



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

Model Abstractions for Waste Package and Drip Shield Degradation for TSPA-SR

Presented to:

**NRC/DOE Technical Exchange on Total System Performance
Assessment (TSPA) for Yucca Mountain
San Antonio, Texas**

Presented by:

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YUCCA
MOUNTAIN
PROJECT

Outline

- **Overview of conceptual model**
- **TSPA-SR nominal case waste package (WP) and drip shield (DS) degradation model**
- **Corrosion initiation threshold abstraction**
- **General corrosion model abstraction**
- **Localized corrosion model abstraction**
- **Stress corrosion cracking abstraction**
- **Manufacturing defects abstraction**
- **WP and DS degradation analysis results**
- **Summary**

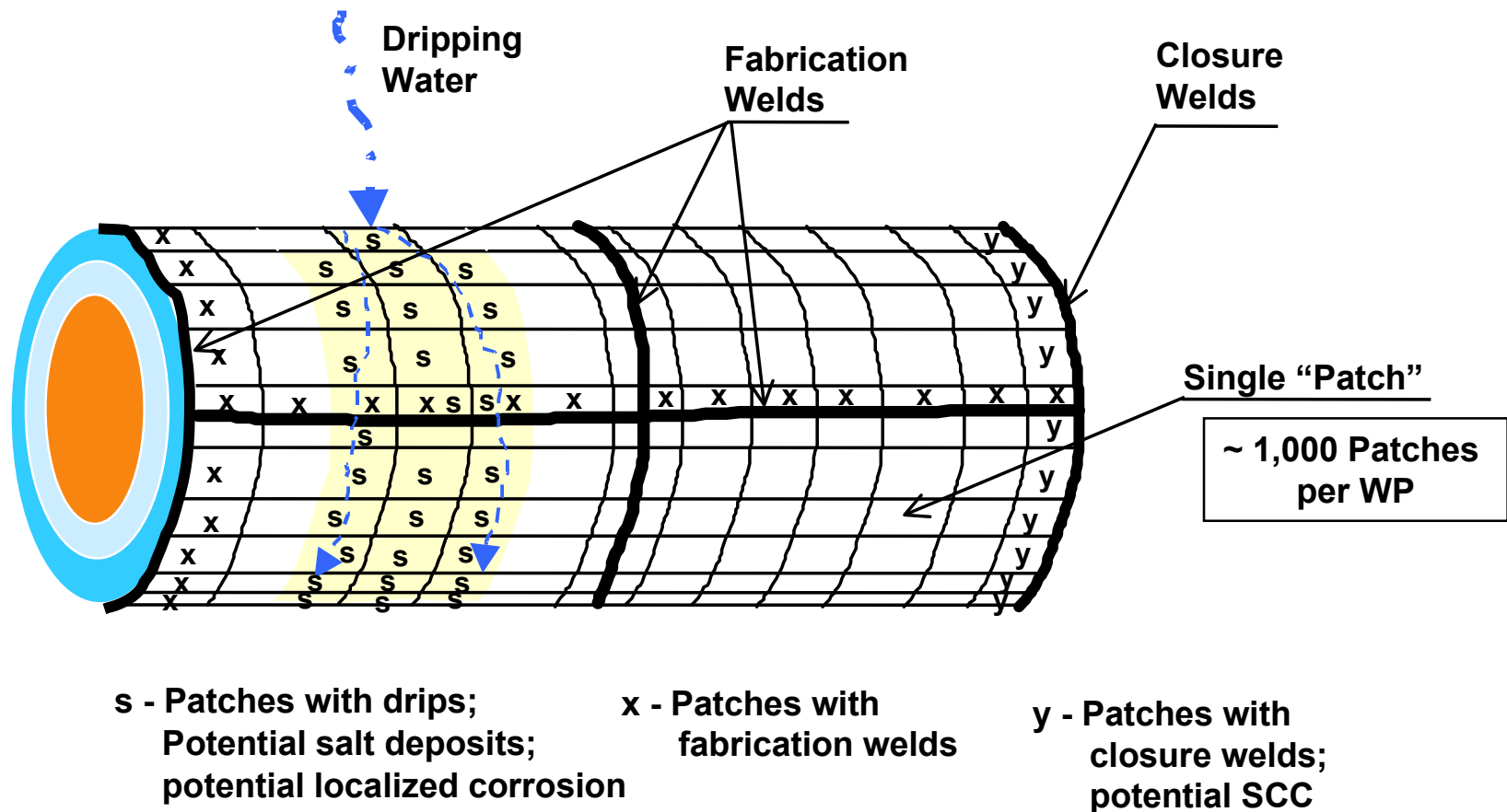
Key Technical Issues

- **Relevant Integrated Subissues from the Total System Performance Assessment and Integration Issue Resolution Status Report Rev. 2 include:**
 - **Engineered Barrier Degradation**
 - **Mechanical Disruption of Engineered Barriers**
 - **Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms**
- **Other relevant acceptance criteria are also found in the Container Life and Source Term Issue Resolution Status Reports (CLST IRSR)**
- **Acceptance criteria related to this topic are also addressed in relevant Process Model Reports (PMRs)**
 - **Waste Package Degradation**
 - **Engineered Barrier System Degradation, Flow, and Transport**
 - **Near-Field Environment**
 - **Disruptive Events**
- **Further details of the acceptance criteria related to this topic will be discussed at a Technical Exchange for each of the PMRs scheduled later this year**

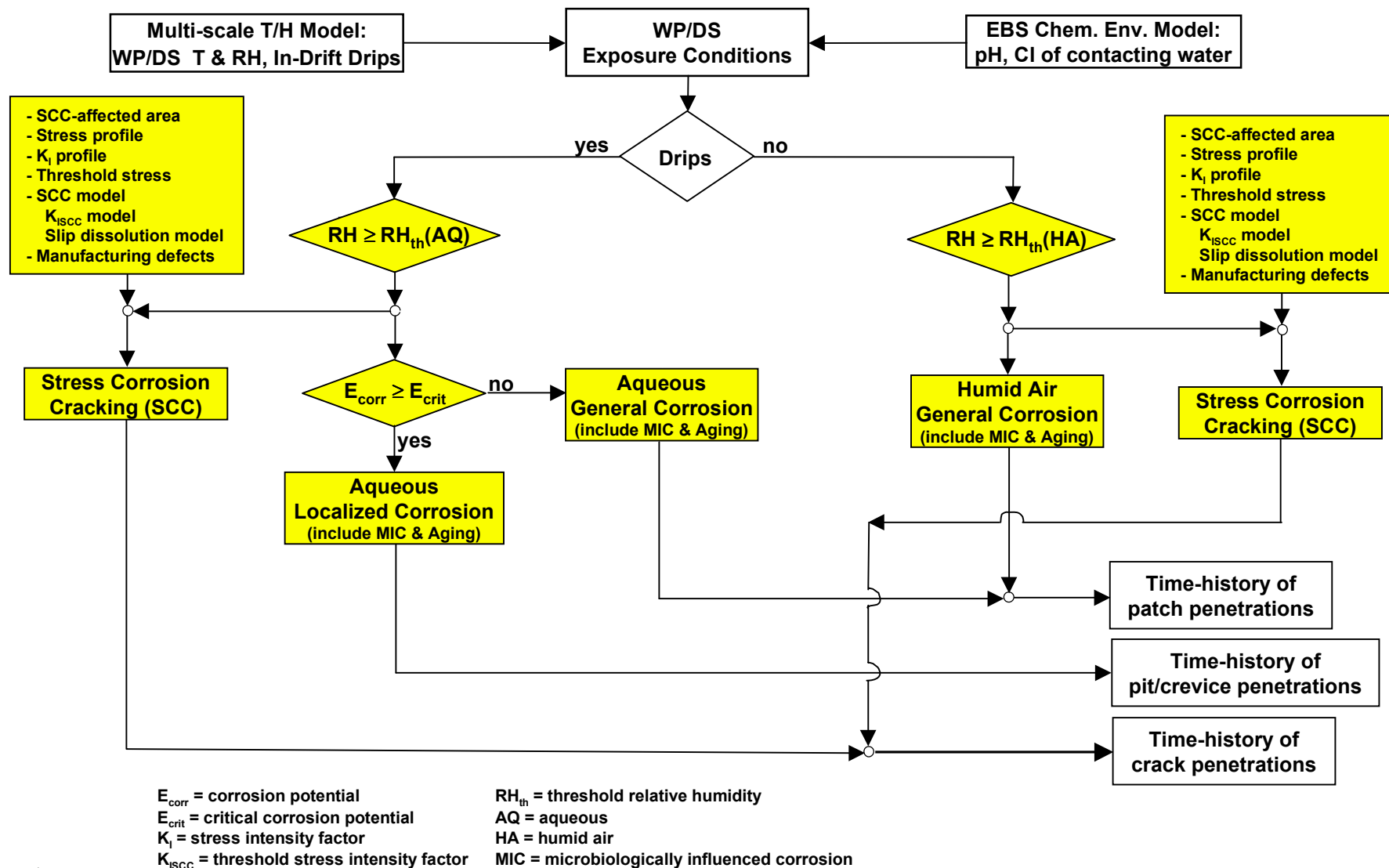
Schematic of the Conceptual Model of Stochastic WP Degradation Model (WAPDEG) for TSPA-SR

* T, RH, in-drift water dripping from multi-scale T-H and UZ model abstraction

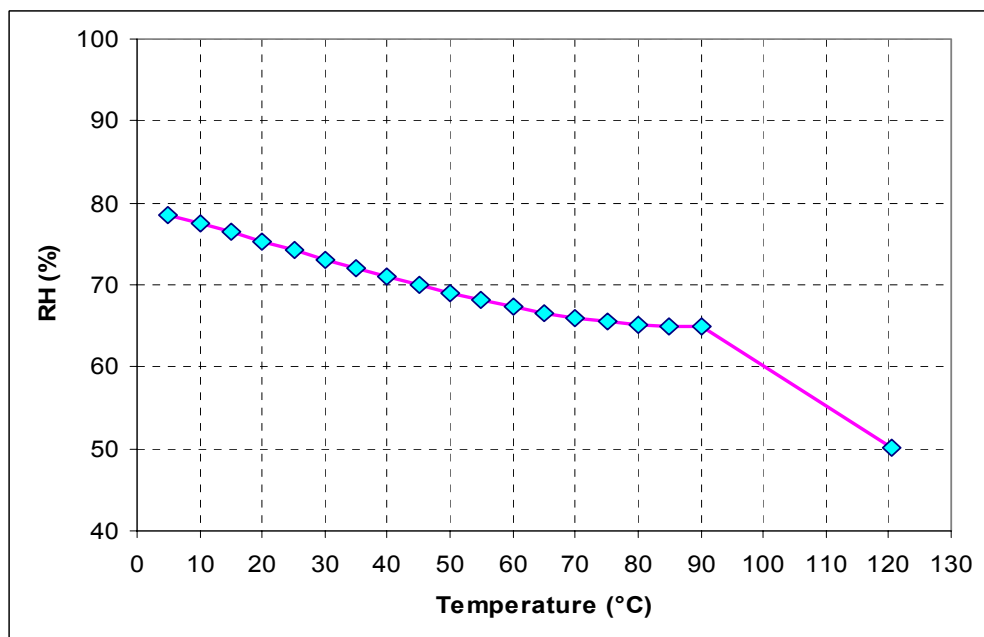
* pH, [Cl⁻] of water contacting WP & DS from EBS chemical environment model abstraction



Nominal-Case WP/DS Degradation Model for TSPA-SR (for DS or a WP layer)

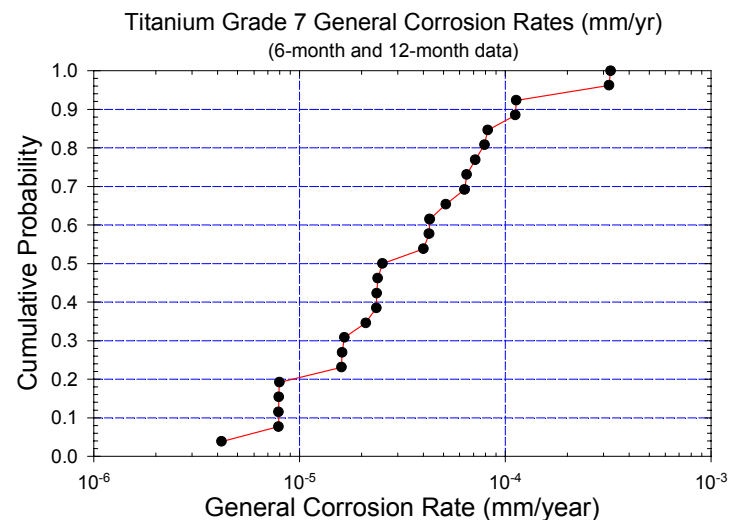
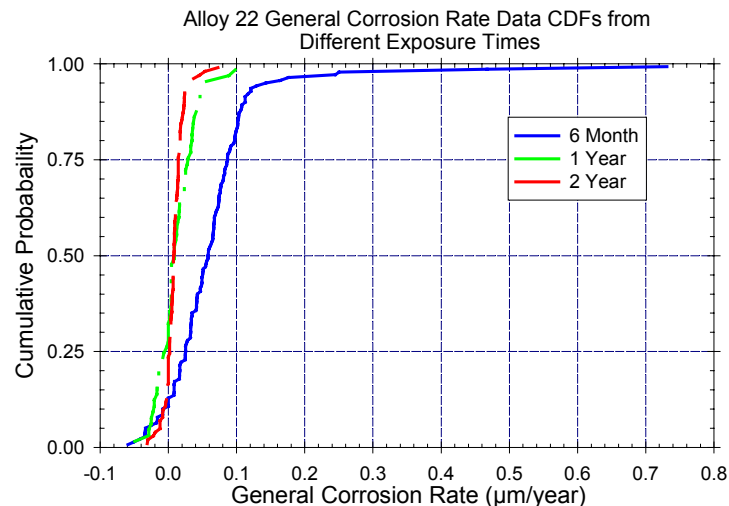


Drip Shield and Waste Package Corrosion Initiation



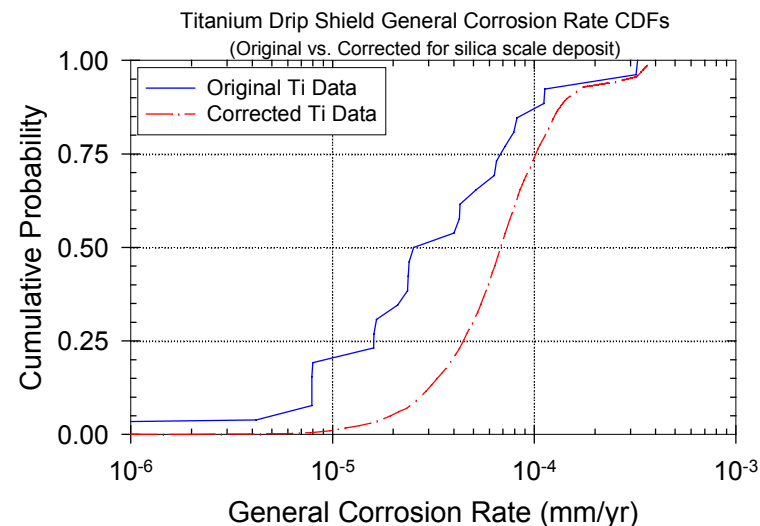
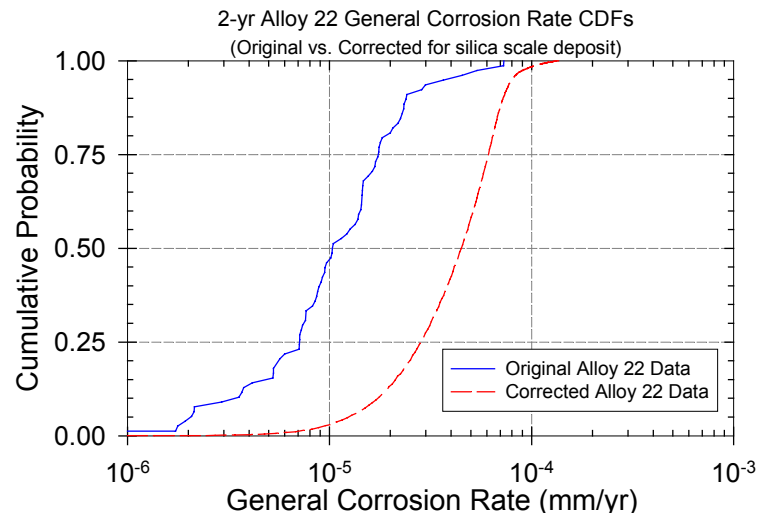
- Threshold relative humidity (RH_{th}) for corrosion initiation is based on the deliquescence point of NaNO₃ salts on surface of drip shield and waste package
- Corrosion initiation occurs several hundred years after closure for 50 yr ventilation design
- Same initiation threshold is used for drip and no-drip conditions

Waste Package and Drip Shield General Corrosion



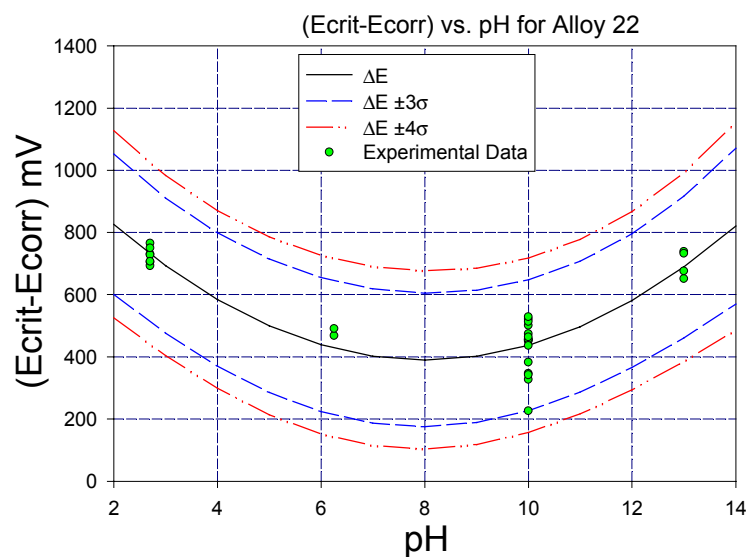
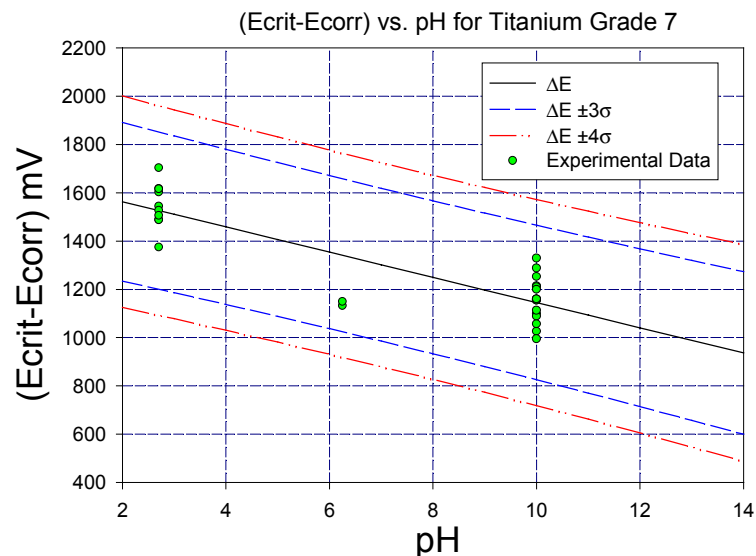
- Alloy 22 general corrosion is based on 2-yr data from Long-Term Corrosion Testing Facility
 - The mean corrosion rate and data variance decrease with exposure time
- Drip shield general corrosion is based on 6-month and 12-month data from Long-Term Corrosion Testing Facility
- Less uncertainty/variability considered than in Viability Assessment (VA)
- Lower mean corrosion rate than used in VA
- Alloy 22 general corrosion rates are increased by 2x for microbiologically influenced corrosion (MIC) effects and an additional 2.5x for aging effects

Alternative Conservative Model for Waste Package and Drip Shield General Corrosion



- **Modify general corrosion rate distribution by adding weight-loss measurement bias caused by potential for silica scale deposit (up to 6.3×10^{-5} mm/yr)**
- **Increases minimum corrosion rate**
- **While the MIC factor (2x) is applied to the entire WP surface, the aging factor (2.5x) is applied to the closure-weld area**
- **NRC model has range from 6×10^{-4} to 2×10^{-3} mm/yr for Alloy 22 based on passive current density data from cyclic polarization tests**

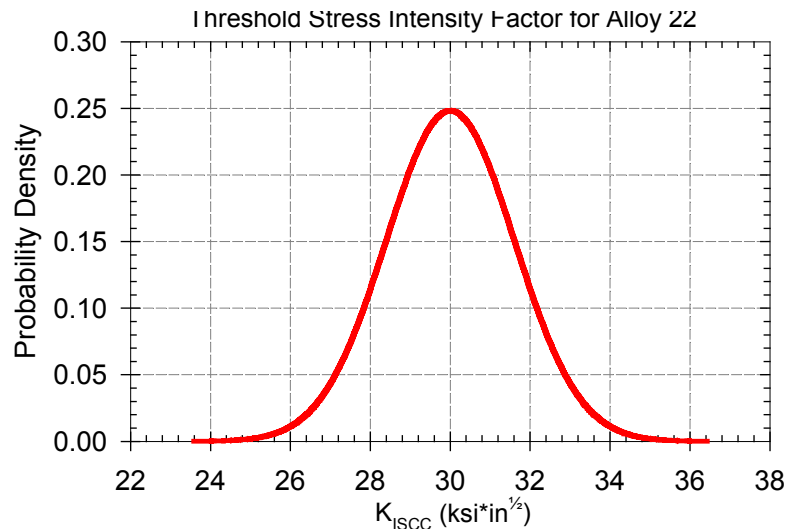
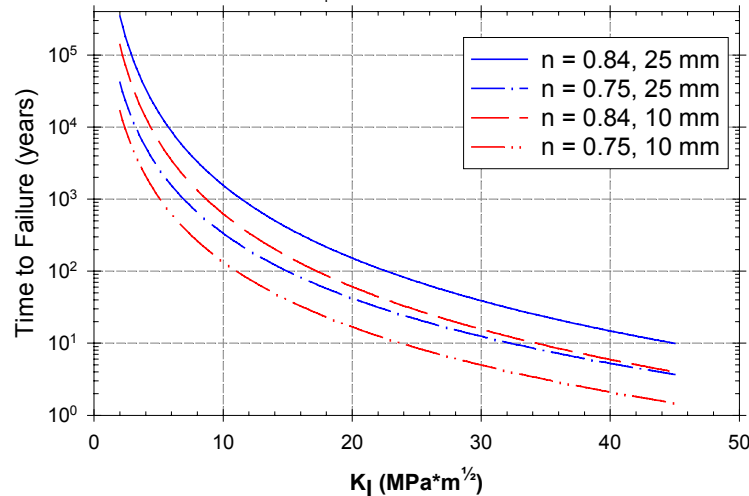
WP and DS Localized (Pitting and Crevice) Corrosion



- **Localized corrosion threshold based on corrosion potential data (cyclic polarization data)**
- **If critical corrosion potential (E_{crit}) \geq corrosion potential (E_{corr}), then localized corrosion initiates**
- **Radiation effects considered (max shift of E_{corr} and E_{crit} by 200 mV), but are insignificant**
- **No localized corrosion is expected under repository conditions**

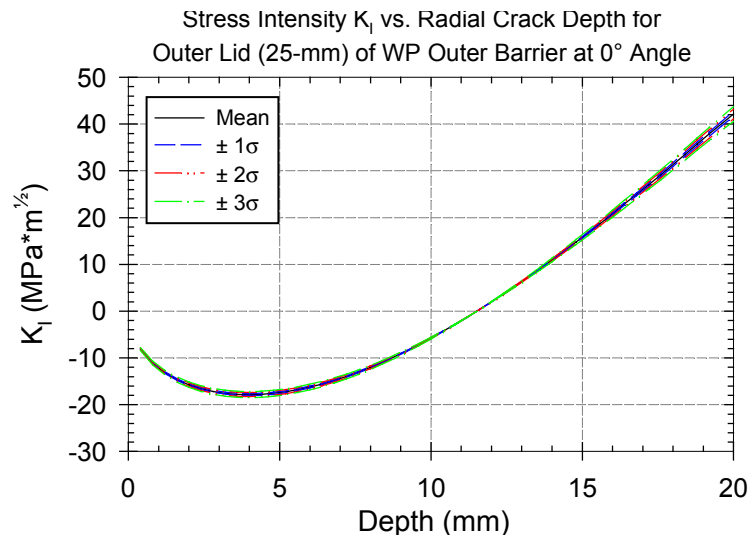
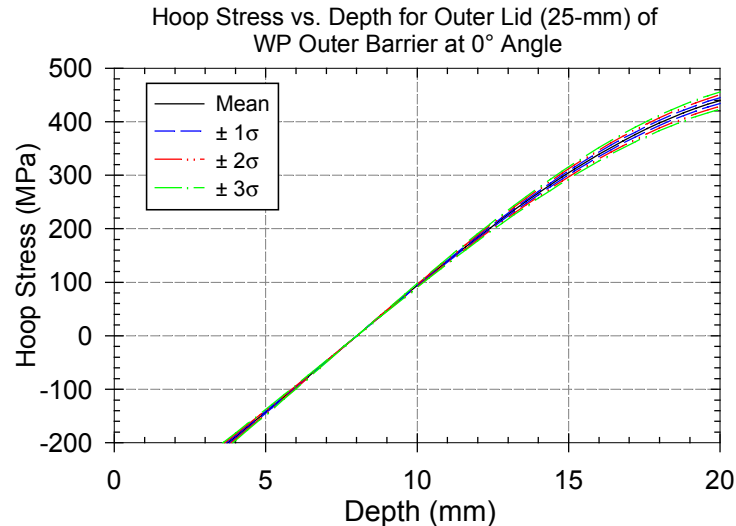
Stress Corrosion Cracking (SCC) - Slip Dissolution Model & K_{ISCC} Model

Bounding Calculations for Time to Failure by Slip Dissolution Model
($v = A * K_I^{4n}$; $A = 7.8E-2 * n^{3.6} (4.1E-14)^n$)



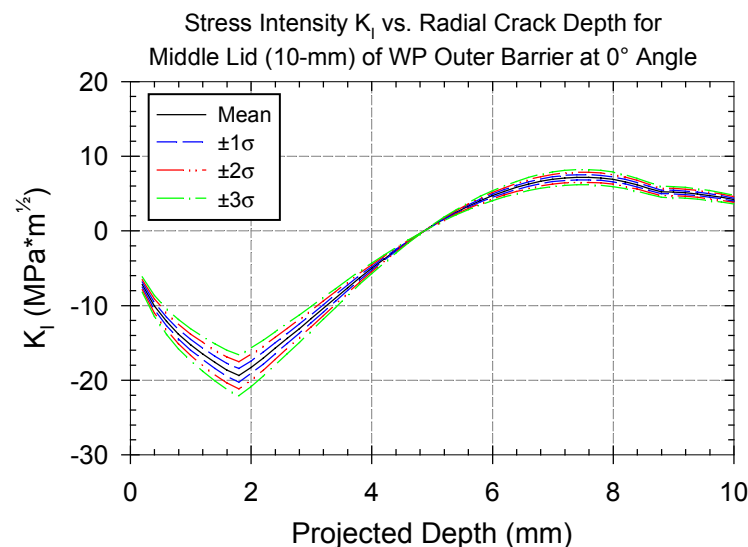
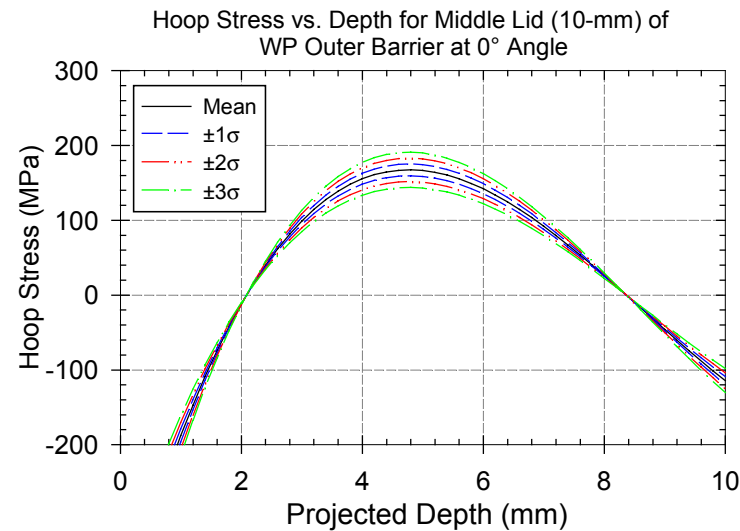
- **Slip dissolution model:**
 - Slip dissolution model is applied to preexisting “incipient” cracks and manufacturing defects
 - In each time step following crack initiation, calculates crack growth rate (v) and incremental crack growth ($\Delta a = v \times \Delta t$) for each of growing SCC cracks
- **K_{ISCC} model:**
 - Applied to pre-existing manufacturing defects in closure-lid welds
 - If K_I of a defect $\geq K_{ISCC}$, assume the patch fails immediately by SCC
- Slip dissolution model is used in WAPDEG SCC analysis

Stress Corrosion Cracking – Solution Annealing of Outer Closure Lid



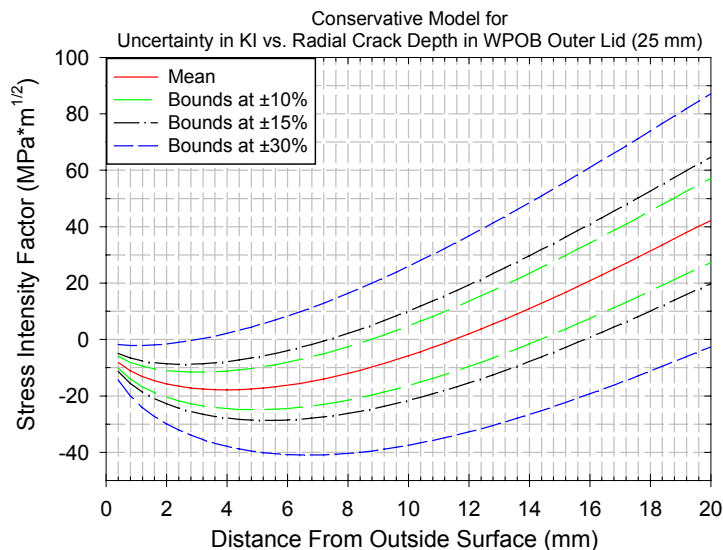
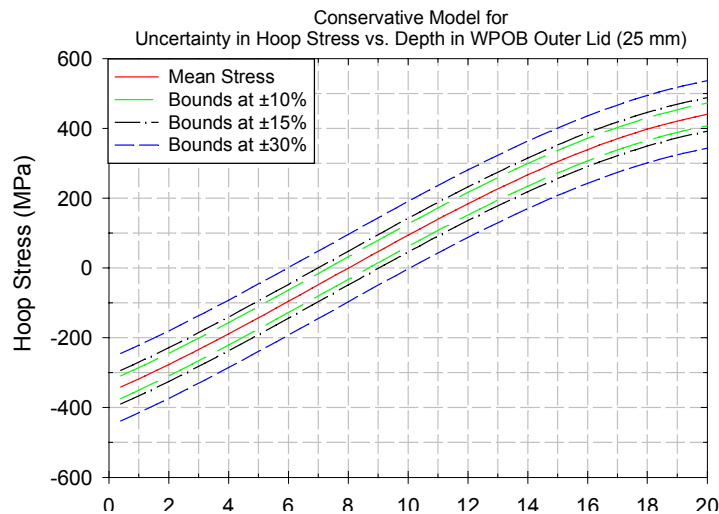
- Hoop stress is the dominant stress driving radial SCC cracks in outer closure-lid weld
- Assume normal distribution bounded at 3 standard deviations for the uncertainty range
- Stress must exceed threshold stress for crack to initiate
 - Assume uniform distribution between 20 and 30% of yield strength
- Stress intensity factor (K_I) must be positive for crack to propagate
- Weld must be corroded to ~12 mm before SCC cracks propagate

Stress Corrosion Cracking – Laser Peening of Inner Closure Lid



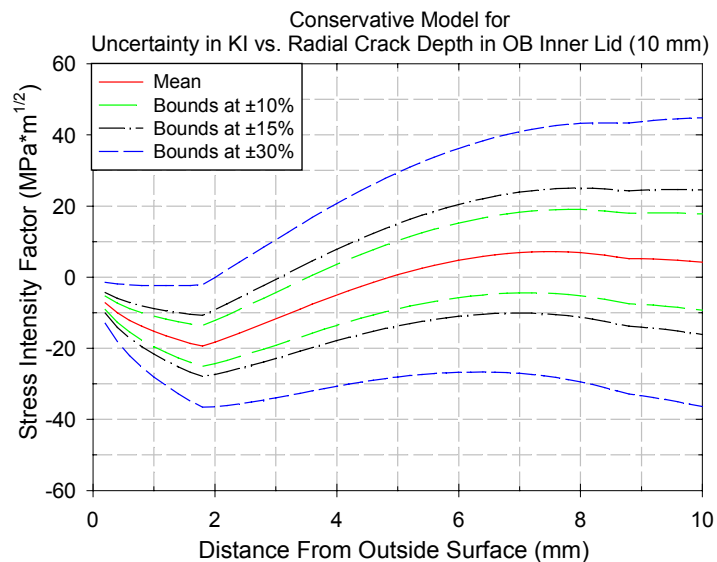
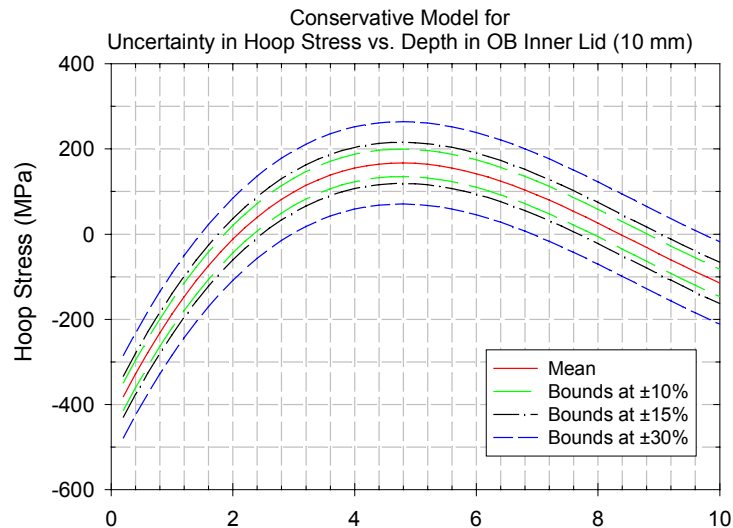
- Hoop stress is the dominant stress driving radial SCC cracks in inner closure-lid weld
- Assume normal distribution bounded at 3 standard deviations for the uncertainty range
- Stress must exceed threshold stress for crack to initiate
 - Assume uniform distribution between 20 and 30% of yield strength
- Stress intensity factor (K_I) must be positive for crack to propagate
- Weld must be corroded to ~5 mm before stress cracks propagate

Alternative Conservative Model for Stress and Stress Intensity Factor Uncertainty in Outer Closure-Lid Weld



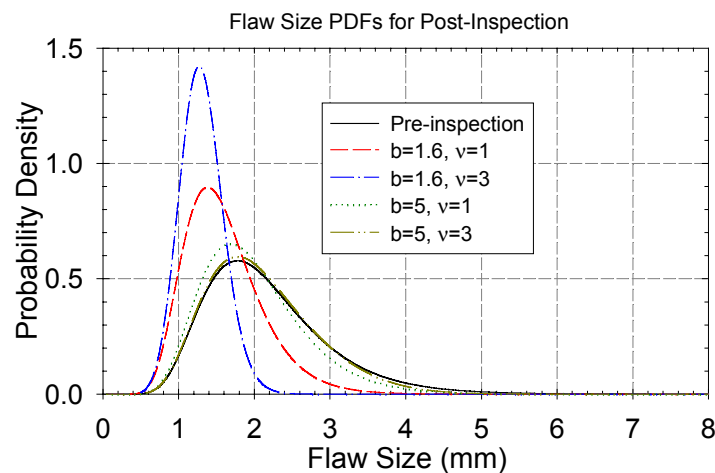
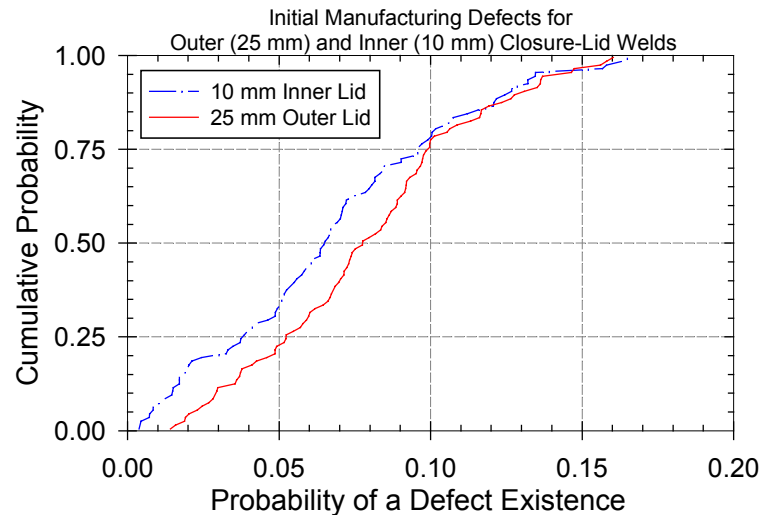
- **Modify stress and stress intensity factor uncertainty distributions to include wider ranges based on present uncertainty**
 - Ultimately expect design process to reduce this uncertainty
- **Assume triangular distribution between the bounds and with the mode at the mean**
- **Conservative because as weld stress can be controlled in design process**
- **Decreases minimum thickness of compressive zone to ~7 mm with $\pm 15\%$ uncertainty bounds**

Alternative Conservative Model for Stress and Stress Intensity Factor Uncertainty in Inner Closure-Lid Weld



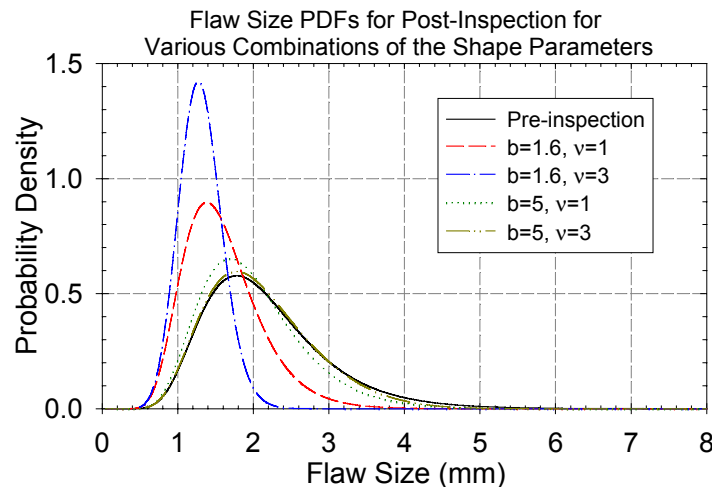
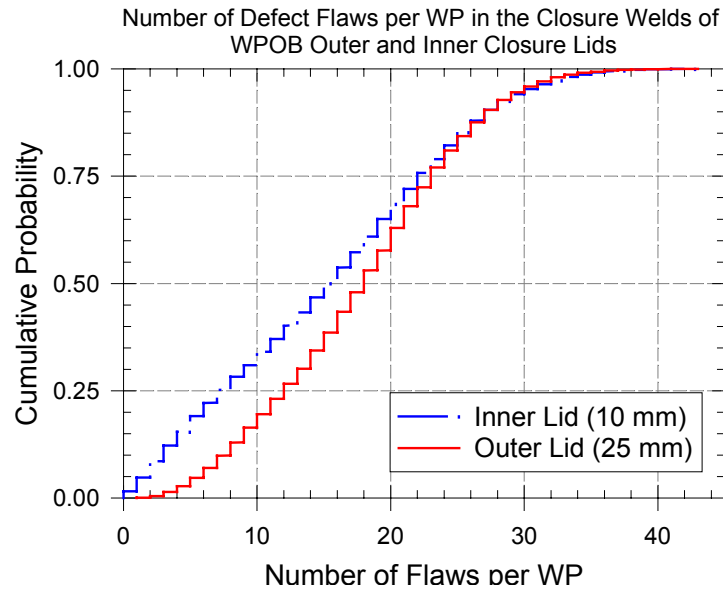
- **Modify stress and stress intensity factor uncertainty distributions to include wider ranges based on present uncertainty**
 - Ultimately expect design process to reduce this uncertainty
- **Assume triangular distribution between the bounds and with the mode at the mean**
- **Conservative because as weld stress can be controlled in design process**
- **Decreases minimum thickness of compressive zone to ~3 mm with $\pm 15\%$ uncertainty bounds**

Initial Manufacturing Defects in WP Closure Welds



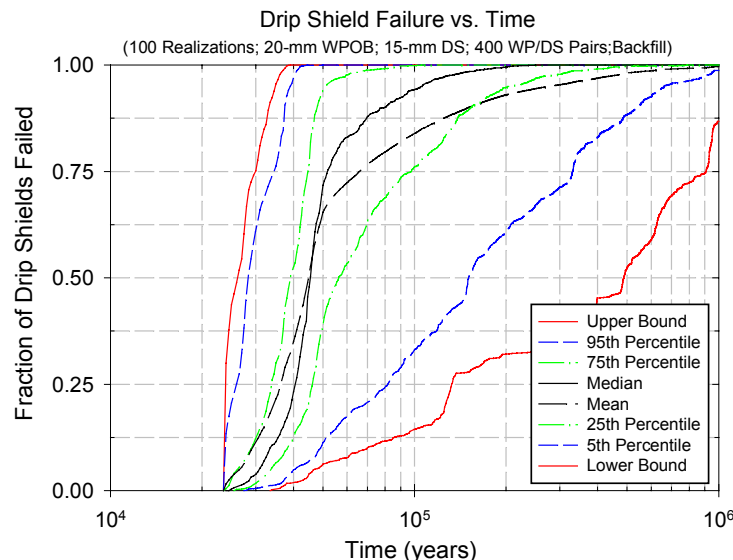
- **Defects in closure-lid welds are considered in SCC analysis**
- **Consider surface breaking defects only**
- **Flaw detection is uncertain and a function of flaw size**
- **Probability of undetected flaws is included in analysis**
- **No flaws of sufficient size to extend through the 25 mm outer lid weld or the 10 mm inner lid weld**

Alternative Conservative Model for Initial Manufacturing Defects in Waste Package Closure Weld

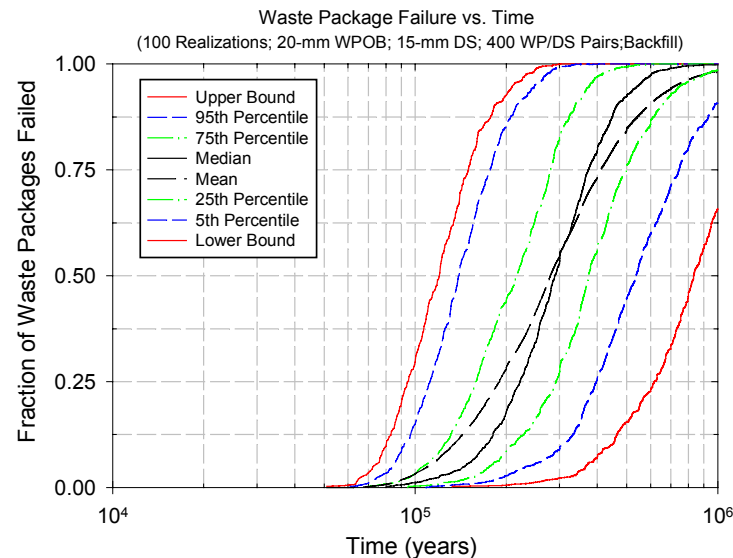


- **Modify defect distribution and size based on surface breaking and embedded defects**
 - Consider embedded defects in the outer quarter region from the literature
- **Conservative because most embedded defects are oriented such that would not lead to radial cracks**
- **Increases likelihood of defects by ~100 x**

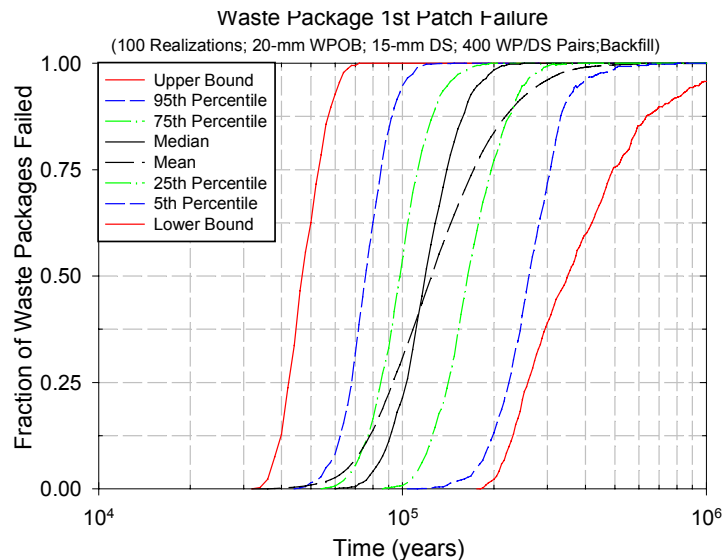
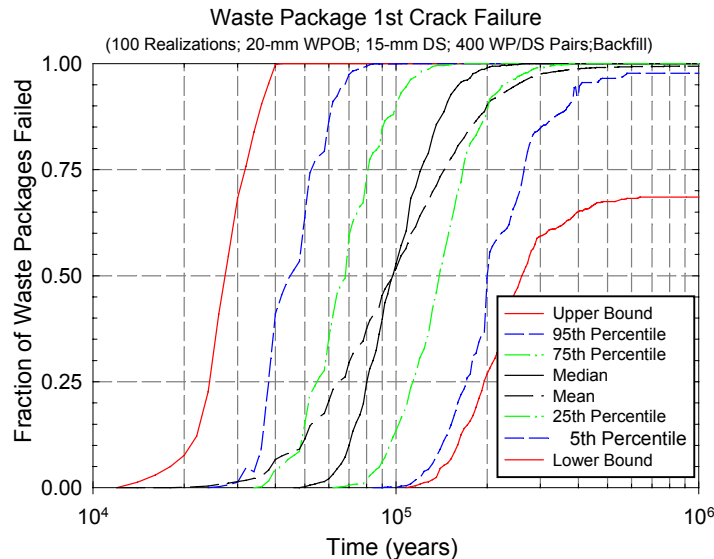
Waste Package Degradation Model Results



- **Drip shield degradation is uncertain and variable**
 - Initial breach of drip shield ranges from ~24 k years to ~34 k years
- **Waste package degradation is uncertain and variable**
 - Initial breach of waste package ranges from ~50 k years to ~130 k years



Effect of Alternative Conservative Models on Waste Package Degradation Results



- **Low probability of initial through-wall SCC cracks prior to 20,000 years (which reduces time to initial release of activity and therefore dose)**
- **Median time to ~ 10% “failure” reduced to ~ 70,000 years**
- **Overall spread of “failures” is reduced (which tends to increase peak dose consequence)**

Summary

- **All key degradation processes expected in the repository have been integrated into the WAPDEG model for TSPA-SR waste package and drip shield degradation analysis**
 - General corrosion
 - Localized corrosion
 - Stress corrosion cracking (applied to waste package closure-lid welds)
 - Manufacturing defects (waste package closure-lid welds)
 - Microbiologically influenced corrosion (Alloy 22 outer barrier)
 - Aging and phase instability (Alloy 22 outer barrier)
- **Alternative conceptual models and model abstractions are included to capture the effects of differing levels of model uncertainty**
- **Waste packages fail initially by SCC in closure-lid welds, then general corrosion**
- **Waste package and drip shield degradation is uncertain and variable**

