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# Treatment of Extreme Geologic Events in Post-Closure Safety Cases for U.S. Repositories for High-Level and Transuranic Radioactive Waste

Peter Swift and Christi Leigh  
Sandia National Laboratories

Abraham van Luik  
U.S. Department of Energy

The Sixteenth Meeting of the Integration Group for the Safety Case (IGSC)  
Nuclear Energy Agency of the Organisation for Economic Cooperation and Development  
Paris, France  
October 7-9, 2014



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# Outline

- Regulatory framework
- Treatment of disruptive events in the safety assessment for the proposed Yucca Mountain repository
  - Igneous disruption
  - Seismic disruption
  - Estimation of mean annual dose
- The Waste Isolation Pilot Plant
- Ongoing disposal R&D
- Summary

# Regulatory Framework

- U.S. Environmental Protection Agency defines the form of the post-closure safety assessment

*“Performance assessment means an analysis that*

- (1) Identifies the features, events, processes, (except human intrusion), and sequences of events and processes (except human intrusion) that might affect the Yucca Mountain disposal system and their probabilities of occurring;*
- (2) Examines the effects of those features, events, processes, and sequences of events and processes upon the performance of the Yucca Mountain disposal system; and*
- (3) Estimates the annual committed effected dose equivalent incurred by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant features, events, processes, and sequences of events and processes, weighted by their probability of occurrence.”*

*(40 CFR part 197.12, emphasis added. This definition is specific to the proposed Yucca Mountain repository, but concept is analogous in generic standards)*

# Regulatory Framework (cont.)

- U.S. Environmental Protection Agency establishes criteria for identifying and screening the features, events, and processes that must be included in a safety assessment

“The DOE’s performance assessments conducted to show compliance with [the long term standards] **shall not include consideration of very unlikely features, events, or processes**, i.e., those that are estimated to have less than one chance in 100,000,000 per year of occurring.

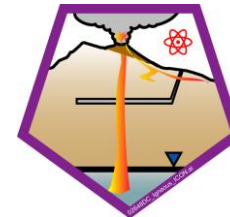
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In addition, unless otherwise specified in these standards or NRC regulations, DOE’s performance assessments **need not evaluate** the impacts resulting from features, events, and processes or sequences of events and processes with a higher chance of occurring **if the results of the performance assessment would not be changed significantly** in the initial 10,000-year period after disposal.”

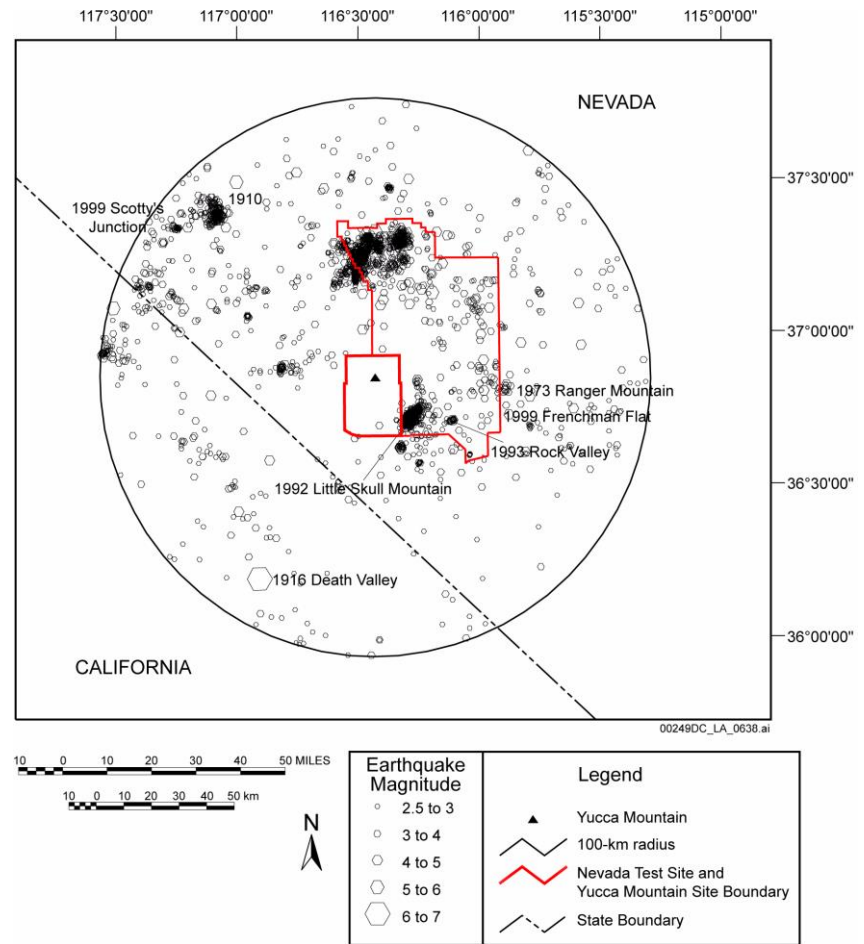
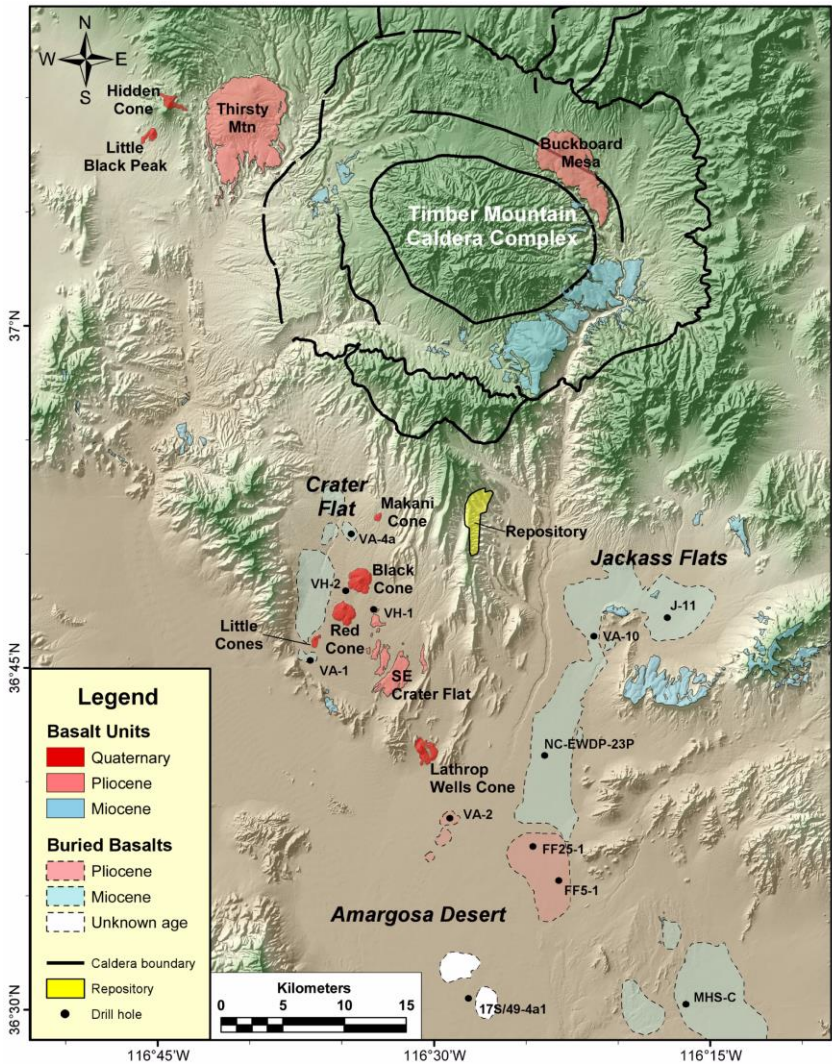
*(40 CFR part 197.36(a)(1), emphasis added. These requirements are specific to the proposed Yucca Mountain repository, but concepts are analogous in generic standards)*

# Regulatory Framework (cont.)

- Regulatory requirements define the process for constructing scenarios based on the occurrence of “unlikely” natural events
  - (for completeness, NRC defines “unlikely” for Yucca Mountain at 10 CFR 63.342 to be events with probabilities between  $10^{-5}/\text{yr}$  and  $10^{-8}/\text{yr}$ )*
  - Likely natural events, even if extreme, are included in the nominal scenario that describes the evolution of the disposal system in the absence of unlikely events
    - For example, climatic effects of glacial cycles are part of the nominal scenario
- Unlikely natural events with the potential to impact repository performance are included in analysis of disruptive event scenarios
  - Two extreme geologic events were identified as “unlikely” (as opposed to “likely” or “very unlikely”) for Yucca Mountain:
    - Igneous disruption and large-magnitude seismic events



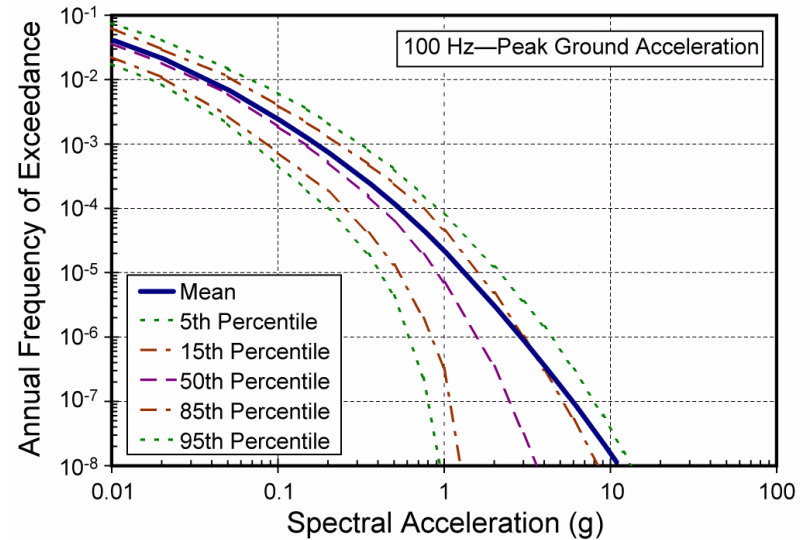
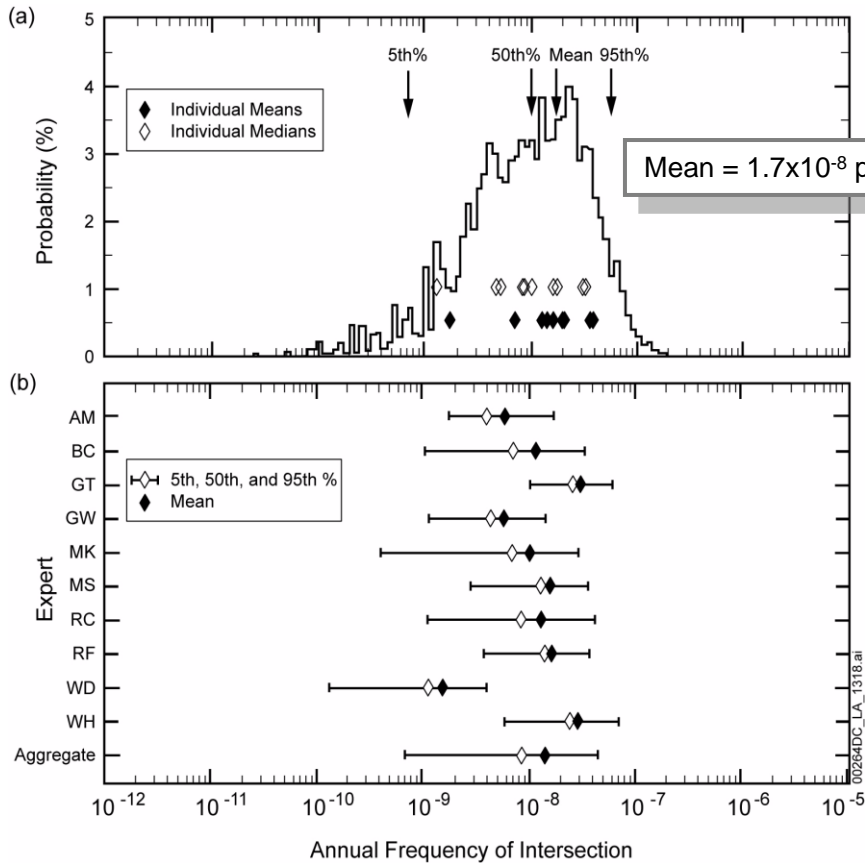
# Igneous and Seismic Activity in the Yucca Mountain Region



Historical Earthquake Epicenters with 100 km of Yucca Mountain (DOE/RW-0573 Rev. 1, Figure GI 5-38)

Distribution of Miocene and younger (< 5.3 Ma) Basaltic Rocks in the Yucca Mountain Region (DOE/RW-0573 Rev. 1, Figure GI 5-39)

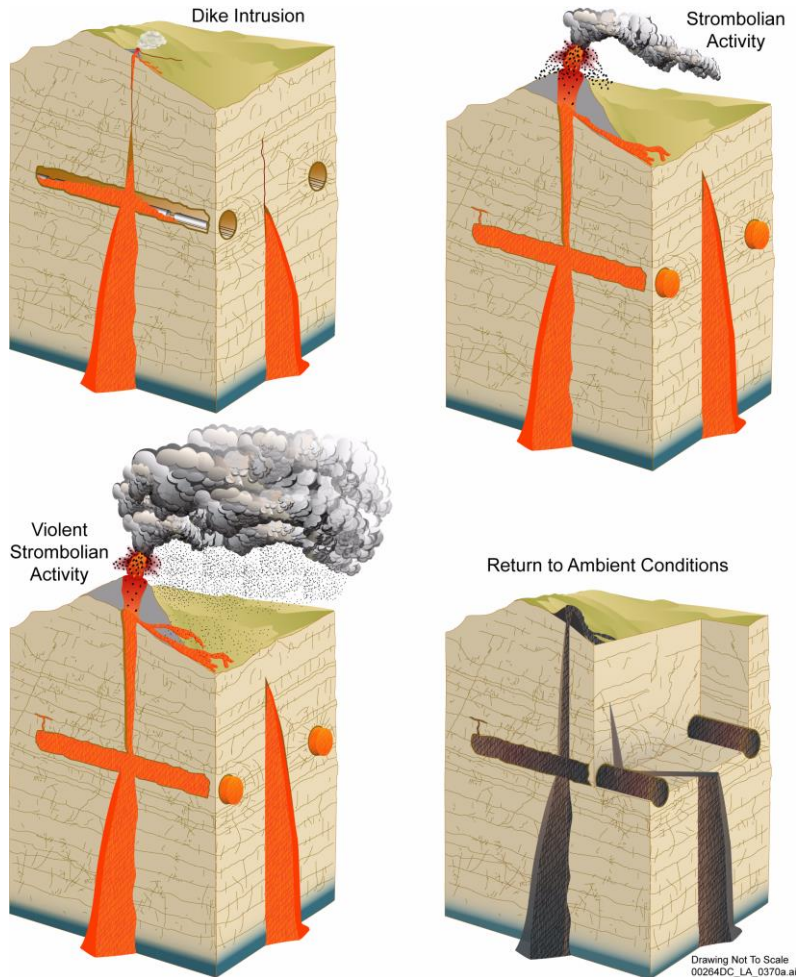
# Yucca Mountain Event Probabilities Estimated by Formal Expert Elicitation



Estimated annual frequency of peak ground acceleration, 100 Hz (DOE/RW-0573 Rev. 1, Figure 2.3.4-7)

Estimated annual frequency of an igneous intrusion intersecting the repository footprint (DOE/RW-0573 Rev. 1, Figure 2.3.11-8)

# Consequence Models for Igneous Disruption at Yucca Mountain

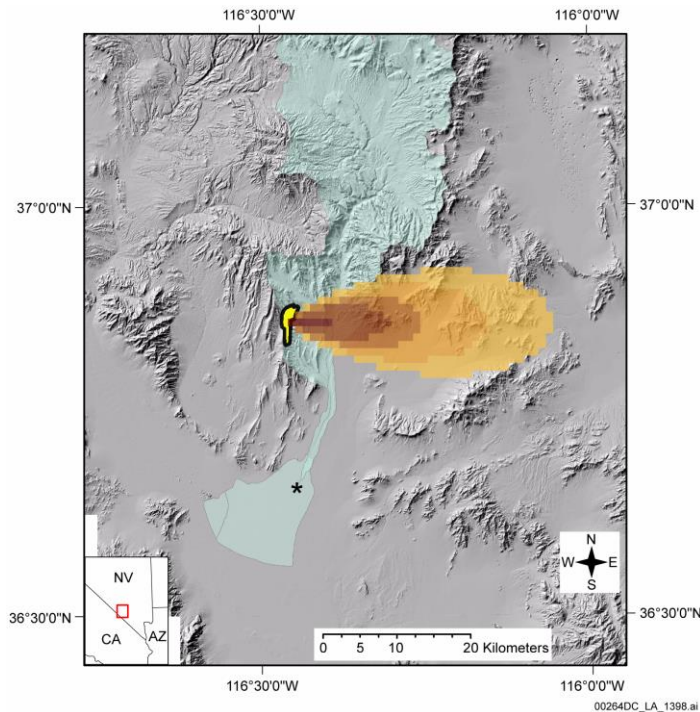


Schematic Drawing of an Igneous Event at Yucca Mountain (DOE/RW-0573 Rev. 1, Figure 2.3.11-5)

## Two Release Scenarios

- Volcanic eruption of contaminated ash
  - Releases limited to waste packages intersected by the volcanic conduit
    - Mean number of waste packages intersected = 3.8
    - Mean fraction of waste package content ejected = 0.3
    - Ash redistribution by fluvial processes after deposition
- Groundwater transport from damaged packages that remain in the repository
  - All waste packages in the repository assumed to be sufficiently damaged to provide no barrier to flow and transport
  - Groundwater flow and radionuclide transport assumed to occur as in nominal scenario

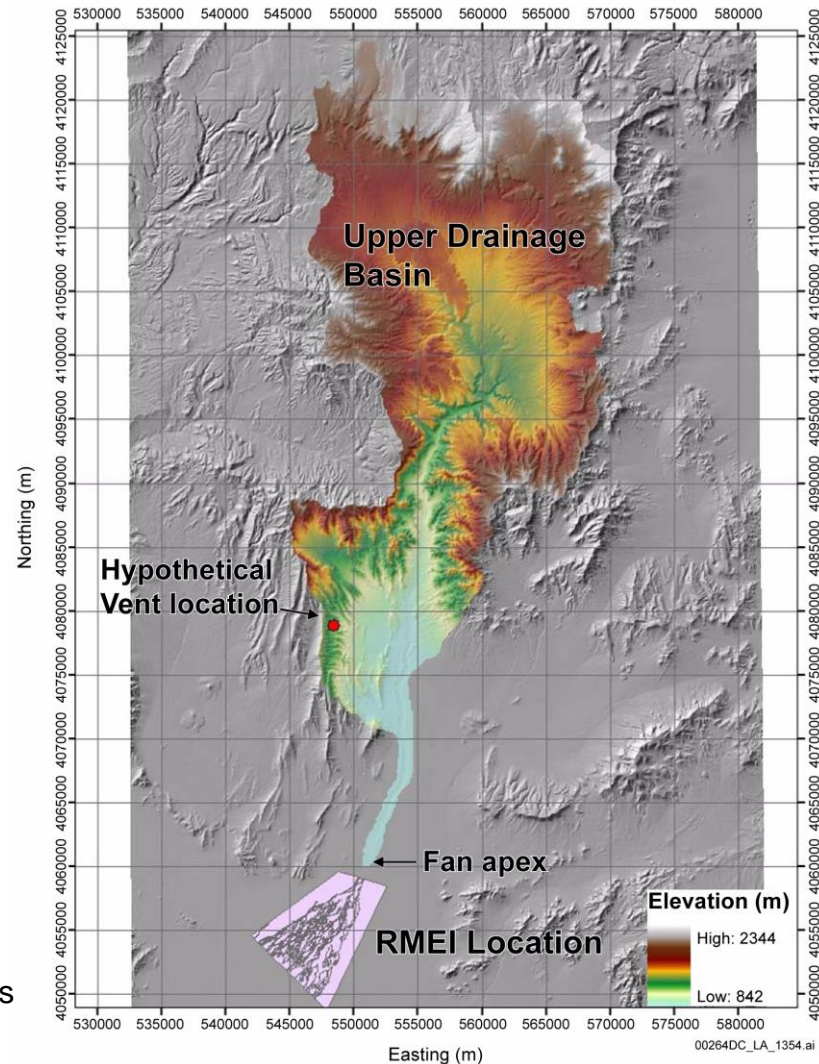
# Modeling Consequences of Volcanic Eruption



Model results showing representative ash deposition following an eruption at Yucca Mountain (wind from west) (DOE/RW-0573 Rev. 1, Figure 2.3.11-16)

## Uncertain variables include:

- Eruption properties, including power and duration
- Conduit diameter (controls number of waste packages)
- Wind speed and direction
- Ash particle size
- Fraction of waste entrained in ash (vs. lava)

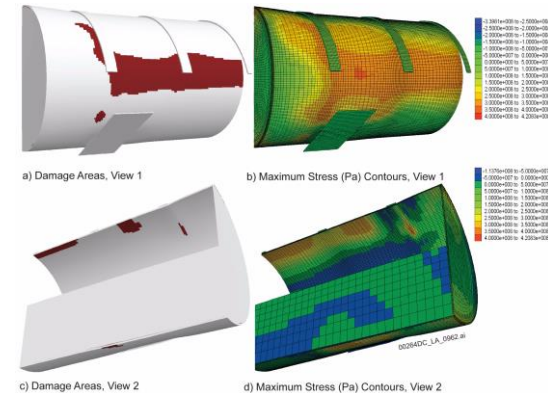


Model domain for surface redistribution of ash (DOE/RW-0573 Rev. 1, Figure 2.3.11-5)

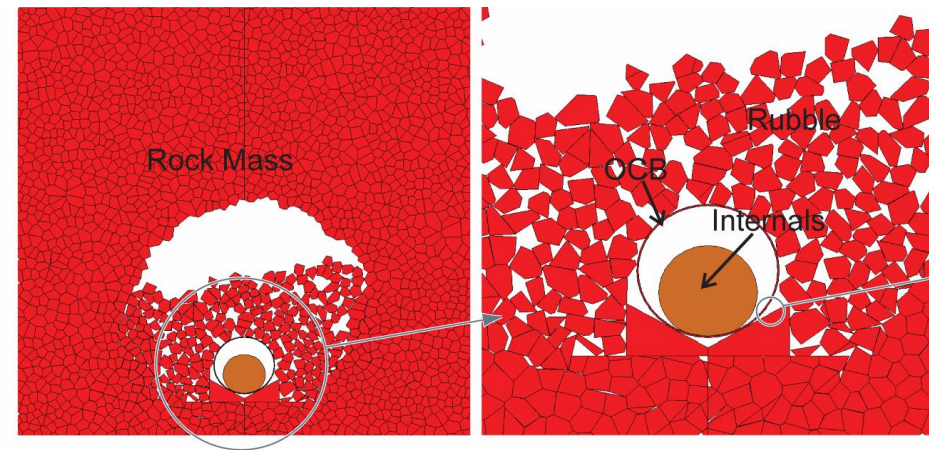
# Consequence Models for Seismic Disruption at Yucca Mountain

- Two Release Scenarios
  - Direct fault displacement ruptures waste packages
    - Minor contributor due to low probability of new fault formation
  - Ground motion damages packages through
    - Vibratory motion and impact
    - Rockfall impact
    - Accumulated loading of rockfall
- Waste package damage is a function of:
  - Event magnitude
  - Type of waste package
  - Time-dependent package degradation

**Right**  
Modeled Waste Package Damage and Stress Contours following vertical loading (DOE/RW-0573 Rev. 1, Figure 2.3.4-91)



**Below**  
Model for Rubble-Waste Package Interactions (DOE/RW-0573 Rev. 1, Figure 2.3.4-88)



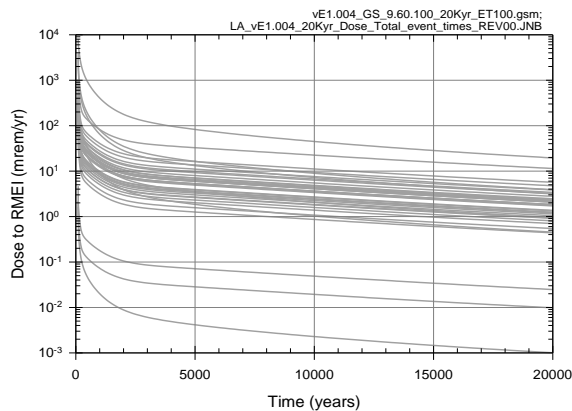
a) Drift Scale

b) WP Scale

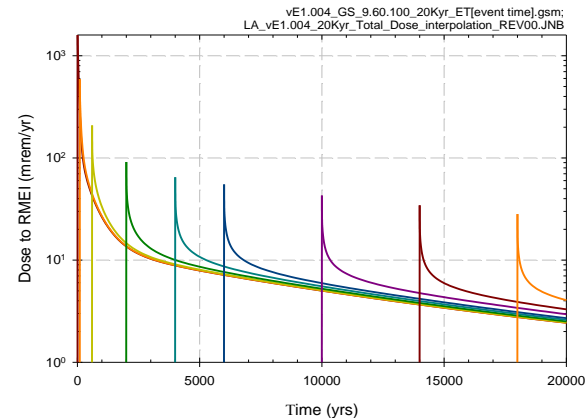
# Results of Seismic Consequence Models for Yucca Mountain

- Seismic Fault Displacement Modeling Case
  - Annual frequency approximately  $2 \times 10^{-7}$  / yr
  - Fault displacements rupture waste packages and drip shields, allowing advection and diffusion
    - Size of rupture uncertain, 0 to cross-sectional area of WP
  - mean of  $\sim 47$  waste packages and drip shields damaged
- Seismic Ground Motion Damage Modeling Case
  - Ground motions result in stress corrosion cracks that allow diffusive releases
    - Frequency of events that damage codisposal (CDSP) packages:  $\sim 10^{-5}$  / yr
    - Frequency of events that damage transportation, aging, and disposal (TAD) packages for commercial spent nuclear fuel (CSNF):  $\sim 10^{-8}$  / yr
  - Cracked area accumulates with additional seismic events
  - Repeated damage may cause package rupture ( $<10^{-8}$  / yr)
  - Drip shield thins by general corrosion and fails due to dynamic loading of accumulated rockfall
- Ground Motion and Nominal scenarios combined for analysis

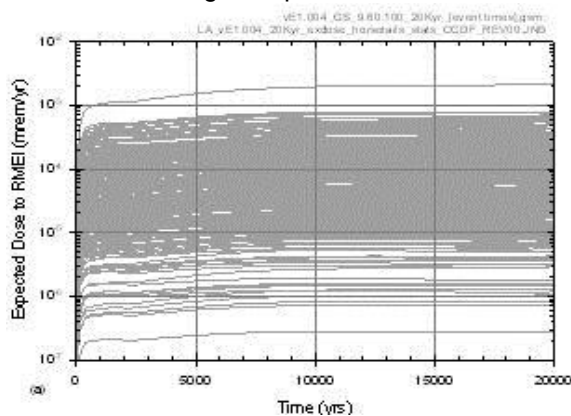
# Estimating Mean Annual Dose from Unlikely Events: Eruptive Dose



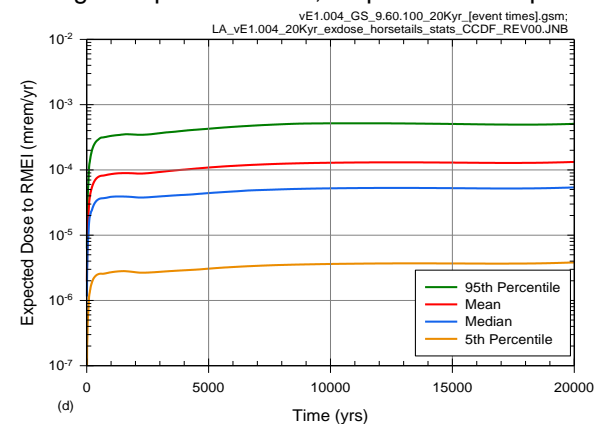
Eruptive dose: 40 realizations of aleatory uncertainty conditional on a single eruption of 1 WP at time zero



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



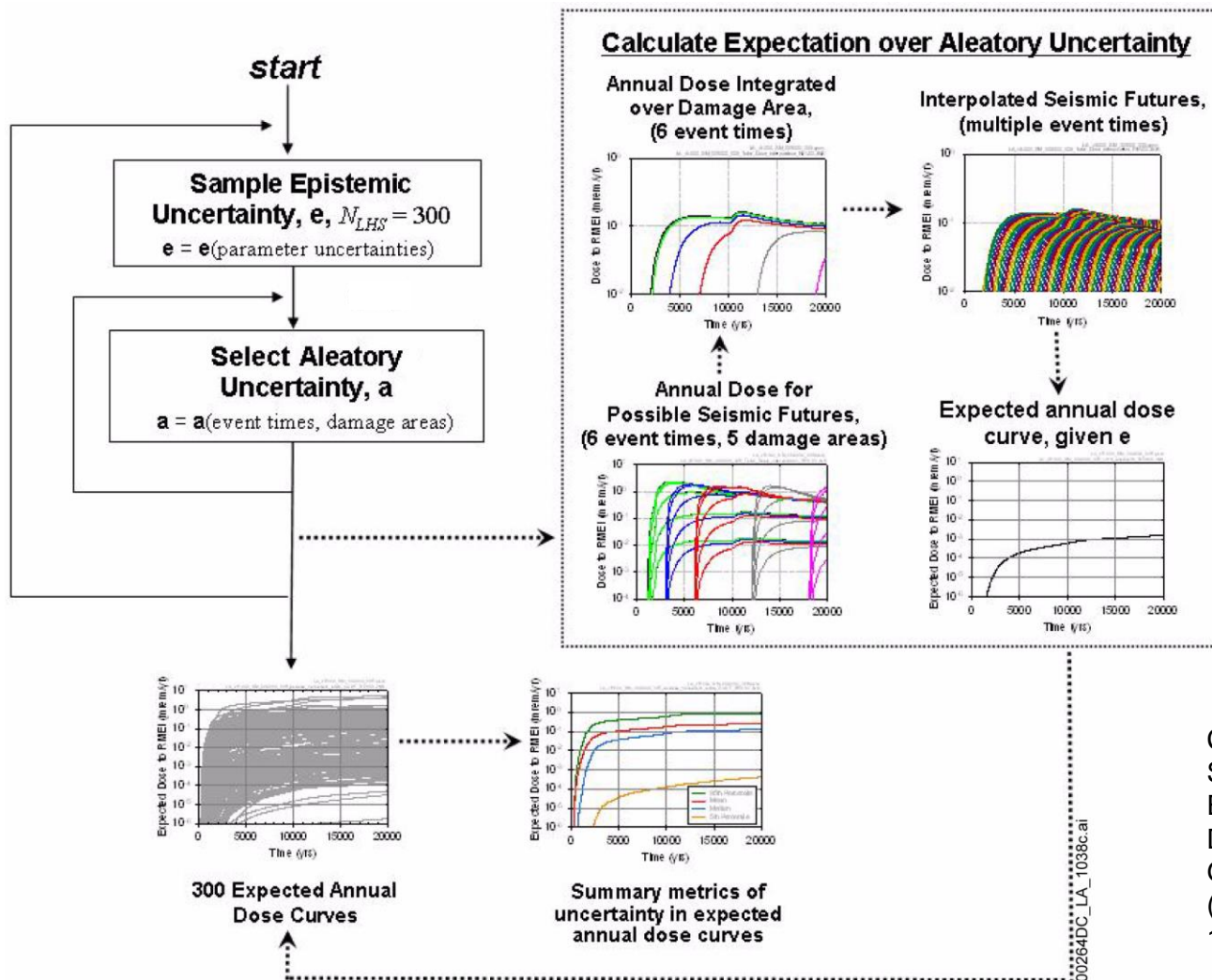
Expected eruptive dose; 300 realizations, each showing expected dose from a single sampling of epistemic uncertainty with events at all times



Summary curves showing overall mean dose from eruption

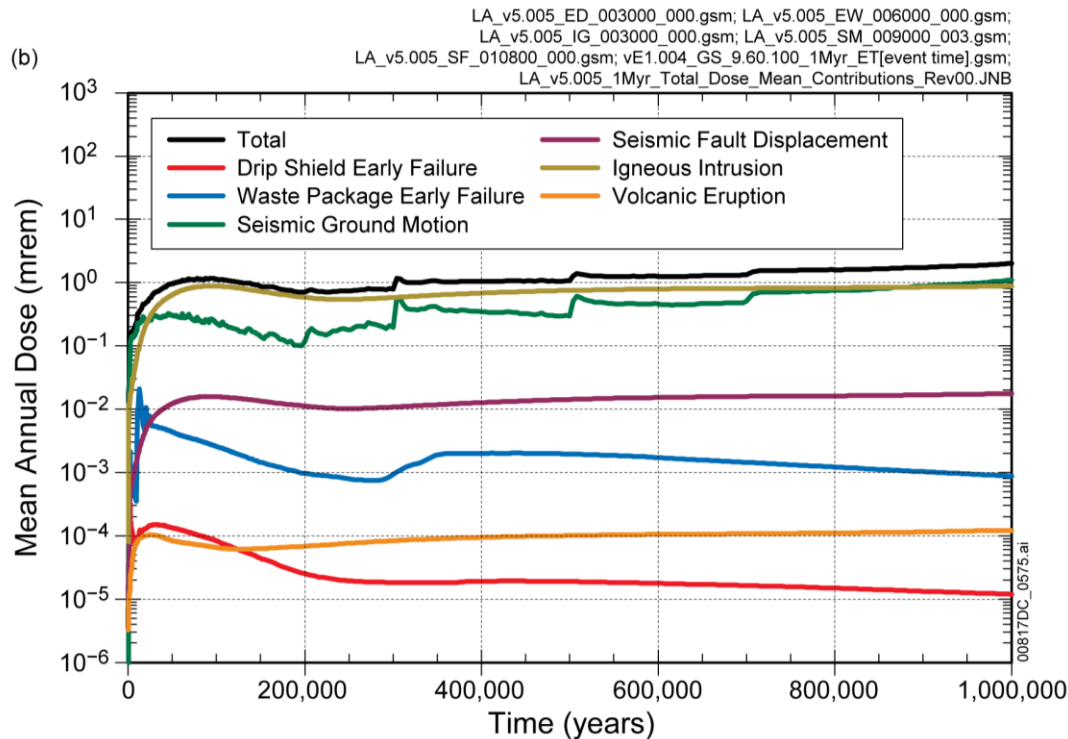
MDL-WIS-PA-000005 Rev 00, Figures J7.3-1, 2,&4

# Estimating Mean Annual Dose from Unlikely Events: Seismic Ground Motion Dose



Computational Strategy for Expected Annual Dose from Seismic Ground Motion (DOE/RW-0573 Rev. 1, Figure 2.4-8)

# Contributions of Extreme Events to Estimated Total Mean Annual Dose for Yucca Mountain



Relative contribution of Yucca Mountain modeling cases to estimated total mean annual dose for 1 million years (DOE/RW-0573 Rev. 1, Figure 2.4-18)

Estimated Yucca Mountain total mean annual dose 1 million years from all scenarios:

- 0.02 mSv (2 mrem)
- EPA regulatory limit at 1,000,000 yrs: 1mSv/yr
- Until approximately 900,000 yrs, largest contribution to total dose comes from igneous intrusion
- At late times, peak dose comes from corrosion failure of packages in the ground motion / nominal scenario
- Estimated doses from other scenarios are orders of magnitude lower

# Treatment of Extreme Geologic Events in Other U.S. Repository Assessments

- Waste Isolation Pilot Plant
  - No extreme geologic events have been identified for WIPP with probabilities greater than  $10^{-8}/\text{yr}$
  - Human intrusion scenarios dominate radionuclide releases in safety assessments
- Ongoing research on disposal options
  - Extreme geologic events are not an R&D priority because research focuses exclusively on generic disposal concepts
    - Both probability and consequence of rare events are site-specific
  - R&D focuses instead on building confidence in the viability of multiple generic disposal concepts
    - Evaluation of potential disruptive events will occur during site selection and site characterization

# Summary

(in the context of the questions posed to the session)

- How does your organization define and handle extreme geological events? Are there any regulatory requirements in defining and handling extreme geological events in your programme?
  - The treatment of extreme geologic events is prescribed by U.S. regulation
- Describe the strategies / design concepts / approaches used in identifying and managing extreme geological events in the post-closure phase.
  - The U.S. uses a process for identifying and screening relevant features, events, and processes that is consistent with regulatory requirements
- What safety functions are expected from the design measures in beyond-design basis situations?
  - This depends on the nature of the disruptive event, the time at which it occurs, and the design of the repository. For example, compliance evaluations for Yucca Mountain did not rely on performance of engineered barriers in modeling consequences of igneous disruption.

# Summary (cont.)

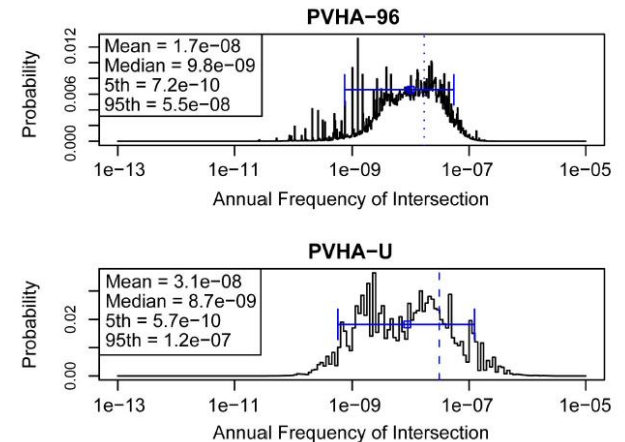
(in the context of the questions posed to the session)

- Based on current knowledge, are there outstanding issues in demonstrating safety of low probability, high impact events? What are the worst potential impacts in your programme (beyond expectation scenarios) and how to resolve these scenarios?
  - WIPP does not have outstanding issues associated with extreme geologic events. The Yucca Mountain licensing process was suspended without resolution.
- What types of R&D works are planned for?
  - Current U.S. disposal R&D focuses on nominal scenarios for generic disposal concepts
- Describe your experience in communicating safety of extreme geological events with regulators and other stakeholders? Early involvement?
  - The Yucca Mountain treatment of disruptive events was a focal point for regulator and stakeholder interactions from the beginning

# Summary (cont.)

(in the context of the questions posed to the session)

- Are there other organization issues e.g. knowledge transfer, record management which may affect the handling of the extreme events? How does your organization incorporate new evidence, technical and non-technical findings?
- Relevant new information is incorporated into the safety assessment as it becomes available, consistent with its impact. For example, a formal update to the *Probabilistic Volcanic Hazard Analysis* for Yucca Mountain was completed in July 2008, after the U.S. Department of Energy had submitted a license application to the U.S. Nuclear Regulatory Commission. This update raised the estimate of mean annual probability of igneous disruption from  $1.8 \times 10^{-8}/\text{yr}$  to  $3.1 \times 10^{-8}/\text{yr}$ . Full documentation of this update and its impacts on the overall safety assessment were provided to the NRC for consideration in their review of the license application.



Comparison of estimates of the probability of igneous disruption used in the Yucca Mountain License Application with those developed in a 2008 update to the earlier expert elicitation. Figure ES-1 of Sandia National Laboratories 2008, *Probabilistic Volcanic Hazard Analysis Update (PVHA-U)*, TDR-MGR-PO-000001 Rev 00.

# Questions?