



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

Effects of Quantified Uncertainties of Corrosion Models on Waste Package Performance

Presented to:
Nuclear Waste Technical Review Board

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**YUCCA
MOUNTAIN
PROJECT**

Outline

- **Stress corrosion cracking**
- **Early waste package failure**
- **Effects of quantified uncertainties on waste package performance**
 - **Total System Performance Assessment-Site Recommendation (TSPA-SR) waste package model results**
 - **Stress corrosion cracking**
 - **Alloy 22 general corrosion**
- **Waste package degradation model for Supplemental Science Performance Analyses (SSPA) TSPA**
- **Summary and conclusions**

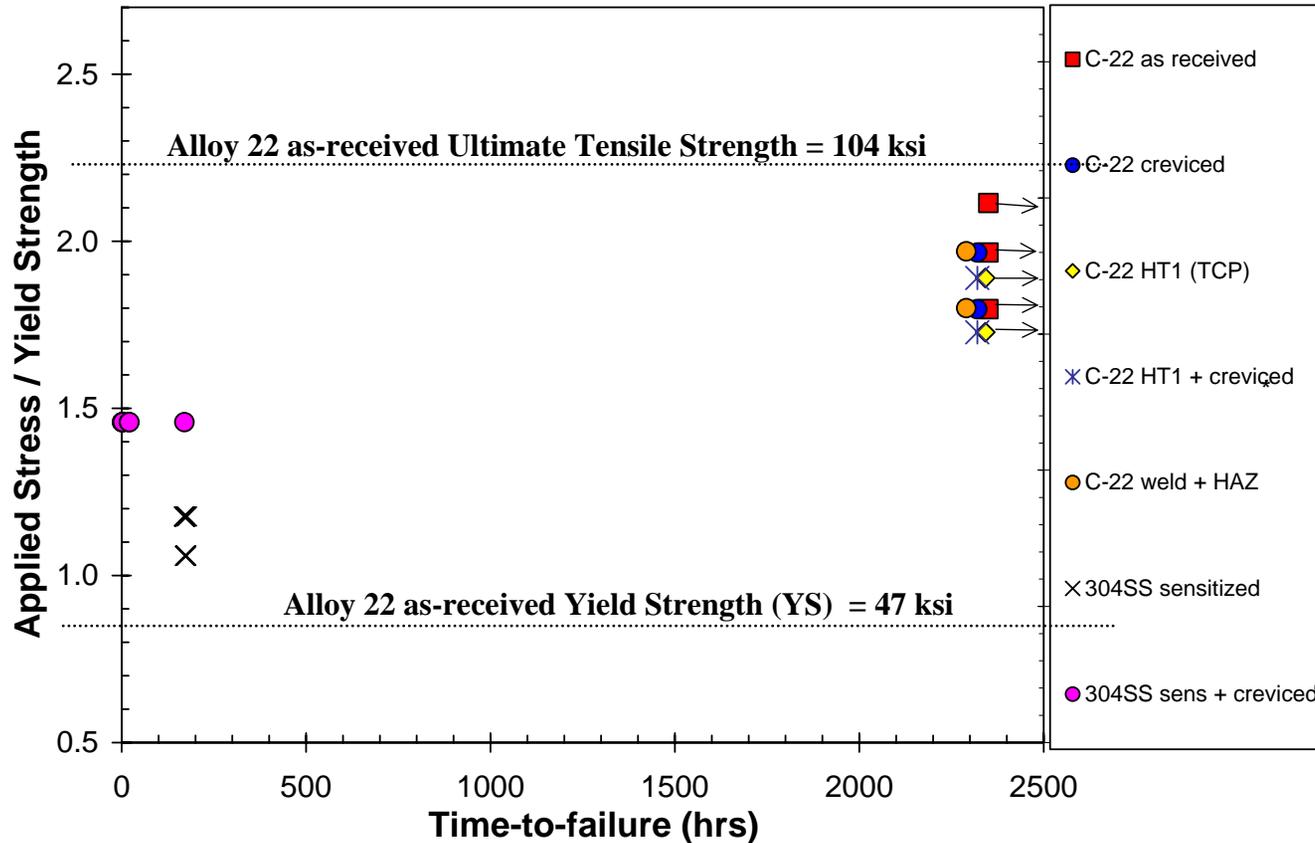
Stress Corrosion Cracking (SCC) Model Parameters in TSPA-SR

- **Waste package stress corrosion cracking applied to the outer barrier closure-lid weld regions**
 - **All pre-existing manufacturing flaws in the closure-lid weld can grow in radial direction in the presence of hoop stress**
 - **All pre-existing manufacturing flaws are surface-breaking and grow at the general corrosion rate of the patch until SCC initiates (highly conservative)**
 - **Residual stress uncertainty bounds at ± 30 percent of yield strength in the closure-lid weld region**
 - **Stress threshold for crack growth initiation is set to 20 to 30 percent of yield strength**
 - **Slip dissolution model is employed to calculate crack growth rate as a function of stress intensity factor**

Quantification/Update of Uncertainties of SCC Model Parameters in SSPA

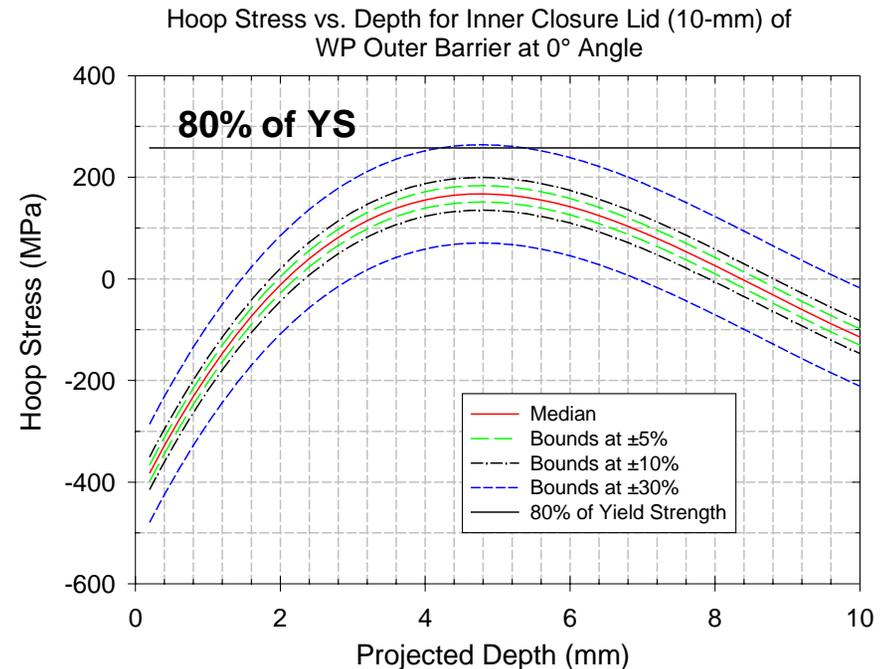
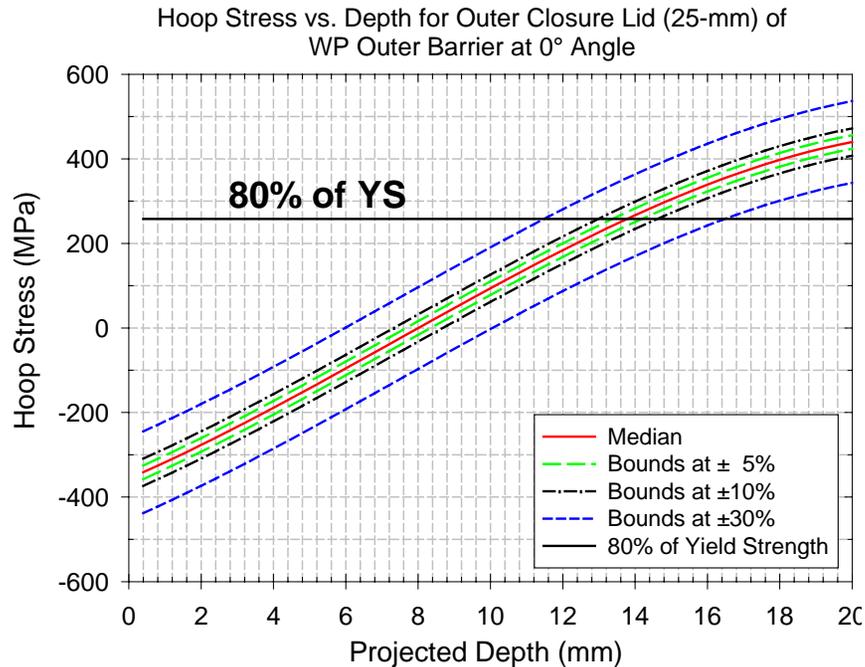
- **Stress threshold for crack growth initiation**
 - Updated to uniform distribution between 80 and 90 percent of the yield strength (322 MPa) (based on recent Alloy 22 and literature data)
- **Residual stress uncertainty bounds in the outer and inner closure-lid weld regions of the outer barrier**
 - Set to ± 21 percent of yield strength (322 MPa) for the outer closure-lid weld region (induction annealing) (based on literature data for appropriate stress mitigation techniques)
 - Sampled from a distribution with a median of ± 15 percent of yield strength and an upper bound of ± 30 percent of yield strength for the inner closure-lid weld region (laser peening) (based on literature data for appropriate stress mitigation techniques)

Alloy 22 Stress Corrosion Cracking Test Results (Constant Load Test Results at 105°C, ~7500X J-13, pH 12.4)



- Alloy 22 SCC initiation threshold stress exceeds 170 percent of yield strength at 2300 hours
- Revised threshold of 80 to 90 percent of yield strength (vs. previous 20 to 30 percent). The revised threshold range is conservatively selected based on these more relevant data plus high resistance of U-bends in boiling $MgCl_2$ and in Long-Term Corrosion Testing Facility (LTCTF) at LLNL

Updated Uncertainties in Stress Threshold and Residual Stress Uncertainty Bounds



- A greater depth of penetration required for SCC crack initiation in the outer closure-lid weld region
- A very small probability of SCC failure of the inner closure-lid weld region
- TSPA-SR used 20 to 30% of yield strength as the stress threshold

Quantification/Update of Uncertainties of SCC Model Parameters in SSPA

(Continued)

- **Repassivation slope (n) in the slip dissolution model**
 - Updated the slope to a range between 0.843 and 0.920 (based on new Alloy 22 data)
- **Orientation of manufacturing flaws**
 - Updated the fraction of the flaws in the closure-lid welds that can grow in radial direction in the presence of hoop stress
 - Lognormal distribution with a median of 0.01 and ± 3 standard deviation bounds at 0.5 and 0.0002 (based on additional literature data and limited mockup measurements)

Early Waste Package Failure Analysis in TSPA-SR

- Extensive literature review identified potential mechanisms for early failure
- All identified mechanisms screened out based on probability of occurrence except weld flaws
- Weld flaw frequency and size used as input to SCC model

Early Waste Package Failure – Improper Heat Treatment in SSPA

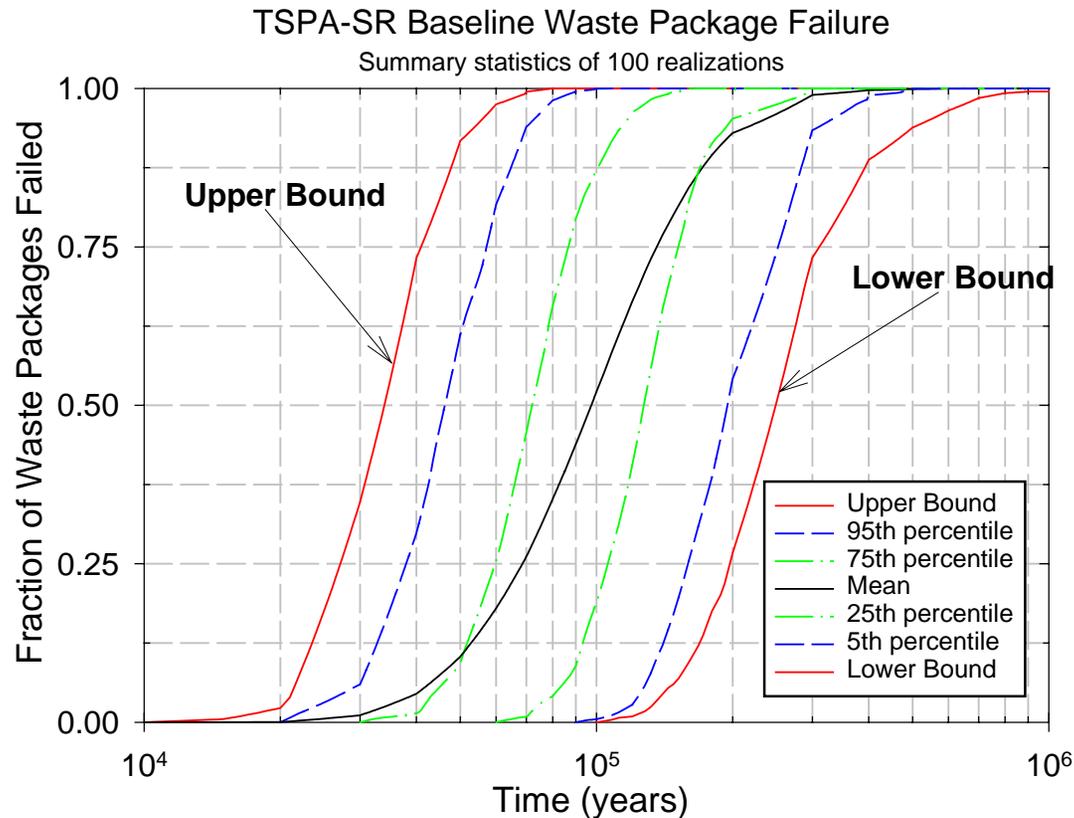
- **Probability of Improper heat treatment estimated to be 2.23×10^{-5}**
 - Include probabilities for non-detected equipment malfunctioning and non-reported operator errors from handbook
- **For 11,770 waste packages, expected number of improperly heat treated waste packages is 0.263**
- **Used a Poisson distribution to model the number of affected waste packages**
- **20 out of 100 realizations have at least one waste package failed early, and 3 realizations have two waste packages failed early**

Early Waste Package Failure – Improper Heat Treatment in SSPA

(Continued)

- **Assume affected waste package(s) fail immediately when corrosion initiates**
 - **Assume conservatively weld regions of both the outer and inner closure-lids of the outer barrier fail immediately**
 - **No credit taken for the stainless steel inner shell**

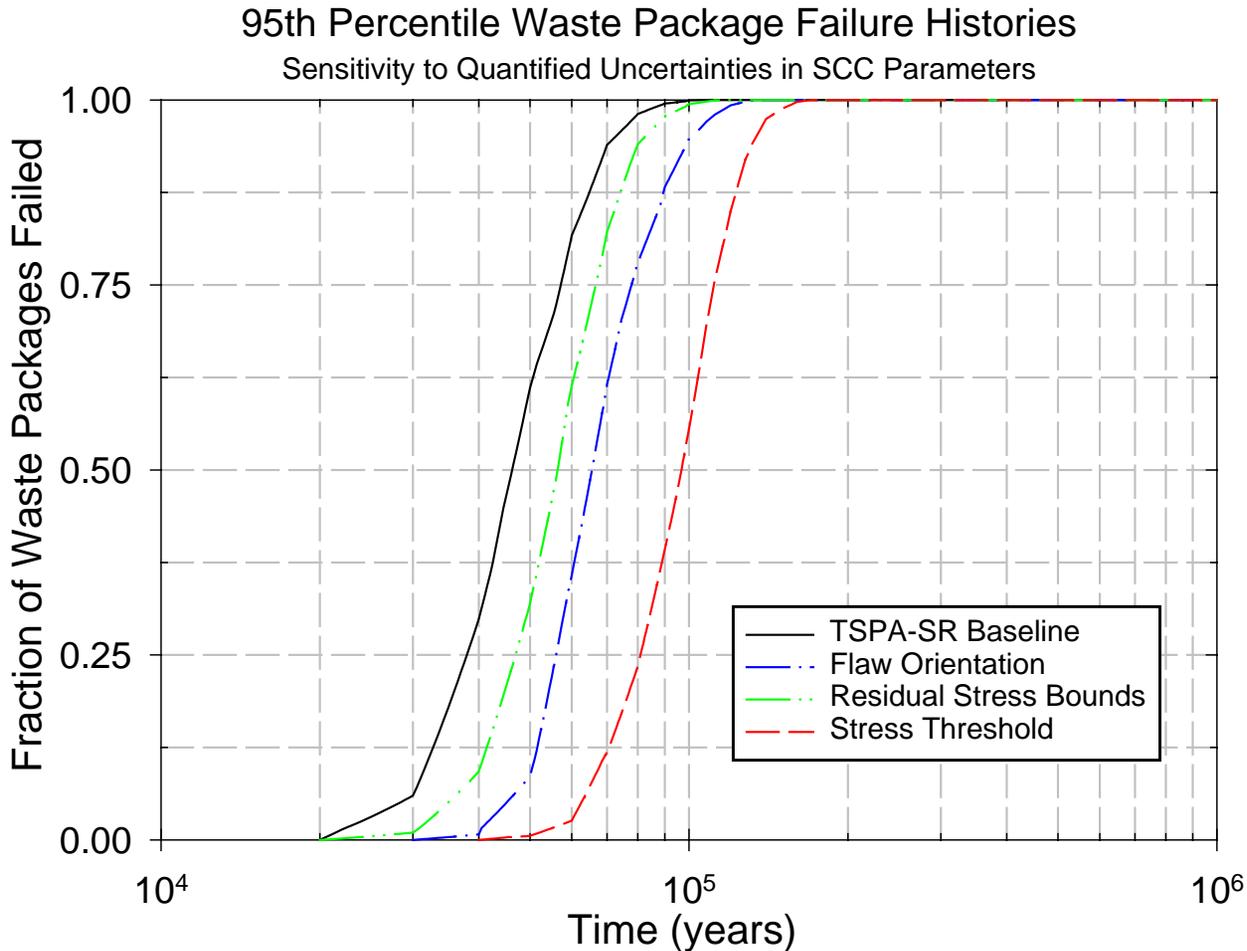
TSPA-SR Baseline WAPDEG Model Results



- **The earliest possible first breach time of waste package is about 11,000 years**
- **The first breach time of the 95th percentile curve is about 21,000 years**

Effects of Quantification/Update of Uncertainty of SCC Model Parameters

95th percentile waste package failure histories

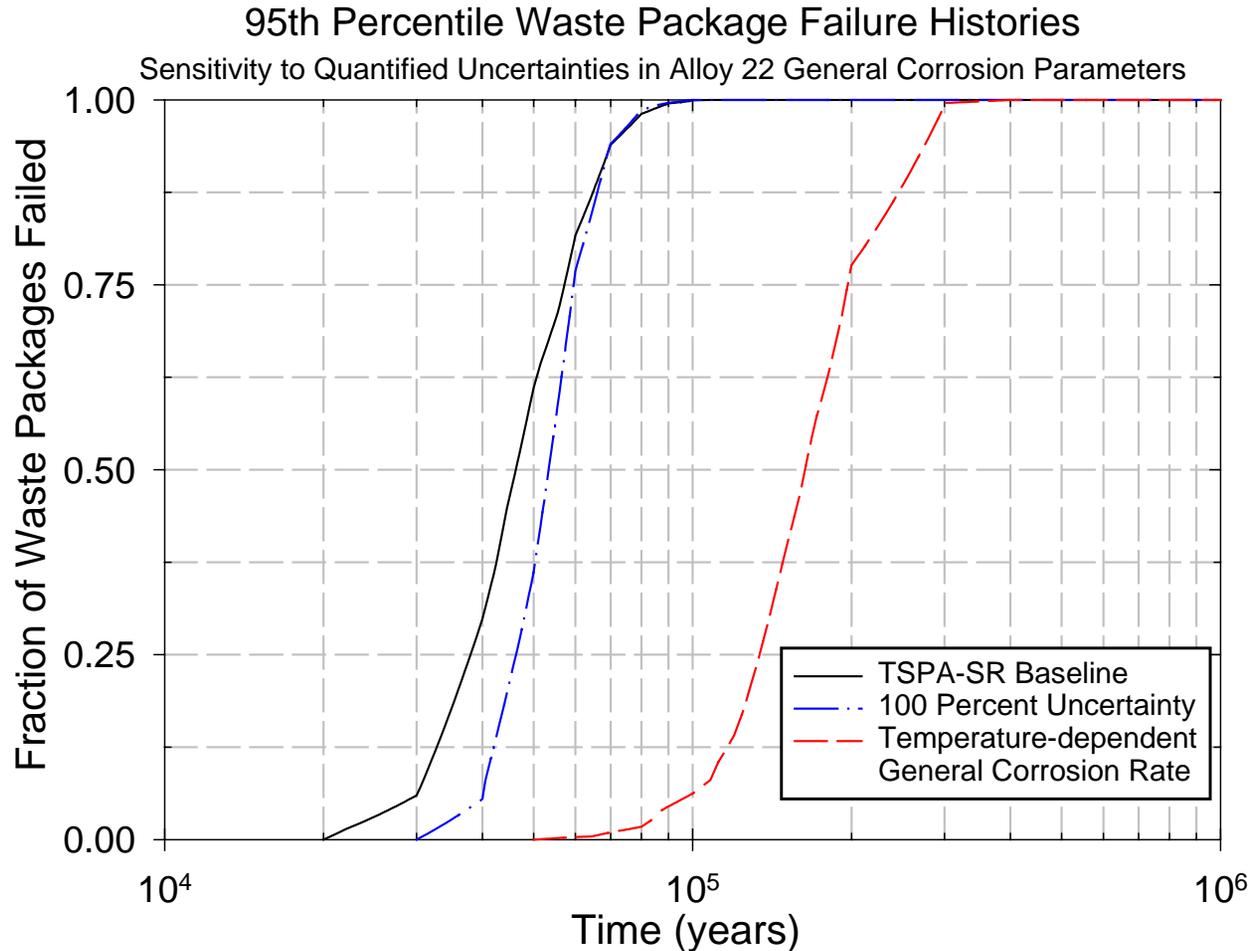


Quantification/Update of Uncertainties of Alloy 22 General Corrosion Model Parameters in SSPA

- **The total variance in the general corrosion rates from weight loss measurements in Long-Term Corrosion Testing Facility is due to uncertainty**
- **Temperature-dependent general corrosion model for Alloy 22**
- **Greg Gdowski has discussed the details**

Effects of Quantification and Update of Uncertainty of Alloy 22 General Corrosion Model Parameters

95th percentile waste package failure histories



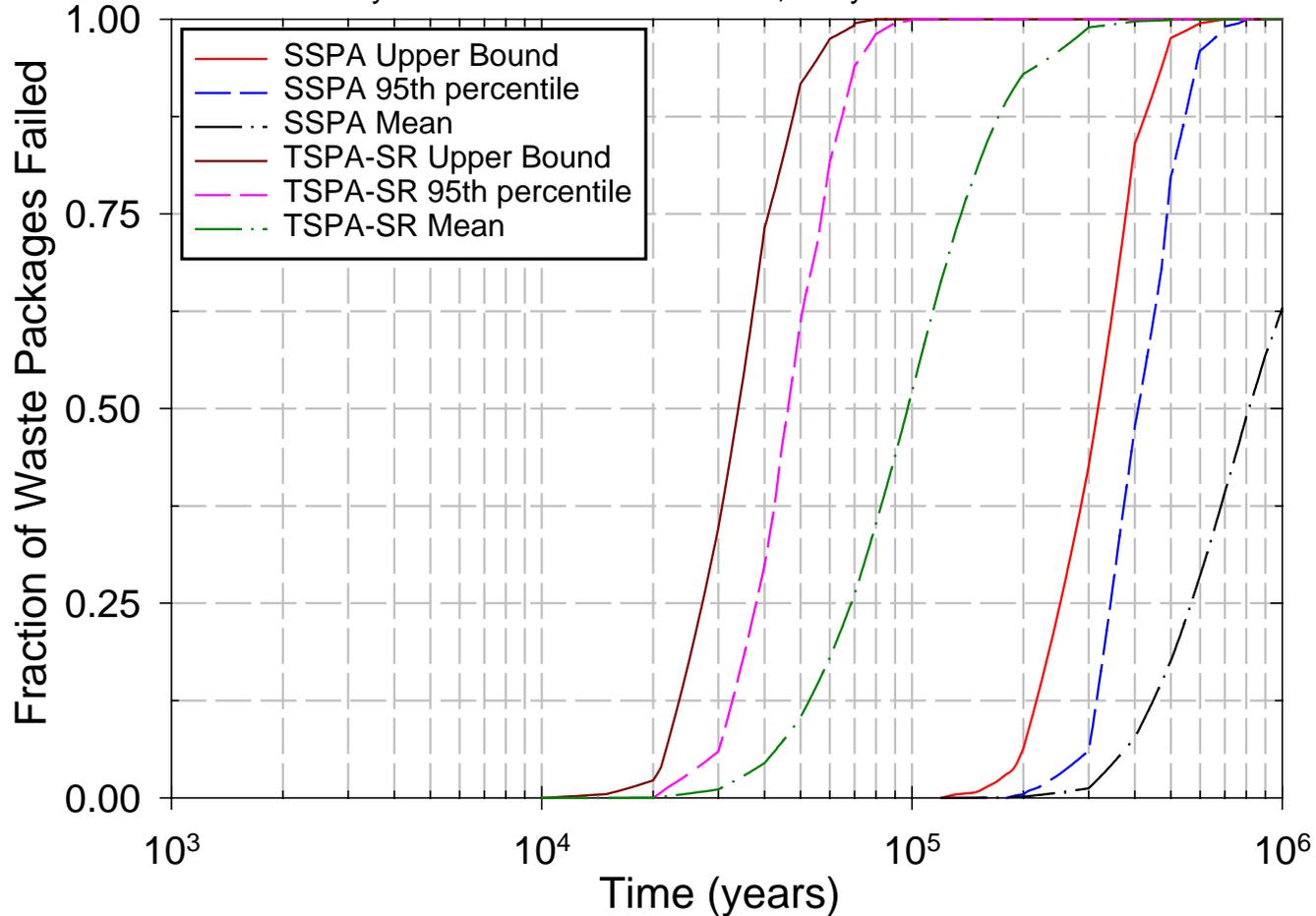
Waste Package Degradation Model for SSPA TSPA

- **Quantified/updated corrosion model parameters for SSPA**
 - **Temperature-dependent general corrosion rate of Alloy 22**
 - **The total variance in Alloy 22 and Titanium Grade-7 general corrosion rates due to uncertainty**
 - **Updated stress threshold for SCC crack growth initiation**
 - **Updated uncertainty bounds for residual stress in outer barrier closure-lid weld regions**
 - **Updated manufacturing flaw orientation in outer barrier closure-lid welds**
 - **Sampling of temperature and relative humidity histories**
 - **Early failure (1 or 2 waste packages) due to improper heat treatment**
 - ◆ **implemented directly into TSPA model (not included in WAPDEG analysis)**

Waste Package Degradation Model for SSPA TSPA

Waste Package Failures SSPA vs. TSPA-SR Baseline

Summary statistics of 100 realizations; Early Failures Not shown



Summary and Conclusions

- **New data and analyses have been developed to**
 - quantify the uncertainties in component models and parameters of waste package degradation model
 - improve the technical basis for the performance assessment of waste package
- **Early waste package failure due to improper heat treatment is included in the SSPA TSPA analysis**

Summary and Conclusions

(Continued)

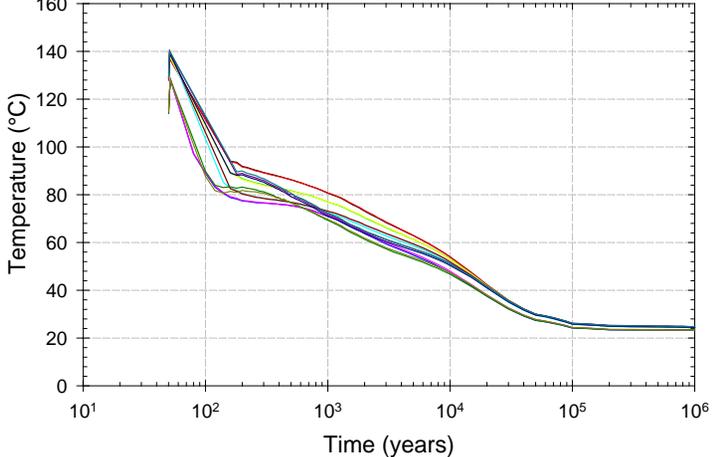
- **Waste package performance is significantly improved from updated stress threshold and temperature-dependent Alloy 22 general corrosion model**
 - Not considering the early waste package failures, the earliest possible failure time of waste package in the SSPA model is about 120,000 years, compared to about 11,000 years in the TSPA-SR baseline model
- **Significant safety margins in waste package performance are provided in the TSPA-SR baseline waste package degradation model**

Backups

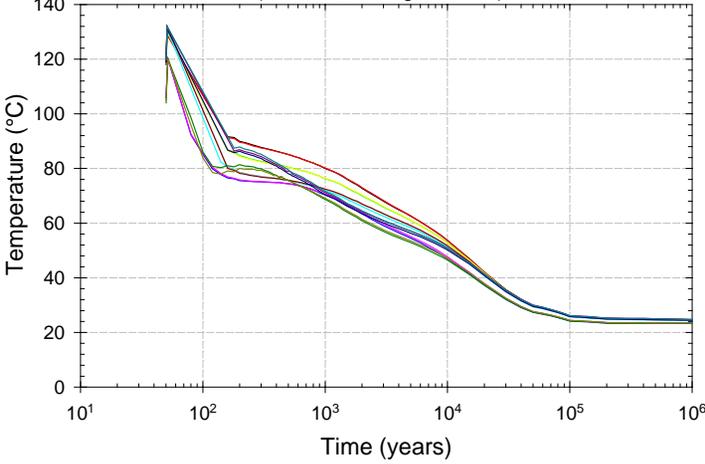


Relative Humidity and Temperature Profiles Used in TSPA-SR Baseline WAPDEG Model

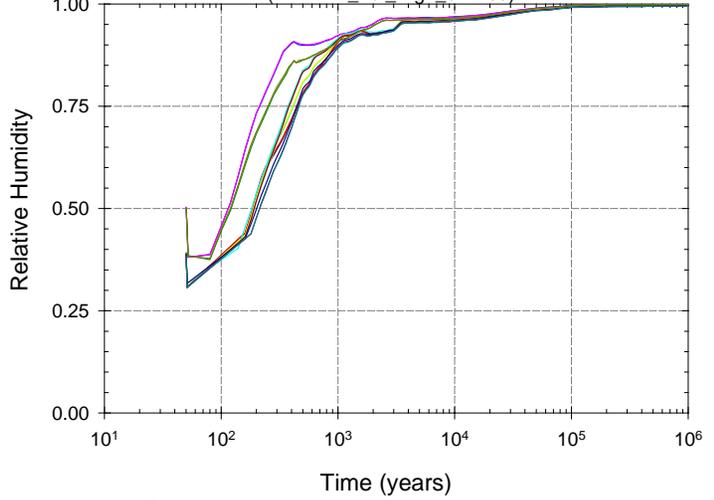
Waste Package Temperature Abstraction vs. Time
(WDHLW_nbf_High_bin2.ou)



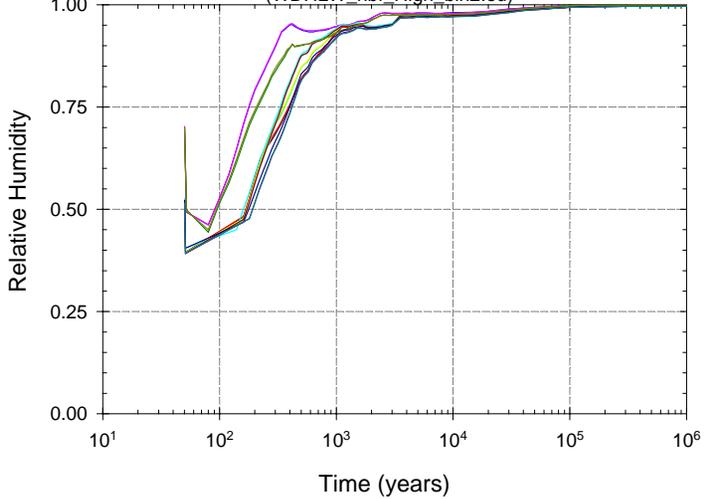
Drip Shield Temperature Abstraction vs. Time
(WDHLW_nbf_High_bin2.ou)



Waste Package Relative Humidity Abstraction vs. Time
(WDHLW_nbf_High_bin2.ou)



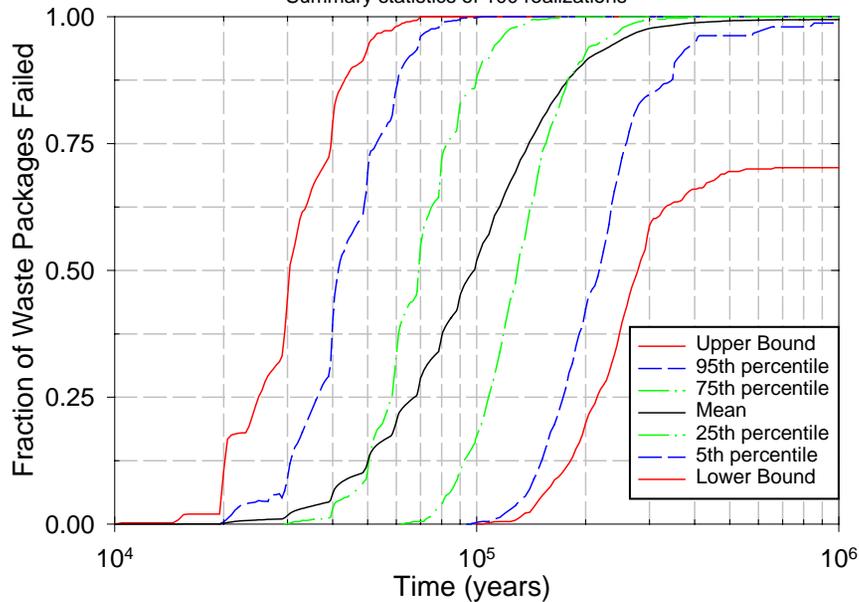
Drip Shield Relative Humidity Abstraction vs. Time
(WDHLW_nbf_High_bin2.ou)



TSPA-SR Baseline WAPDEG Model Results

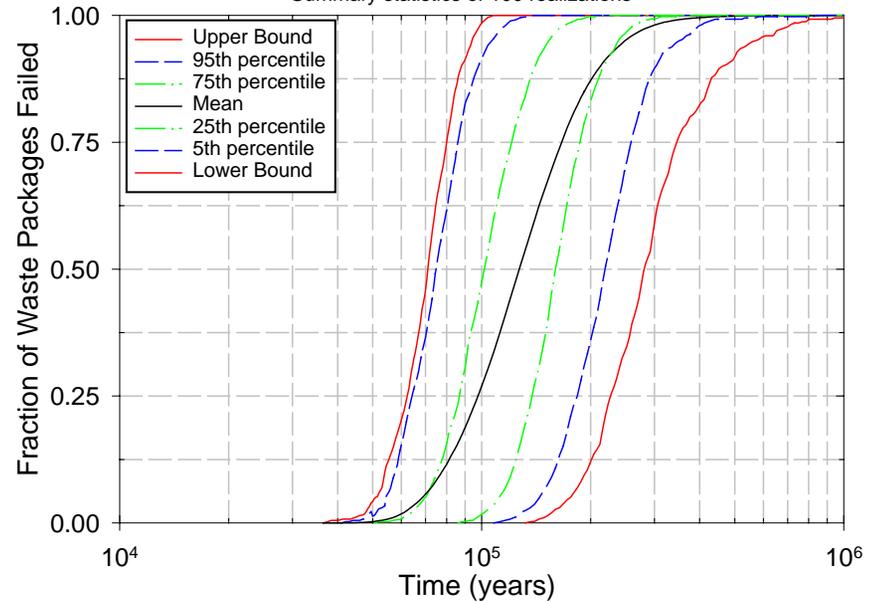
TSPA-SR Baseline Waste Package 1st Crack Breach

Summary statistics of 100 realizations



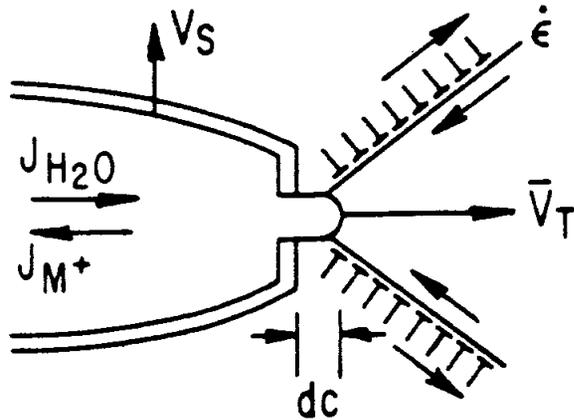
TSPA-SR Baseline Waste Package 1st Patch Breach

Summary statistics of 100 realizations



Stress Corrosion Cracking Mechanism

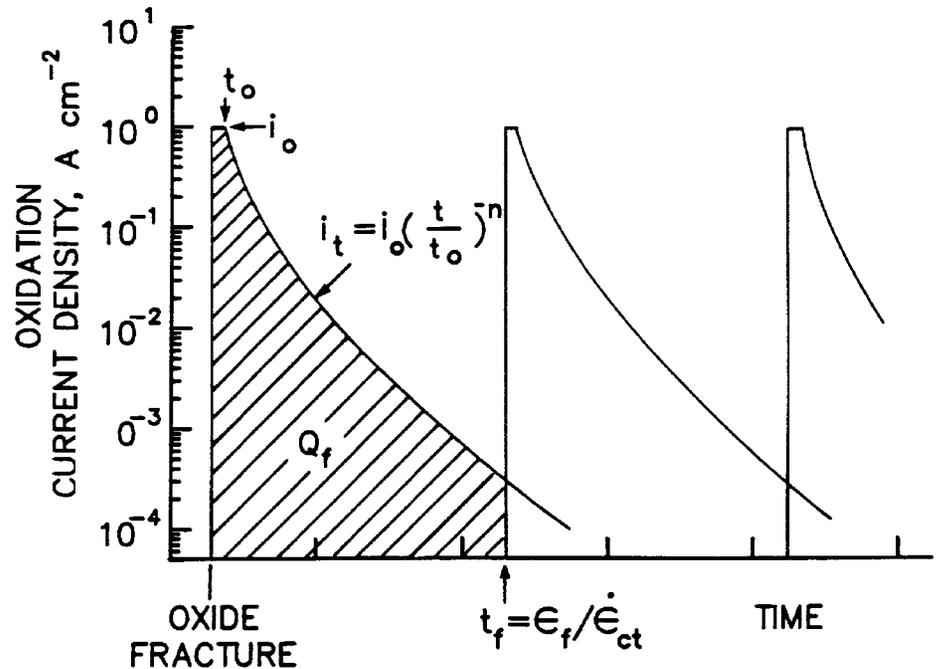
SCC Mechanism



Crack Propagation Rate

$$V = \bar{A}(K_I)^{4n}$$

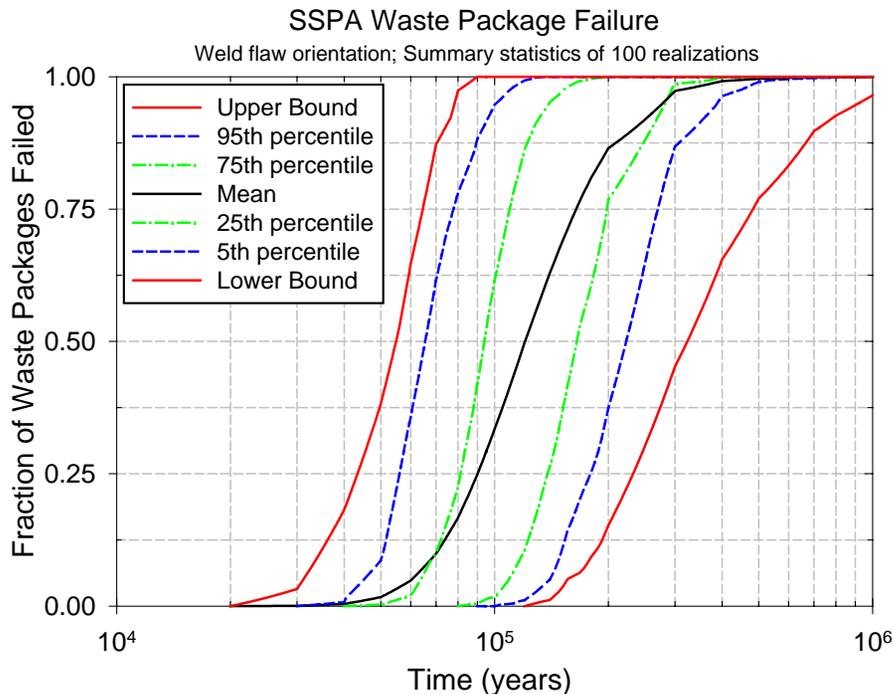
$$\bar{A} = 7.8 \times 10^{-2} n^{3.6} (4.1 \times 10^{-14})^n$$



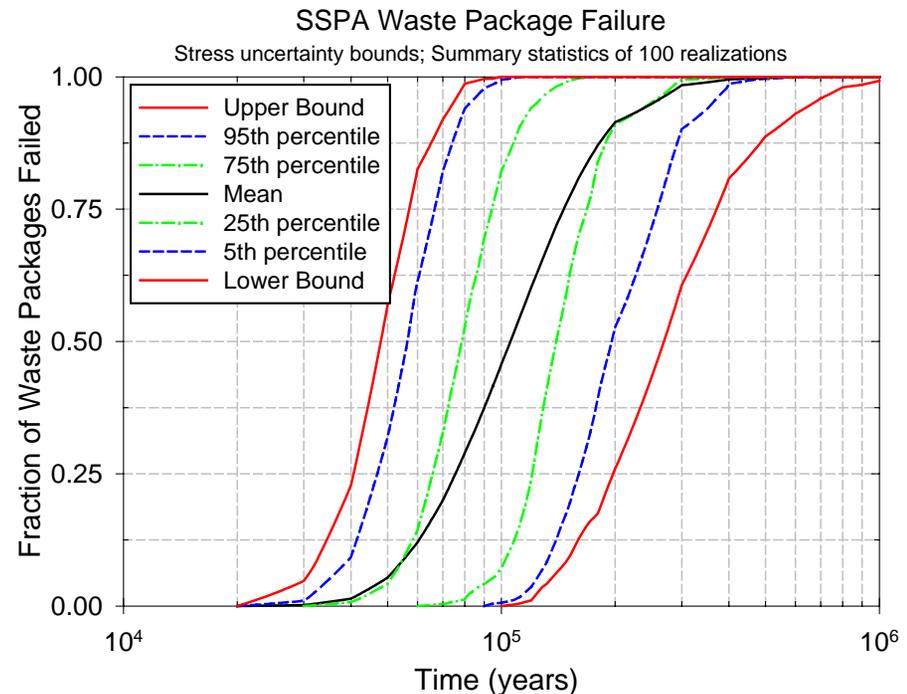
$$V = \frac{da}{dt}; \bar{V}_{av} = \frac{M}{ZtF} \cdot \frac{Q_f}{t_f}$$

Effects of Quantified Uncertainty of SCC Model Parameters

- **Manufacturing flaw orientation**



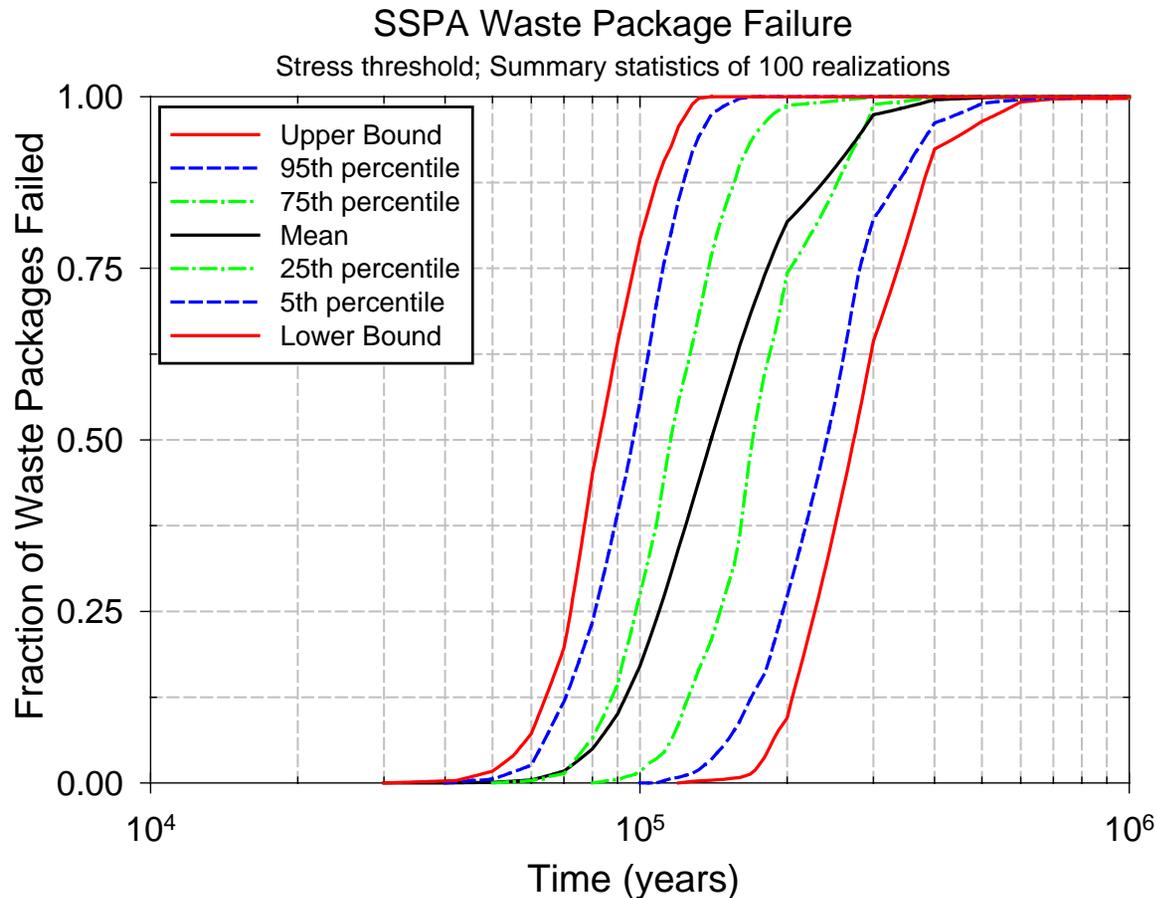
- **Uncertainty bounds of residual stress in the weld regions of the outer and inner closure-lids of the waste package outer barrier**



Effects of Quantified Uncertainty of SCC Model Parameters

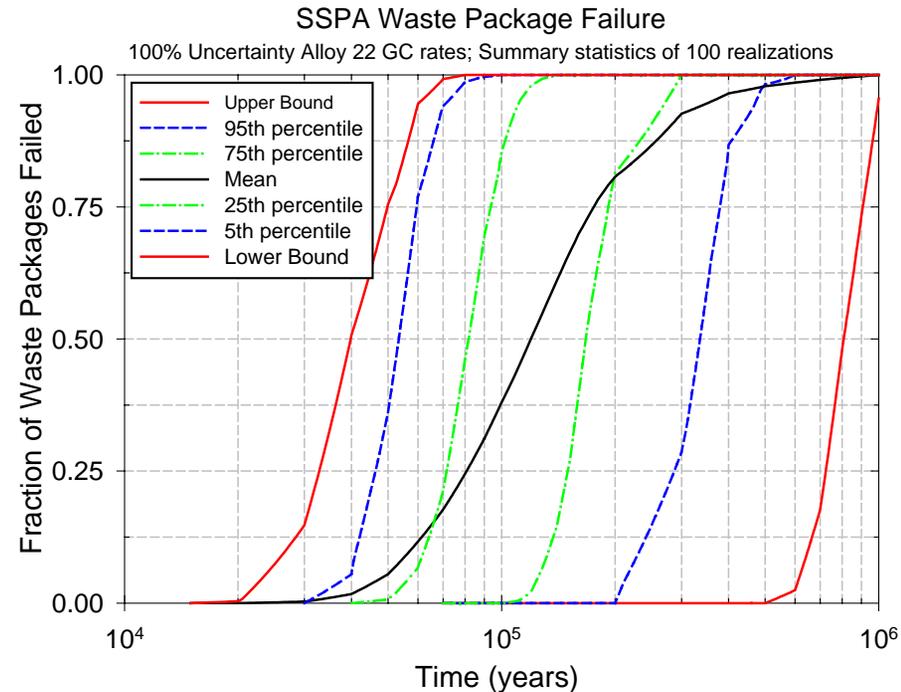
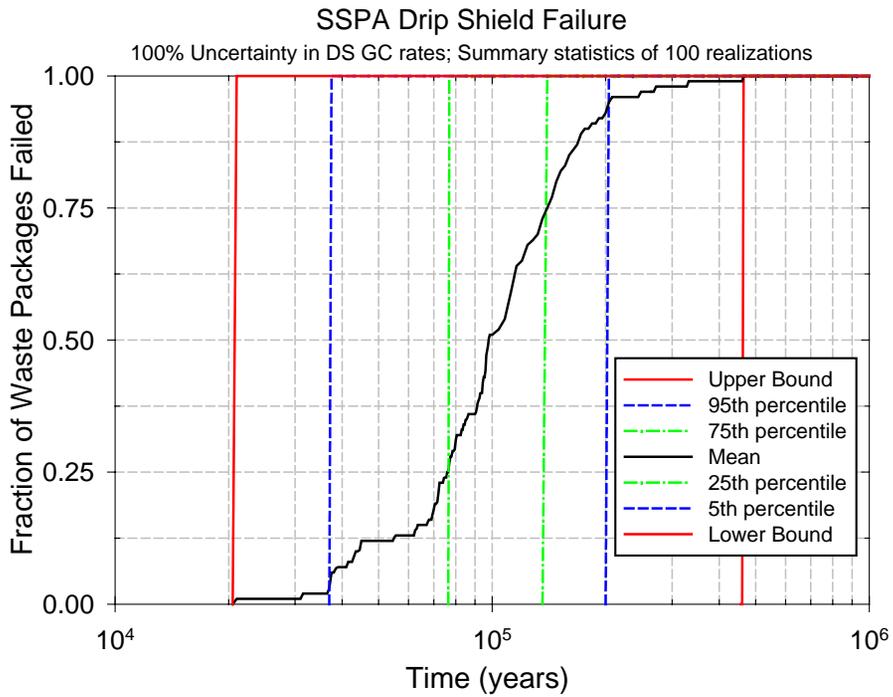
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- Stress threshold for crack growth initiation



Effects of Quantified Uncertainty of General Corrosion Model Parameters

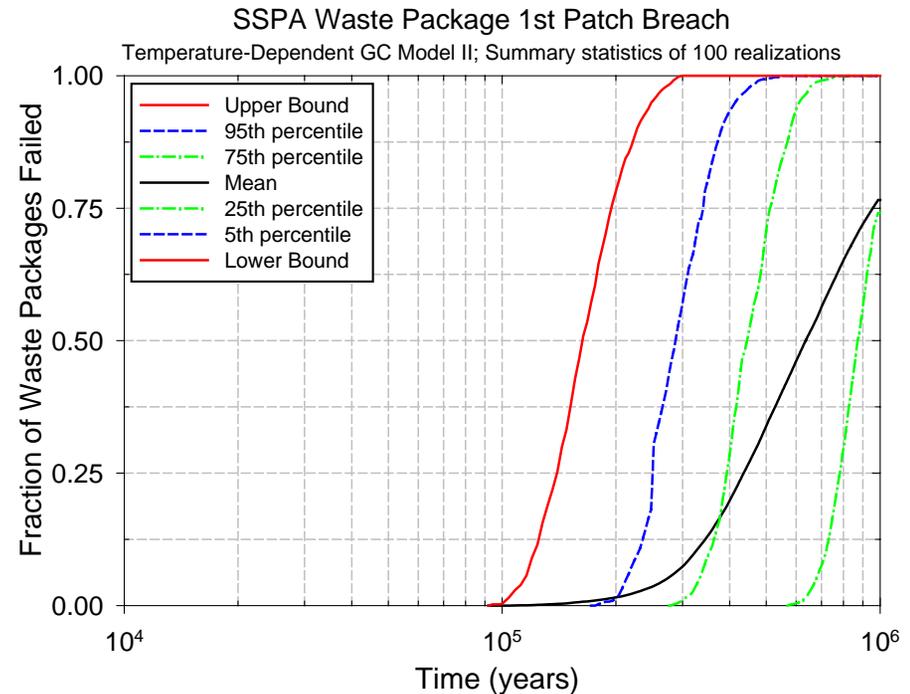
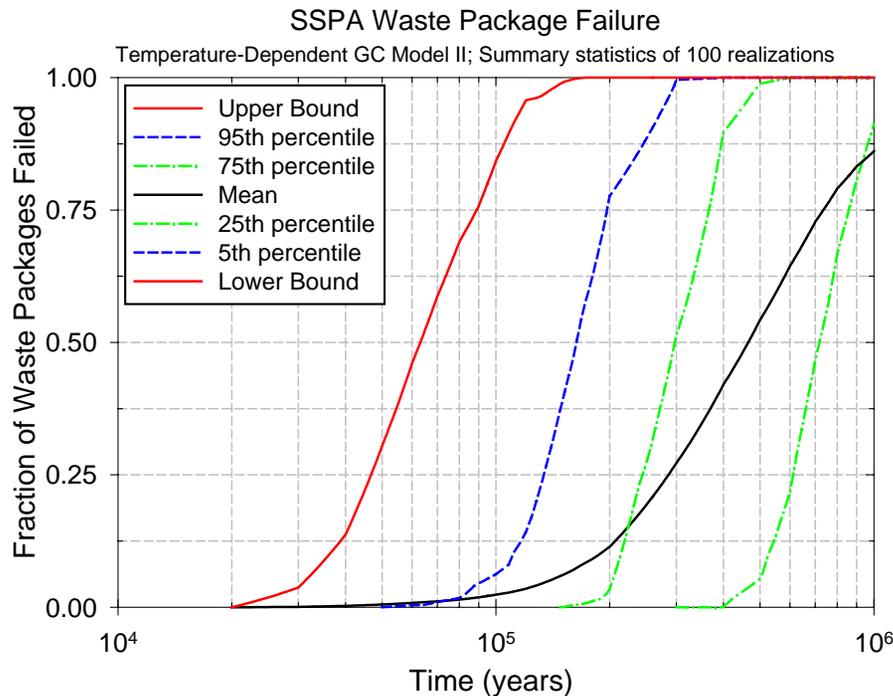
- Assume the total variance in the general corrosion rates from weight loss measurements in Long-Term Corrosion Testing Facility is due to uncertainty



Effects of Quantified Uncertainty of General Corrosion Model Parameters

(Continued)

- Temperature dependent Alloy 22 general corrosion rate
- Assume the total variance in the general corrosion rates from weight loss measurements in Long-Term Corrosion Testing Facility is due to uncertainty



Effects of Quantified Uncertainty of General Corrosion Model Parameters

(Continued)

- Temperature dependent Alloy 22 general corrosion rate
- Assume the total variance in the general corrosion rates from weight loss measurements in Long-Term Corrosion Testing Facility is due to uncertainty
- Temperature and relative humidity histories are sampled from all thermal hydrology histories for the entire repository

