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

Performance Assessment: Engineered Barrier System Question Groups 2 and 3

Presented to:
Nuclear Waste Technical Review Board

Presented by:
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YUCCA MOUNTAIN PROJECT

NWTRB Agenda Items for EBS

Question Group 2

1. To what extent does TSPA account for localized environmental effects when single stand-alone or coupled drip shield configurations are utilized with variable waste package separation?
2. What is the potential for
   a) significant surface-temperature differences between adjacent waste packages and drip shields
   b) the formation of thin or thick films on the surface of the waste package;
   c) dripping to occur under the drip shield?
   d) Do current drip shield models adequately characterize and bound drip shield performance?

Question Group 3

1. If the potential repository were operated in a cooler thermal mode, which FEP's previously screened out would be included and vice versa?
2. If subgrade structural steel corrodes, the drip shield may misalign as a result of settlement into the invert structure. At a minimum, this would produce asymmetry in the surface temperatures of the waste package and the drip shield. To what extent do this or similar events have a significant effect on waste package, drip shield, and invert performance?
3. Have the corrosion products of the EBS, and materials such as the ground support, been considered in the postclosure EBS environment?

Summary of Supplemental Models and Analyses to Science and Engineering Report

Key Attributes of System	Process Model Factor	Topic of Supplemental Model or Analysis	Reason for Supplemental Model or Analysis			Treatment in Supplemental Science & Performance Analyses Document		
			Unquantified Uncertainty	Update in Scientific Information	Cooler Thermal Operating Mode	Section of Vol. 1	TSPA Sensitivity Analysis	Included in Supplemental TSPA Model
Prolonging Waste Package Lifetime	In-Drift Physical & Chemical Environments	Multiscale thermal-hydrologic model, including effects of rock dryout {Group 2, Part 2a}	X		X	5.3.1	X	X
		Effect of in-drift convection temperatures, humidities, invert saturations, and evaporation rates {Group 2, Parts 1 and 2c}	X		X	5.3.2		
	In-Drift Moisture Distribution	Environment on surface of drip shields and waste packages {Group 2, Item 2b}	X			6.3.4		
		Effect of breached drip shields or waste package on seepage {Group 2, Part 3; and Group 3, Part 2}	X		X	8.3.2	X	X
Limiting Radionuclide Mobilization & Release from the Engineered Barrier System	In-Package Radionuclide Transport	Diffusion inside waste package {Group 2, Part 2b}	X		X	10.3.1	X	X
	EBS (Invert) Degradation &Performance	Sorption in invert {Group 3, Parts 2 and 3}	X			10.3.5	X	X

Question Group 2, Part 1

Agenda Item:

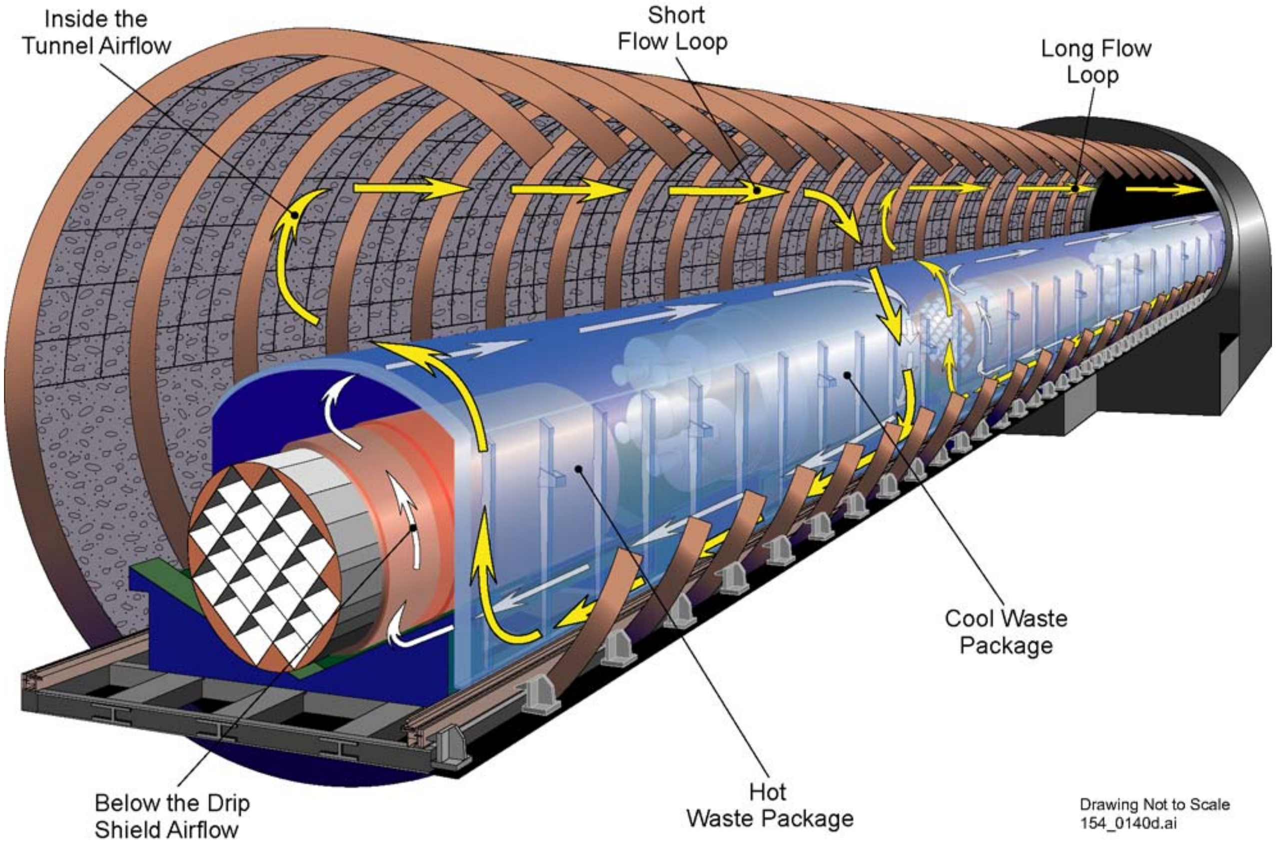
Natural convection could produce localized environmental conditions within the emplacement drifts; under this scenario, it is not clear if the drip shield will function as intended. To what extent does TSPA account for localized environmental effects when single stand-alone or coupled drip shield configurations are utilized with variable waste package separation?

- **Three Primary Scales of Variability**
  - **Local – on the scale of a waste package (WP)**
  - **Drift – between nearby hot and cool WPs**
  - **Repository – between central regions of the drifts and the repository edge**
- **TSPA Represents Repository-Scale Variability in Engineered Barrier System (EBS) Environmental Conditions**
  - **Average thermal conditions include WP to WP variability**
    - **Radiation and heat conduction calculations account for all three scales of variability, including variable WP spacing under a continuous Drip Shield (DS)**

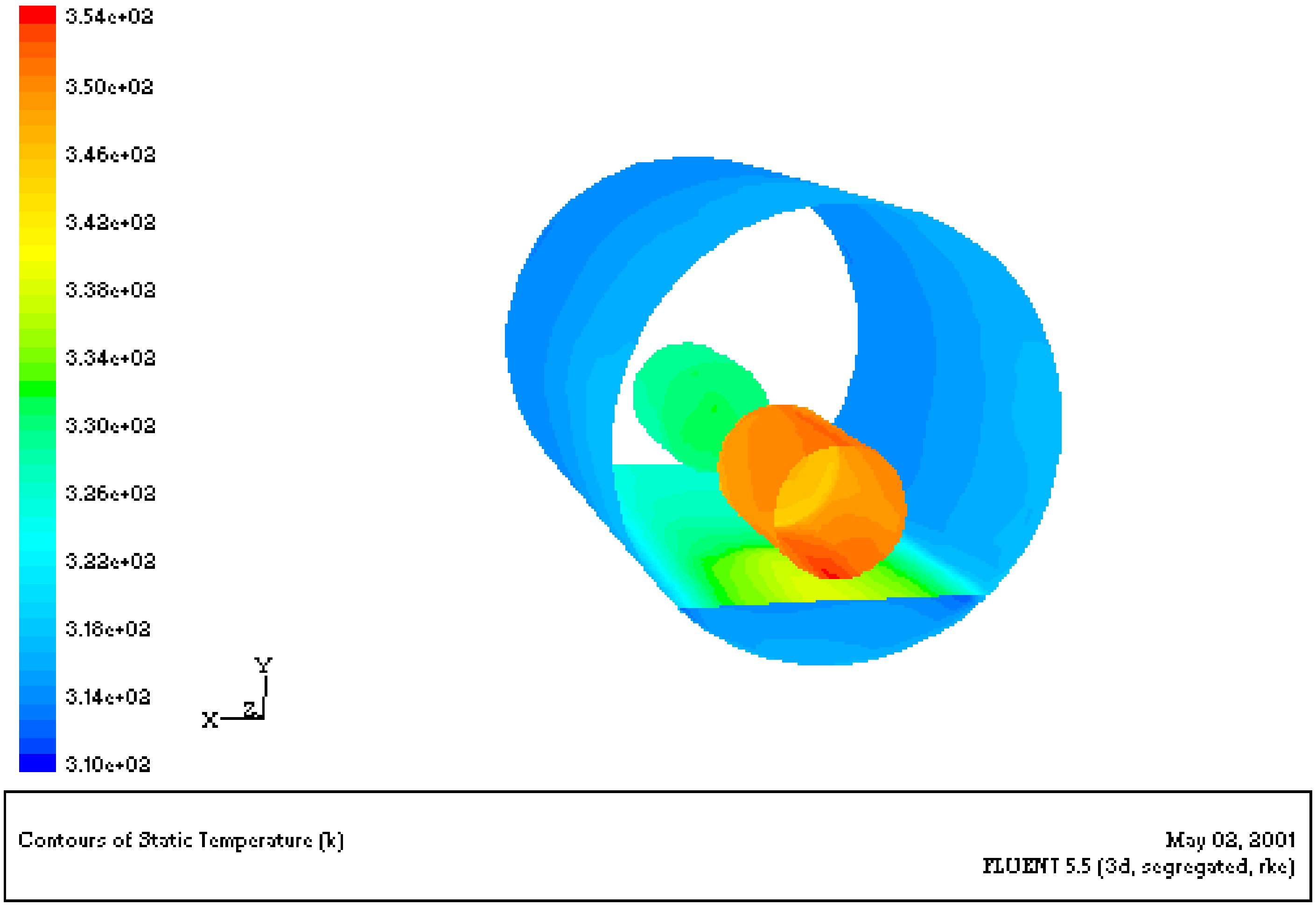
Question Group 2, Part 1
(Continued)

- **TSPA Represents Repository-Scale Variability in EBS Environmental Conditions**
  - Local processes are represented in an average sense
    - invert chemical conditions based on average invert evaporation rates
    - drip shield condensation computed with average thermal/hydrologic conditions
    - seepage evaporation accounts for WP spacing
  - Gaseous-phase conditions in the drift and in the air gap between DS and WP are assumed to be well mixed
    - Technical basis for assumption is being strengthened as part of ongoing in-drift convection analyses
  - Calculation of axial movement of moisture is planned for a potential License Application (LA)

3-D Natural Convection Flow Pattern

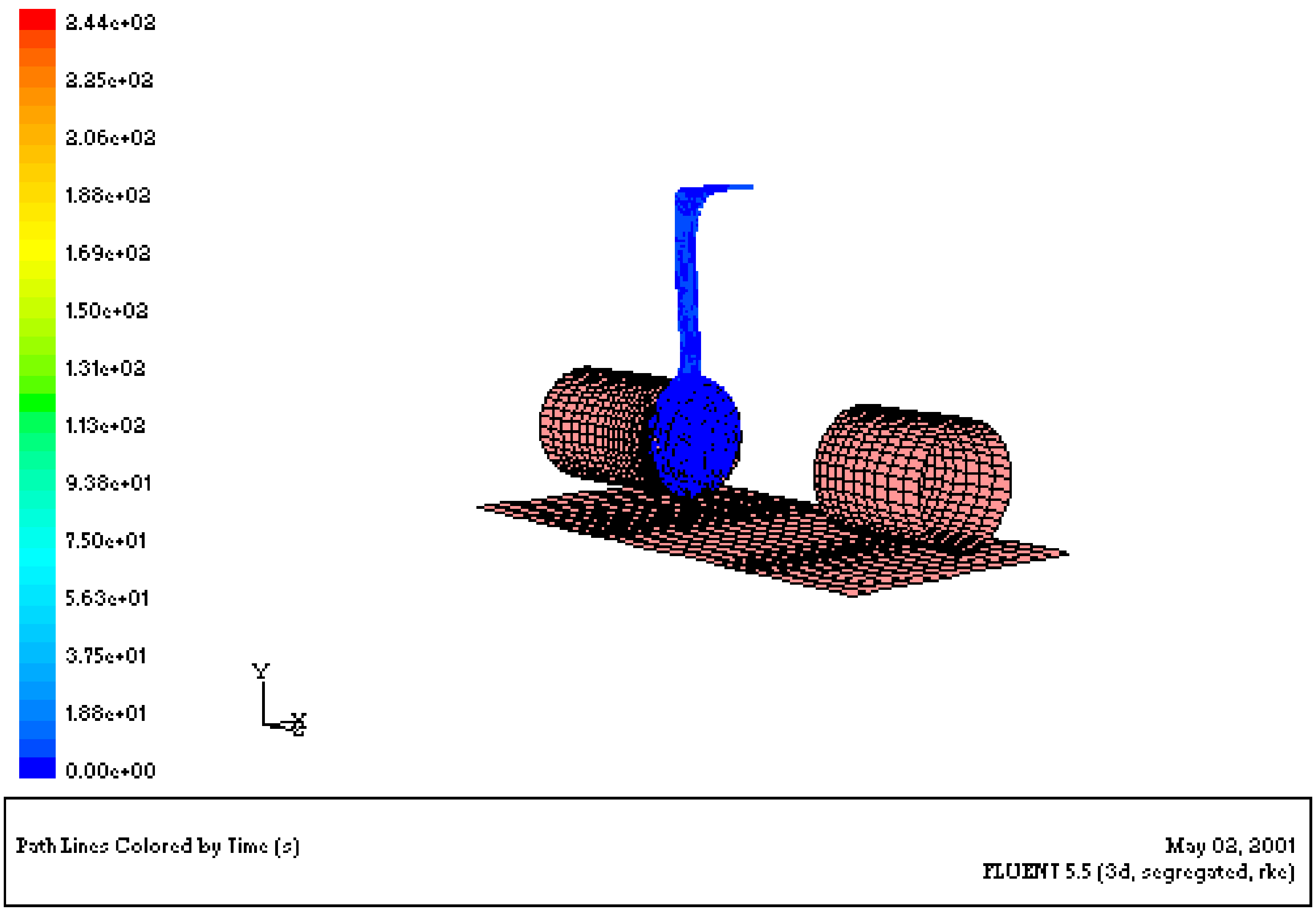


3-D Model for 1/4 Scale Natural Convection Test: Temperature Contours (°k)



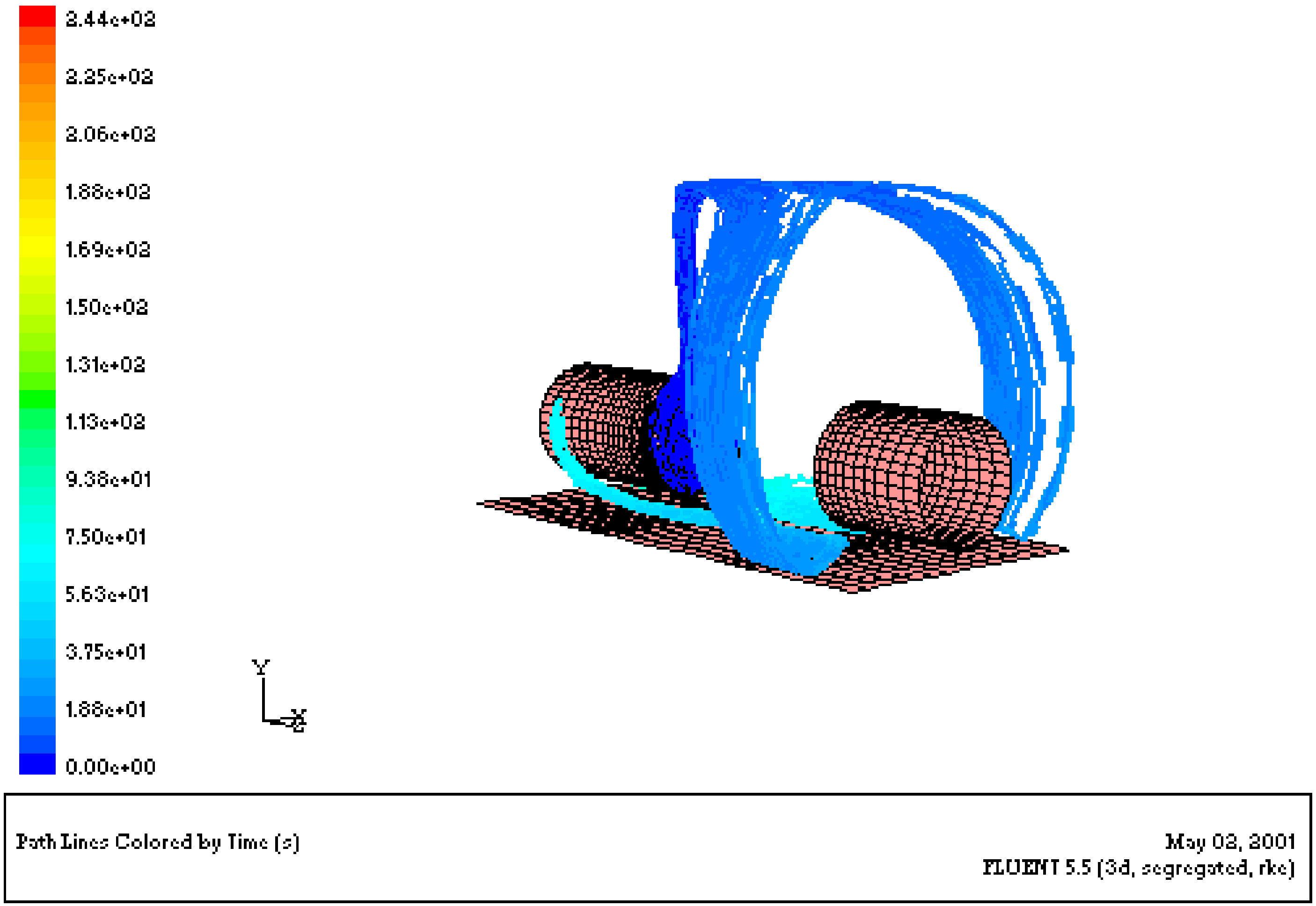
- 21-PWR next to 5-DHLW Short
- Decay Power at 300 Years
- 0.345 kW/WP for 21-PWR
- 0.008 kW/WP for 5-DHLW Short
- 0.81 m between packages
- 300 K Environmental Temperature (27 C)

3-D Model for 1/4 Scale Natural Convection Test: Flow Path Lines at 50 s



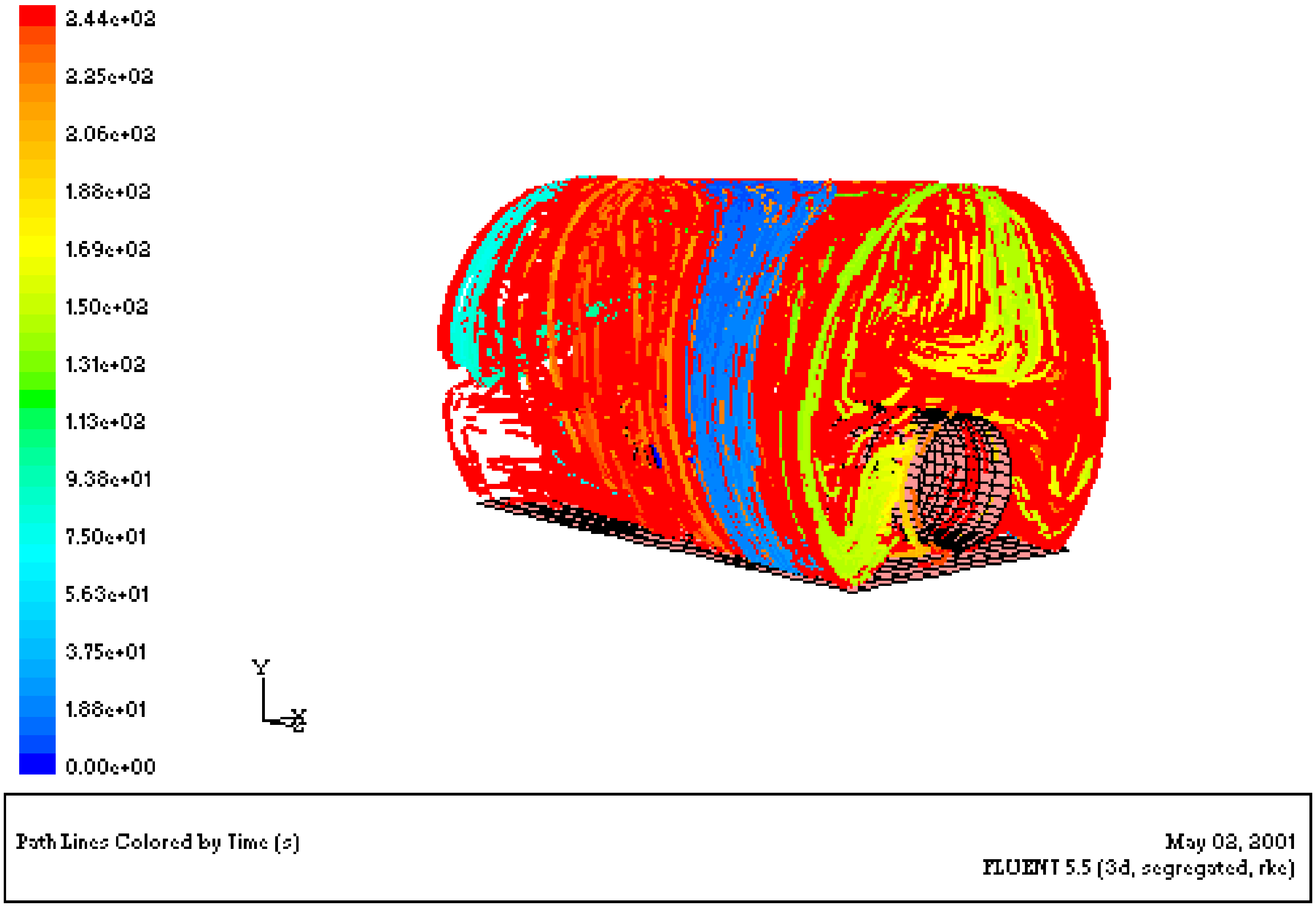
- **Flow Path Lines from End of PWR at 50 steps**
- **Flow Lines Straight Up – Turn Over When Reach Drift Wall**
- **Orientation Opposite of Temperature Contours**

3-D Model for 1/4 Scale Natural Convection Test: Flow Path Lines at 200 s



- **Flow Path Lines from End of PWR at 200 steps**
- **Fluid Flows Back Along Invert Towards Hotter Package**

3-D Model for 1/4 Scale Natural Convection Test: Flow Path Lines at 1000 s



- **Flow Path Lines from End of PWR at 1000 steps**
- **Entire Volume is Almost Mixed**

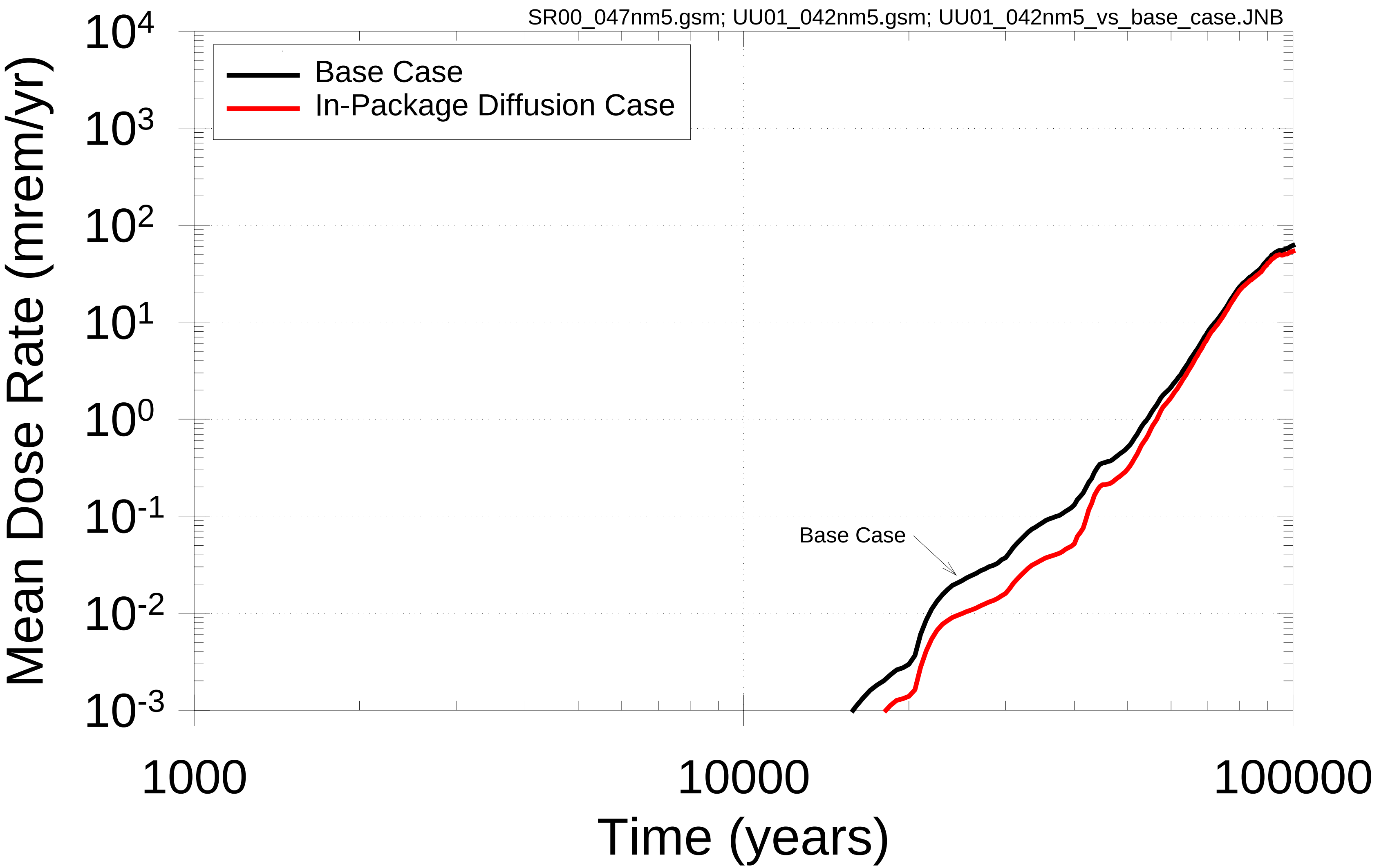
Question Group 2, Part 2a

- What is the potential for significant surface-temperature differences between adjacent waste packages and drip shields, i.e., cold traps?
  - Adjacent WP may have contrasting thermal powers at time of emplacement, i.e., 11.5 kW 21 PWR adjacent to 3 kW DHLW
    - Significant surface-temperature differences will occur but dissipate with time
  - Cold traps are not expected to have a significant consequence on calculated dose (FEP Cold Traps - YMP 2.1.08.02.00)
    - Effect would be localized to regions with sufficiently low temperature
    - Magnitude of extra dripping is expected to be small relative to that already calculated
- NRC KTI Agreement to provide additional technical basis for exclusion of cold-trap effects from TSPA
- Enhanced Characterization of the Repository Block (ECRB) data (closed section) being analyzed, for a potential LA, to estimate quantity of in-drift condensation from near-field water vapor

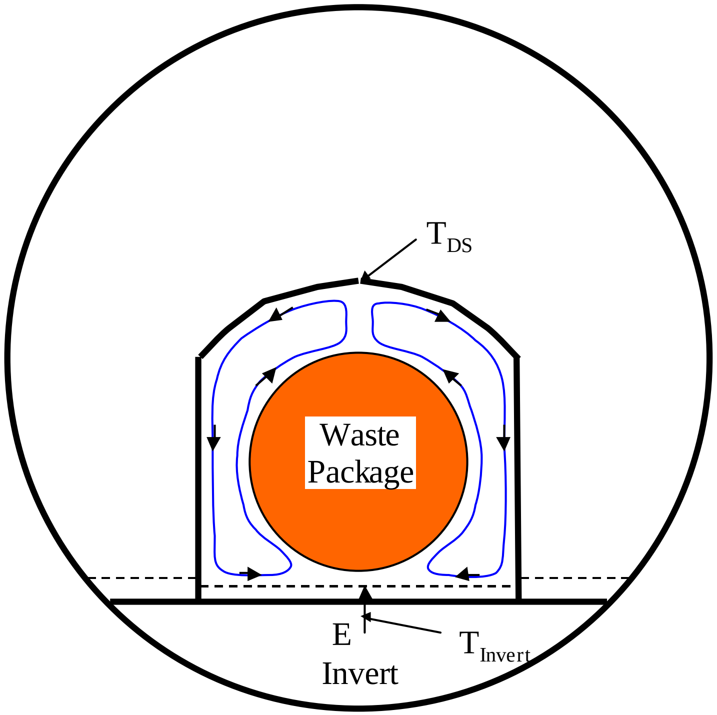
Question Group 2, Part 2b

- **What is the potential for the formation of thin or thick films on the surface of the WP?**
  - **Aqueous films will form on WP by condensation, dripping and adsorption processes**
  - **Uncertainties and sensitivities associated with effects of condensation, dripping and adsorption on performance have been evaluated for the SSPA**
- **TSPA-SR: Diffusion across outer WP barrier only**
- **Supplemental Analysis: quantify impact of in-package diffusion on release**
  - **All internal (non-fuel) components oxidize to hematite (Fe_2O_3)**
  - **Fe_2O_3 adsorption isotherm used (function of RH)**
  - **1-D diffusion through adsorbed water film under non-degraded conditions (use free water diffusion coefficient)**
  - **Effective diffusion coefficient given by Archie's Law under degraded conditions**

In-Package Diffusion Sensitivity

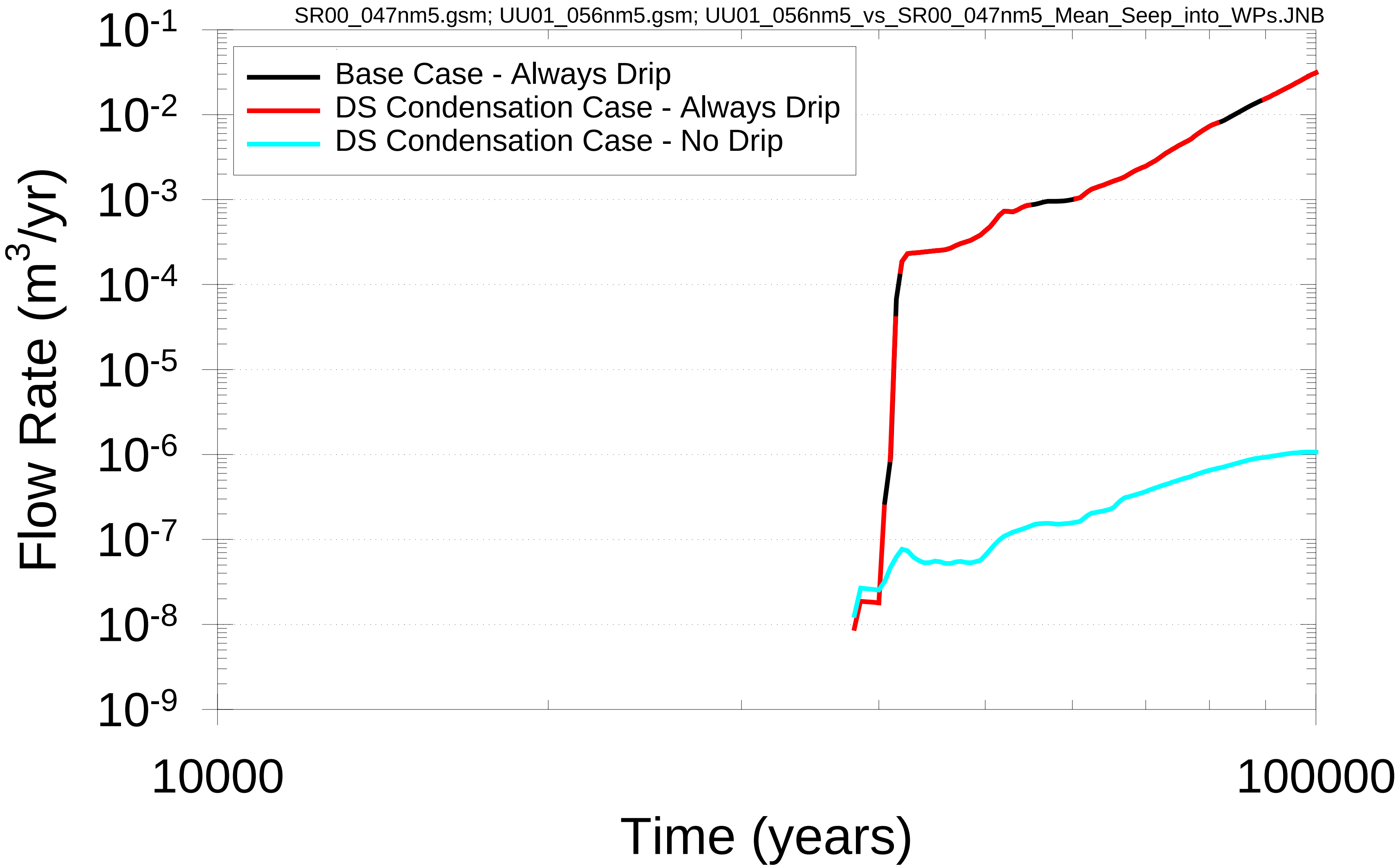


Question Group 2, Part 2c

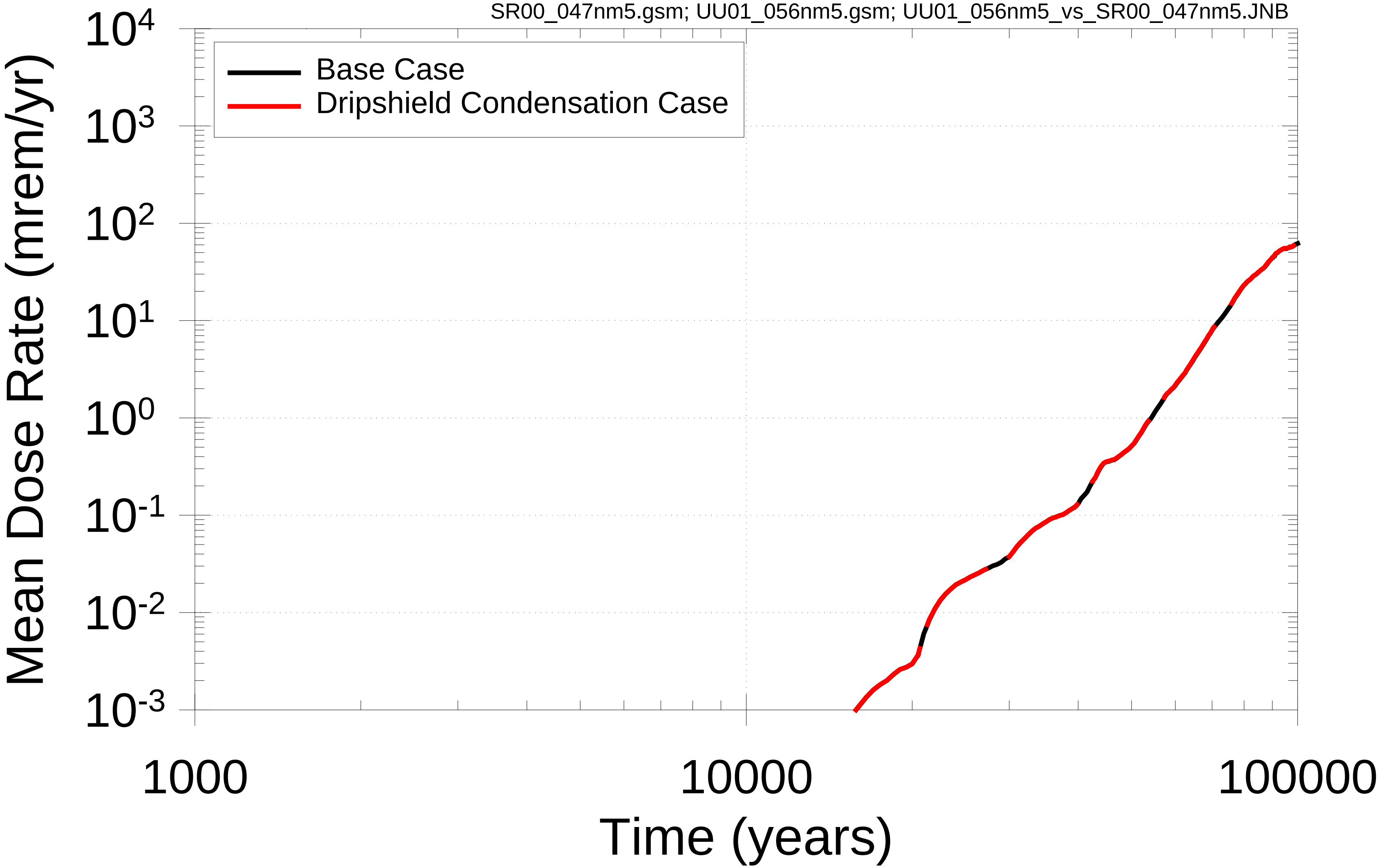


- **What is the potential for dripping to occur under the drip shield?**
  - **Condensation under the drip shield may occur if the following condition exists**
    - **Partial vapor pressure in the invert material is high enough such that its dew-point temperature is equal to or greater than the drip shield temperature**
  - **TSPA bounding implementation**
    - **Allow condensation when $T_{Invert} > T_{DS}$**
    - **Condensation drip rate equal to uncertain fraction of invert evaporation rate**

Dripshield Condensation Model
Mean Seep Flow Entering the Waste Package, CSNF Bin 5

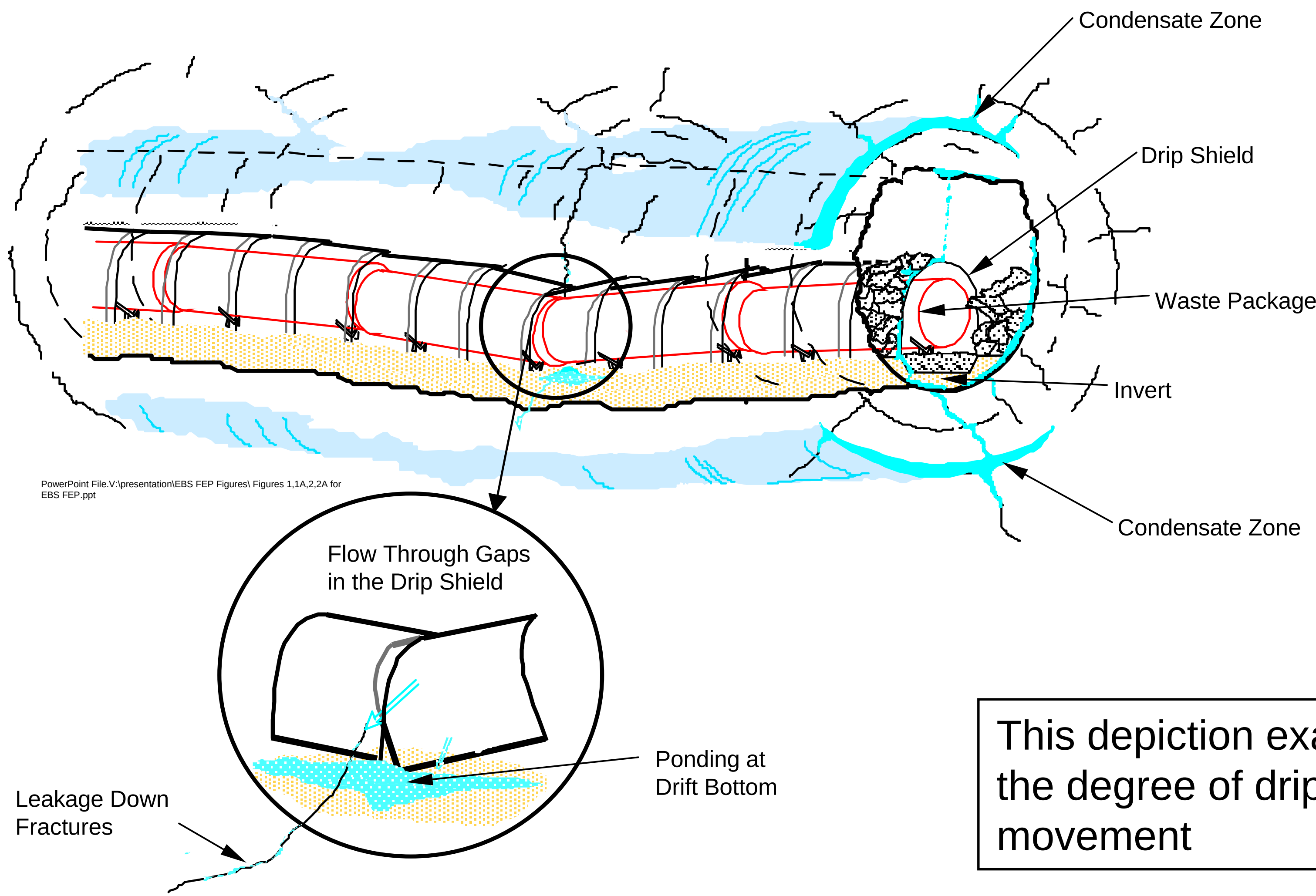


Dripshield Condensation Sensitivity



Question Group 2, Part 2d

Do current drip shield models adequately characterize and bound drip shield performance?



This depiction exaggerates the degree of drip shield movement

Question Group 2, Part 2d
(Continued)

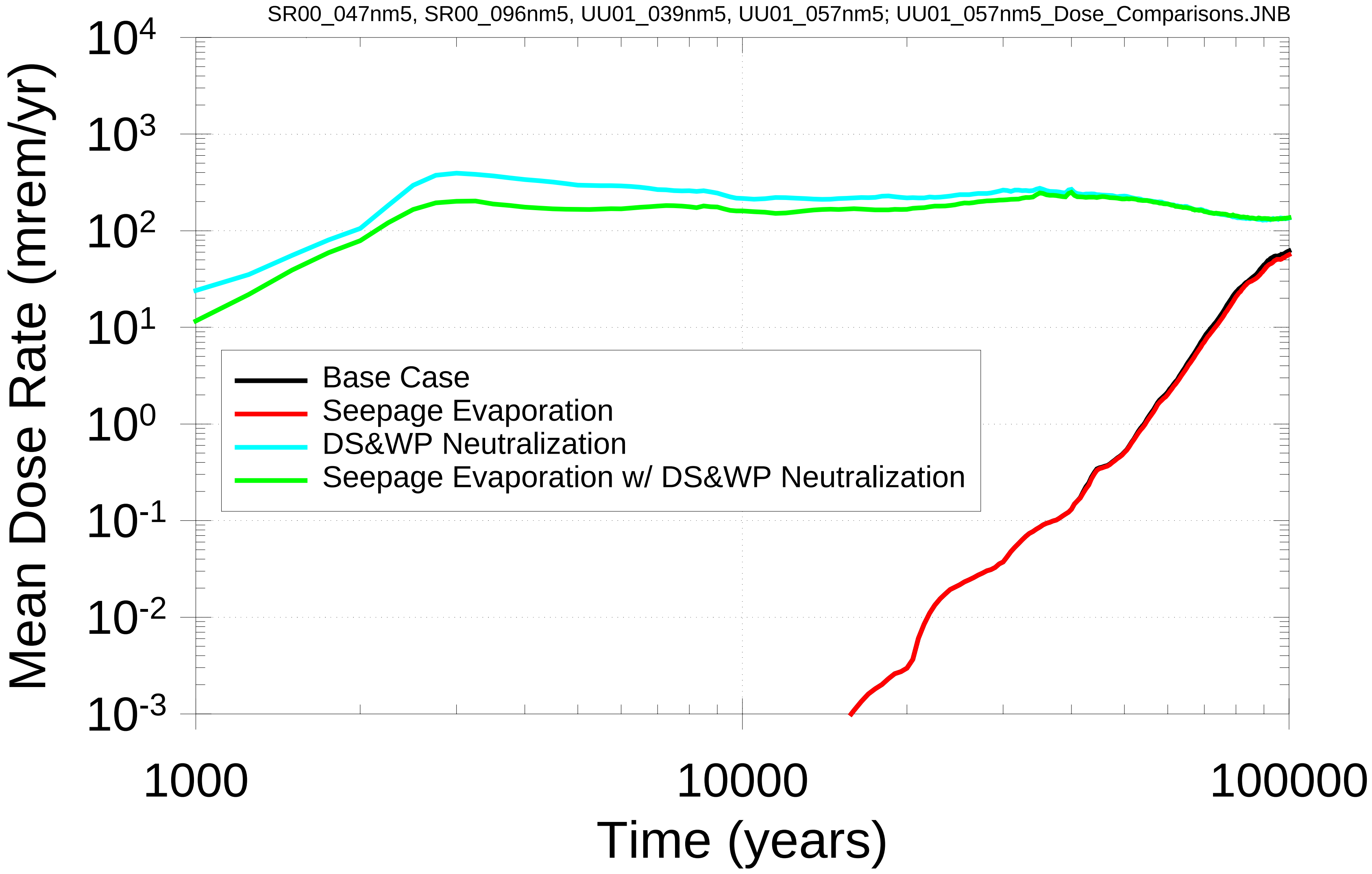
- Thermal and mechanical responses of the DS have been evaluated for five mechanisms
  - Thermal expansion (used drip shield temperatures and expansion coefficients)
  - Floor heave (calculated 1 cm per drip shield segment)
  - Rock fall (drip shield structural analysis and design basis rock)
  - Seismic response (design requirement for design basis earthquake)
  - Emplacement pallet failure (changed design so that pallet life as long as WP life)
- These mechanisms produce minor structural responses that do not significantly impact performance of the DS
- Recognize that uncertainties in these analyses exist
  - Floor heave, rock fall, seismic response are being further evaluated for a potential LA
- TSPA-SR EBS transport model assumes WP is resting on invert

Question Group 2, Part 2d

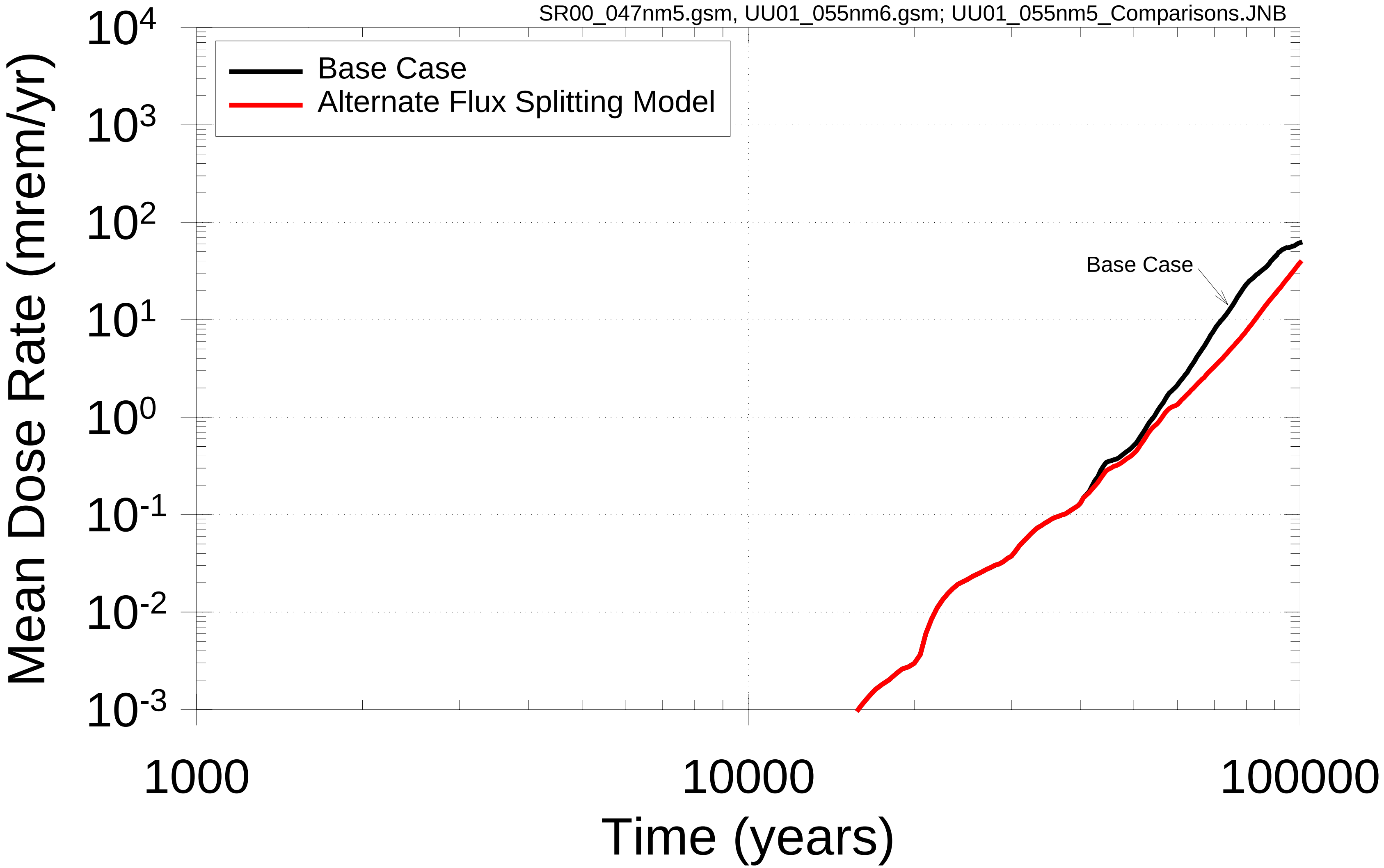
(Continued)

- **TSPA-SR water flux model for DS reasonably bounds DS diversion performance**
  - All seepage entering a drift falls on the crown of the DS
  - Seepage evaporation is ignored
  - Probability of random seep intercepting a breach is based on the ratio of total axial length of patches to length of DS [WP] (Σpatch_length)/(DS [WP]_length)
- **Supplemental Analysis: quantify impact of uncertainty in DS and WP flux**
  - Drips assumed to fall randomly on the upper surfaces of the DS and WP
    - Probability of a drip intercepting a breach is given by the ratio of projected breach area to upper DS/WP projected surface area
  - Evaporation rate is uncertain
  - Drips that do not intercept a breach directly may contribute an uncertain fraction of flux through the DS [WP] due to splashing or surface flow

Seepage Evaporation Model with DS and WP Neutralization



Drip Shield and Waste Package Flux Splitting Sensitivity



Question Group 3, Part 1

- **If the potential repository were operated in a cooler thermal mode, which FEP's previously screened out would be included and vice versa?**
  - **23 Near-Field, EBS and WP FEPs that are directly related to thermal conditions**
  - **9 of the 23 FEPs are excluded from TSPA-SR**
  - **None of the 9 excluded FEPs would need to be included for lower thermal operating mode conditions**
  - **None of the 14 included FEPs would be excluded for lower thermal operating mode conditions**
    - **Some may be addressed with higher confidence for the lower temperature**
  - **FEPs are continually reevaluated as models are refined and uncertainties are quantified**
    - **NRC is conducting an exhaustive review of FEPs and identifying FEPs that need improved technical basis**

Question Group 3, Part 2

- **Agenda Item: If subgrade structural steel corrodes, the drip shield may misalign as a result of settlement into the invert structure. At a minimum, this would produce asymmetry in the surface temperatures of the waste package and the drip shield. To what extent do this or similar events have a significant effect on waste package, drip shield, and invert performance?**
- **The current PA EBS transport model uses an as-built invert geometry with the WP settled flat onto the floor. The emplacement pallet life is about the same as the WP, but no credit is taken for transport along the pallet or sorption in the invert**
- **Design solutions are feasible that minimize differential settlement of the DS and WP**
  - **For example, the DS could be supported on a foot extending outward from the Emplacement Pallet. Work in this area is just beginning**

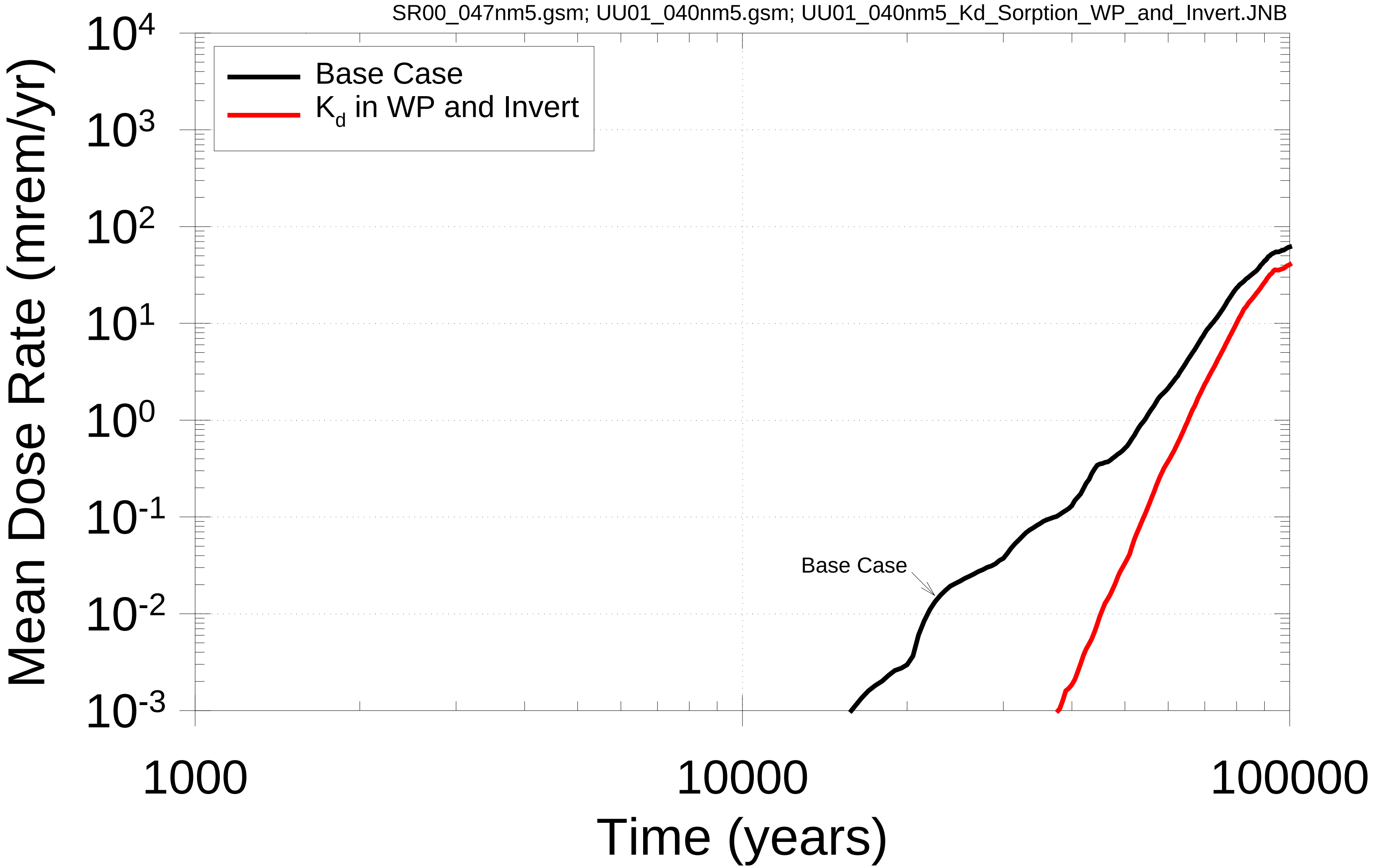
Question Group 3, Part 2
(Continued)

- EBS FEPs analyses have addressed
  - Thermal stresses due to differential thermal expansion of WP components (YMP - 2.1.11.05.00)
  - Effects at material interfaces (YMP - 2.1.06.07.00)
- Thermal asymetries in the WP shell are expected to be small due to the high metal conductivity and the thickness of the shell
- Several excluded FEPs are related to post-closure changes in the EBS configuration
- FEPs are continually reevaluated as models are refined and uncertainties are quantified

Question Group 3, Part 3

- **Agenda Item: Have the corrosion products of EBSs and materials, such as the ground support, been considered in the postclosure EBS environment?**
- **The effects of degradation products on the EBS environment are not explicitly included in TSPA**
- **Processes excluded based on FEPs Analyses**
  - **Degradation of Cementitious Materials in Drift – YMP 2.1.06.01.00**
  - **Interaction with Corrosion Products – YMP 2.1.09.02.00**
  - **In-drift Sorption – YMP 2.1.09.05.00**
- **Supplemental Analysis: Quantify impact of sorption in the WP and invert on performance**
  - **Iron-based materials in the invert degrade quickly**
  - **Kd ranges for Am, I, Np, Pu, Tc, Th and U estimated from several sources for hydrous ferric oxides or iron-rich soils**

Kd Sorption in WP and Invert Sensitivity



Backup

Excluded Thermal FEPS

- Cold traps - YMP 2.1.08.02.00
- Thermal and other waste and EBS-related changes in the adjacent host rock – YMP 2.2.01.02.00
- Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock – YMP 2.2.06.01.00
- Thermo-mechanical alteration of fractures near repository – YMP 2.2.10.04.00
- Thermo-mechanical alteration of rocks above and below the repository – YMP 2.2.10.05.00
- Thermo-chemical alteration (solubility speciation, phase changes, precipitation/dissolution) – YMP 2.2.10.06.00
- Condensation on underside of drip shield – YMP 2.1.08.14.00
- Thermally-induced stress changes in waste and EBS – YMP 2.1.11.07.00
- Differing thermal expansion of repository components – YMP 2.1.11.05.00

Included Thermal FEPS

- Effects of pre-closure ventilation – YMP 1.1.02.02.00
- Repository dry-out due to waste heat – YMP 2.1.08.03.00
- Desaturation/Dewatering of the repository – YMP 2.1.08.10.00
- Nonuniform heat distribution/edge effects in repository – YMP 2.1.11.02.0
- Condensation zone forms around drifts – YMP 2.2.07.10.00
- Return flow from condensation cap/resaturation of dry-out zone – YMP 2.2.07.11.00
- Two-phase buoyant flow/heatpipes – YMP 2.2.10.10.00
- Geosphere dry-out due to waste heat – YMP 2.2.10.12.00
- Density-driven groundwater flow (thermal) – YMP 2.2.10.13.00
- Heat Output/Temperature in Waste and EBS – YMP 2.1.11.01.00
- Temperature Effects/Coupled Processes in Waste and EBS – YMP 2.1.11.04.00

Included Thermal FEPS

- Thermal Effects: Chemical and Microbiological Changes in the Waste and EBS – YMP 2.1.11.08.00
- Thermal Effects on Liquid or Two-phase Fluid Flow in the Waste and EBS – YMP 2.1.11.09.00
- Thermal Sensitization of Waste Containers and Drip Shields Increases Fragility –YMP 2.1.11.06.00

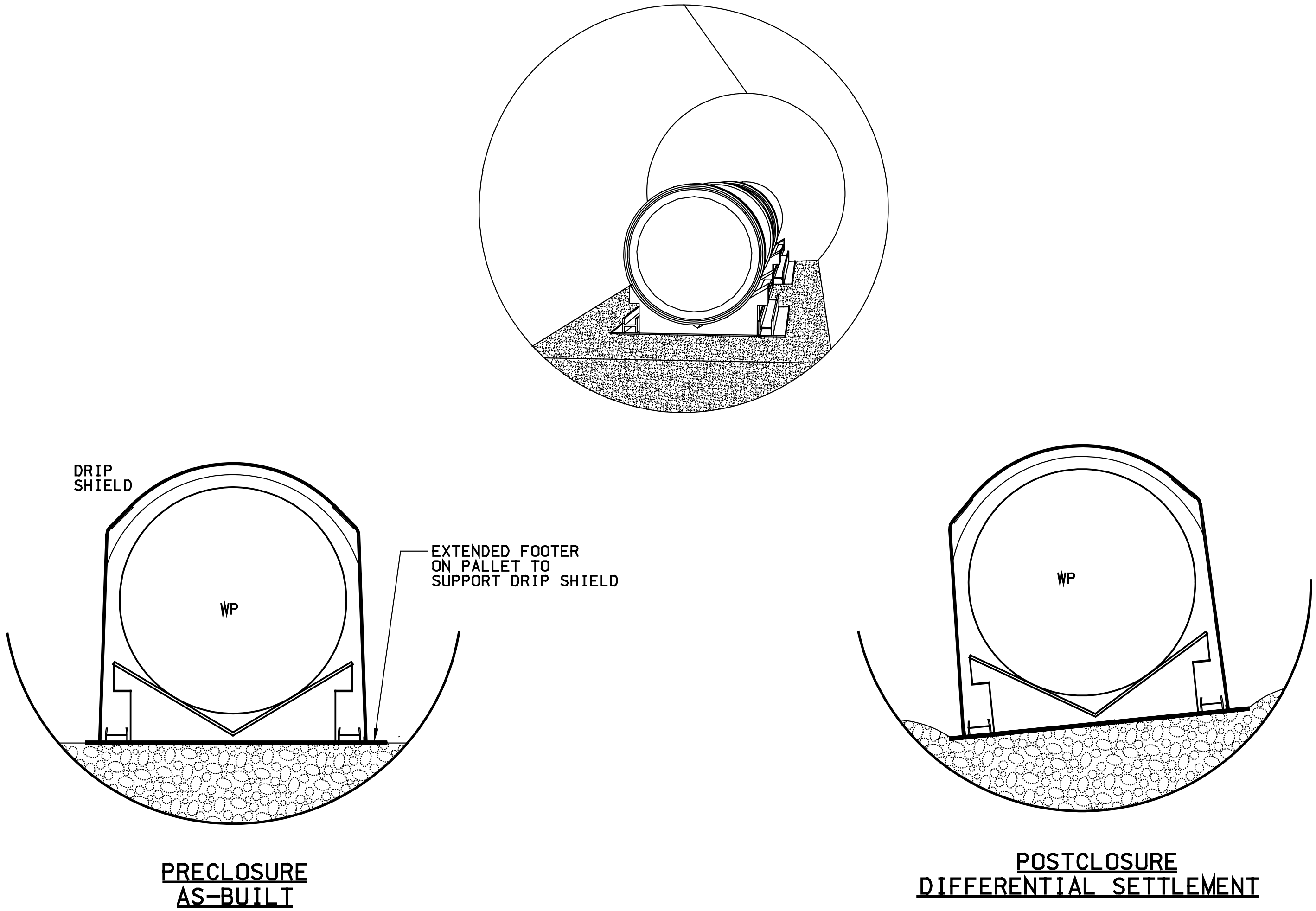
Question Group 3, Part 2

- Several excluded FEPs are related to post-closure changes in the EBS configuration
  - Degradation of Cementitious Materials in drift – YMP 2.1.06.01.00
  - Effects of Rock Reinforcement Materials – YMP 2.1.06.02.00
  - Degradation of Invert and Pedestal – YMP 2.1.06.05.00
  - Effects and Degradation of Drip Shield – YMP 2.1.06.06.00
  - Rockfall (Large Block) – YMP 2.1.07.01.00
  - Mechanical Degradation or Collapse of Drift – YMP 2.1.07.02.00
  - Movement of Containers – YMP 2.1.07.03.00
  - Floor Buckling – YMP 2.1.07.06.00
  - Interaction with Corrosion Products – YMP 2.1.09.02.00
  - In-drift Sorption – YMP 2.1.09.05.00
  - Differing Thermal Expansion of Repository Components – YMP 2.1.11.05.00
  - Drainage with Transport – Sealing and Plugging – YMP 2.1.08.12.0

Invert Mechanical Requirements

- **The invert structural members shall be composed of carbon steel. [1.2.1.9]**
- **The invert ballast material shall be granular. [1.2.1.11]**
- **The invert and WP emplacement pallet shall maintain the WP's nominal emplacement position for a minimum of 300 years. [1.2.1.20]**
- **The invert and WP emplacement pallet shall maintain the WP's nominal horizontal emplacement position for a minimum of 10,000 years after closure. [1.2.1.21]**
- **The invert and WP emplacement pallet shall provide structural support for the: Waste Packages, Drip Shields, Waste Emplacement/Retrieval System mobile equipment, Performance Confirmation Emplacement Drift Monitoring System mobile equipment, Subsurface Emplacement Transportation System, and Subsurface Excavation System. [1.2.1.22]**

PRECLOSURE LOADS OF DRIPSHIELD SUPPORTED BY WP EMPLACEMENT PALLET, WHICH IS DIRECTLY SUPPORTED BY THE BALLAST



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Conservatisms in the EBS Water Flux Model

(1) approximation is equivalent to assuming that a breach intercepts all fluid at the relevant axial location

(2) overlap between patches is ignored

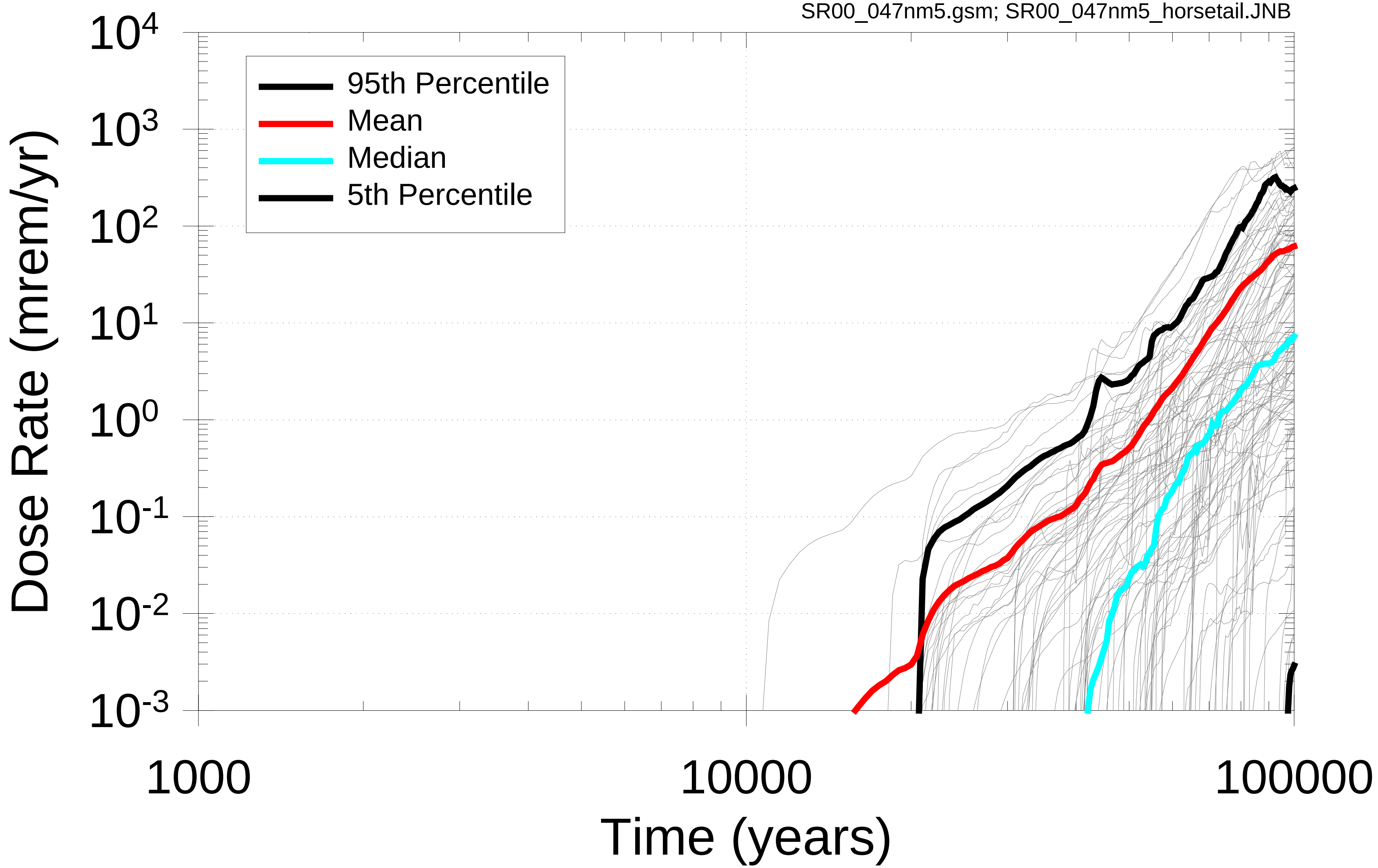
(3) split for left/right hand sides of package is ignored

Note: There is no direct uncertainty in TSPA-SR flux calculations other than input seepage and waste package/drip shield performance uncertainties

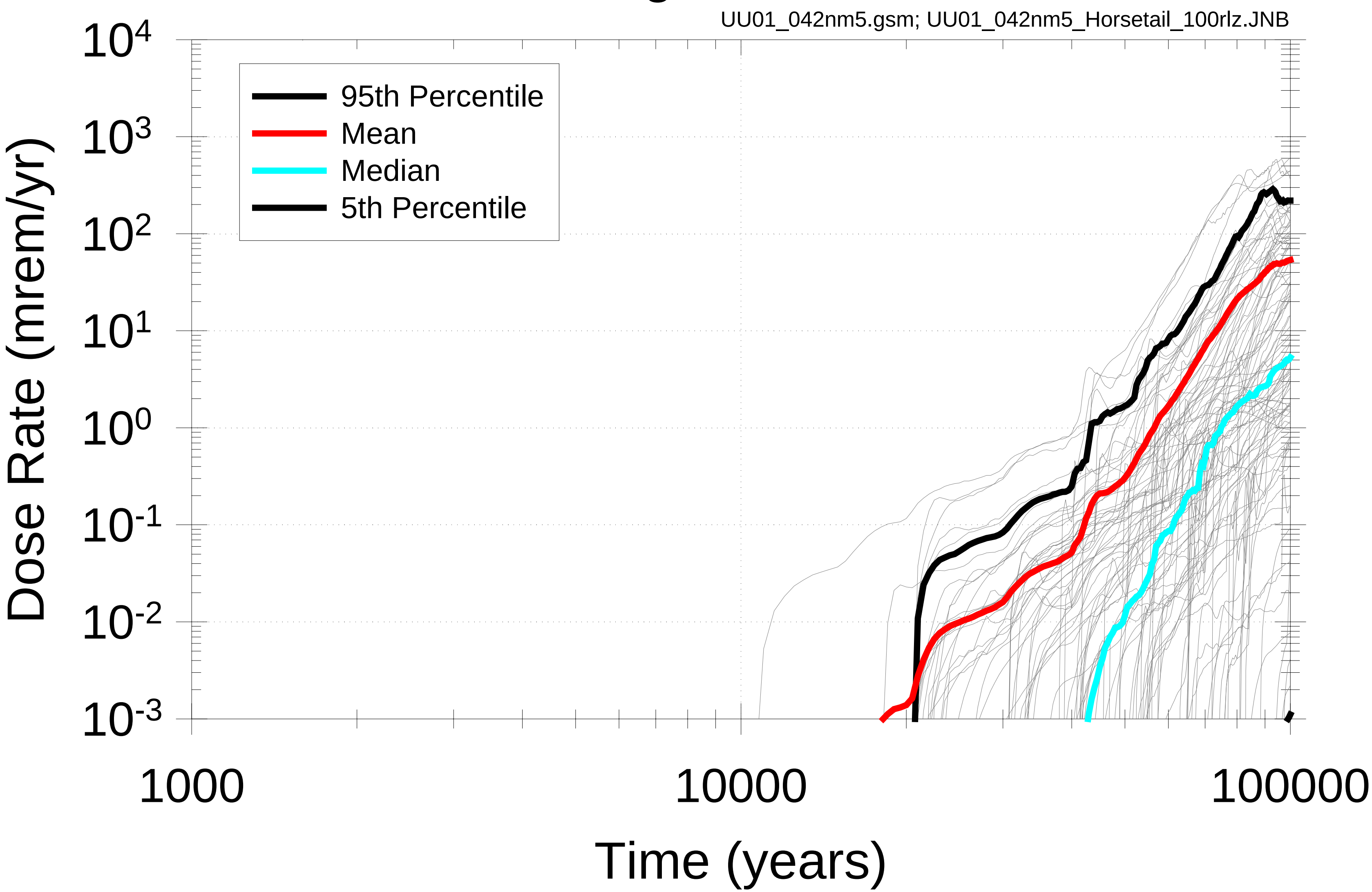
Conservatisms in the EBS Sorption Model

- **TSPA-SR assumes no sorption in WP or invert**
  - **Very conservative because iron corrosion products (hydrous ferric oxides) are excellent sorbers for many radionuclides**
  - **Copper corrosion products may sorb technetium and iodine**

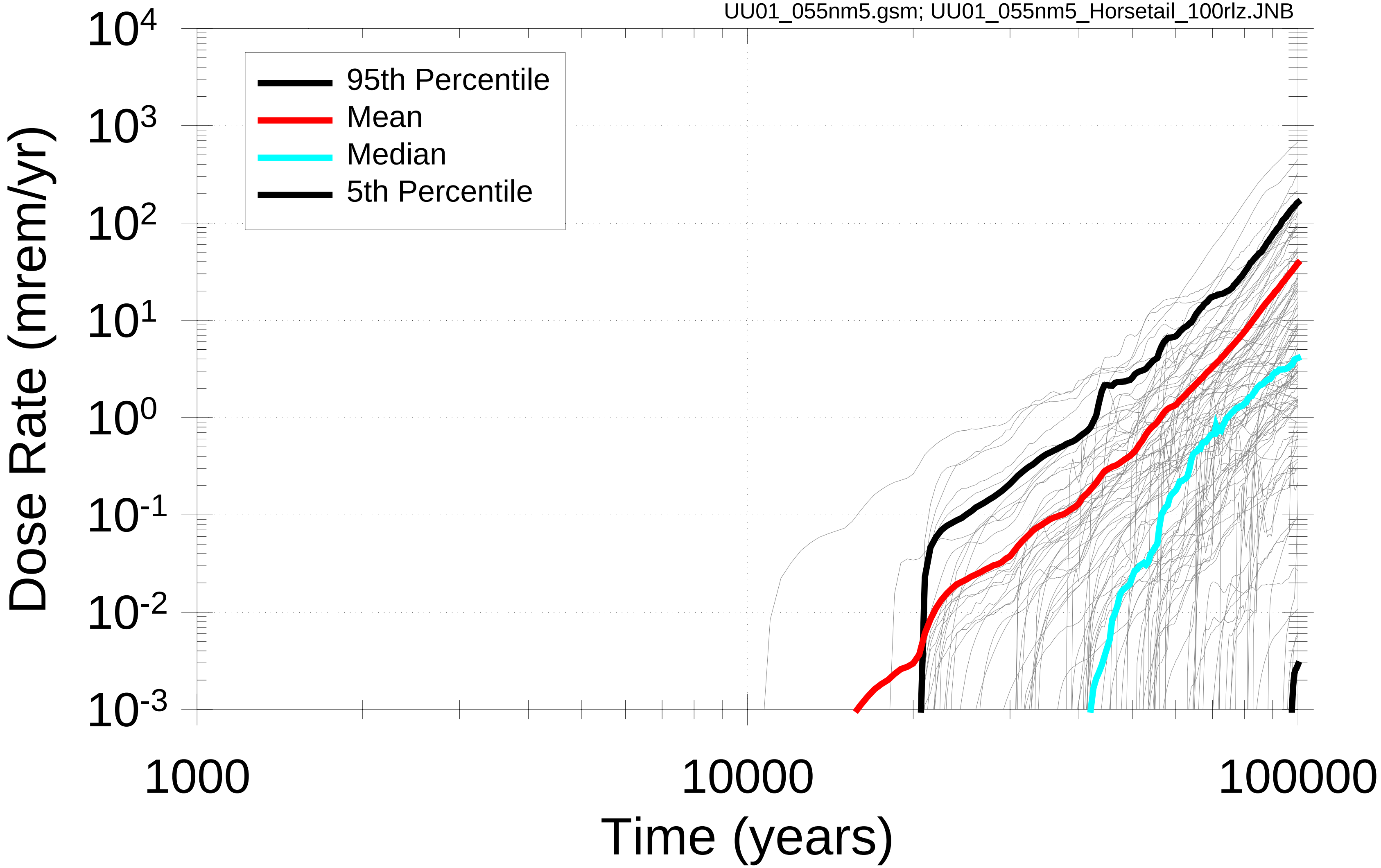
TSPA-SR Base Case



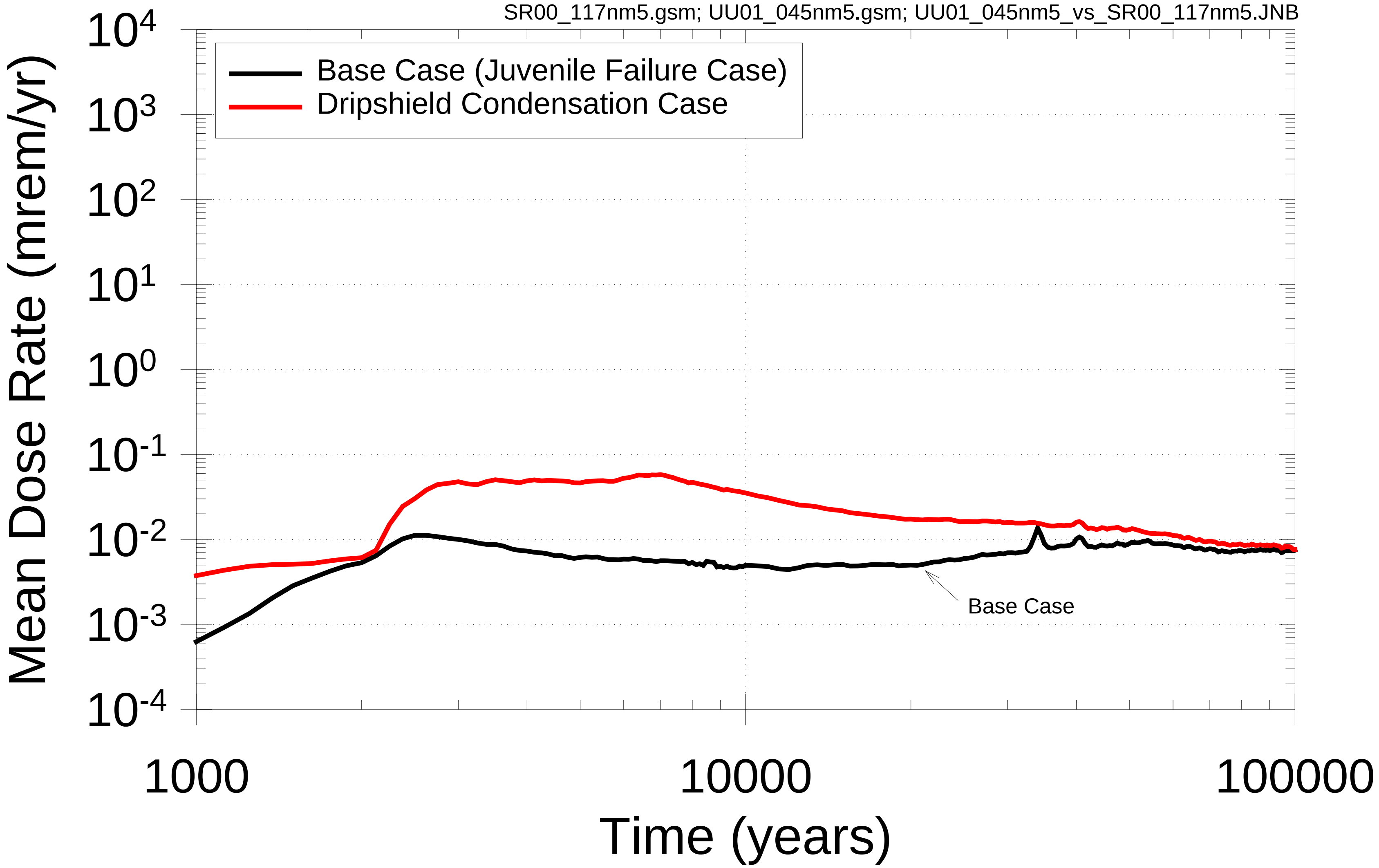
In-Package Diffusion



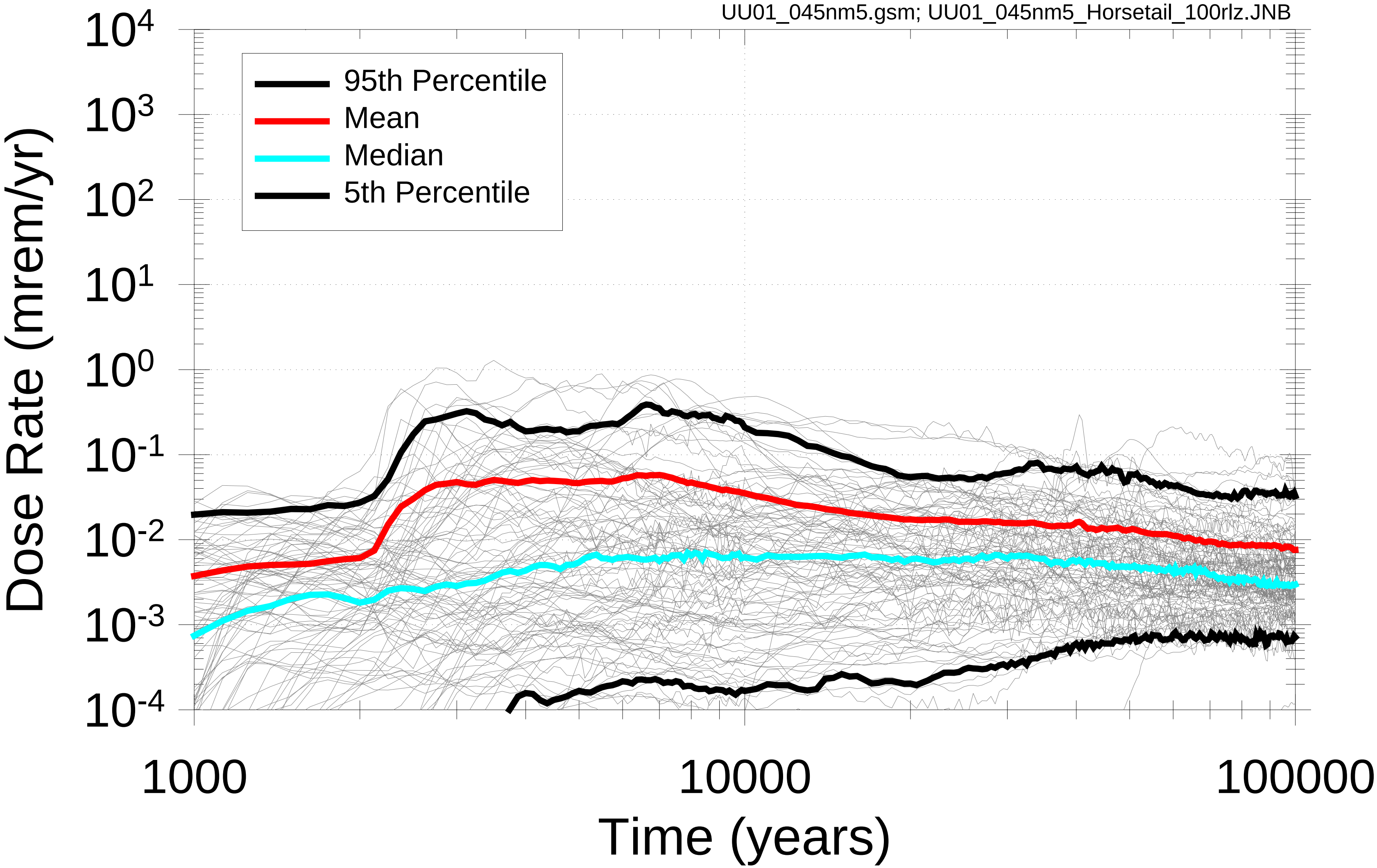
Drip Shield and Waste Package Flux Model



Dripshield Condensation Sensitivity



Dripshield Condensation Model



Kd Sorption in WP and Invert