U.S. Nuclear Regulatory Commission High-Level Waste Repository Safety:

Insights from Performance Assessment

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MIT Course on Nuclear Plant Safety

June 2005

High-Level Nuclear Waste Legislative History

- Nuclear Waste Policy Act of 1982
  - Established permanent disposal as a national policy
- Nuclear Waste Policy Act of 1987
  - Characterization of a single site at Yucca Mountain
- Energy Policy Act of 1992 (Section 801)
  - Directs new site-specific EPA standards

Agency Roles and Responsibilities

- **U.S. Environmental Protection Agency**
  - Establish site-specific standards for Yucca Mountain
- **U.S. Department of Energy**
  - Study Site and Design Potential Repository
  - Prepare Environmental Impact Statement to accompany Site Recommendation
  - Submit application to NRC showing proposed action is safe and regulations are met
  - If authorized, construct repository consistent with regulation and authorization conditions
  - Provide more information on request
  - Keep accurate and detailed records

What is NRC's Role at Yucca Mountain?

- Set regulations that are consistent with the Environmental Protection Agency standards for Yucca Mountain
- Review the license application, including repository safety
- Decide whether it is practicable to adopt DOE's environmental impact statement
- Conduct public pre-licensing interactions
- Ensure openness and that stakeholders are appropriately informed and involved in the regulatory process

Steps to a licensing decision

DOE Submits a License Application

NRC Accepts Application for Review?

NRC Adopts DOE's Environmental Impact Statement?

NRC completes safety review?

NRC completes licensing hearing?

Time for Key Milestones

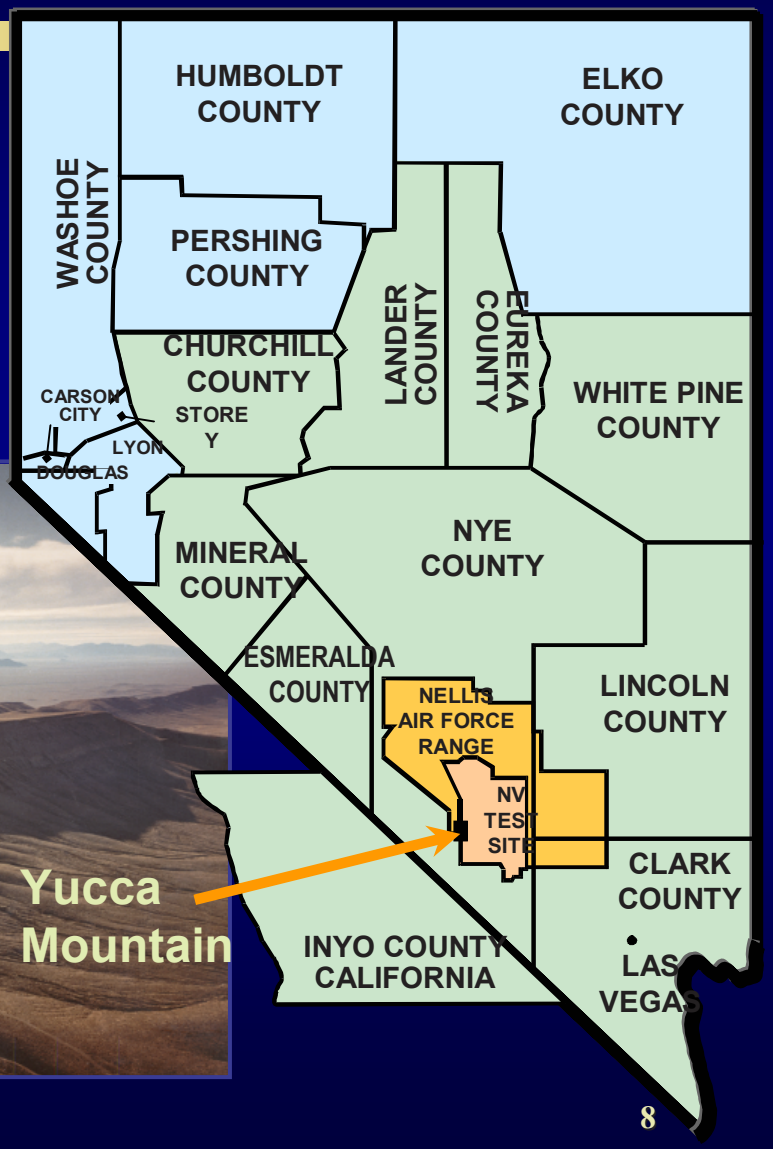
DOE must certify that its documents are on the Licensing Support Network (LSN)	At least 6 months before application is submitted
NRC must certify that its documents are on the LSN	30 days after DOE's certification
Governmental participants and potential parties must certify that their documents are on the LSN	90 days after DOE's certification
Possible docketing of application (if NRC accepts for review); Notice of Hearing and Environmental Impact Statement Adoption	Within 90 days after receipt of application
Petitions for leave to intervene must be filed	Within 30 days after federal register (FR) notice

Time for Key Milestones (continued)

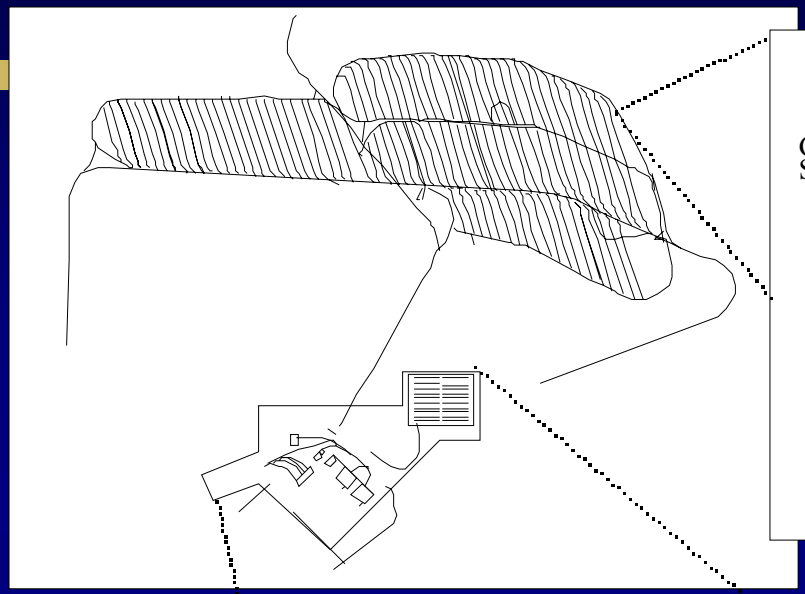
Prehearing Conference order on intervention	Within 100 days after federal register (FR) notice
Deposition and Interrogatory discovery begins	Within 100 days after notice
NRC Staff completes Safety Evaluation Report	Within 18 months after FR notice
Evidentiary hearing begins	Within 24 months after FR notice
Initial Decision	Within 32 months after notice
Commission decision on any appeals filed	About 3 years after FR notice

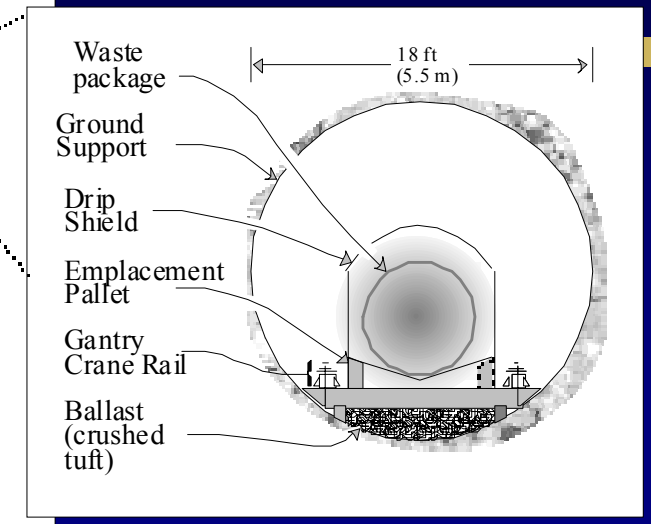
Potential Yucca Mountain Geological Repository

- 161 kilometers (100 miles) northwest of Las Vegas, Nevada
- Federal land
  - Nellis Air Force Base
  - Nevada Test Site

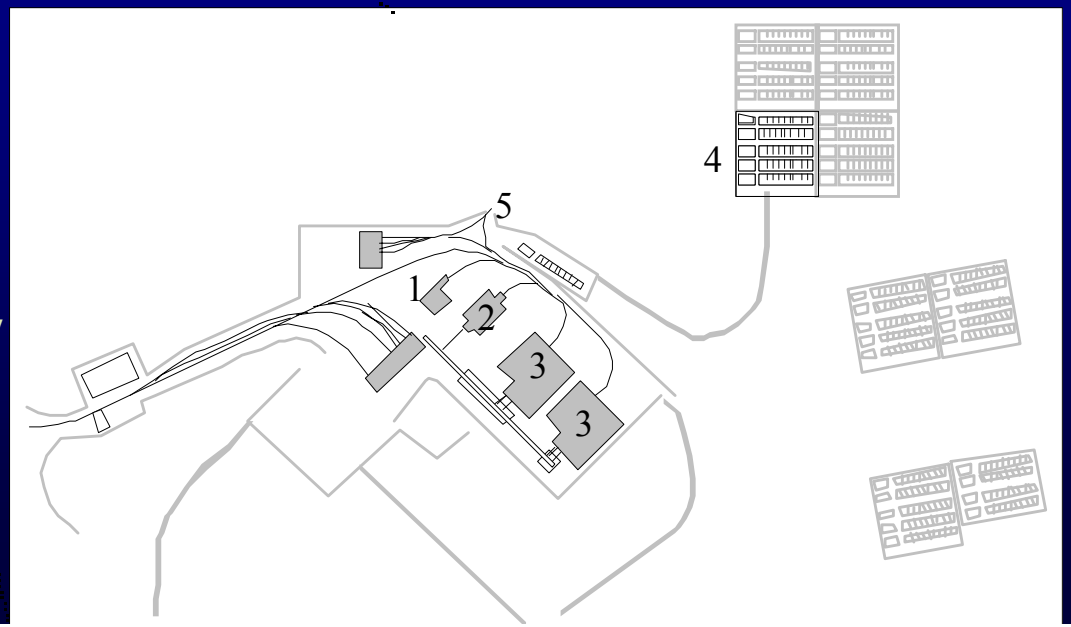


Potential Yucca Mountain Facility Layout





1. Fuel Handling Facility
2. Canister Handling Facility
3. Dry Transfer Facility
4. Aging Pad
5. North Portal



Regulatory Requirements in 10 CFR Part 63

- Preclosure Safety
- Postclosure Safety
  - Performance objective – releases do not result in an expected annual dose of > 15 mrem for 10,000 years to reasonably maximally exposed individual (RMEI)
  - Groundwater protection standards
  - Human intrusion standard
  - Demonstration – requires <u>performance assessment</u> and multiple barriers (at least one engineered and one natural)

What is Performance Assessment?

- Systematic analysis of what could happen at a repository
- One of many NRC safety requirements

What is assessed?

- What can happen?
- How likely is it?
- What can result?

Performance Assessment

- Considers uncertainties
  - Parameter sensitivity analyses
  - Alternative conceptual models
  - Scenario analyses
  - Impact of parameter and model uncertainties
- Identifies key attributes of safety
  - Important processes and assumptions
  - Important sensitivities (e.g., release rate and temperature)

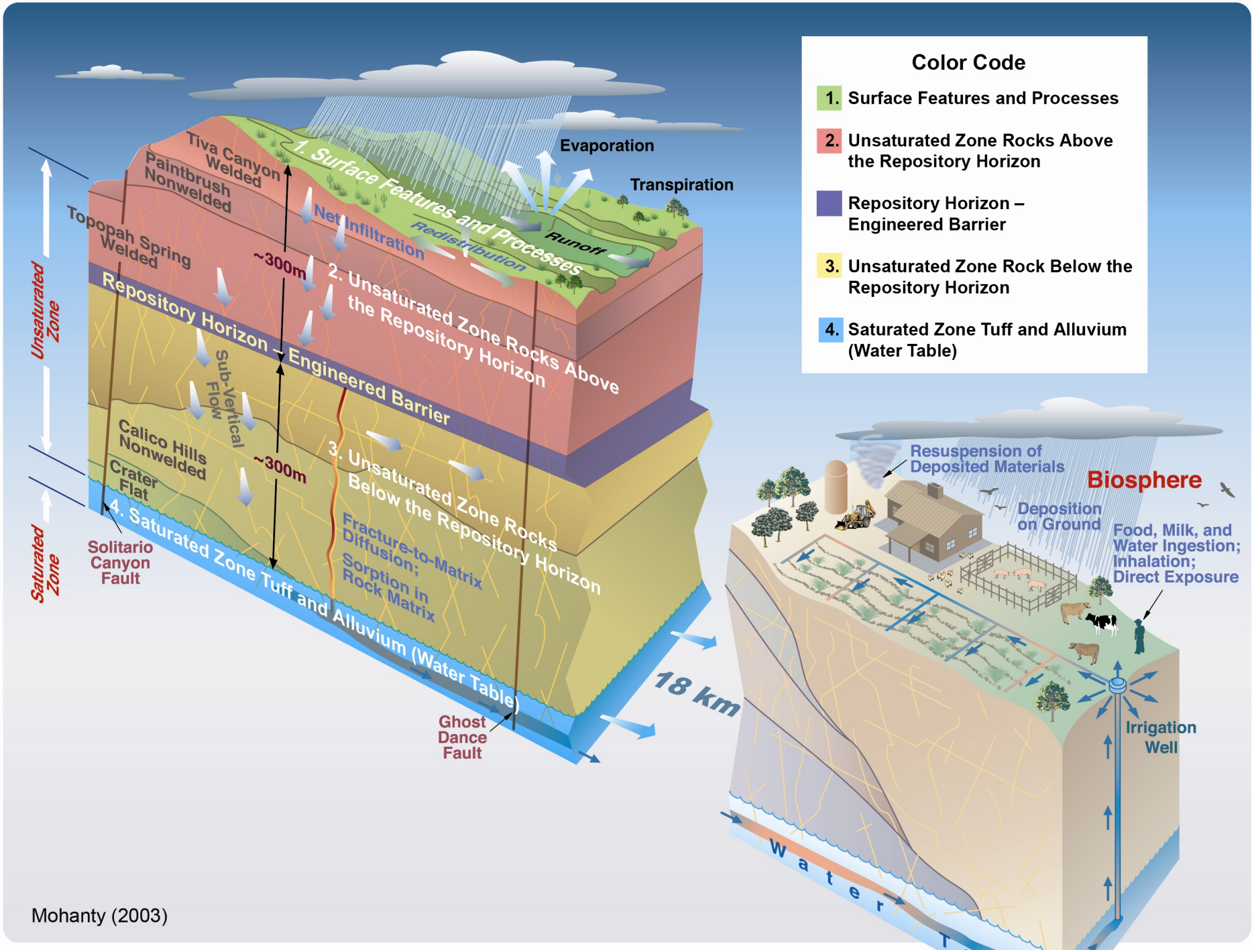
NRC's Total-System Performance Assessment (TPA)

- An independent review tool
- TPA conducts probabilistic dose calculations for specified time periods
- Scenario classes include:
  - A nominal "base case" including climate changes and seismic activity
  - Disruptive cases, including one involving igneous activity,* (events < 10^{-8}/yr excluded)

* Assessment of risk from disruptive events must consider likelihood of occurrence of events (probability weighted dose)

TPA Input Parameters, Sampling, Monte Carlo

- Uncertain input values can be assigned a diverse range of probability distribution types (e.g., lognormal distribution, uniform distribution) and can be correlated.
- Latin Hypercube Sampling (LHS) is used to sample the probability distributions.
- Uncertainty in the input parameters are propagated through LHS and Monte Carlo Simulation to system-level performance (i.e., dose to receptor).



Mohanty (2003)

TPA – Major Processes in the Base Case

Climate and Infiltration

↓

Water Flow in the Unsaturated Zone
Above the Repository

↓

Water Percolation into Repository Drifts

↓

Degradation of Engineered Barriers
(e.g., drip shield, waste package)

↓

Radionuclide Release from Waste Form

→

Radionuclide Release and Transport Out of Engineered Barrier System

↓

Radionuclide Transport through Unsaturated Zone Below Repository

↓

Radionuclide Transport in Saturated Zone
to a Potential Receptor
(18 km from repository)

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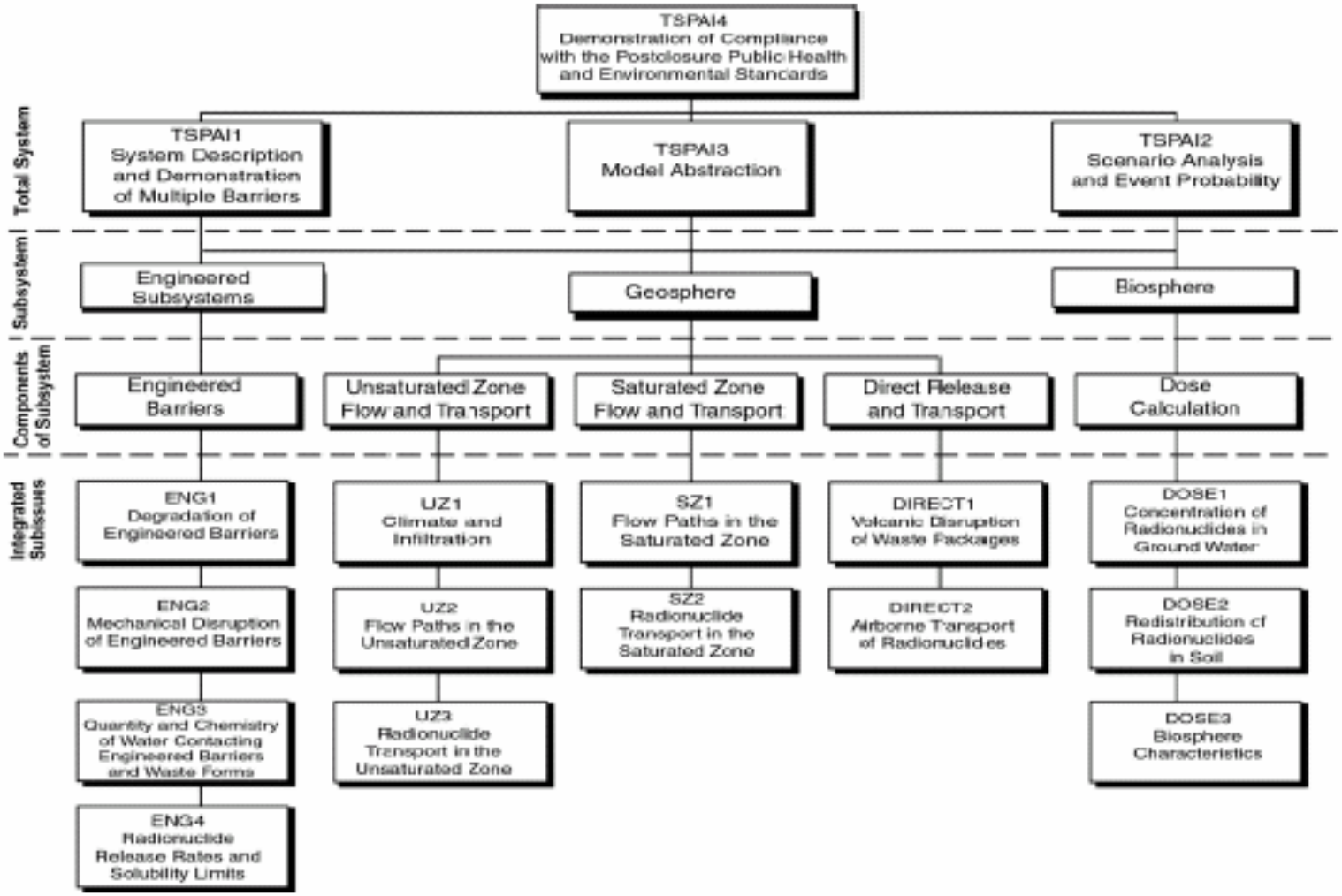
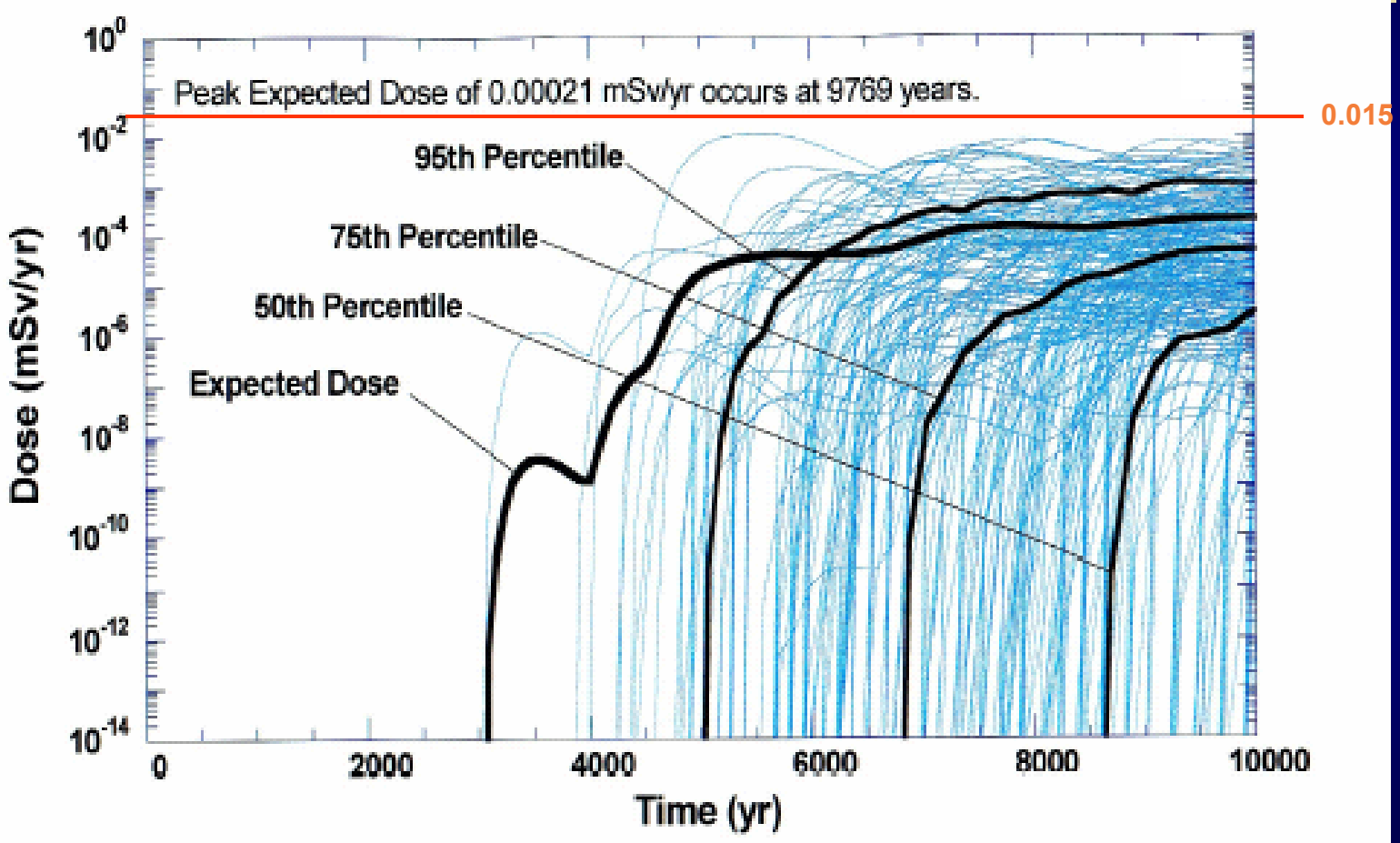
System-Level Performance:
Dose to Reasonably Maximally Exposed Individual (RMEI)

Components of NRC PA Review

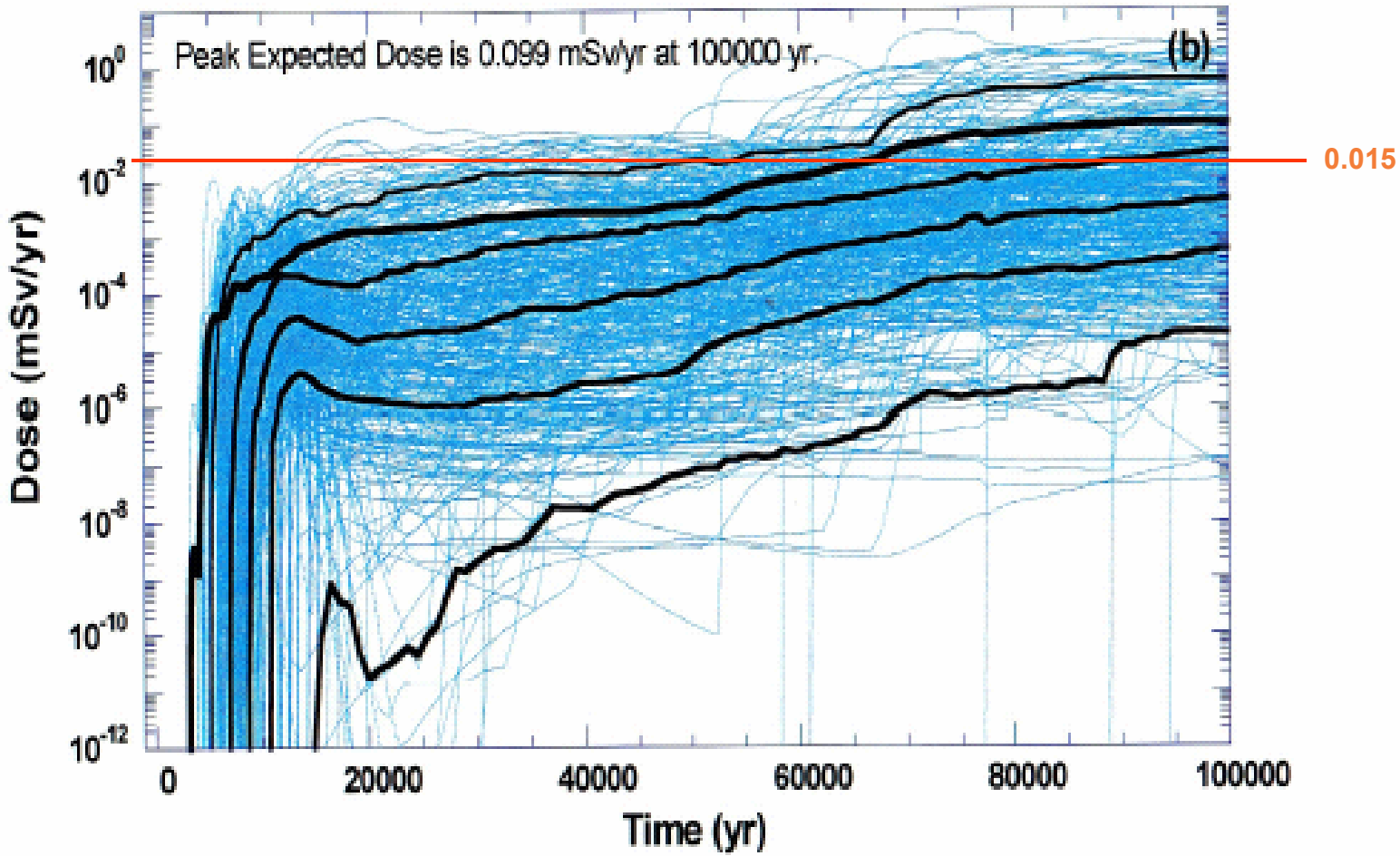


Example Results: Base Case for 10,000 years



Source: NRC/CNWRA, Risk Insights Baseline Report, April 2004

Example Results: Base Case for 100,000 years



Source: NRC/CNWRA, Risk Insights Baseline Report, April 2004

Dominant Radionuclide Contributors to Dose

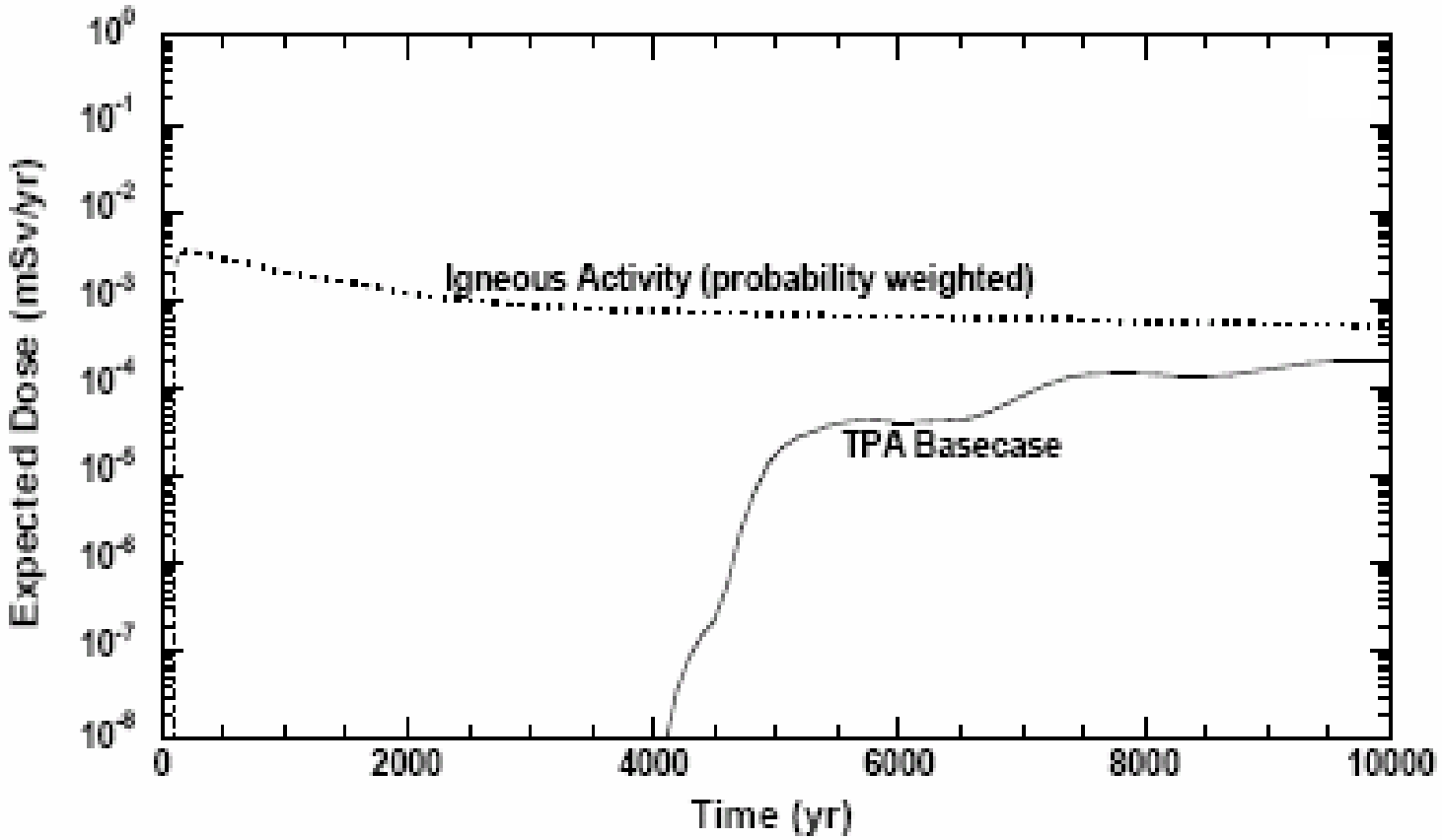
	10,000 Years		100,000 Years	
Radio-nuclide	mSv/yr	% contri-bution	mSv/yr	% contri-bution
Np-237	4.29×10^{-5}	21%	9.54×10^{-2}	96%
I-129	5.34×10^{-5}	26%	1.33×10^{-3}	1%
Tc-99	1.09×10^{-4}	53%	2.09×10^{-3}	2%

Reference: NRC/CNWRA, System-level Performance Assessment of the Proposed 4.1 Code, March 2004 Repository at Yucca Mountain Using the TPA Version

Disruptive Events – Igneous Activity

- TPA calculates consequences of extrusive and intrusive releases of radionuclides
- Extrusive Release – radionuclides entrained in magma are transported by volcanic ash
- Intrusive Release – waste packages are damaged by magma in drifts and radionuclides can be transported by water contacting the waste

Results for Disruptive Igneous Scenario



Source: NRC/CNWRA, System-level Performance Assessment of the Proposed Repository at Yucca Mountain Using the TPA Version 4.1 Code, March 2004

Risk Insights Ratings

- Rating of significance (high, medium, or low) helps to prioritize activities, focus staff resources, and support risk-informed project management and decision-making

- Three criteria in evaluating significance:
  - Effect on the integrity of waste packages;
  - Effect on the release of radionuclides from the waste form and waste package; and
  - Effect on the transport of radionuclides through the geosphere and biosphere.

Findings: High Significance to Waste Isolation

- Degradation of Engineered Barriers
  - Persistence of a passive film on waste packages
- Quantity and Chemistry of Water Contacting Engineered Barriers and Waste Forms
  - Chemistry of seepage water
- Flow Paths in the Unsaturated Zone
  - Seepage into drifts
- Radionuclide Transport in the Saturated Zone
  - Retardation in the saturated zone alluvium
- Volcanic Disruption of Waste Packages
  - Probability of igneous activity
  - Number of waste packages affected by eruption
- Airborne Transport of Radionuclides
  - Inhalation of resuspended volcanic ash

Benefits of Performance Assessment

- Performance assessments (PAs) help understand repository by studying a range of conditions that challenge safety
- PAs provide *risk insights*, i.e., identify important parameters, models, and assumptions
- Risks insights used to help focus confirmatory information collection, model development and documentation, and enhancing regulatory review capability

NRC's Risk Insights Baseline Report

- Developed by NRC and Center for Nuclear Waste Regulatory Analyses (CNWRA) Staffs in 2003-2004

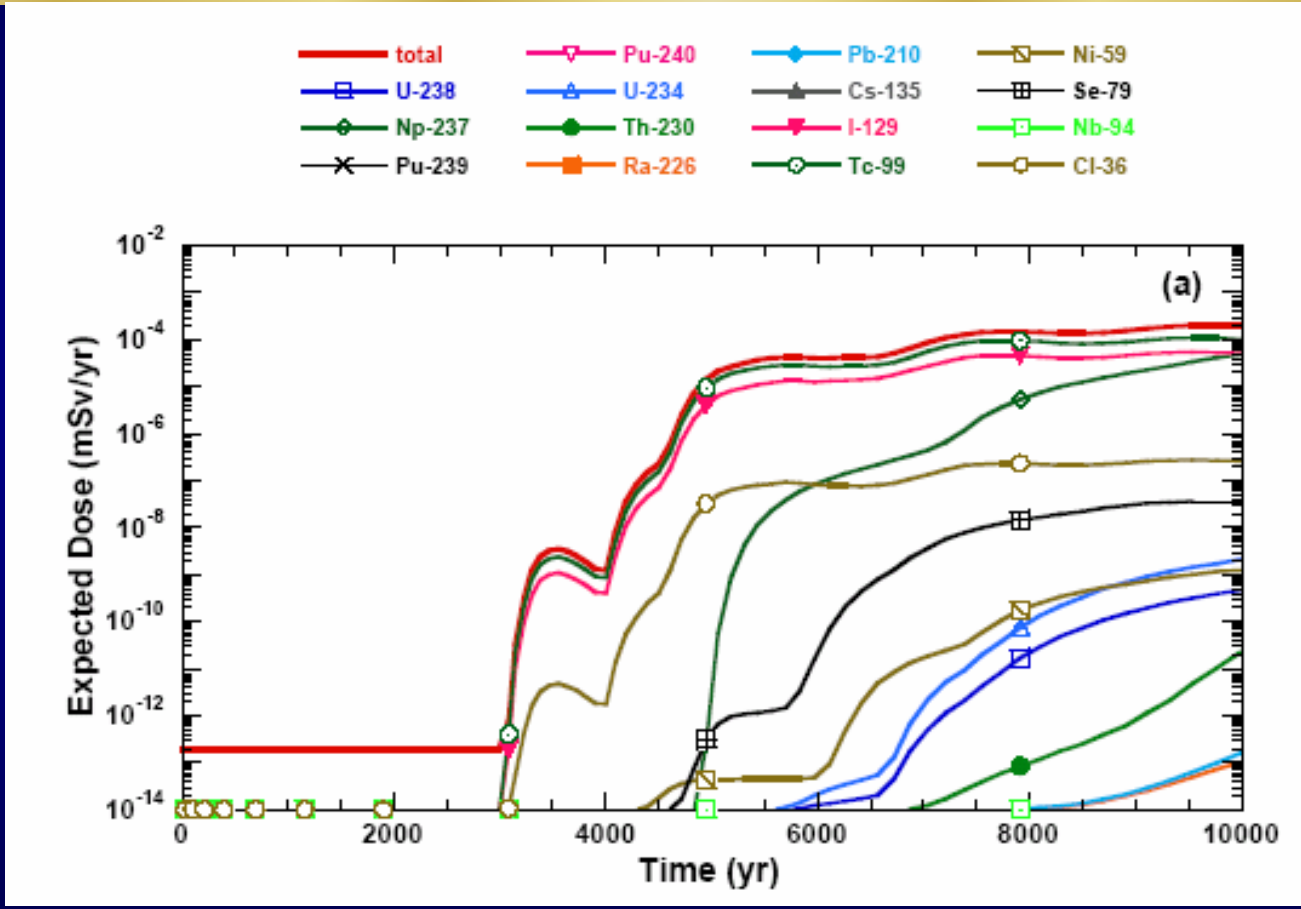
- Risk Insights Baseline - April 2004
  - www.nrc.gov/waste/hlw-disposal/reg-initiatives/ml040560162.pdf

Conclusions

- TPA code is used as a review tool. Licensing decisions and conclusions will be based on DOE's TSPA - LA
- Understanding and explanation of PA results is an essential aspect to developing confidence in PA models.
- TPA provides a flexible framework to independently evaluate the performance of a potential Yucca Mountain repository system.

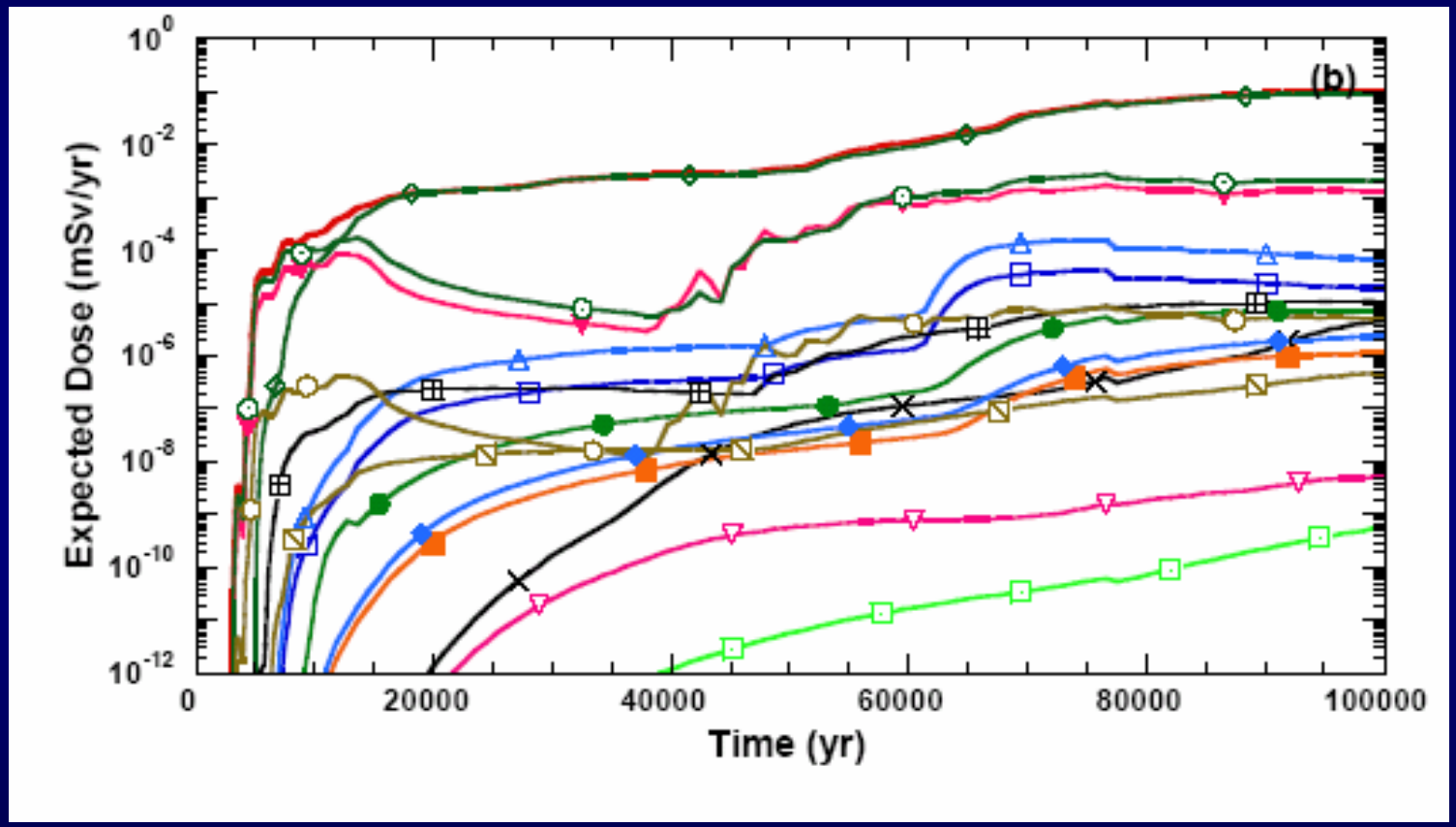
Supplementary/ Back-up Slides

Radionuclide Dose Contributions in 10,000 years



Reference: NRC/CNWRA, System-level Performance Assessment of the Proposed Repository at Yucca Mountain Using the TPA Version 4.1 Code, March 2004

Radionuclide Dose Contributions in 100,000 years



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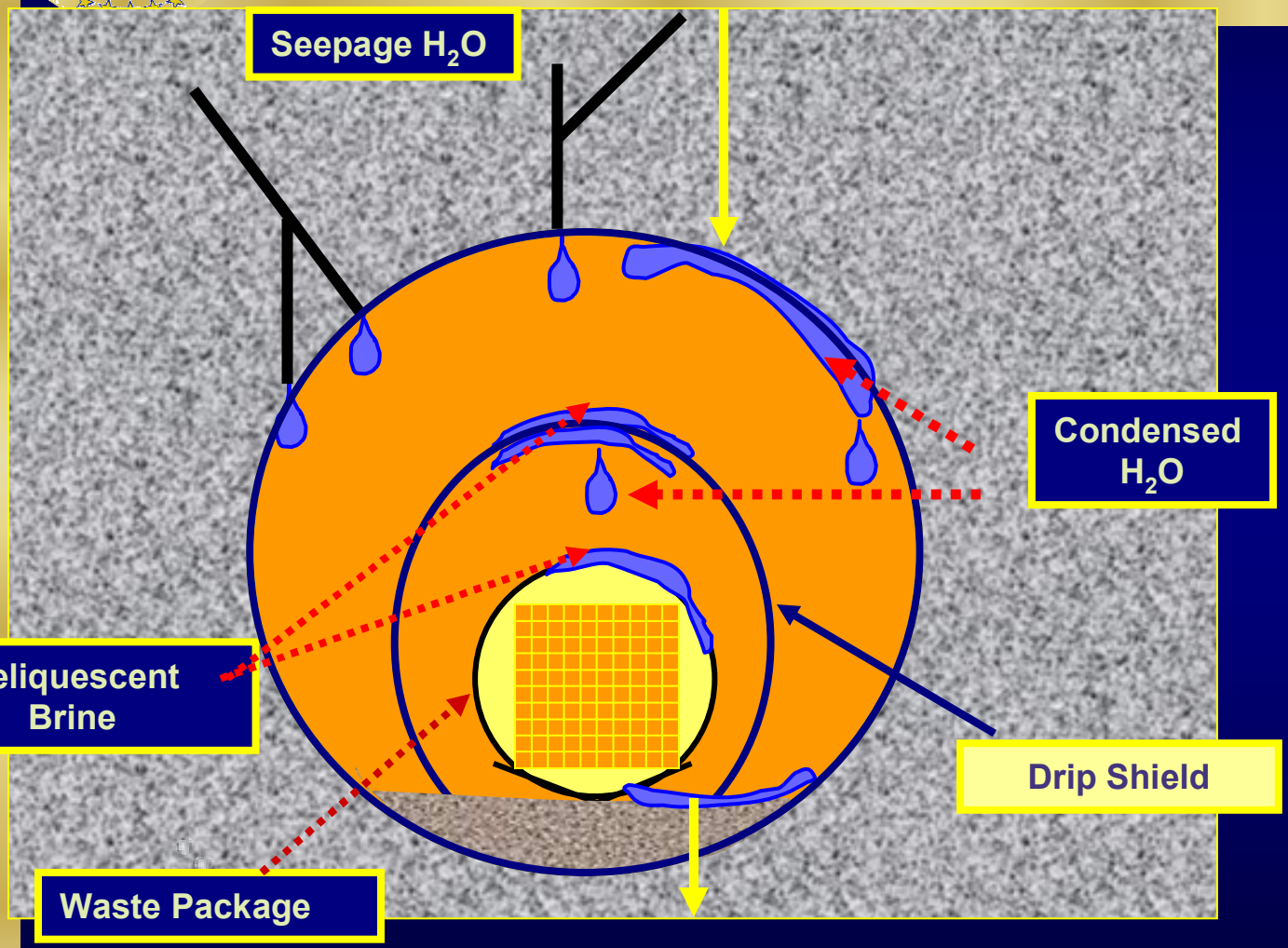
Drift/Engineered Barrier System

Water entering drift



- Seepage and water contacting waste
- Drip shield corrosion
- Waste Package corrosion
- Spent fuel degradation
- Cladding failure
- Radionuclide Release

Water and radionuclides exiting the drift

Performance Assessment:

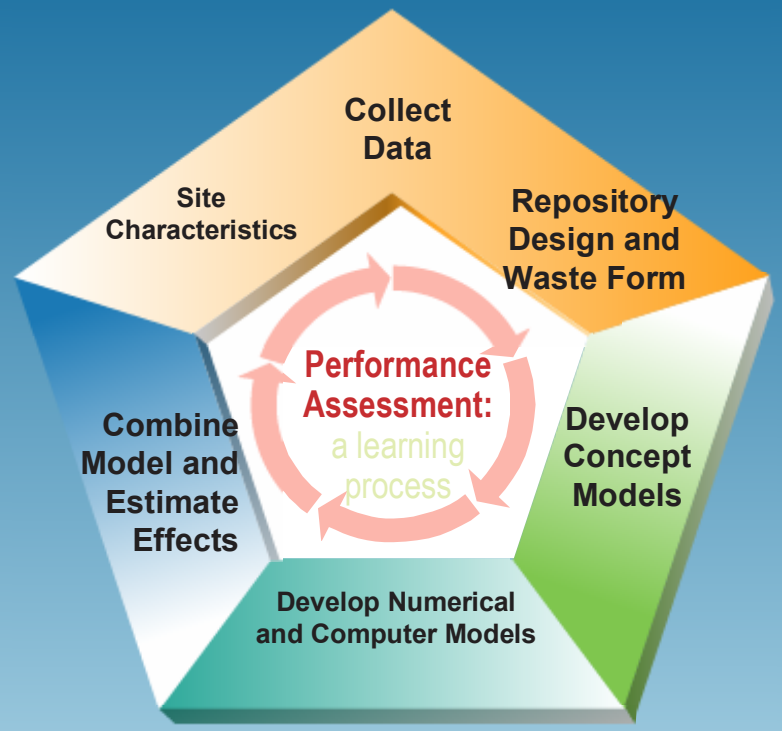
Part of Evaluating the Safety of a Proposed Repository at Yucca Mountain, Nevada

What is Performance Assessment?

- Systematic analysis of what could happen at a repository
- One of many NRC safety requirements

Why use it?

- Complex system
- Systematic way to evaluate data
- Internationally accepted approach



What is assessed?

- What can happen?
- How likely is it?
- What can result?

How is it conducted?

- Collect data
- Develop scientific models
- Develop computer code
- Analyze results

NRC would require DOE's Performance Assessment to

- Provide site and design data
- Describe barriers that isolate waste
- Evaluate features, events, and processes that affect safety
- Provide technical basis for models and inputs
- Account for variability and uncertainty
- Evaluate results from alternative models

Pre-closure Safety Analysis (PCSA)

- Systematic risk analysis using event tree / fault tree methods to determine event sequences
- Two categories of event sequences considered during pre-closure period
  - Category 1: expected to occur one or more times
  - Category 2: chance of 1/10,000
- Performance objectives
  - Category 1 sequences taken together
    - Occupational dose: .05 Sv (5 rem) annual
    - Public dose: 0.15 mSv (15 mrem) annual
  - Category 2 sequences taken individually
    - Public dose: 0.05 Sv (5 rem) per event