SAND2010-3754C

Summary of the Total System Performance Assessment for Yucca Mountain License Application

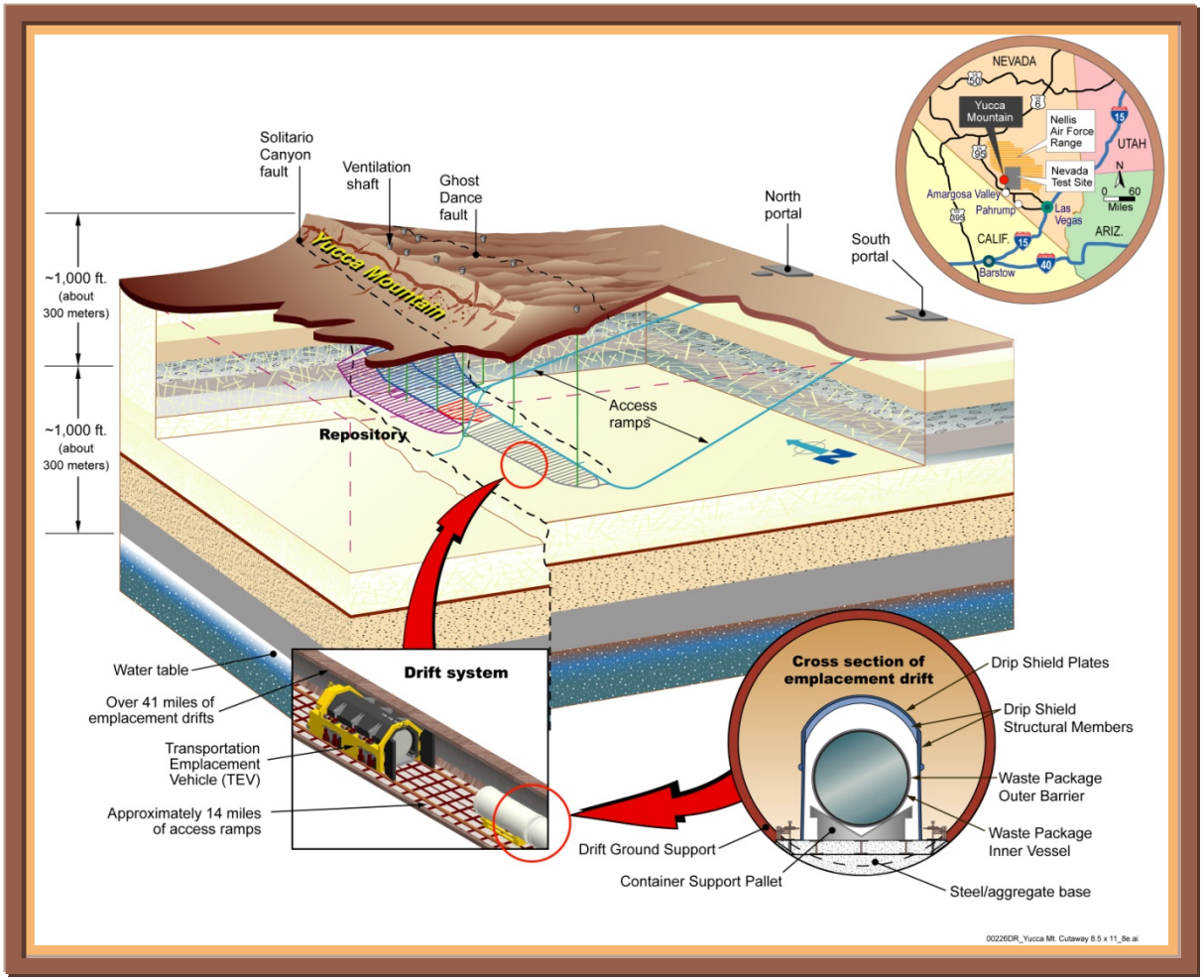
Presentation to PSAM 2010

Clifford W. Hansen, M. Kathryn Knowles,
Robert J. MacKinnon, S. David Sevougian, Peter N. Swift
Sandia National Laboratories
June 10, 2010

The content of this presentation reflects the views of the authors and does not necessarily reflect the views or policies of the United States Department of Energy or Sandia National Labs

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

Proposed Repository at YM



National Nuclear Security Administration

Sandia National Laboratories

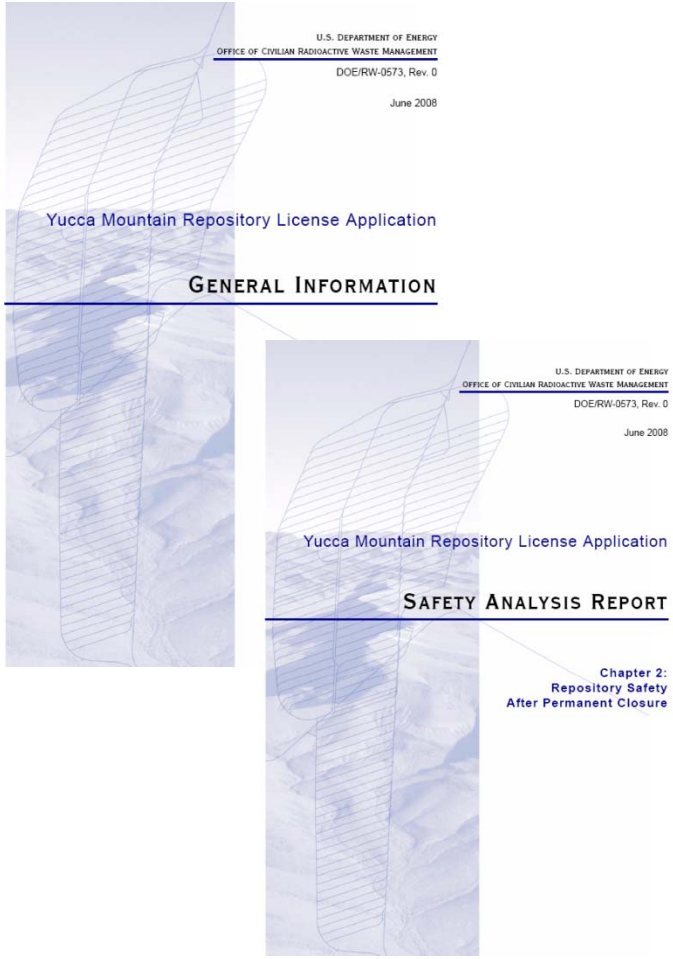
Yucca Mountain License Application

DOE/RW-0573 Rev 0 June 2008

- General Information (GI)
  - General Description
  - Proposed Schedules for Construction, Receipt and Emplacement of Waste
  - Physical Protection Plan
  - Material Control and Accounting Program
  - Site Characterization

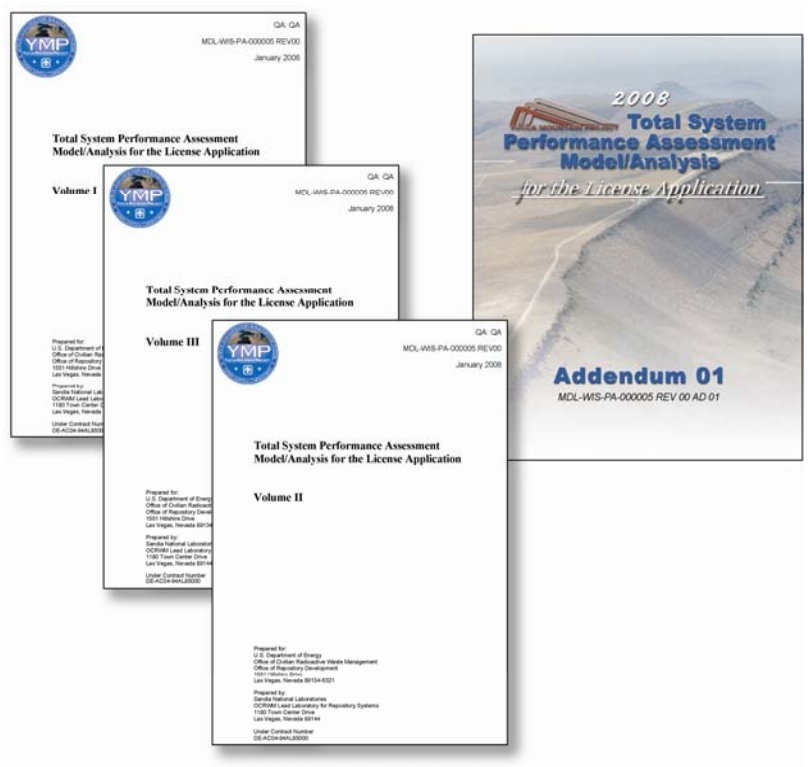
- Safety Analysis Report (SAR)
  - Repository Safety Before Permanent Closure
  - Repository Safety After Permanent Closure
  - Research and Development Program to Resolve Safety Questions
  - Performance Confirmation Program
  - Management Systems

- Available from the NRC (http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html#appdocuments)



TSPA-LA Documentation

SNL 2008, *Total System Performance Assessment Model/Analysis for the License Application*, MDL-WIS-PA-000005 REV 00 AD 01



Four volumes
4272 pages

11,843 pages of supporting technical documents that provide direct input

	Total Pages	Number of Tables	Number of Figures
Volume I	1111	183	255
Volume II	600	41	221
Volume III	1767	130	519
Addendum	794	34	321
TOTALS	**4272**	**388**	**1316**

10 CFR 63 and 40 CFR Part 197 Core Regulatory Requirements for YM Repository

- Maximum value of mean dose to the reasonably maximally exposed individual (RMEI) over time interval [0, 10^4 yr] less than 15 mrem/yr
- Maximum value of mean dose to the RMEI over time interval [10^4, 10^6 yr] less than 100 mrem/yr
- Take uncertainties and gaps in knowledge into account
- Requirements lead to Performance Assessment that
  - Computes measures of performance (e.g. mean dose)
  - Accounts for and quantifies uncertainty in measures of performance

Four Questions Underlying TSPA

1. What events and processes can take place at the facility?

2. How likely are these events or processes?

3. What are the consequences of these events or processes?
   - Kaplan and Garrick (1979) “risk triplet”

4. How certain are the answers to the first 3 questions?

TSPA-LA Scenarios

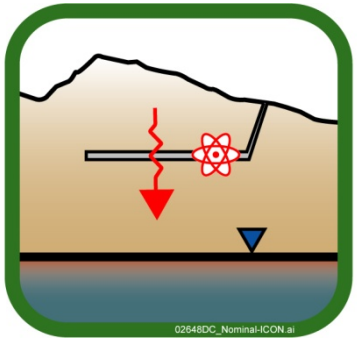
Screened-in events are grouped by event type to form four scenario classes (divided into seven modeling cases by effect of event on disposal system)

Nominal Scenario Class

- **Nominal Modeling Case (included with Seismic Ground Motion for 1,000,000-yr analyses)**

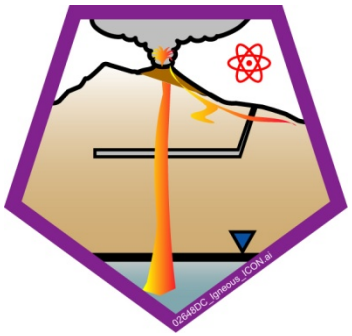
Early Failure Scenario Class

- **Waste Package Modeling Case**
- **Drip Shield Modeling Case**



Igneous Scenario Class

- **Intrusion Modeling Case**
- **Eruption Modeling Case**



Seismic Scenario Class

- **Ground Motion Modeling Case**
- **Fault Displacement Modeling Case**

Mathematical Entities Underlying the YM TSPA

EN1: Probability space characterizing what can happen in the future

- Answers "What can happen" and "How likely"
- Provides formal characterization of aleatory uncertainty

E.G. Assumption that igneous event occurrence is a Poisson process

EN2: Mathematical models for predicting consequences

- Answers "What are the consequences"

E.G. Flow and Transport Models

EN3: Probability space characterizing uncertainty in TSPA inputs

- Basis for answering "How certain are the answers to the other three questions"
- Provides formal characterization of epistemic uncertainty

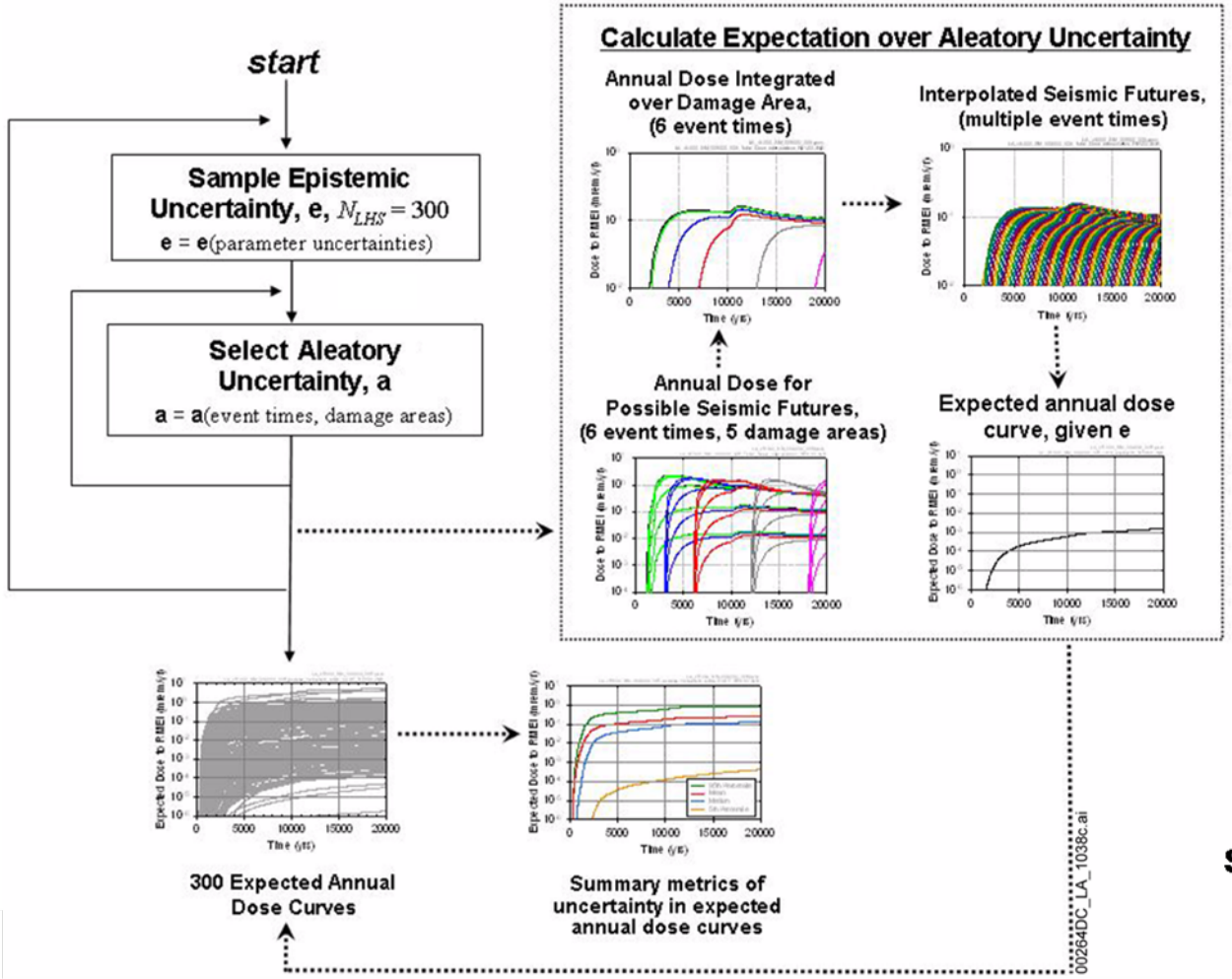
E.G. Distribution assigned to rate for a Poisson process

Conceptual Calculation

- Regulation requests "mean" values of dose to a reasonably maximally exposed individual
- Uncertainty in future events **a** and in model inputs **e**
- Calculation proceeds in three stages:

$$
\begin{aligned}
\bar{\bar{D}}(\tau) &= E_E\left[E_A\left(D(\tau \mid \mathbf{a},\mathbf{e})\right)\right] \\
&= \int_{\mathcal{E}}\left[\int_{\mathcal{A}} D(\tau \mid \mathbf{a},\mathbf{e})\, d_A(\mathbf{a} \mid \mathbf{e})\, dA\right] d_E(\mathbf{e})\, dE \\
&\cong \int_{\mathcal{E}}\left[\int_{\mathcal{A}} \left\{\sum_{MC} D_{MC}(\tau \mid \mathbf{a},\mathbf{e})\right\} d_A(\mathbf{a} \mid \mathbf{e})\, dA\right] d_E(\mathbf{e})\, dE \\
&= \int_{\mathcal{E}} \sum_{MC}\left[\int_{\mathcal{A}} \boxed{D_{MC}(\tau \mid \mathbf{a},\mathbf{e})}\, d_A(\mathbf{a} \mid \mathbf{e})\, dA\right] d_E(\mathbf{e})\, dE
\end{aligned}
$$

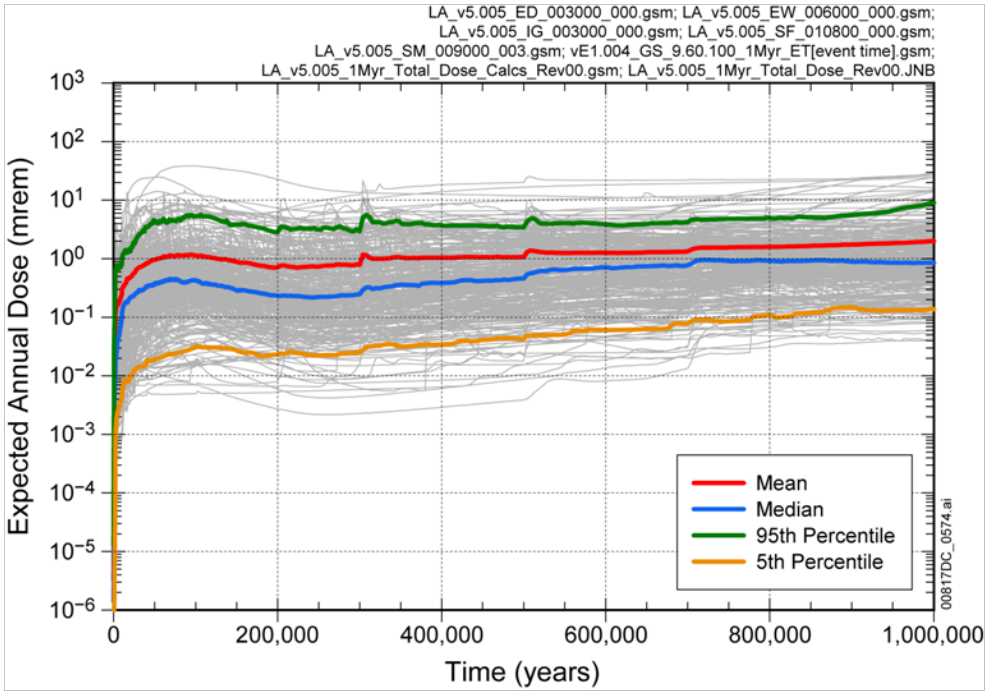
Example: Calculation of Expected Dose for Seismic Ground Motion Modeling Case



SAR Figure 2.4-8

Total System Performance Assessment Results

Total Expected Annual Dose for 1M yr post-closure

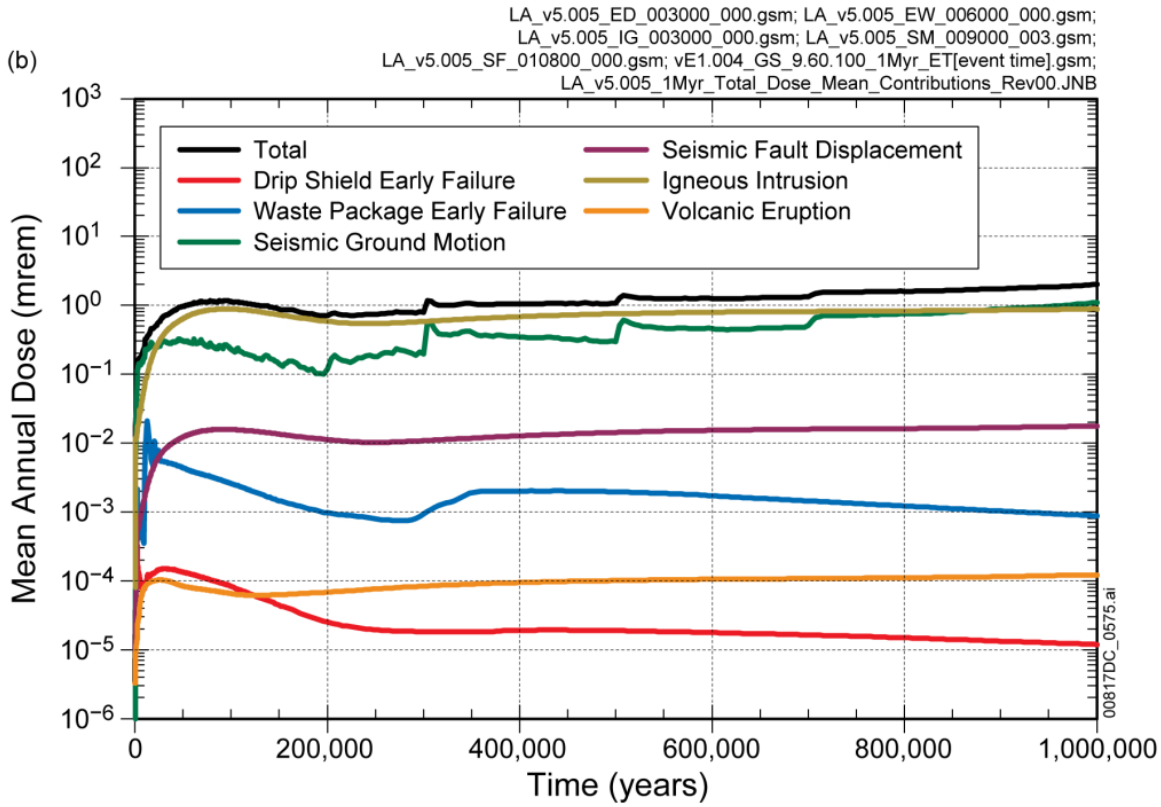


MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-2[a]b

Three questions:

1. What determines the <u>shape</u> of these curves?
2. What determines the <u>magnitude</u> of total mean dose?
3. What determines the <u>uncertainty</u> in total expected dose?

Modeling Cases Contributing to Total Mean Annual Dose



MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-3[a]b

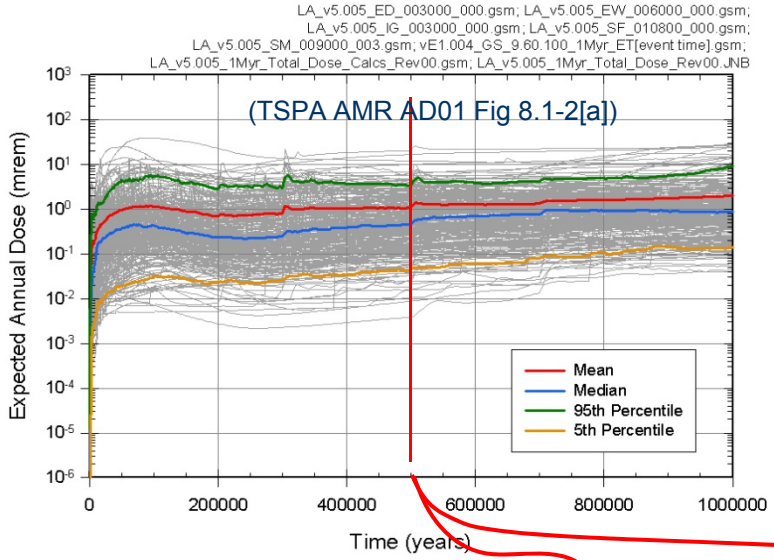
In order of importance:

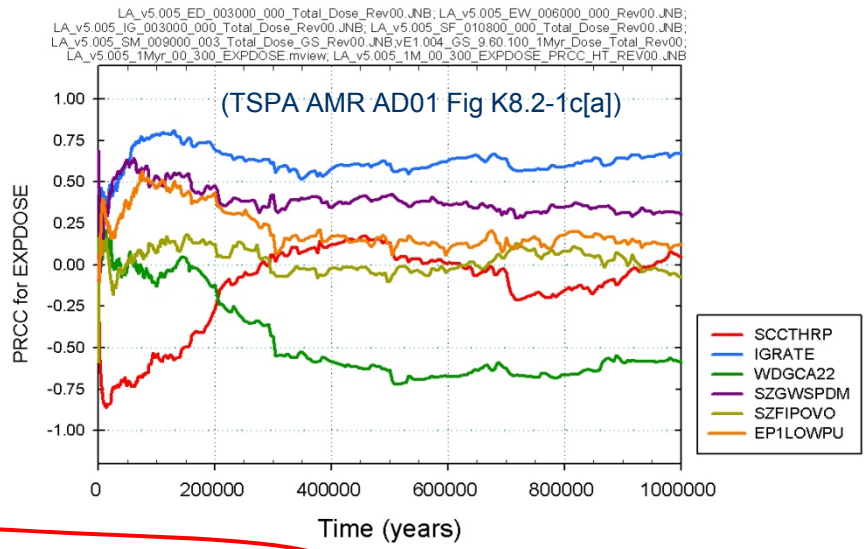
Igneous Intrusion and Seismic Ground Motion (includes effects of nominal processes)

Seismic Fault Displacement

Early Failure, Volcanic Eruption

Uncertainty in Total Expected Dose

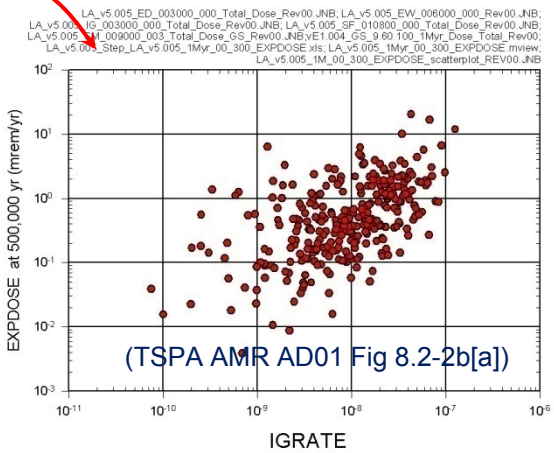


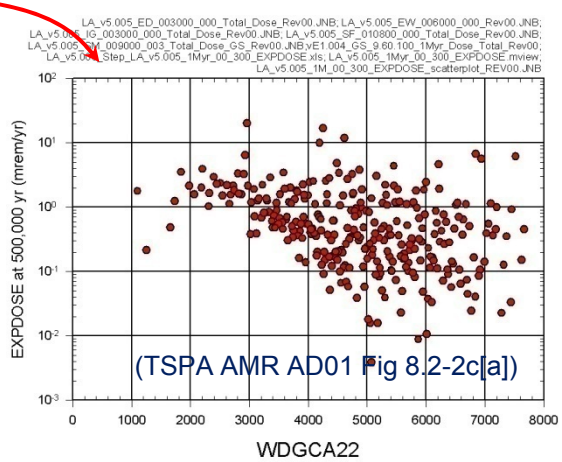


SCCTHRP – Stress threshold for SCC initiation

IGRATE – Frequency of igneous events

WDGCA22 – Temperature dependence in A22 corrosion rate





Features and Processes Contributing to Repository Performance

- Precipitation ⇨ infiltration ⇨ seepage into repository drifts

Climate	Precipitation (mm/yr)	Infiltration (mm/yr)	Seepage (mm/yr)
Present-day[1]	150	4	0.04
Post-10k yr[2]	-	22	8.6

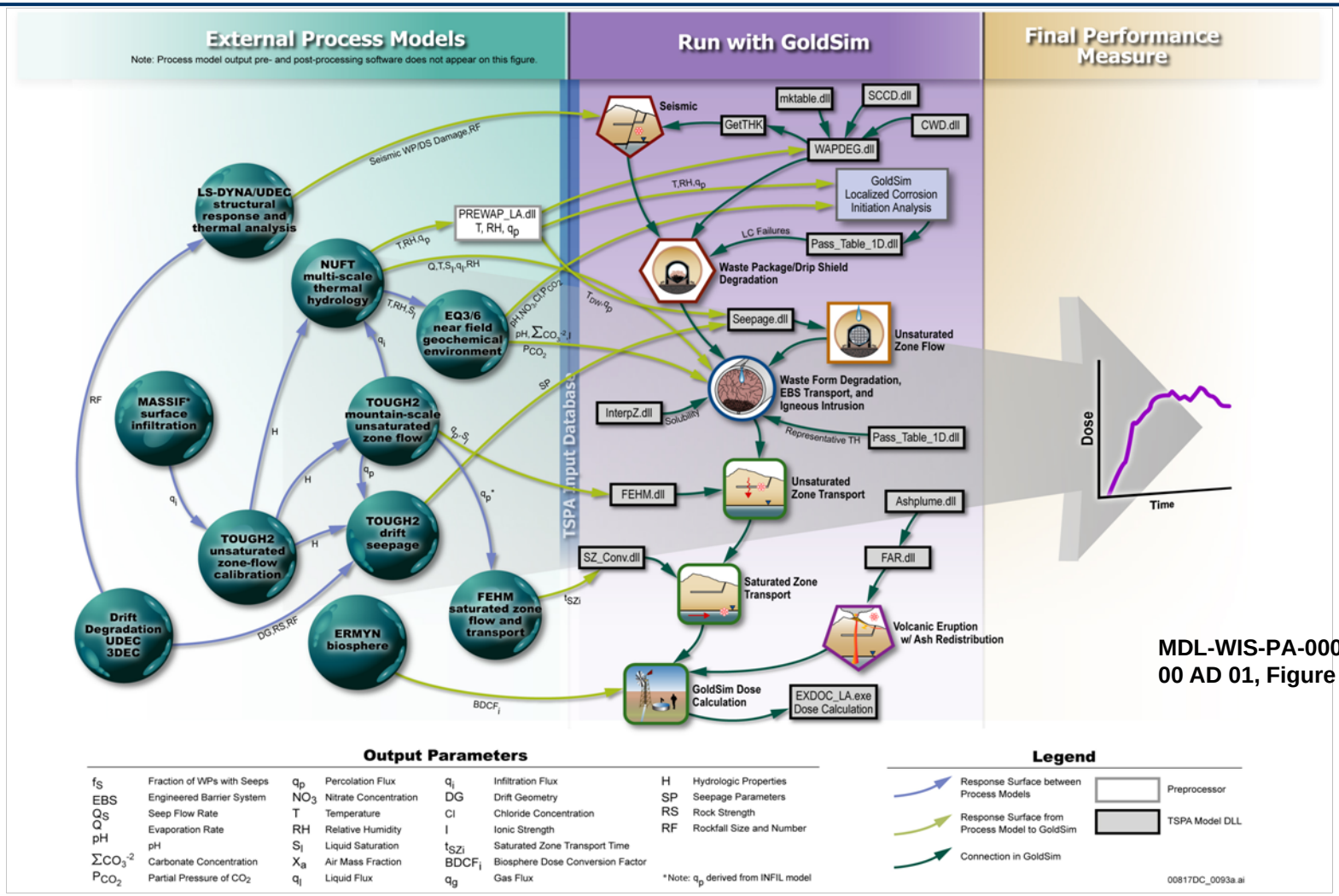
1) Nominal scenario, 10th percentile infiltration scenario, spatial averages, seepage converted from m3/WP/yr
2) Seismic + nominal, 10th percentile infiltration scenario, spatial averages, seepage converted from m3/WP/yr

- Low likelihood of advection through WP outer barrier
  - WP outer barrier failure generally consists of stress corrosion cracking
  - Low likelihood of igneous events, rupture, general corrosion failures
  - Limited water available interior to WPs
- Iron oxyhydroxides from degraded WP materials sorb actinides, buffer water chemistry away from acidic conditions
- Travel times preclude transport of relatively short-lived radionuclides (e.g. ^{240}Pu), reduce concentrations of long-lived radionuclides

Conclusions

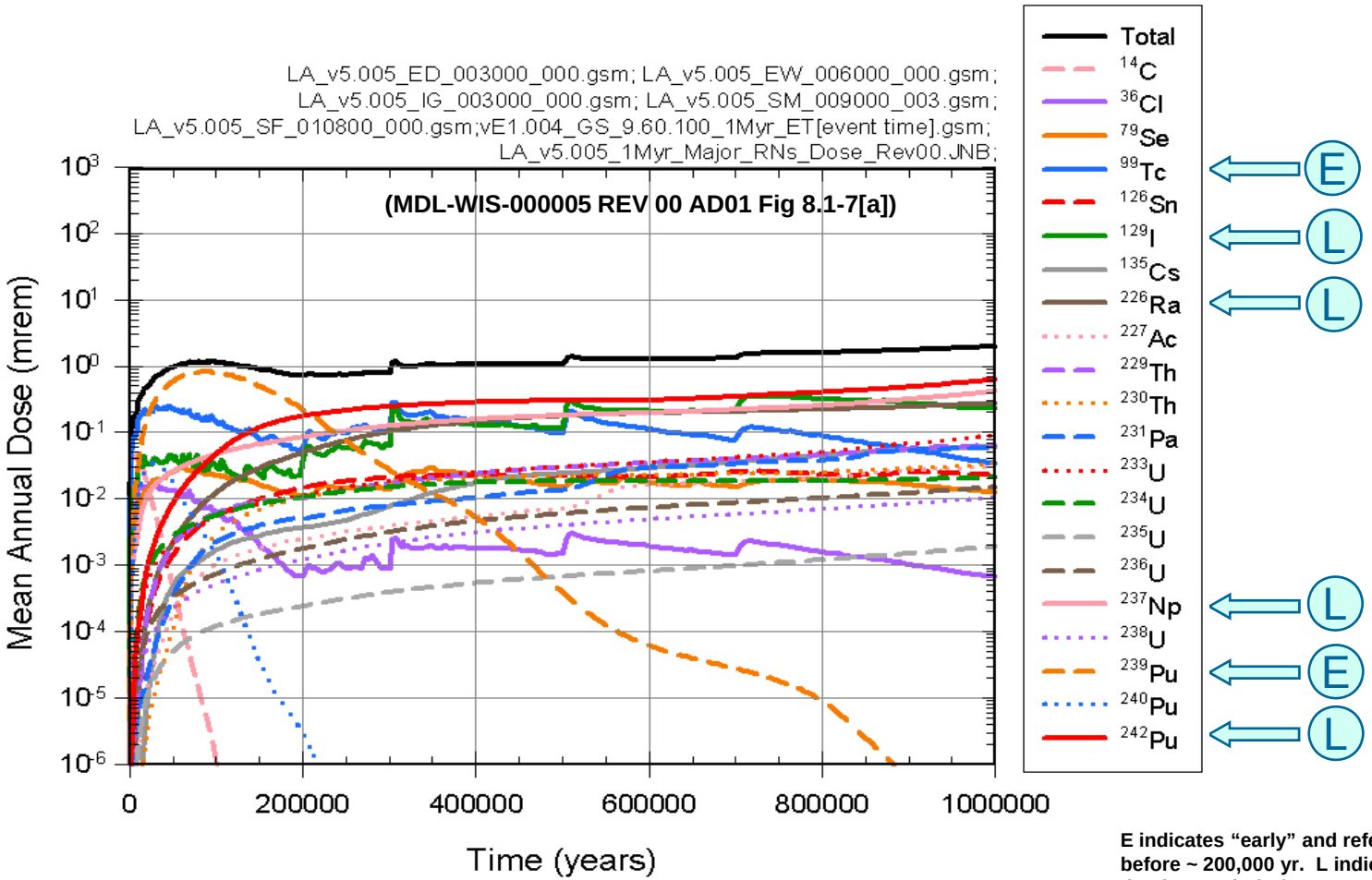
- The TSPA-LA supports the DOE's License Application to the NRC for authorization to construct a repository at Yucca Mountain.
- The TSPA provides probabilistic estimates of long- term performance, consistent with supporting technical information and taking into account uncertainties in the future occurrence of disruptive events and in knowledge of the repository system.
- All performance measures are well below regulatory limits.

TSPA Model Architecture



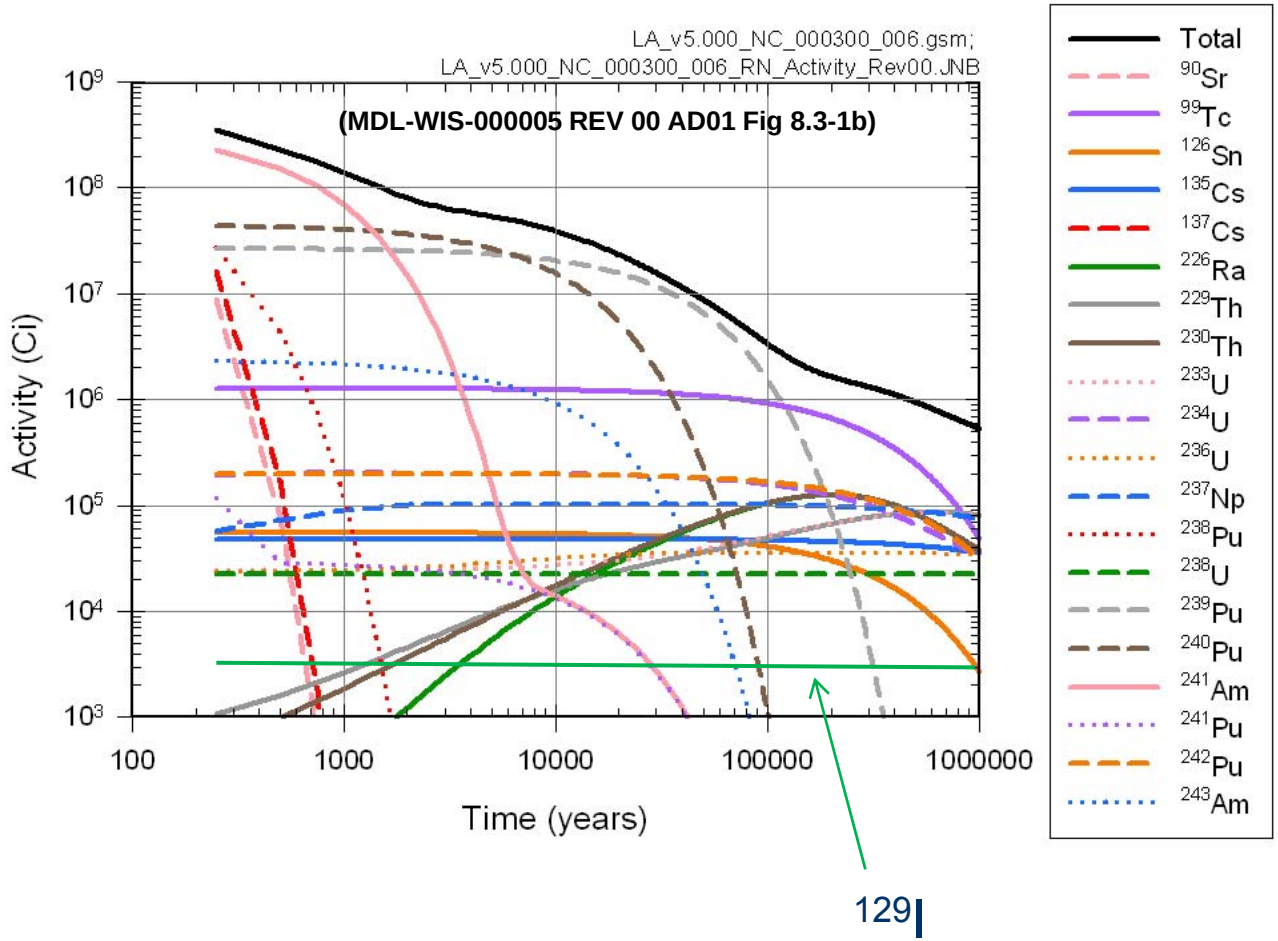
MDL-WIS-PA-000005 REV 00 AD 01, Figure 3-2[a]

Radionuclides Important to Mean Dose



E indicates "early" and refers to the time period before ~ 200,000 yr. L indicates "late" and refers to the time period after ~ 200,000 yr

Radionuclide Inventory



Early (in order of total activity):

^{241}Am, ^{239}Pu, ^{240}Pu

Late (in order of total activity):

^{99}Tc, ^{237}Np

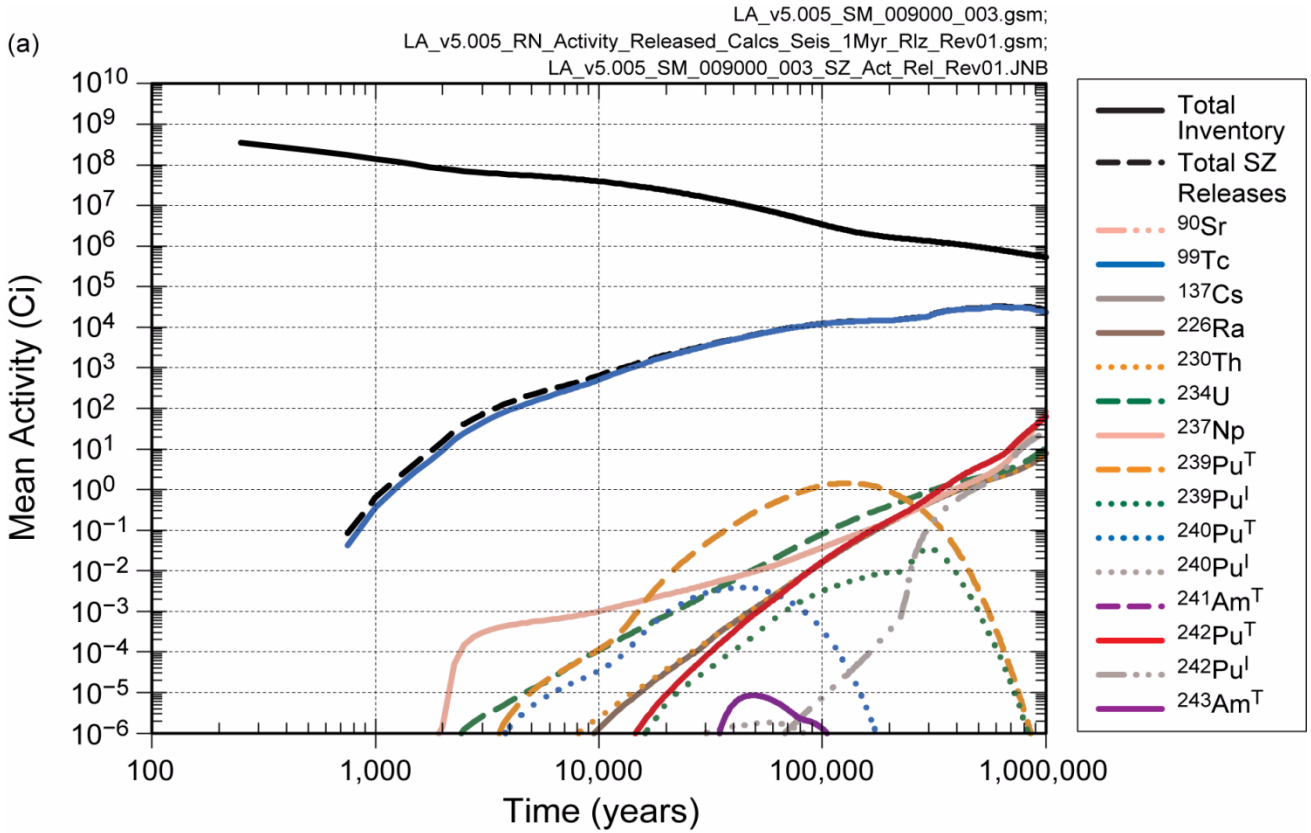
Note that activity in inventory does not necessarily correlate with importance to mean dose

Example Barrier Capability Analysis
Seismic GM + Nominal Processes

At 1M yr, total mean activity released from SZ is about 5 % of total inventory

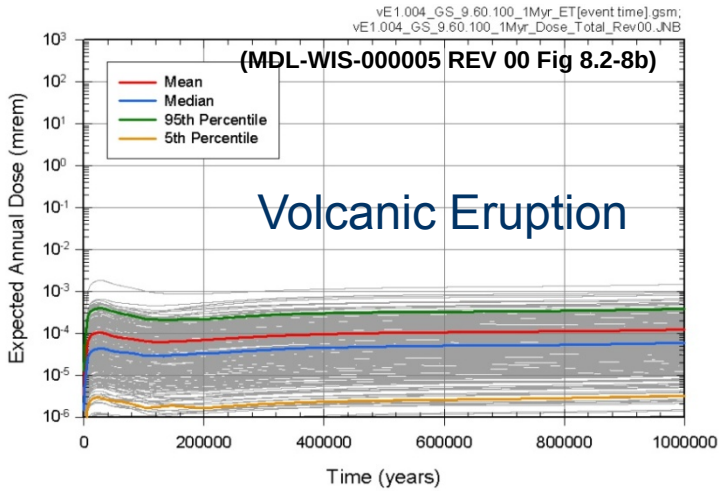
Short-lived species (e.g., Sr-90, Cs-137) are fully contained

Maximum releases of intermediate-lived species (e.g, Pu-239) are a small fraction of the total activity and occur before 1,000,000 yr

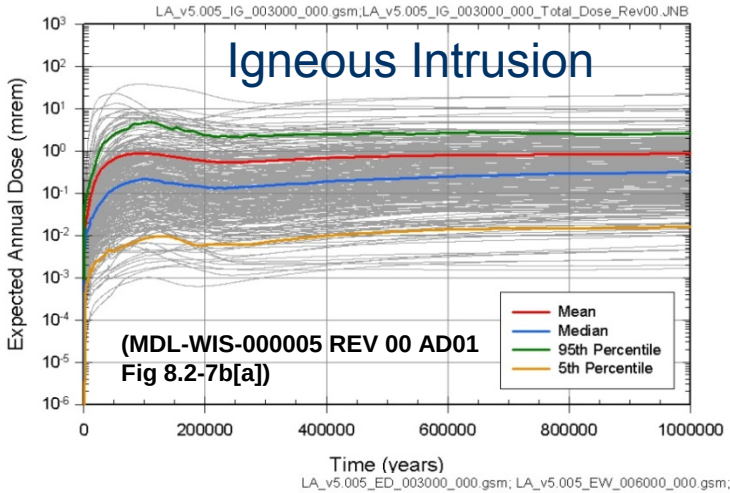


Mean Activity Released from the Saturated Zone
Seismic Ground Motion Modeling Case
Representative Subset of all Radionuclides
MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.3-26[a]a

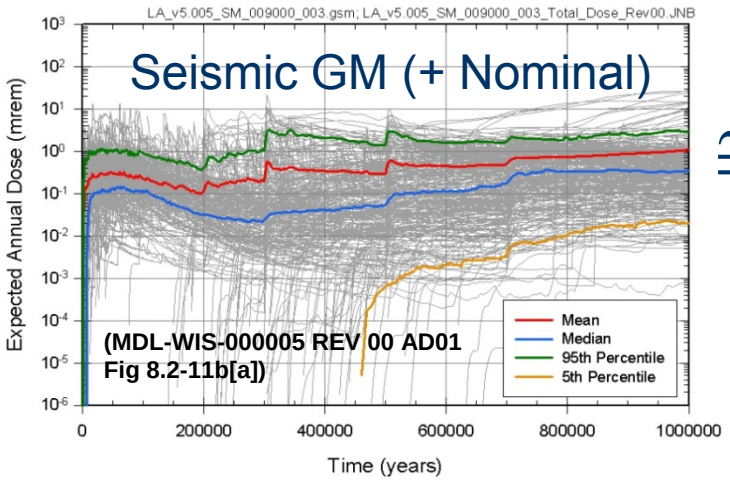
Construction of Total Expected Dose



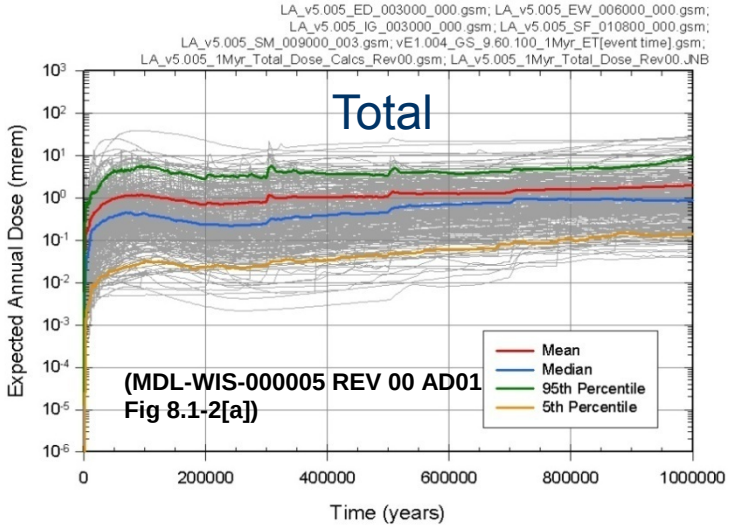
+



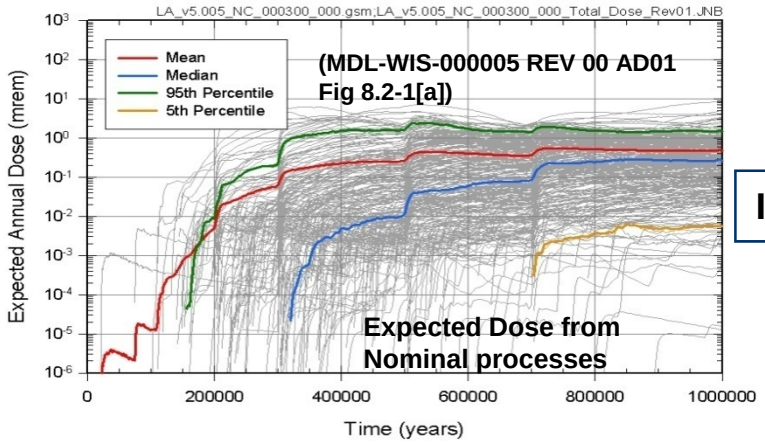
+



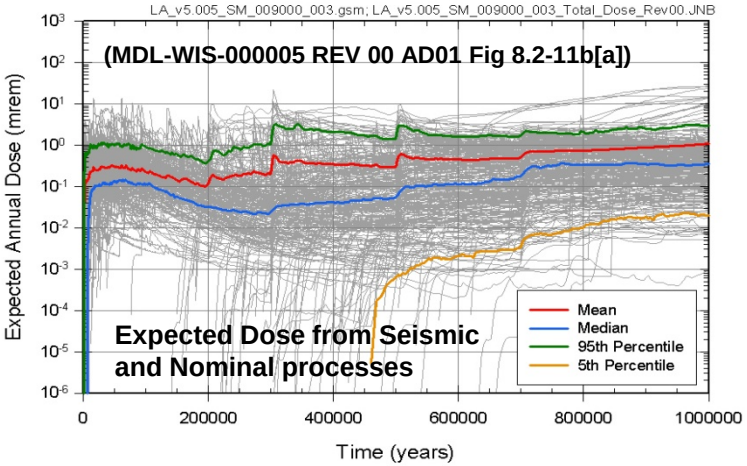
≅

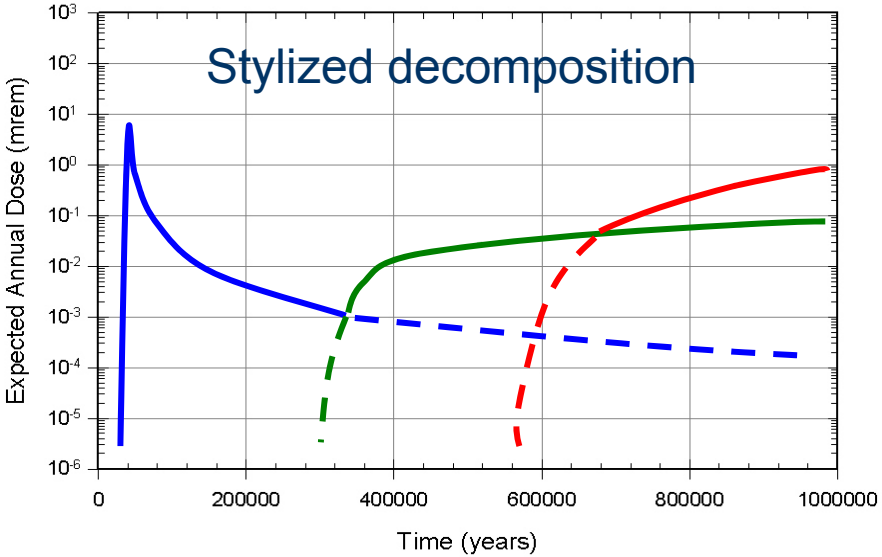


Composition of Seismic Ground Motion Dose



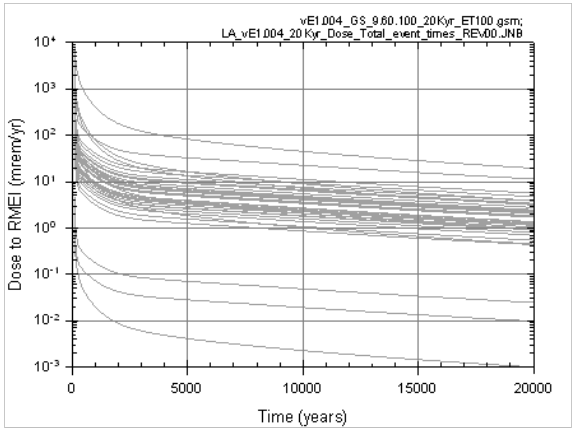
Included



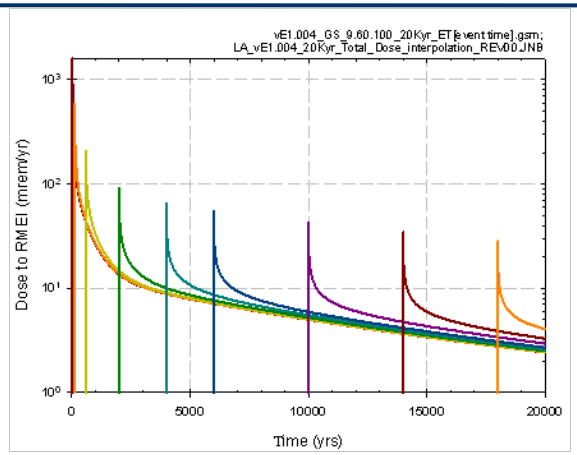


- From seismic damage to CDSP WP (diffusion)
- From SCC failure of CSNF WP (diffusion)
- From general corrosion failure of both WPs (advection)

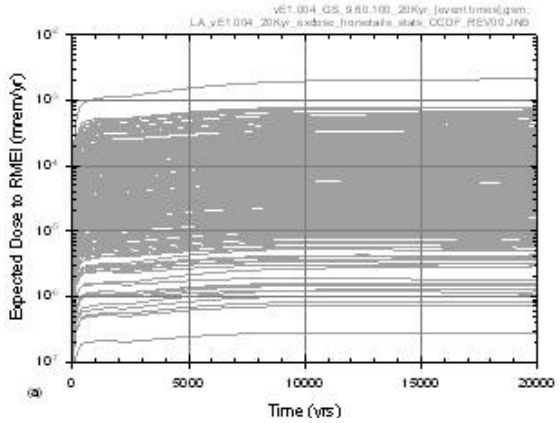
Computation of Expected Dose



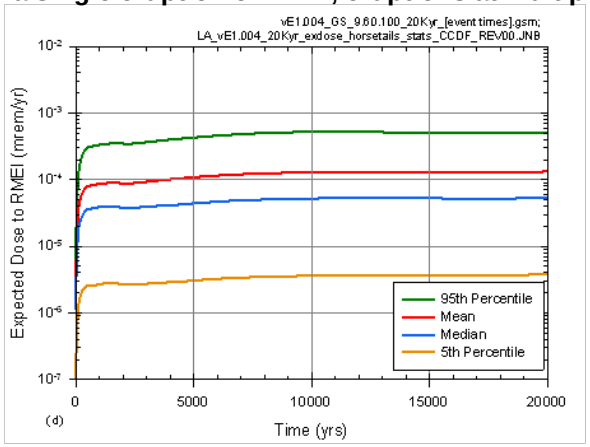
Eruptive dose: 40 realizations of aleatory uncertainty conditional on a single eruption of 1 WP at time zero



Eruptive dose averaged over aleatory uncertainty associated with a single eruption of 1 WP, eruptions at multiple times



Expected eruptive dose; 300 realizations, each showing expected dose from a single sampling of epistemic uncertainty with events at all times



Summary curves showing overall mean dose from eruption

MDL-WIS-PA-000005 Rev 00, Figures J7.3-1, 2,&4