Total System Performance Assessment: Performance Margin Analysis

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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 2\textsuperscript{nd}
- Top contributor in PMA is Igneous Intrusion, Seismic GM greatly reduced
Comparison of Mean Doses
Seismic GM and Igneous Intrusion

- Contribution from seismic ground motion scenario greatly reduced
  (from 0.2 mrem/yr to 7x10^{-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

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LL_Hansen_NWTRB_052908.ppt
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

\[ 1 - \exp\left( -\lambda_f\left(RST\right)T \right) \]

where

\[ -\lambda_f\left(RST\right) \]

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

- 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 ($K_d < 13 \text{ mL/g}$)

- **PMA:**
  - Reducing environments in the SZ may affect the mobility of redox-sensitive radionuclides $^{99}$Tc and $^{237}$Np
  - $K_d$ sampled from $N(\mu=1000 \text{ mL/g}, \sigma=150)$

- **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
Transport of $^{239}\text{Pu}$ in Igneous Intrusion

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.

\[ D_{\text{eff}} = \left( \int_a^b \tau dD \right) D_{\text{free}} \]

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

Source: DTN: LB0303A8N3MDLG.001 [DIRS 162773], files: BTC.dat, BTC_odis.dat.
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
Comparison of Mean Dose
Seismic GM and Igneous Intrusion

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
• 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)