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

Update on Uncertainties

Presented to:
Nuclear Waste Technical Review Board

Presented by:
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YUCCA MOUNTAIN PROJECT

Overview: Update on Uncertainties

- **Quantified uncertainties review**
- **Unquantified uncertainties activity**
  - Development of representative models and parameter uncertainties
  - Analysis of significance of uncertainties

Quantified Uncertainties Review

Purpose: To review the manner in which uncertainties have been treated and documented to date for the future Site Recommendation decision; identify the lessons learned for future uncertainty treatment

Methods:

- **Review treatment of uncertainties in AMRs, PMRs, and TSPA**
- **Conducted by independent review team**
- **Including treatment and documentation of parameter, model and scenario uncertainties**
- **Evaluating transparency and traceability**

Quantified Uncertainties Review: Observations to Date

- **Identification and treatment of uncertainty is one of many issues focused on by AMR authors**
- **Several approaches to uncertainty treatment utilized (e.g. assumption, conservative value, probability distribution)**
  - Approach varies, reflecting differences in availability of data, scientific disciplines, and individual authors
- **Of all the types, the treatment of parameter uncertainty appears to be the most completely documented**
  - Clear discussions of the source of uncertainty, how it was treated, and the basis is generally provided (e.g. SZ stochastic parameters and DHLW glass dissolution AMRs)

Quantified Uncertainties Review: Observations to Date

(Continued)

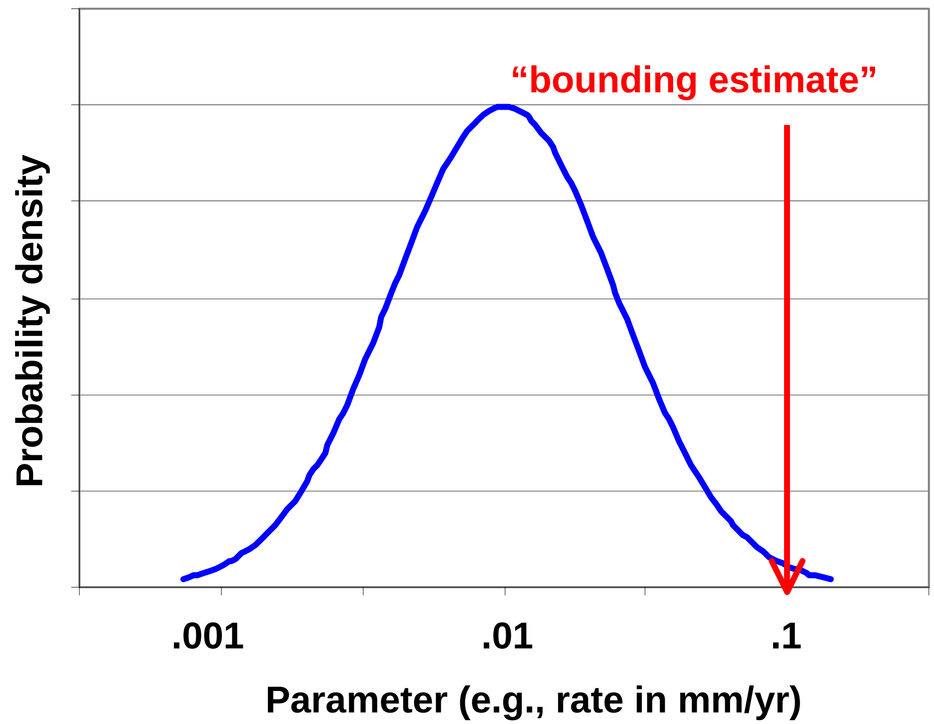
- **Discussions regarding the treatment of model/scenario uncertainty are less transparent**
  - Recommendations regarding improved documentation will be provided
- **Recommendations to improve consistency and clarity are under development**

Unquantified Uncertainties (UU) Activity

Purpose: To evaluate the significance of unquantified uncertainties (conservatisms and optimisms) in the TSPA-SR and to develop insights and guidance

Inputs to UU Activity

- **Conservatism review**
- **Initial results from quantified uncertainties review**
- **Insights from TSPA-SR Rev.00**



UU Activity and Context

Step 1:	Identify key unquantified uncertainties; important to dose, presently unquantified	Working list developed
Step 2:	Develop representative models and quantify uncertainties	Meetings conducted with all technical groups; analyses and follow-on meetings in progress
Step 3:	Evaluate the implications of newly quantified inputs and uncertainties	Total System Performance Assessment abstractions and analyses, sensitivity analyses planned; Interim Integrated Report
Step 4:	Develop recommendations for uncertainty treatment for license application	Results and recommendations documented in report; Final Integrated Report
Step 5:	Manage uncertainty treatment in the future	Ongoing during development of Total System Performance Assessment for the License Application, should the site be found suitable

Working List of Key Unquantified Uncertainties

Topic	Model/Parameter
Unsaturated Zone	Effects of drift degradation and rock bolts on seepage
	Thermal effects on seepage
	Engineered Barrier System release to unsaturated zone: drift shadow zone
	Matrix diffusion
	Thermal-hydrologic-chemical effects
Engineered Barrier System	Convection/evaporation and condensation in drift
	Transport pathway from inside waste package to invert
	Retardation for pathway out of waste package
	Invert properties
Waste Package Degradation	Uncertainty in weld stress state following mitigation
	Geometry of defects
	General corrosion rate of Alloy 22 (uncertainty/variability partition)
	Long-term stability of passive films on Alloy 22
	Aging effects on Alloy 22
Waste Form Degradation	In package chemistry (HLW glass degradation rate, steel degradation rate)
	Cladding degradation (mechnical perforation, unzipping velocity)
	Neptunium, thorium, uranium solubility
	Colloid concentrations
Saturated Zone	Specific discharge
	Effective diffusion coefficient in volcanics
	Flowing interval spacing
	Effective posrosity in alluvium
	Bulk density of alluvium
	Pu colloid retardation in alluvium
	Sorption coefficient in alluvium for Np, I, Tc, U
	Sorptiion coefficient for Np in volcanics

Developing Representative Models and Quantifying Uncertainties

- **Quantify uncertainties by having technical investigators provide representative estimates of models and parameters**
- **Probability training; iterative series of interviews followed by calculations, modeling, and analyses with five topical teams**
- **Investigators use their knowledge of project-specific data, literature data, analogous systems or processes, and technical judgment**
- **Parameter uncertainties quantified with probability distributions**
- **Topical teams include Total System Performance Assessment representatives**
- **Technical basis for assessments will be documented**

Evaluating the Implications of Quantified Uncertainties

- **<u>Purpose</u>: to analyze the newly quantified uncertainties with the TSPA model to gain insight into the significance of uncertainties and the overall degree of conservatism in the TSPA-SR results**
- **All of the uncertainty and sensitivity analyses conducted for TSPA-SR Rev.00 could potentially be conducted using the newly quantified uncertain inputs**

Potential Sensitivity Analyses

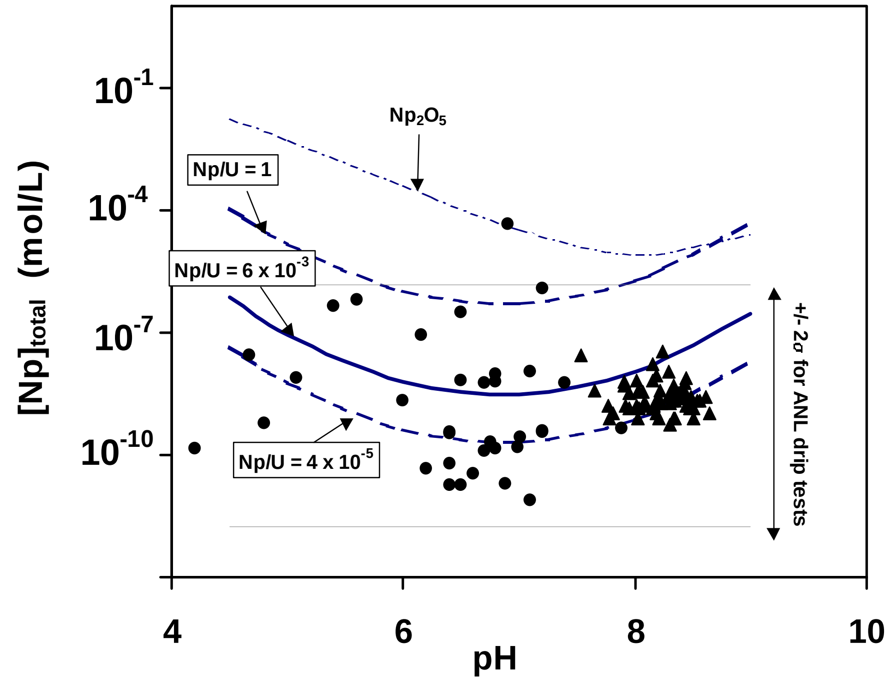
- **A range of analyses is planned:**
  - Dose estimates over time, with <u>all</u> newly-quantified uncertainties incorporated
  - Dose estimates over time, with newly-quantified uncertainties incorporated <u>one at a time</u>
  - Estimates of the impact of each (or all) model/parameter changes on dose rate, by comparison with TSPA-SR results
  - Contribution of input uncertainty to both total dose uncertainty and uncertainty in individual radionuclide dose (e.g., Np dose)
  - Time to a specified dose rate, e.g., 1 mrem/yr
  - Time and magnitude of peak dose rate
  - Analysis of subsystem performance metrics, e.g.,
    - Residence time in a particular barrier system
    - Cumulative release at subsystem boundaries
  - Degradation or neutralization of specific barriers to better illustrate the effects of the newly quantified uncertainties

Examples of Uncertainty Quantification

- **Neptunium solubility**
- **Welding effects on waste package**
  - Aging effects on Alloy-22 welds
  - Defect geometry
  - Weld stress state following mitigation
- **Transport pathway from waste package to invert (presented in Bob Andrews' talk)**

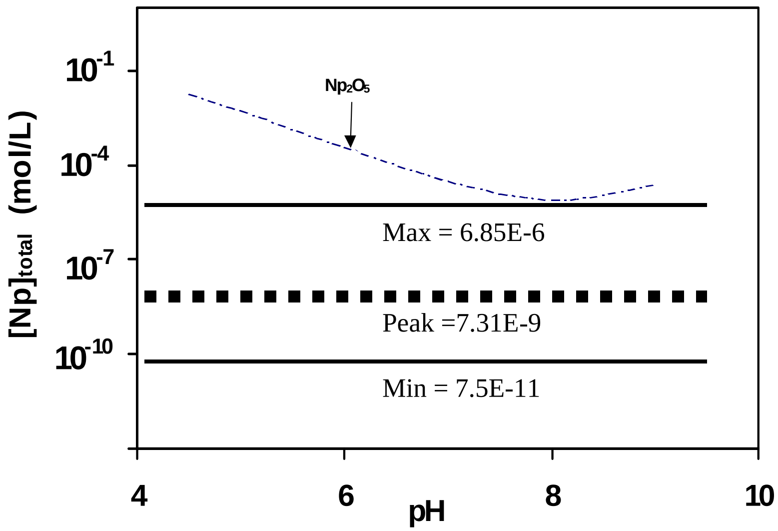
Neptunium Solubility Model in TSPA-SR Rev.00

- TSPA-SR Rev.00 assessment of dissolved Np concentration based on conservative assumptions
  - Uses bounding chemistries
  - Pure phases (Np_2O_5) assumed to control concentrations
  - Np solubility is a function of pH and f_{CO2}
- Np_2O_5 solubility curve (as a function of pH) bounds laboratory measured Np concentrations from ANL drip tests
- TSPA-SR Rev.00 model, which is based on Np_2O_5 solubility, does not explain the large spread (uncertainty) in measurements of Np concentration



Alternative Model for Np Solubility

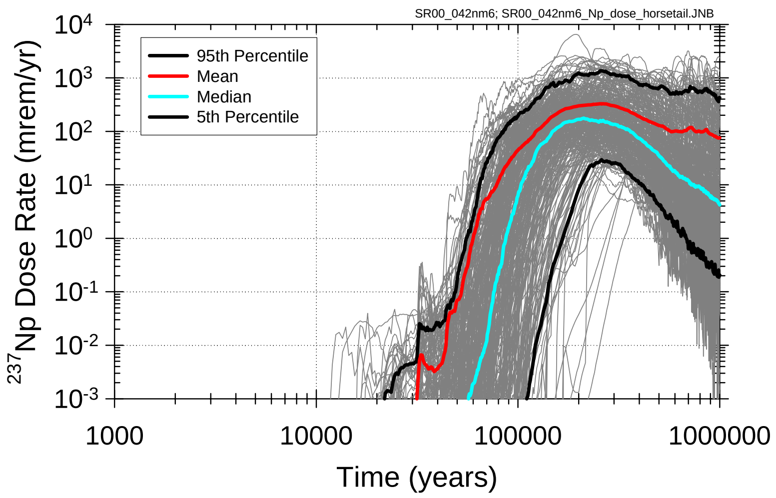
- Np solubility controlled by U-bearing secondary phase: dehydrated schoepite
  - Np is predicted to be incorporated into uranyl minerals (based on crystal chemistry)
  - Np has been observed in dehydrated schoepite in ANL laboratory tests
  - Congruent dissolution relationship between Np and U observed in spent fuel drip and batch tests
  - Long-term stability of schoepite is still being studied
- Abstracted uncertainty distribution spans 5 orders of magnitude
- The uncertainty distribution is assumed valid between pH 4.5 and 9.0; pH dependency being evaluated



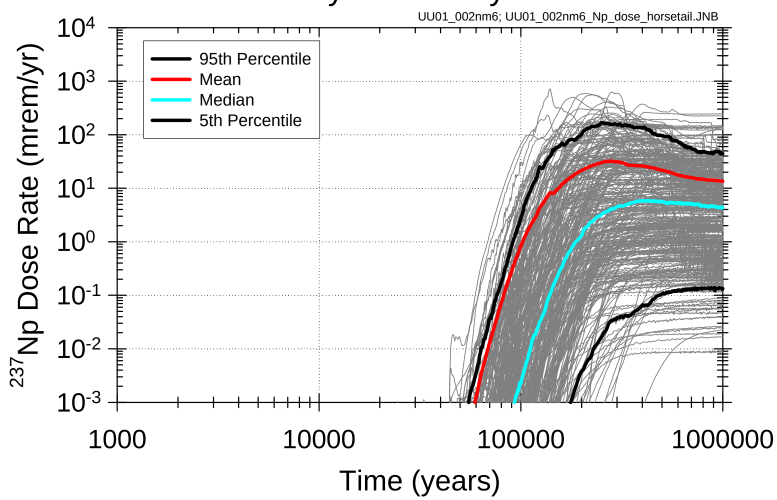
Comparison of Np Dose Rate Between TSPA-SR Rev.00 and the Preliminary UU Secondary-Phase Model

- Quantified-uncertainty secondary-phase Np solubility model results in greater spread in Np dose and lower mean doses
- Uncertainty in Np dose rate in TSPA-SR Rev.00 model controlled by
  - Waste package degradation parameters up until about 150,000 years
  - Natural system parameters, i.e., infiltration scenario and SZ groundwater flux, beyond 150,000 years (i.e., at time of peak dose)
- Uncertainty in <u>peak</u> Np dose rate in preliminary UU secondary phase model controlled by
  - Natural system parameters, i.e., infiltration scenario and saturated-zone groundwater flux, beyond 150,000 years (i.e., at time of peak dose)
  - Np solubility uncertainty distribution

TSPA-SR Rev.00 ICN 01 Np Solubility Model



UU Preliminary Secondary Phase Model



Unquantified Uncertainties Related to Welds on Waste Packages

- **Aging: potential that annealing or welding could lead to intermetallic precipitation or long-range ordering**
  - Present model: aging enhancement factor of 1x – 2.5x the general corrosion rate for welds; based on measured ratios of passive current densities of aged/unaged samples
  - UU assessment: 1 of10,000 weld patches have general corrosion rate increased by 1000x due to aging effects; 1000x chosen to be consistent with recent measurements by the CNWRA; no enhancement factor for other weld patches
    - Additional uncertainty definition being developed
- **Defect geometry: possibility that defects are oriented radially, leading to through-wall propagation**
  - Present model: conservatively assumes that all defects are radial (100%)
  - UU assessment: 1% of all defects are radial; based on statistical analysis of literature data on defect geometry in carbon steel and an analysis of the potential for circumferential cracks to propagate radially
    - Additional uncertainty definition being developed

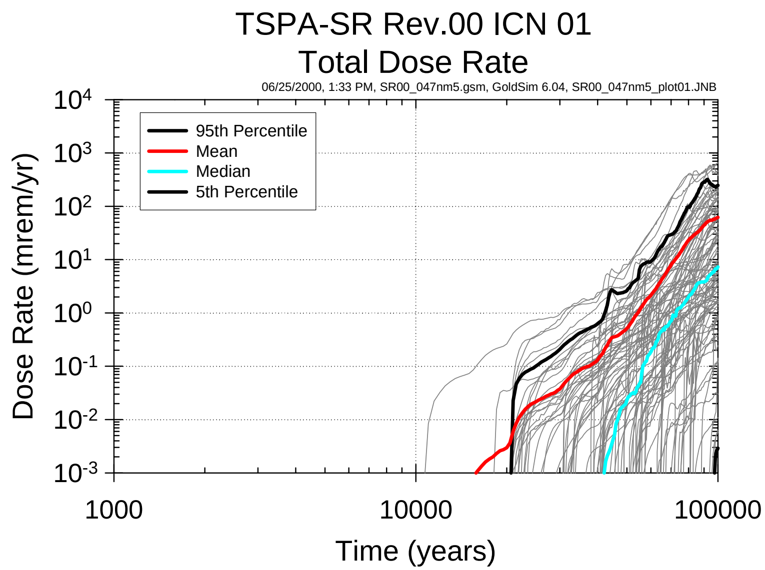
Unquantified Uncertainties Related to Welds on Waste Packages

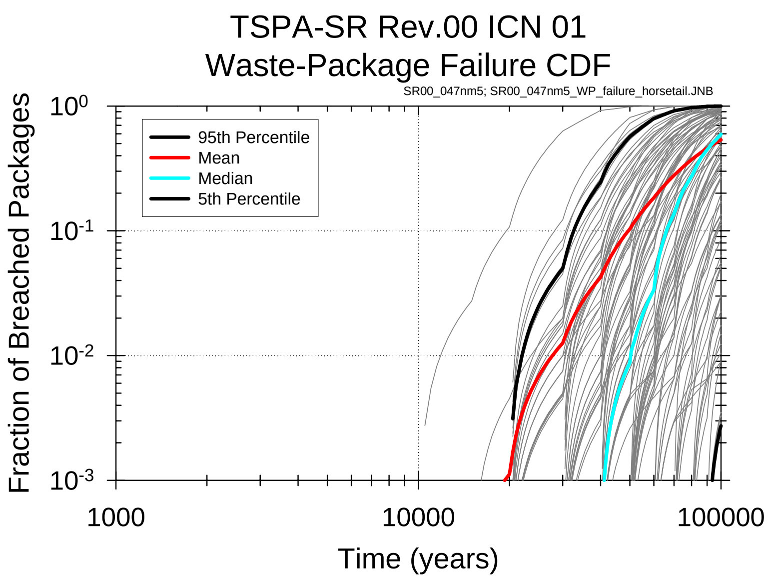
(Continued)

- **Stress state in the weld region following mitigation (by laser peening of inner lid or induction annealing of outer lid)—determines the thickness of the compressive layer**
  - Present model: conservative range of ±30% of yield strength (triangular distribution) applied to median stress profile; median stress profile determined by ANSYS calculations
  - UU assessment: ±15% based on recent statistical analysis of residual surface stresses from shot peening of nickel alloys, consideration of stresses as function of depth in shot-peened steel, and EPRI data on induction annealing stress improvement

TSPA-SR Rev.00 Waste Package Uncertainty Model

- Spread in waste-package failure and dose rate before 100,000 years is dominated by uncertain waste-package model parameters
  - Uncertainty in weld stress state on middle and outer lids, ± 30% of yield strength
  - Uncertainty in the Alloy-22 general corrosion rate
- Rev. 00 model uses an enhancement factor for all welds to simulate the effect of aging on general corrosion
- Conservatisms exist in the uncertainty distributions for stress state, crystal defect orientation, and the aging model

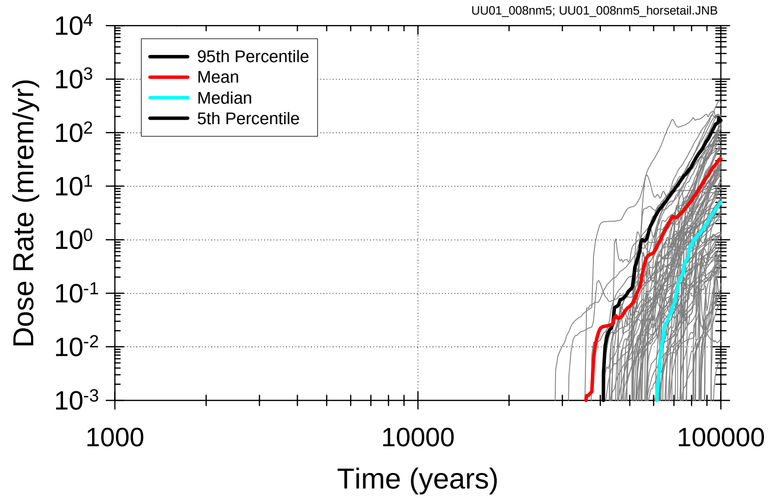




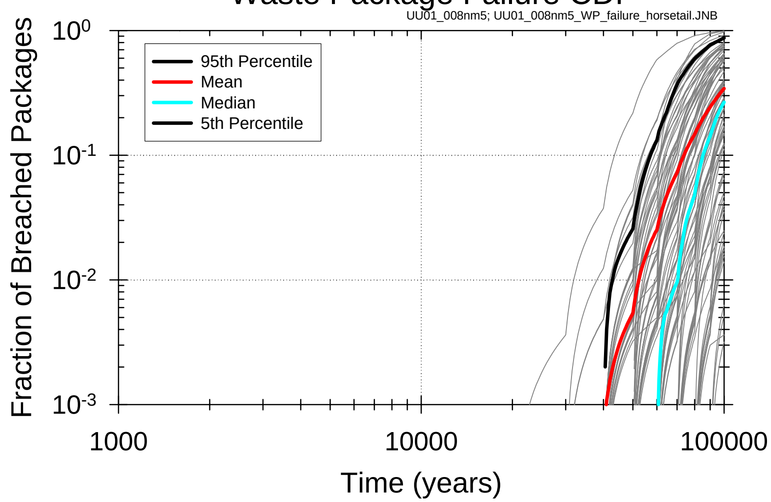
Alternative Uncertainty Model for Stress States and Defect Geometry

- Compared to TSPA-SR Rev. 00 model, the narrower stress state uncertainty distribution and the fewer radial defects (1%) causes
  - narrower spread in package failure distribution and narrower spread in total dose rate
  - first waste package failures occur later in time
  - not much change in maximum dose in 100,000 year time frame
- This alternative uncertainty model still includes the TSPA-SR Rev.00 aging enhancement factor on all welds

1% Radial Defects; Stress Unc. = ± 15% Y.S.
Total Dose Rate



1% Radial Defects; Stress Unc. = ± 15% Y.S.
Waste Package Failure CDF

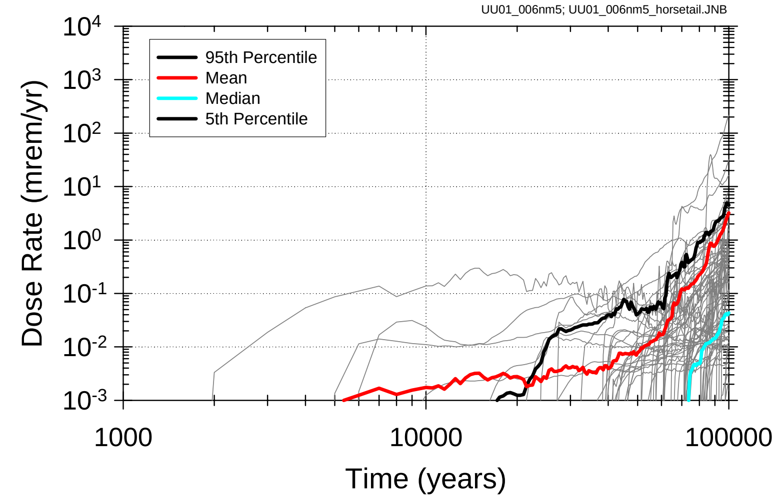


Alternative Uncertainty Model for Aging in Weld Region

- Compared to TSPA-SR Rev. 00 model, the alternative aging model causes
  - much earlier failures for a few packages, i.e., those with low-probability (and fast corrosion) weld failures caused by aging
  - much greater spread (uncertainty) in waste package failures and dose rate
  - lower peak dose rates in 100,000-year time frame because of fewer waste-package failures—caused by elimination of aging enhancement factor on every weld patch

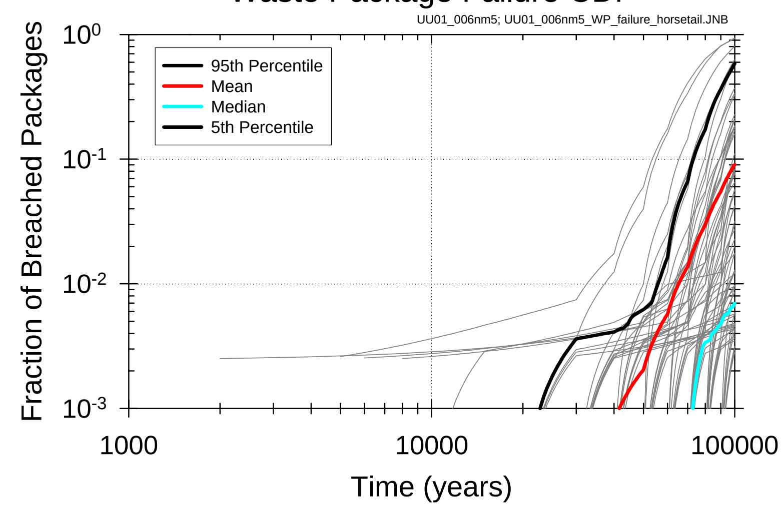
Aging: 1/10^4 Patches, $10^3 \times$ G.C. Rate

Total Dose Rate



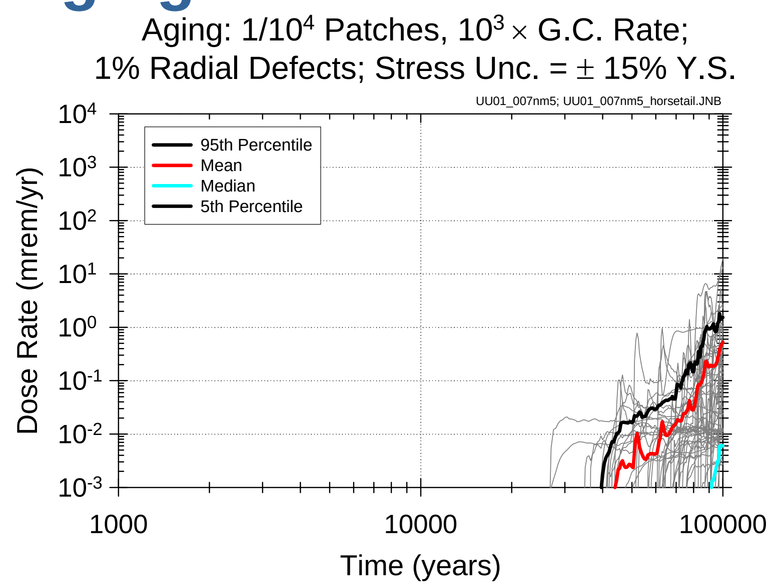
Aging: 1/10^4 Patches, $10^3 \times$ G.C. Rate

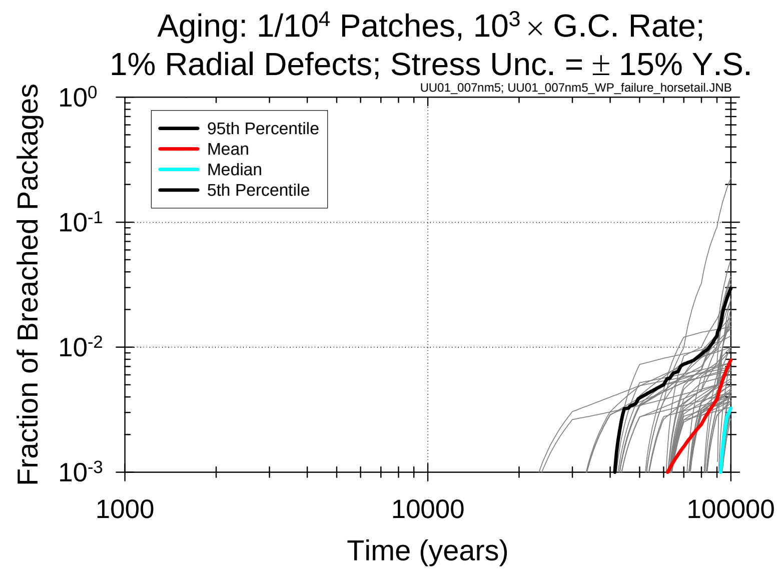
Waste Package Failure CDF



Alternative Uncertainty Models for Stress States, Defect Geometry, and Aging

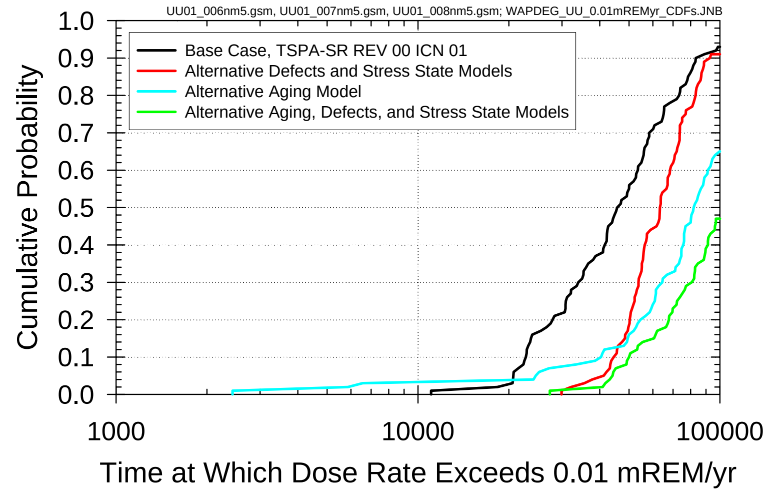
- Compared to TSPA-SR Rev. 00 model, the combined effect of alternative models for stress state (narrower), radial defects (fewer), and aging (lower probability, higher consequence) causes
  - later first failures, because of narrowing of the tails of the stress state distribution and fewer radial defects
  - fewer waste package failures and lower dose rates in 100,000-year time frame, because of fewer weld failures and thus fewer breached packages

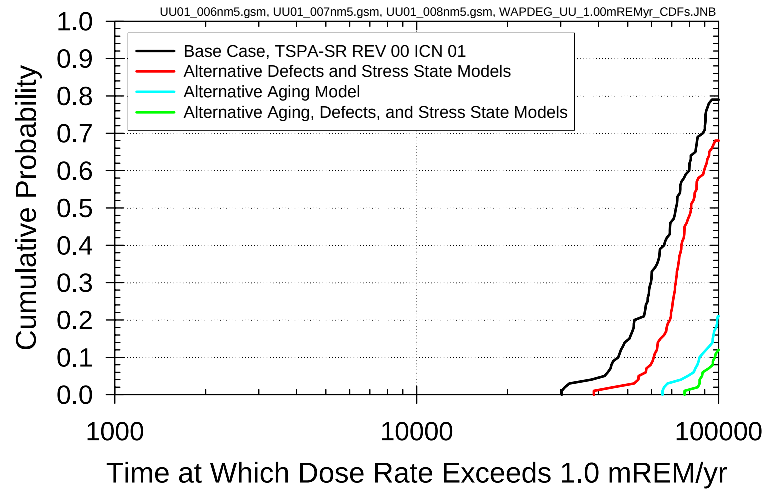




Another Metric to Quantify the Effect of Alternative Uncertainty Models—Time to a Specified Dose Rate

- Slice the dose rate horsetail horizontally, i.e., plot the time that each realization reaches a specified dose rate—choose both a "low" (0.01 mrem/yr) and a "high" (1 mrem/yr) dose rate
- All CDFs indicate that some realizations never exceeded the given dose rate, e.g., only about 10% of the realizations exceeded 1 mrem/yr for the combination of all three alternative uncertainty models
- Both the low and high dose rate CDFs indicate later, but only slightly lower, doses for the defect/stress-state model
- The low dose rate CDF indicates much earlier but lower doses for the aging model
- The high dose rate CDF indicates both later and lower doses for the aging model
- Both the low and high dose rate CDFs indicate later and much lower doses for the combination of the three models





Schedule and Planned Products

- **Interim Integrated Report**
  - Summary of Quantified Uncertainties Review
  - Summary of Conservatism Review
  - Summary of UU assessments and their technical basis
  - Preliminary TSPA sensitivity analyses
  - Preliminary assessment of significance of unquantified uncertainties
- **Assessment of unquantified uncertainties for TSPA-SR Rev.01 insights**
  - Evaluation of key unquantified uncertainties for a low-temperature thermal operating mode
  - Sensitivity analyses to assess significance of unquantified uncertainties
- **Final Integrated Report**
  - Finalized assessments from Interim report
  - Guidance to Technical PIs on the methods and processes for treating uncertainties

Managing Uncertainties for the LA

- **Uncertainty strategy will be aligned with licensing approach**
- **Implement DOE's overall approach to dealing with uncertainties**
- **Manage quantified and unquantified uncertainties**
- **Communicate uncertainty treatment, significance of uncertainties to make a defensible safety argument**