



Long-Term Performance of the Proposed Yucca Mountain Repository, USA

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- **Overview of Yucca Mountain Mission**
 - Location of the repository, waste types, subsurface design
- **Summary of the Total System Performance Assessment Model for the License Application (TSPA-LA)**
 - Regulatory framework
 - Evaluation of Features, Events, and Processes (FEPs)
 - Selection of Scenario Classes for Analysis
 - Overview of the TSPA Model
- **Summary of the TSPA-LA results**

The Yucca Mountain Mission

Current locations of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) destined for geologic disposal:

120 sites in 39 states

United States Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) Mission: to manage and dispose of high-level radioactive waste and spent nuclear fuel in a manner that protects health, safety, and the environment; enhances national and energy security; and merits public confidence.

Proposed Yucca Mountain Repository



As of July 2004

Waste for Yucca Mountain



**Commercial Spent Nuclear Fuel:
63,000 MTHM (7796 waste packages)**



**DOE & Naval Spent Nuclear Fuel:
2,333 MTHM
(417 naval waste packages)
(DSNF packaged with HLW)**

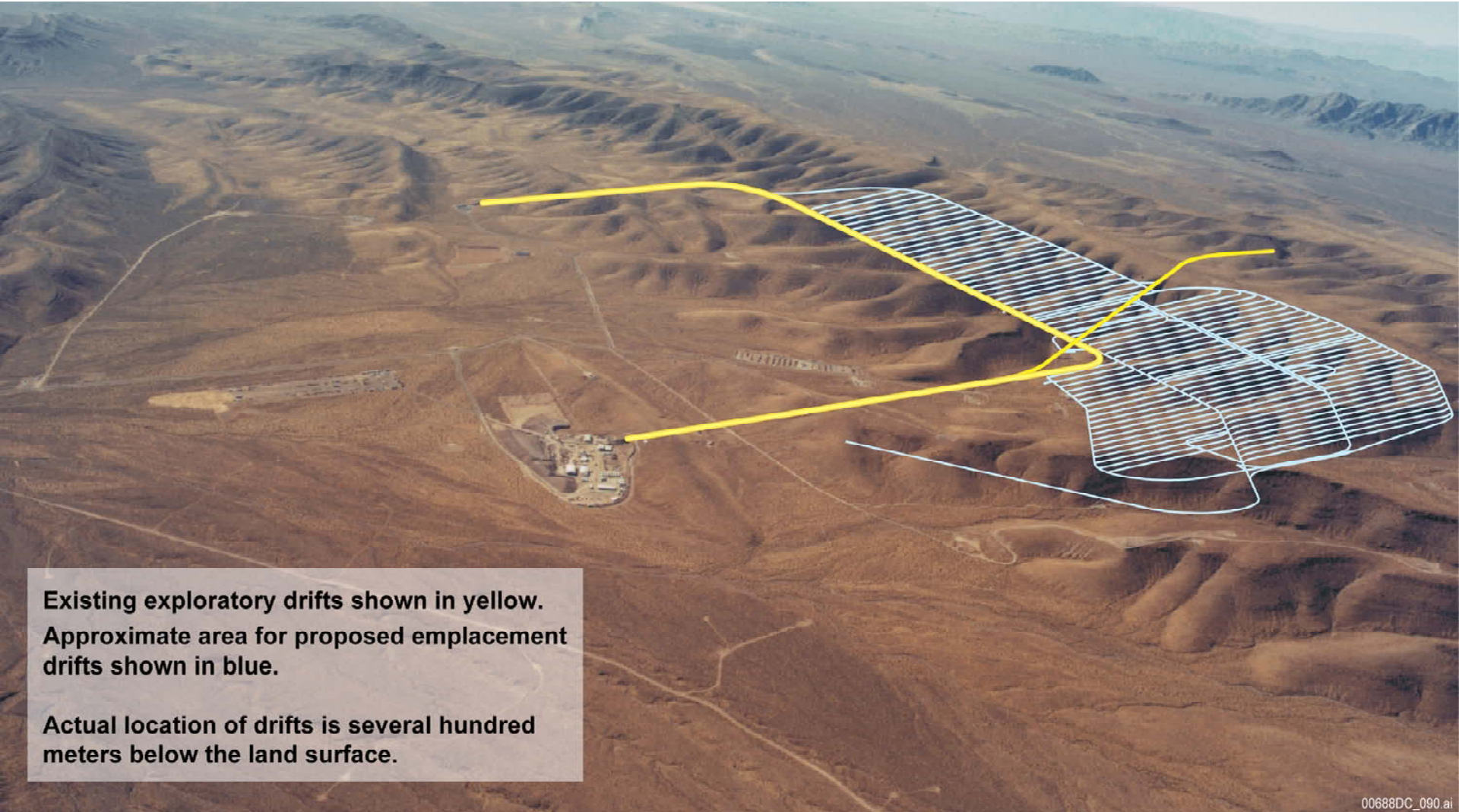


**DOE & Commercial High-Level Waste:
4,667 MTHM
(3416 waste packages of co-disposed DSNF and HLW)**



DSNF: Defense Spent Nuclear Fuel
HLW: High Level Radioactive Waste
MTHM: Metric Tons Heavy Metal

Proposed Repository for High-Level Waste and Spent Fuel at Yucca Mountain



**Existing exploratory drifts shown in yellow.
Approximate area for proposed emplacement
drifts shown in blue.**

**Actual location of drifts is several hundred
meters below the land surface.**

00688DC_090.ai

Yucca Mountain Subsurface Design

Emplacement drifts

5.5 m diameter

approx. 100 drifts, 600-800 m long

Waste packages

~12,000 packages

~ 5 m long, 2 m diameter

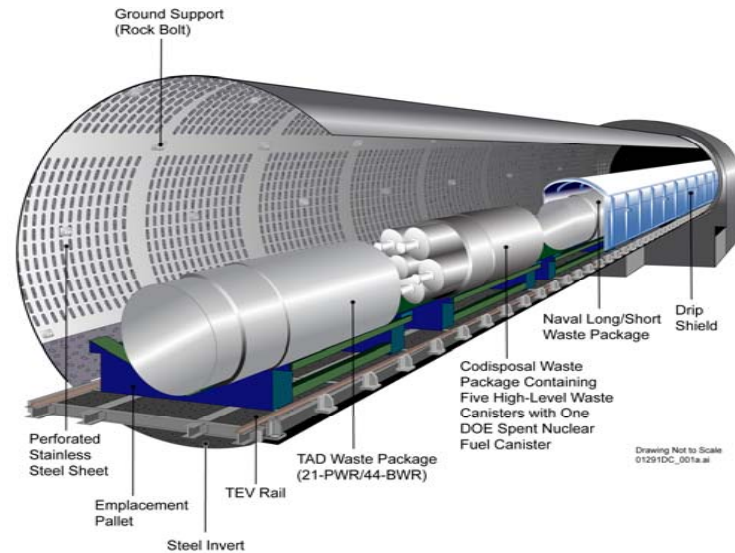
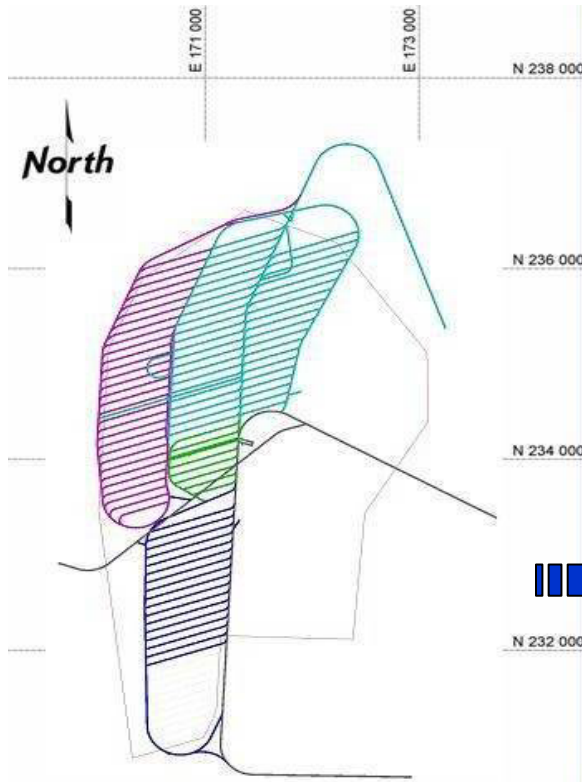
outer layer 2.5 cm Alloy 22 (Ni-Cr-Mo-V)

inner layer 5 cm stainless steel

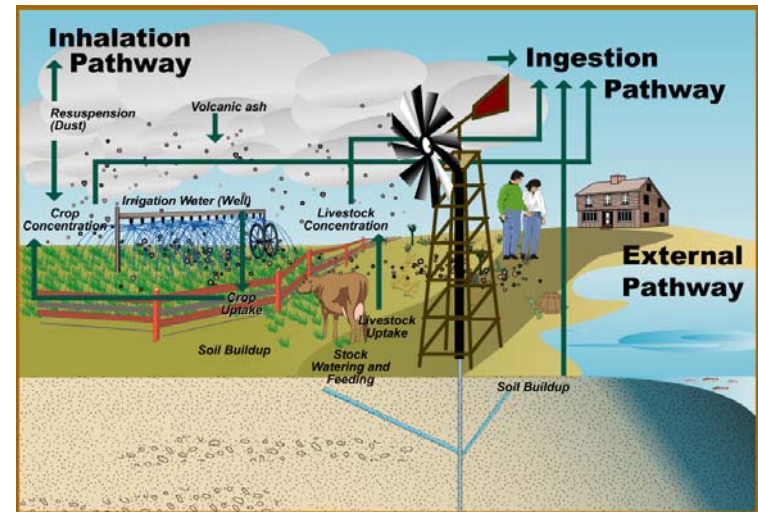
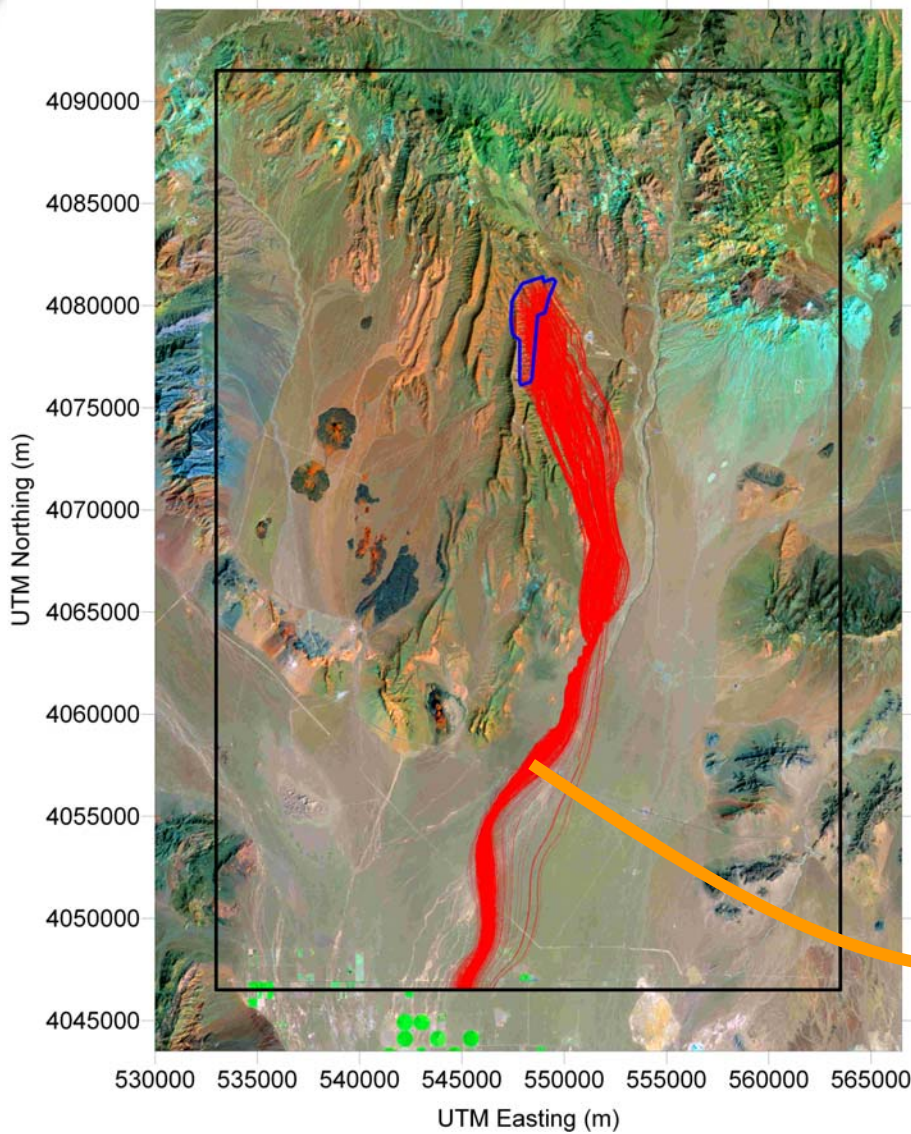
Internal TAD (transportation, aging, and disposal) canisters for commercial spent fuel, 2.5 cm stainless steel

Drip shields

free-standing 1.5 cm Ti shell



Estimating Dose to Hypothetical Future Humans



Modeled groundwater flow paths and hypothetical exposure pathways



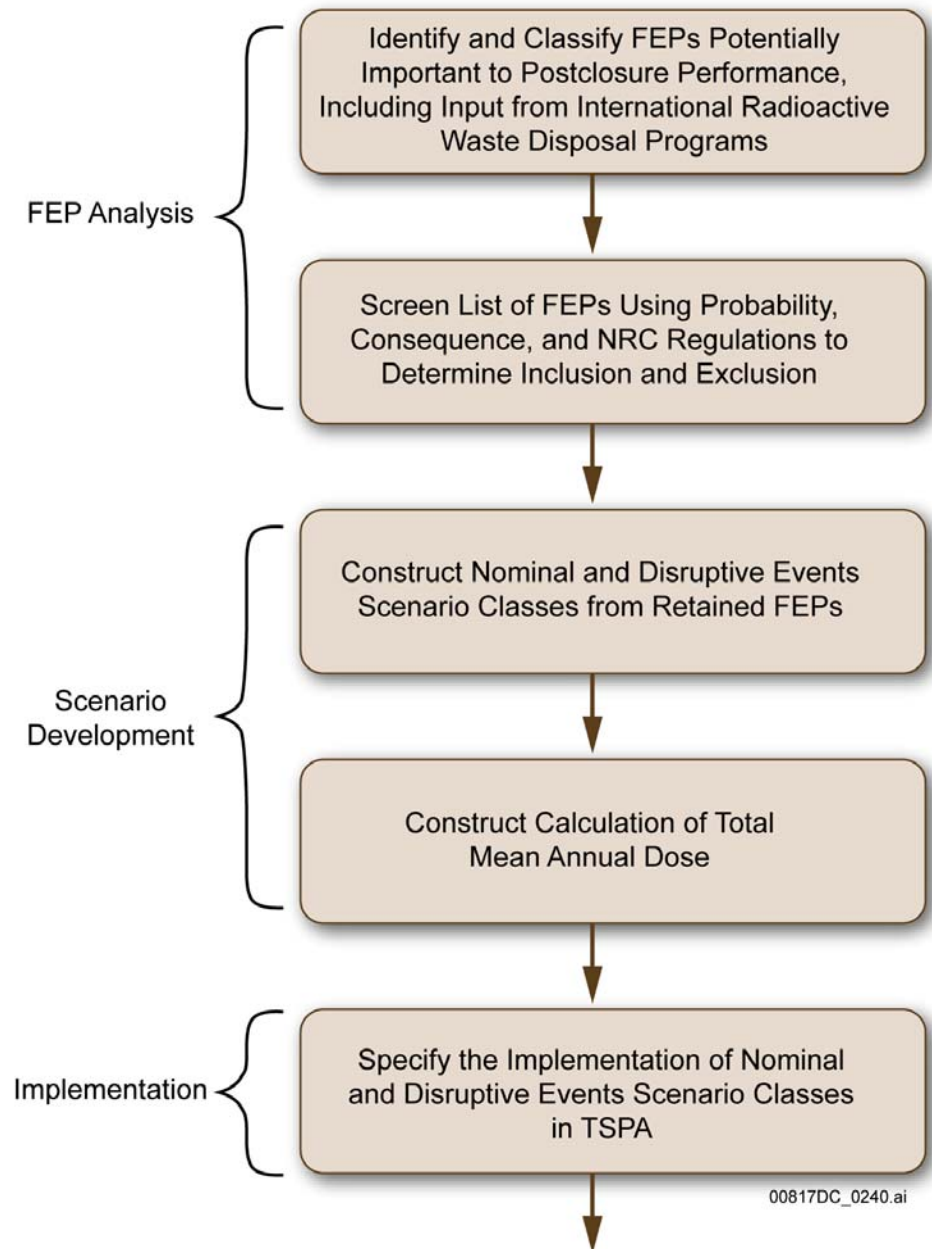
Regulatory Framework for the TSPA-LA

- **United States Environmental Protection Agency (EPA) sets *Public Health and Environmental Protection Standards for Yucca Mountain*, 40 CFR Part 197**
- **United States Nuclear Regulatory Commission (NRC) defines licensing criteria for *Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada*, 10 CFR Part 63 consistent with the EPA Standard**
- **The TSPA-LA addresses the criteria established by the NRC in 10 CFR Part 63**
- **In the absence of final dose standards that apply beyond 10,000 years, the TSPA-LA addresses the criteria proposed by the NRC in *Implementation of a Dose Standard After 10,000 Years, proposed rule* (Federal Register v. 70, p. 53313) that implements the standards proposed by the EPA in 2005**

- **Relevant to TSPA, 10 CFR Part 63 defines**
 - **The scope of the performance assessment**
 - ◆ Criteria for the screening of FEPs
 - ◆ Characteristics of the “Reasonably Maximally Exposed Individual” (RMEI)
 - **Probabilistic performance measures**
 - ◆ Implemented through a Monte Carlo uncertainty analysis
 - **A requirement for the identification and description of multiple barriers that contribute to waste isolation**
 - **Compliance limits for estimated mean annual dose and groundwater concentrations for**
 - ◆ Individual protection
 - ◆ Individual protection following human intrusion
 - ◆ Groundwater protection

Evaluating FEPs and Defining Scenarios

- **Probability and significance criteria for FEPs provided in 10 CFR 63.114**
- **374 FEPs evaluated**
 - **222 excluded from TSPA**
 - **152 included**
- **Four scenario classes defined for analysis**



TSPA-LA Scenarios

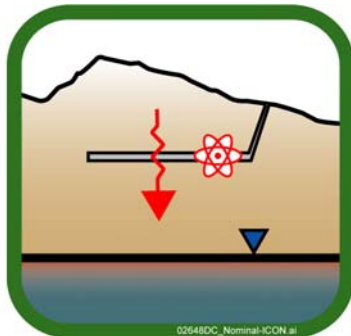
Four scenario classes divided into seven modeling cases

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

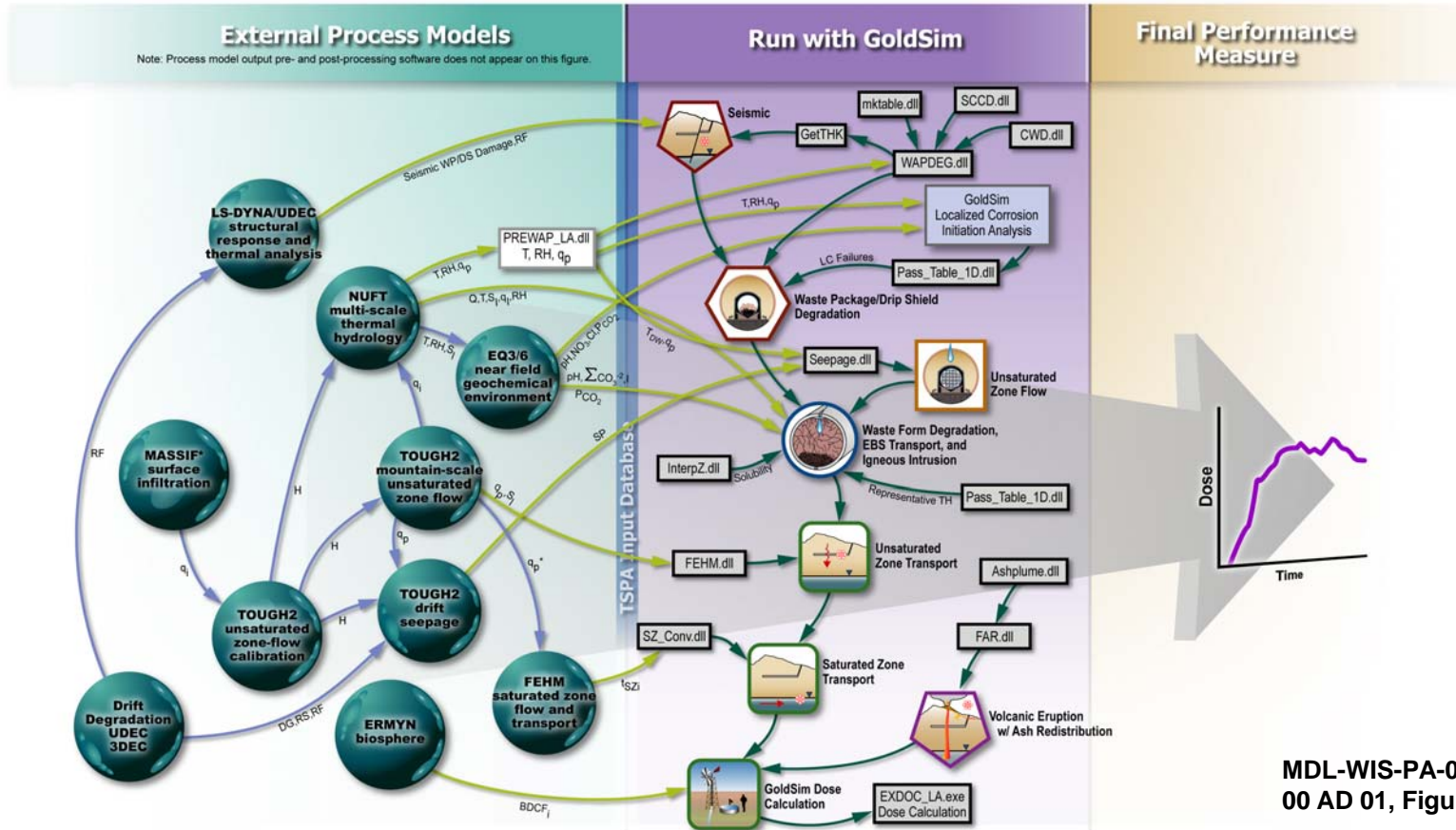


Seismic Scenario Class

- Ground Motion Modeling Case
- Fault Displacement Modeling Case



TSPA Architecture



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

Output Parameters

f_s	Fraction of WPs with Seeps	q_p	Percolation Flux	q_i	Infiltration Flux	H	Hydrologic Properties
EBS	Engineered Barrier System	NO_3	Nitrate Concentration	DG	Drift Geometry	SP	Seepage Parameters
Q_s	Seep Flow Rate	T	Temperature	Cl	Chloride Concentration	RS	Rock Strength
Q	Evaporation Rate	RH	Relative Humidity	I	Ionic Strength	RF	Rockfall Size and Number
pH	pH	S_j	Liquid Saturation	t_{SZi}	Saturated Zone Transport Time		
ΣCO_3^{2-}	Carbonate Concentration	X_a	Air Mass Fraction	BDCF _i	Biosphere Dose Conversion Factor		
PCO_2	Partial Pressure of CO ₂	q_l	Liquid Flux	q_g	Gas Flux		

*Note: q_p derived from INFIL model

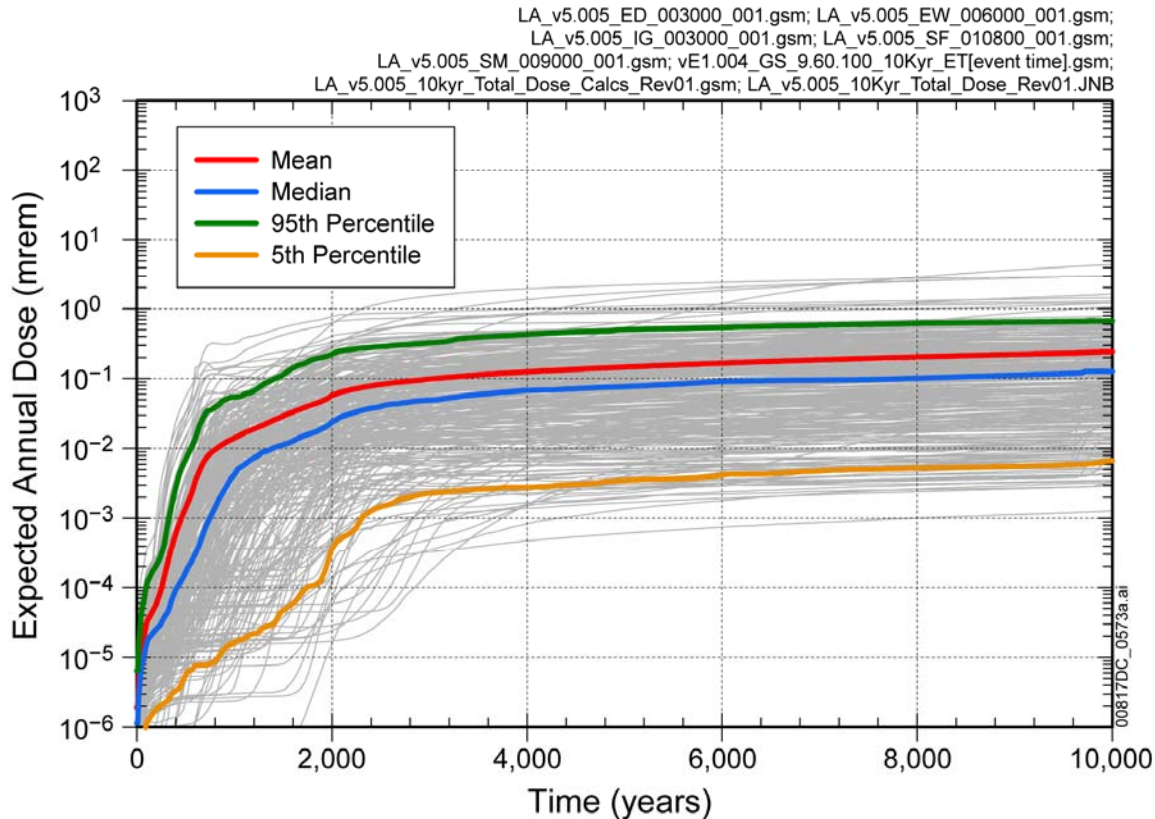


Multiple Barriers and Features Contribute to Waste Isolation

- **Upper Natural Barrier System**
 - Topography and surficial soils
 - Unsaturated zone above the repository
- **Engineered Barrier System**
 - Drift environment
 - Drip Shield
 - Waste Package
 - Waste forms and associated shipping containers
 - Emplacement pallet
 - Drift invert
- **Lower Natural Barrier System**
 - Unsaturated zone below the repository
 - Saturated zone between the repository and the accessible environment

Total System Performance Assessment Results

Individual Protection Standard: 10,000 yr



10,000-year Standard:

**Mean annual dose
no more than 15
mrem**

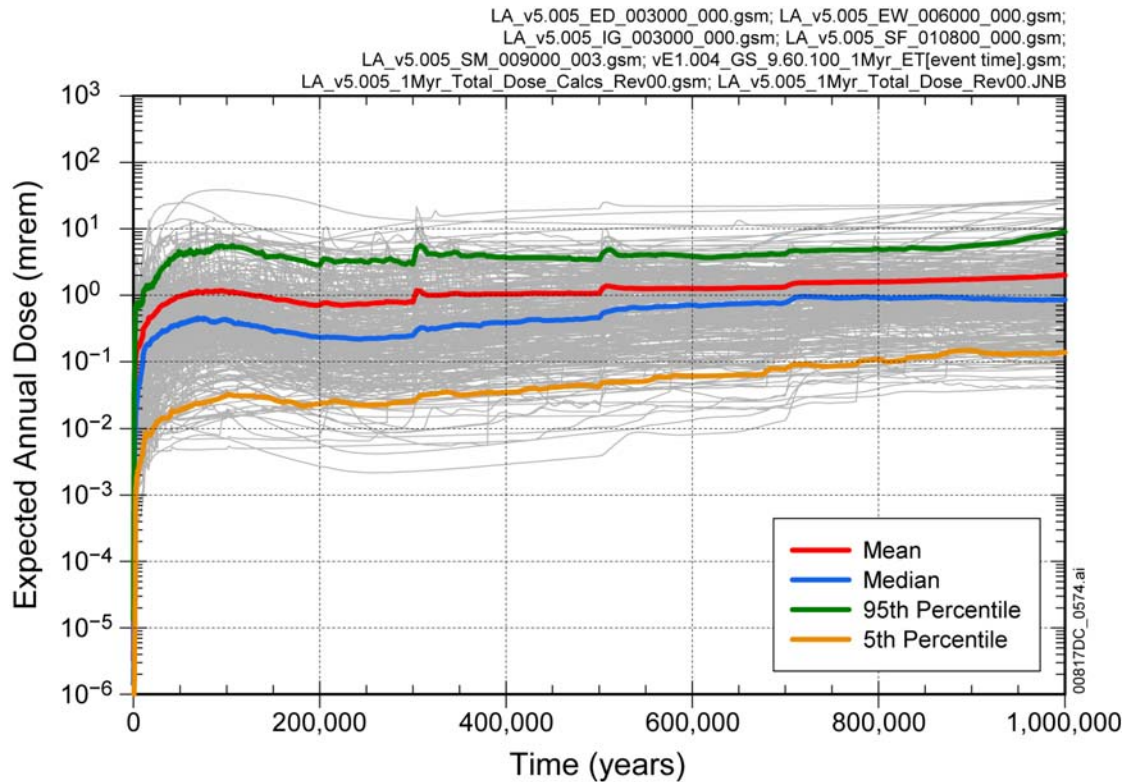
**TSPA-LA estimated
10,000 yr maximum
mean annual dose:**

0.24 mrem

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-1[a]

Total System Performance Assessment Results

Proposed Individual Protection Standard: 1,000,000 yr



**Proposed 1,000,000-year
Standard:**

**Median annual dose no
more than 350 mrem**

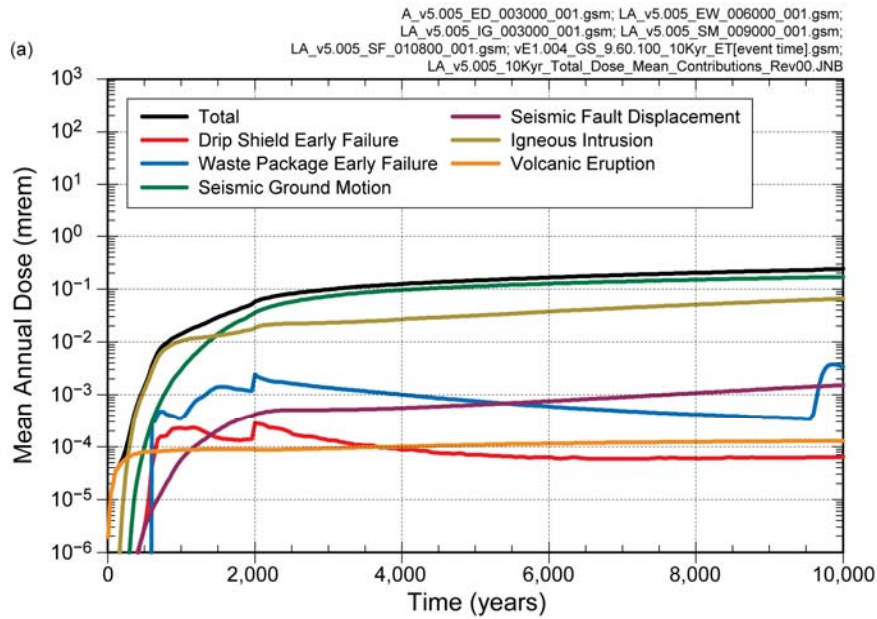
**TSPA-LA estimated
1,000,000- yr maximum
median annual dose:**

0.96 mrem

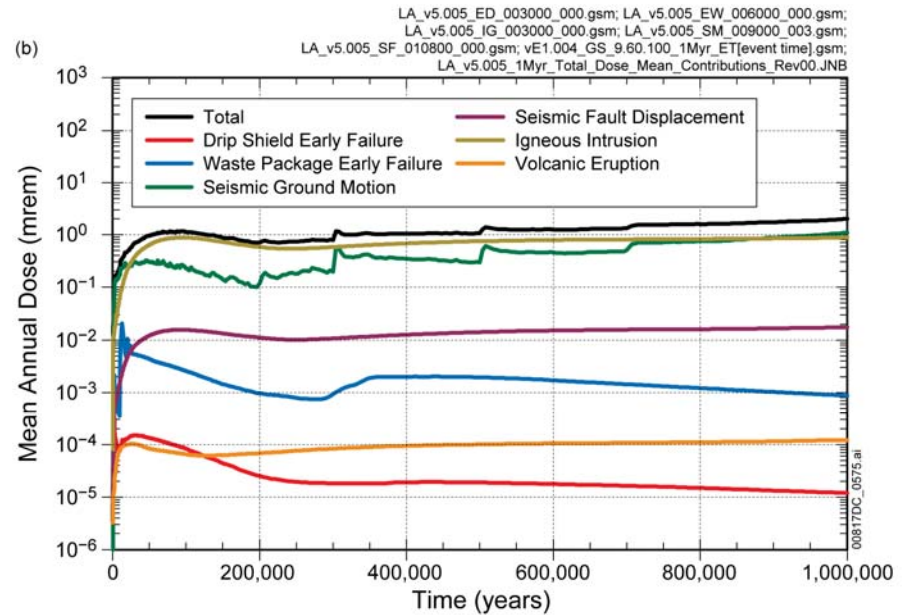
**(Maximum mean annual
dose: 2.0 mrem)**

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

TSPA Results: Modeling Cases Contributing to Total Mean Annual Dose



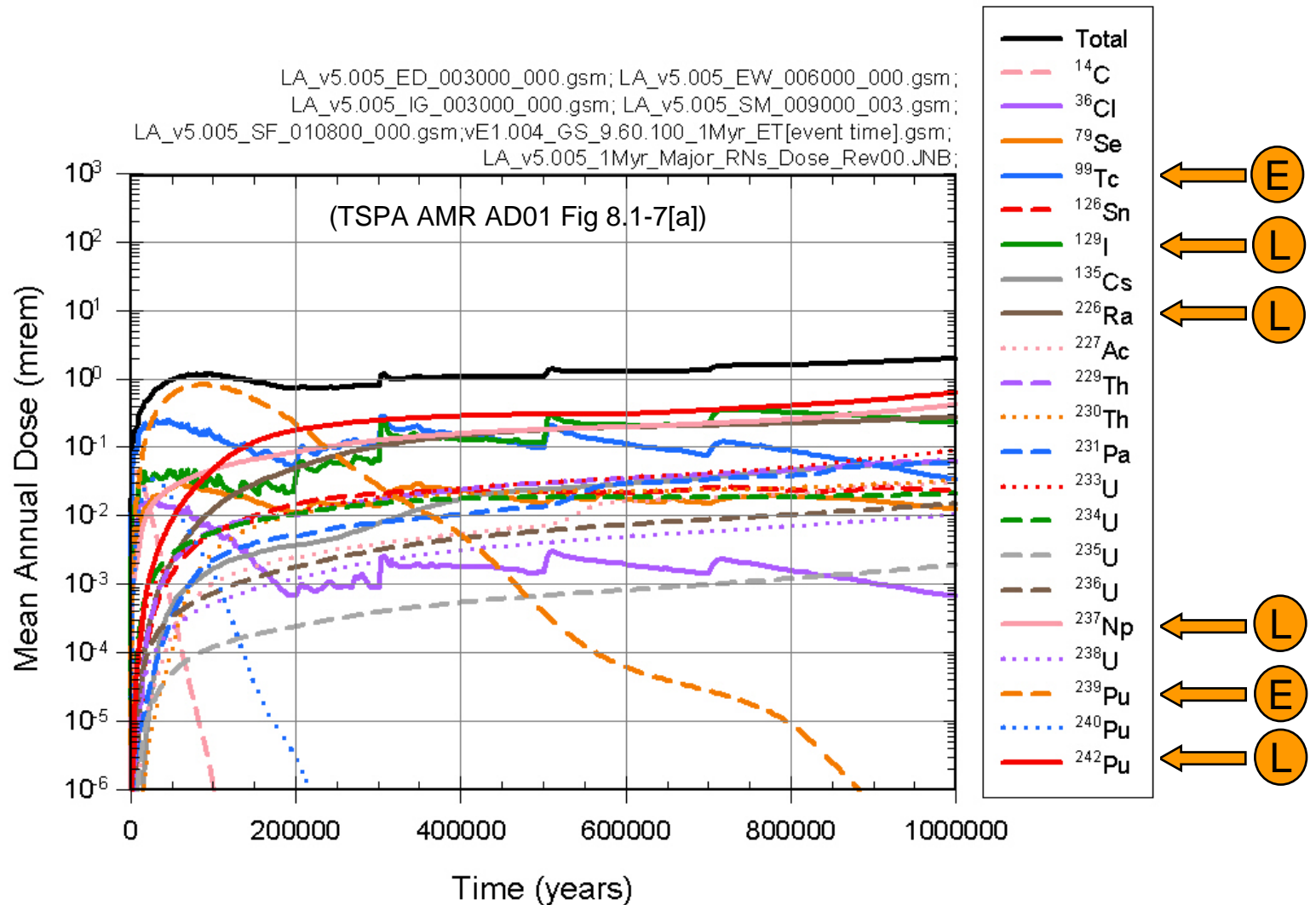
10,000 years



1,000,000 years

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

Radionuclides Important to Mean Dose Early (E) and Late (L)



- **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**
- **All performance measures are well below proposed regulatory limits**

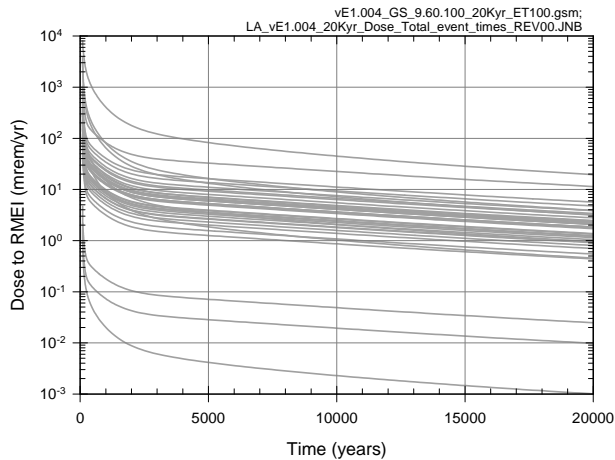
- US DOE (United States Department of Energy), *Yucca Mountain Repository License Application*, DOE/RW-0573, Rev. 0 (2008) (available at <http://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html#appdocuments>)
 - Documentation of the TSPA is provided in Section 2.4 of the Safety Analysis Report contained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



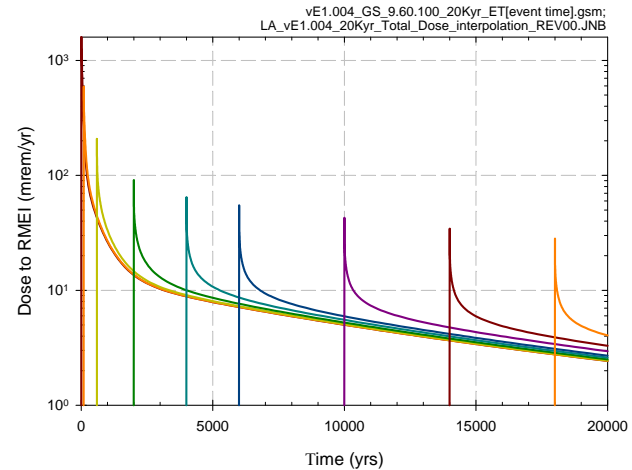
Backup



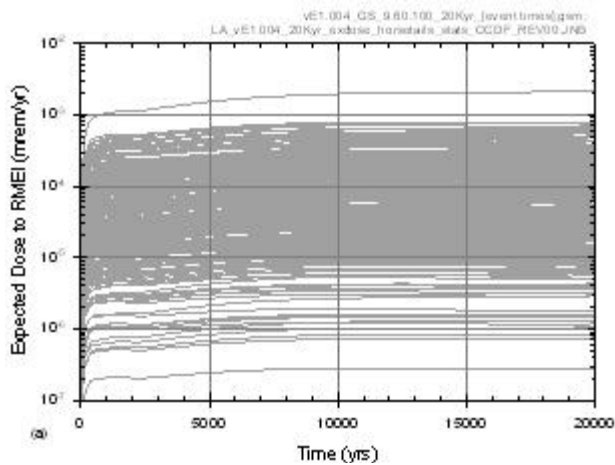
Example Treatment of Disruptive Events: Eruptive Dose



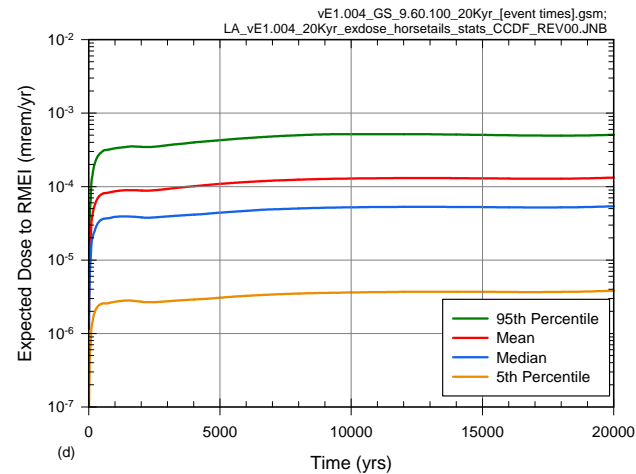
Eruptive dose: 40 realizations of aleatory uncertainty conditional on a single eruption of 1 WP at time zero



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



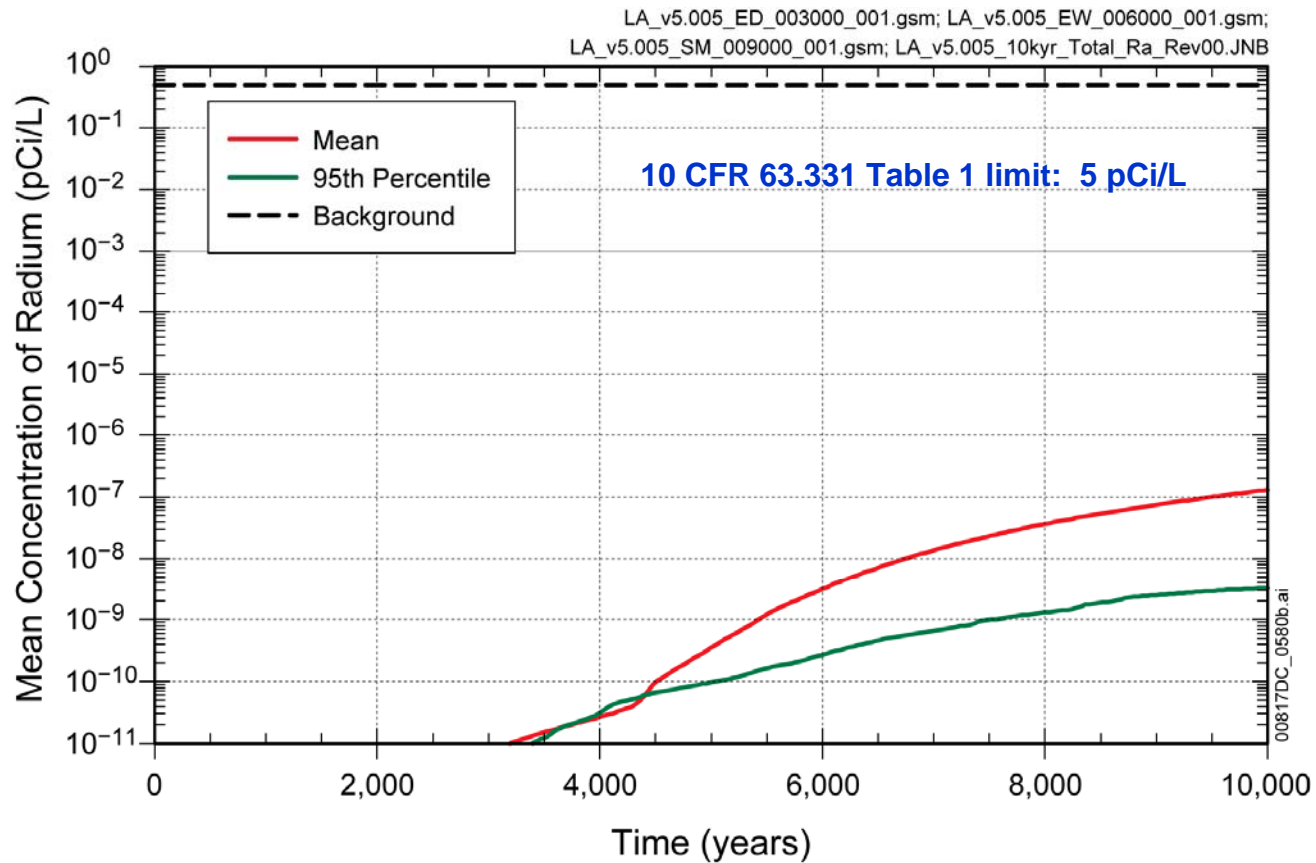
Expected eruptive dose; 300 realizations, each showing expected dose from a single sampling of epistemic uncertainty with events at all times



Summary curves showing overall mean dose from eruption

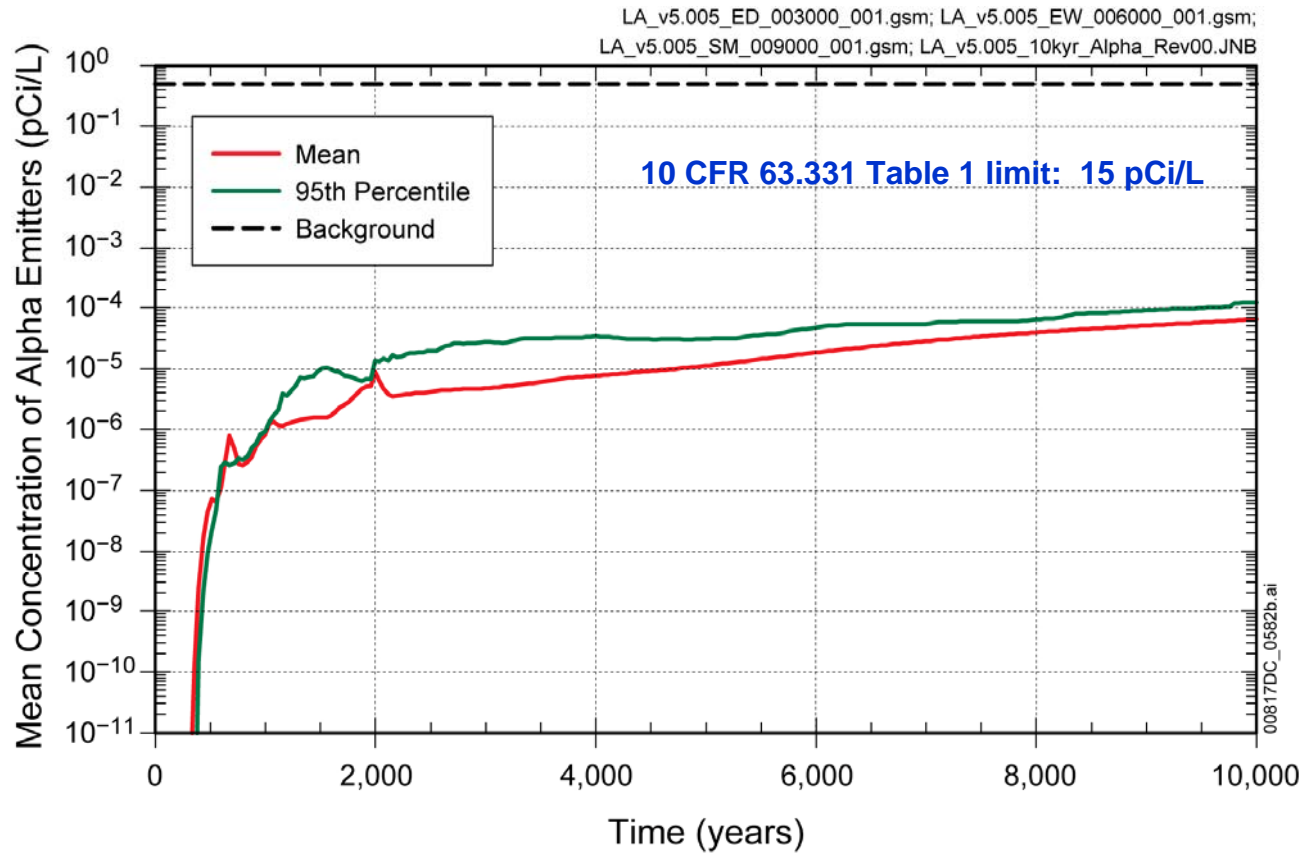
MDL-WIS-PA-000005 Rev 00, Figures J7.3-1, 2,&4

Groundwater Protection Standard



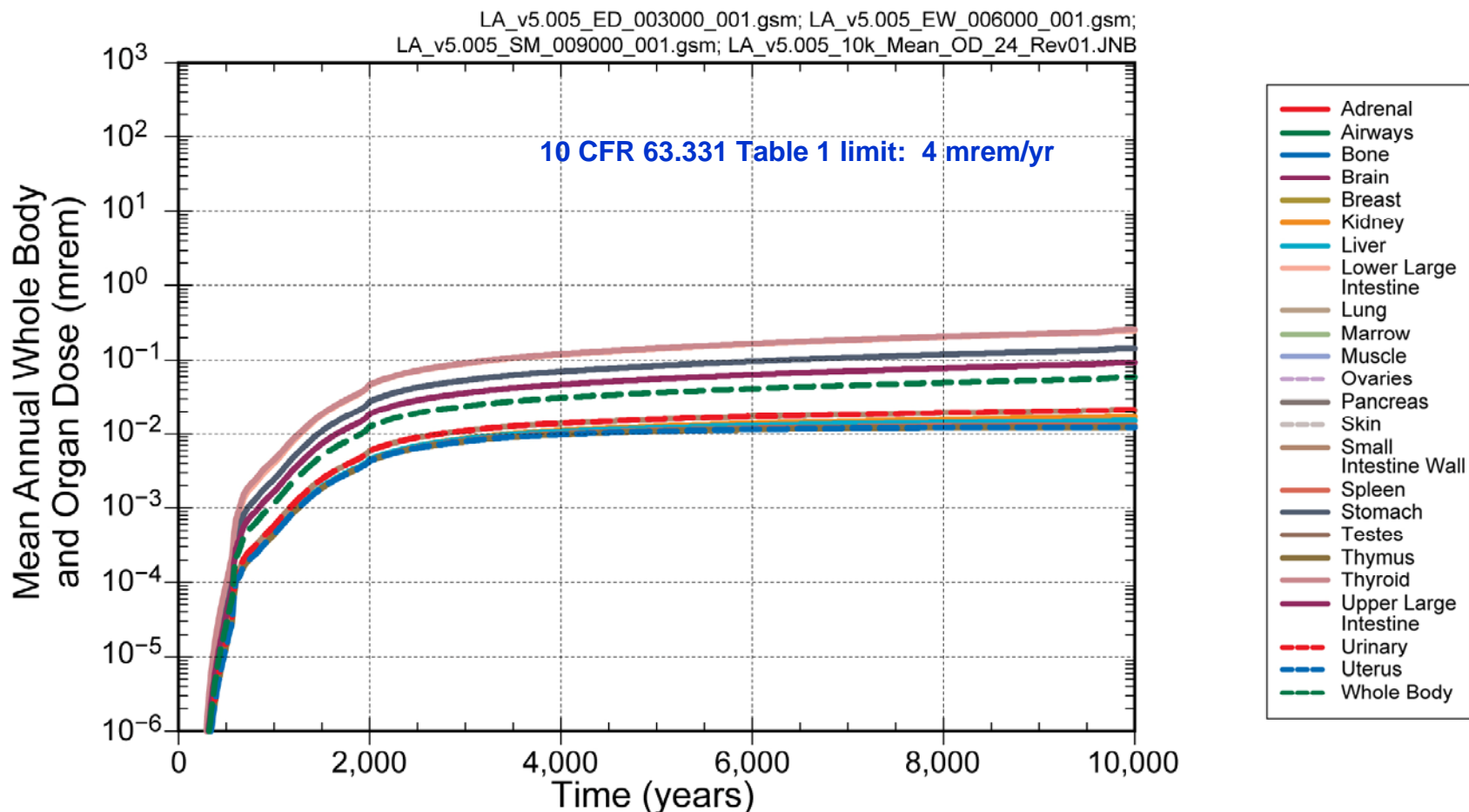
Total Radium Activity in Groundwater
MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-9[a]

Groundwater Protection Standard (cont.)



**Total Gross Alpha Activity in Groundwater,
Excluding Radon and Uranium
MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-9[a]**

Groundwater Protection Standard (cont.)



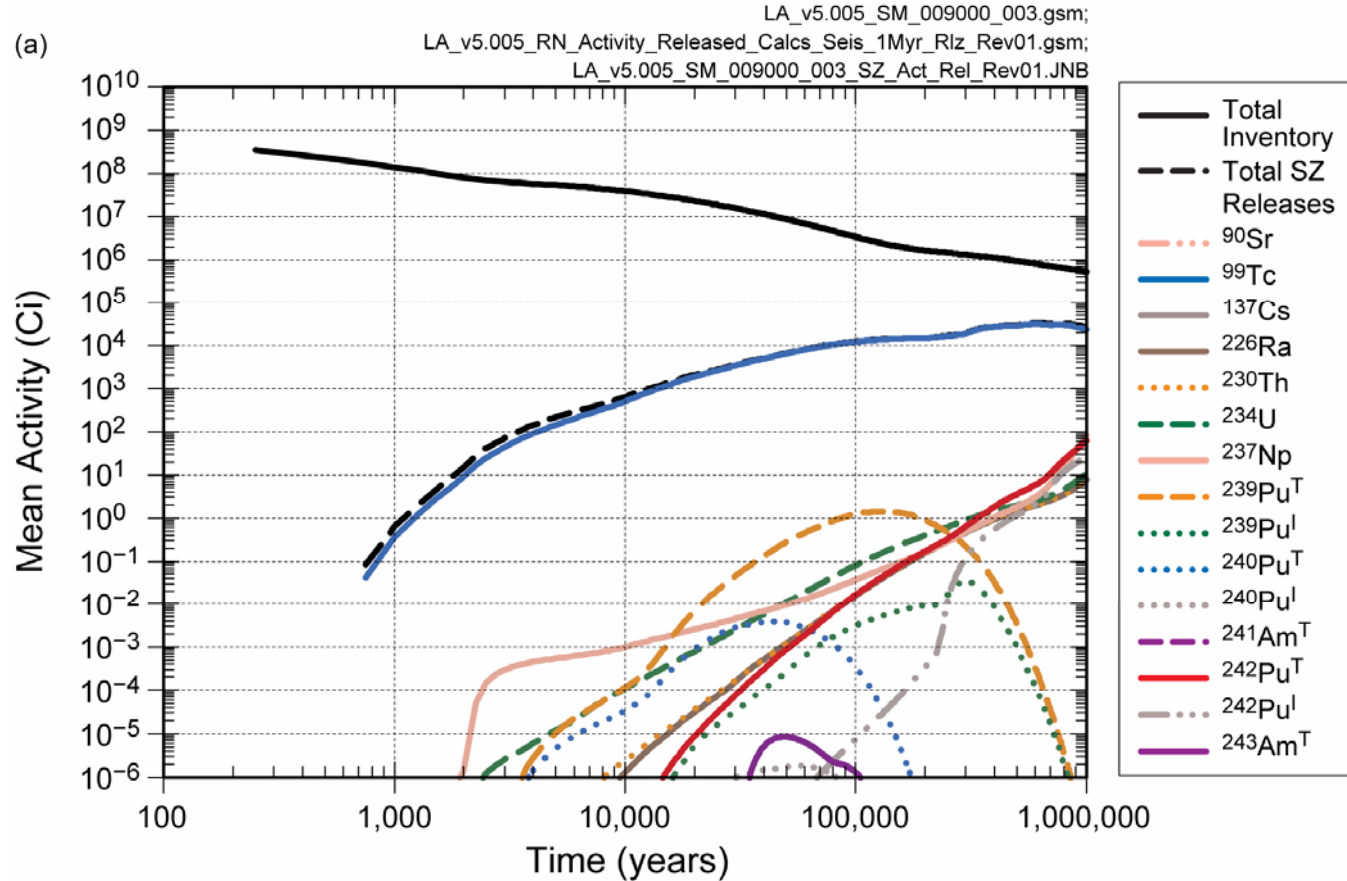
**Mean Annual Beta and Photon Dose from Groundwater,
 excluding natural background
 MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-13[a]**

Example Barrier Capability Analysis

At 1 million 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]

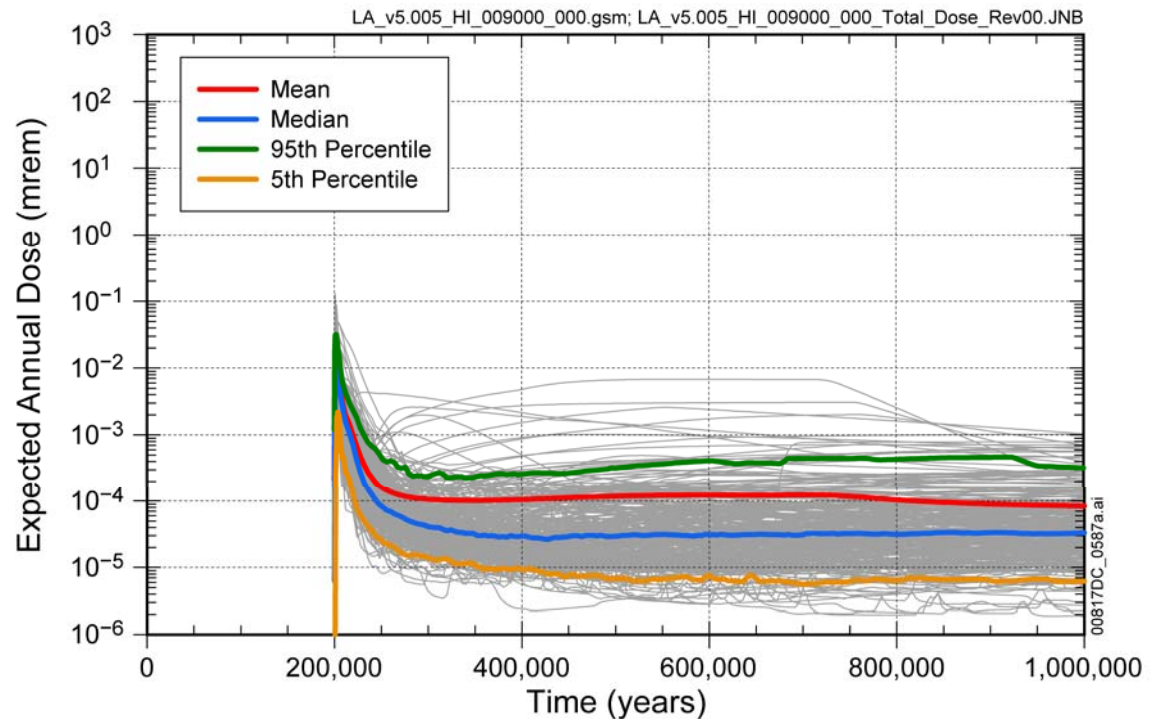
Human Intrusion Standard

Consistent with 10 CFR 63.321, borehole penetration of a single waste package occurs at the earliest time a driller would not recognize the repository, and releases occur through groundwater

Intrusion assumed to occur at 200,000 years

Proposed regulatory limit after 10,000 yr is a median annual dose of 350 mrem

Maximum median annual dose is 0.011 mrem



MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-16[a].



Groundwater Protection Standard

- **Consistent with 10 CFR 63.331, analyses consider 10,000 yr and do not include human intrusion or unlikely natural events (i.e., igneous disruption)**
- **Combined Ra-226 and Ra-228 activity, including background, must be less than 5 pCi/L**
 - **Natural background is approximately 0.5 pCi/L**
 - **Maximum mean Ra-226 and Ra-228 activity derived from the repository is 1.3×10^{-7} pCi/L**
- **Total gross alpha activity including Ra-226 but excluding U and Rn must be less than 15 pCi/L**
 - **Maximum mean total gross alpha activity derived from the repository is 6.7×10^{-5} pCi/L**
- **Mean annual dose from beta and photon emitters in 2 L/day of drinking water must be less than 4 mrem**
 - **Maximum mean annual beta and photon dose is 0.06 mrem for the whole body and 0.26 mrem for the thyroid**