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

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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

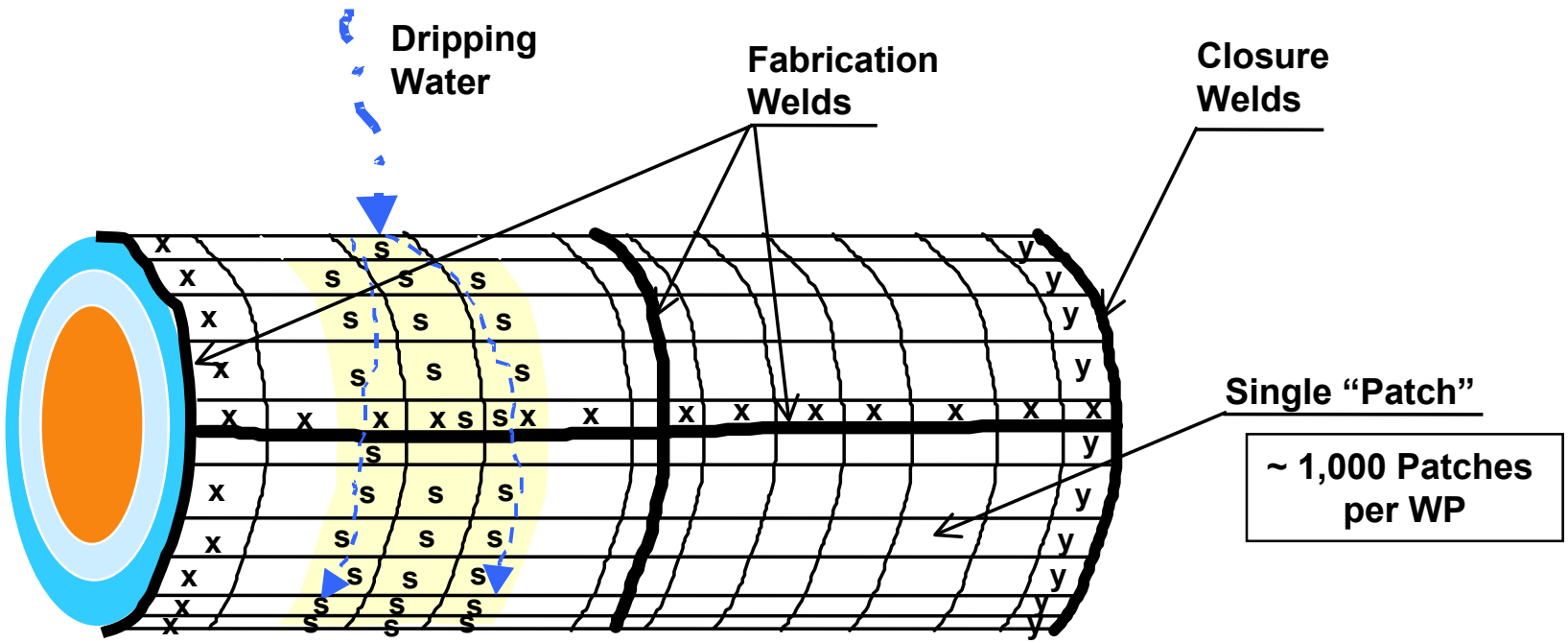
Key Technical Issues

- 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

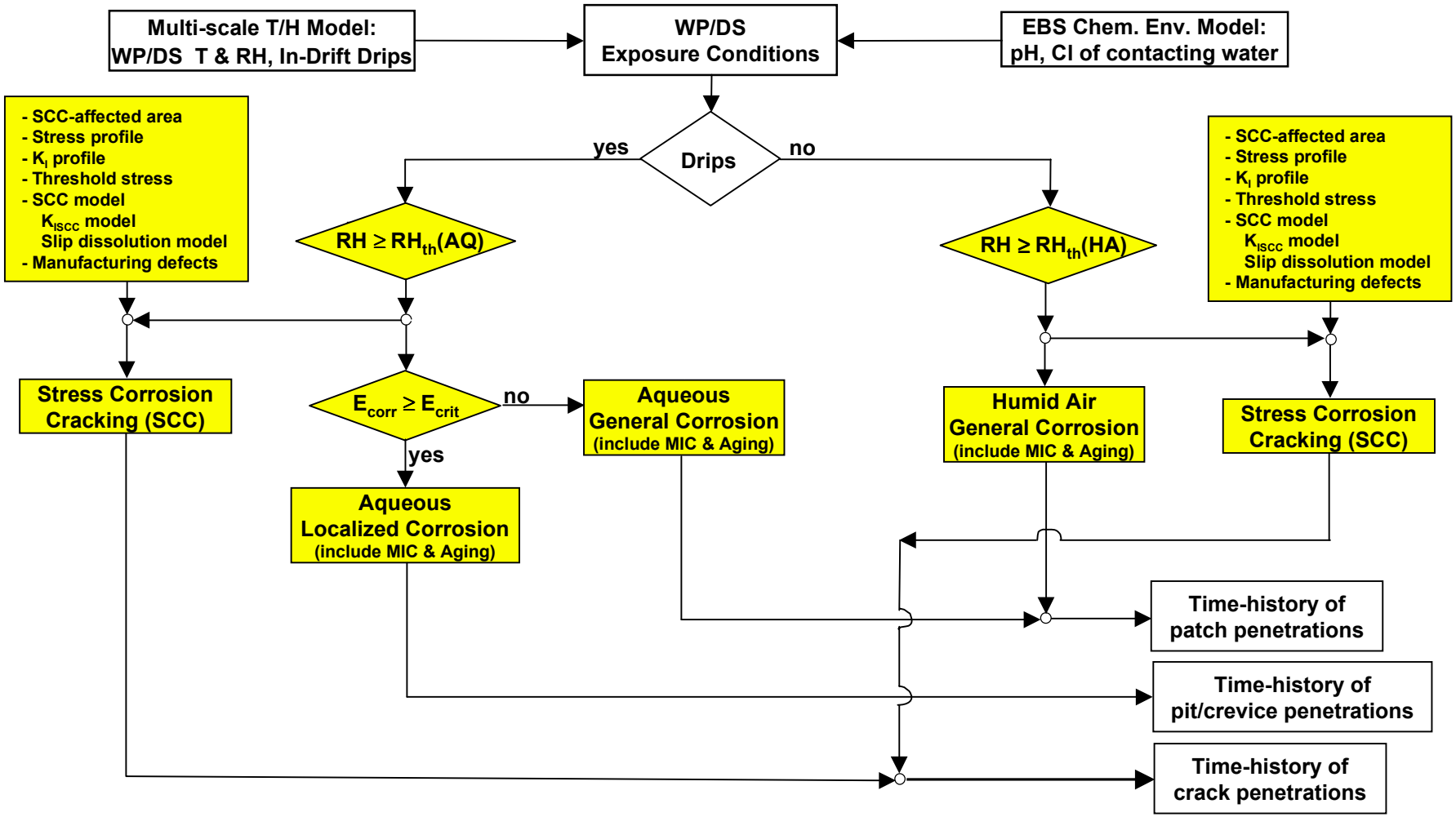


s - Patches with drips; Potential salt deposits; potential localized corrosion

x - Patches with fabrication welds

y - Patches with closure welds; potential SCC

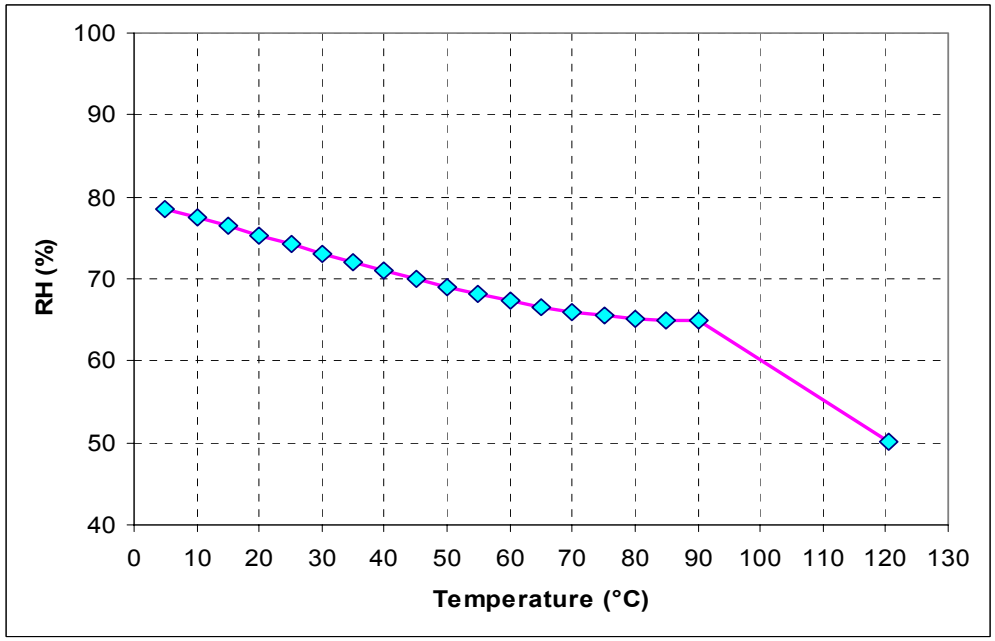
Nominal-Case WP/DS Degradation Model for TSPA-SR (for DS or a WP layer)



E_{corr} = corrosion potential
E_{crit} = critical corrosion potential
K_I = stress intensity factor
K_{ISCC} = threshold stress intensity factor

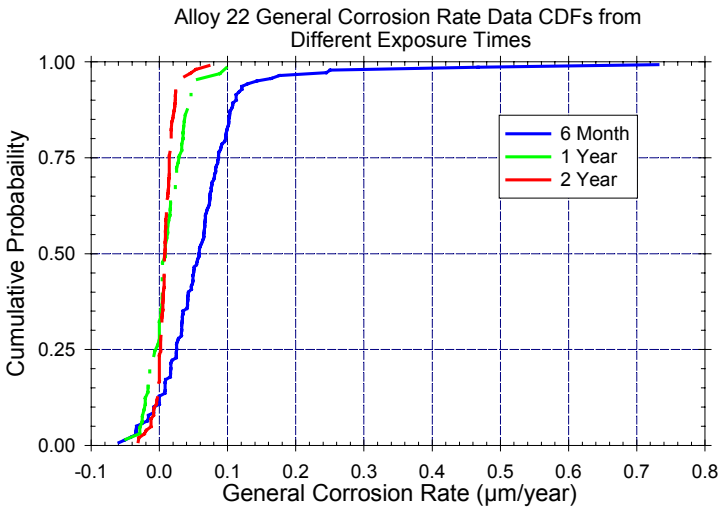
RH_{th} = threshold relative humidity
AQ = aqueous
HA = humid air
MIC = microbiologically influenced corrosion

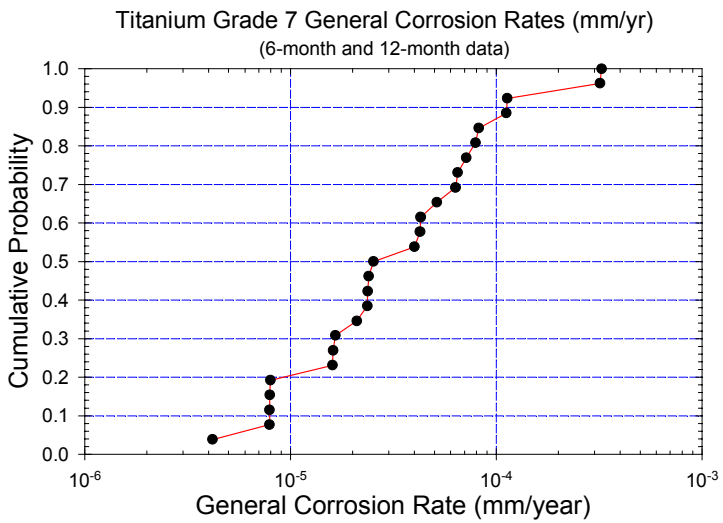
Drip Shield and Waste Package Corrosion Initiation



- **Threshold relative humidity (RH_{th}) for corrosion initiation is based on the deliquescence point of $NaNO_3$ 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**

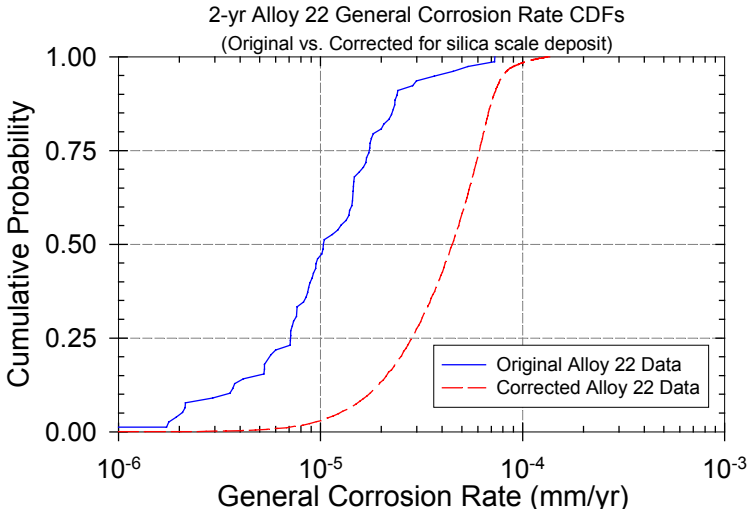
Waste Package and Drip Shield General Corrosion

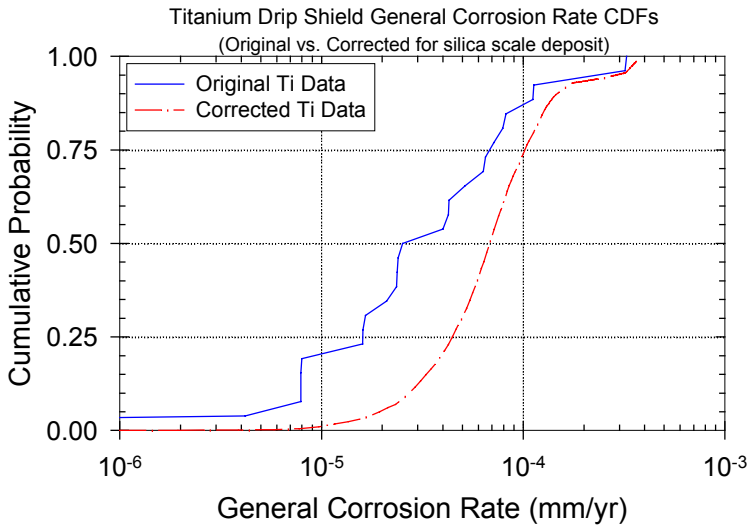




- **Alloy 22 general corrosion is based on 2-yr data from Long-Term Corrosion Testing Facility**
  - **The mean corrosion rate and data variance decrease with exposure time**
- **Drip shield general corrosion is based on 6-month and 12-month data from Long-Term Corrosion Testing Facility**
- **Less uncertainty/variability 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**

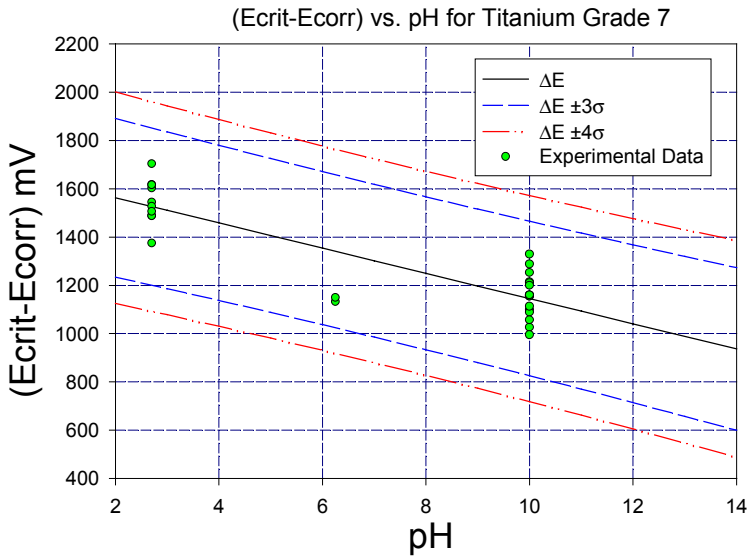
Alternative Conservative Model for Waste Package and Drip Shield General Corrosion

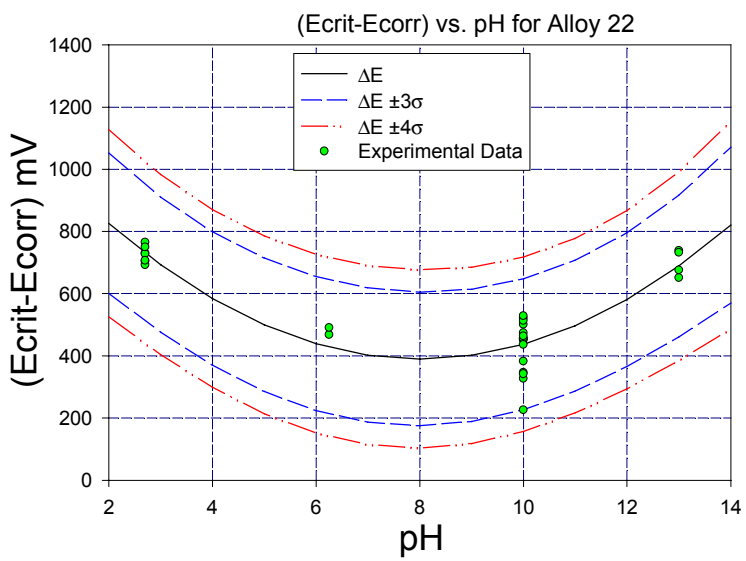




- **Modify general corrosion rate distribution by adding weight-loss measurement bias caused by potential for silica scale deposit (up to 6.3 x 10^{-5} mm/yr)**
- **Increases minimum corrosion rate**
- **While the MIC factor (2x) is applied to the entire WP surface, the aging factor (2.5x) is applied to the closure-weld area**
- **NRC model has range from 6x10^{-4} to 2x10^{-3} mm/yr for Alloy 22 based on passive current density data from cyclic polarization tests**

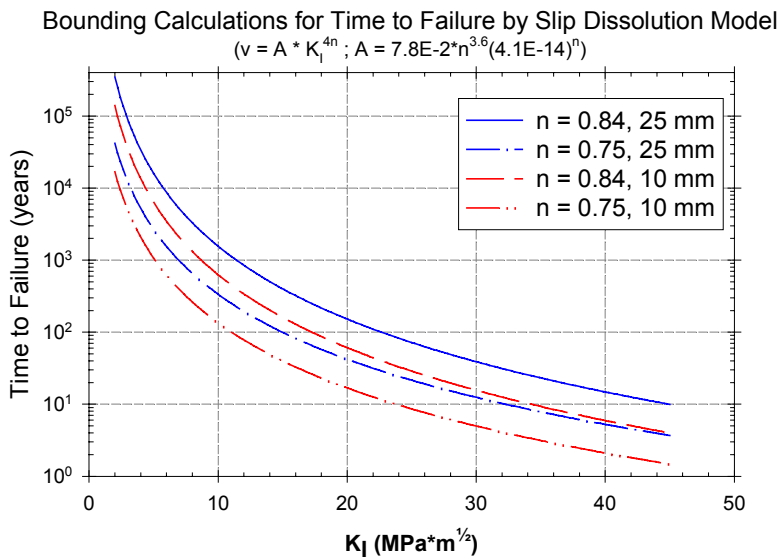
WP and DS Localized (Pitting and Crevice) Corrosion

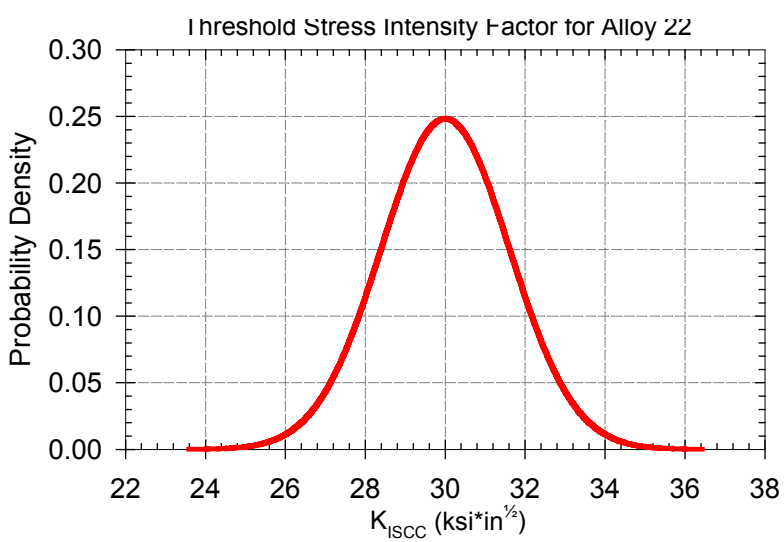




- **Localized corrosion threshold based on corrosion potential data (cyclic polarization data)**
- **If critical corrosion potential (E_{crit}) ≥ corrosion potential (E_{corr}), then localized corrosion initiates**
- **Radiation effects considered (max shift of E_{corr} and E_{crit} by 200 mV), but are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

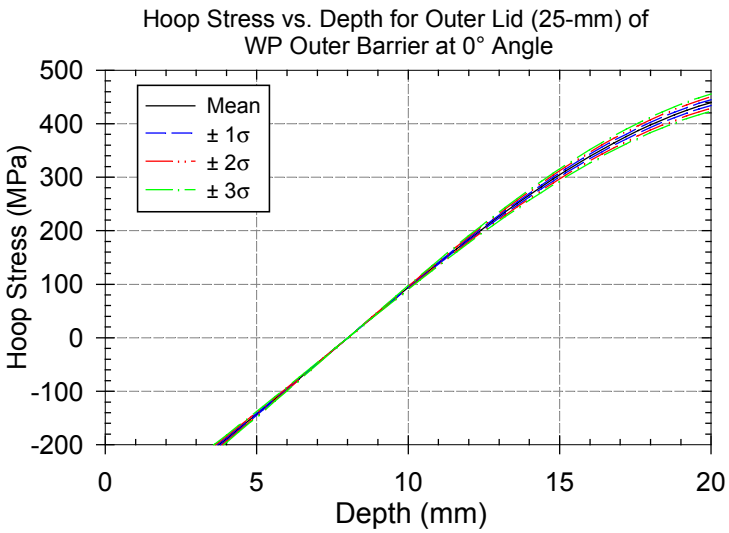
Stress Corrosion Cracking (SCC) - Slip Dissolution Model & K_{ISCC} Model

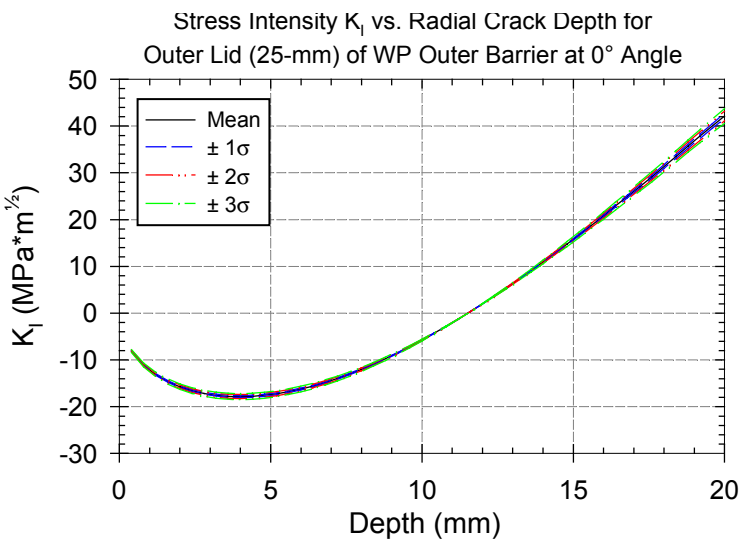




- **Slip dissolution model:**
  - **Slip dissolution model is applied to preexisting "incipient" cracks and manufacturing defects**
  - **In each time step following crack initiation, calculates crack growth rate (*v*) and incremental crack growth ($\Delta a = v \times \Delta t$) for each of growing 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**

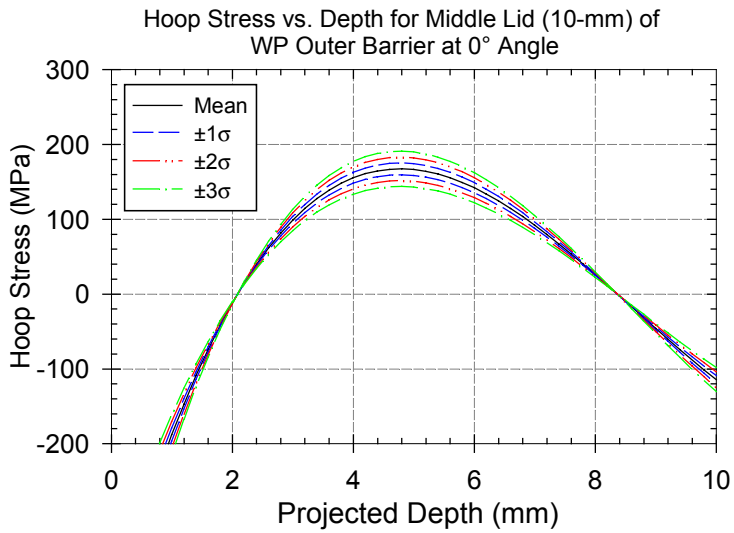
Stress Corrosion Cracking – Solution Annealing of Outer Closure Lid

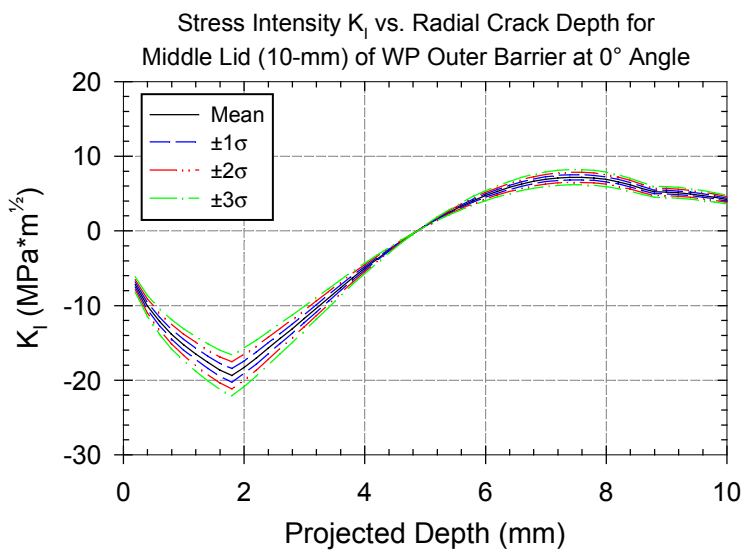




- **Hoop stress is the dominant stress driving radial SCC cracks in outer closure-lid weld**
- **Assume normal distribution bounded at 3 standard deviations for the uncertainty range**
- **Stress must exceed threshold stress for crack to initiate**
  - **Assume uniform distribution between 20 and 30% 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**

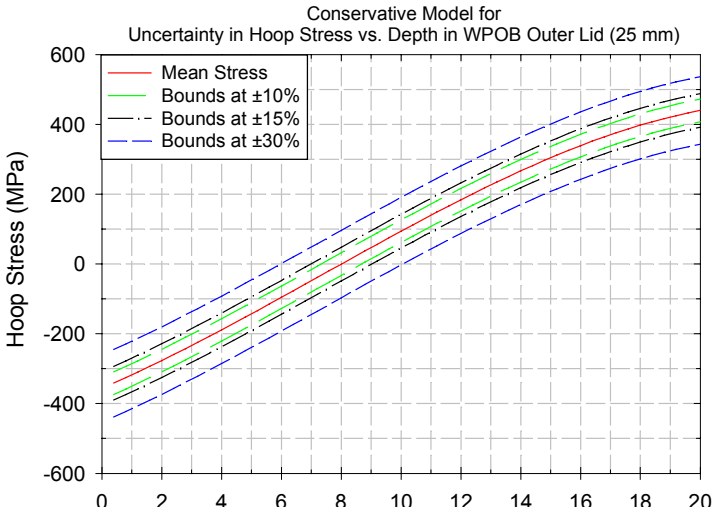
Stress Corrosion Cracking – Laser Peening of Inner Closure Lid

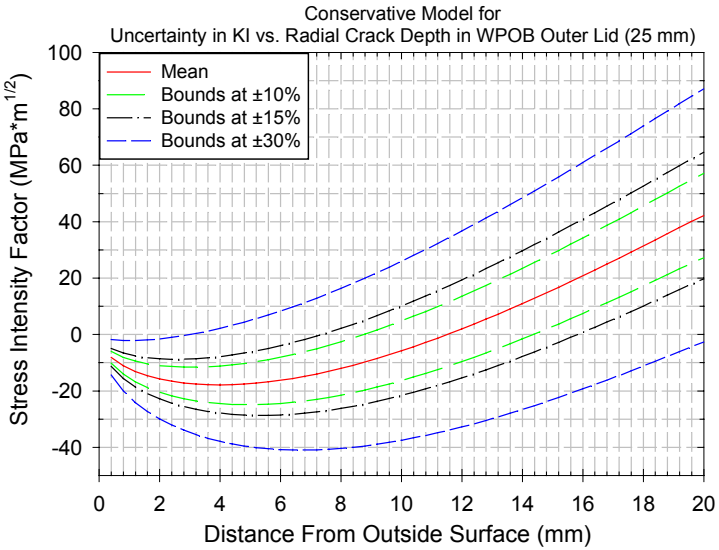




- **Hoop stress is the dominant stress driving radial SCC cracks in inner closure-lid weld**
- **Assume normal distribution bounded at 3 standard deviations for the uncertainty range**
- **Stress must exceed threshold stress for crack to initiate**
  - **Assume uniform distribution between 20 and 30% 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**

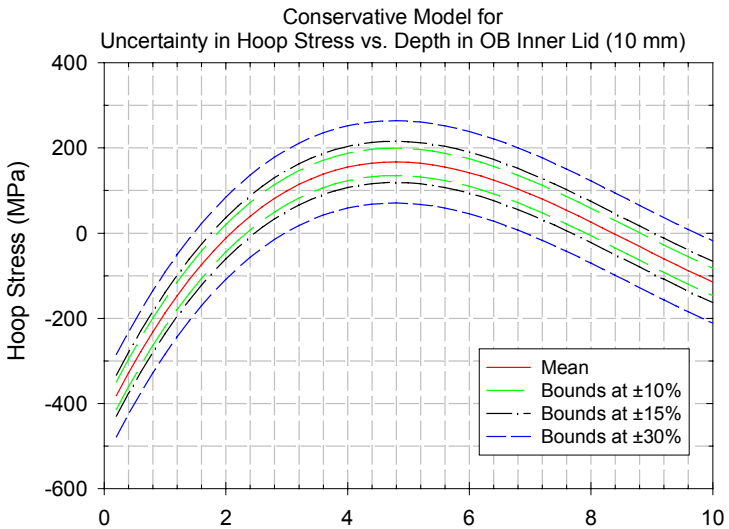
Alternative Conservative Model for Stress and Stress Intensity Factor Uncertainty in Outer Closure-Lid Weld

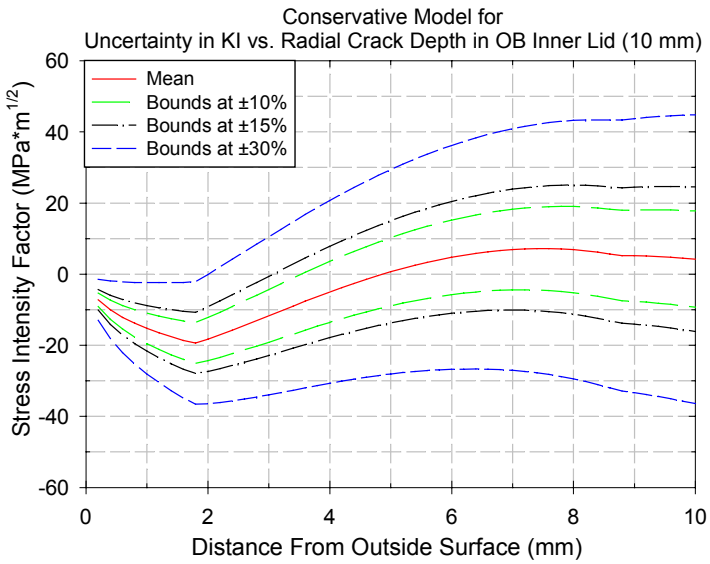




- **Modify stress and stress intensity factor uncertainty distributions to include wider ranges based on present uncertainty**
  - **Ultimately expect design process to reduce this uncertainty**
- **Assume triangular distribution between the bounds and with the mode at the mean**
- **Conservative because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

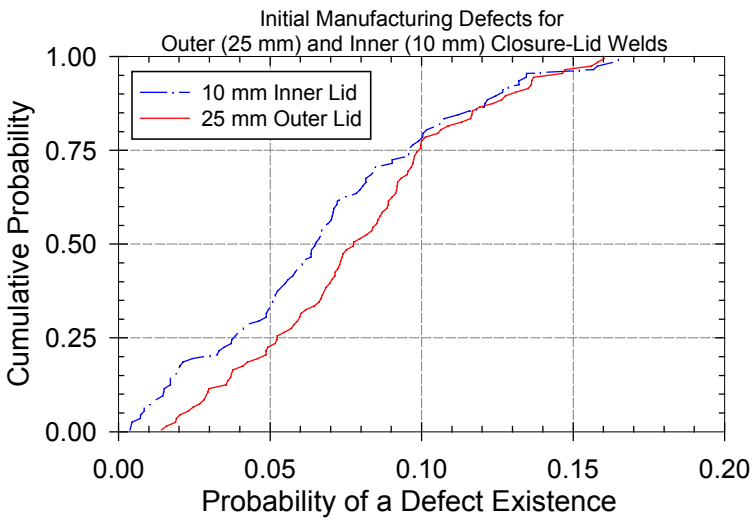
Alternative Conservative Model for Stress and Stress Intensity Factor Uncertainty in Inner Closure-Lid Weld

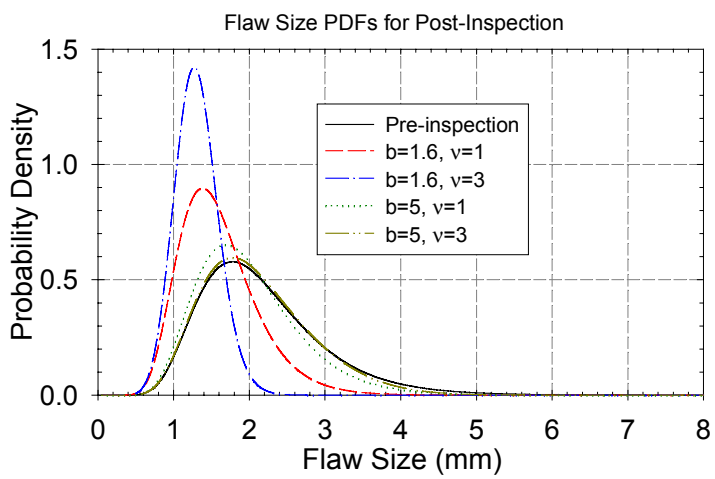




- **Modify stress and stress intensity factor uncertainty distributions to include wider ranges based on present uncertainty**
  - **Ultimately expect design process to reduce this uncertainty**
- **Assume triangular distribution between the bounds and with the mode at the mean**
- **Conservative because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

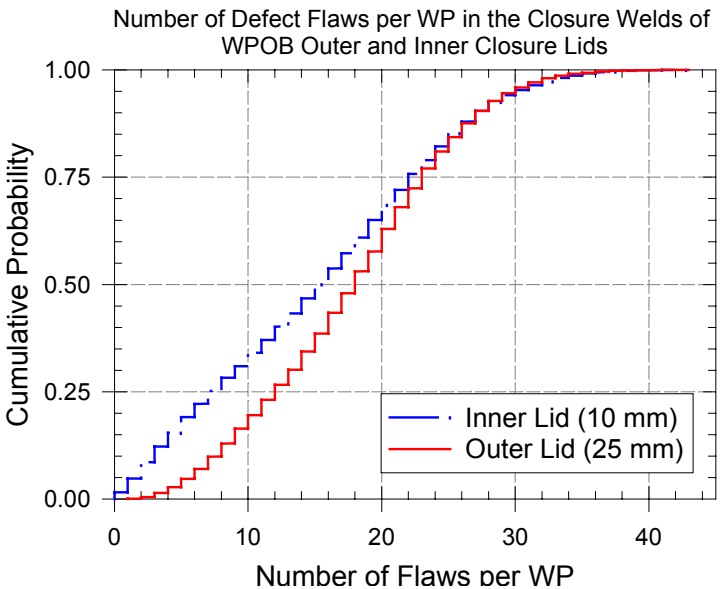
Initial Manufacturing Defects in WP Closure Welds

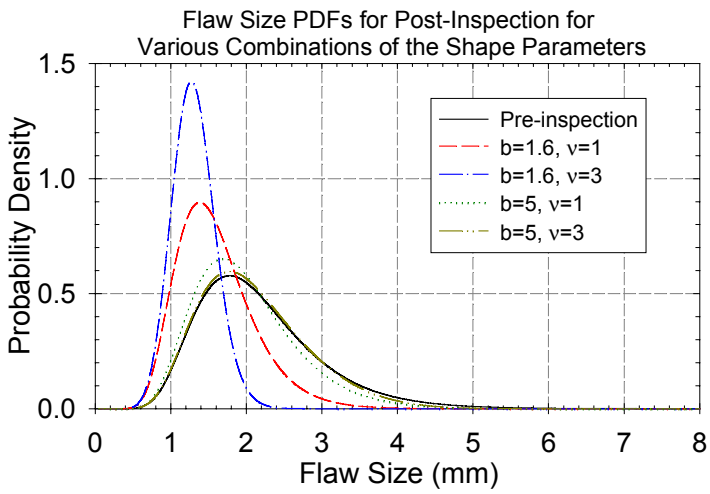




- **Defects in closure-lid welds are considered in SCC analysis**
- **Consider surface breaking defects only**
- **Flaw detection is uncertain and a function of flaw size**
- **Probability of undetected flaws is included in analysis**
- **No flaws of sufficient size to extend through the 25 mm outer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

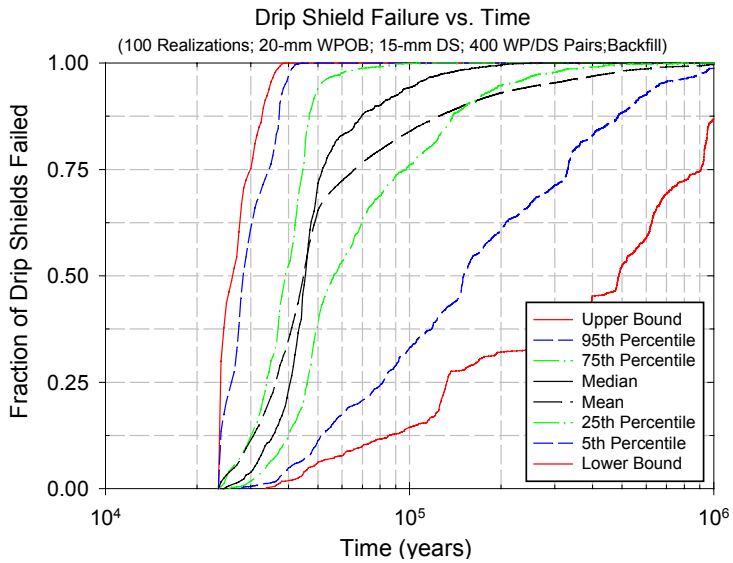
Alternative Conservative Model for Initial Manufacturing Defects in Waste Package Closure Weld

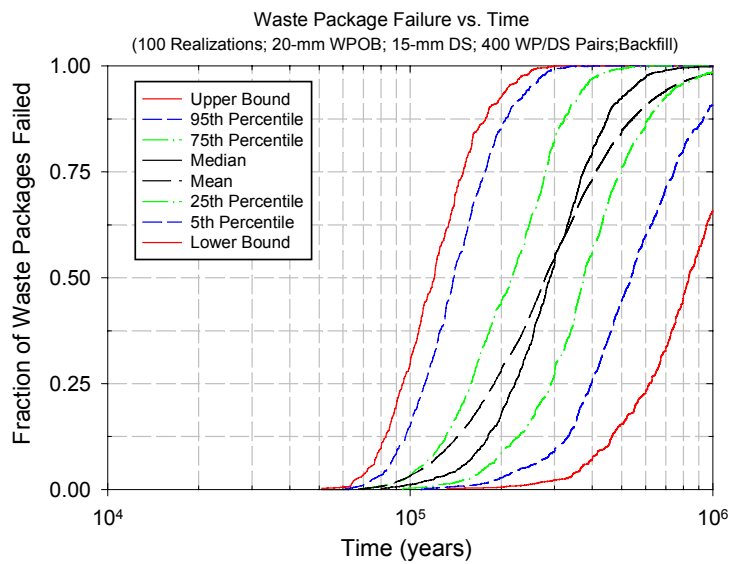




- **Modify defect distribution and size based on surface breaking and embedded defects**
  - **Consider embedded defects in the outer quarter region from the literature**
- **Conservative because most embedded defects are oriented such that would not lead to radial cracks**
- **Increases likelihood of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

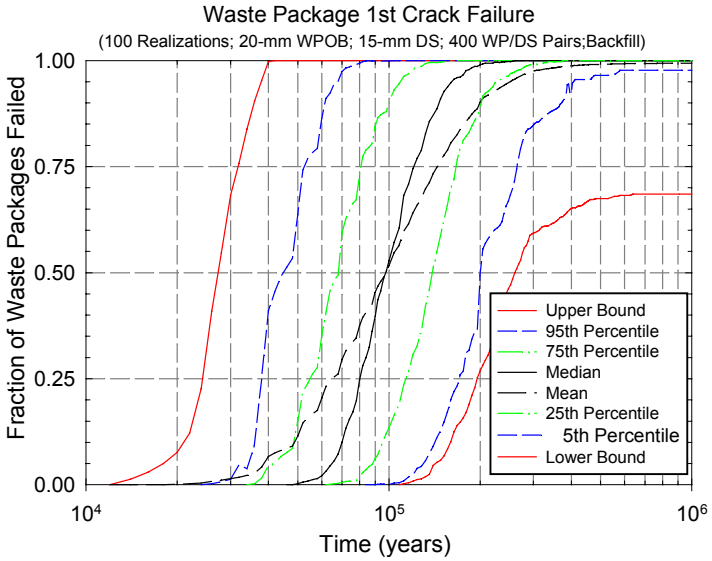
Waste Package Degradation Model Results

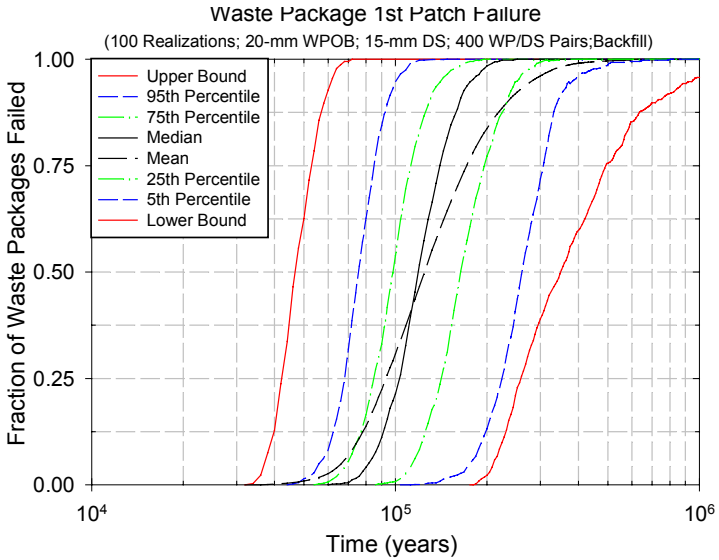




- **Drip shield degradation is uncertain and variable**
  - **Initial breach of drip shield ranges from ~24 k years to ~34 k years**
- **Waste package degradation is uncertain and variable**
  - **Initial breach of waste package ranges from ~50 k years to ~130 k years**

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