Class) · Igneous Intrusion · Volcanic Eruption (Section 6.5)
Seismic Activity (Seismic Scenario Class) · Ground Motion · Fault Displacement (Section 6.6)
Human Intrusion (Human Intrusion Scenario) (Section 6.7)
Altered seepage flux
Mobilization and release of radionuclides
Potential damage to EBS components from seismically-induced rockfall, ground motion, and fault displacement
Precipitation and infiltration
North
Water Table
Contaminated groundwater pumped to surface
South
Transport of radionuclides through saturated zone
00817DC_0002a.ai

Source Term: Seismic Hazard

- The annual exceedance frequency (λ) of seismic events of varying magnitudes (PGV) is defined by the (mean) bounded seismic hazard curve
- Hazard curve is derived from an expert elicitation (PSHA); but bounded with additional site-specific data regarding rock strength
- Aleatory uncertainty is represented by a set of 17 possible ground motion time histories:



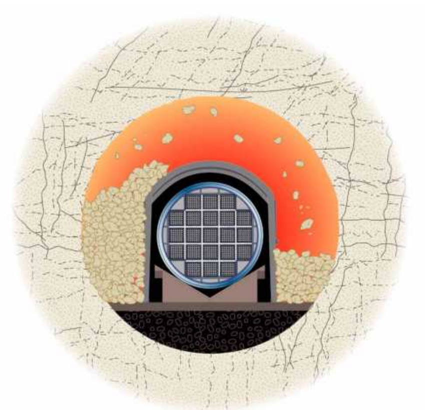




Conceptual Model for EBS Evolution

State 1

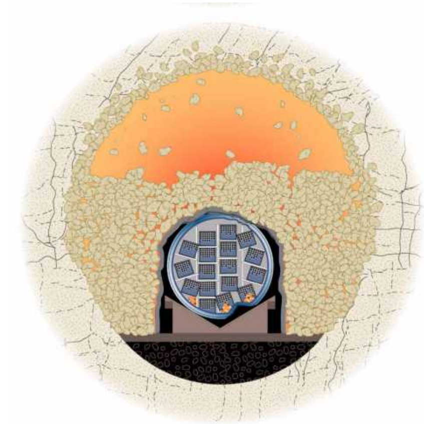
(a) Initial Configuration



Kinematic analyses and damage catalogs define damaged areas for a WP moving freely beneath the DS. WP SCC or rupture may occur, degrading internals

State 2

(b) After Drip Shield Framework Failure



Fragility analysis for buckling of DS framework. Additional WP damage may occur.

State 3

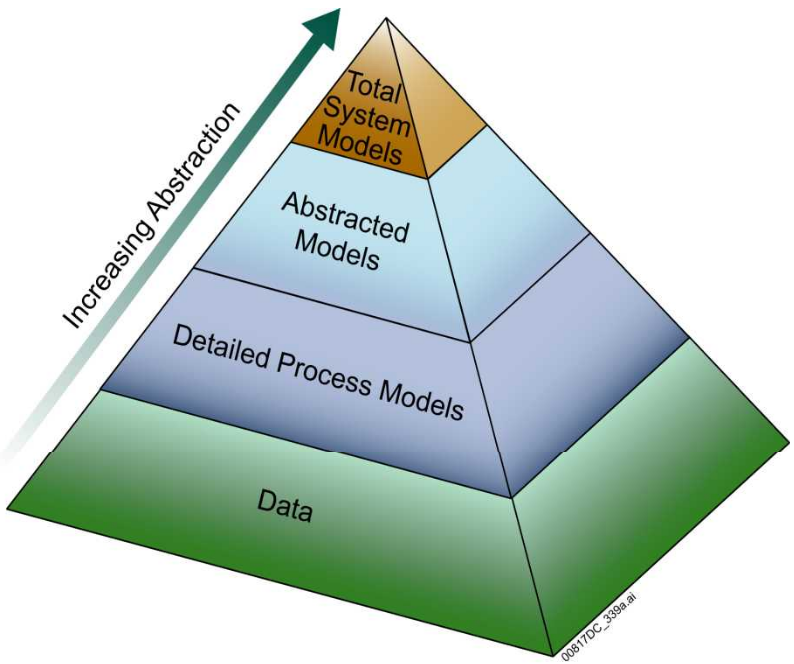
(c) After Drip Shield Plate Failure

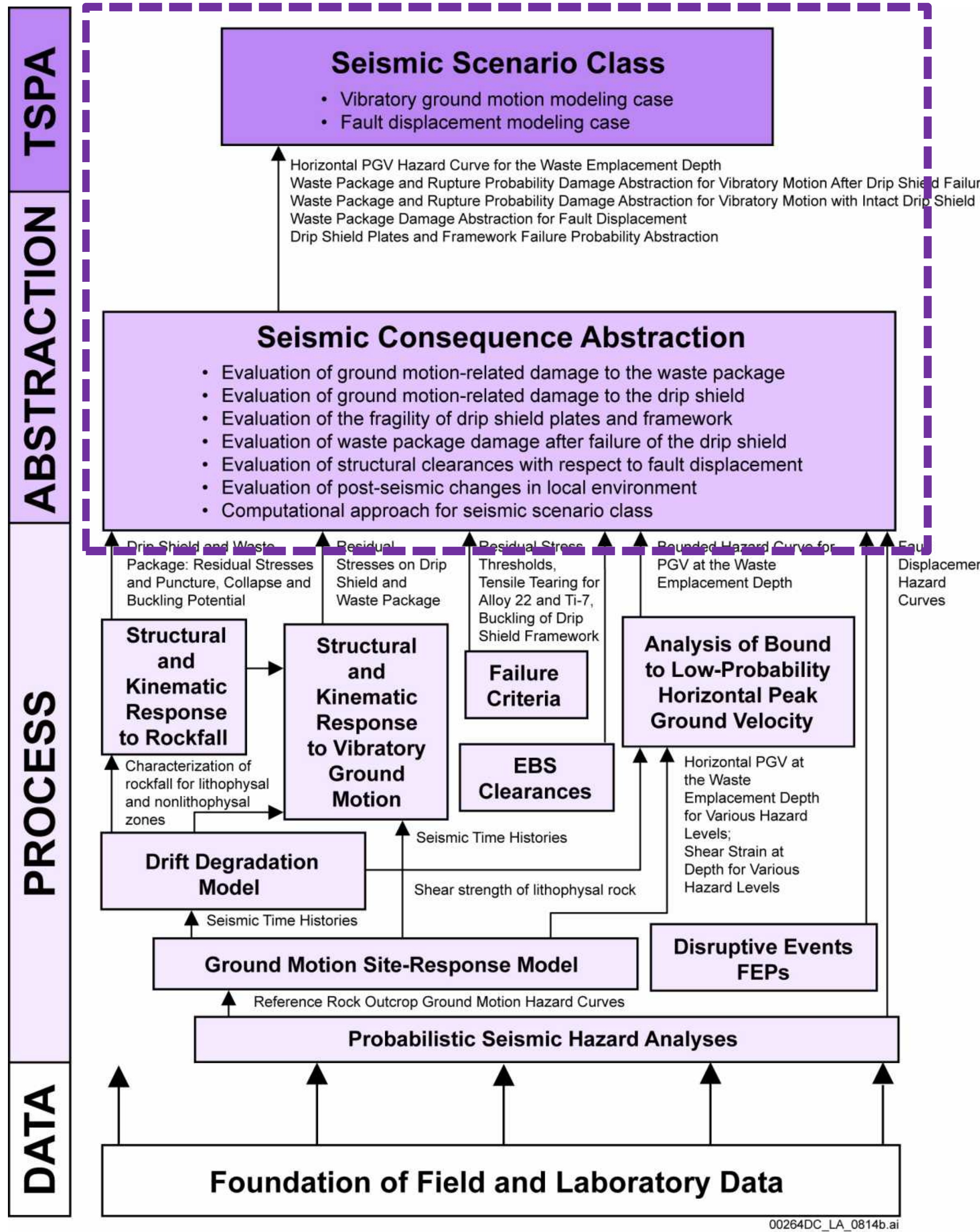
Fragility analysis for rupture of DS plates. WP damage defined by 2-D calcs for WP surrounded by rubble

DS Failure

Time

Seismic Consequences Abstraction Methodology

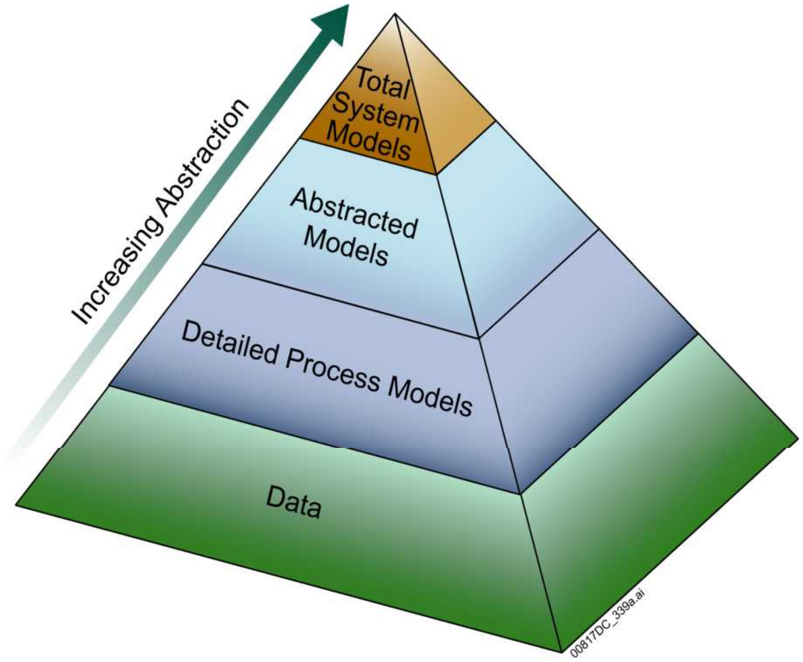


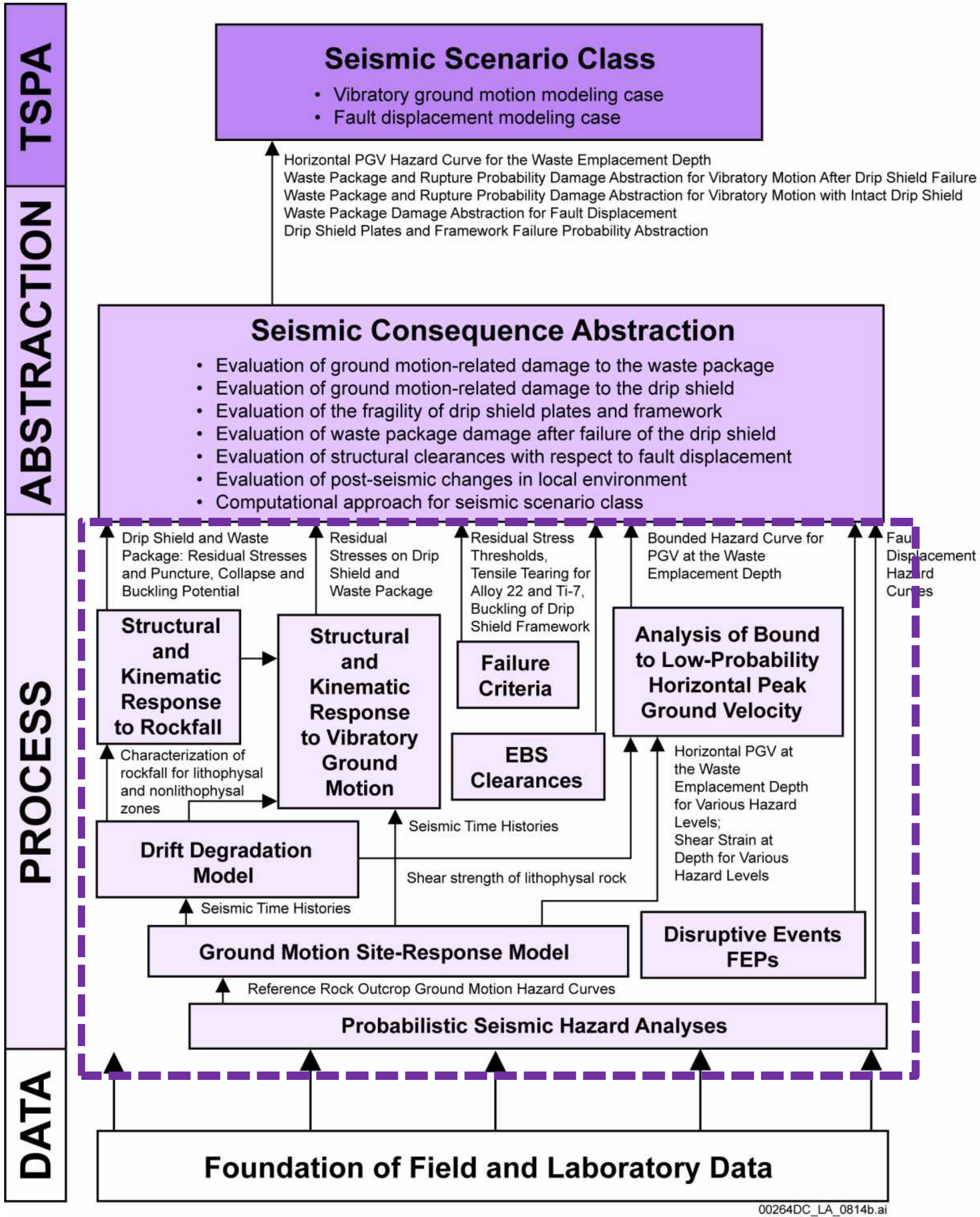


Summary of Waste Package Damage States

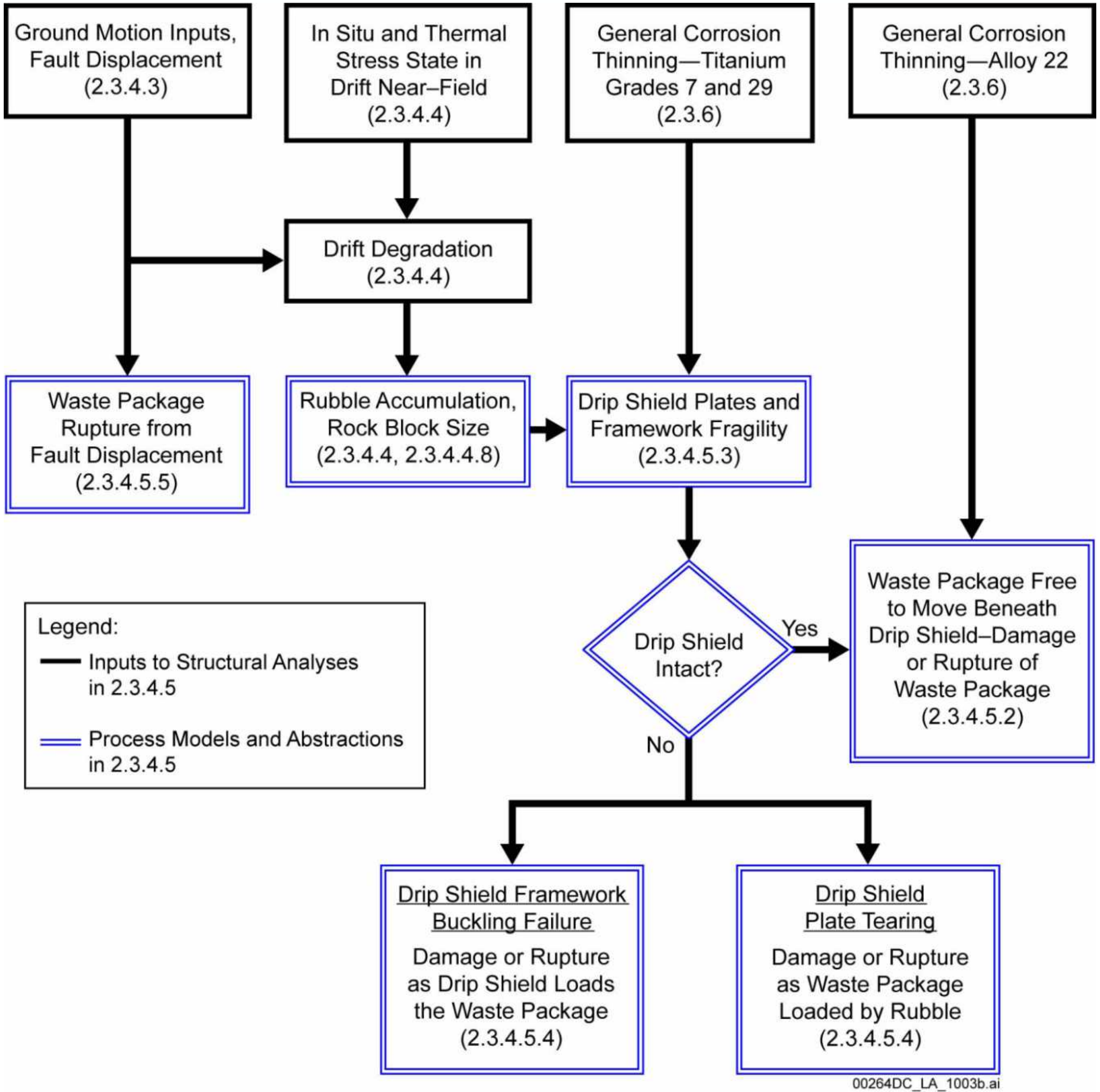
- **There are eight possible WP damage states and associated abstractions:**
    1. **No damage**
    2. **SCC of WP under an intact DS with WP internals intact**
    3. **SCC of WP under an intact DS with WP internals degraded**
    4. **WP rupture under an intact DS with WP internals degraded**
    5. **SCC of WP under a buckled DS with internals intact**
    6. **SCC of WP under a buckled DS with internals degraded**
    7. **SCC of WP under a failed DS**
    8. **WP puncture under a failed DS**
- **Consequences are based on the magnitude of the event (PGV), the residual stress threshold (RST) for Alloy 22, and the Alloy 22 thickness for the eight modeled states of the system at the time of the event**

Seismic Consequences Abstraction Methodology



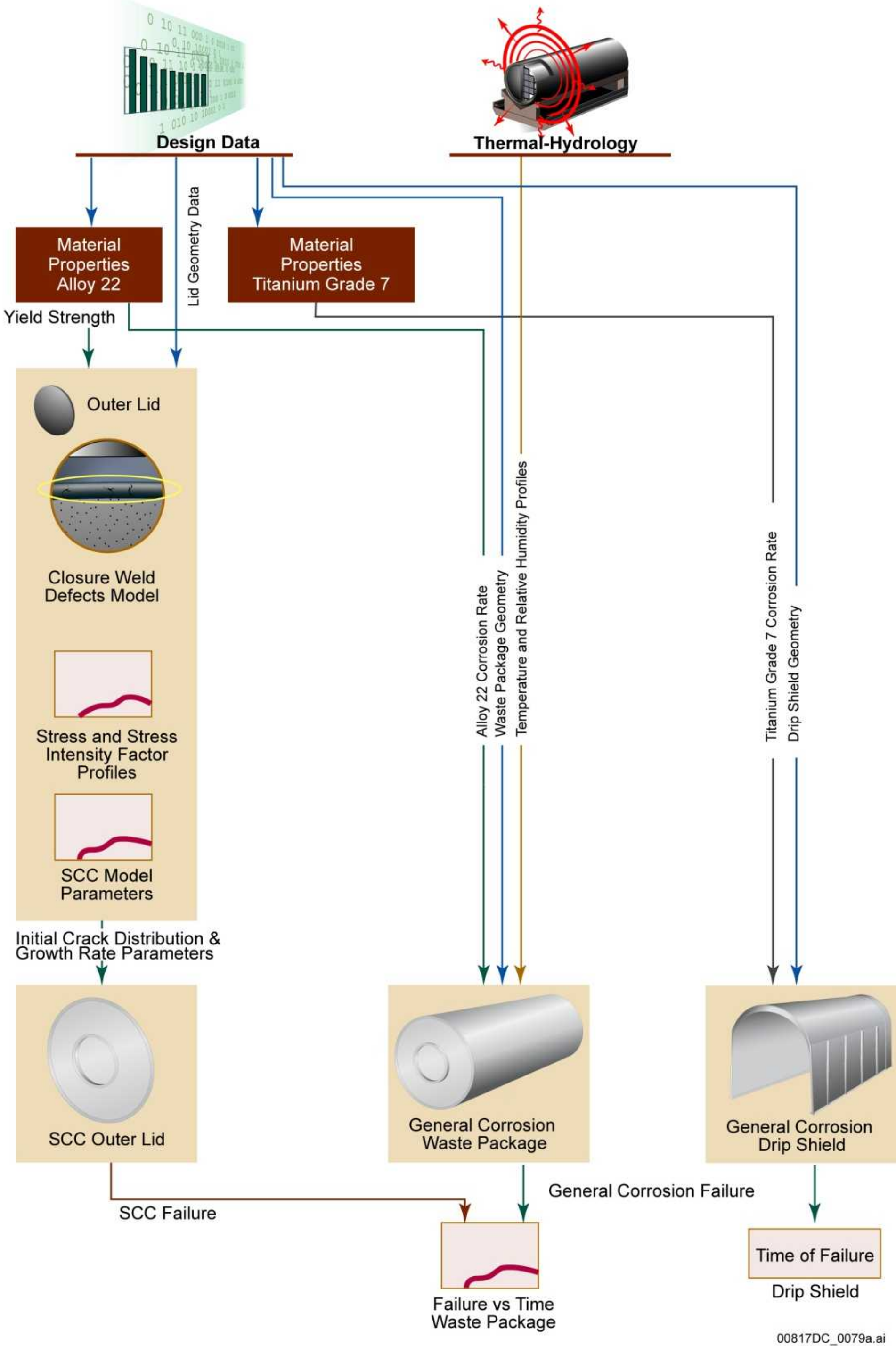


Seismic Ground Motion Consequences:
Flow Chart Showing Interrelationship of Process Models

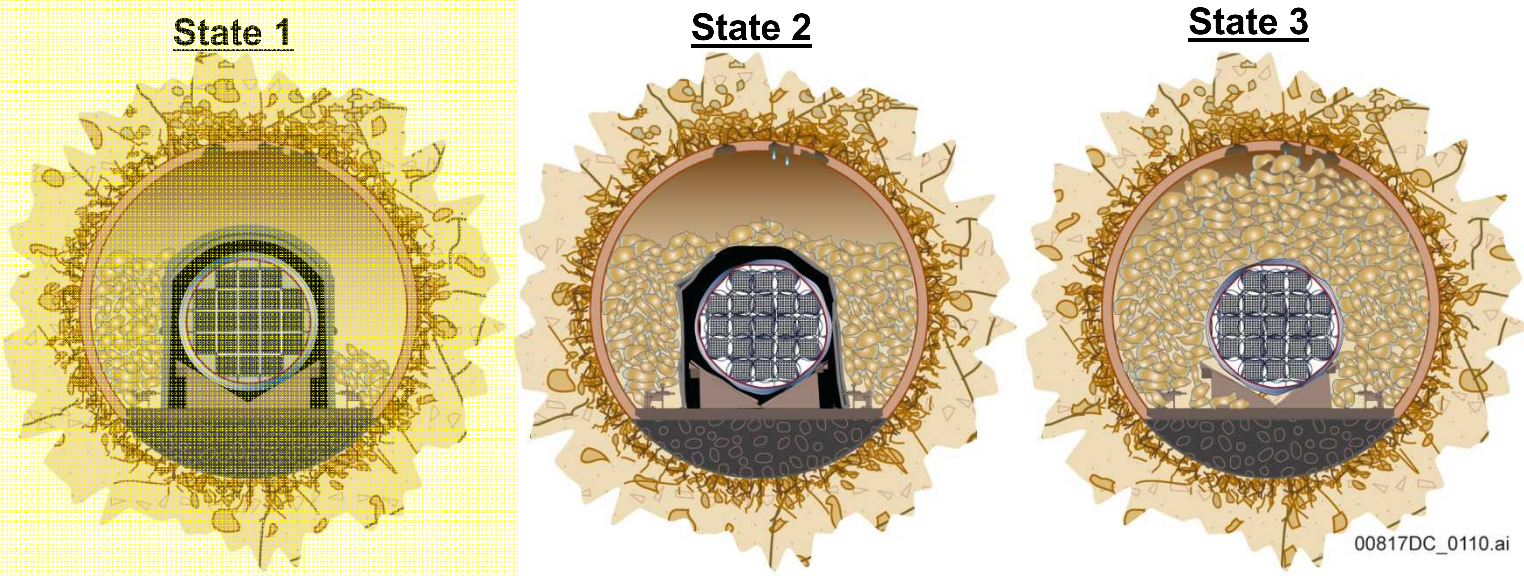


Nominal Corrosion/Degradation Processes for the Waste Package and Drip Shield

- **Stress corrosion cracking (SCC) in the closure lid welds**
- **General corrosion of Alloy 22 and Ti, with an explicit temperature dependence for the activation energy in the Arrhenius rate law for Alloy 22**
- **Measured rates of Alloy 22 general corrosion do not show an explicit chemical dependence**
- **Nominal corrosion processes determine the initial conditions for seismic degradation of the waste package and drip shield, i.e., they provide the material thickness vs. time**



Conceptual Model for EBS Evolution



(a) Initial Configuration

(b) After Drip Shield Framework Failure

(c) After Drip Shield Plate Failure

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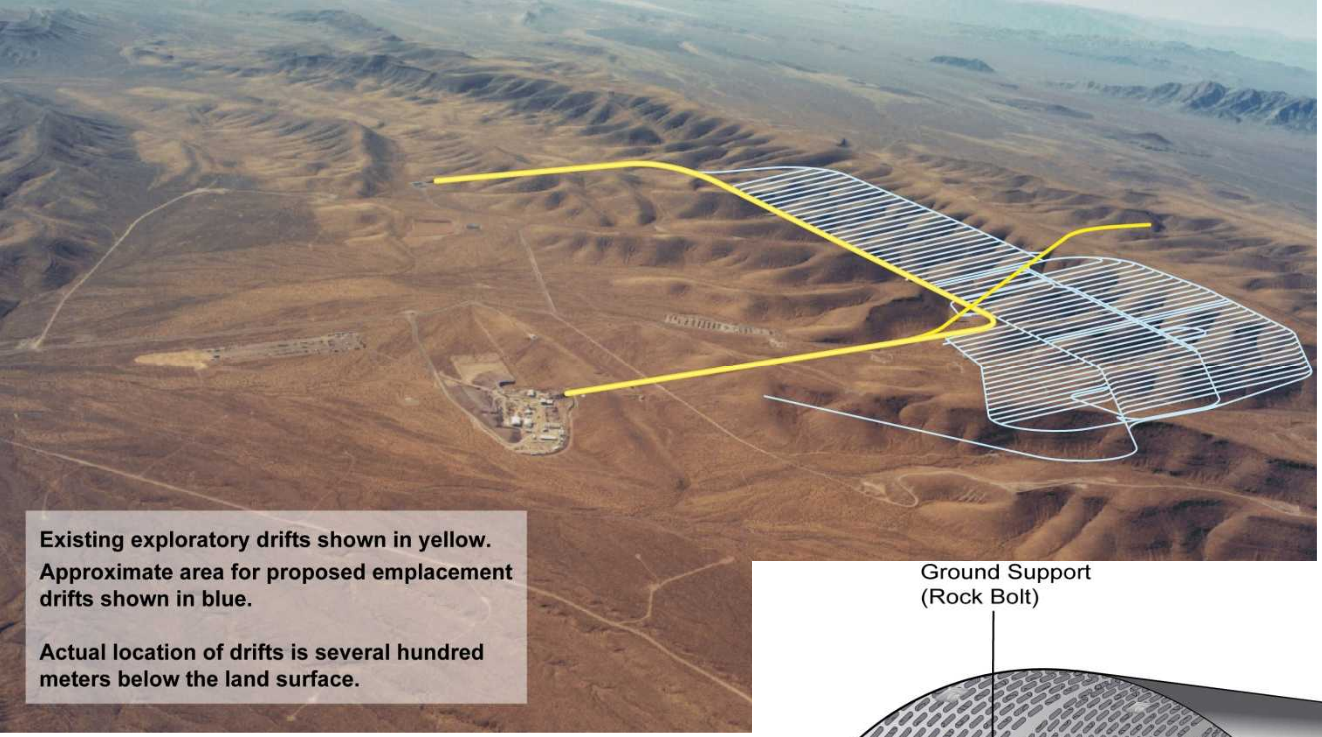
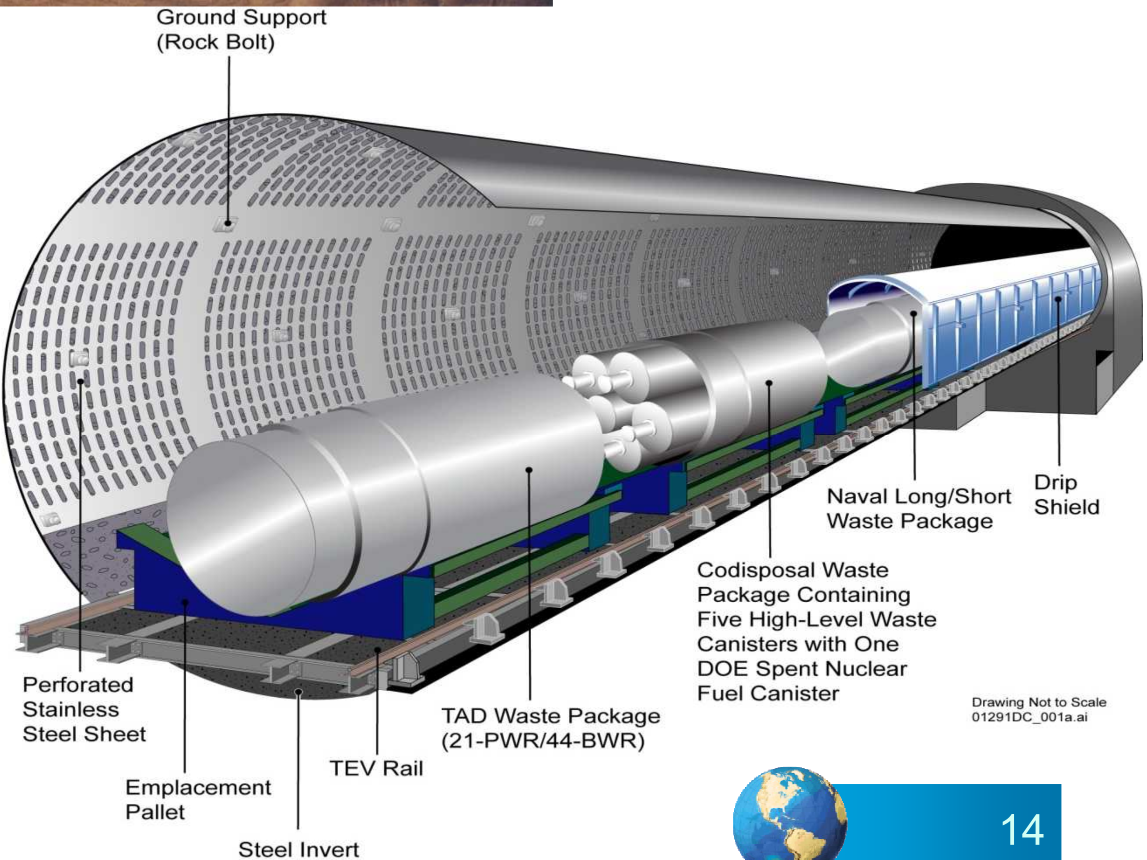
DS Failure

Time

MDL-WIS-PA-000005, Figure 6.6-5

Subsurface Design





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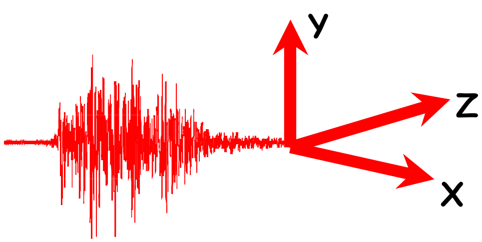
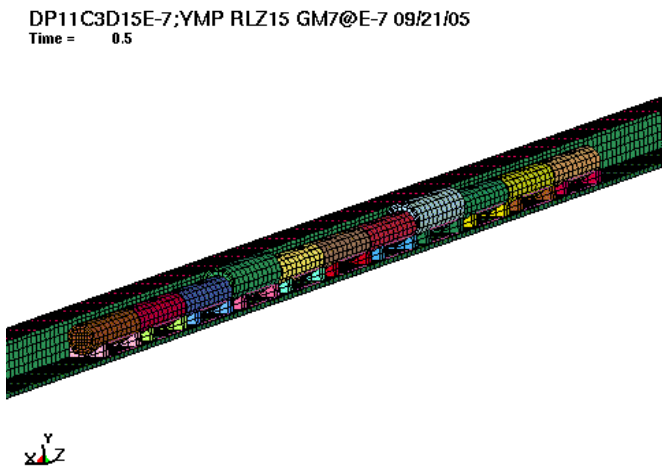
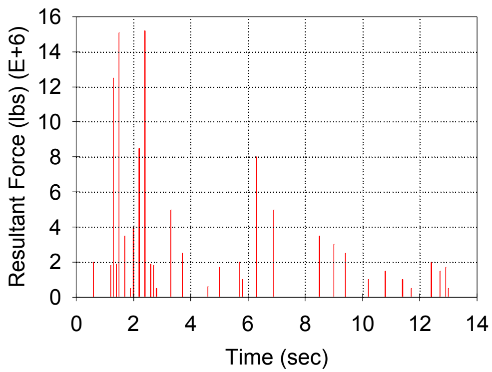
EBS Evolution State 1

- **Kinematic analyses (LS-DYNA finite elements)**
  - **3-D kinematic analyses of CSNF/TAD and codisposal WPs produce histories of <u>multiple</u> WP impacts for each of 17 ground motion time histories at four horizontal PGV levels**
  - **Coarse discretization of package for kinematic analyses**

Schematic Ground Motion Time History → **Representative Drift Configuration** → **Illustrative Impact Force History**





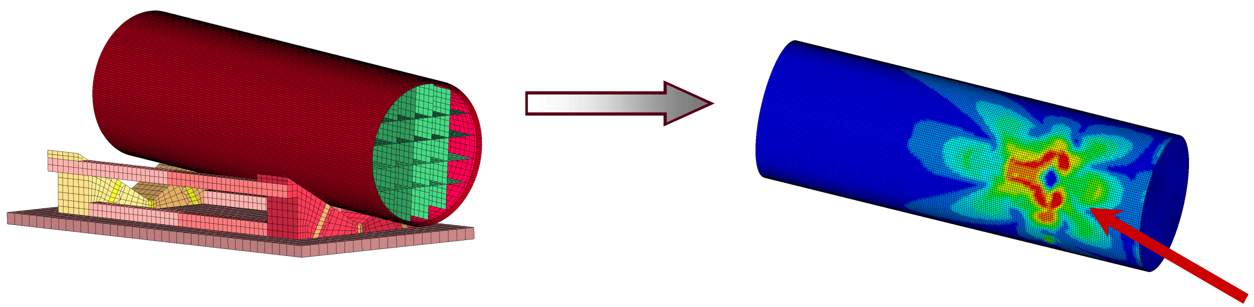


Input → **Analysis** → **Output**

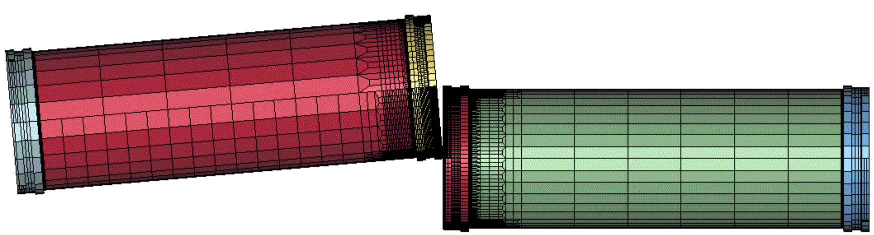
[DIRS 178851] Figures 6-17 and 6-18

EBS Evolution State 1

- **Kinematic analyses** (continued)
  - Develop catalogs for damage area and rupture condition for <u>individual</u> impacts in the impact force history—fine discretization of WP
    - Catalogs consider either intact or degraded states of WP internals
    - Catalogs consider multiple impact locations and impact velocities for three angles for WP-pallet impacts and one angle for WP-WP impacts
  - WP-to-pallet impacts:



  - WP-to-WP impacts:

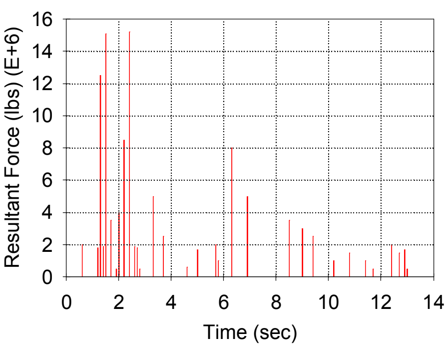


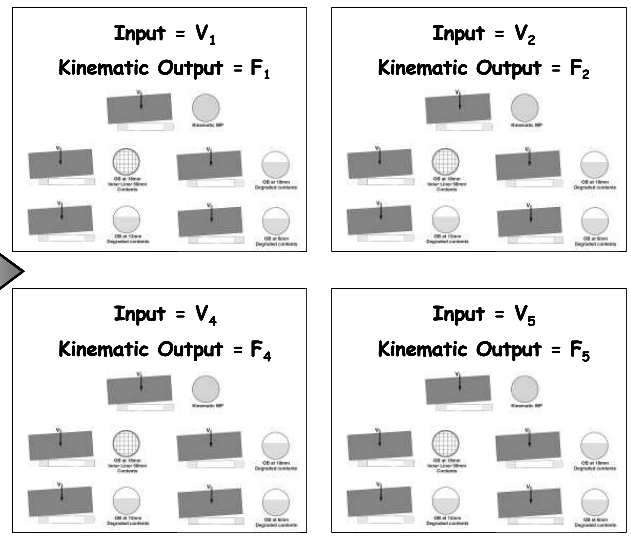
EBS Evolution State 1

- **Kinematic Analyses** (continued)
  - Combination of impact force history and damage catalogs generates potential WP damage (residual stress field and/or rupture condition) for a given seismic event

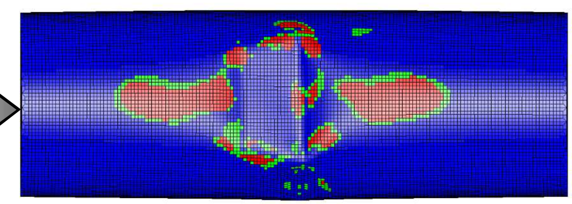
Damage Catalog

Illustrative Impact Force History





Residual Stress Field

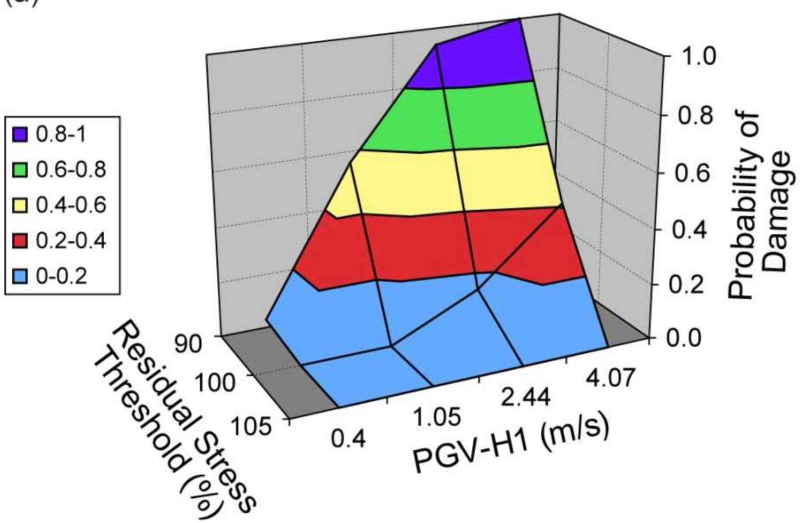


  - Results define both the probability of damage and the amount of damaged area as a function of the WP state and PGV level; damaged area is the area with residual stress above the threshold for initiation of stress corrosion cracking (90% to 105% of yield strength for Alloy 22)

EBS State 1 SCC Damage: (Intact DS, Intact Internals)

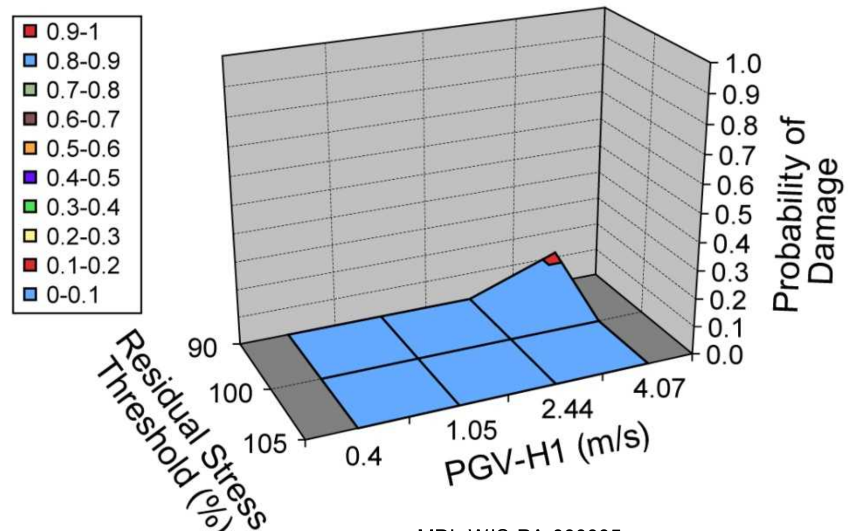
- **Codisposal WP probability of SCC damage for a 23-mm thick**

(a)



- **CSNF WP probability of SCC damage for a 23-mm thick**

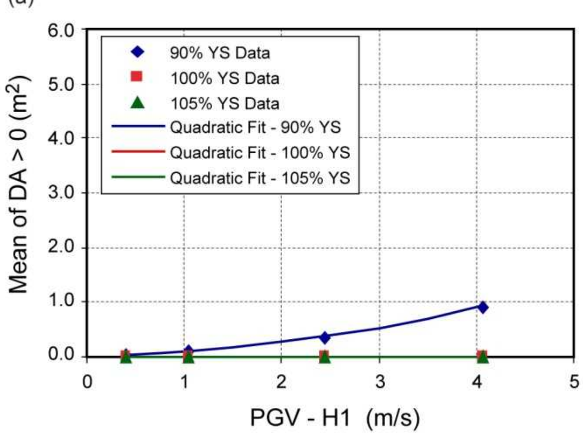
(a)



MDL-WIS-PA-000005, Figure 6.6-10(a)

- **Codisposal WP mean damage area for a 23-mm thick**

(a)

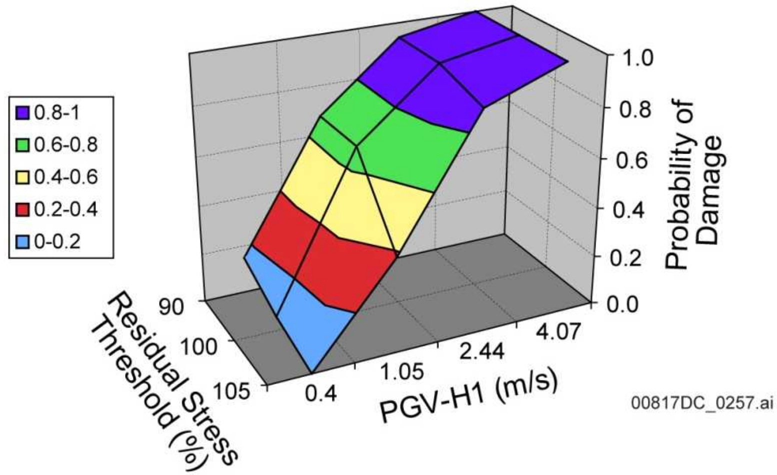


MDL-WIS-PA-000005, Figures 6.6-11 and 6.6-13

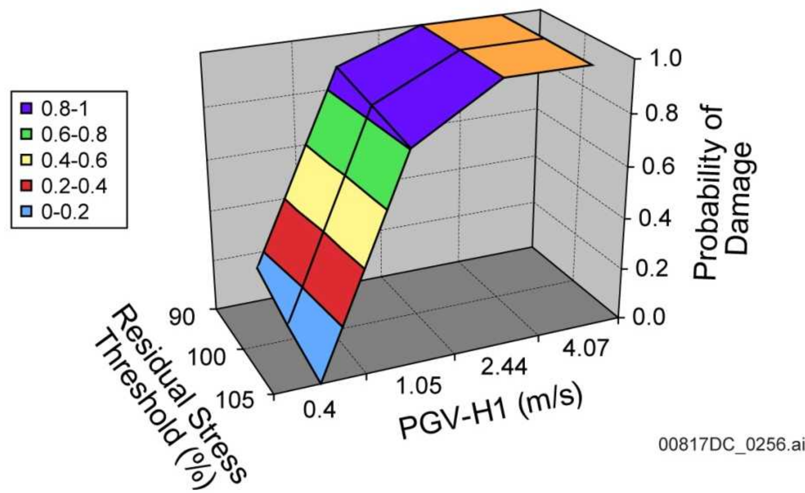
- **CSNF WP mean damage area for a 23-mm thick**
  - **0.00408 m^2 at PGV=4.07 m/s and RST=90% Y.S.**
  - **0.0 m^2 for all other data points**

EBS State 1 SCC Damage: (Intact DS, Degraded Internals)

- **Codisposal WP probability of SCC damage for a 17-mm thick**



- **CSNF WP probability of SCC damage for a 17-mm thick**



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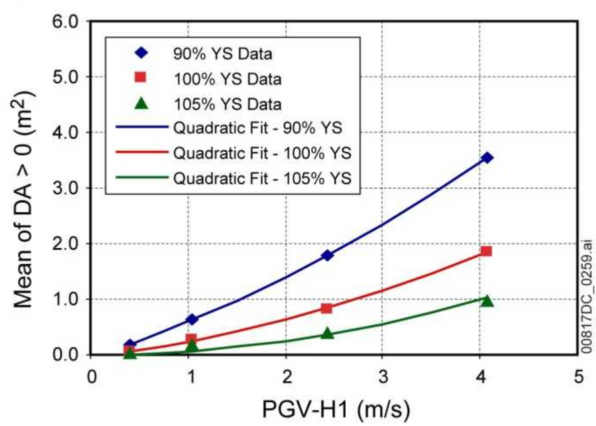
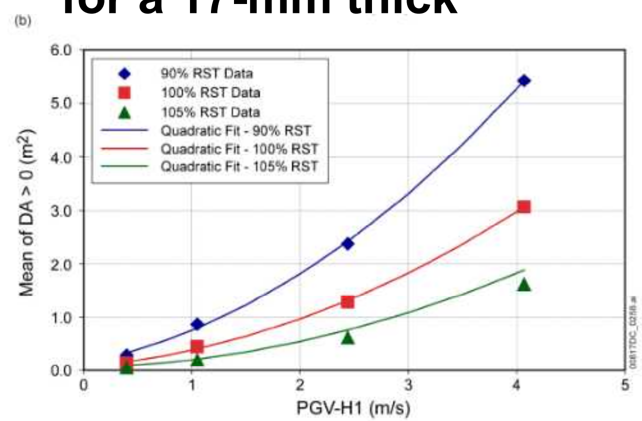


MDL-WIS-PA-000005, Figures 6.6-11 and 6.6-13

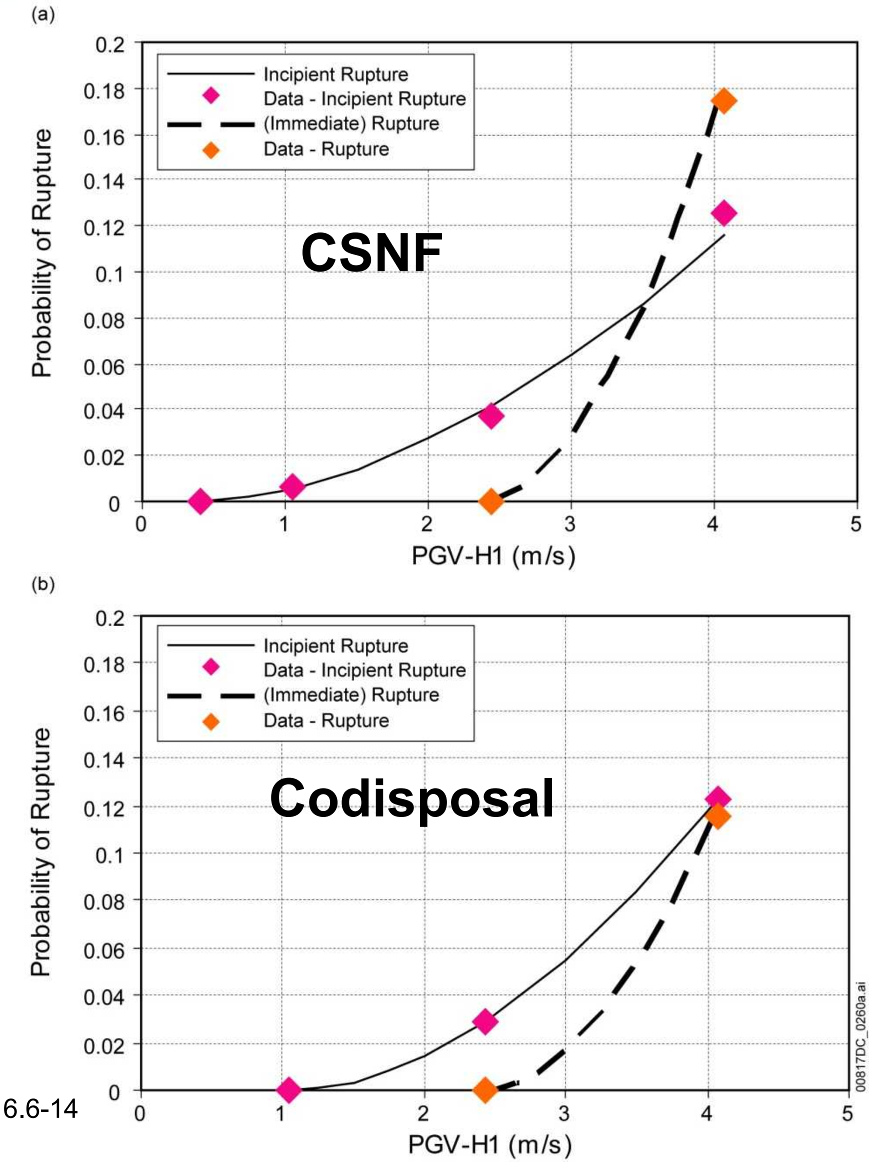
- **CSNF WP mean damage area for a 17-mm thick**



MDL-WIS-PA-000005, Figures 6.6-10 and 6.6-12

EBS State 1: WP Rupture
(Intact DS, Degraded Internals)

- **Probability of incipient and immediate rupture**
  - **incipient rupture requires a subsequent seismic event to cause damage**
  - **WP rupture allows advective releases**
- **Mean damage area is sampled uniformly**
  - **between 0 m^2 and the WP cross-sectional area 2.78 or 3.28 m^2**



MDL-WIS-PA-000005, Figure 6.6-14

Conceptual Model for EBS Evolution

State 1 | **State 2** | **State 3**

(a) Initial Configuration

Kinematic analyses and damage catalogs define damaged areas for a WP moving freely beneath the DS. WP SCC or rupture may occur, degrading internals

(b) After Drip Shield Framework Failure

Fragility analysis for buckling of DS framework. Additional WP damage may occur.

(c) After Drip Shield Plate Failure

Fragility analysis for rupture of DS plates. WP damage defined by 2-D calcs for WP surrounded by rubble

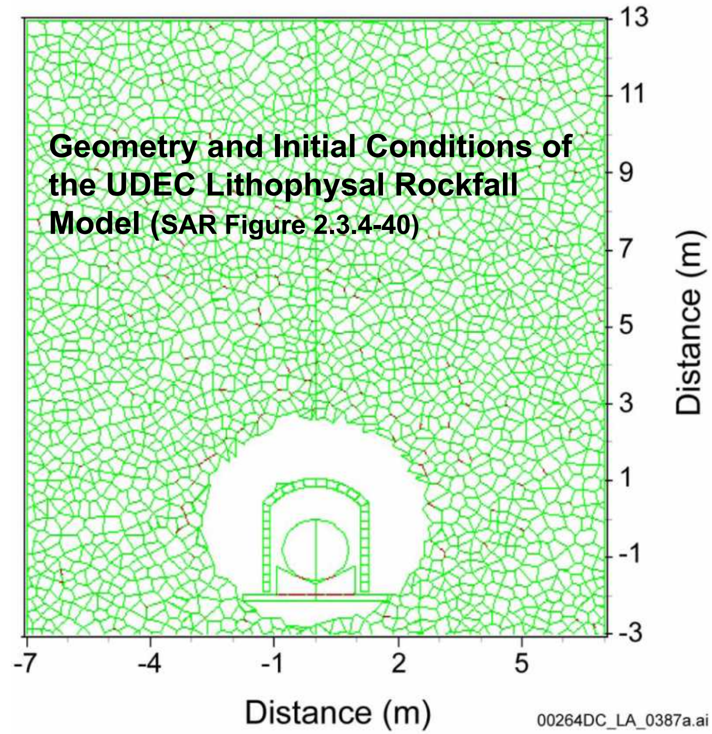
MDL-WIS-PA-000005, Figure 6.6-5

DS Failure

Time

EBS Evolution State 2: Rubble Accumulation

- **Probability of lithophysal rubble accumulation from a seismic event is based on UDEC distinct-element computational results for 15 ground motions and 3 PGV levels (0.4 m/s, 1.05 m/s, and 2.44 m/s)**
- **Rock compressive strength is an uncertain parameter represented by 5 rock strength categories**



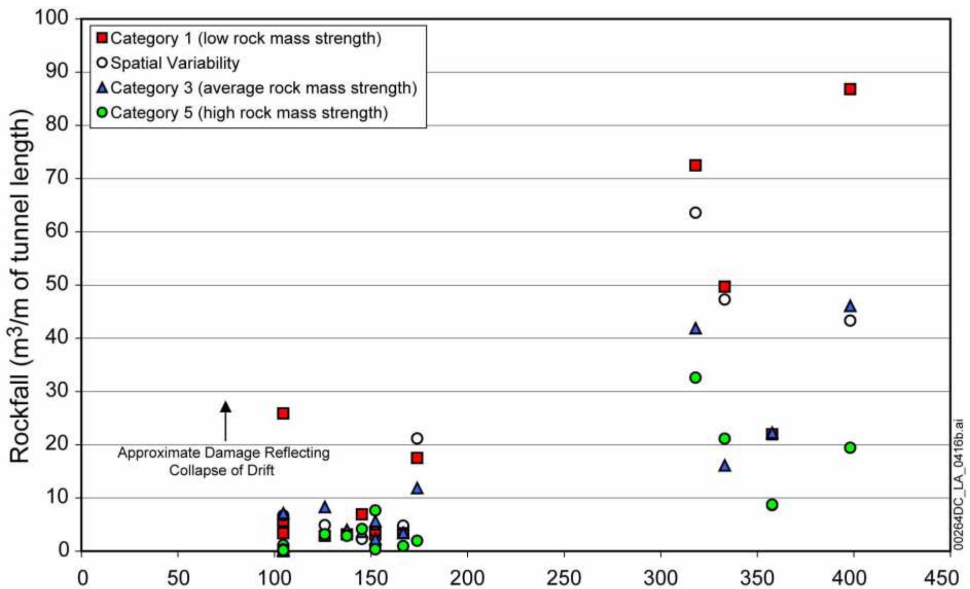


Figure 2.3.4-41. Estimated Lithophysal Rock Damage Level for All 10^{-5} Ground Motion Time Histories, Expressed as m^3/m of Emplacement Drift Length for Rock Strength Categories 1, 3, and 5

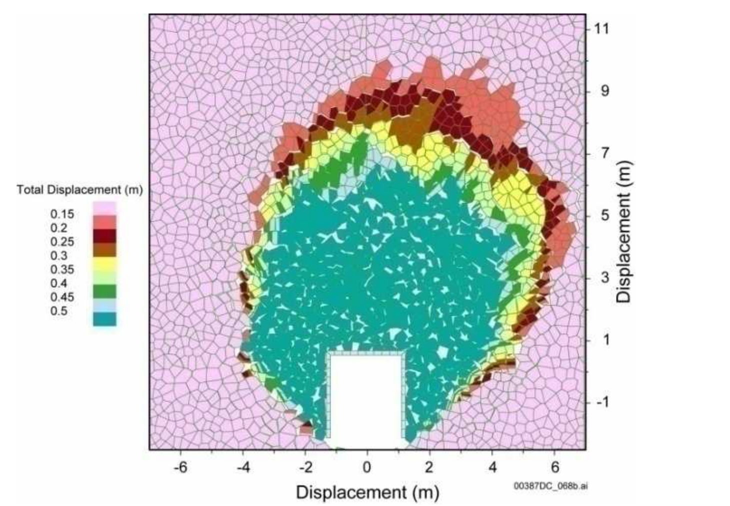
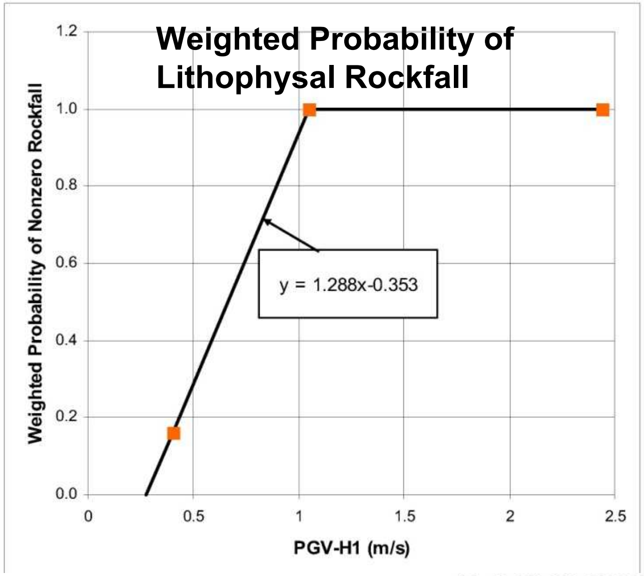
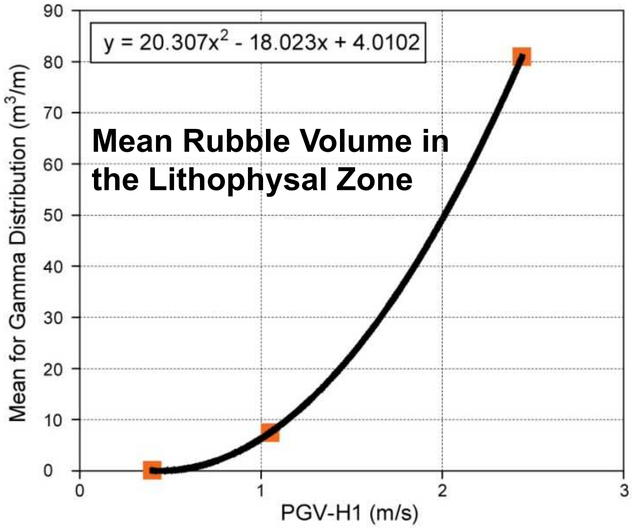
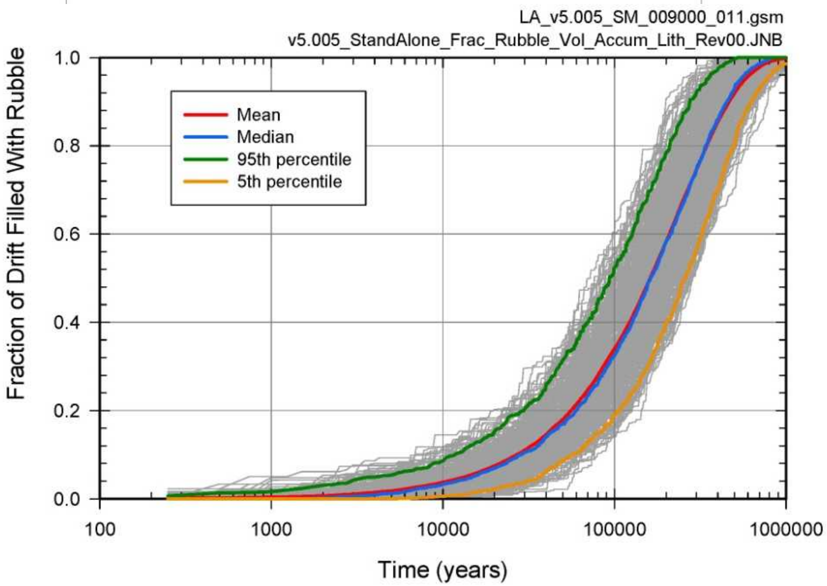


Figure 2.3.4-42. Typical Geometry of the Emplacement Drift in Lithophysal Rock after Simulations for Postclosure Ground Motions with Annual Exceedance Probability of 10^{-6}

Rubble Accumulation Abstraction and TSPA Results







- **Rubble from multiple events is defined as the sum of the volumes from individual events until the drift is full**
- **Volume of rubble that fills the drift is an epistemic parameter [U(30,120) m^3/m]**
- **DS fragility abstractions are based on lithophysal rubble volume**
- **Abstractions for nonlithophysal rockfall are developed for use in the seepage abstraction**

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(b) After Drip Shield Framework Failure

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Fragility analysis for rupture of DS plates. WP damage defined by 2-D calcs for WP surrounded by rubble

MDL-WIS-PA-000005, Figure 6.6-5

DS Failure

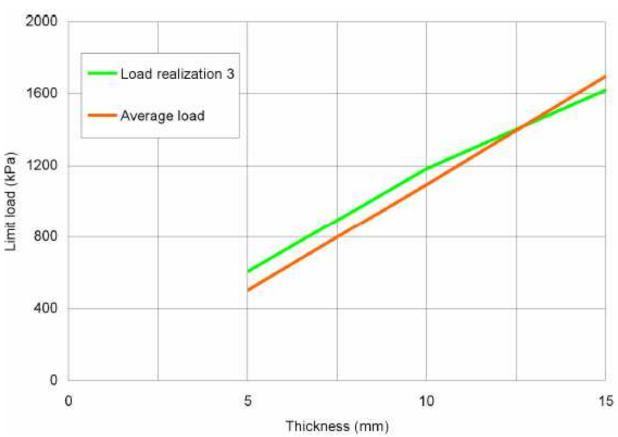
Time

EBS Evolution States 2 & 3: DS Fragility Analysis

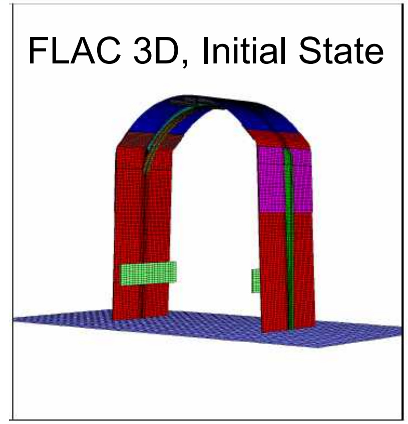
- **Key parameters for fragility analysis**
  - **Vertical component of PGA (peak ground acceleration) from a seismic event**
  - **Static load of rubble on the crown of the DS**
    - **based on lithophysal rubble**
  - **Plastic load capacity of the DS framework or plates**
- **Fragility analysis based on dynamic vertical load on DS (framework or plates)**
  - **static load from rubble plus the vertical component of PGA**
- **Failure occurs when the dynamic vertical load exceeds the plastic load capacity for a given thickness**

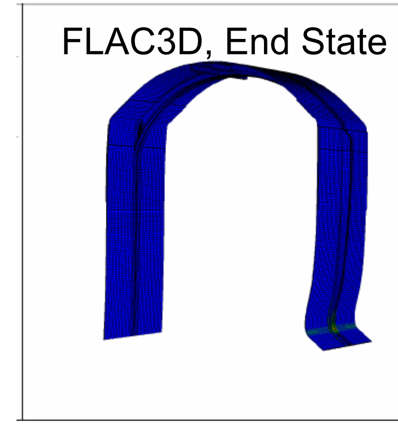
EBS Evolution State 2: DS Framework Collapse

- **Framework failure mode is buckling of the DS legs under combined load of vibratory ground motion and rock rubble**
  - **FLAC3D, 3-D finite-element, quasi-static calculations (basis of abstraction)**
  - **UDEC, 2-D distinct-element, coupled DS-rubble dynamic confirmatory calculations ("snap-through" mode eliminated)**
- **Load-bearing capacity of the DS framework with intact plates defined by FLAC3D finite-element calculations**
  - **2 non-uniform load patterns**



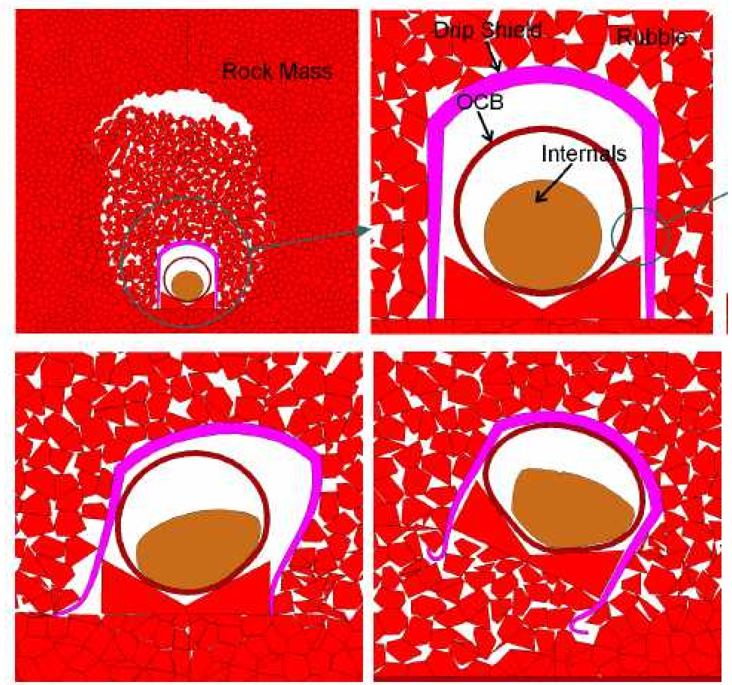
MDL-WIS-AC-000001, Rev00, Figure s 6-49, 6-55, 6-57, 6-58, and 6-63





UDEC, Initial State

UDEC, End State



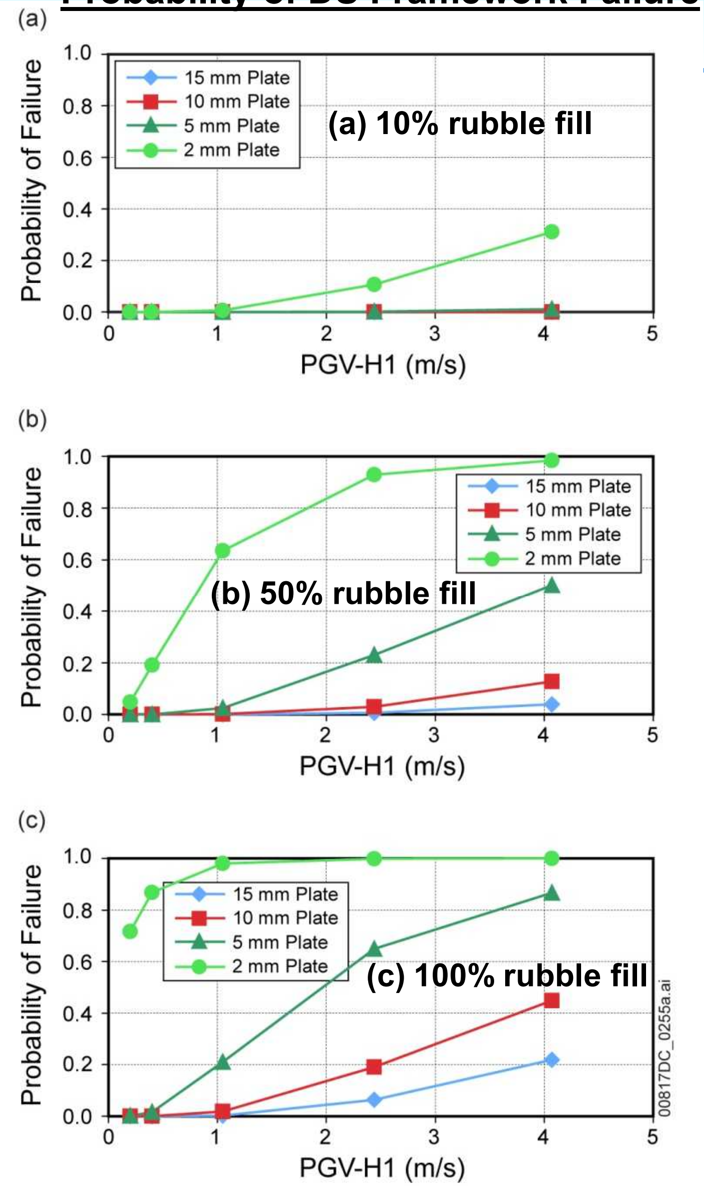
PGV 2.44 m/s; case 13

PGV 4.07 m/s; case 13

EBS Evolution State 2:
DS Framework Collapse (continued)

- **Failure of the DS framework prevents kinematic motion of the waste packages (always occurs before plate failure)**
- **Response surface for the probability of DS framework failure:**
  - **PGV levels of 0.2, 0.4, 1.05, 2.44, and 4.07 m/s**
  - **thickness reductions of 0, 5, 10, 13 mm for plates and structural elements of framework**
  - **Static rubble loads for drifts that are 10%, 50%, and 100% filled with lithophysal rubble**
- **DS is still a barrier to seepage**

Probability of DS Framework Failure



MDL-WIS-PA-000005, Figure 6.6-9

EBS State 2 Waste Package SCC Damage:
(DS Framework Failure, Degraded WP Internals)

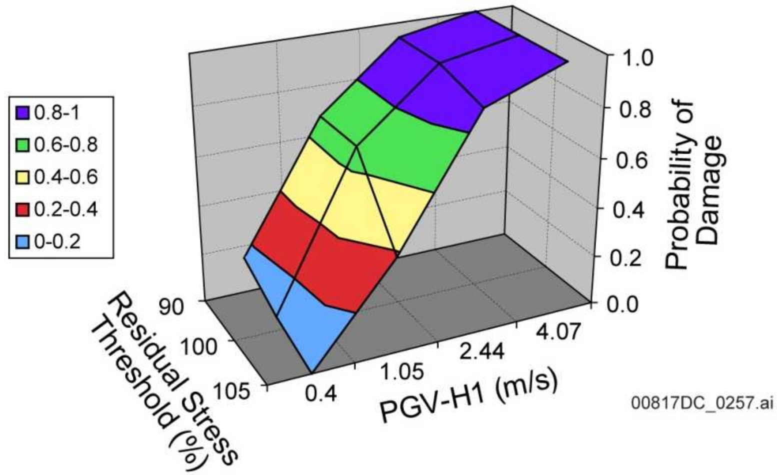
- **Use a bounding (conservative) approach for calculating WP damage, i.e., use damage response surfaces developed for some of the other eight states (combinations) of DS and WP damage:**

  1. **Failed DS framework, WP internals not degraded: use WP damage abstraction for WP surrounded by rubble (i.e., failed DS plates), as described later in this presentation**
  2. **Failed DS framework, WP internals are degraded: use WP damage abstraction for a WP under an intact DS with degraded internals (previously shown in this presentation)**

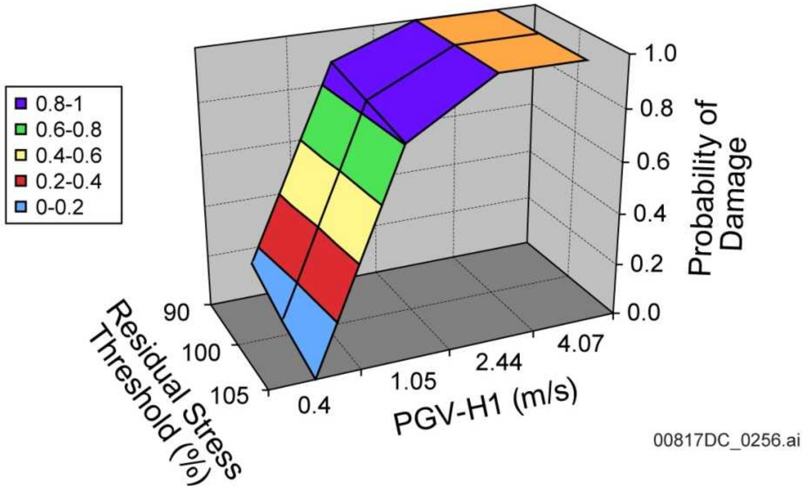
EBS State 2 WP SCC Damage:

(DS Framework Failure, Degraded WP Internals—same as for intact DS, degraded WP internals)

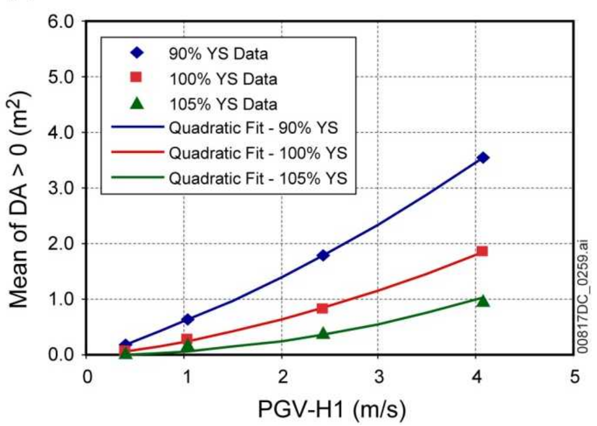
- **Codisposal WP probability of SCC damage for a 17-mm thick**



- **CSNF WP probability of SCC damage for a 17-mm thick**

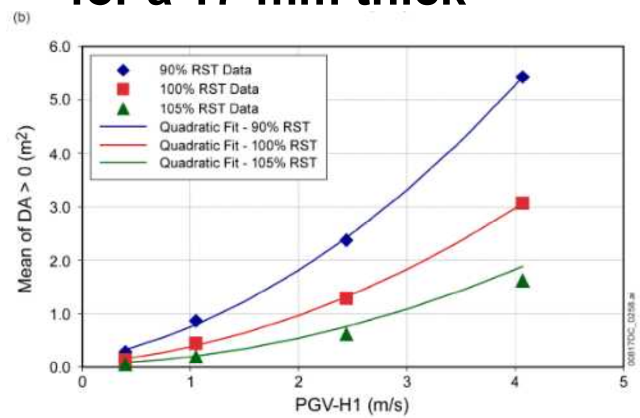


- **Codisposal WP mean damage area for a 17-mm thick**



MDL-WIS-PA-000005, Figures 6.6-11 and 6.6-13

- **CSNF WP mean damage area for a 17-mm thick**



MDL-WIS-PA-000005, Figures 6.6-10 and 6.6-12

Conceptual Model for EBS Evolution

State 1 | **State 2** | **State 3**

(a) Initial Configuration

(b) After Drip Shield Framework Failure

(c) After Drip Shield Plate Failure

Kinematic analyses and damage catalogs define damaged areas for a WP moving freely beneath the DS. WP SCC or rupture may occur, degrading internals

Fragility analysis for buckling of DS framework. Additional WP damage may occur.

Fragility analysis for rupture of DS plates. WP damage defined by 2-D calcs for WP surrounded by rubble

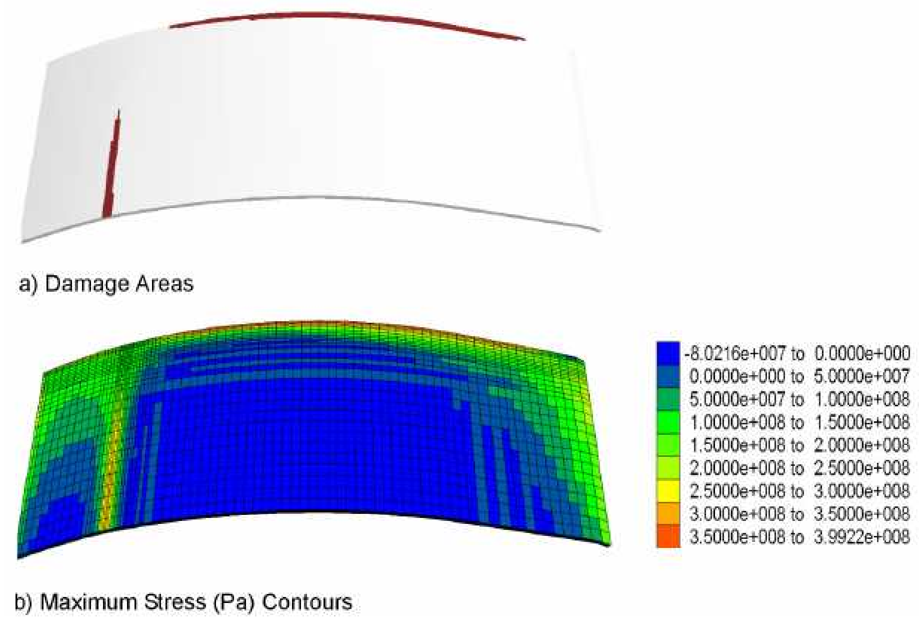
DS Failure

MDL-WIS-PA-000005, Figure 6.6-5

Time

EBS Evolution State 3: Drip Shield Plate Rupture

- **Load-bearing capacity of the DS plates defined by FLAC3D finite-element calculations**
  - **define the magnitude of a uniform load that causes an element of the plate to exceed the ultimate tensile strain of Ti Grade 7**
- **Range of potential boundary conditions represented by two extremes**
  - **Case 1: a plate that is fixed to maximize the load-bearing capacity**
  - **Case 2: a plate that is free to move laterally which minimizes the load-bearing capacity**



Output DTN: MO0701DRIPSHLD.000, file *\case2\10mm\plate-1.6200e+006.sav.*

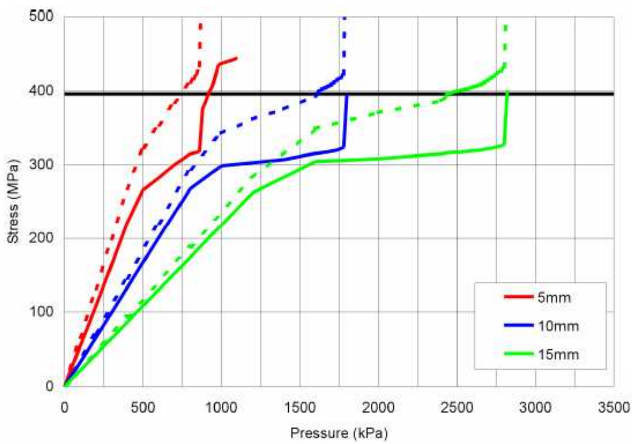
NOTES: The damage area is the inner or outer surface of the drip shield plate with maximum stress greater than 80% of the yield strength of Titanium Grade 7. Damage area is shown in brown color. Compressive stresses are negative.

Figure 6-40. Damage Areas and Maximum Stress Contours in the 10-mm-Thick Drip Shield Plate for Case 2 Boundary Conditions and a Pressure of 1,620 kPa

MDL-WIS-AC-000001, Rev00, Figure 6-40

M-M-C Coupling: EBS State 3:
Drip Shield Plate Rupture

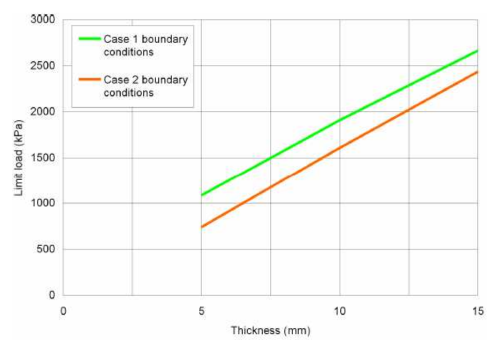
- **Failure of the DS plate results in complete failure as a barrier to flow**
- **Response surface for probability of DS plate failure:**
  - **PGV levels of 0.2, 0.4, 1.05, 2.44, and 4.07 m/s**
  - **plate thicknesses of 2 mm, 5mm 10 mm, and 15 mm**
  - **static rubble loads for drifts that area 10%, 50%, and 100% filled with lithophysal rubble**



Output DTN: MO0701DRIPSHLD.000, file *\drip shield plate fragility\summary\summary 3d free laterally7.xls*, sheet "ch plate 3d stress."

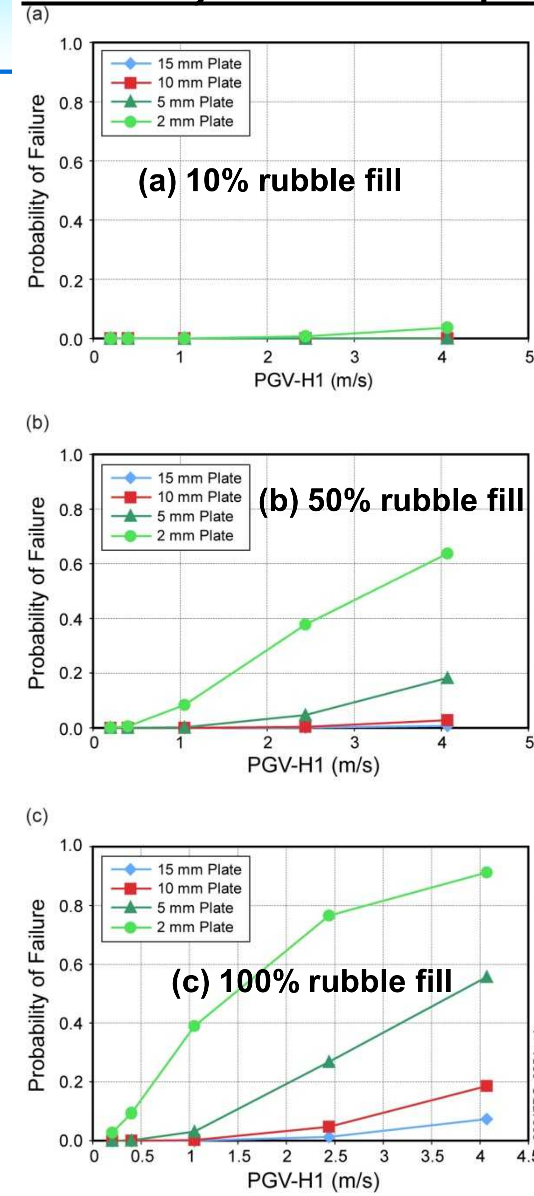
NOTE: Ultimate stress is indicated by the solid horizontal black line. Maximum principal stress is shown by the dashed lines; maximum stress difference is shown by the solid lines.

Figure 6-47. Maximum Principal Stress and Maximum Stress Difference in the Drip Shield Plate as Function of Load: Case 2 Boundary Conditions



MDL-WIS-AC-000001, Rev00, Figure s 6-47 and 6-48

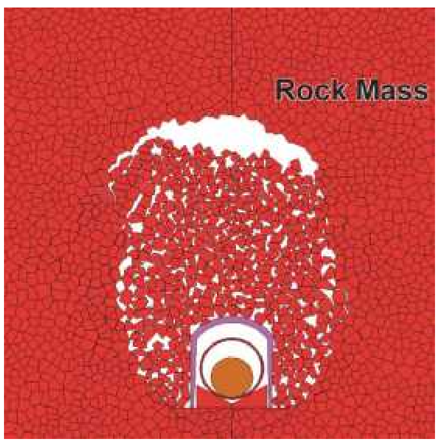
Probability of DS Plate Rupture

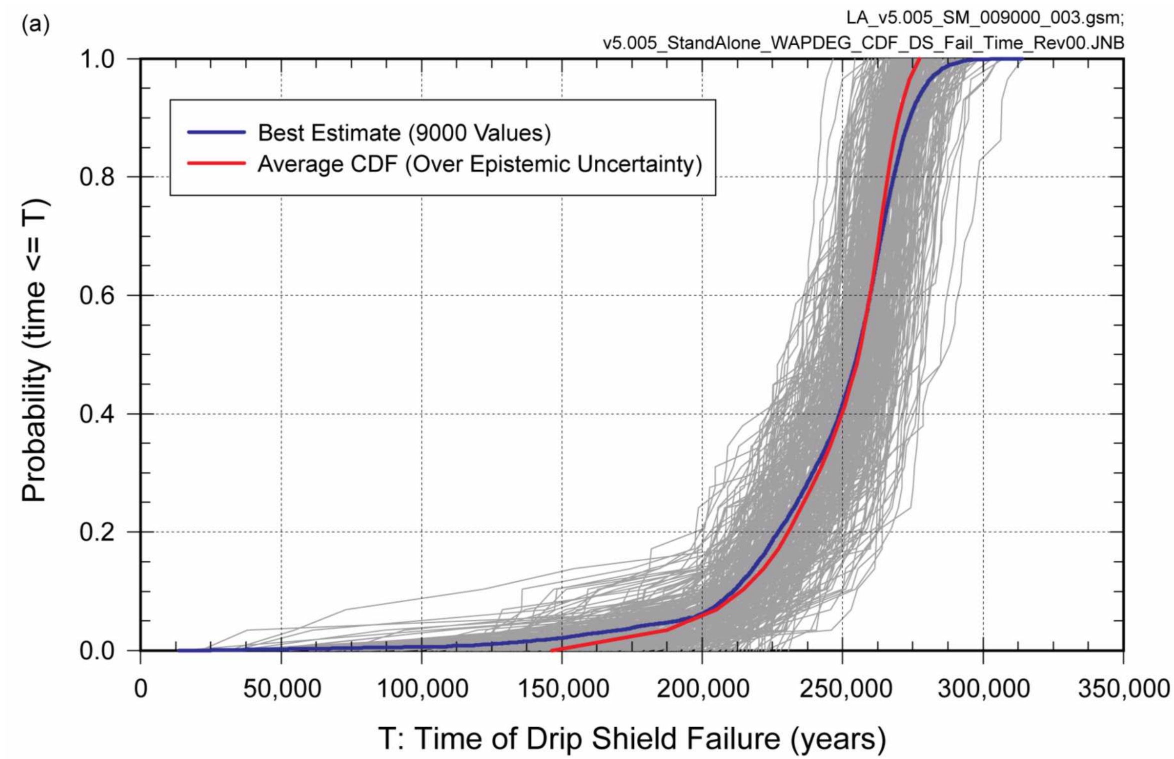


MDL-WIS-PA-000005, Figure 6.6-8

EBS State 3 Summary: Seismic DS Plate Rupture Results

- **Drip shield failure caused by strong seismic ground motion includes the effect of (1) rubble accumulation (M-M), i.e., static load combined with the dynamic seismic load and (2) plate thinning by titanium general corrosion processes (M-C)**

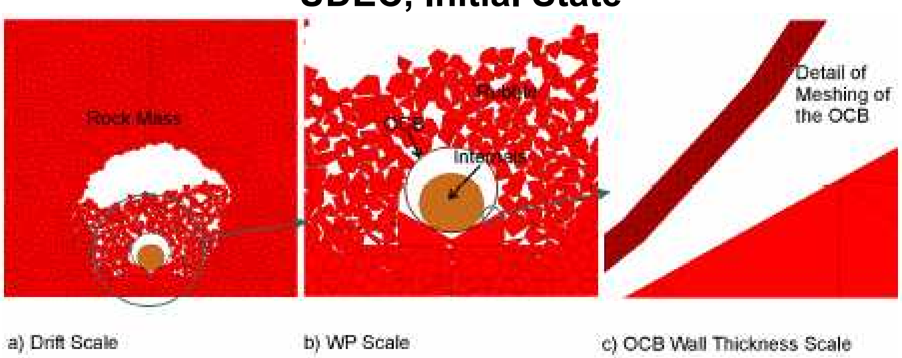




EBS State 3 Waste Package SCC Damage: M-M-T-C Coupling
(Failed Drip Shield, WP surrounded by rubble, <u>Degraded</u> WP Internals)

- **Waste package failure mode is when the residual stress exceeds an uncertain fraction (0.9 to 1.05) of the Alloy 22 yield strength**
  - **UDEC distinct element, 2-D rubble-WP coupled calculations**
- **Range of ground motion histories, rock patterns, and horizontal PGVs**
  - **17 possible ground motion time histories combined randomly with 17 possible rock joint patterns**
  - **PGV = 0.4 m/s, 1.05 m/s, 2.44 m/s, 4.07 m/s**

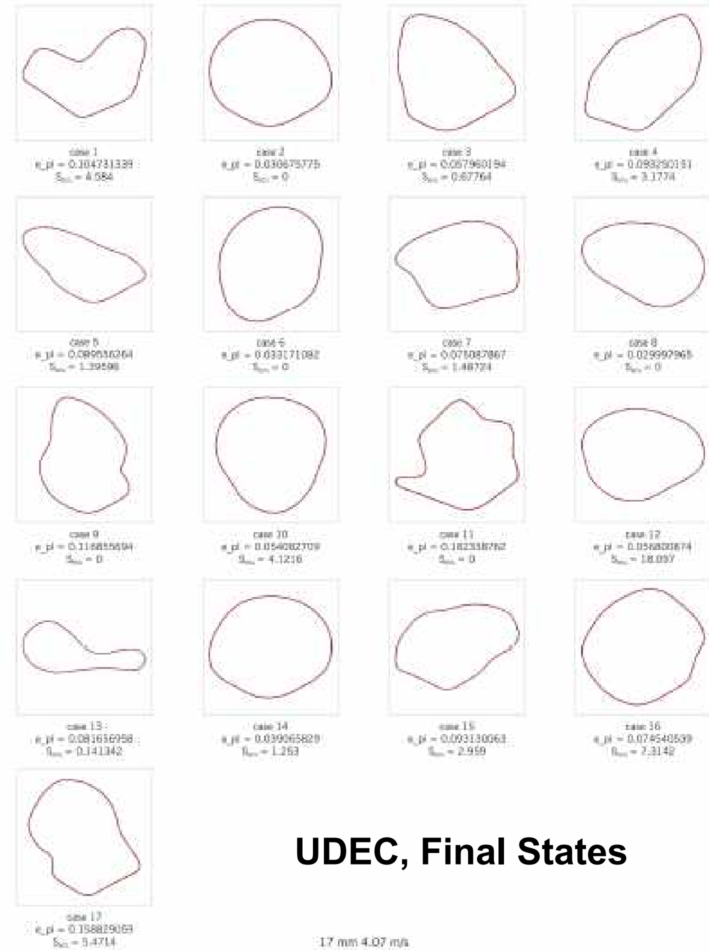
UDEC, Initial State



Source: Created for illustrative purposes only.

NOTE: WP = waste package.

Figure 6-78. Geometrical Representation Used in the Analysis of the Mechanical Interaction between the Waste Package and the Rubble During Seismic Ground Motions

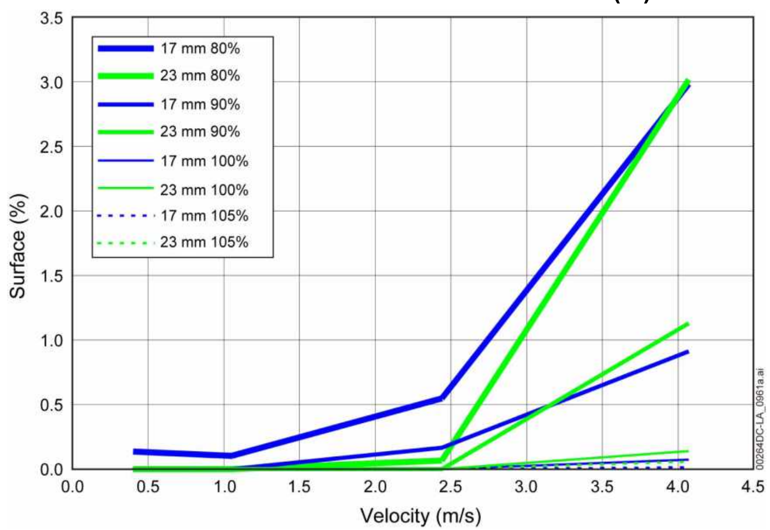


Output DTN: MO0704PUNCTURE.000, file *17mm407msC.pcx*.

Figure 6-86. Deformed Shapes, Maximum Effective Plastic Strains and Percent of Surface Area with Residual Principal Tensile Stress Greater Than 80% of the Yield Strength for 17-mm-Thick OCB at the 4.07 m/s PGV Level

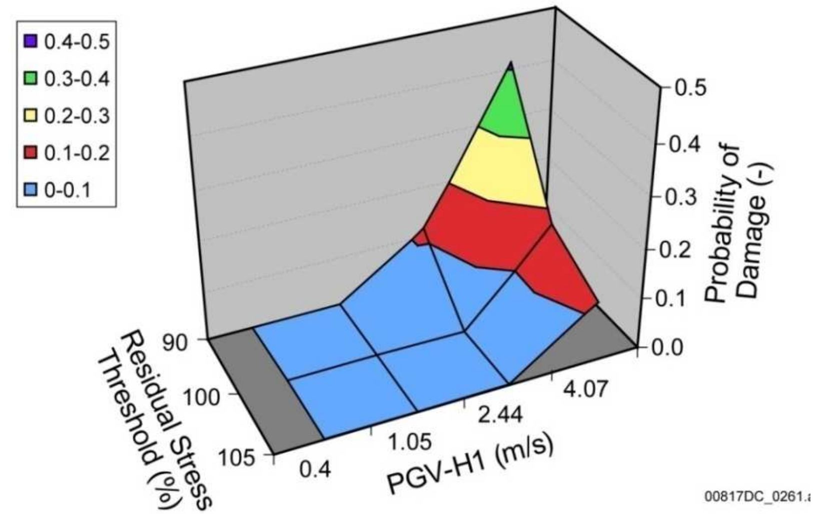
M-M-T-C Coupling, EBS State 3: Seismic Waste Package Crack Damage: Failed Drip Shield, Degraded WP Internals

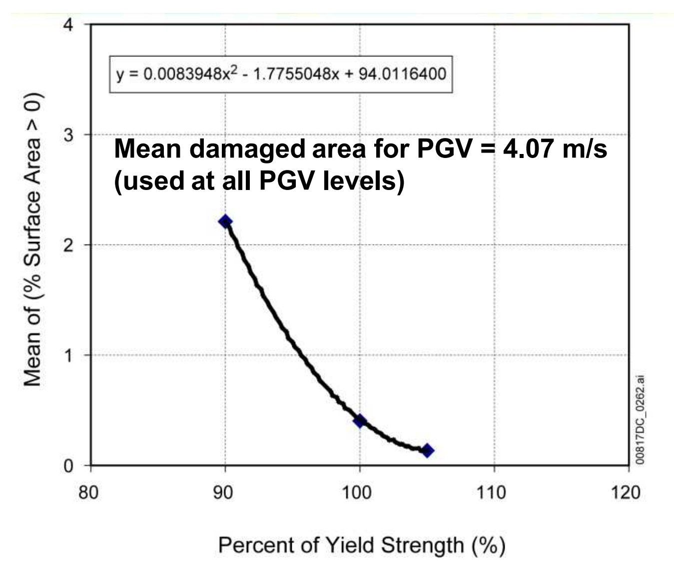
Percent surface area damaged vs. PGV as a function of residual stress threshold (%)



Stress Threshold	Thickness (mm)	PGV Level (m/s) 0.4	1.05	2.44	4.07
80% σ_y	17	1.37×10^{-1}	1.04×10^{-1}	5.46×10^{-1}	2.98
	23	0.00	0.00	6.64×10^{-2}	3.01
90% σ_y	17	0.00	0.00	1.64×10^{-1}	9.12×10^{-1}
	23	0.00	0.00	0.00	1.13
100% σ_y	17	0.00	0.00	0.00	7.21×10^{-2}
	23	0.00	0.00	0.00	1.39×10^{-1}
105% σ_y	17	0.00	0.00	0.00	1.60×10^{-2}
	23	0.00	0.00	0.00	5.95×10^{-2}

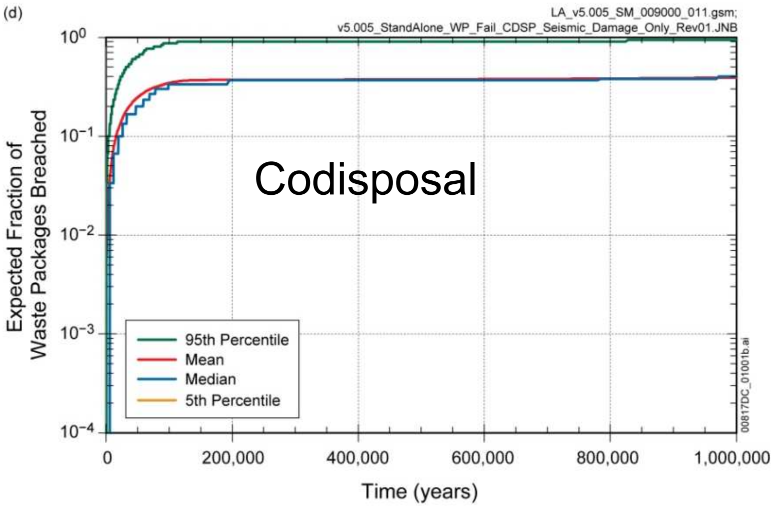
- **<u>TSPA abstraction</u> for probability of damage (top) and mean damage area (bottom) for a 17-mm thick CSNF (or CDSP) waste package surrounded by rubble under a failed drip shield:**



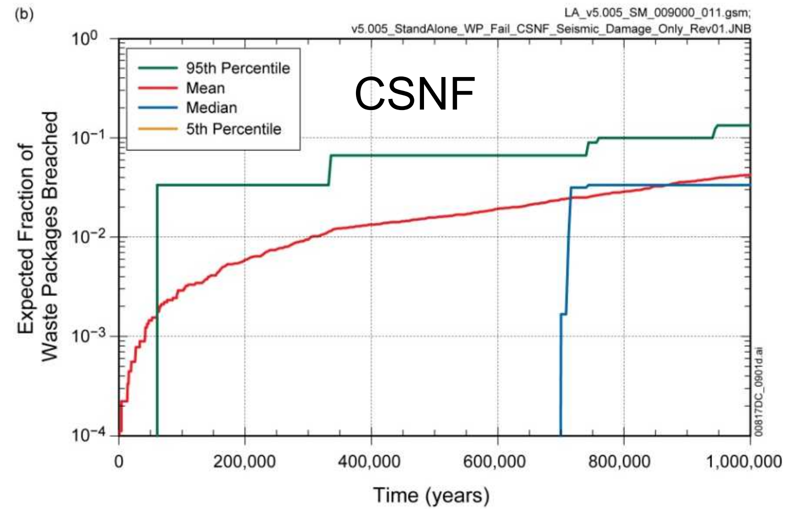


M-M-T-C Coupling, All EBS States: Expected Fraction of Breached Waste Packages by Nominal & Seismic Processes

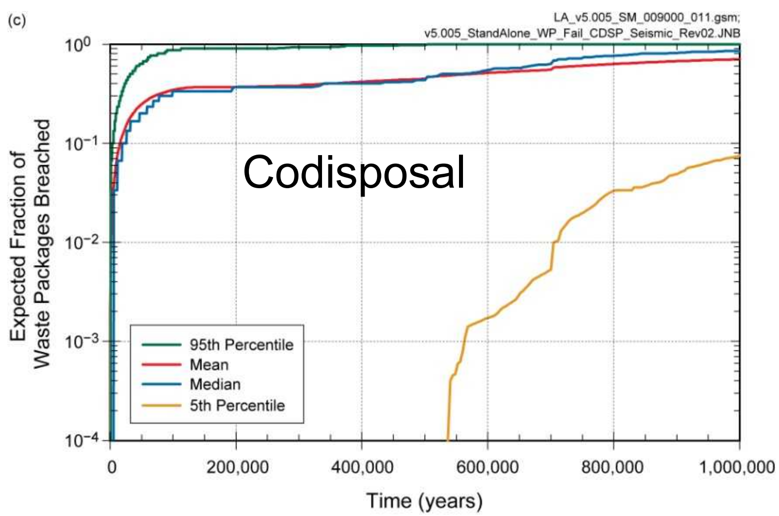
- **By seismic processes only**



- **By seismic processes only**

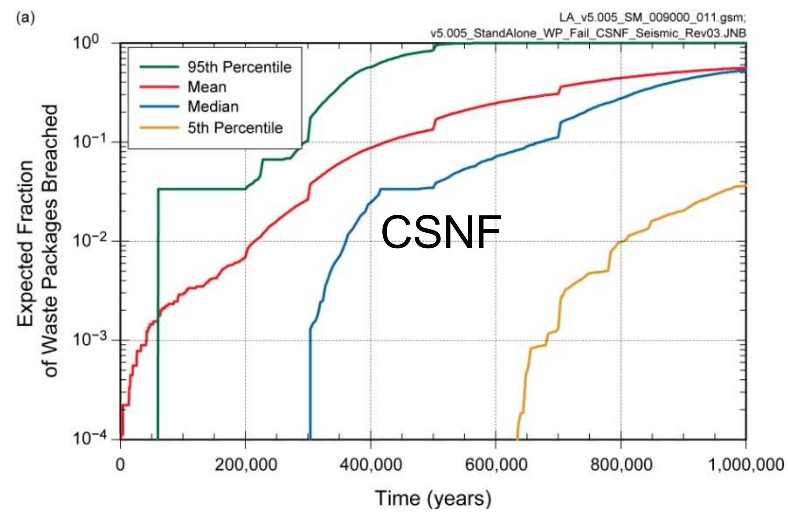


- **By seismic and nominal processes**



MDL-WIS-PA-000005, Figure 8.3-8(c and d)[a]

- **By seismic and nominal processes**

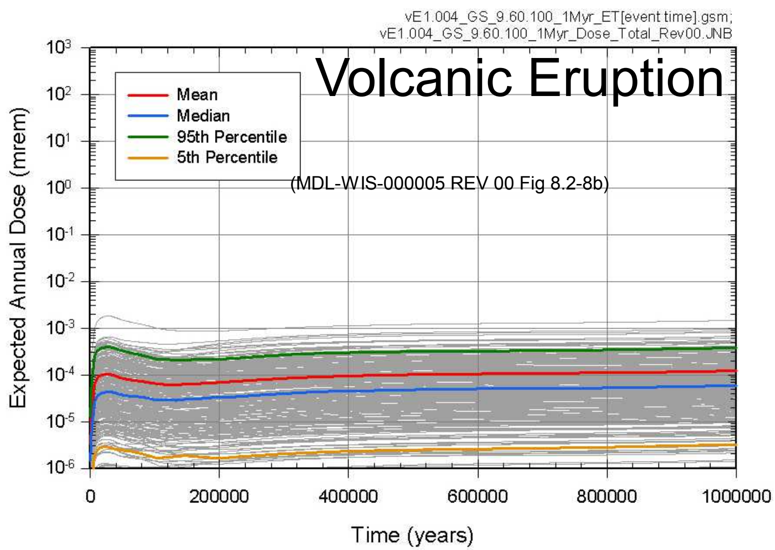


MDL-WIS-PA-000005, Figure 8.3-8(a and b)[a]

Key Processes for Seismic Ground Motion Case

- **Nominal corrosion processes included for million-year analyses, and they affect the EBS response:**
  - Damage analyses consider thinning of Alloy 22 and titanium
  - Nominal SCC in the closure lid welds allows corrosion of internal steel components
- **Drip shield thins by general corrosion and fails due to dynamic loading of accumulated rockfall**
- **Ground motions result in stress corrosion cracking (SCC) of the waste packages that allow diffusive releases:**
  - Frequency of events that damage codisposal (CDSP) packages: ~ 10^{-5} / yr
  - Frequency of events that damage transportation, aging, and disposal (TAD) packages for commercial spent nuclear fuel (CSNF): ~ 10^{-8} / yr
- **Cracked area accumulates with additional seismic events**

Effect of Seismicity on Total Dose to RMEI



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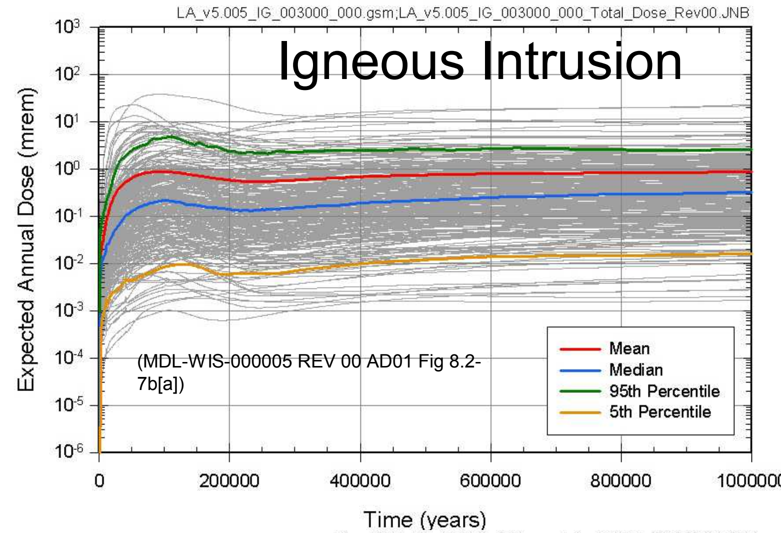

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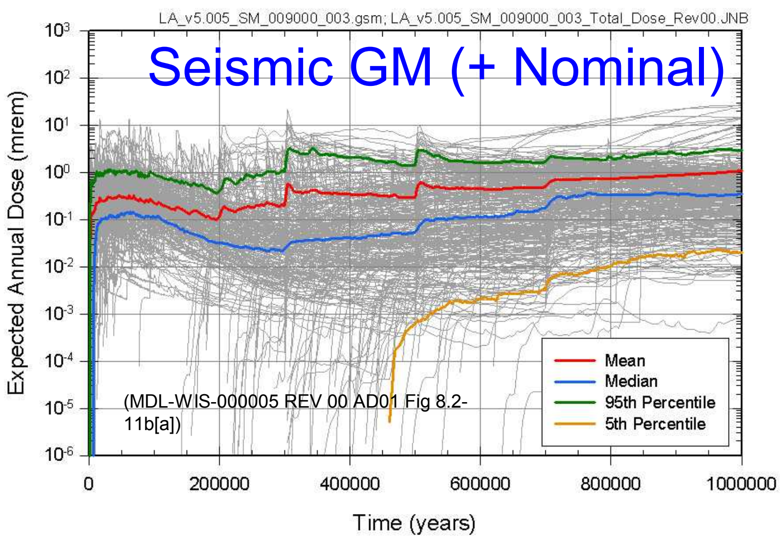

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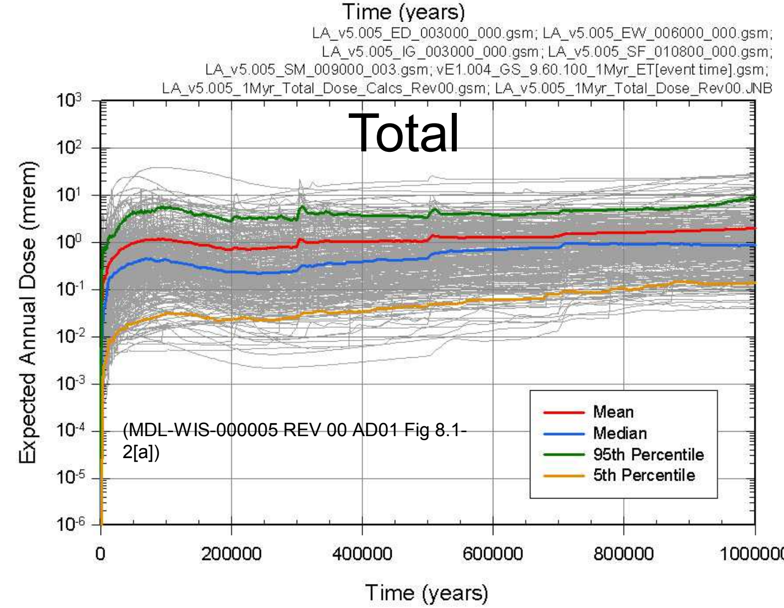
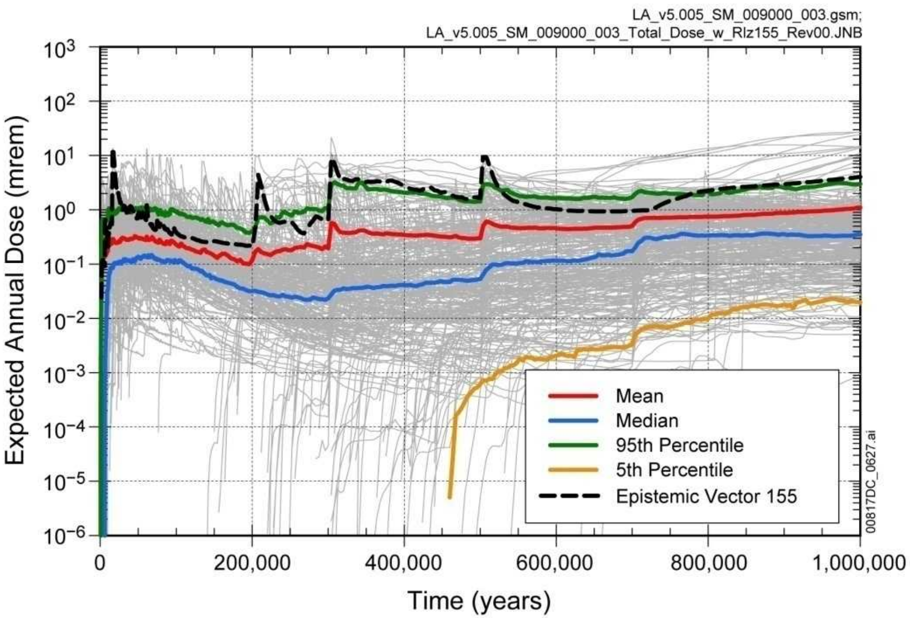
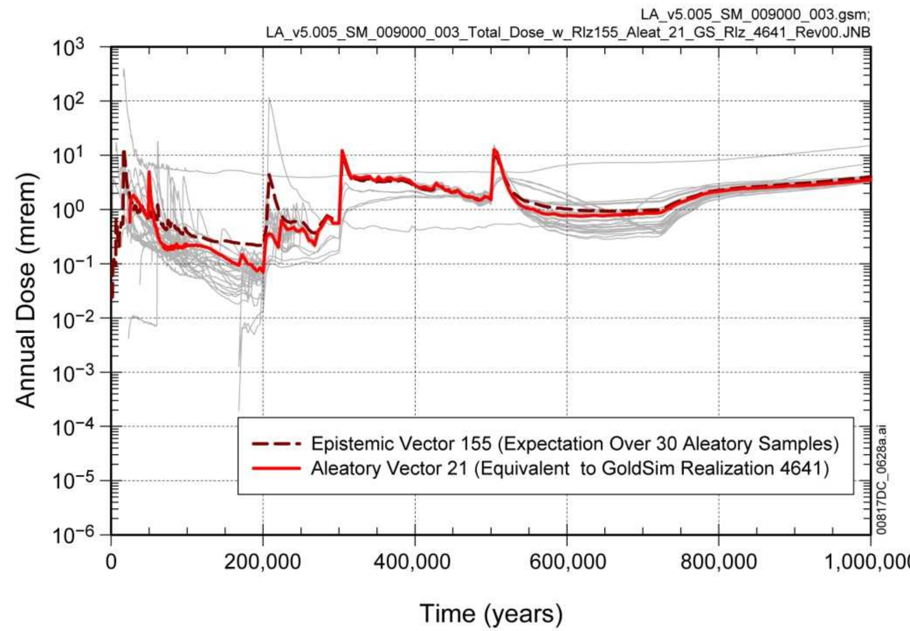
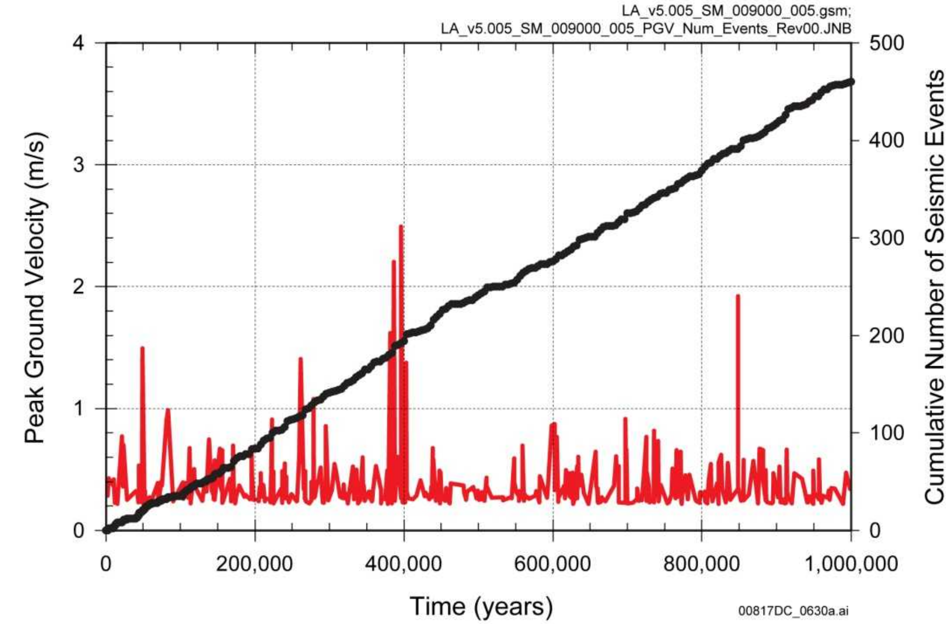


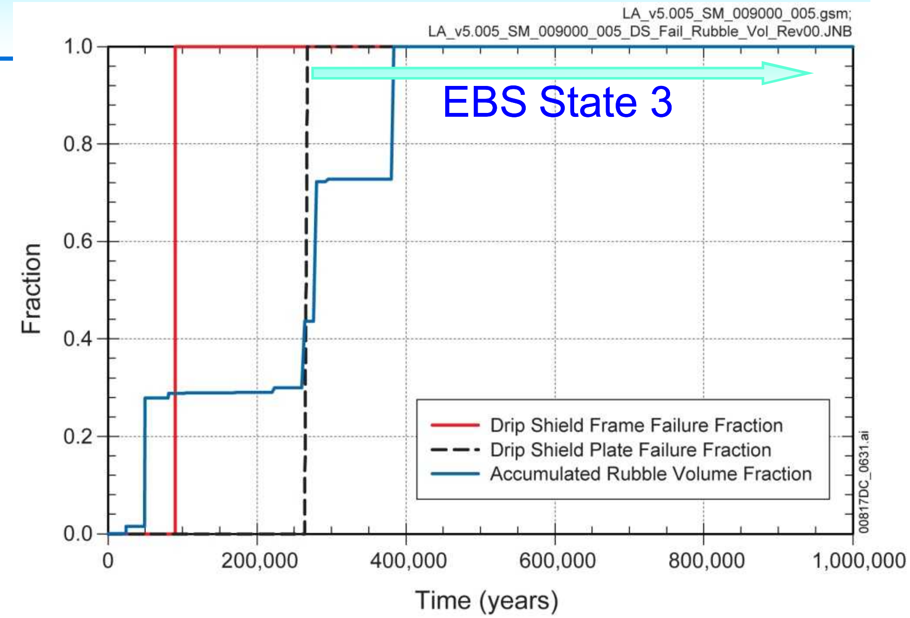
Single Realization Analysis of Seismic Ground Motion Modeling Case – 1,000,000 years

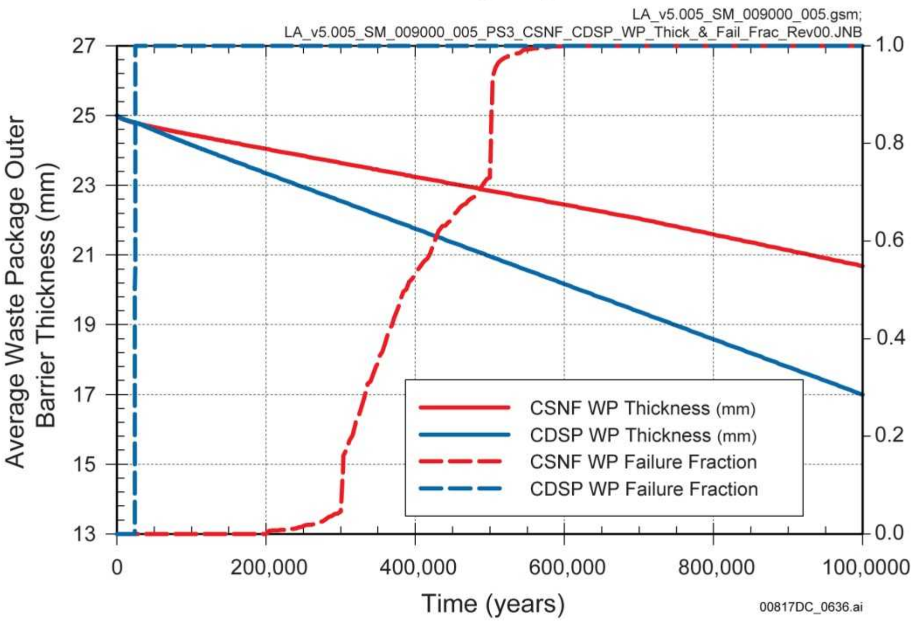


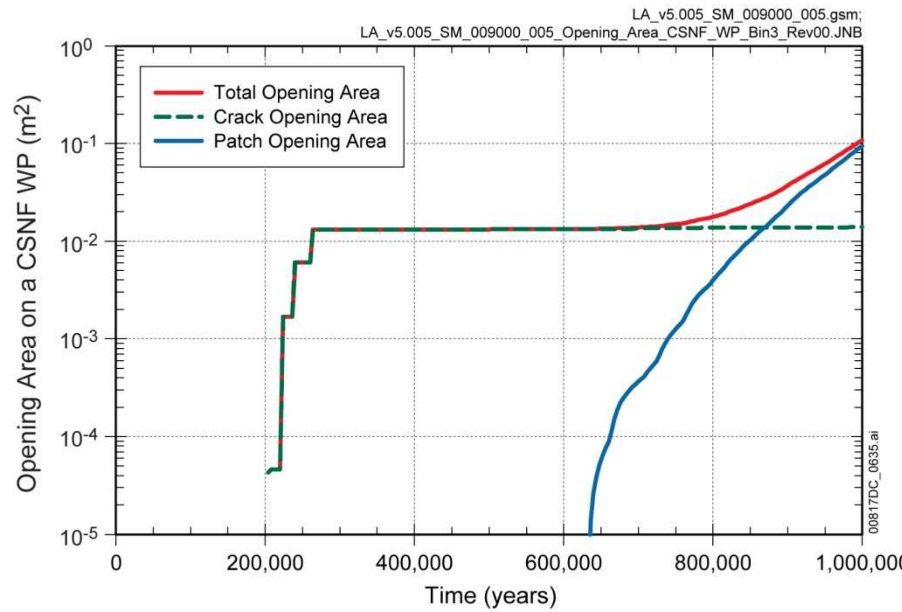


Analysis of Single Realization 4641





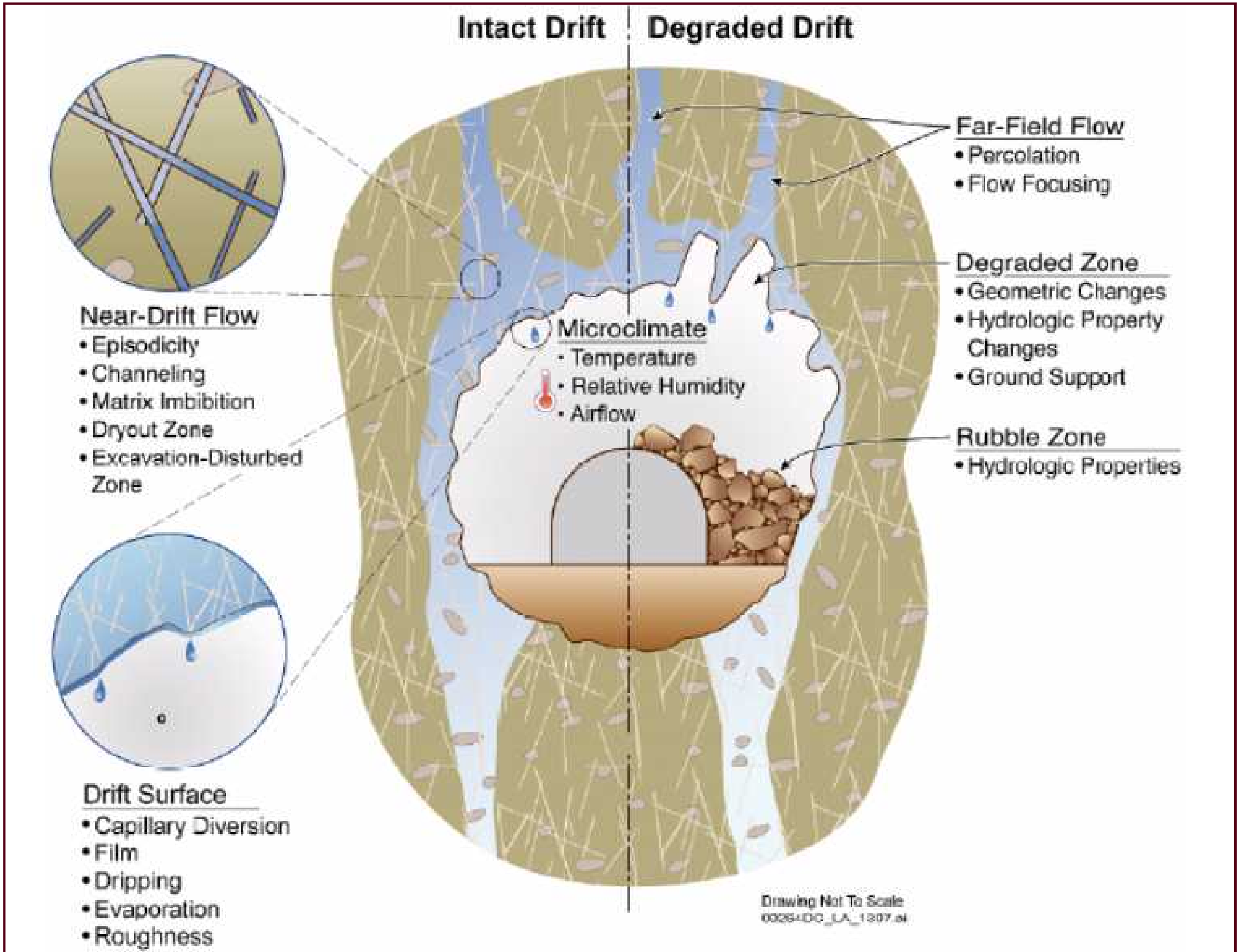




Other Coupled Processes for Seismic Scenario Class

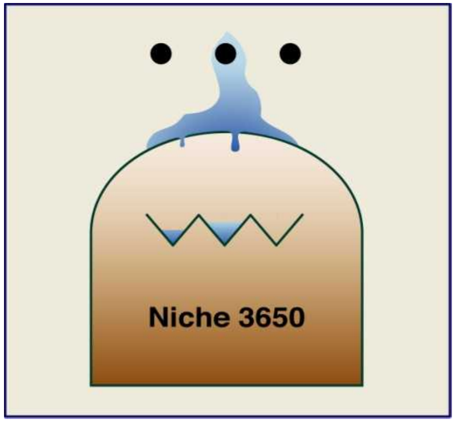
- **Seepage**
  - Seepage flux is interpolated between the intact-drift seepage flux and the fully collapsed seepage flux as a function of rubble accumulation in lithophysal zones
  - Separate calculations of rubble (rockfall) accumulation for lithophysal and nonlithophysal zones
  - Collapsed-drift seepage fractions are used for the entire simulation but different seepage fractions are applicable for the first 10,000 years versus the post-10,000-year period
- **EBS Environment**
  - WP temperature and WP relative humidity are changed after the drift fills with rubble (small effect because rubble accumulation is slow)
- **EBS Flow and Transport**
  - The WP damage area fraction (sum of seismic damage and corrosion damage) is an input to the diffusive transport and the water flux calculations of the EBS Transport submodel

Processes Potentially Affecting Long-Term Seepage



Definitions

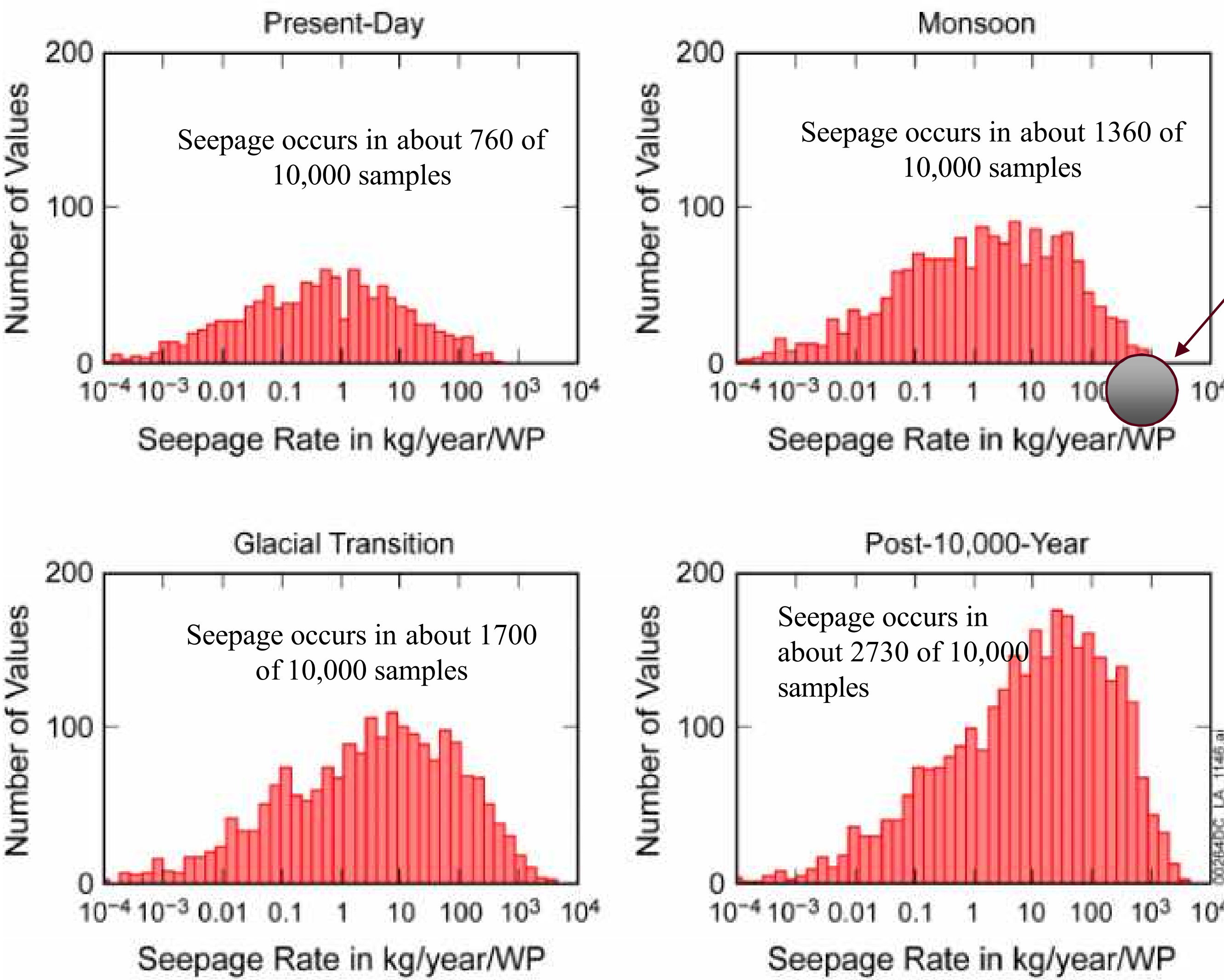
- Seepage: dripping of liquid water from the formation into an underground opening (<< percolation flux)



- Seepage rate: mass of seepage water per time, given for drift section containing one waste package
- Seepage percentage: ratio of seepage rate divided by percolation flux across drift footprint
- Seepage fraction: fraction of waste packages affected by seepage

Range of Seepage Rates for Intact Drifts

Intact Drift in Tptpll, 10th Percentile Infiltration Scenario

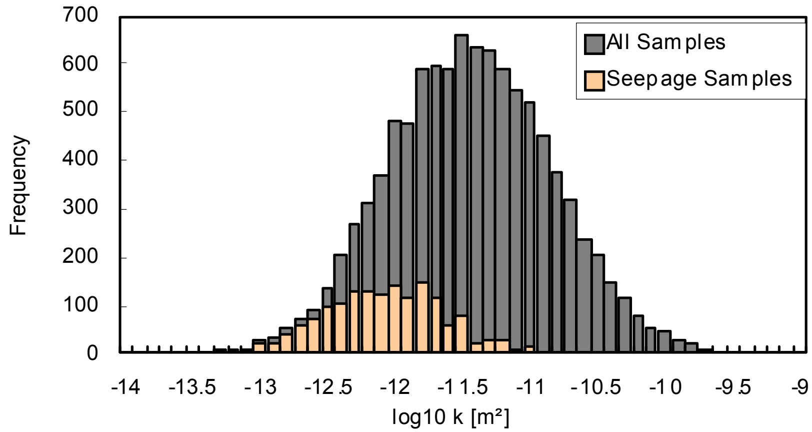


100 kg/yr per waste package is roughly 1 drop of water every minute

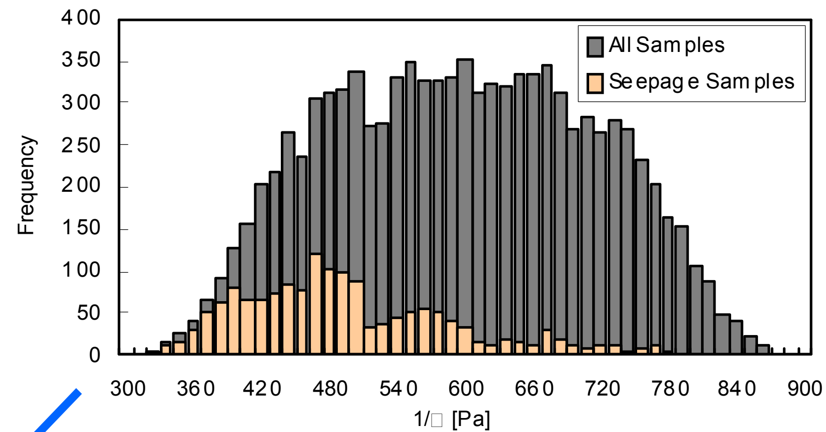
Source of Seepage Plots: MDL-NBS-HS-000019 REV 01 Figures 6-10[a]

Effect of Rock Characteristics and Liquid Flux

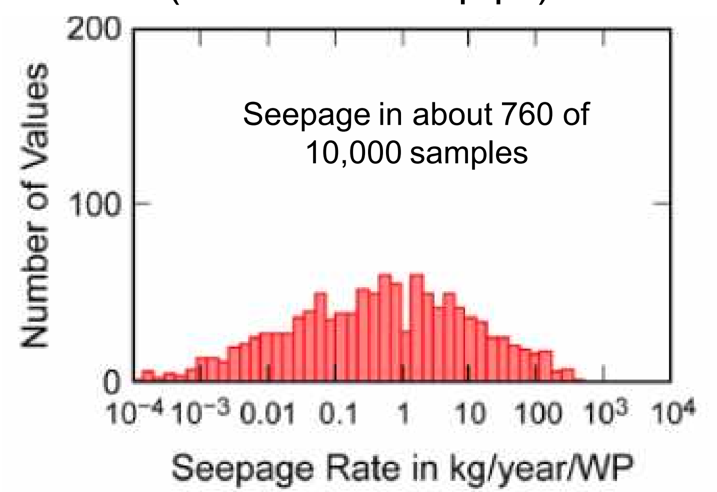
Fracture Permeability



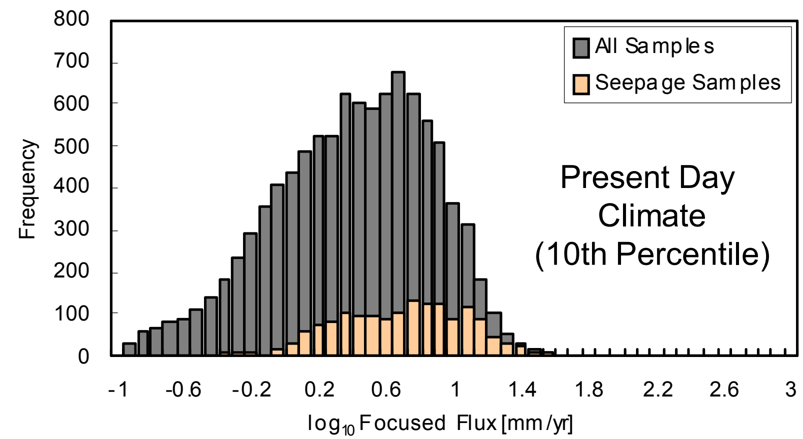
Fracture Capillary Strength



Variability of Seepage Rates (Intact Drift in Tptpll)



Percolation Flux (with focusing)

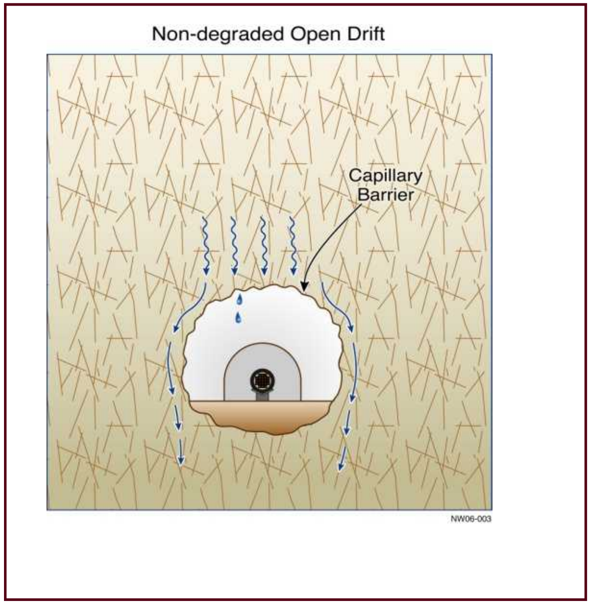


Source of Seepage Plots: MDL-NBS-HS-000019 REV 01 Figures 6-10[a], 6-12[a]

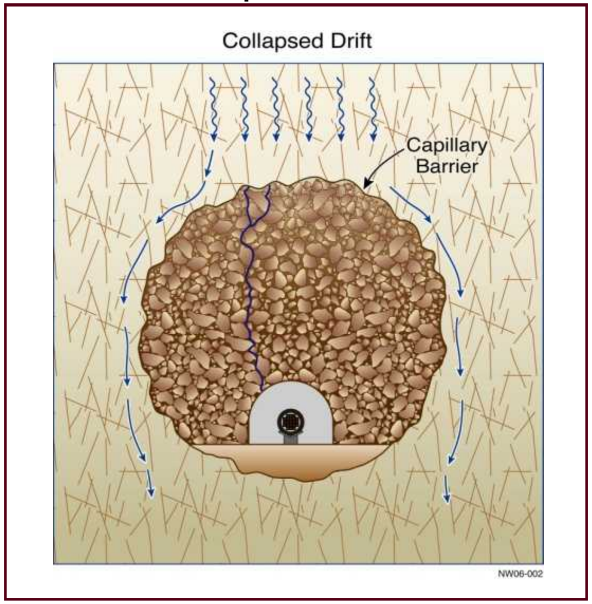
Drift Collapse in Lithophysal Units

- **Drift collapse can occur in case of single or multiple seismic events during TSPA simulation period**
- **Categorization of drifts based on cumulative rockfall volume**
- **Cumulative rockfall volume provided by regression curves linking rockfall and horizontal PGV (Seismic Consequence Abstraction)**
- **Rockfall threshold values based on visual inspection of predicted drift shapes, with the threshold for lithophysal rock defined as:**
  Intact: $V < 5\ m^3/m$; Collapsed: $V > 60\ m^3/m$; linear in-between

Intact Drift



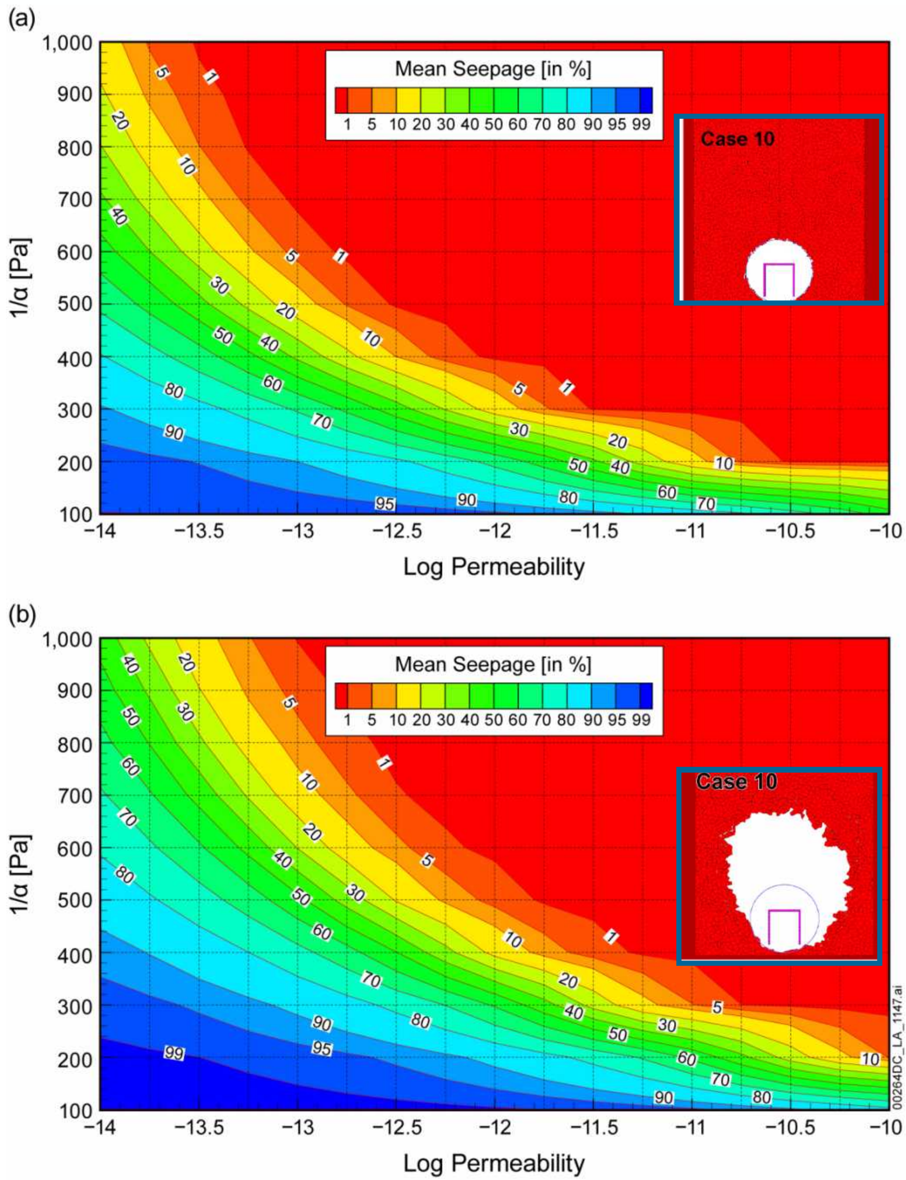
Collapsed Drift



Stochastic Variability in Drift Shapes and Volumes

Drift Profiles and Rockfall Volumes (in m^3/m) for Seismic Ground Motion at Horizontal PGV = 2.44 m/s

M-H Coupling: Effect of Rockfall on Seepage

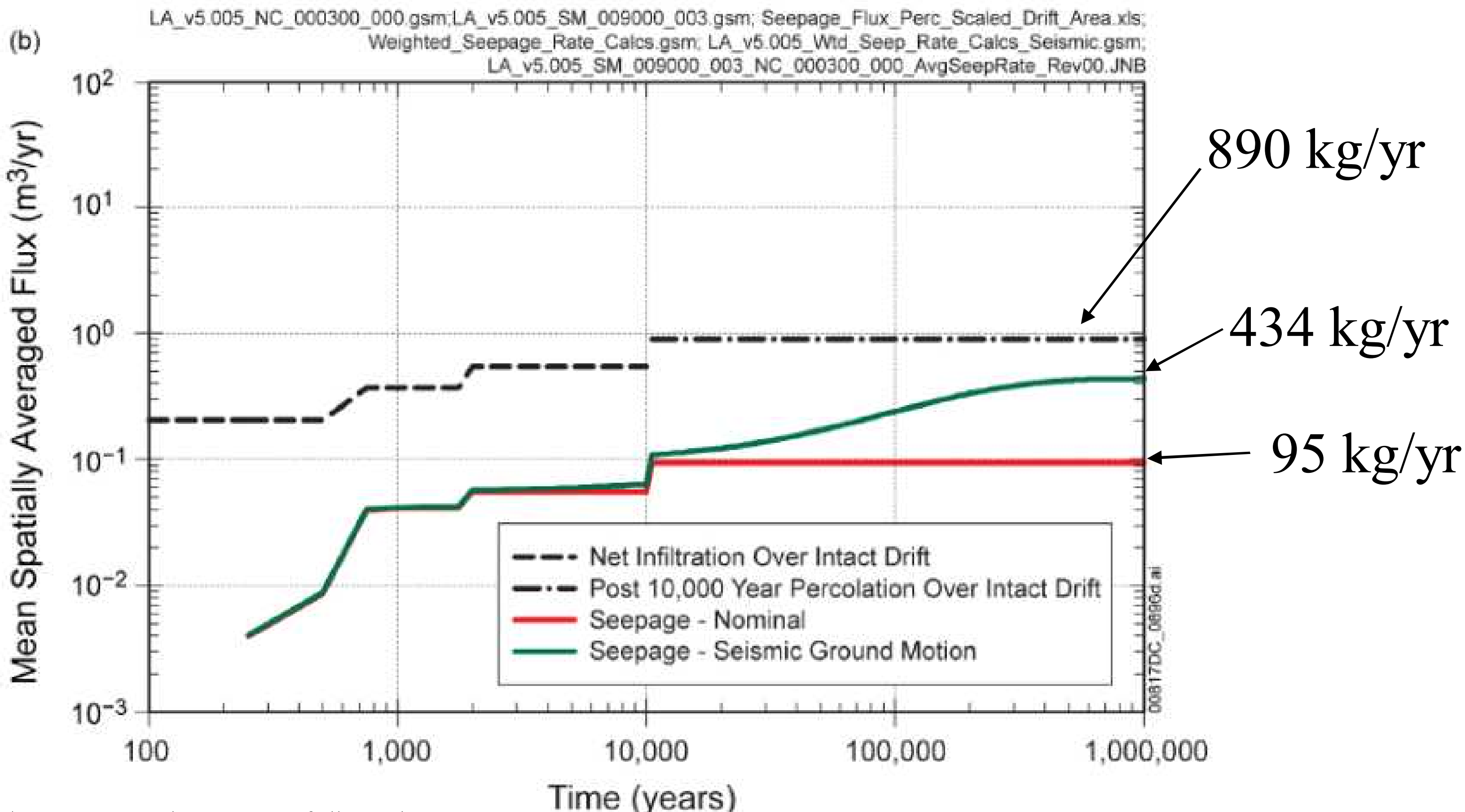


Seepage Percentage for (a) Intact Drifts and (b) Collapsed Drifts as a Function of Capillary Strength Parameter and Log Permeability for a Percolation Flux of 5 mm/year

From SAR Figures 2.3.3-20 and 2.3.3-32

Seepage Rates* from TSPA Submodel

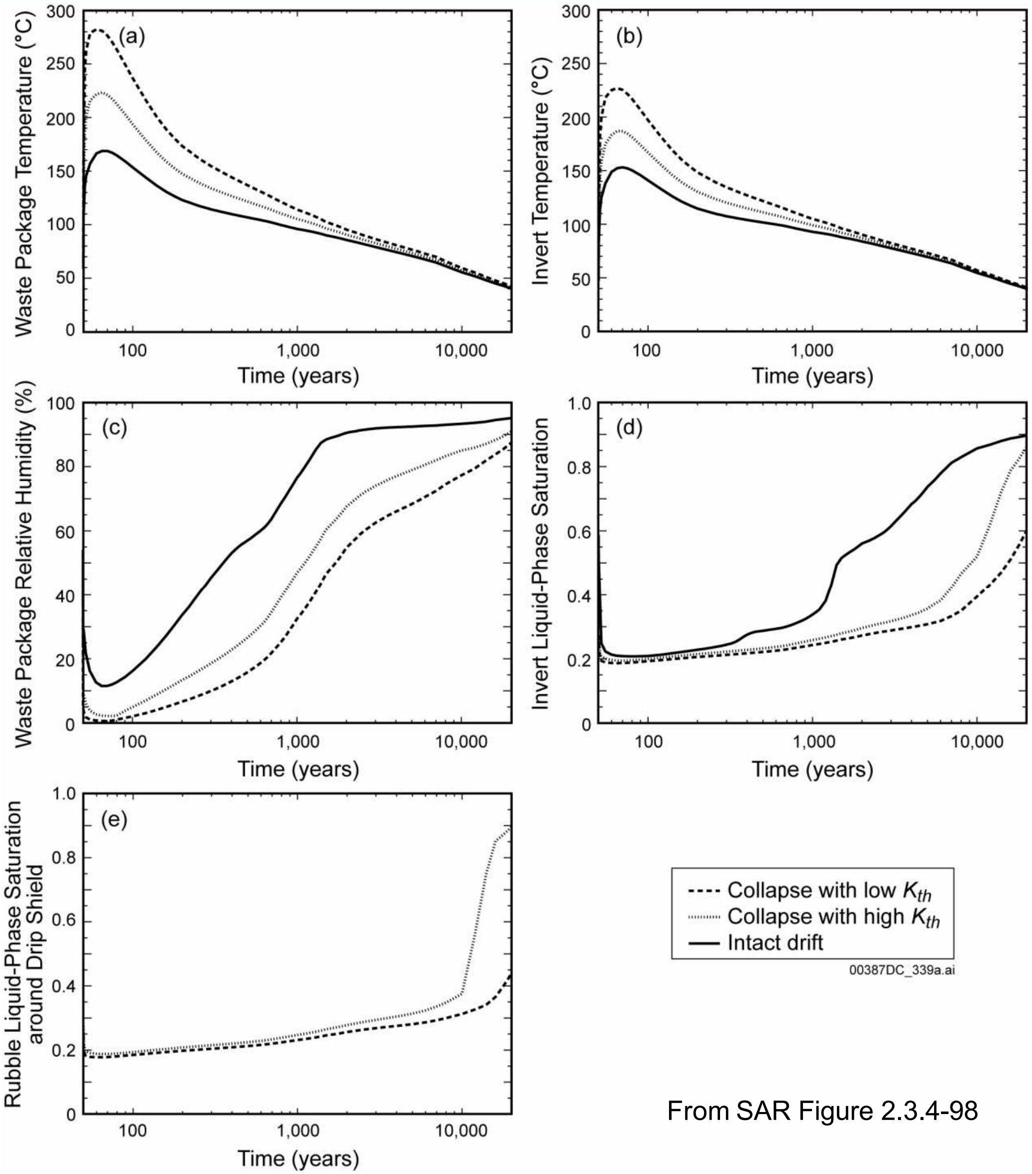
- Illustrates combined results simultaneously accounting for variability and uncertainty, actual drift location, thermal barrier, alternative UZ flow fields, lithological units, time-dependent drift collapse, etc.

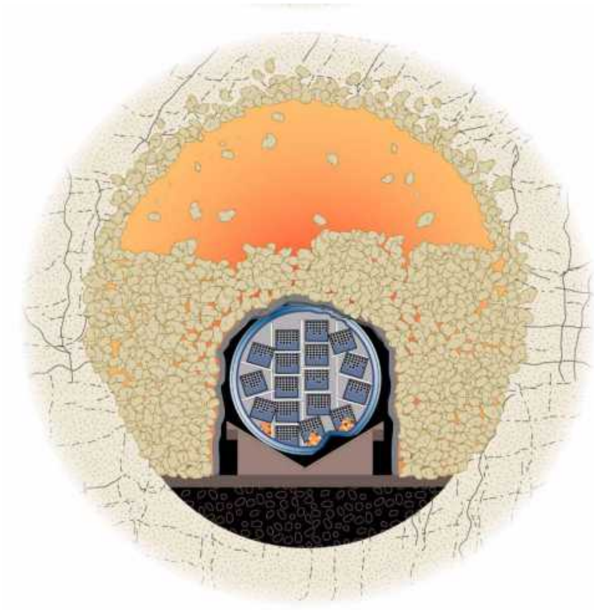


* in kg/yr per waste package; mean of all samples

Source: MDL-WIS-PA-000005 REV 00 AD 01 Figure 8.3-3b[a]

T-M-H Coupling: Effect of Rockfall on T, RH, S_w





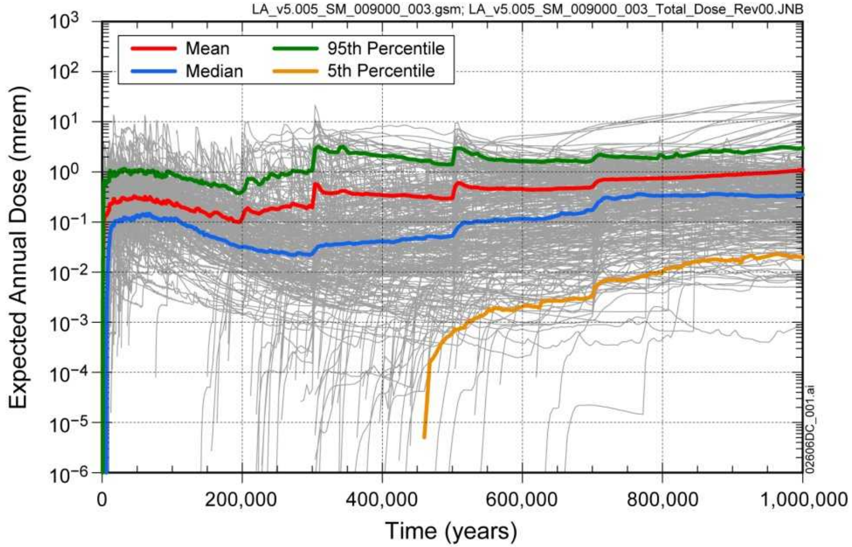
From SAR Figure 2.3.4-98

Stepwise Regression Sensitivity Analyses:

Effect of Input Uncertainties on Output Uncertainty for the Seismic Ground Motion Case

SCCTHRP – Stress threshold for SCC initiation

WDGCA22 – Temperature dependence in A22 corrosion rate



	50,000 Years			200,000 Years			500,000 Years		
Step[a]	Variable[b]	R^2 [c]	SRRC[d]	Variable	R^2	SRRC	Variable	R^2	SRRC
1	SCCTHRP	0.71	−0.85	SCCTHRP	0.54	−0.72	WDGCA22	0.62	−0.77
2	MICTC99	0.72	0.09	WDDSGC29	0.58	−0.18	SCCTHRP	0.71	−0.28
3	HLWDRACD	0.73	0.10	WDGCA22	0.60	−0.14	WDNSCC	0.72	−0.12
4	DSNFMASS	0.74	0.11	DSNFMASS	0.61	0.11	SZPORSAL	0.73	0.08
5	SZLODISP	0.75	−0.10	CSNFMASS	0.62	0.10	SZGWSPDM	0.73	0.11
6	SZKDSEVO	0.76	−0.09				SZCONCOL	0.74	0.09
7	CPUPERCS	0.77	0.09				EP1LOWNU	0.75	0.10
8							UZFAG4	0.76	−0.08

a: Steps in stepwise rank regression analysis
b: Variables listed in order of selection in stepwise regression
c: Cumulative R^2 value with entry of each variable into regression model
d: Standardized rank regression coefficients (SRRCs) in final regression model

Summary

- **Thermo-hydro mechanical chemical (THMC) effects, and particularly mechanical effects, associated with seismic events can have a strong influence on the evolution of the engineered barrier system in a geologic repository**
- **There are a variety of methods of THMC coupling that are appropriate for including in a suite of performance assessment models and a variety of degrees of coupling that may be used:**
  - **Both a bottoms-up (process-level) and a top-down (TSPA level) approach are important for conceptualizing the degree of coupling and model complexity**
  - **Varying degrees of simplification may applied to component models, depending in part on their risk significance**
  - **Uncertainty and variability should characterized and included for all important processes/models**
- **The TSPA process is iterative—new data, analyses, and understanding lead to future refinements in conceptual and numerical models**
  - **Sensitivity analyses help determine the areas that need further study/ improvement**

References

- **US DOE (United States Department of Energy), *Yucca Mountain Repository License Application*, DOE/RW-0573, Rev. 0 (2008) (available at http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html#appdocuments)**
  - **Documentation of the TSPA is provided in Section 2.4 of the Safety Analysis Report (SAR) contained in the License Application**
  - **Documentation of the Seismic Consequences and Seismic Source Term is provided Section 2.3.4 of the Safety Analysis Report**
- **Supporting documents available at the Nuclear Regulatory Commission's Licensing Support Network (LSN) at http://www.lsnnet.gov/**