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

www.ocrwm.doe.gov

Total System Performance Assessment: Performance Margin Analysis

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Clifford Hansen
Sandia National Laboratories

May 29, 2008
Las Vegas, Nevada

Performance Margin Analysis (PMA)

- **Quantify the effect of a set of model conservatisms on system performance**
  - **Reduce conservative treatment by use of more physically descriptive models**
  - **Selected conservatisms**
    - **Effect on system performance (total mean dose)**
    - **Basis for alternative model**
  - **Documented in MDL-WIS-PA-000005 REV 00 AD 01, Appendix C**
- **Enhances confidence in the compliance case**

Outline

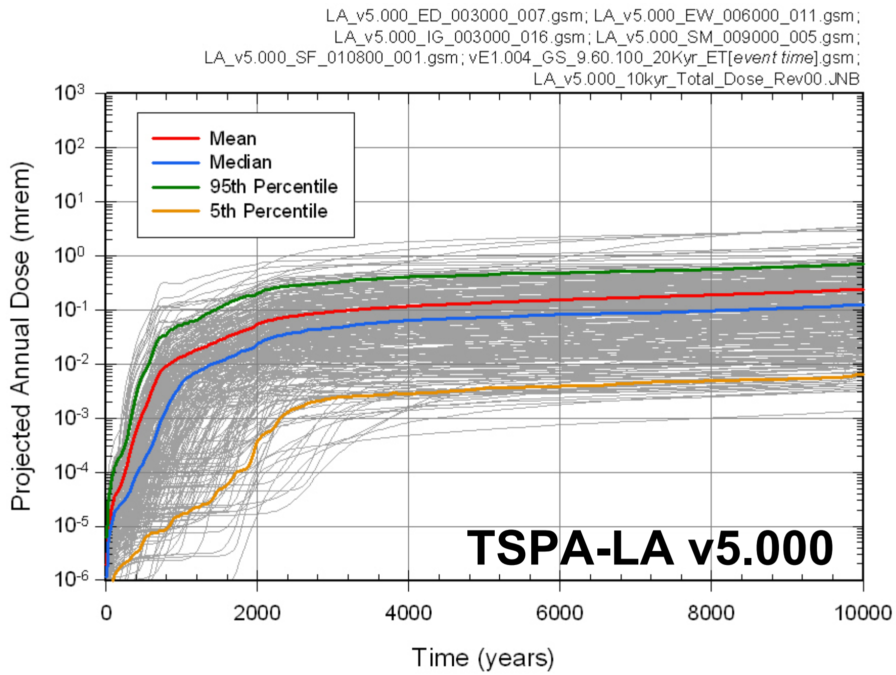
- **Summary of results for 10,000 years**
  - **How is mean dose affected**
  - **Which model changes affected mean dose**
- **Summary of results for 1,000,000 years**
- **PMA compared to TSPA-LA Model v5.000**

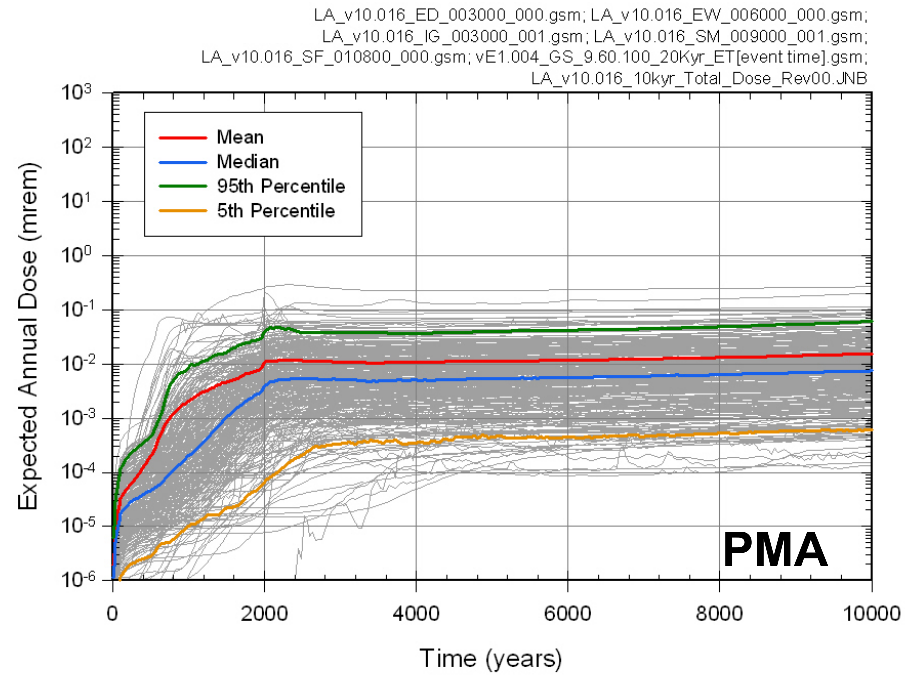
Model Areas Addressed in PMA

- Drift seepage in seismic ground motion (GM) modeling case
- Waste package and drip shield degradation
- Engineered Barrier System (EBS) flow (water balance)
- Waste form degradation and radionuclide mobilization
- Unsaturated Zone (UZ) and Saturated Zone (SZ) transport
- Damage from seismic events

Total Expected Dose for 10,000 Years
TSPA-LA vs. PMA

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-1 and Figure C7-1

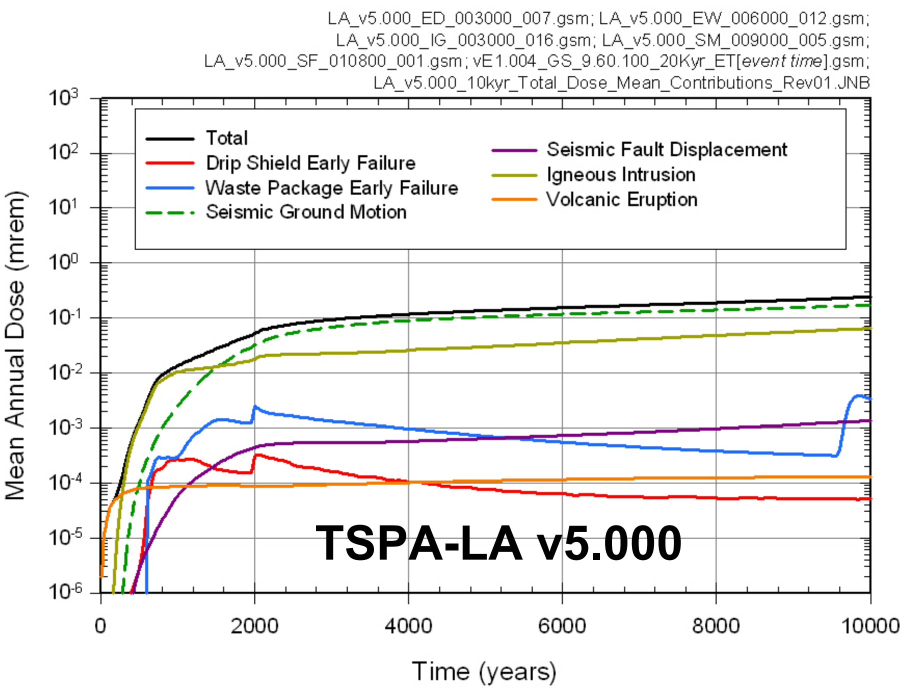


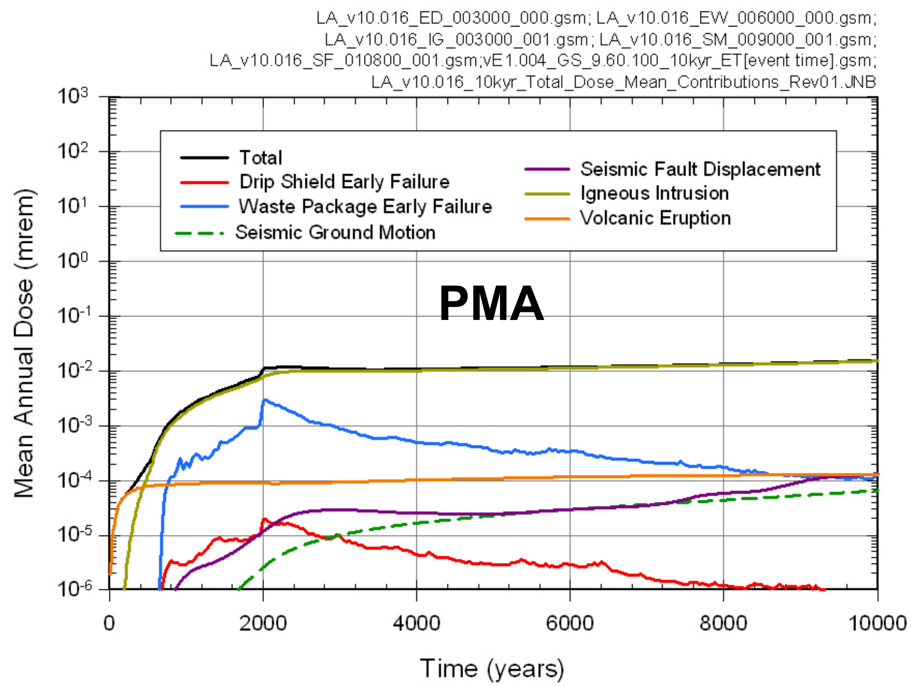


- **Magnitude of total expected dose reduced approx. one order of magnitude**
- **Uncertainty range similar**
- **Timing of earliest expected dose somewhat changed**

Contributions by Modeling Case
TSPA-LA vs. PMA

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-3a and Figure C7-7f

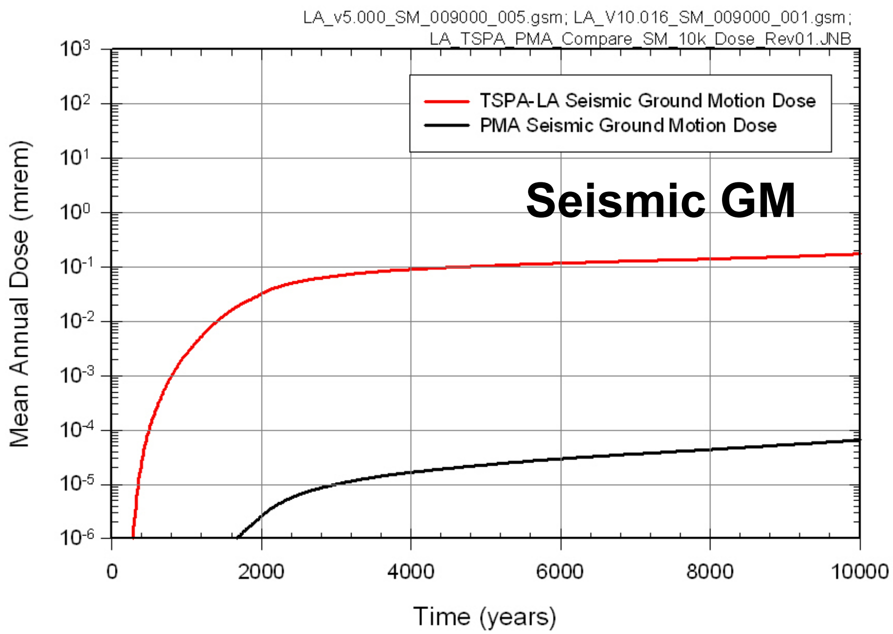


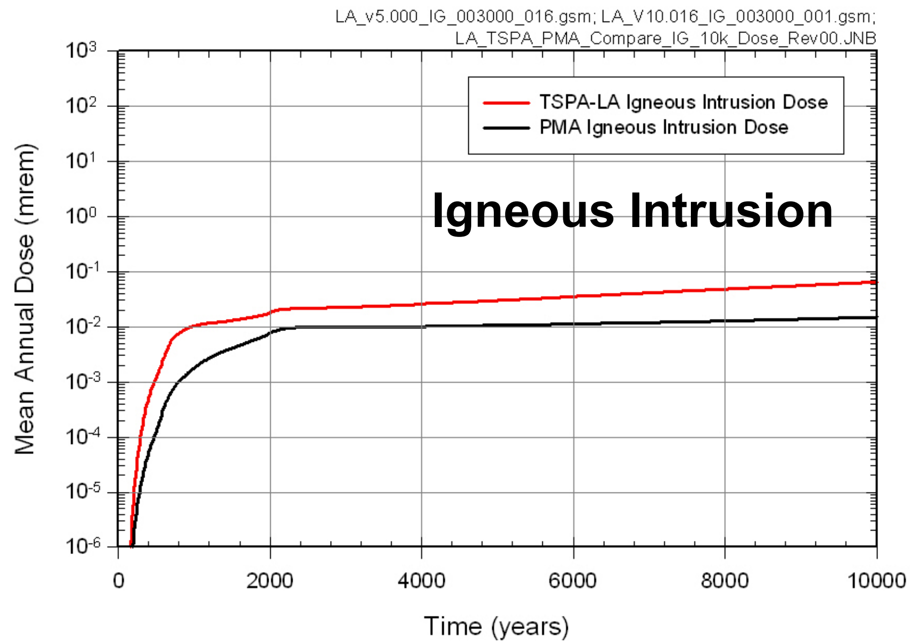


- **Top contributor in TSPA-LA is Seismic Ground Motion (GM), Igneous Intrusion 2nd**
- **Top contributor in PMA is Igneous Intrusion, Seismic GM greatly reduced**

Comparison of Mean Doses
Seismic GM and Igneous Intrusion

MDL-WIS-PA-000005 REV 00 AD 01, Figure C7-7c and Figure C7-7e

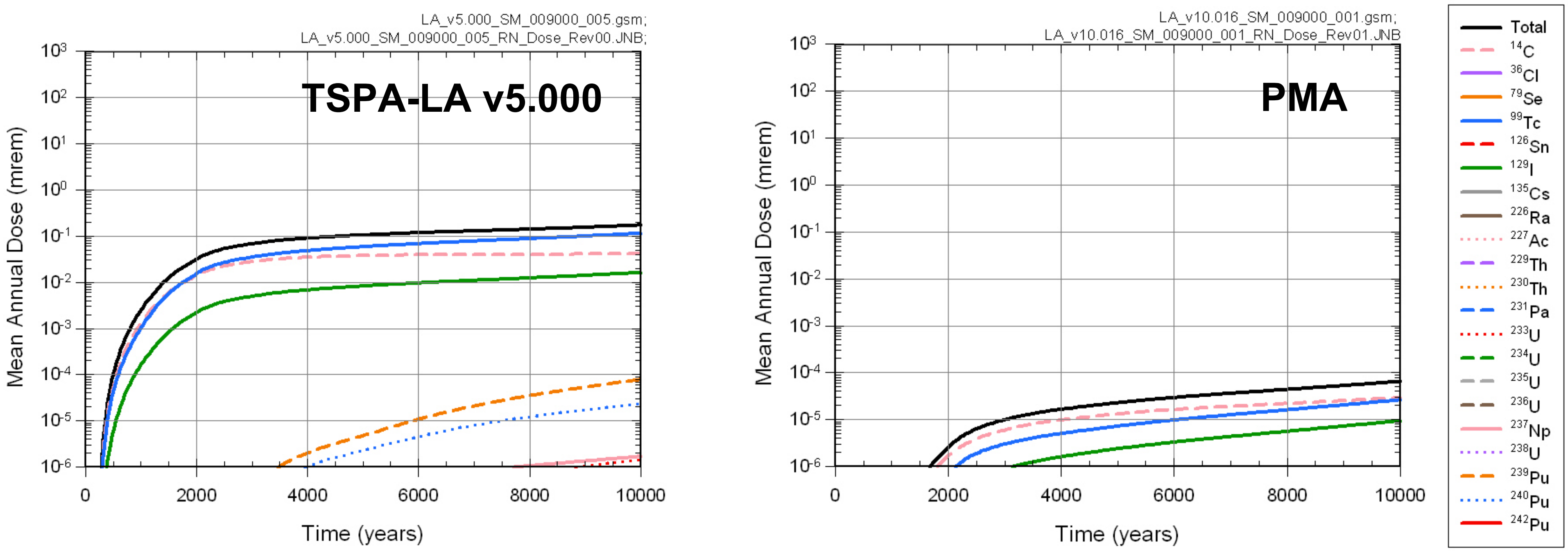




- **Contribution from seismic ground motion scenario greatly reduced (from 0.2 mrem/yr to $7\text{x}10^{-5}$ mrem/yr at 10,000 yr)**
- **Contribution from igneous intrusion somewhat reduced (0.065 mrem/yr to 0.015 mrem/yr)**

Radionuclide Contribution to Mean Dose
Seismic Ground Motion

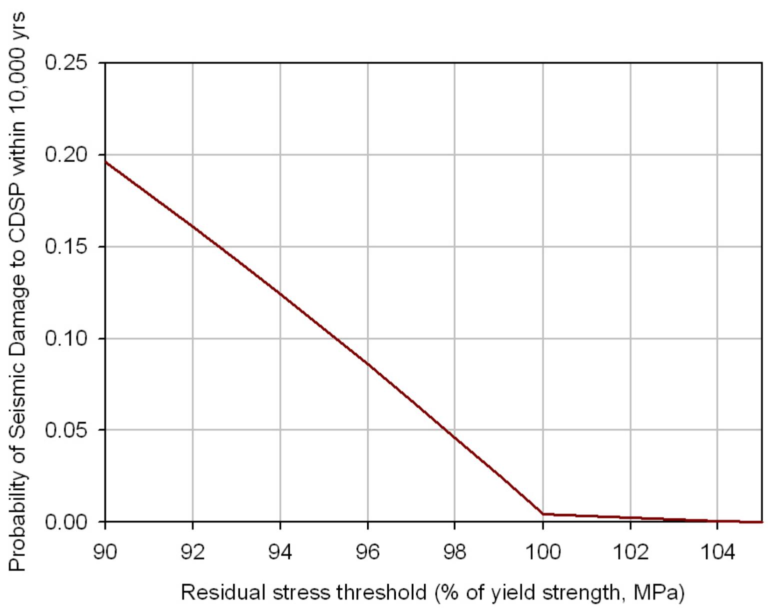
MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.2-12a and Figure C7-9c



- Change in magnitude of mean primarily due to change in residual stress threshold for stress corrosion cracking
- Reduces probability of damage (function of residual stress threshold)
- Mean dose determined by contribution from ^{99}Tc, ^{14}C, ^{129}I

Model Change: SCC Threshold

- **Seismic-induced impacts may result in deformation with residual stress**
- **When residual stress exceeds the residual tensile stress threshold (RST), a network of stress corrosion cracks is modeled to form**
- **TSPA-LA v5.005 uses an uncertain range for RST (90 to 105% of yield strength, 351MPa for Alloy-22)**
- **PMA uses uncertain range for RST of 100% to 105%**



Computed as

$$1-\exp\left(-\lambda_I\left(RST\right)T\right)$$

where

$$-\lambda_I\left(RST\right)$$

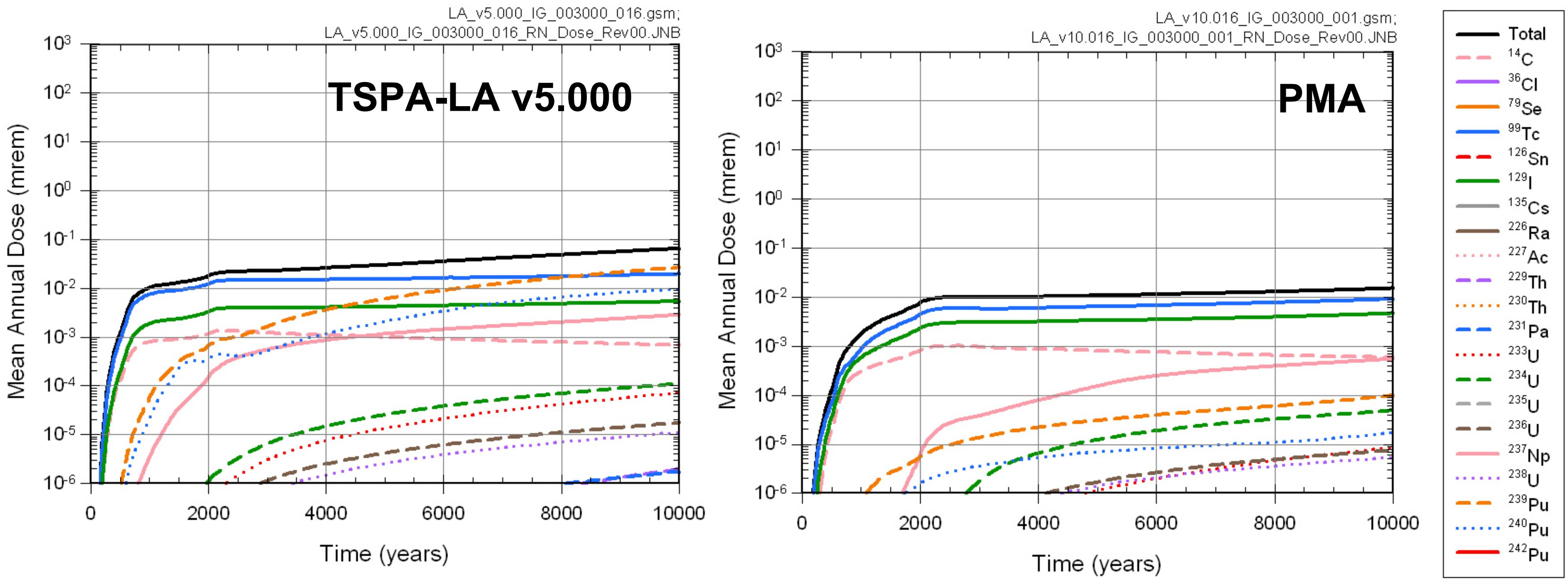
is the frequency of seismic event that cause damage to intact CDSP WPs, and *T* = 10,000 yrs

(Source: DTN MO0708CDSPSEIS.000, File FreqDamageCDSP_v5.xmcd)

Radionuclide Contribution to Mean Dose

Igneous Intrusion

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.2-12a and Figure C7-9e



- Contribution from ^{99}Tc, ^{237}Np somewhat less (reducing zones in SZ)
- Contribution from ^{239}Pu, ^{240}Pu greatly reduced (enhanced matrix diffusion, colloid diversity in SZ)

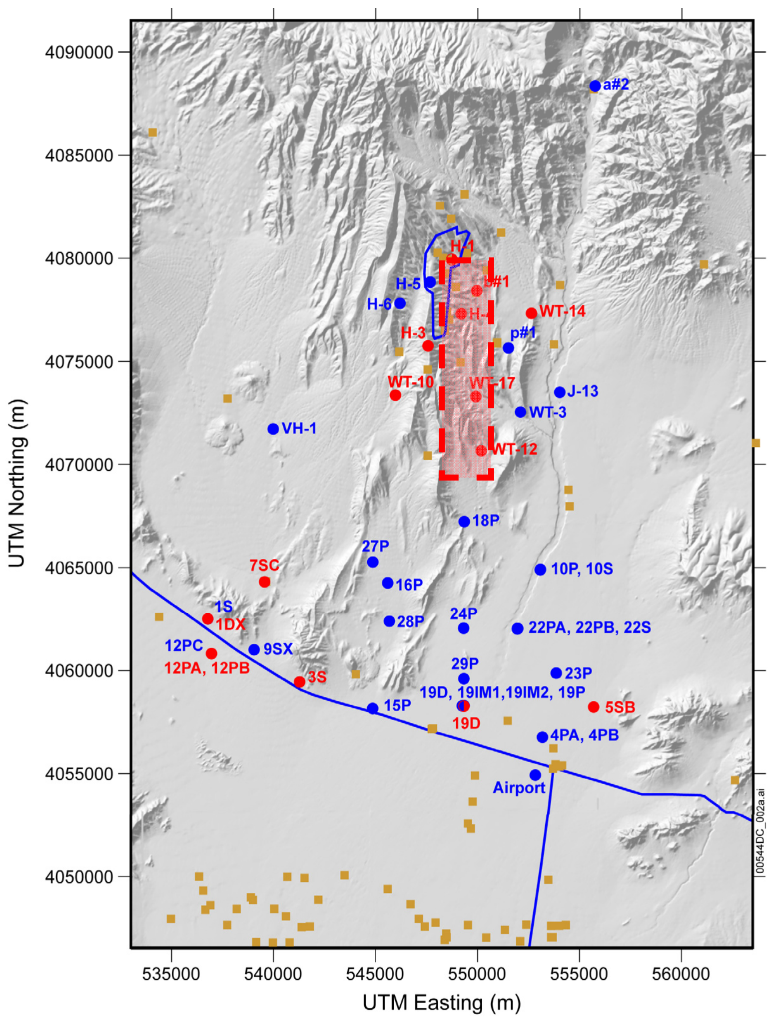
Model Change: Redox Conditions in the SZ

- **TSPA-LA:**
  - **^{99}Tc modeled as non-sorbing**
  - **^{237}Np modeled as moderately-sorbing (K_d < 13 mL/g)**
- **PMA:**
  - **Reducing environments in the SZ may affect the mobility of redox-sensitive radionuclides ^{99}Tc and ^{237}Np**
  - **K_d sampled from N(μ=1000 mL/g, σ=150)**
- **Basis for Reducing Zones in the SZ:**
  - **Redox state of groundwater in the SZ inferred from measurements of dissolved oxygen, Eh from platinum electrode, and total iron concentration**
  - **Sorption coefficients for similar mineralogy reported in literature**
  - **Working hypothesis is that reducing conditions to the east and south of Yucca Mountain may be caused by primary pyrite in the Tram tuff unit**

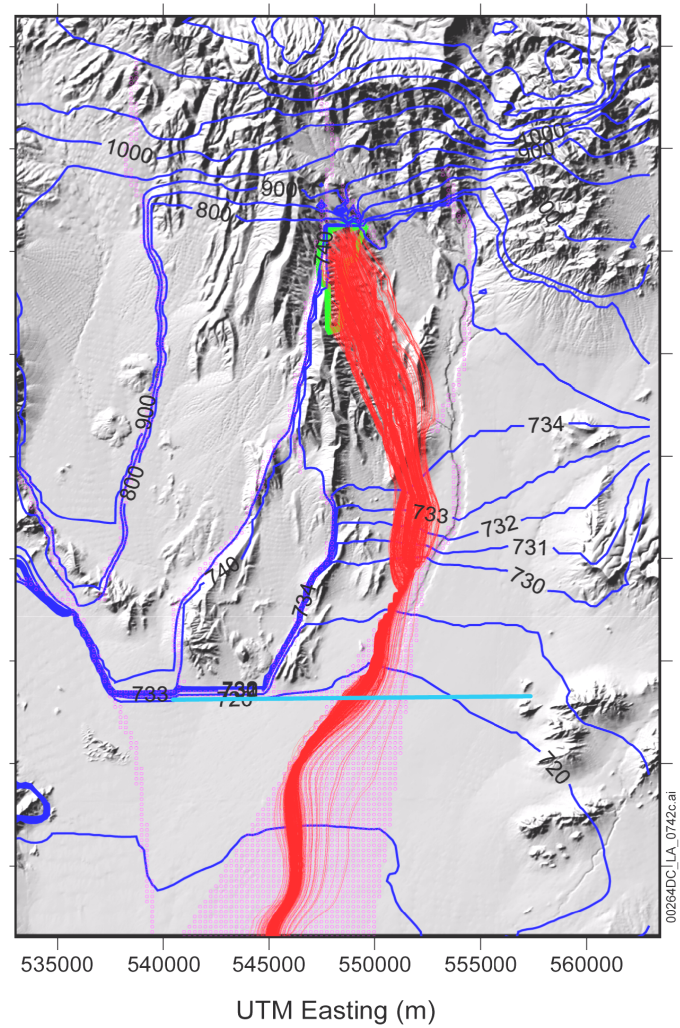
Reference: ***Impacts of Solubility and Other Geochemical Processes on Radionuclide Retardation in the Natural System – Rev 01*** **(BSC 2006 [DIRS 178672])**

Transport in the Saturated Zone

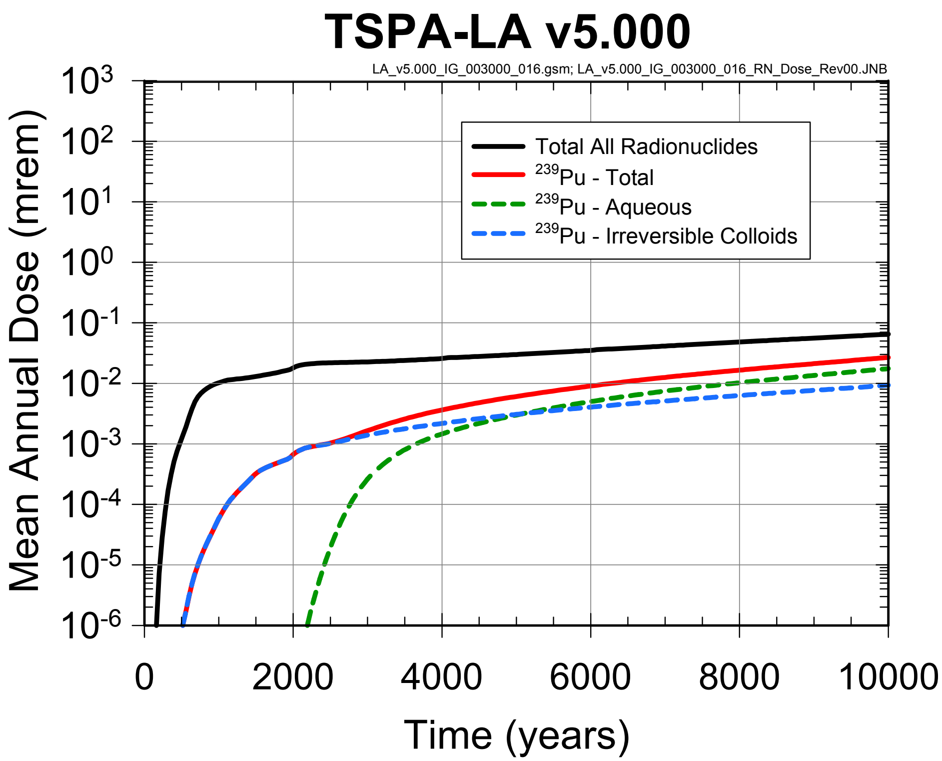
MDL-WIS-PA-000005 REV 00 AD 01, Figure C6-30

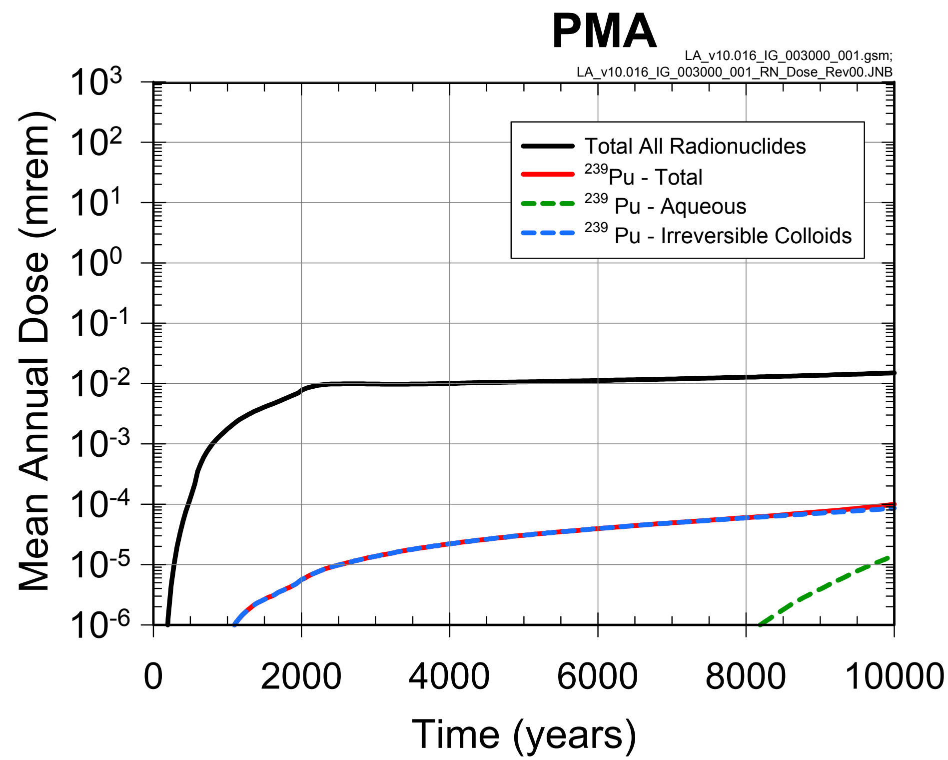


MDL-WIS-PA-000005 REV 00 AD 01, Figure 6.3.10-7



Transport of ^{239}Pu in Igneous Intrusion





Aqueous = Dissolved and Reversibly Sorbed on Colloids

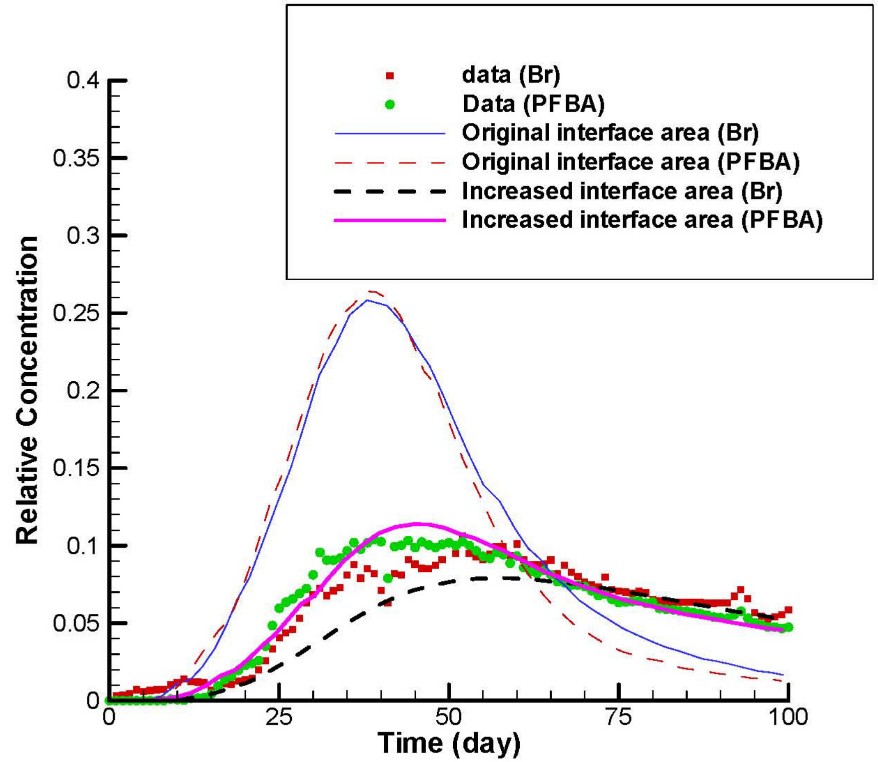
Derived from MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.2-12a and Figure C7-9e

Model Change: Matrix Diffusion in the UZ

- **TSPA-LA v5.000: Fracture-matrix diffusion modeled without enhancement to account for effects of small fractures**
- **PMA: Enhancement factor (1 to 45) applied to effective matrix diffusion coefficient**
  - **Seepage and tracer test conducted in Alcove 8/Niche 3**
  - **To match the results of the field test by simulation required larger interface areas than used in TSPA-LA**
  - **Differences could be explained by effects of small-scale fractures**
  - **Effect can be represented by applying an enhancement factor to the effective diffusion coefficient**

$$D_{eff} = f_d \tau_D D_{free}$$

MDL-NBS-HS-000006 Rev 03 AD01 (SNL 2007 [DIRS 184614]) Fig 7.8-9



Source: DTN: LB0303A8N3MDLG.001 [DIRS 162773], files: *BTC.dat*, *BTC_odis.dat*.

Figure 7.8-9. Comparisons between Simulated Breakthrough Curves at the Niche for Two Different Fault-Matrix Interface Areas and the Observed Data

Model Change: Colloid Retardation

- **TSPA-LA v5.000: Colloids are represented as homogenous**
  - Subdivided into irreversible and reversible
  - Constant (uncertain) retardation factors applied to all mass sorbed to each component
- **PMA: Account for variability in colloid population**
  - Variability arises due to colloid size, surface charge, mineralogy, and chemical properties
  - Subdivided into same components
    - Irreversible: Alternative distribution of retardation factors sampled independently for each colloid particle
    - Reversible: Effect of colloid retardation accounted for in local equilibrium model using mean value for colloid retardation factor
  - Results in general increase in travel times through the lower barrier for both irreversible and aqueous (dissolved + reversible) species

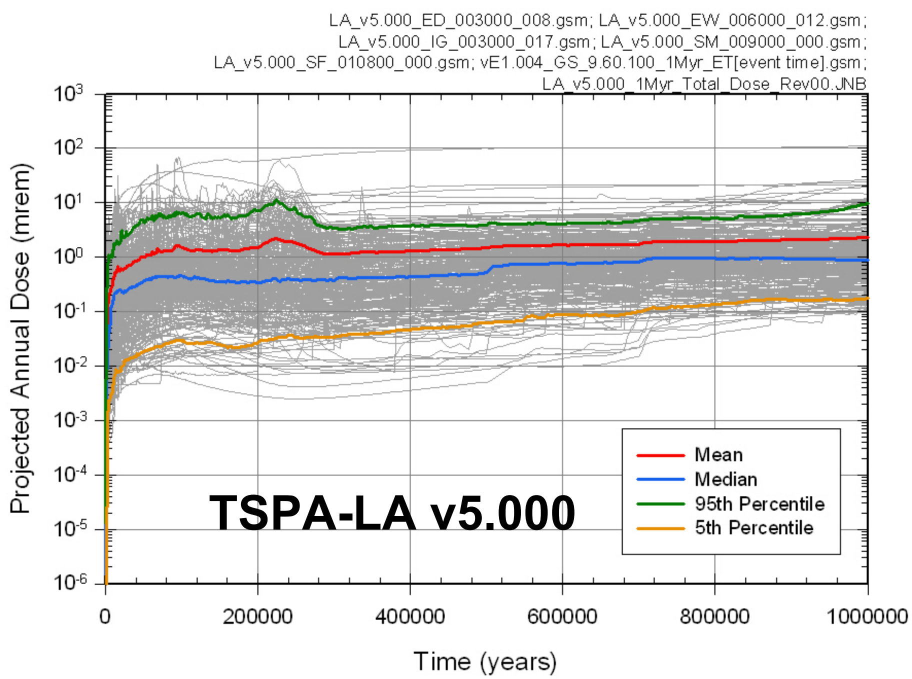
Reference: Robinson et al. (2007 [DIRS 184614])

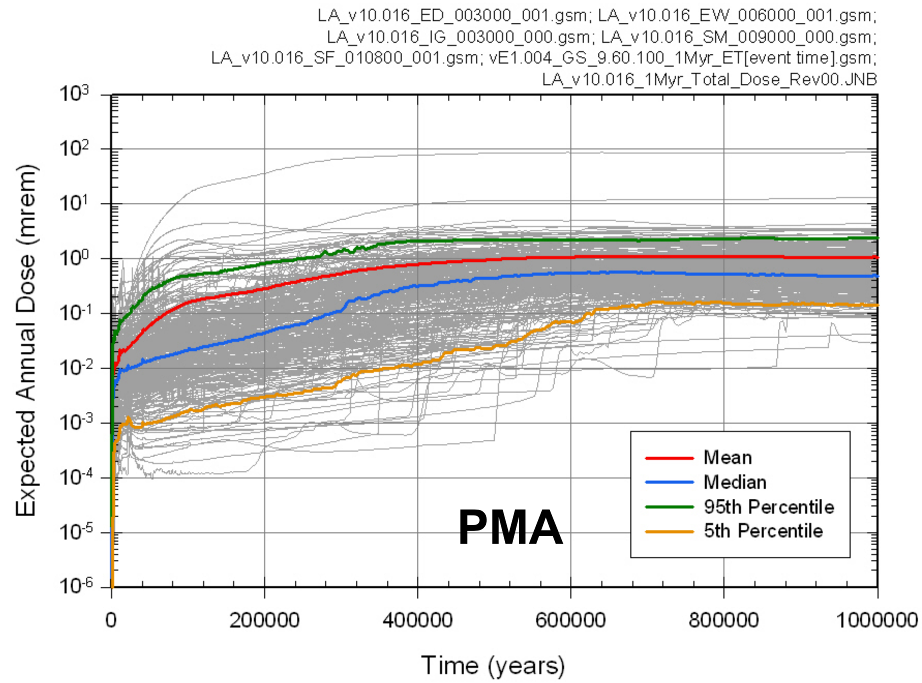
Summary of PMA Results for 10,000 Years

- **Reducing conservatisms decreased estimate of mean dose by factor of 10**
  - Residual stress threshold for Alloy-22
  - Enhanced fracture-matrix diffusion to account for small scales
  - Variability in colloid retardation
- **Effects of other conservatisms were not quantified**
  - Extent of magma flow in an intrusion

Total Expected Dose for 1,000,000 Years
TSPA-LA vs. PMA

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-2 and Figure C7-2

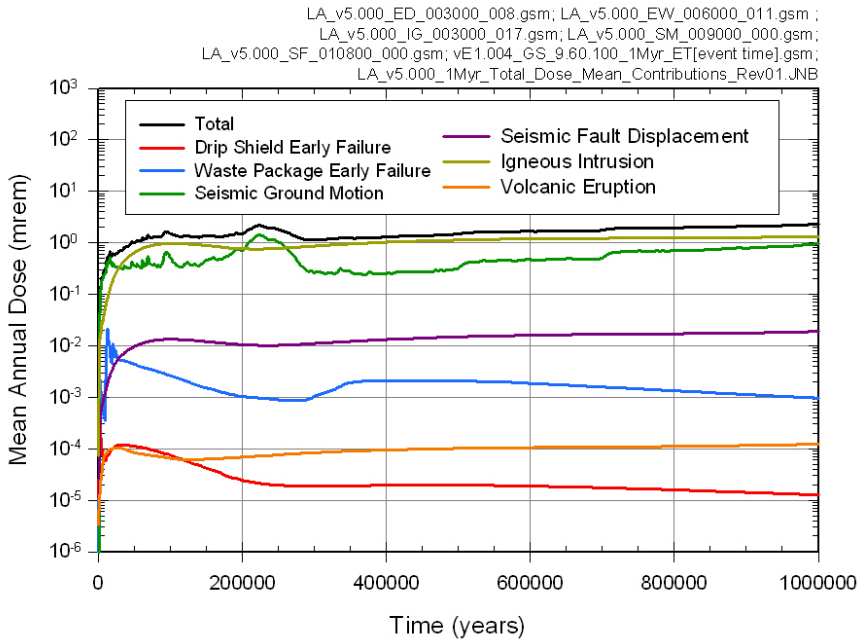




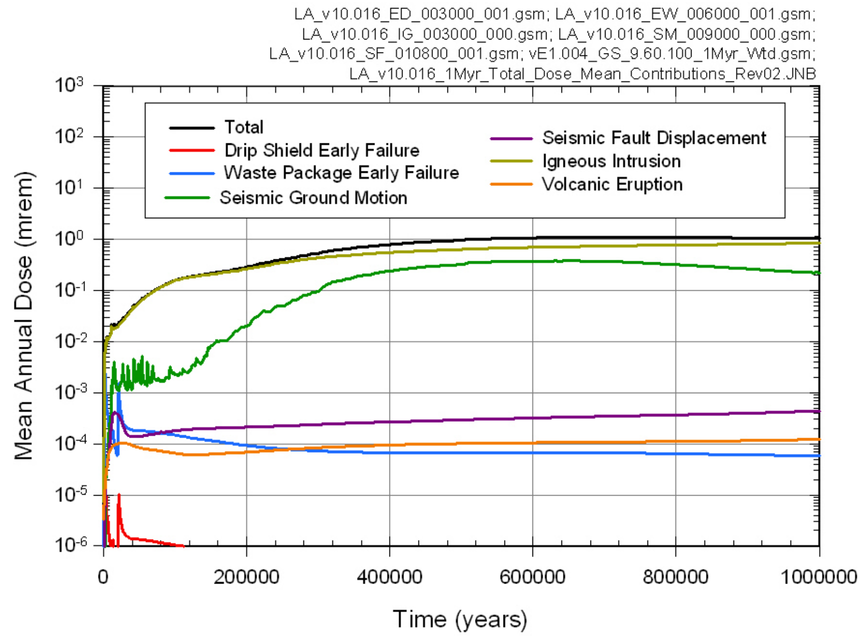
- **Magnitude of expected dose reduced approx. one order of magnitude before 200,000 yr**
- **Magnitude similar at later times**
- **Uncertainty range similar**

Contributions by Modeling Case
TSPA-LA vs. PMA

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-3a and Figure C7-7f



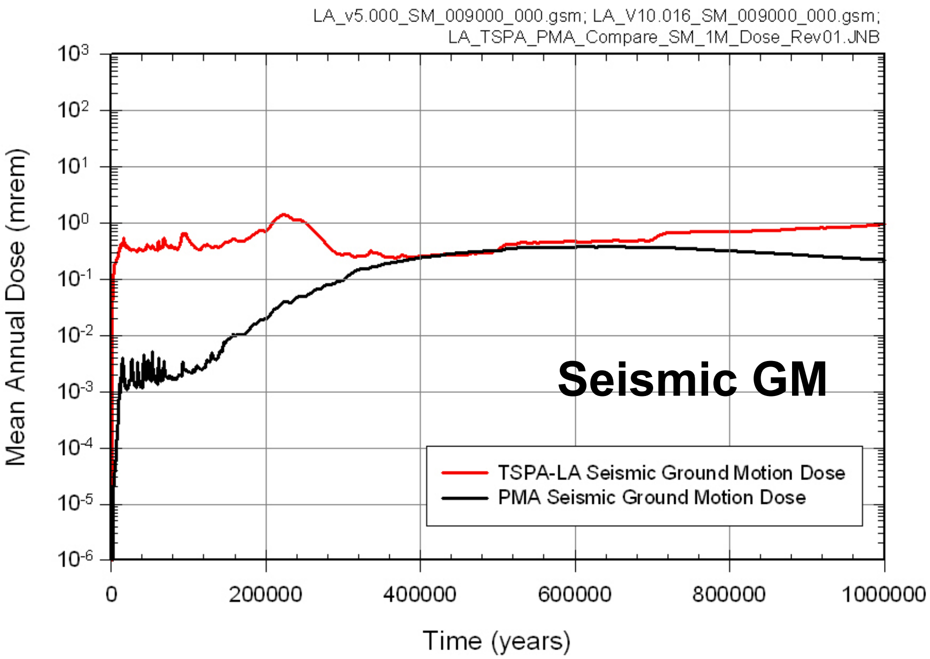
TSPA-LA v5.000

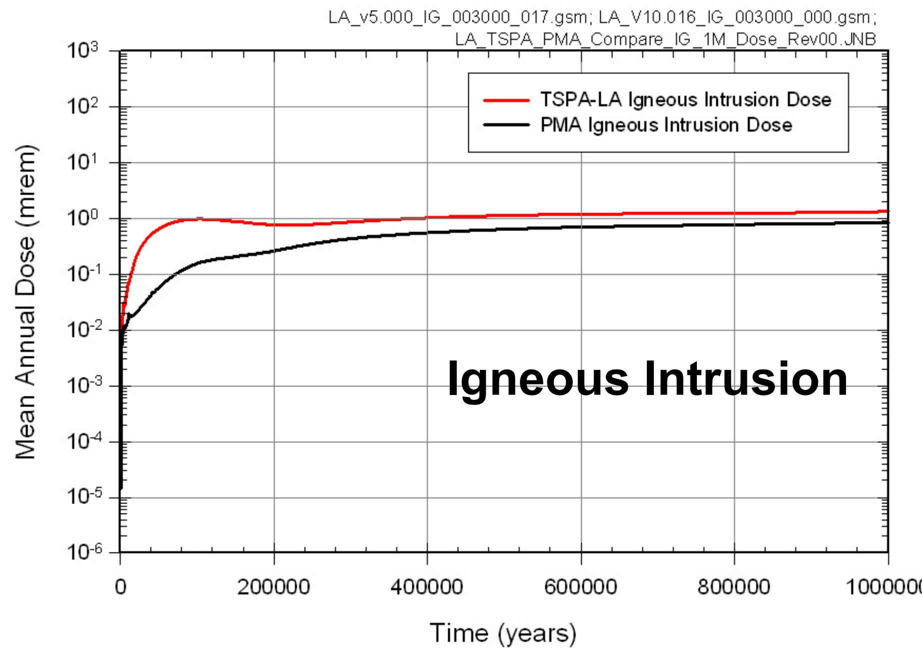


PMA

Comparison of Mean Dose
Seismic GM and Igneous Intrusion

MDL-WIS-PA-000005 REV 00 AD 01, Figure C7-8c and Figure C7-8e



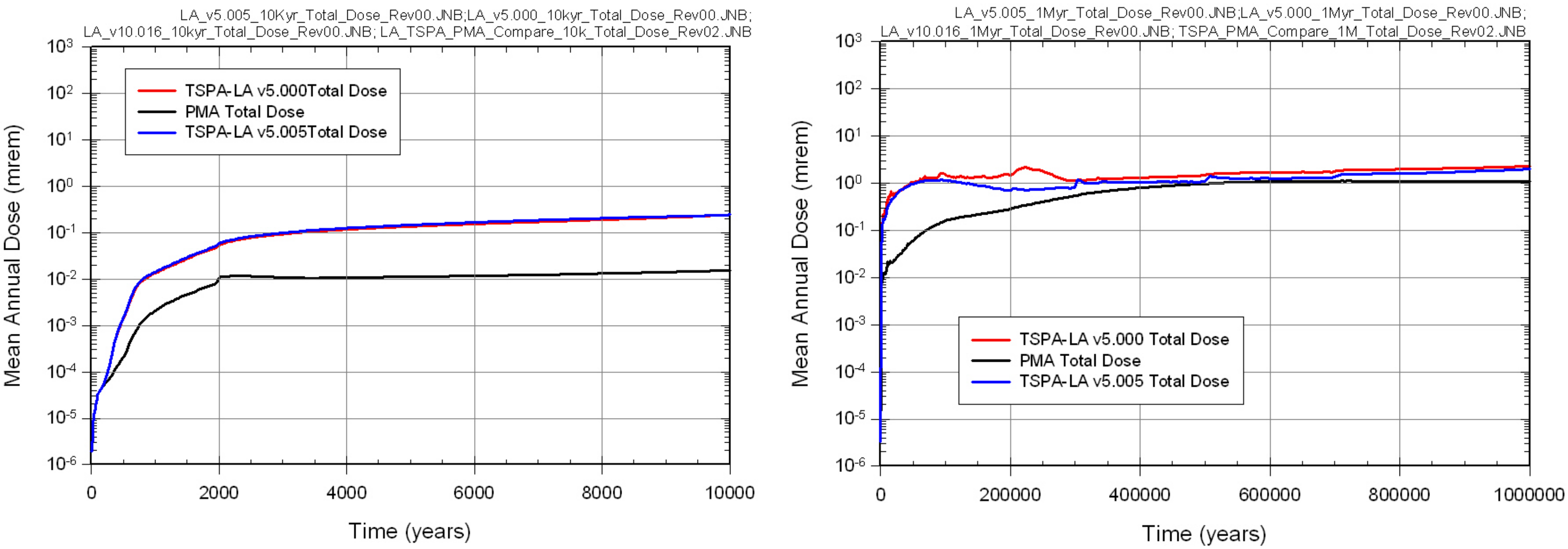


Reduction in Seismic GM:
- **Before 400,000 yrs: change in SCC threshold**
- **After 700,000 yrs: slower transport of actinides (combination of fracture-matrix diffusion in UZ and colloid retardation in SZ)**

Reduction in Igneous Intrusion:
- **Slower transport of actinides**

TSPA-LA v5.000, v5.005 and PMA

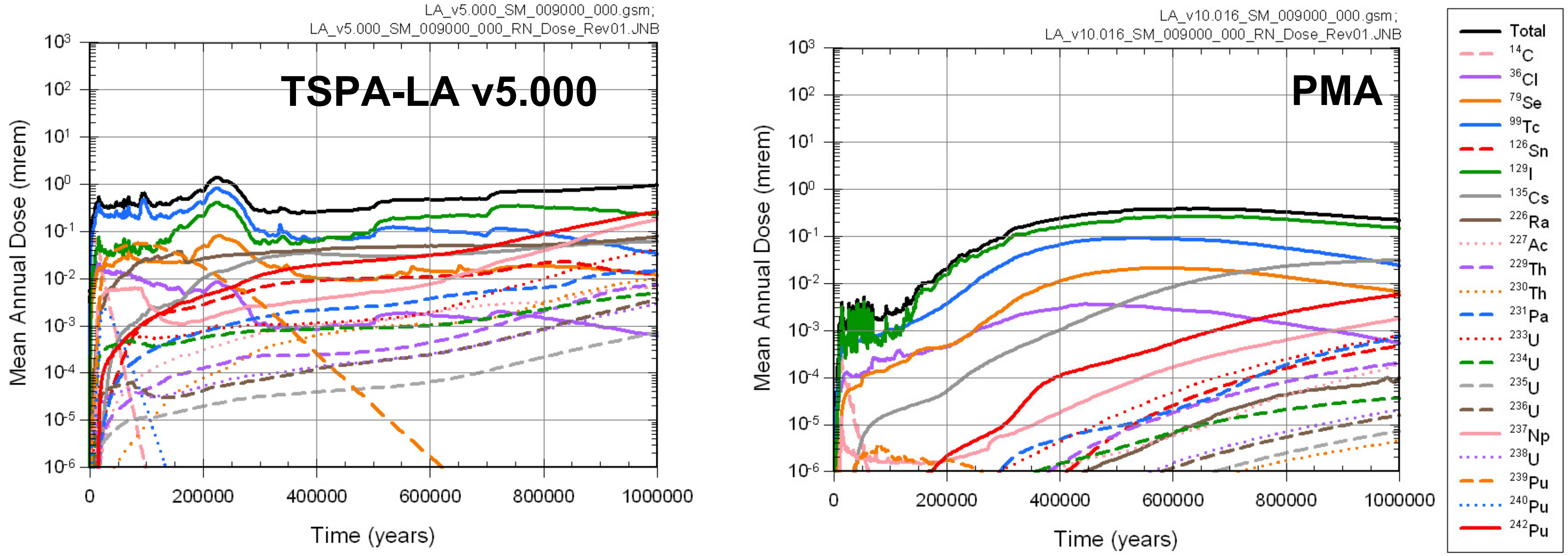
MDL-WIS-PA-000005 REV 00 AD 01, Figure 7.7.4-7 [a]



Backup

Radionuclide Contribution to Mean Dose
Seismic Ground Motion

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.2-12b and Figure C7-10c

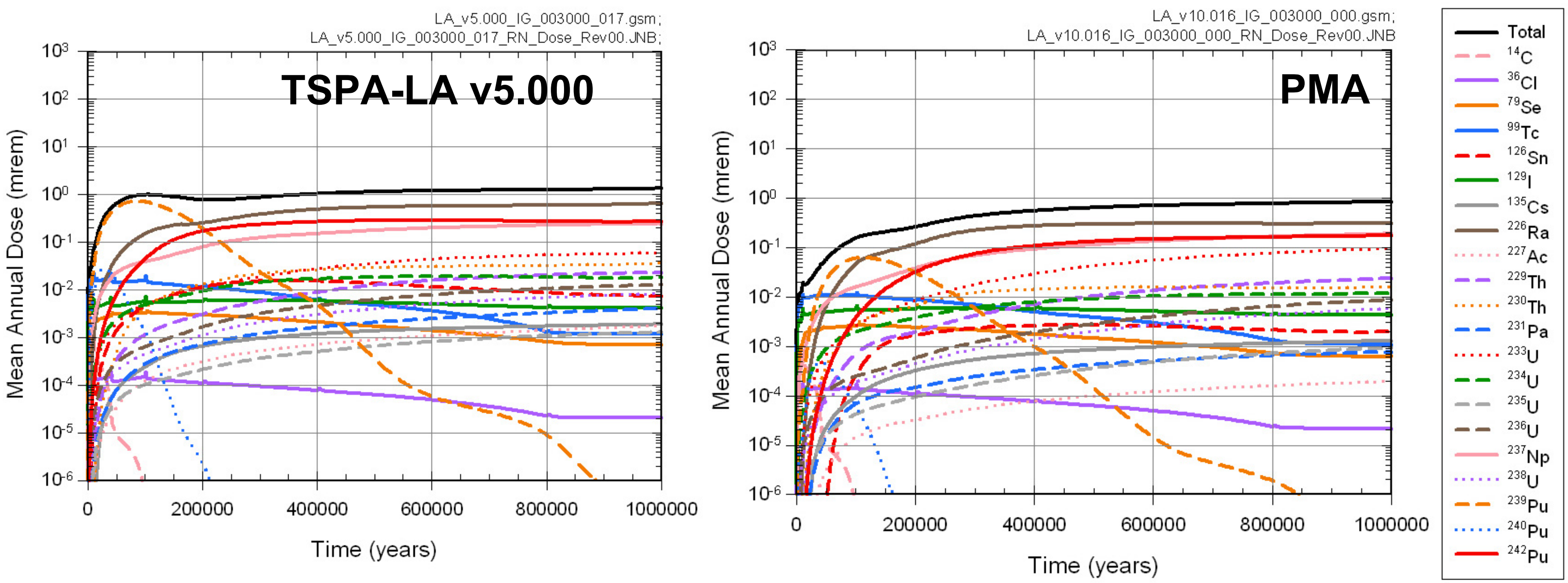


- **Reduction in mean dose before 200k yr primarily due to change in threshold for SCC**
- **Mean dose determined by contribution from ^{99}Tc, ^{129}I**
- **Additional reduction in ^{242}Pu, etc., due to longer travel times (fracture-matrix diffusion and colloid retardation)**

Radionuclide Contribution to Mean Dose

Igneous Intrusion

MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.2-12a and Figure C7-9e



- **Contribution from ^{239}Pu significantly reduced (longer transport time permits significant decay)**
- **Contribution from ^{226}Ra somewhat reduced (solubility limits on ^{234}U)**
- **Contribution from ^{242}Pu, ^{237}Np somewhat reduced (longer transport time but also longer half-lives)**