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

Repository Safety Strategy

Presented to:
Nuclear Waste Technical Review Board

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YUCCA MOUNTAIN PROJECT

What is the Repository Safety Strategy?

- **Repository Safety Strategy (RSS) defines the preclosure and postclosure safety cases to address the defined performance objectives for the system**
- **It provides the focus and integration of all work related to preclosure and postclosure safety**
- **As required by the siting guidelines, the safety case for SR focuses on the performance objectives of NRC's regulation**
- **The safety case must address the standard for reasonable assurance in NRC's regulation; consequently, the RSS provides the strategy for establishing confidence in the safety case**

Safety Case--Postclosure

- **The postclosure safety case rests on knowledge of the geologic setting and the waste isolation attributes of the system**
- **It incorporates performance assessment and includes additional elements to provide increased confidence**
- **It identifies the principal factors to**
  - **Provide transparency**
  - **Identify the areas where uncertainty is important**

Geologic Framework

- **The geologic repository provides characteristics that lend themselves to waste isolation**
  - **Yucca Mountain has changed little over the last several millions of years**
  - **No significant erosion or natural hazards**
  - **Physically and chemically stable host rock**
  - **Ability to isolate waste from surface conditions**
  - **Environments at depth that support long-lived engineered barriers**
  - **Sorption and retention of vast majority of radionuclides by natural barriers**
  - **Ample rock between repository and people**

Waste Isolation Attributes of the System

- **Limited water entering emplacement drifts**
- **Long-lived waste package and drip shield**
- **Limited release of radionuclides from the engineered barriers**
- **Delay and dilution of radionuclide concentrations by the natural barriers**
- **Low expected dose rate even considering potentially disruptive events**

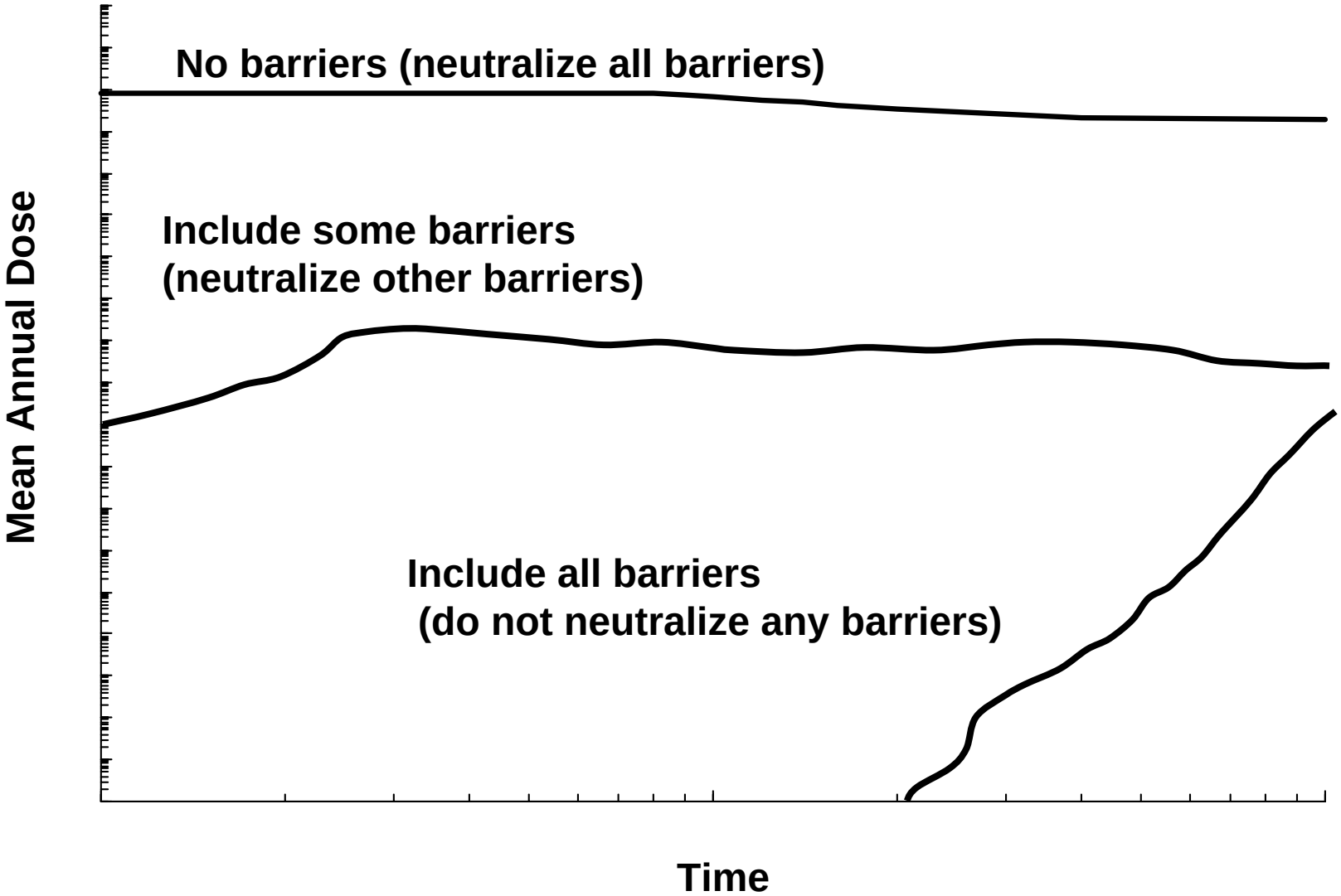
Principal Factors

- **Comprehensive set of factors is considered for evaluation of siting criteria and is taken into account in TSPA-SR**
  - **However, only principal factors are explicitly credited in the postclosure safety case**
- **Principal factors are those essential to determining postclosure safety; they are identified to**
  - **Increase transparency**
  - **Identify areas where uncertainty is important**
- **They rest on understanding of system and take into account results of TSPA sensitivity and barrier importance analyses**

Using Neutralization Analyses

- **Sensitivity studies within the range of known uncertainty are useful for evaluating uncertainty in factors, but cannot determine absolute contributions of factors**
- **Only approach for evaluating absolute contributions is through neutralization analyses**
- **Factors are completely neutralized in order to limit arbitrariness and bias**

Schematic of Neutralization Analyses



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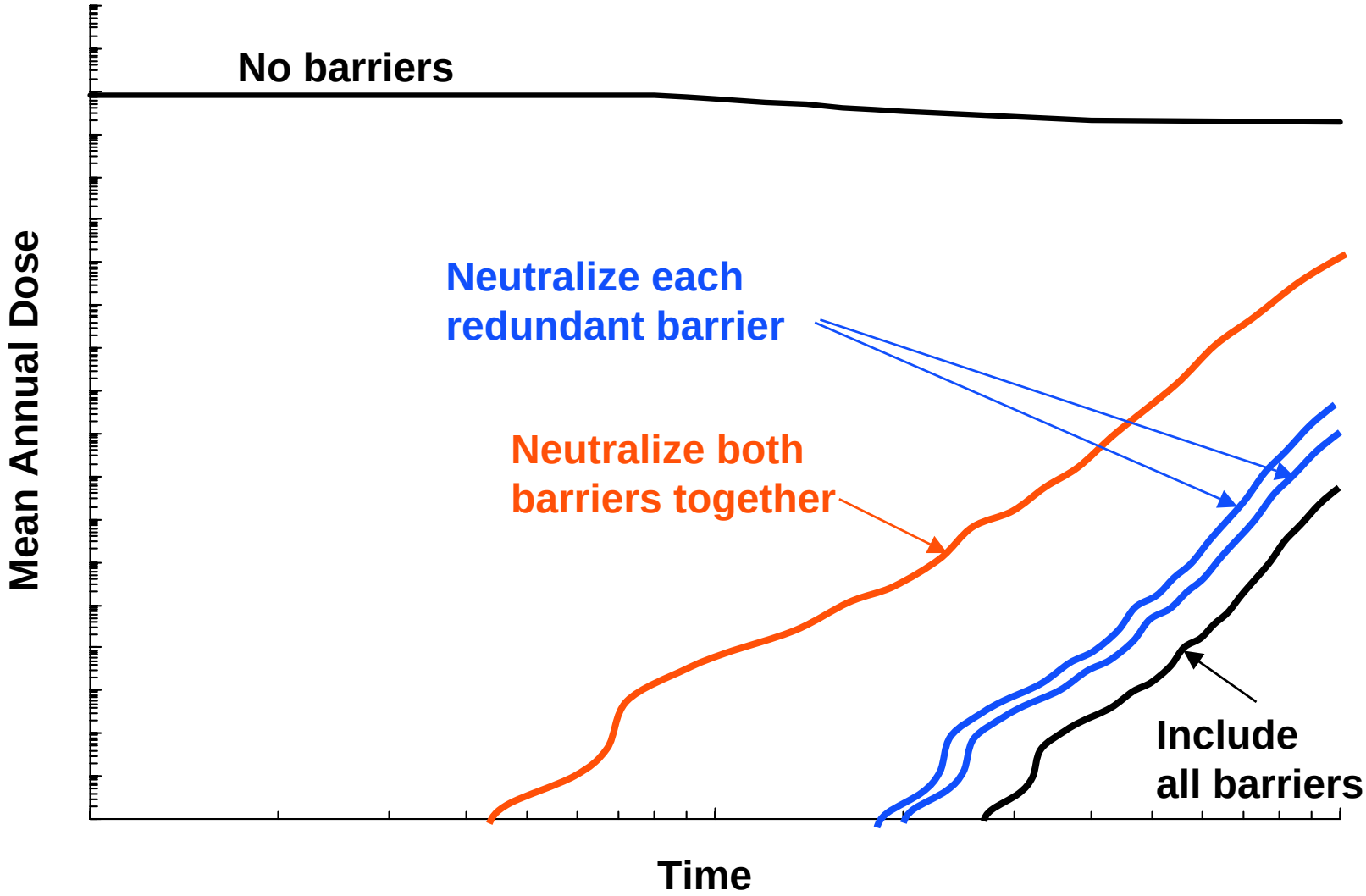
Assessing Defense-in-Depth

- **Defense-in-depth means that barriers are redundant**
  - **Failure of any one barrier does not mean failure of the system because barriers back up each other (belt and suspenders)**
  - **System failure requires multiple independent, low-probability failures--probability of system failure is reduced through defense-in-depth**
- **Defense-in-depth cannot be evaluated by neutralizing only single barriers or single factors**
- **Complete assessment of system requires neutralization of combinations of barriers or factors as well as individual neutralizations**

Schematic of Defense-in-Depth Analyses



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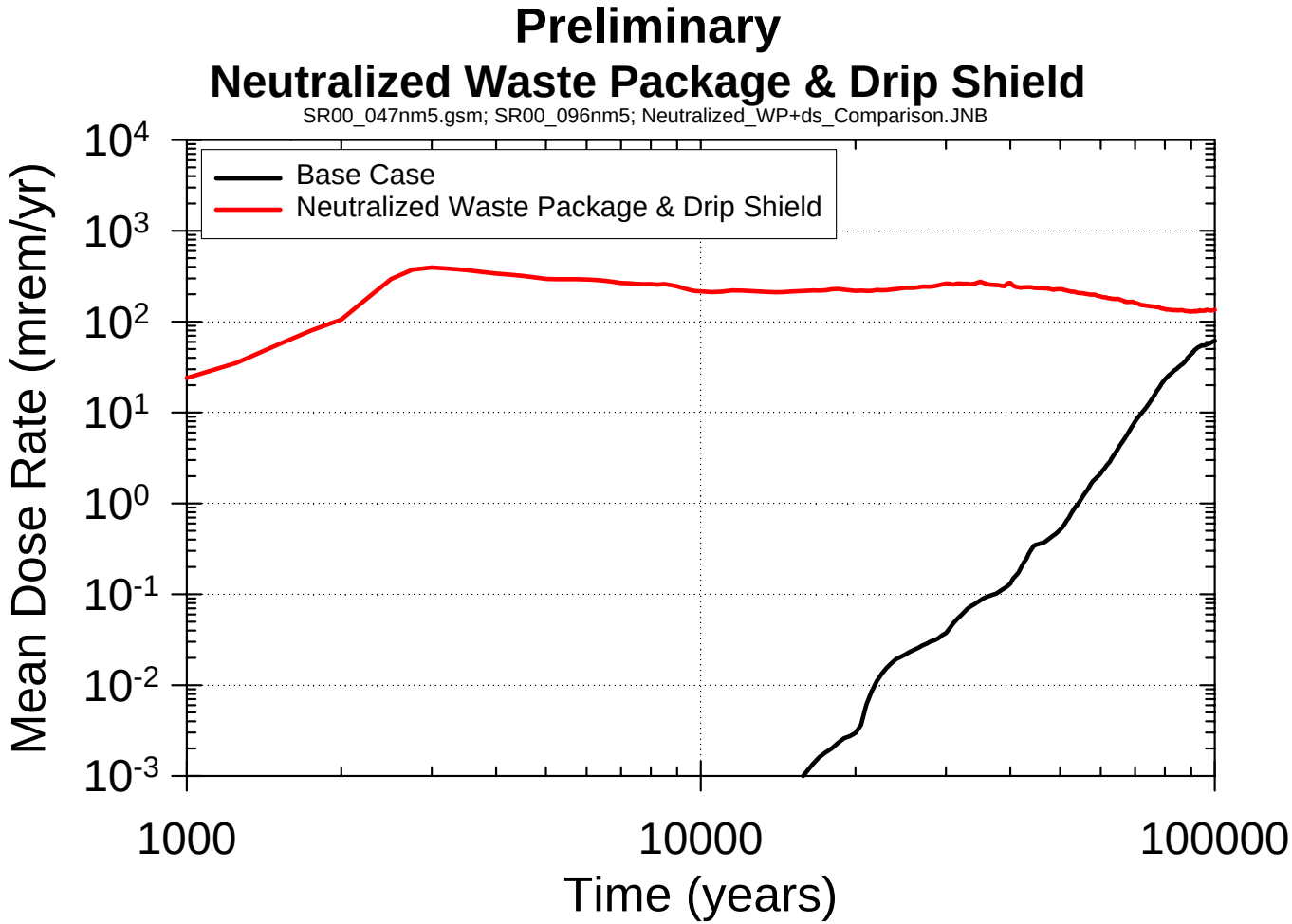
Identifying Principal Factors

- **Neutralization analyses apply to barrier functions (e.g., limiting radionuclide migration) and other factors (e.g., concentrations limits)**
- **Analyses are used to determine contribution of a factor, not to explore what might possibly happen**
- **Neutralizations provide insight into the TSPA analysis and do not indicate performance possibilities--those are addressed in the TSPA "horsetail" diagrams**

Neutralization Analysis of EBS Factors



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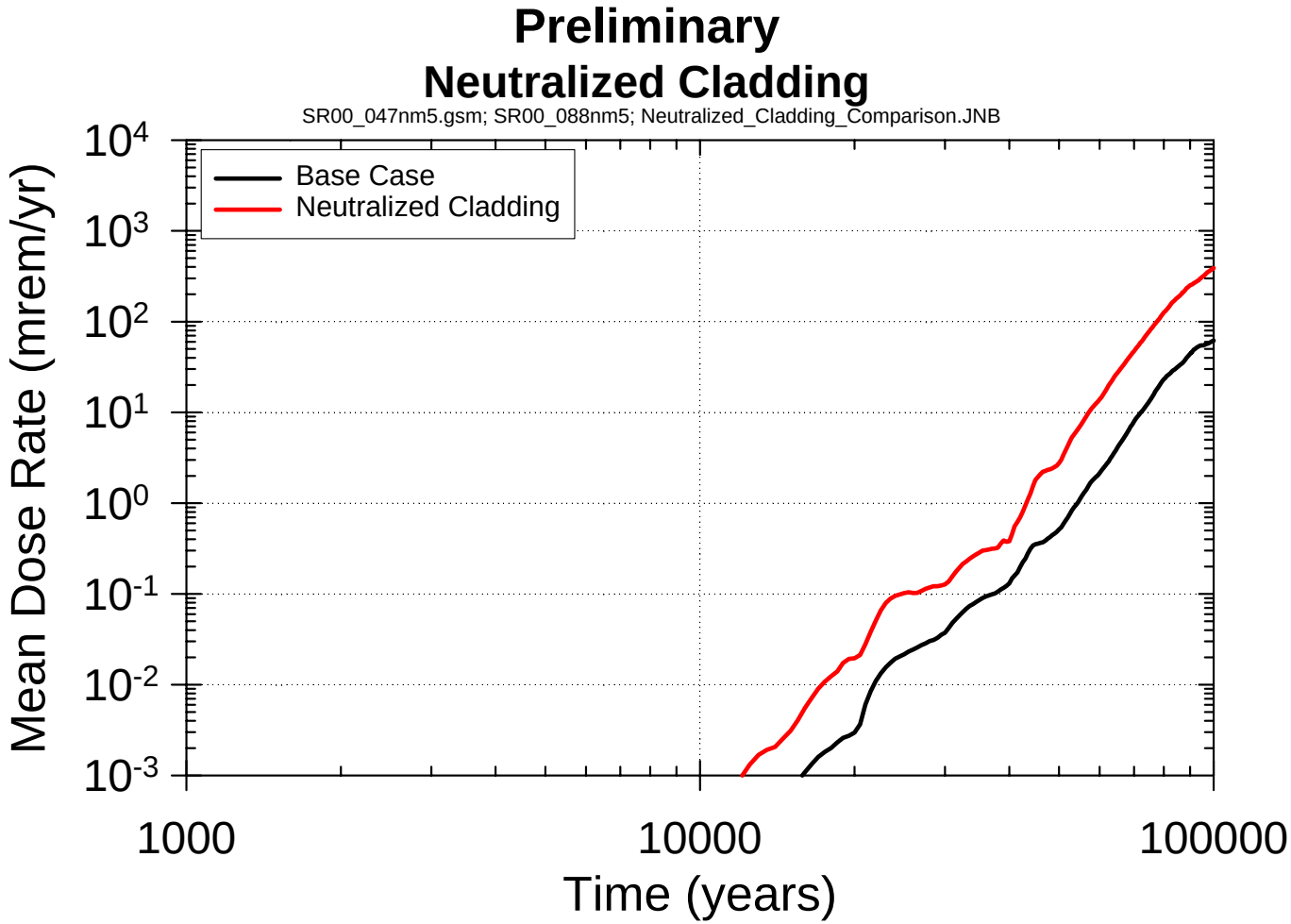
Neutralization Analysis of Cladding



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Factors for Nominal Scenario

Geologic Framework	Waste Isolation Attributes	Principal Factors
• Yucca Mountain has changed little over last several million years • No significant erosion or natural hazard • Protection of waste at depth from surface conditions • Isolation of waste from the water table • Physically and chemically stable host rock • Environments at depth that support long-lived engineered barriers • Ample rock to sorb and retain radionuclides	Limited water entering emplacement drifts	**Seepage into emplacement drifts**
	Long-lived waste package and drip shield	**Performance of the drip shield and drift invert system**
		Performance of the waste package
	Limited release of radionuclides from the engineered barriers	**Dissolved radionuclide concentrations and Colloid-associated radionuclide concentrations at the source**
	Delay and dilution of radionuclide concentrations provided by the natural barriers	**Radionuclide delay through the unsaturated zone**
		Radionuclide delay through the saturated zone

Factors for Disruptive Event Scenarios

<table>
<tr><th>Geologic Framework</th><th>Waste Isolation Attributes</th><th>Principal Factors</th></tr>
<tr><td rowspan="3">Yucca Mountain has changed little over last several million years
No significant erosion or natural hazard
Protection of waste at depth from surface conditions
Isolation of waste from the water table
Physically and chemically stable host rock
Environments at depth that support long-lived engineered barriers
Ample rock to sorb and retain radionuclides</td><td rowspan="3">Low expected dose rate even considering potentially disruptive events</td><td>Probability of igneous activity</td></tr>
<tr><td>Repository response to igneous intrusion (damage to waste packages and drip shields)</td></tr>
<tr><td>Additional factors that also apply to the nominal scenario
Seepage into emplacement drifts
Dissolved radionuclide concentrations and colloid-associated radionuclide concentrations at the source
Radionuclide delay through the unsaturated zone
Radionuclide delay through the saturated zone</td></tr>
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Principal Factors

Principal Factors	RSS3	RSS4
Seepage into emplacement drifts	✓	✓
Performance of the drip shield and drift invert system	✓	✓ ✓
Waste package performance	✓	✓
Dissolved radionuclide concentrations and colloid-associated radionuclide concentrations at the source	✓	✓ ✓
Radionuclide delay through the unsaturated zone	✓	✓
Radionuclide delay through the saturated zone	✓	✓
Dilution at the wellhead	✓	
Probability of igneous activity		✓
Repository response to igneous intrusion (damage to waste packages and drip shields)		✓

Elements of the Postclosure Safety Case

- **The postclosure safety case includes five elements**
  - **Performance assessment**
  - **Margin and defense-in-depth**
  - **Explicit consideration of potentially disruptive processes and events**
  - **Insights from natural analogues**
  - **Performance confirmation**

Performance Assessment

- **In addition to TSPA analyses, to enhance confidence performance assessment includes**
  - **Supporting data for models and parameters**
  - **Accounting for uncertainty and variability**
  - **Consideration of credible alternative models**
  - **Technical bases for specific features, events, and processes, EBS degradation processes, and models used in the performance assessment**
  - **Barrier importance assessment**
    - **Identification of barriers important to waste isolation.**
    - **Description of capability of these barriers and basis for this description**

Safety Margin and Defense-in-Depth

- **Standard approach to safety--addresses broad confidence issues**
- **Safety Margin**
  - **Margin in both magnitude of estimated annual dose (within 10,000 years) and time (time after 10,000 years before standard is exceeded)**
  - **TSPA results indicate substantial margin in both magnitude and time**
- **Defense-in-Depth**
  - **No undue reliance on any single element**
  - **Preliminary results indicate neutralization of any individual barrier does not exceed 100 mrem/year**

Potentially Disruptive Events

- **Addresses confidence issue by addressing key concerns explicitly. These include**
  - **Seismic activity, future climate change**
    - **No separate scenario--included in the nominal scenario**
  - **Water table rise**
    - **Water table rise to level of repository is not credible**
  - **Postclosure nuclear criticality**
    - **Excluded because of long-lived waste packages**
  - **Inadvertent human intrusion**
    - **Addressed as a separate scenario as dictated by regulation**

Potentially Disruptive Events
(Continued)

- **Igneous activity**
  - **Direct (eruptive) release scenario has mean probability of occurrence in 10,000 years that is less than one chance in 10,000**
    - **Evaluating this scenario but considering not including it in the licensing case**
  - **Indirect release scenario is sufficiently probable to warrant consideration and is explicitly evaluated in TSPA though a groundwater release scenario**

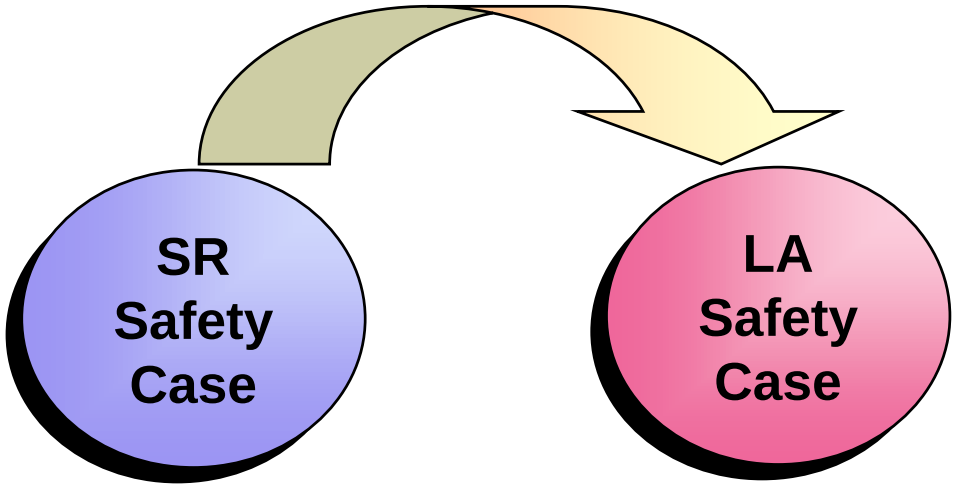
Natural Analogues

- **Current analogue information is limited**
- **However, current data base contains some natural analogue data complementing lab and site data**
  - **Natural analogue of the unsaturated zone flow system--variably saturated, fractured basalt at Box Canyon, Idaho**
  - **Natural analogue of unsaturated zone radionuclide transport--uranium deposit at Peña Blanca, Chihuahua, Mexico**
  - **Natural analogue of metal stability deep underground--Akrotiri archeological site, Santorini, Greece**
- **We are evaluating other studies to provide additional confidence-building information**

Performance Confirmation

- **Increases confidence by committing to conduct long term (post LA) tests to confirm**
  - **Barriers important to waste isolation are performing as expected**
  - **Key parameters fall into the ranges specified in LA**
- **Testing is dictated by three considerations**
  - **Specific requirements of the regulation**
  - **Address the principal factors**
  - **Decision-making associated with permanent closure and possible need to exercise retrieval option**

RSS Also Provides Plans for Key Issues



- **In the event the Yucca Mountain site is found suitable for repository development, a license application (LA) would have to be prepared**
- **In this event certain issues would have to be addressed to complete a postclosure safety case for LA**

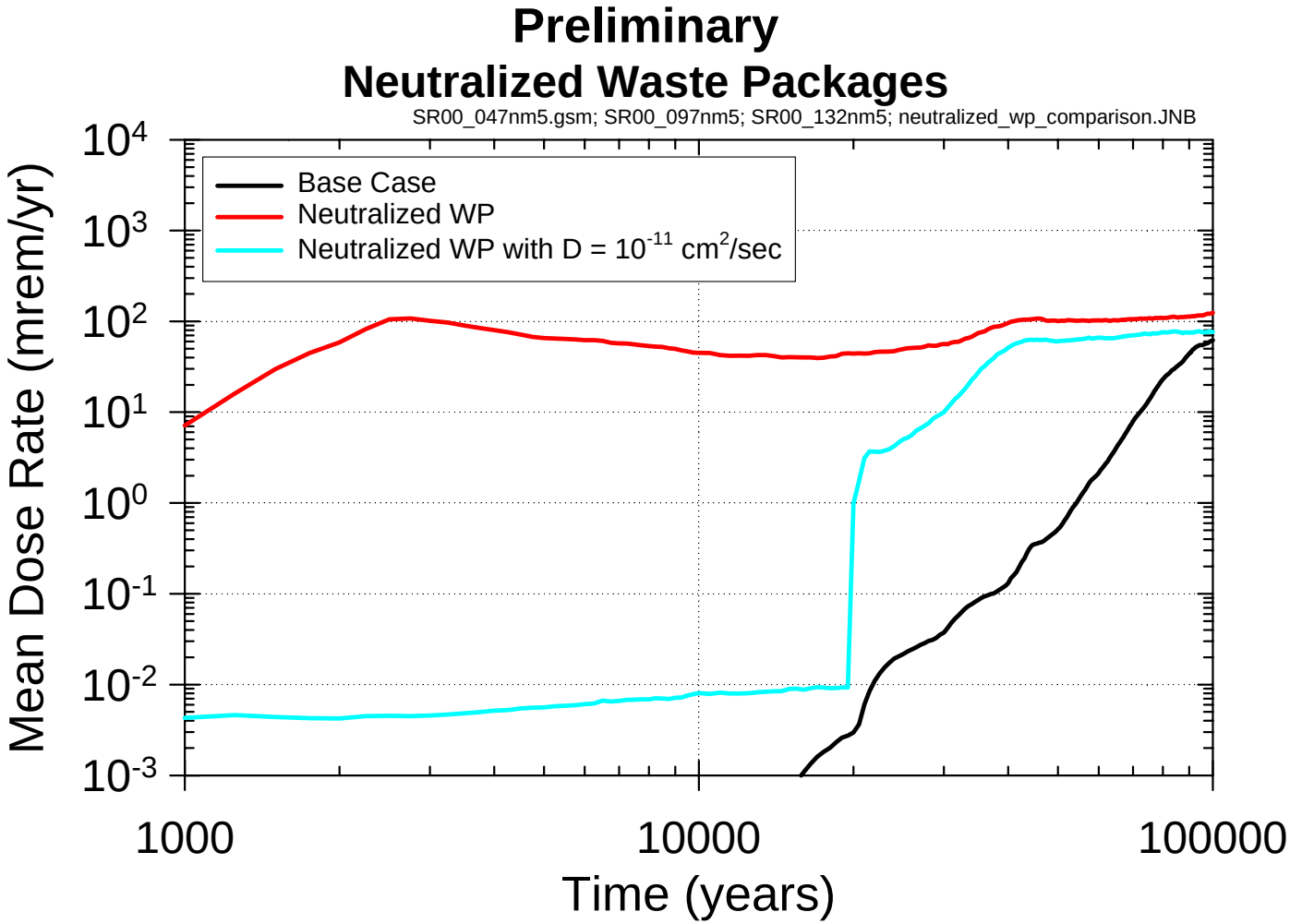
Issues--Waste Package Performance

- **Waste package performance would be a key factor in a postclosure safety case for LA**
- **Technical basis for the degradation model must be sufficient to justify probability of waste package failure before 10,000 years is very low**
- **Approach**
  - **Continue to increase data base for waste package degradation**
  - **Conduct modeling to evaluate consequence of low probability modes**
  - **Continue to utilize defense-in-depth to address residual uncertainty**

Issues--Defense-in-Depth

- **Defense-in-depth is essential to the safety case; in particular, defense-in-depth is needed to prevent undue reliance on the waste package**
- **Conservative representation of drift invert diffusive transport model does not currently support complete defense-in-depth by drip shield**
- **Approach**
  - **Additional study of drift invert diffusive transport model**
  - **Evaluate conservatism in flow and transport models**

Defense-in-Depth Analysis



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Issues--Model Over-Conservatism

- **Conservatism, where appropriate, generally lends to confidence in the case**
- **However, conservatism limits detailed understanding**
- **Over-conservatism may be inconsistent with risk-informed, performance-based approach**
- **Approach**
  - **Assess over-conservatism in key models**
    - **In-package transport model (including thermal effects)**
    - **Drift invert diffusive transport model**
    - **UZ and SZ transport model**

Issues--Model Stability

- **Confidence affected by continued changes in models**
  - **Enhancements desirable, but prospects for significant changes affect confidence in current models**
  - **Lack of settled models affects confidence and credibility of system assessments using them**
- **Approach**
  - **Focus on models in areas associated with principal factors**
  - **Except for significant changes, maintain models from SR to LA--use new information for arguments regarding defensibility, margin, and importance of uncertainties**

Summary

- **The RSS focuses on increasing confidence in the postclosure safety case, including the TSPA analyses central to that case**
- **The RSS provides transparency and identifies the key uncertainties**
- **A key element of the RSS is margin and defense-in-depth to address unquantified uncertainties (e.g., those that could lead to changes in the estimates in the future)**
- **Important to the RSS is the scientific soundness of the TSPA sensitivity and barrier importance analyses**