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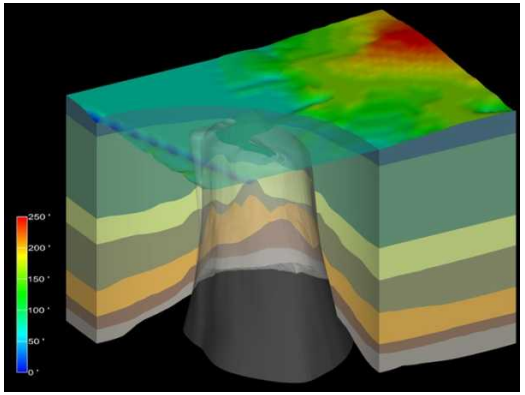

Repository Development and Performance Assessment

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June 27, 2017

SNL, Albuquerque, NM

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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What is a Deep Geologic Repository?

An engineered facility for safe handling and disposal of nuclear waste that includes disposal rooms or tunnels excavated sufficiently deep beneath the surface to ensure <u>isolation</u> of the waste from external changes or events. The underground facility typically comprises engineered and geologic barriers that act together to <u>contain</u> the waste within the facility and to <u>limit and delay</u> the release of radionuclides to the surrounding geosphere subsequent to loss of containment. Typical engineered barrier systems include the following components - waste form (and inventory), waste package, buffer/backfill, and engineered seals.

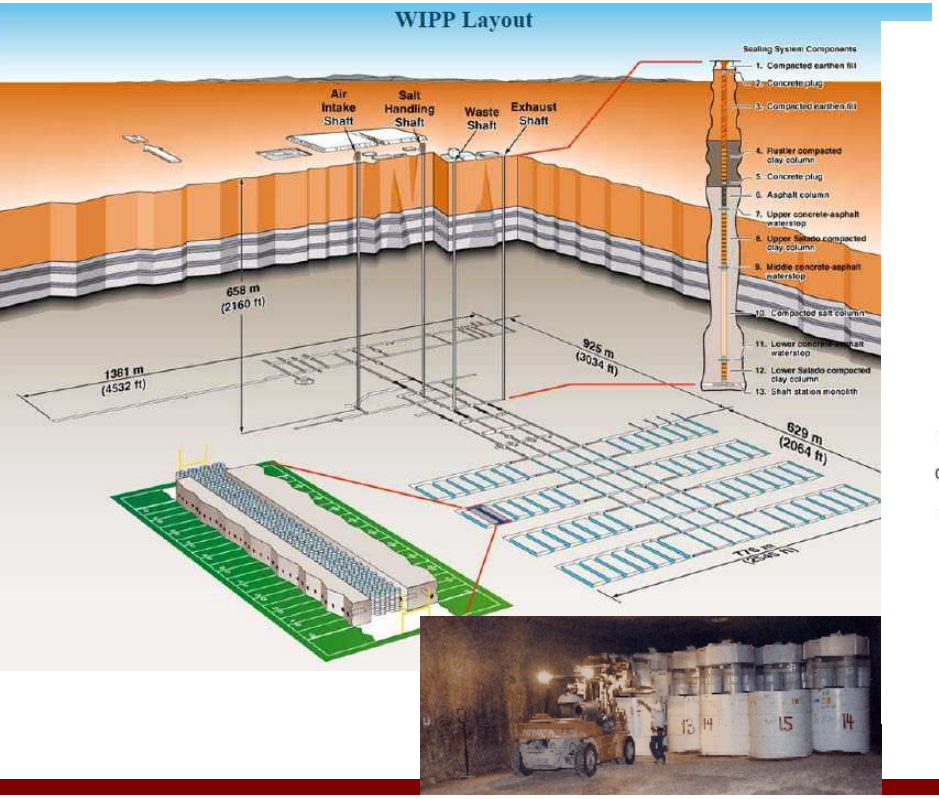
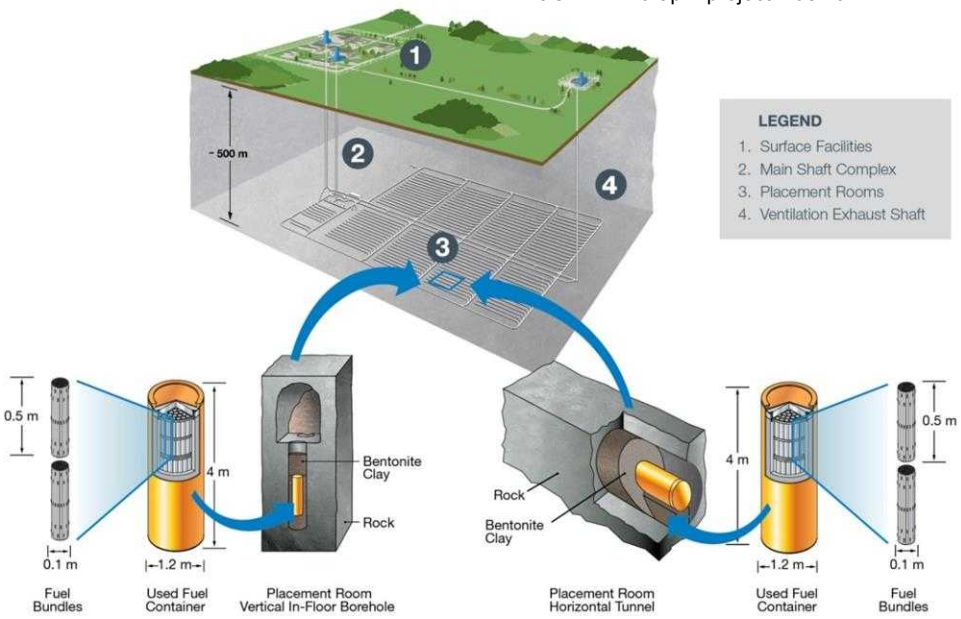
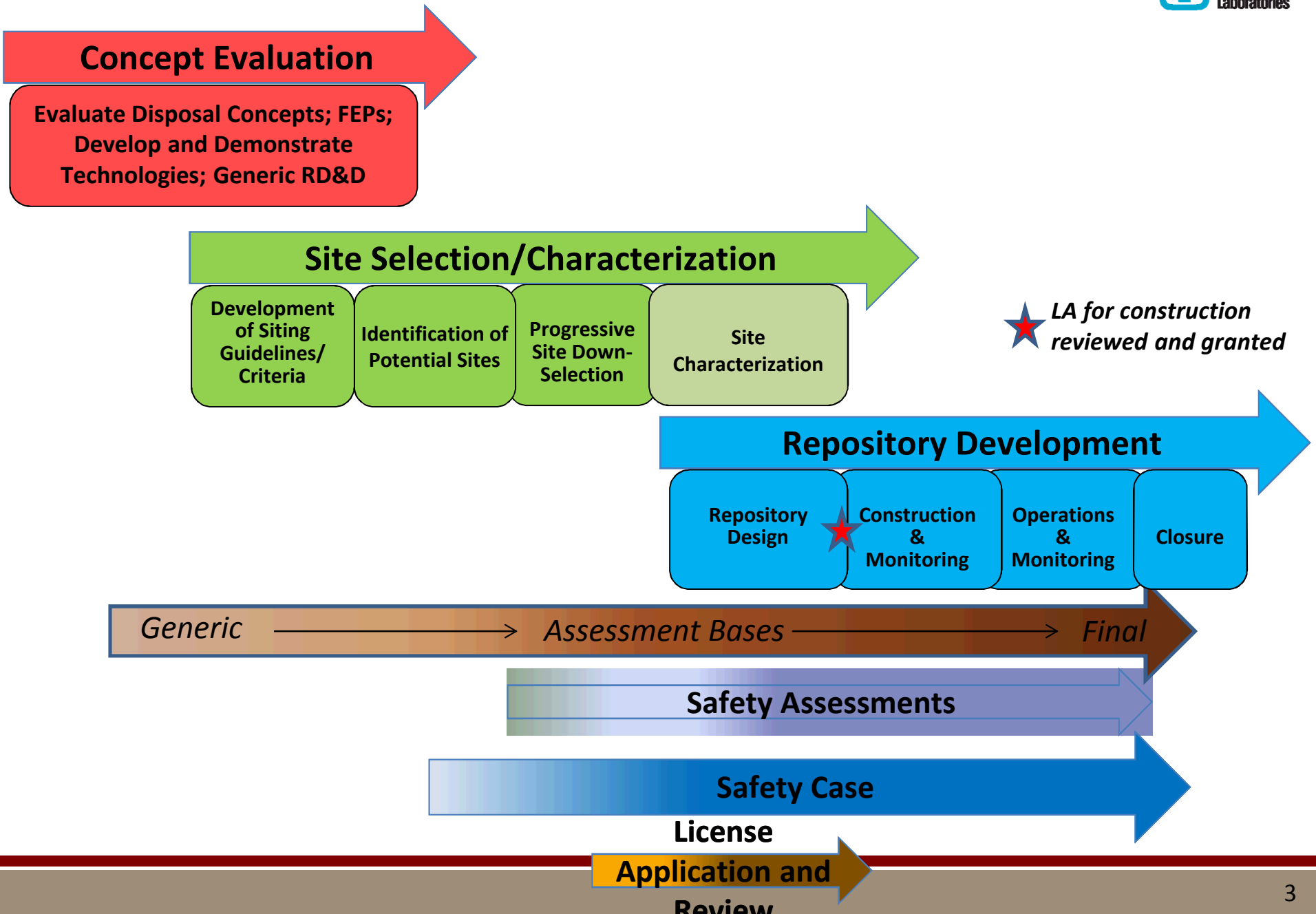


Figure Source: https://www.cnsc-ccsn.gc.ca/eng/waste/high-level-waste/cnsc-role-in-nwmo-apm-project/index.cfm



Phases of Repository Development



What is Performance Assessment?

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- **Performance assessment (PA) is a method for estimating how a disposal system will perform over geologic time**
- **Defined by the U.S. Environmental Protection Agency (EPA) at 40 CFR 191.12 (Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes)**

  –*Performance assessment* means an analysis that
  - Identifies the process and events that might affect the disposal system;
  - examines the effects of those processes and events on the performance of the disposal system; and
  - estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable.

- **Yucca Mountain Standards (40 CFR 197) define PA in terms of annual dose**
- **Nuclear Regulatory Commission regulation 10 CFR 63 prescribes rules governing licensing at Yucca Mountain**

Long-Term Performance of Yucca Mountain

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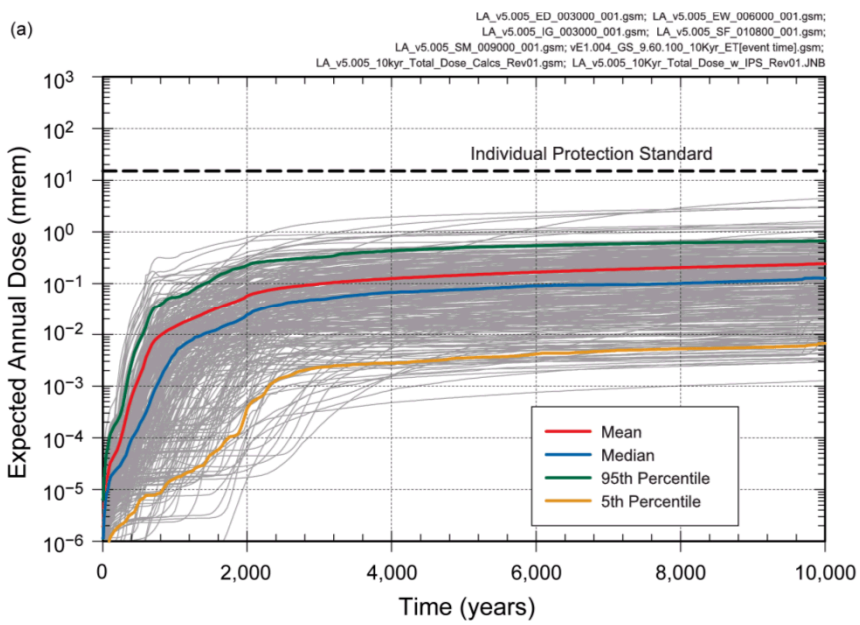

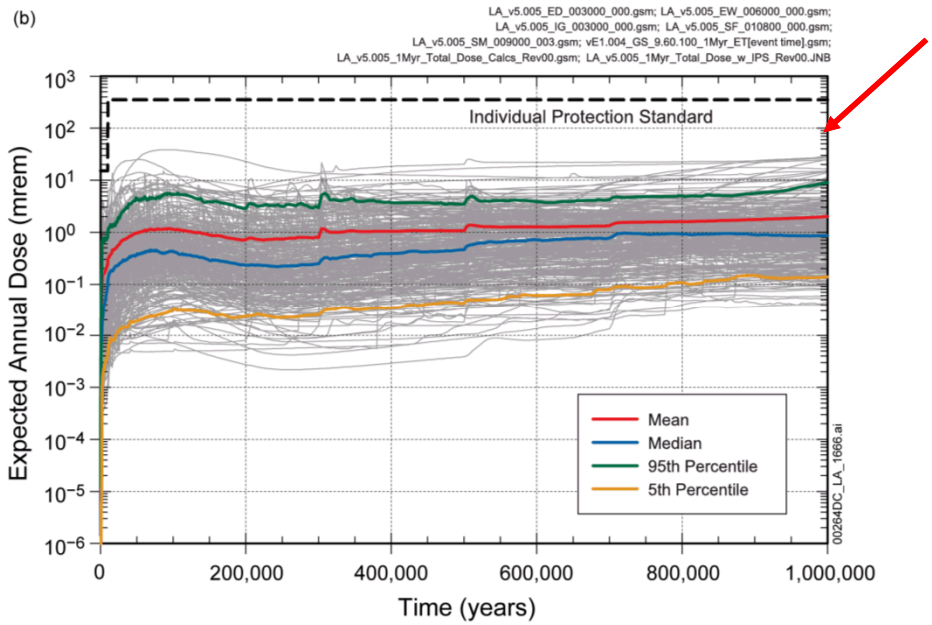

DOE/RW-0573 Rev 1 Figure 2.4-10

10,000 years

10,000-year Standard:
Mean annual dose no more than 0.15 mSv (15 mrem)

TSPA-LA estimated 10,000 yr maximum mean annual dose: 0.0024 mSv (0.24 mrem)

1,000,000 years

1,000,000-year Standard:
Mean annual dose no more than 1 mSv (100 mrem)

TSPA-LA estimated 1,000,000- yr maximum mean annual dose: 0.02 mSv (2.0 mrem)

Long-Term Performance

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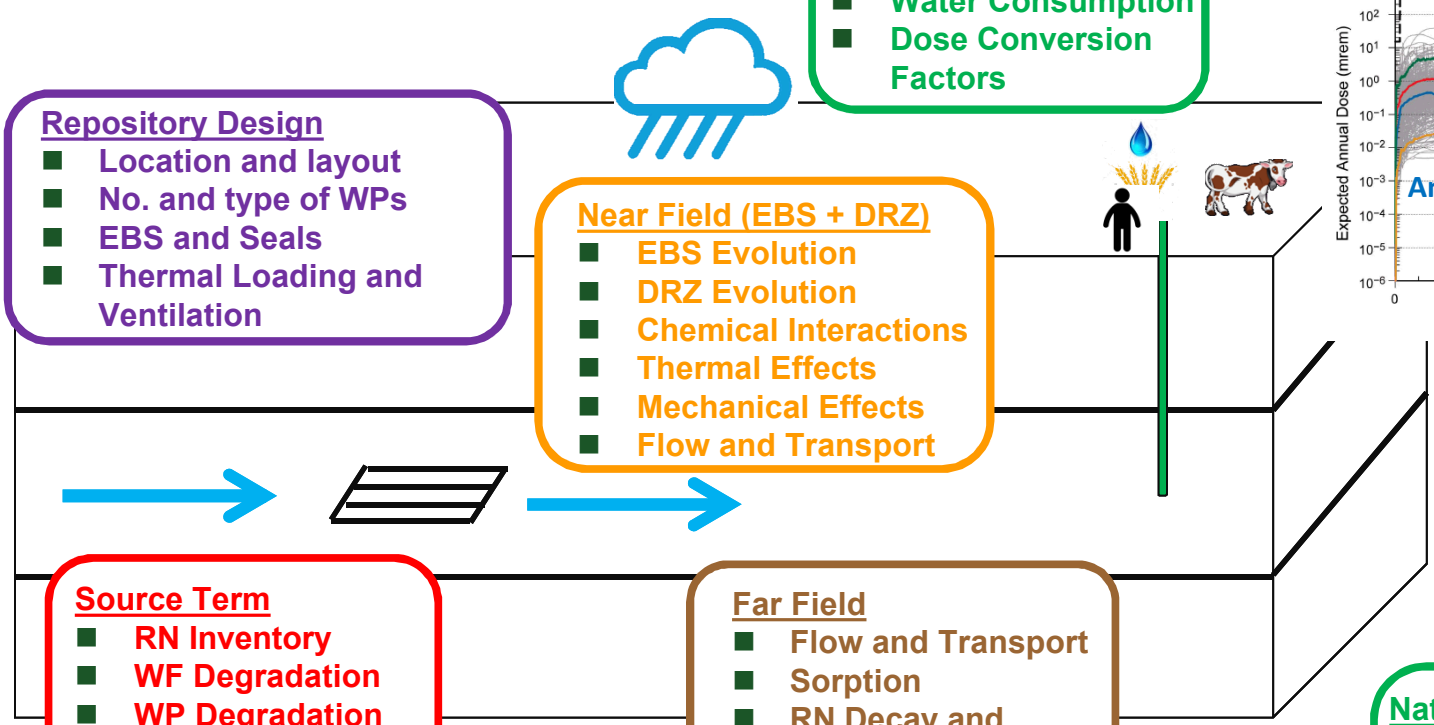
Biosphere
- Dilution
- Irrigation
- Water Consumption
- Dose Conversion Factors

Repository Design
- Location and layout
- No. and type of WPs
- EBS and Seals
- Thermal Loading and Ventilation

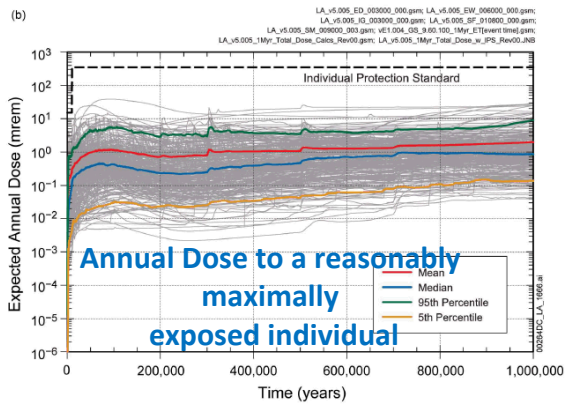
Near Field (EBS + DRZ)
- EBS Evolution
- DRZ Evolution
- Chemical Interactions
- Thermal Effects
- Mechanical Effects
- Flow and Transport



Source Term
- RN Inventory
- WF Degradation
- WP Degradation
- Gas Generation
- RN Release

Far Field
- Flow and Transport
- Sorption
- RN Decay and Ingrowth

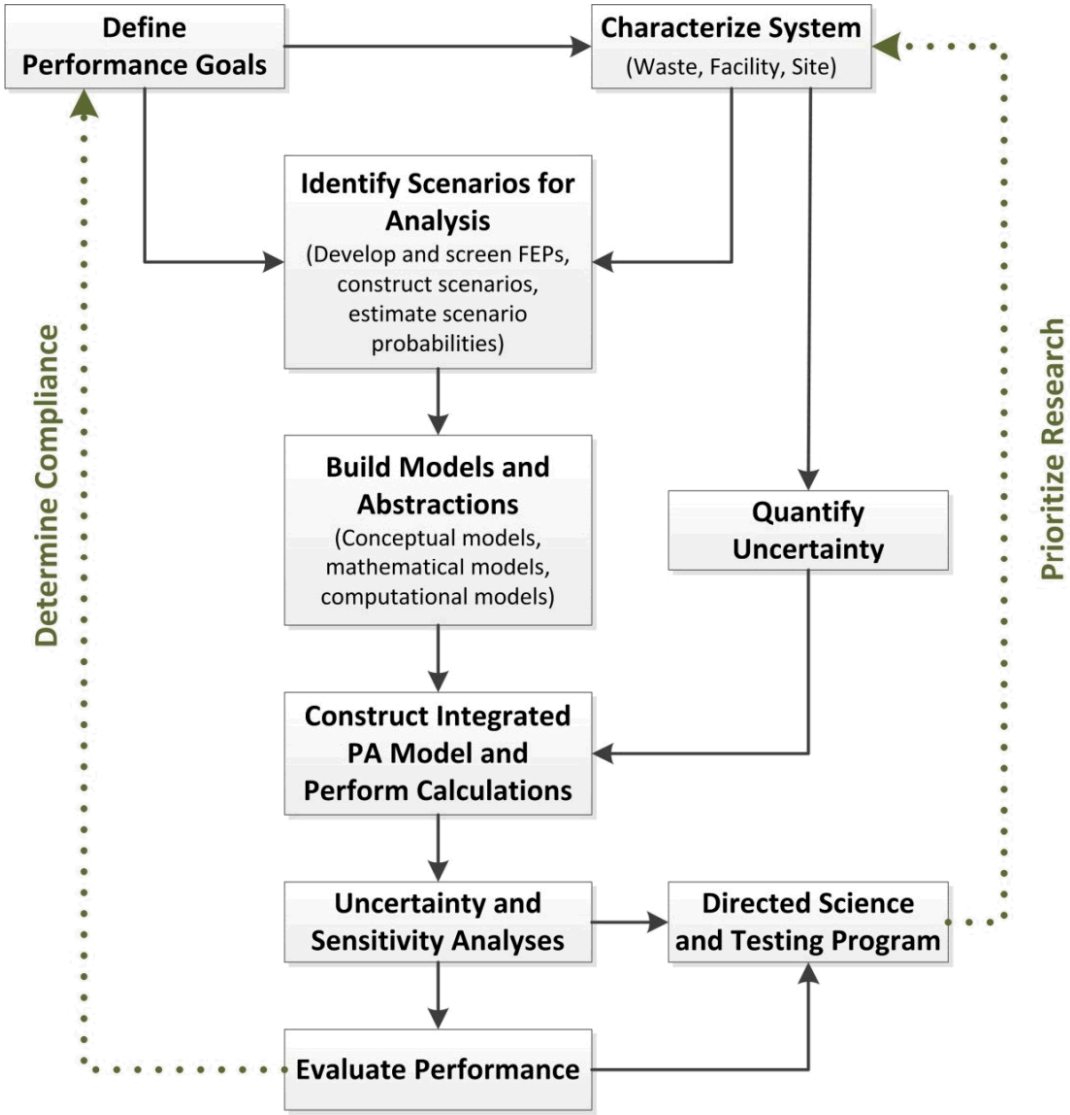
Performance Goal



Natural System
- Climate
- Stratigraphy
- Hydrogeology
- Geochemistry
- Material properties
- Disruptive events

Engineered Barrier System (EBS)
Radionuclide (RN)
Waste Form (WF)
Waste Package (WP)
Disturbed Rock Zone (DRZ)

Overview of Performance Assessment (PA) Methodology



Build Models and Abstractions

The total system performance assessment model consists of sets of data and information, assumptions, and computational models that together describe the essential processes of the repository system and its long-term performance

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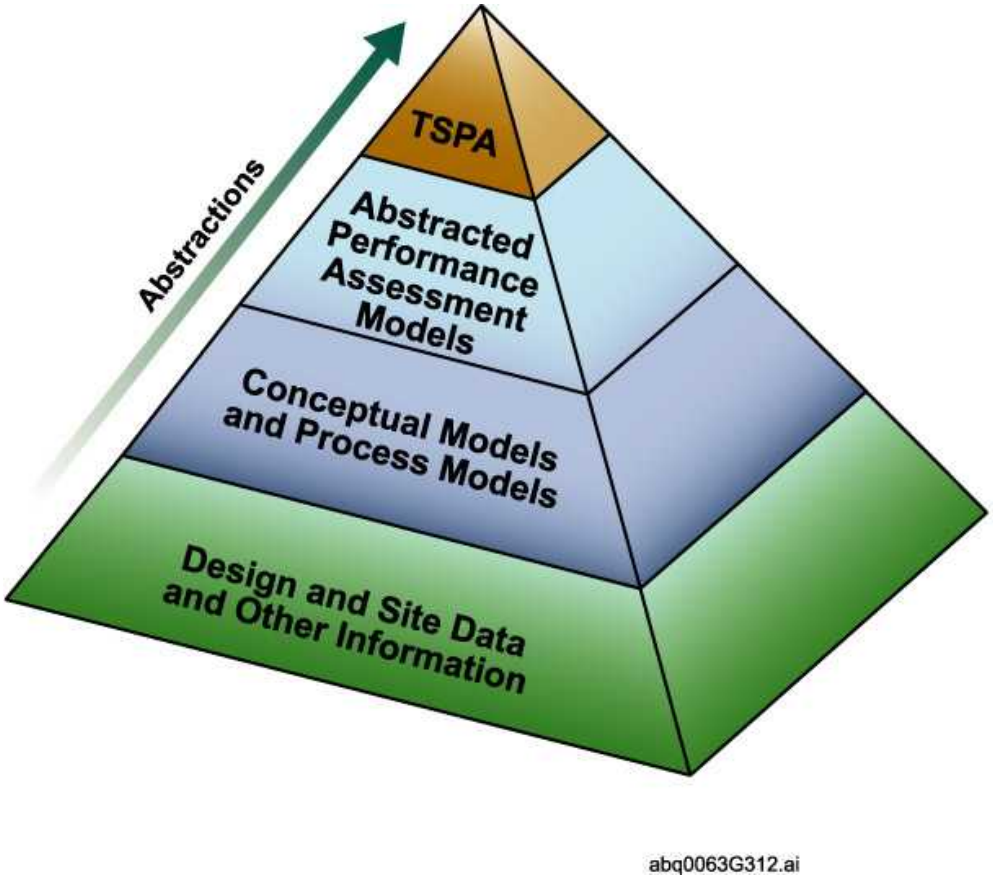

Waste for Yucca Mountain

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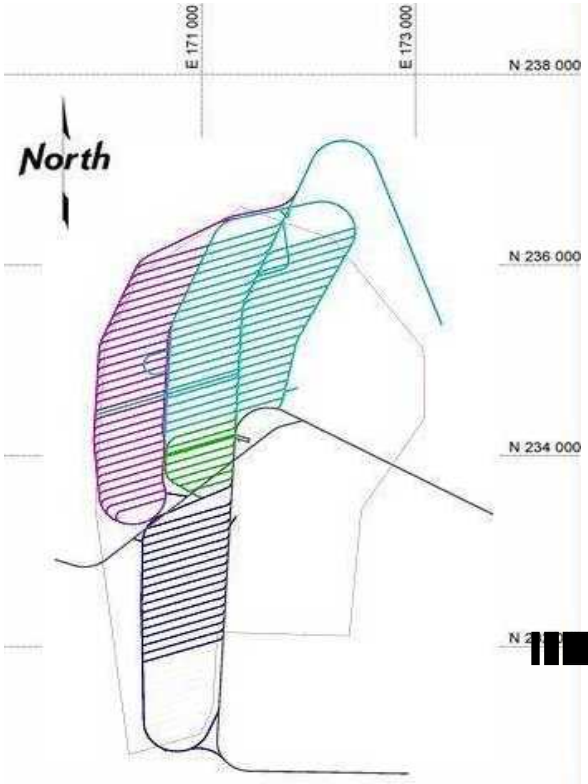
Commercial Spent Nuclear Fuel:
63,000 MTHM (~7500 waste packages)

DOE & Naval Spent Nuclear Fuel:
2,333 MTHM
(~400 naval waste packages)
(DSNF packaged with HLW)

DOE & Commercial High-Level Waste:
4,667 MTHM
(~3000 waste packages of co-disposed DSNF and HLW)

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

Yucca Mountain 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

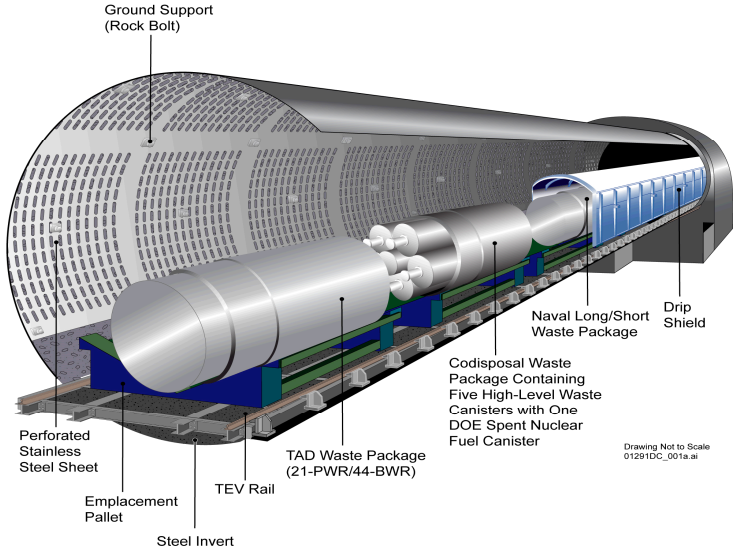
outer layer 2.5 cm Alloy 22 (Ni-Cr-Mo-V)

inner layer 5 cm stainless steel

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



Yucca Mountain
Exploratory Studies Facility (ESF)

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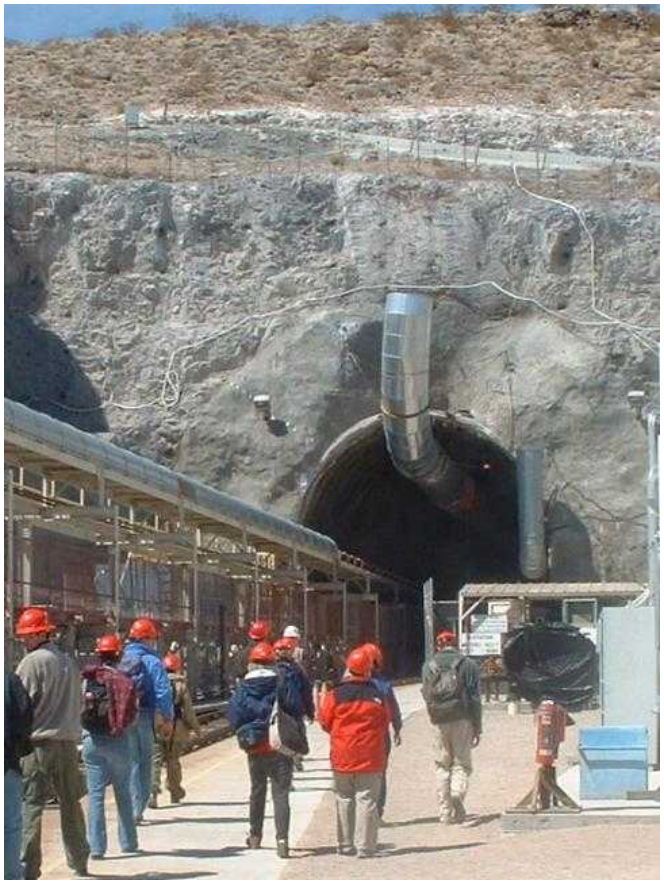
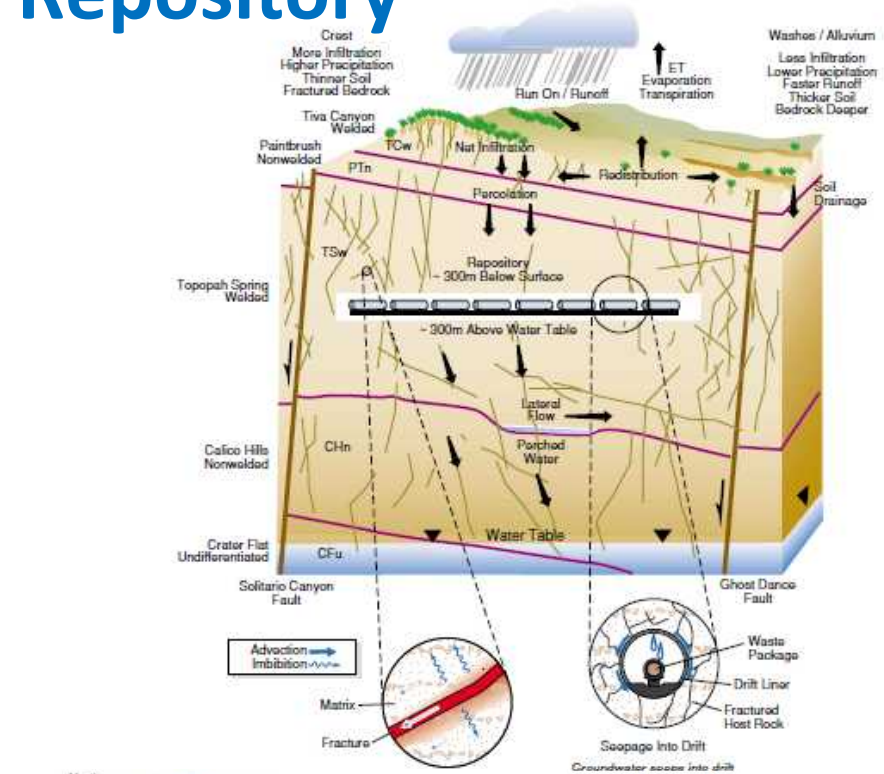
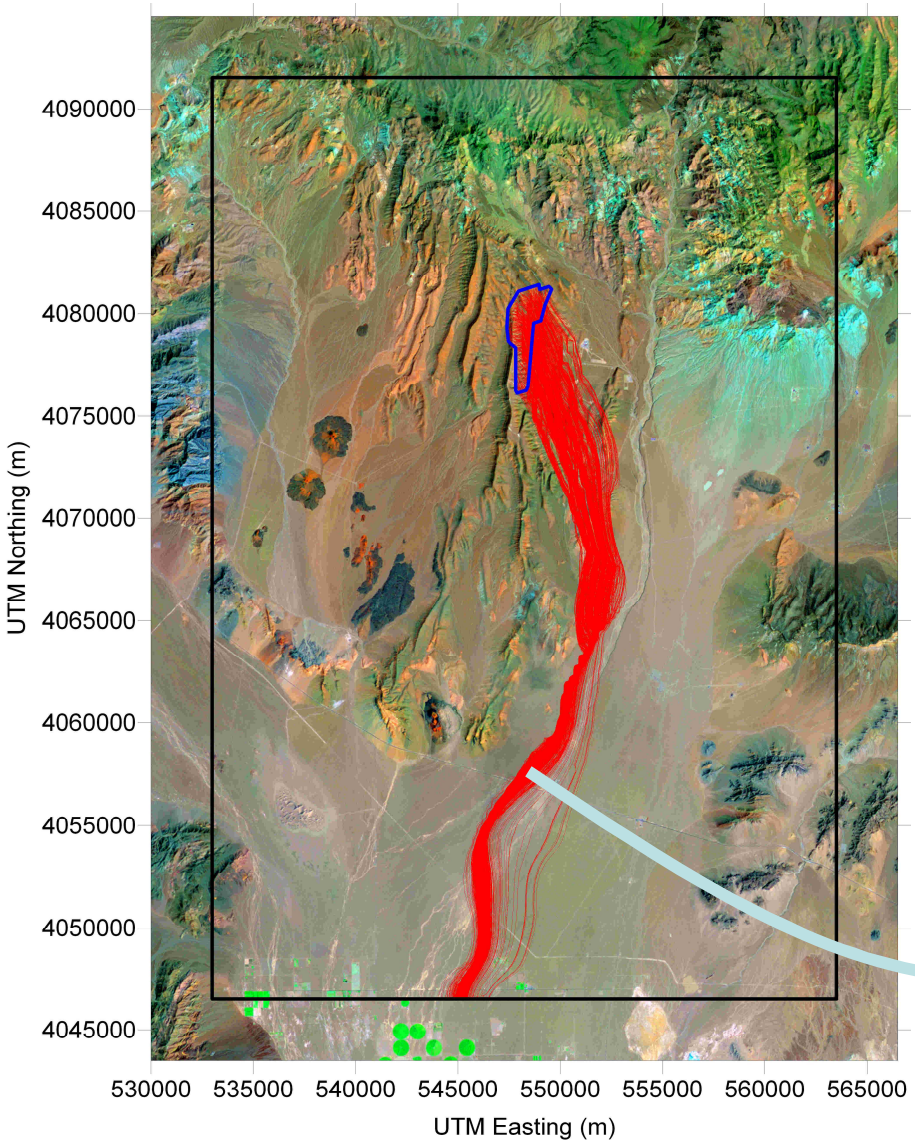


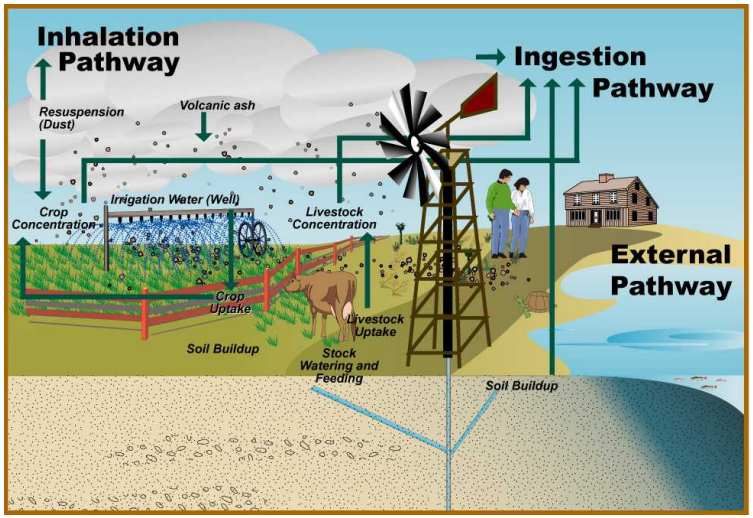
Long-Term Performance of the Proposed Yucca Mountain Repository

- Water provides the primary release mechanism
  - Precipitation infiltrates and percolates downward through the unsaturated zone
  - Corrosion processes degrade engineered barriers, including the waste form
  - Radionuclides are mobilized by seepage water and percolate downward to the water table
  - Lateral transport in the saturated zone leads to biosphere exposure at springs or withdrawal wells



Estimating Dose to Hypothetical Future Humans





Modeled groundwater flow paths and hypothetical exposure pathways

Four scenario classes divided into seven modeling cases

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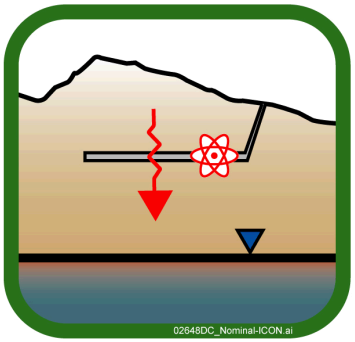
Nominal Scenario Class

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

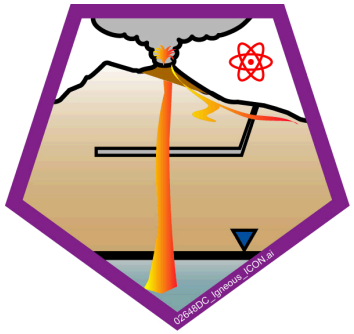
Early Failure Scenario Class

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



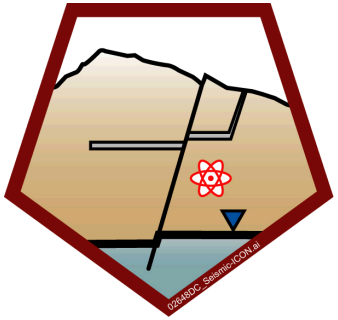
Igneous Scenario Class

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



Seismic Scenario Class

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



Modeling Topics

- Nested Modeling
- Uncertainty quantification
- Modern approach to V&V
- Coupling of porous medium processes with natural convection and radiation in an open excavation
- Solving porous media flow and reactive transport with higher-order methods
- Adaptive mesh refinement
- Geomechanics (ALBANY, Satish, creep/TOUGHFLAC)
- Multiphase convergence/time-stepping (including state switching)

Nested Engineered System

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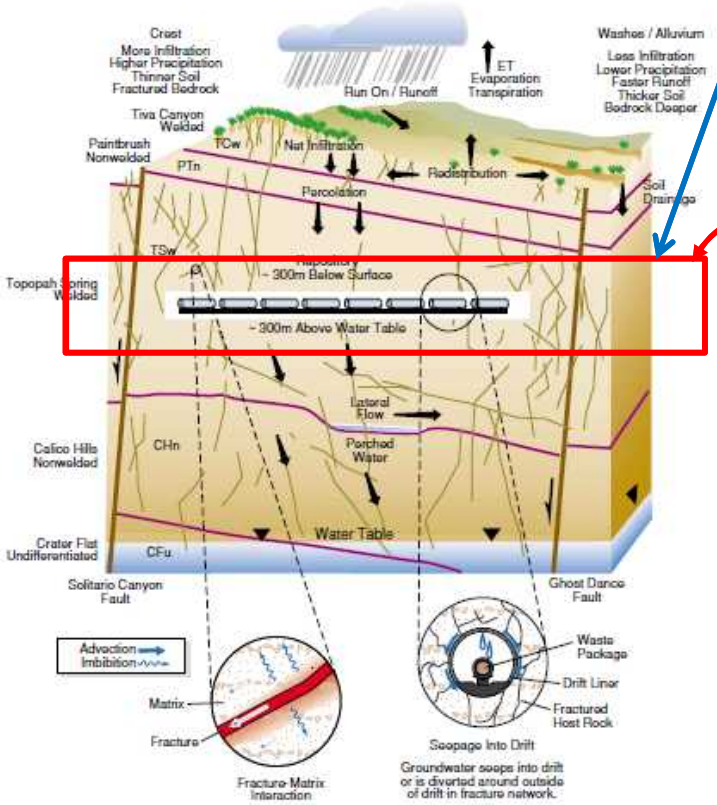
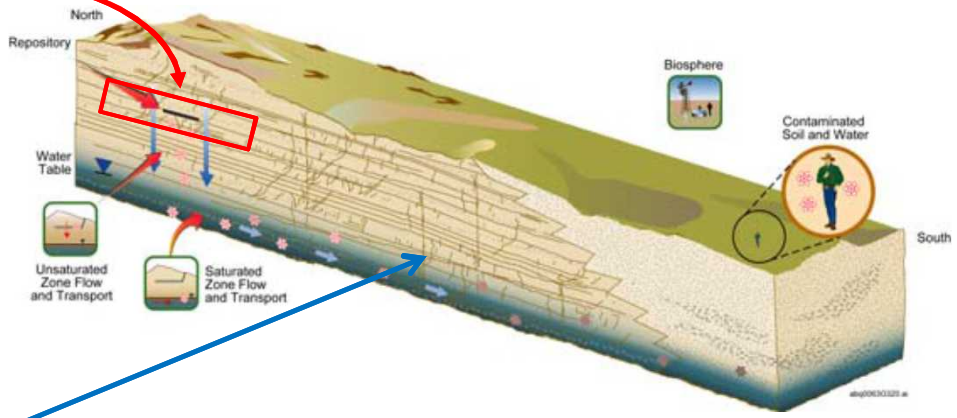
Coupled THMC Processes
Short time and spatial scales





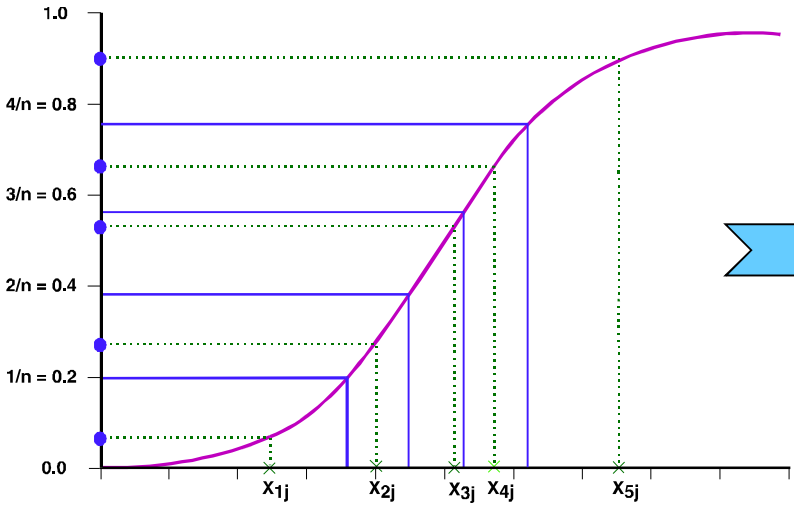
Loosely coupled Flow and Transport Processes
Longer time and spatial scales

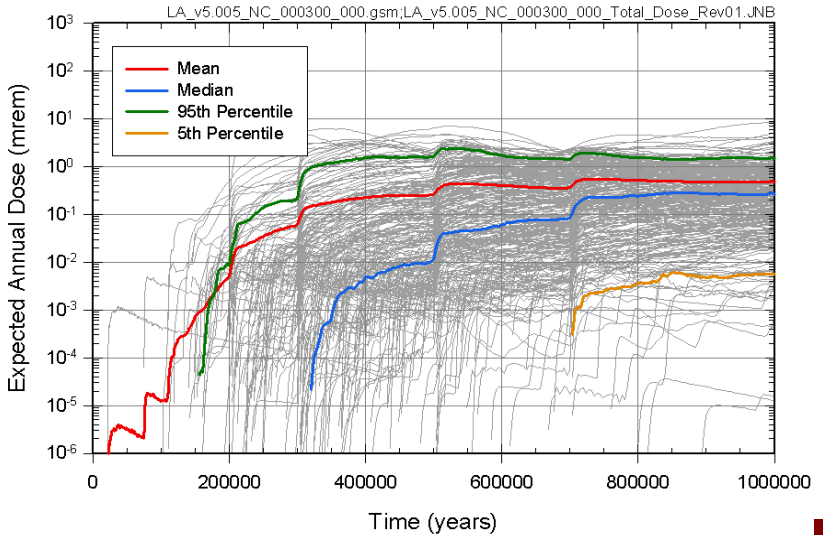
Quantify Uncertainty

- **Three major sources of uncertainty should be considered in a performance assessment:**
  - **Uncertainty in the future state of the system (aleatory uncertainty)**
    - **Example: time and size of a seismic event**
  - **Data and parameter uncertainty (aleatory and epistemic uncertainty)**
    - **Examples: permeabilities, porosities, sorption coefficients, corrosion rates**
  - **Model uncertainty (usually epistemic, but in general both aleatory and epistemic)**
    - **Example: dual porosity vs dual permeability**

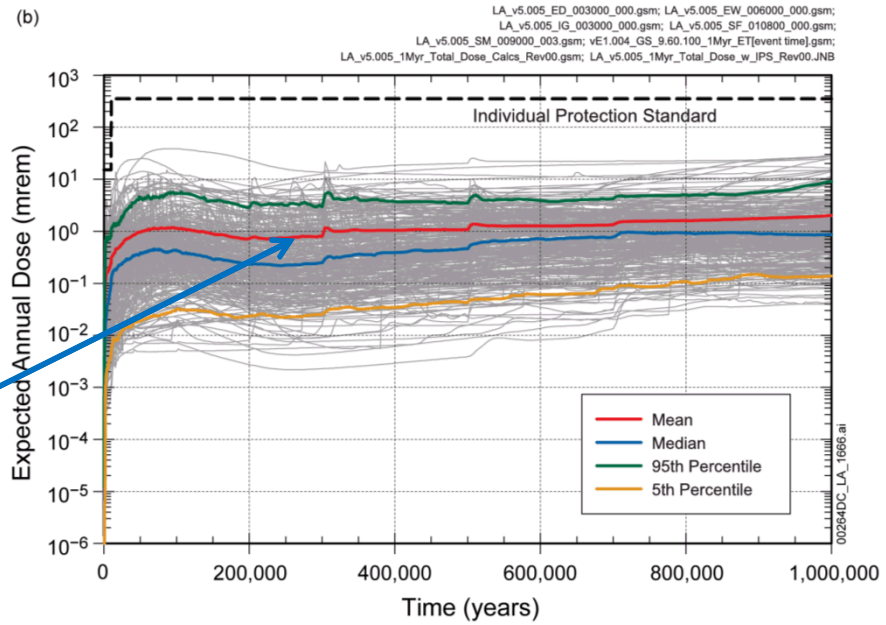
Epistemic uncertainty incorporated through Latin hypercube sampling of cumulative distribution functions and Monte Carlo simulation with multiple realizations

Approx. 400 uncertain epistemic parameters incorporated directly in Yucca Mountain TSPA-LA





Verification and Validation



How accurate is the mean performance measure?

DOE/RW-0573 Rev 1 Figure 2.4-10

1,000,000 years

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Enhanced PA Computational Model Architecture

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