U.S. Department of Energy
Office of Civilian Radioactive Waste Management

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Barrier Capability and the Assessment of System Performance

Presented to:
Nuclear Waste Technical Review Board, Full Board Meeting

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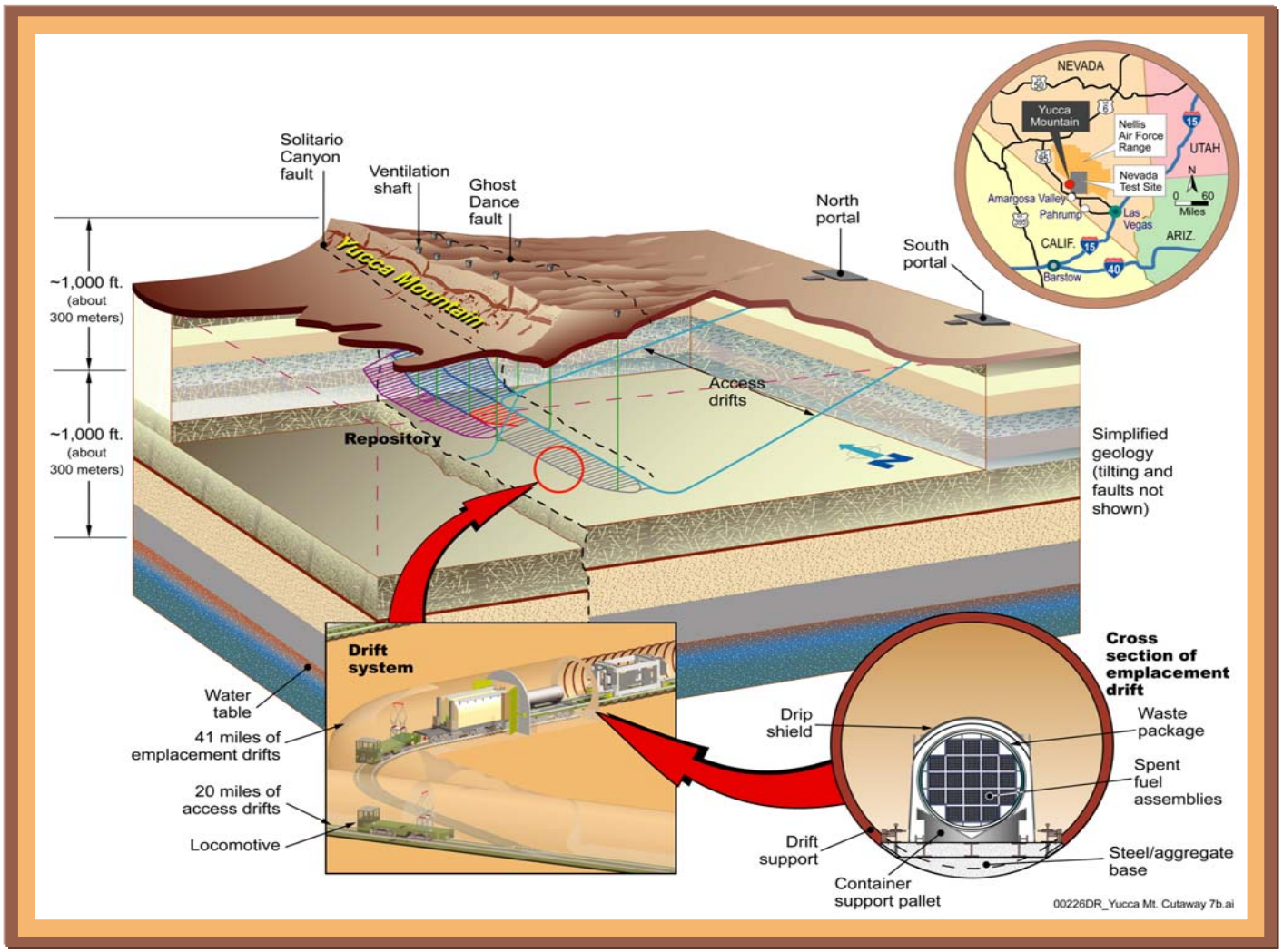
Overview

- Quantitative aspects of the safety case
  - Barrier capability
  - System performance
- Building confidence in quantitative assessments through an iterative process
  - Evaluate component and system performance
  - Acknowledge uncertainty
- Representative examples of quantitative estimates of barrier capability and system performance

Evaluating Barrier and System Performance is an Iterative Process

- Characterize the system and its components
- Identify important features, events, and processes
- Construct component models
- Characterize uncertainty
- Construct system model and evaluate component and system performance
- Identify important uncertainties
- Iterate

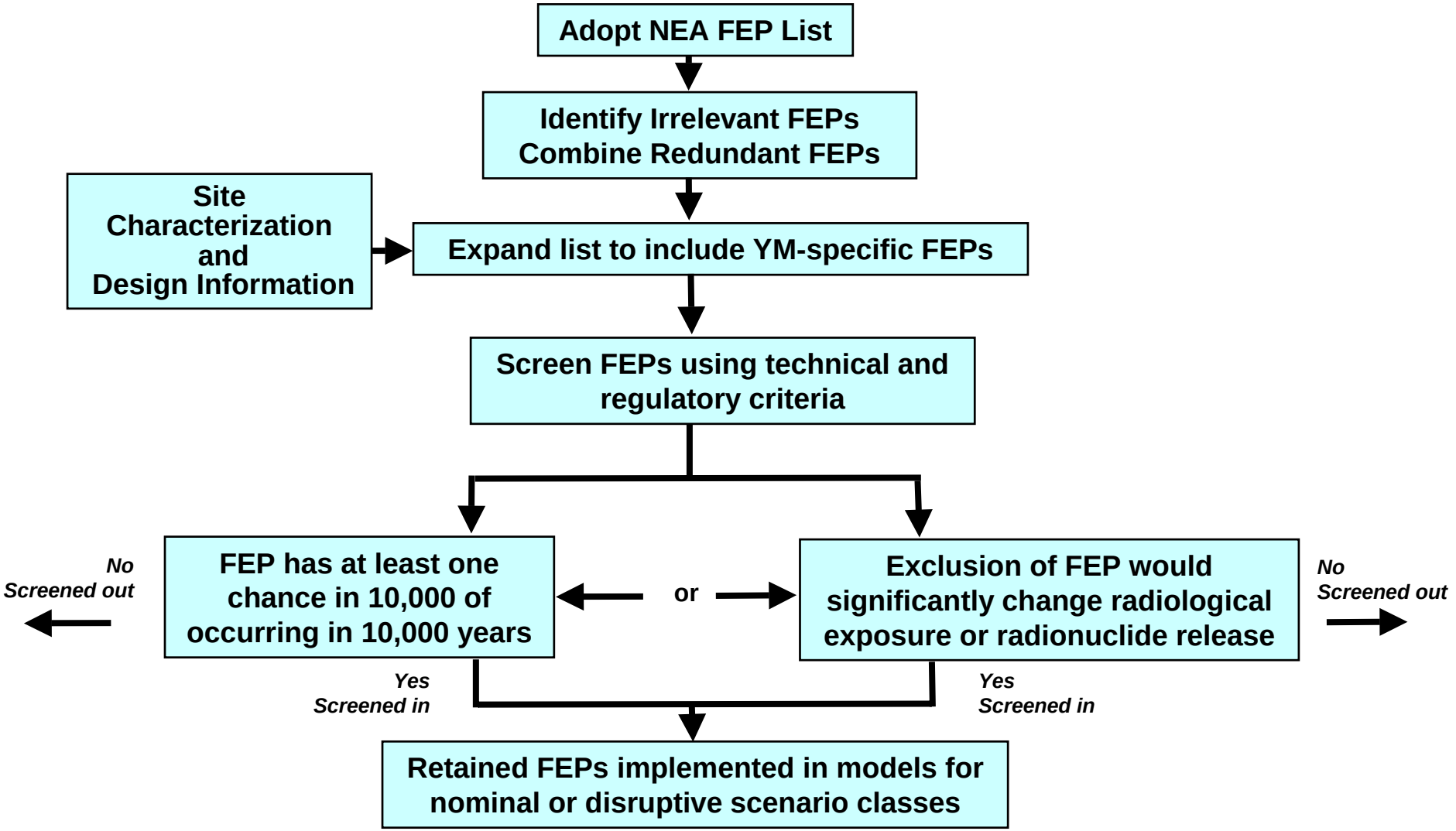
Site Characterization and Design



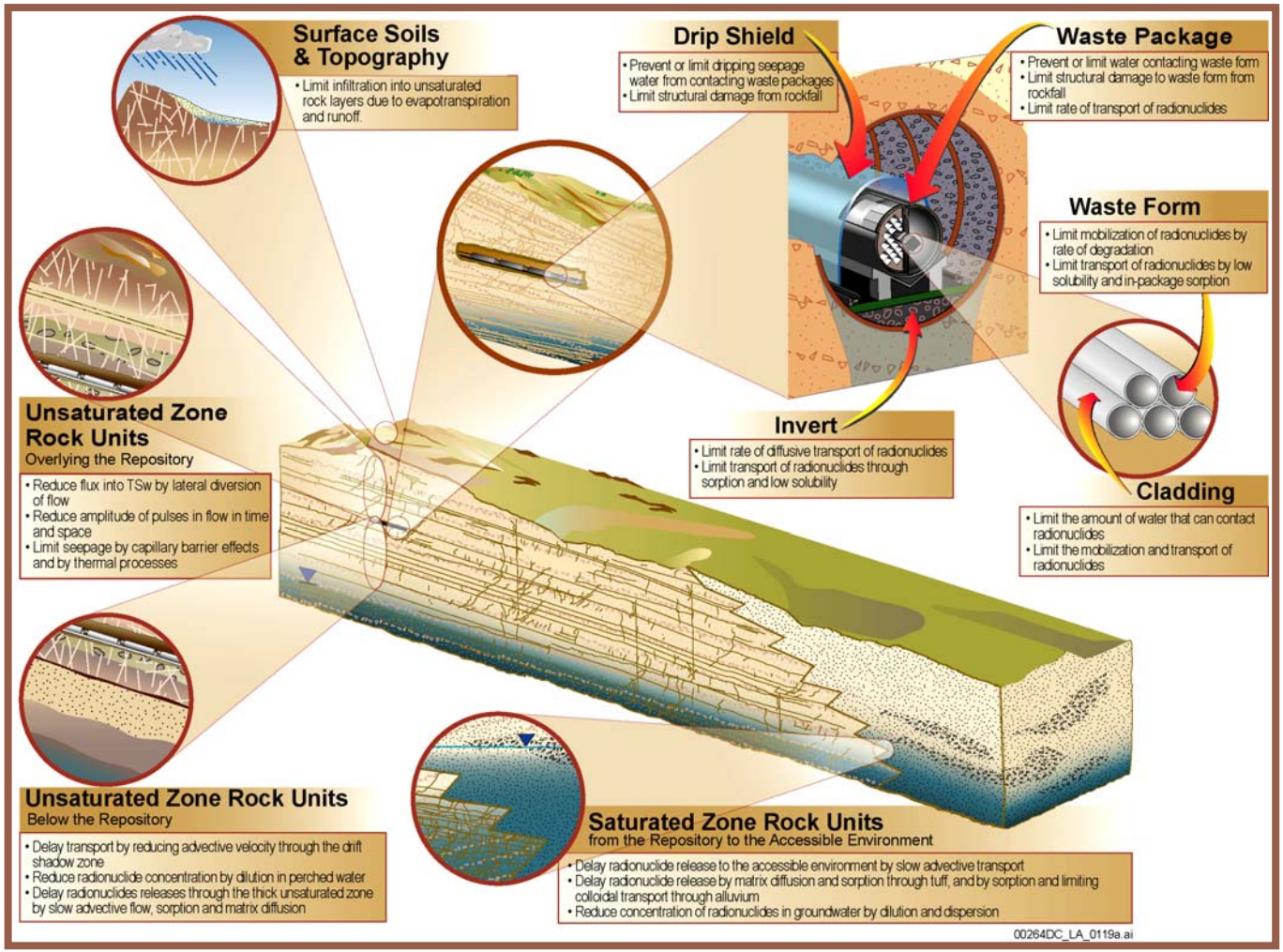
Identification of Features, Events, and Processes Relevant to Yucca Mountain

- **Demonstrate the completeness of the analysis through systematic consideration of all features, events, and processes (FEPs) that are potentially relevant to the Yucca Mountain repository**
- **YMP FEPs are a comprehensive list that address all issues identified from:**
  - **Nuclear Energy Agency (NEA) international FEP database**
  - **Site-specific FEPs from YMP literature**
  - **Iterative reviews (internal and external) of earlier YMP FEP lists**
- **Currently, approximately 370 FEPs evaluated for Yucca Mountain**
  - **Total number of FEPs is a subjective function of the level of detail desired**
- **New FEPs can be added and evaluated as they are identified**

Evaluating FEPs

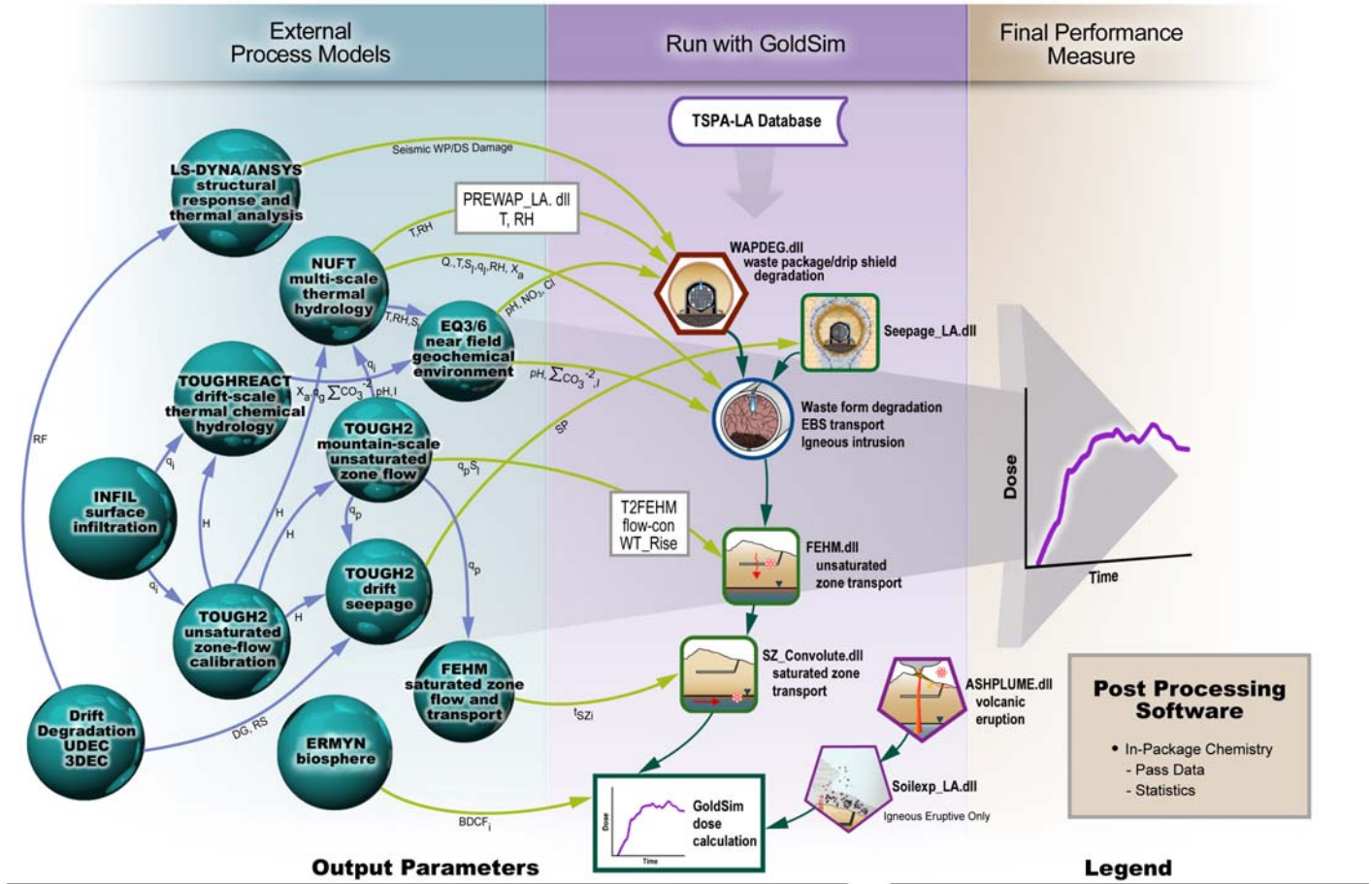


Yucca Mountain Component Models (nominal performance)



- Surface soils and topography
- Unsaturated zone (UZ) above (seepage, drift effects)
- Drip shield
- Waste package
- Cladding
- Waste form
- Invert
- UZ below (transport)
- Saturated zone (SZ)

TSPA Architecture



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

Confidence in Component and System Models

- **Multiple approaches to building confidence in component and system models**
  - **Corroboration with direct observation**
  - **Corroboration with analogue information**
  - **Corroboration with independent evaluations**
  - **Corroboration with auxiliary analyses and by comparison of system and subsystem analyses**
  - **Peer review**
- **Component models are evaluated individually and in the context of the system model**

Acknowledging Uncertainty

- **Sources of uncertainty**
  - **Incomplete data**
    - **E.g., hydrologic material properties can never be obtained for all locations**
  - **Spatial variability and scaling issues**
    - **E.g., data may be available from small volumes or discrete locations but may be used in models to represent large volumes**
  - **Measurement error**
    - **Usually only a minor contributor to total uncertainty**
  - **Lack of knowledge about the future state of the system**
    - **E.g., uncertainty about the occurrence of disruptive events**
  - **Alternative conceptual models**
- **Monte Carlo techniques used to incorporate uncertainty in modeling**

Representative Quantitative Estimates of Barrier Capability and System Performance

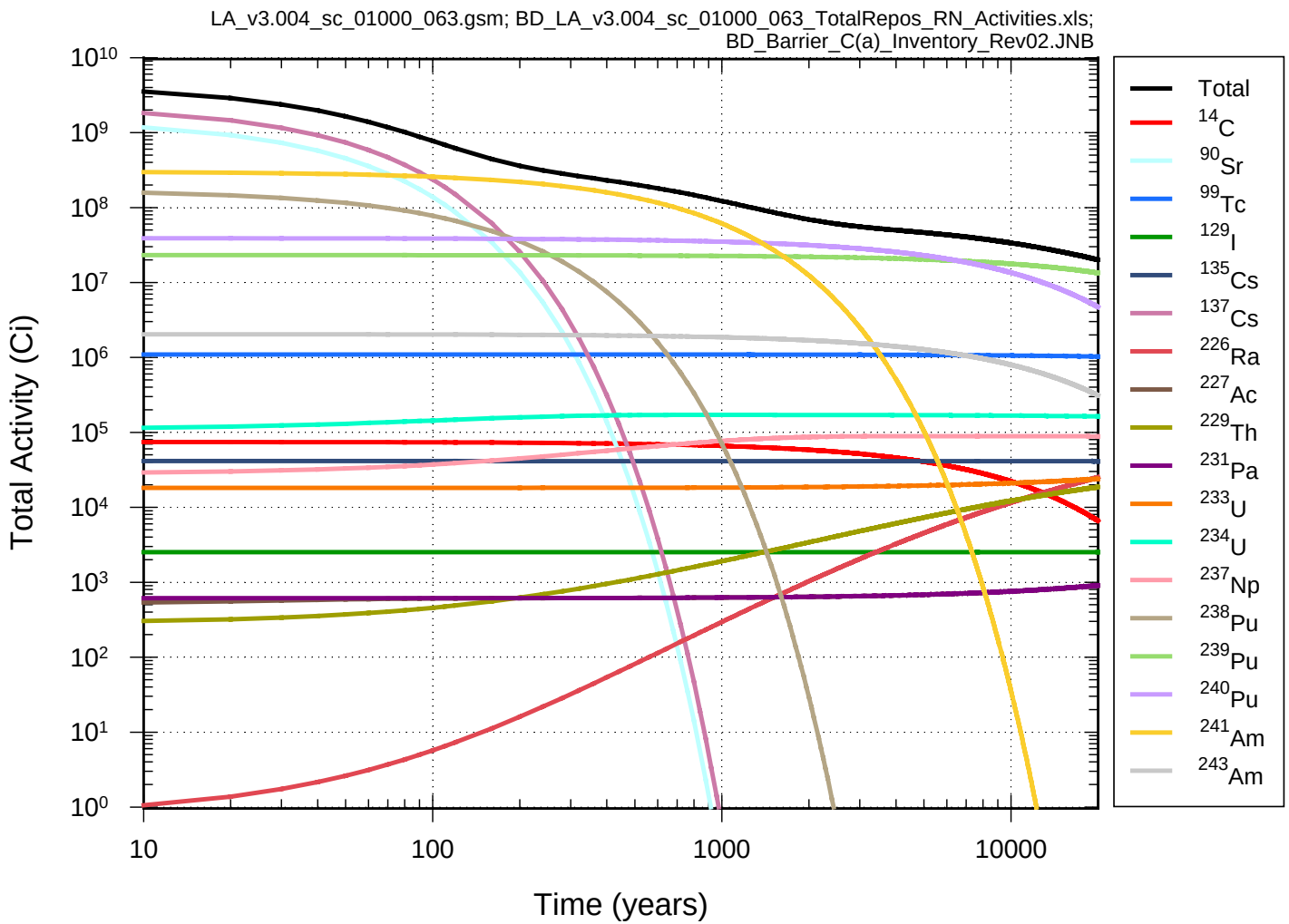
All quantitative model results shown in this presentation are for illustration purposes and are not intended for comparison to regulatory standards

Barrier Capability

- **Barriers may**
  - **Limit water reaching the waste**
  - **Limit the release of radionuclides from the waste form**
  - **Limit the transport of radionuclides from the waste form to the human environment**
- **Barrier performance may be evaluated separately or as part of a system**
  - **Separately, barrier components have potential capabilities that may not be fully realized within the full system**
  - **The full system relies on complementary and overlapping capabilities of multiple barriers to ensure performance**

Yucca Mountain Radionuclide Inventory

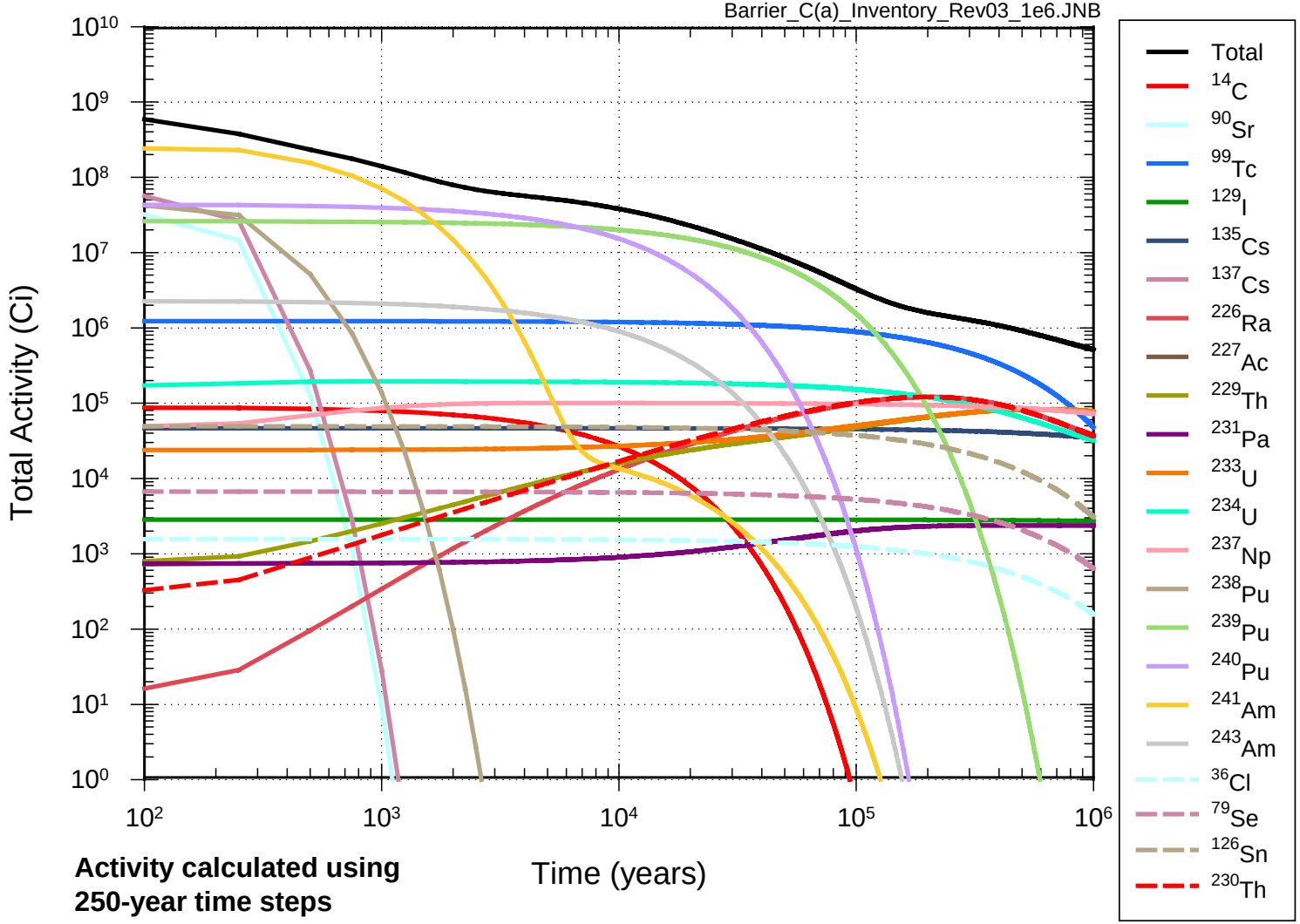
20,000 years



Yucca Mountain Radionuclide Inventory

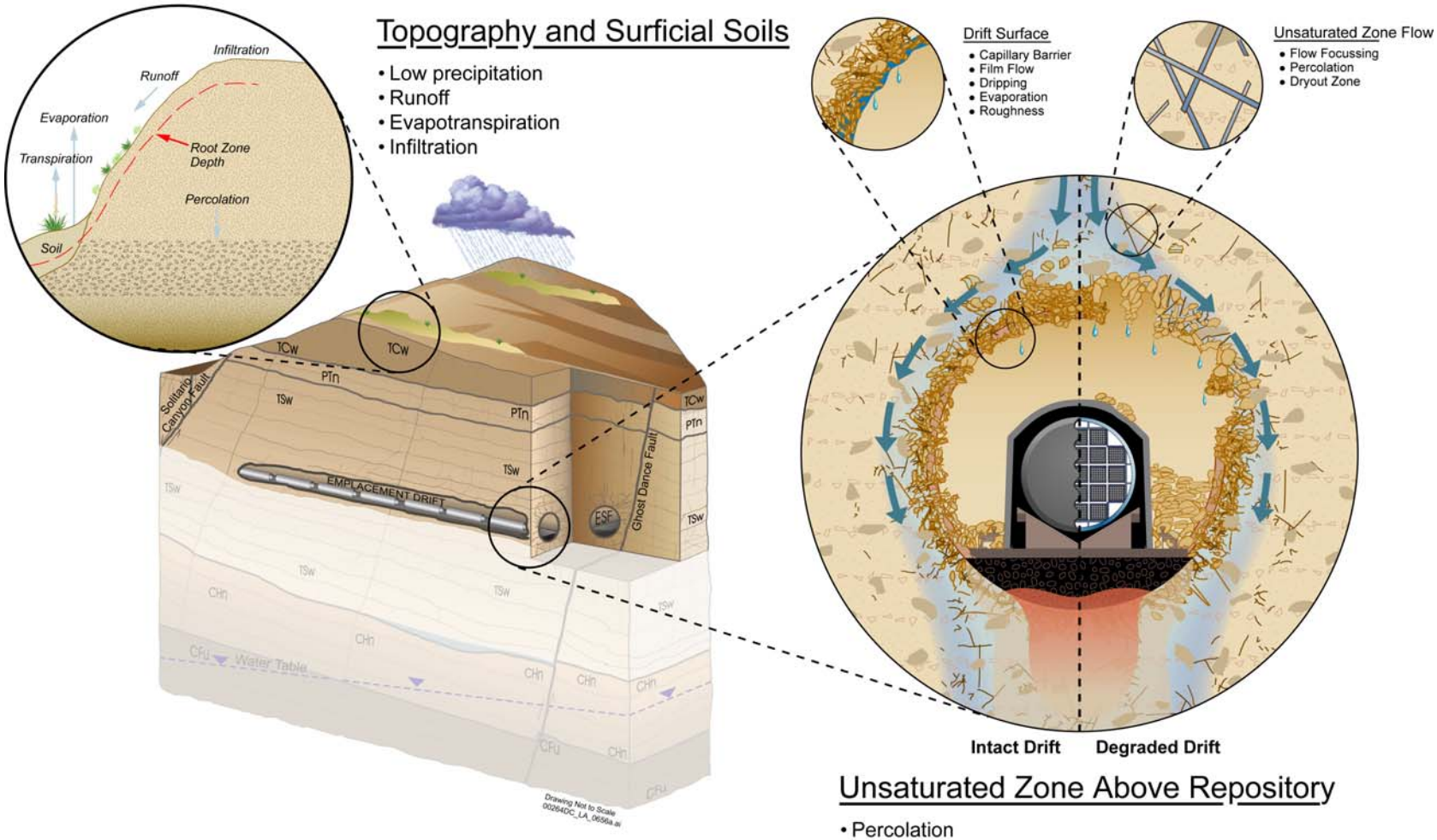
1 million years

v4.008_GS_9.21.000_Nom_Seis_1e6.gsm; Convert_Grams_to_Ci_v4.008_1e6.xls;
Barrier_C(a)_Inventory_Rev03_1e6.JNB



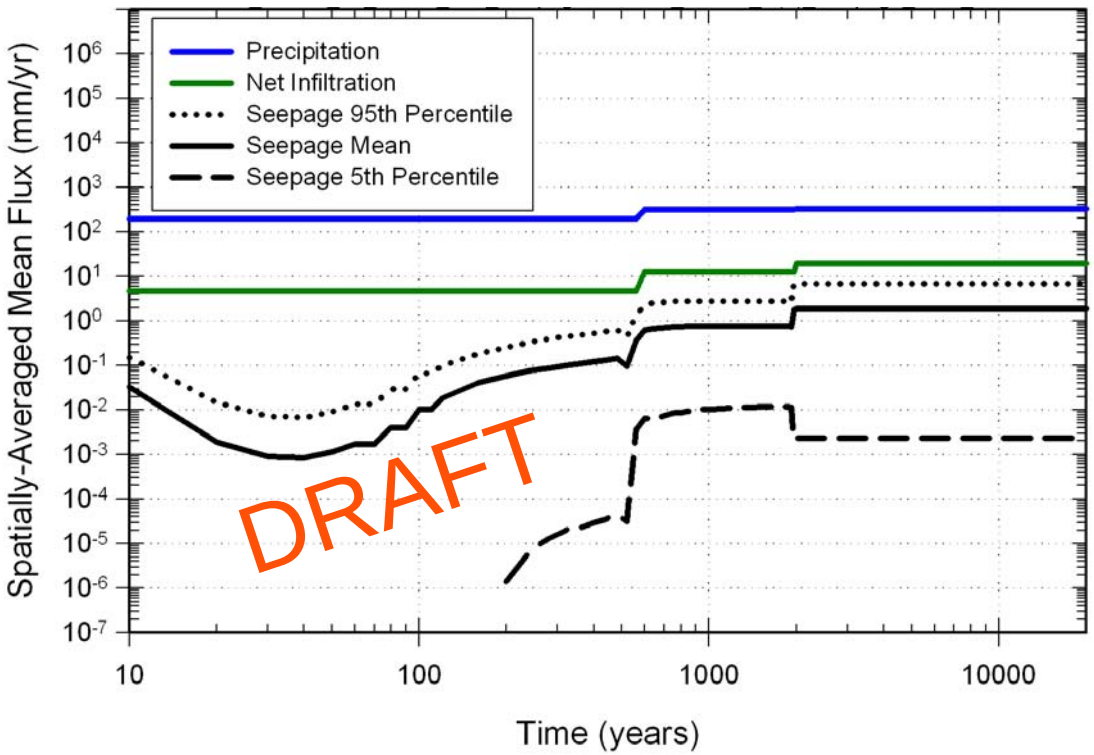
Activity calculated using 250-year time steps

Upper Natural Barrier

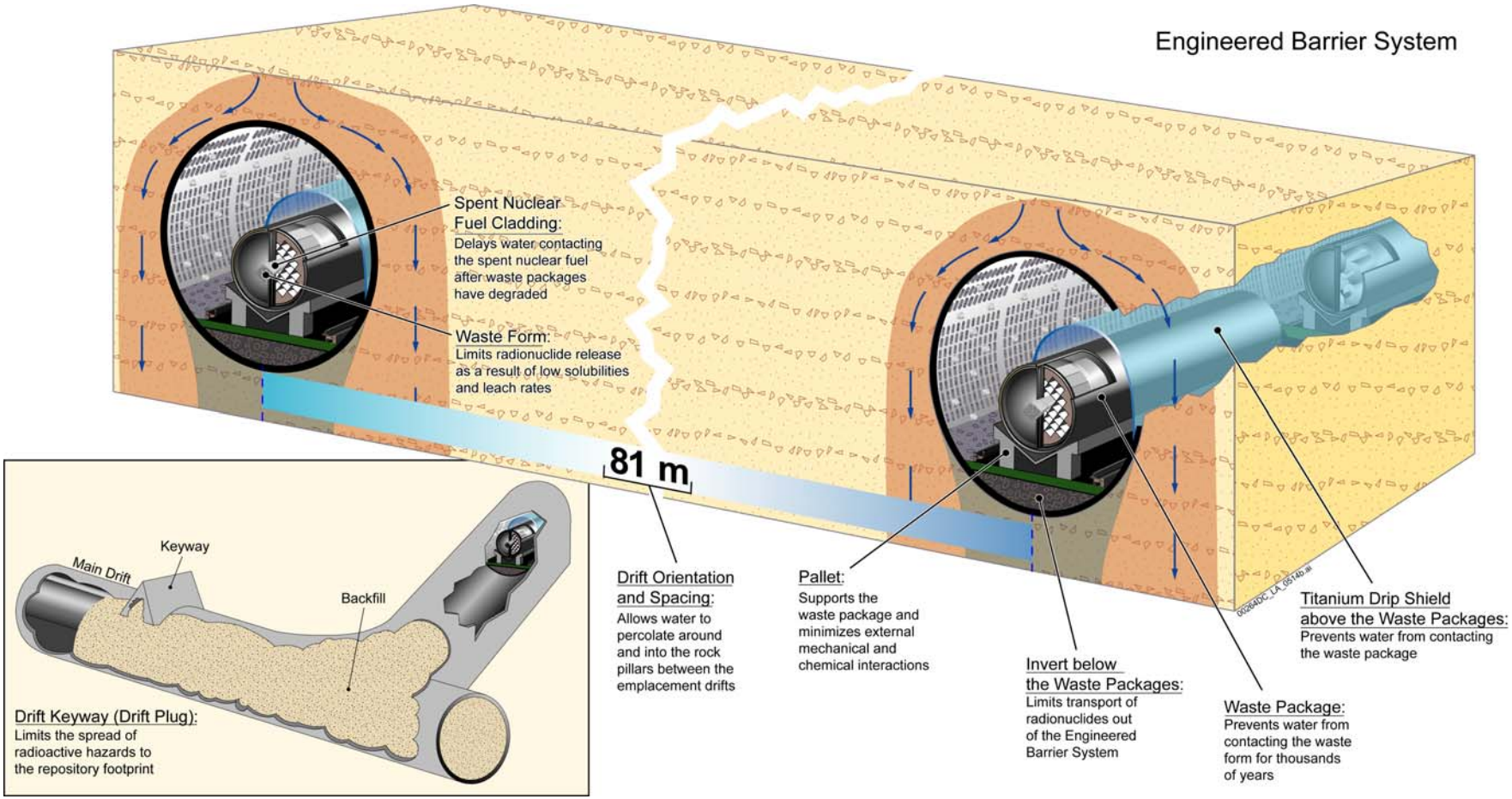


Example Barrier Capability
Components of the Upper Natural Barrier

- **Draft comparison of precipitation, infiltration, and seepage**
  - **Precipitation and infiltration are shown as spatial averages for 38.7 km² domain, including uncertainty in infiltration and climate**
  - **Distribution of seepage values includes spatial variation in thermal history**
  - **Steps in time history correspond to climate changes**
- **The upper natural barrier has the potential to reduce spatially-averaged water flux approx. 100x**

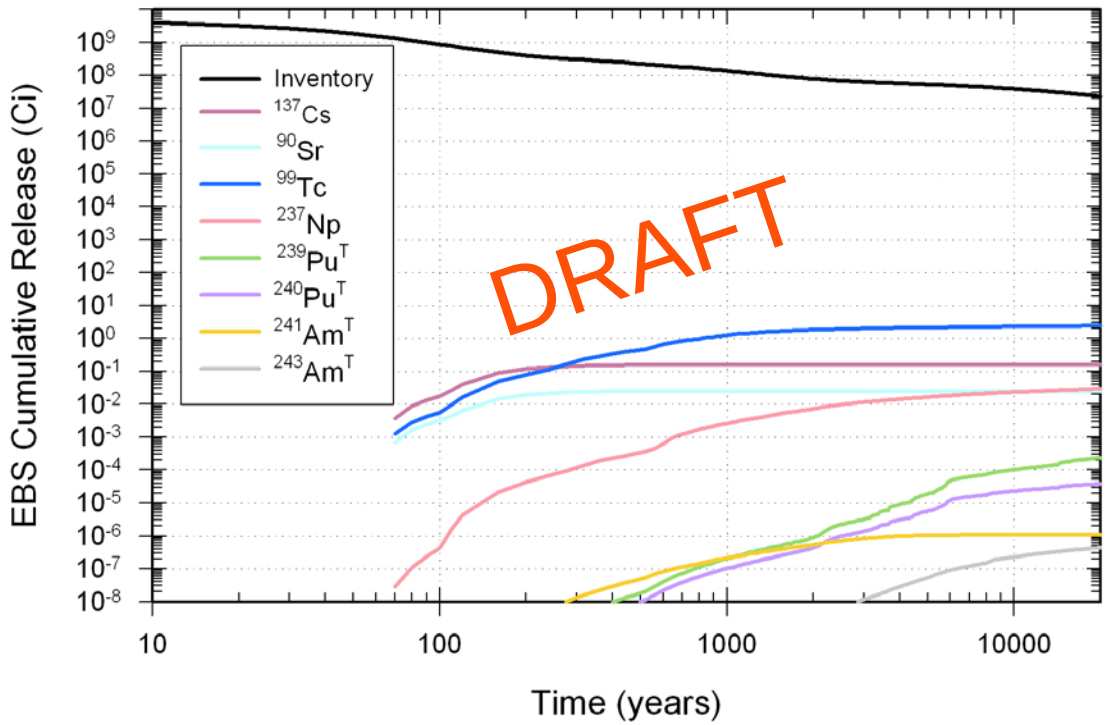


Engineered Barrier System



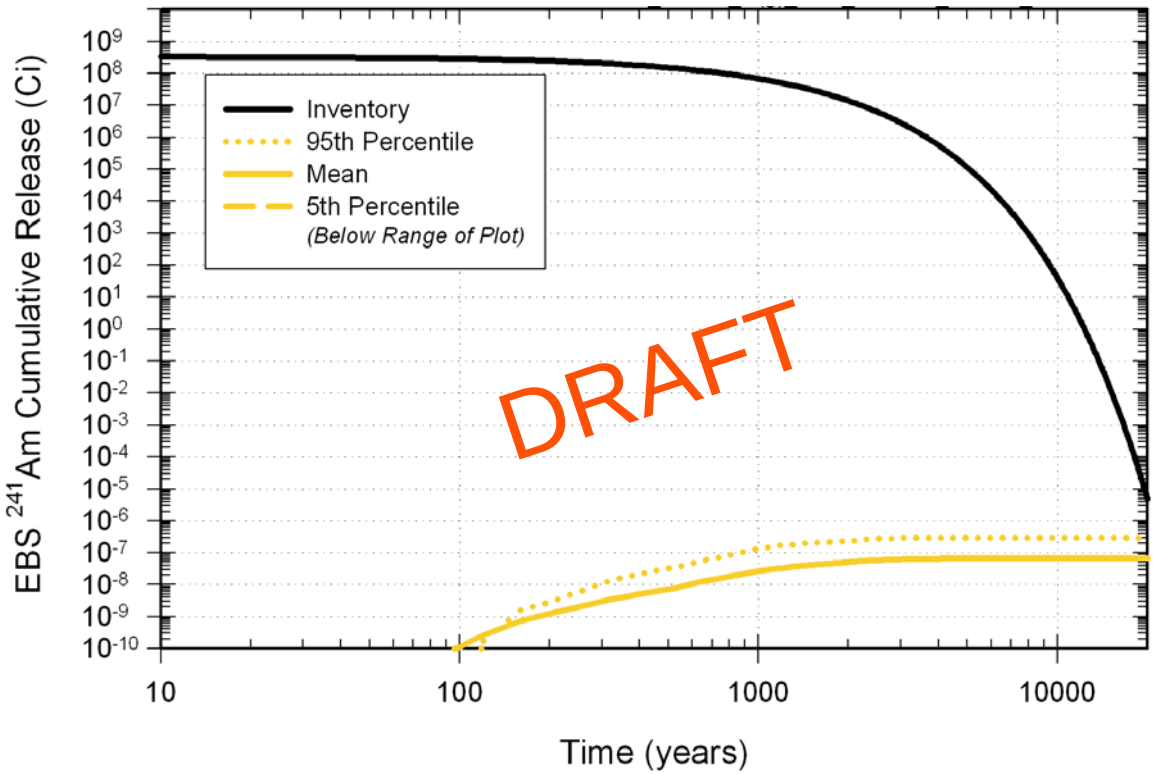
Example Barrier Capability
Engineered Barrier System

- **Draft cumulative releases from the engineered barrier system**
  - **Results shown for preliminary analyses of nominal performance with early waste package failures and intact drip shields**
  - **Total radionuclide inventory (curies) shown for comparison**
- **The engineered barrier system has the potential to retain the overwhelming majority of the total radioactivity for 10,000 years and beyond**

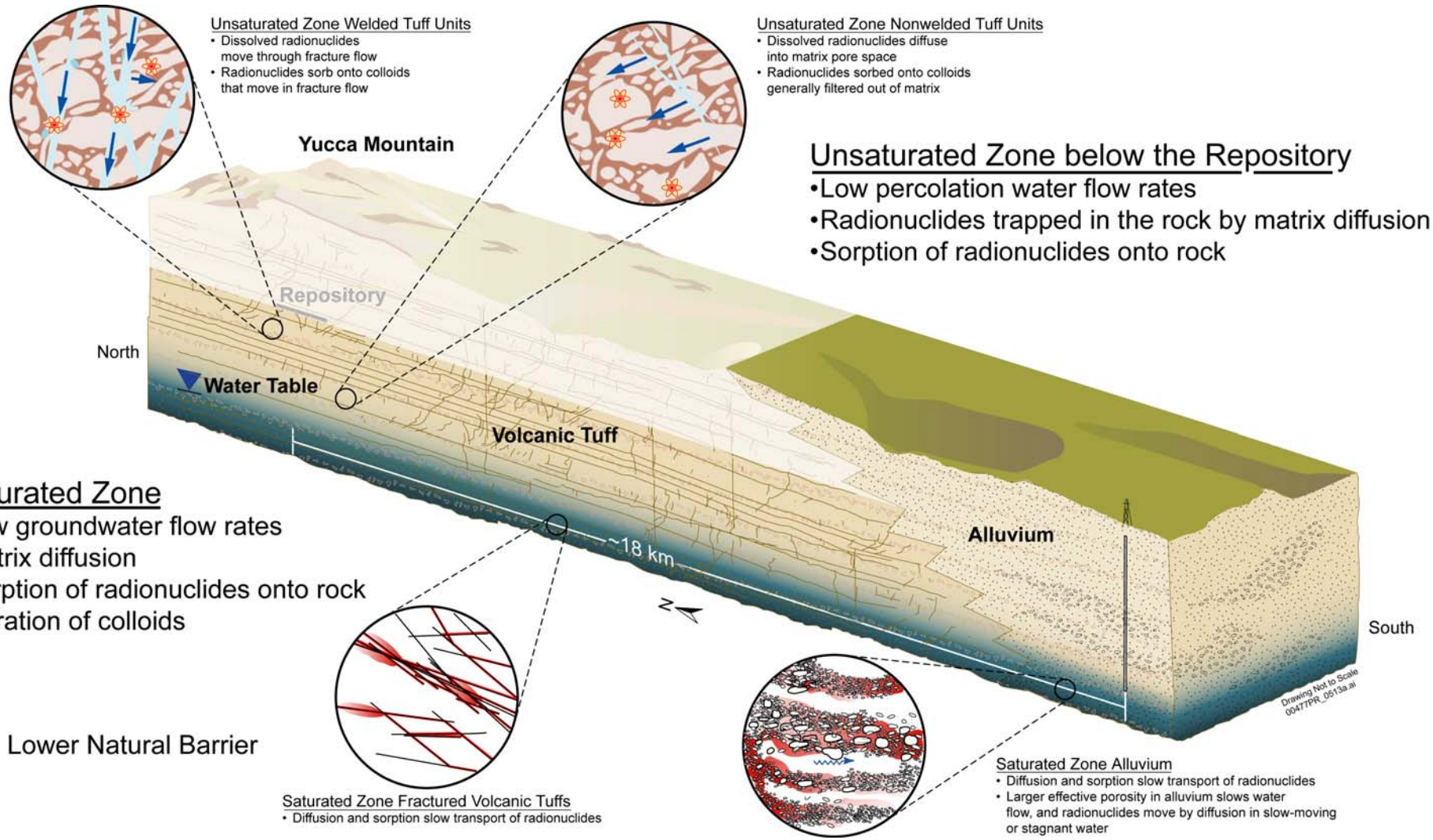


Example Barrier Capability
Engineered Barrier System (continued)

- **Draft cumulative releases of a single species (^{241}Am) from the engineered barrier system**
  - **Results shown for preliminary analyses of nominal performance with early waste package failures and intact drip shields**
  - **Total ^{241}Am inventory (curies) shown for comparison**

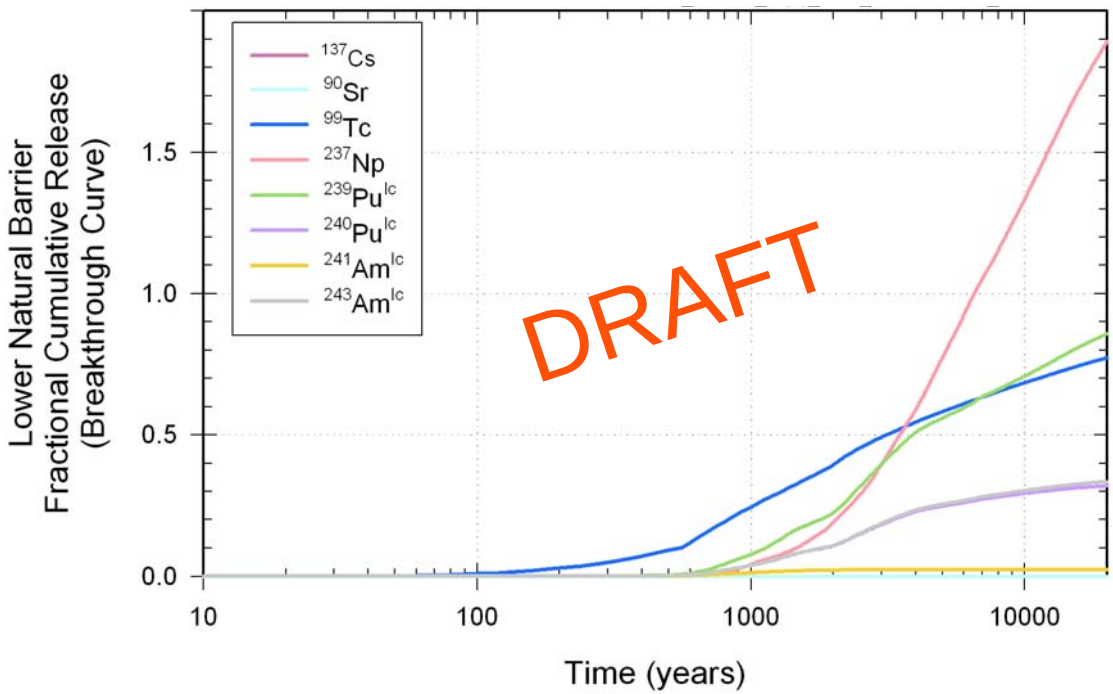


Lower Natural Barrier



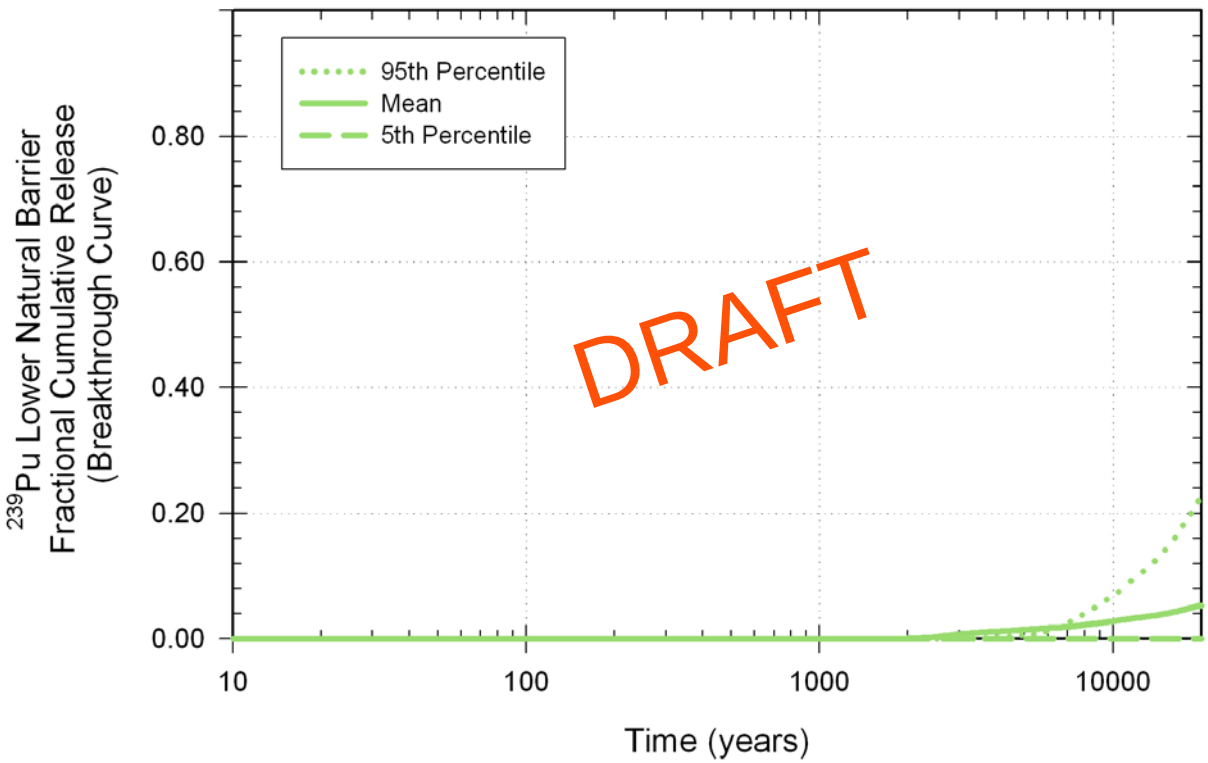
Example Barrier Capability
Lower Natural Barrier System (continued)

- **Draft releases from the lower natural barrier system**
  - **Mean cumulative fractional releases from a hypothetical unit pulse at time zero**
  - **Radioactive decay and ingrowth are included**
- **The lower natural barrier has the potential to retain most radionuclides many thousands of years; some species much longer**

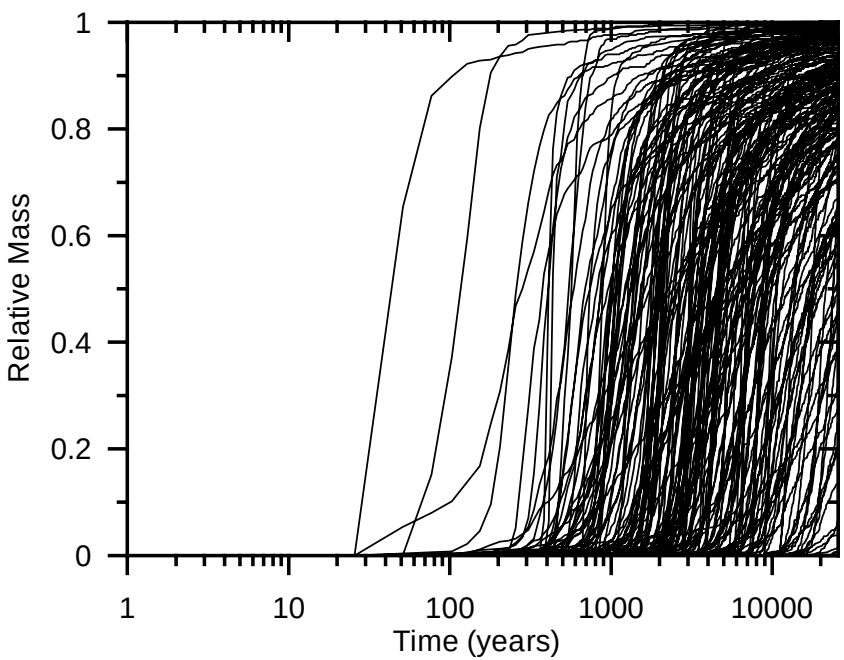


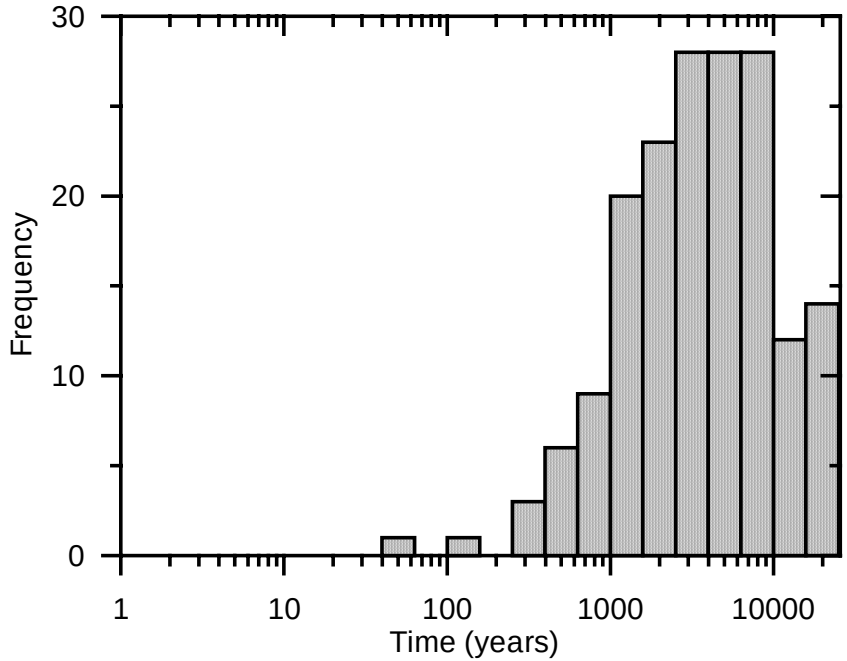
Example Barrier Capability
Lower Natural Barrier System (cont.)

- **Draft releases of ^{239}Pu from the lower natural barrier system: example for a strongly-sorbing species**
  - **Mean cumulative fractional releases of dissolved ^{239}Pu from a hypothetical unit pulse at time zero**
  - **Radioactive decay and ingrowth are included**



Example Barrier Component Capability
Saturated Zone Transport
Np: A Moderately-Sorbing Species





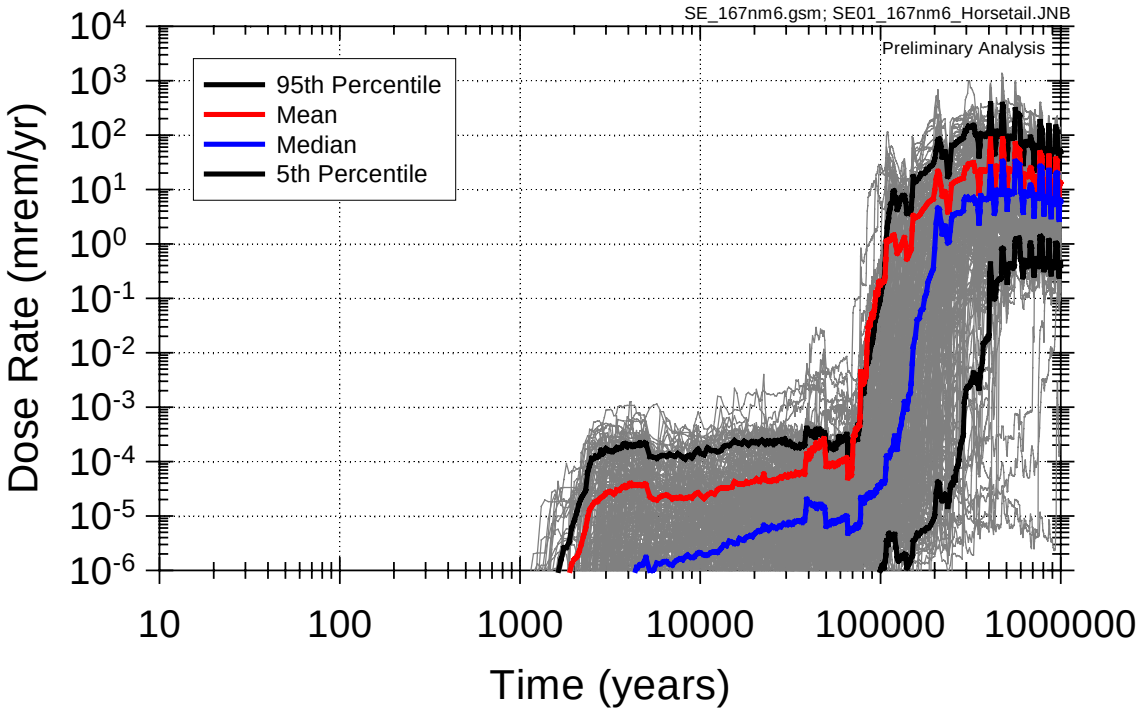
Mass breakthrough fraction (left) and distribution of median transport times (right)

Multiple realizations showing uncertainty in material properties

Radioactive decay and ingrowth not included

MDL-NBS-HS-000021 Rev. 02, Figure 6-42. Preliminary results for illustration purposes only. Glacial transition climate.

System Performance
2002 Example, Nominal Performance Only



Mean annual dose based on 300 realizations of high-temperature operating mode nominal performance. Models and input values are preliminary. Results are for information only, and are not suitable for comparison to regulatory standards. ANL-WIS-PA-000004 Rev. 00 ICN 01 (2002 "one-on analysis" case 12).

Each curve is a dose history calculated using a single set of sampled input parameter values

Each curve is a possible "realization" of the model; each is an equally likely outcome of the model

Summary statistical measures are derived from the distribution of model outcomes

Stability of the mean (or median) is related to sample size

Distribution of model results allows detailed sensitivity and uncertainty analysis of intermediate performance measures

System Performance

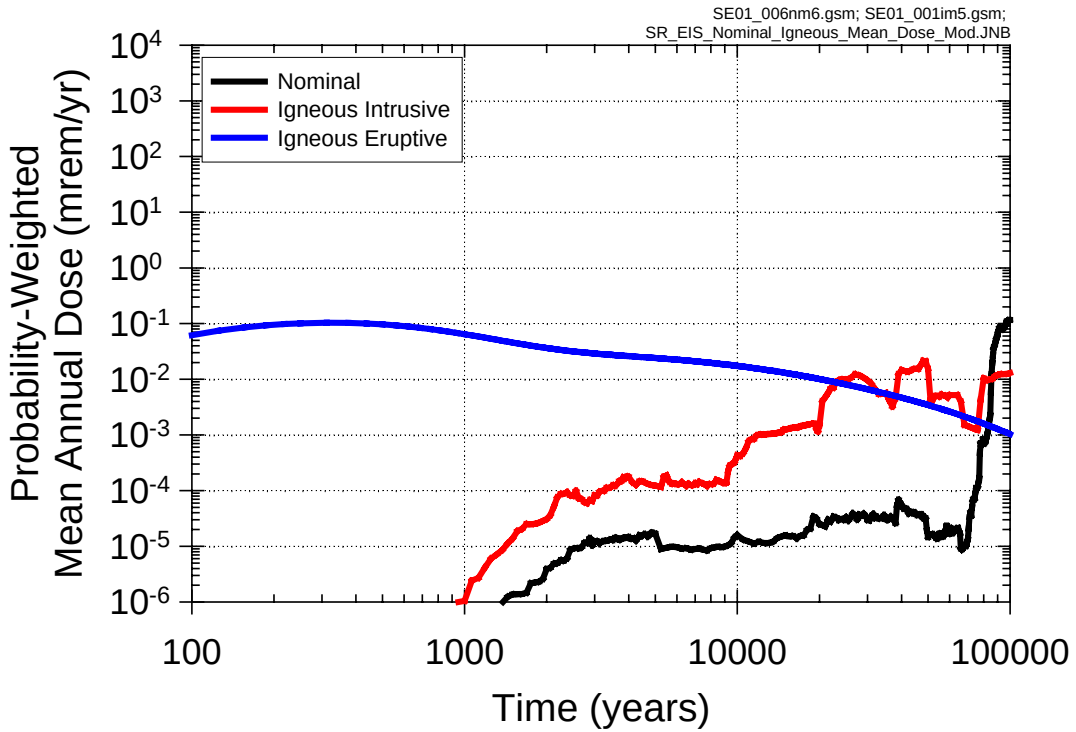
2001 Example, Disruptive Events

Probability-Weighted Consequences of Igneous Disruption

100,000-year probability-weighted mean annual doses for both igneous disruption pathways and nominal performance shown for comparison

Mean annual probability of igneous intrusion in this example is 1.6×10^{-8}

Results from the September 2001 Revised Supplemental TSPA to support the Final Environmental Impact Statement and Site Suitability Evaluation (high-temperature operating mode)



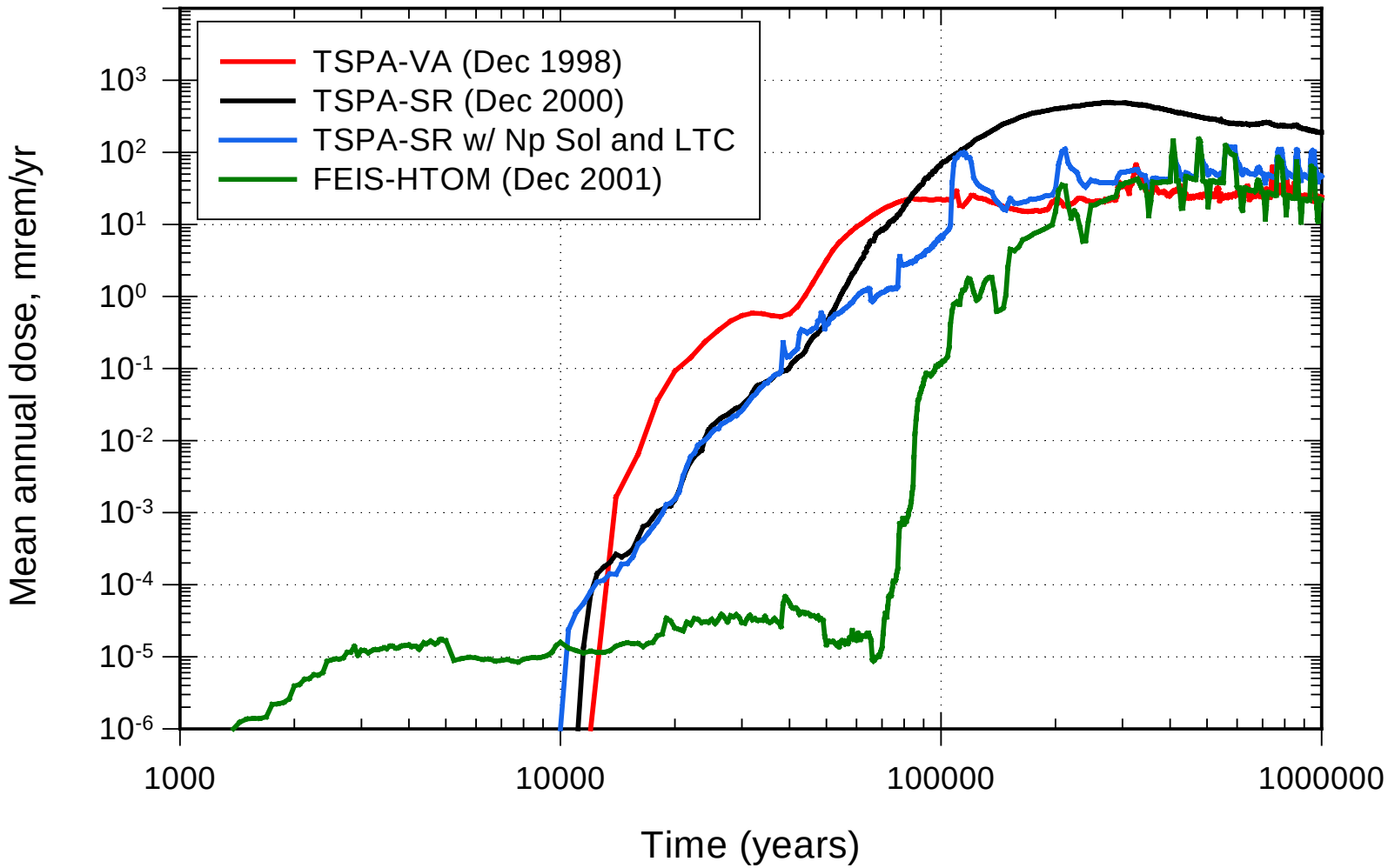
Eruptive doses peak near 300 years and dominate for ~ 20,000 years in this example

Intrusive groundwater doses peak with 38,000 year full glacial climate in this example

Nominal dose remains below mean igneous dose until ~ 80,000 years in this example

Iterative Estimates of System Performance

Examples from 1998-2001, Nominal Performance



Conclusions

- **Quantitative estimates of barrier capability and system performance are part of the safety case**
- **Confidence in the quantitative estimates comes from**
  - **Understanding components and their capabilities**
  - **Understanding system performance**
  - **A clear display of uncertainty**
  - **Following a process that demonstrates completeness**
- **Confidence in the overall safety case comes from multiple lines of evidence**