YUCCA
MOUNTAIN
PROJECT

Studies

Waste Package Degradation Modeling in the Total System Performance Assessment for the Viability Assessment (TSPA-VA)

Presented to:
Nuclear Waste Technical Review Board
Full Board Meeting

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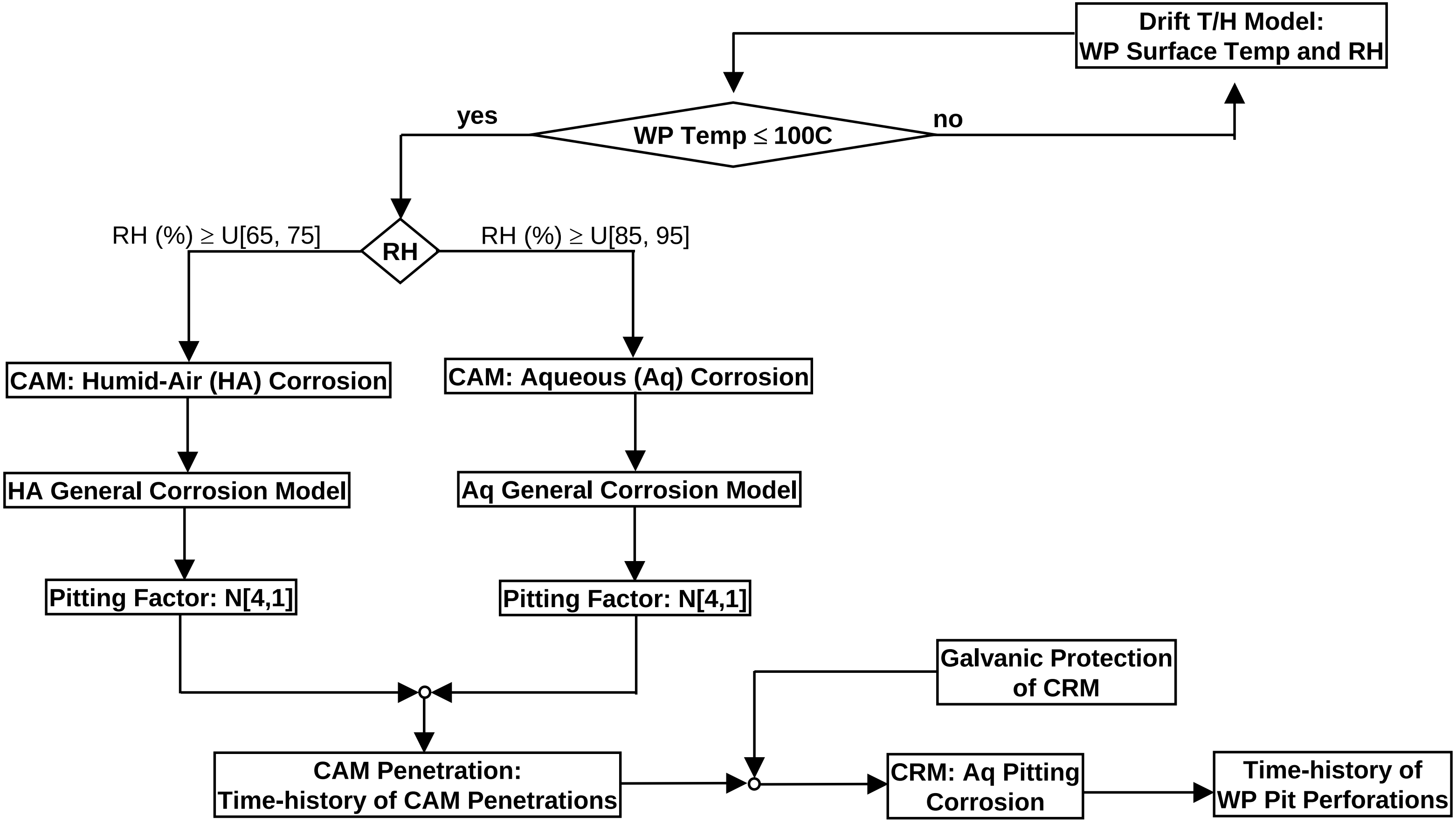
Office of Civilian Radioactive
Waste Management

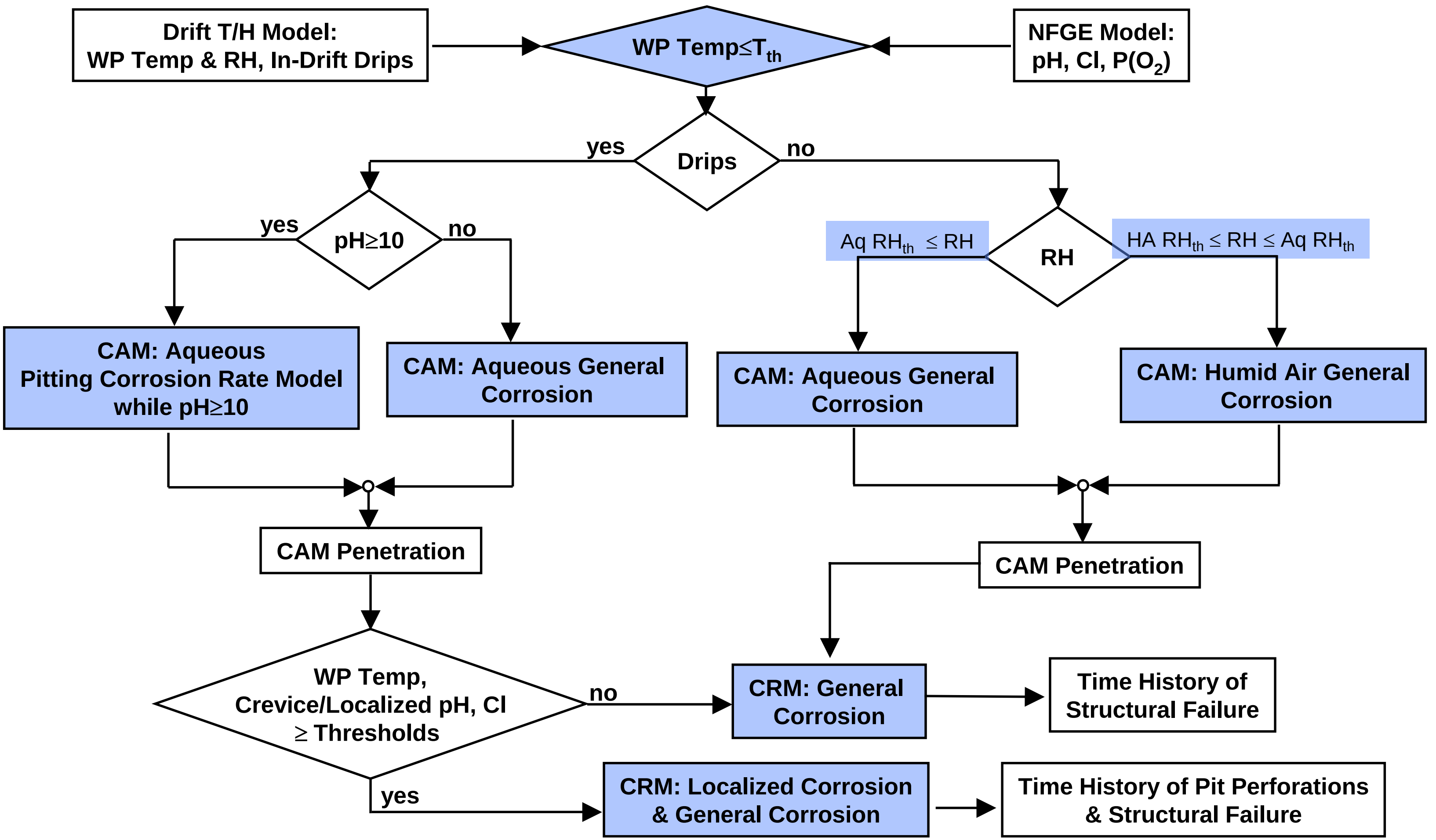
Outline of Presentation

- Waste package degradation modeling in TSPA-1995
- TSPA-VA base case waste package degradation model
- Key parameters for waste package degradation model derived from Expert Elicitation
- Concluding remarks

Logic Diagram for WP Degradation Modeling in TSPA-1995



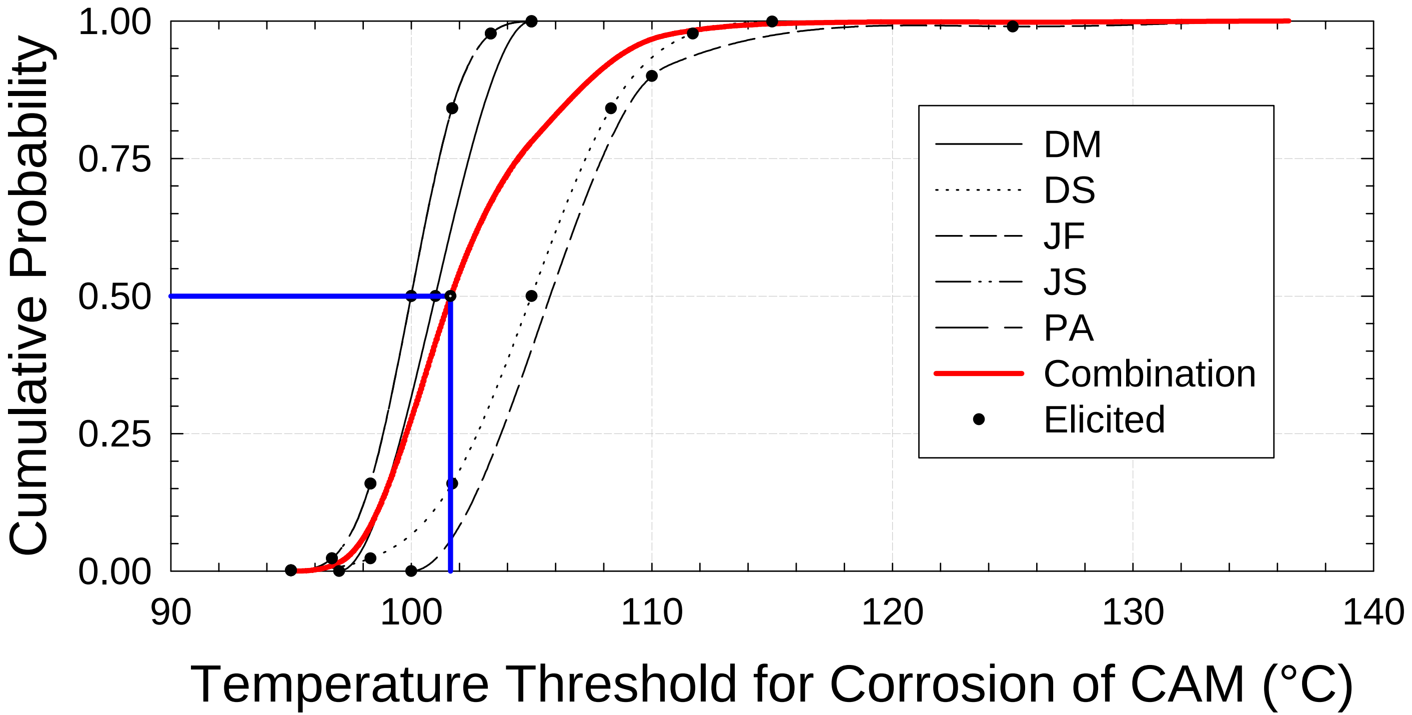
Logic Diagram for the Base Case TSPA-VA WP Degradation Model



Key Parameters for the TSPA-VA Base Case Waste Package Degradation Model

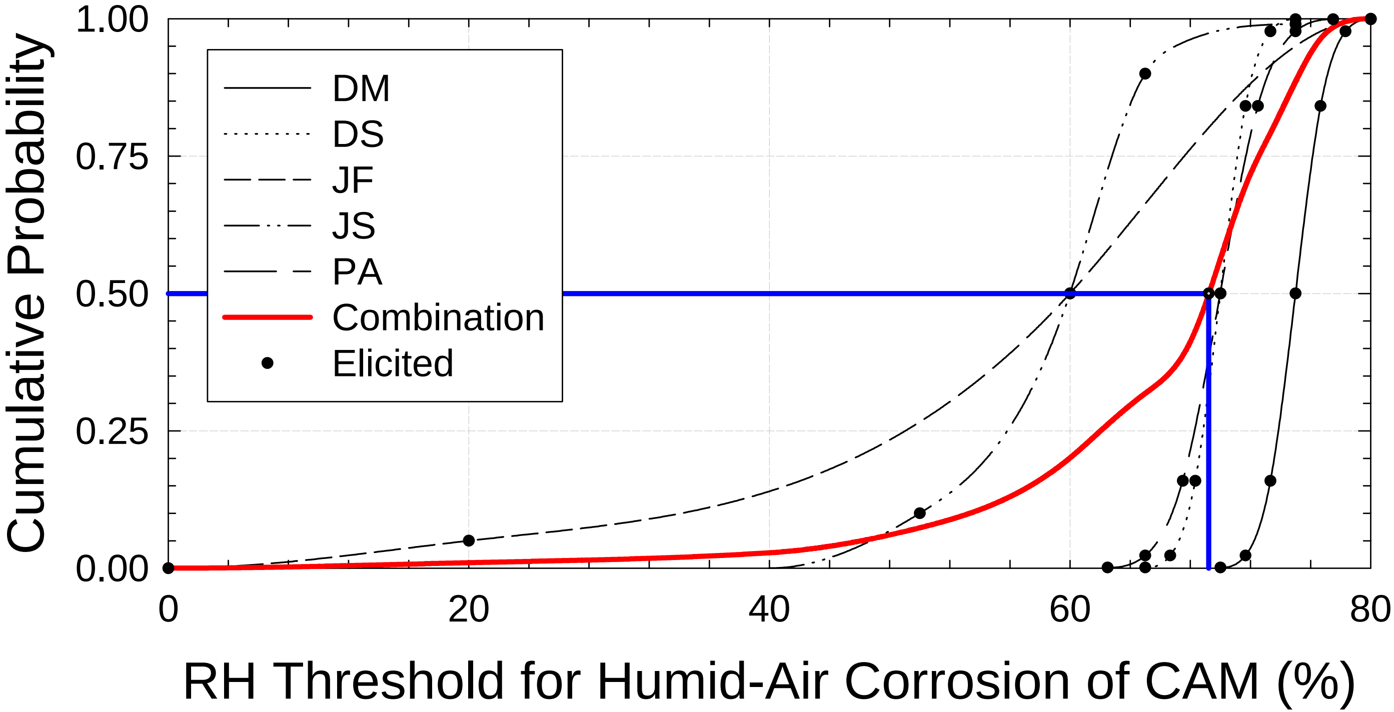
- Thresholds for CAM corrosion initiation
  - thresholds dependent on the surface condition (dust, oxides, salts), dripping, location on a WP (top, sides, bottom)
  - temperature threshold
  - RH threshold for humid-air corrosion
  - RH threshold for aqueous corrosion

Distribution for Temperature Threshold for CAM Aqueous or Humid Air Corrosion Initiation



"Preliminary Draft"

Distribution for RH Threshold for CAM Humid-Air Corrosion Initiation



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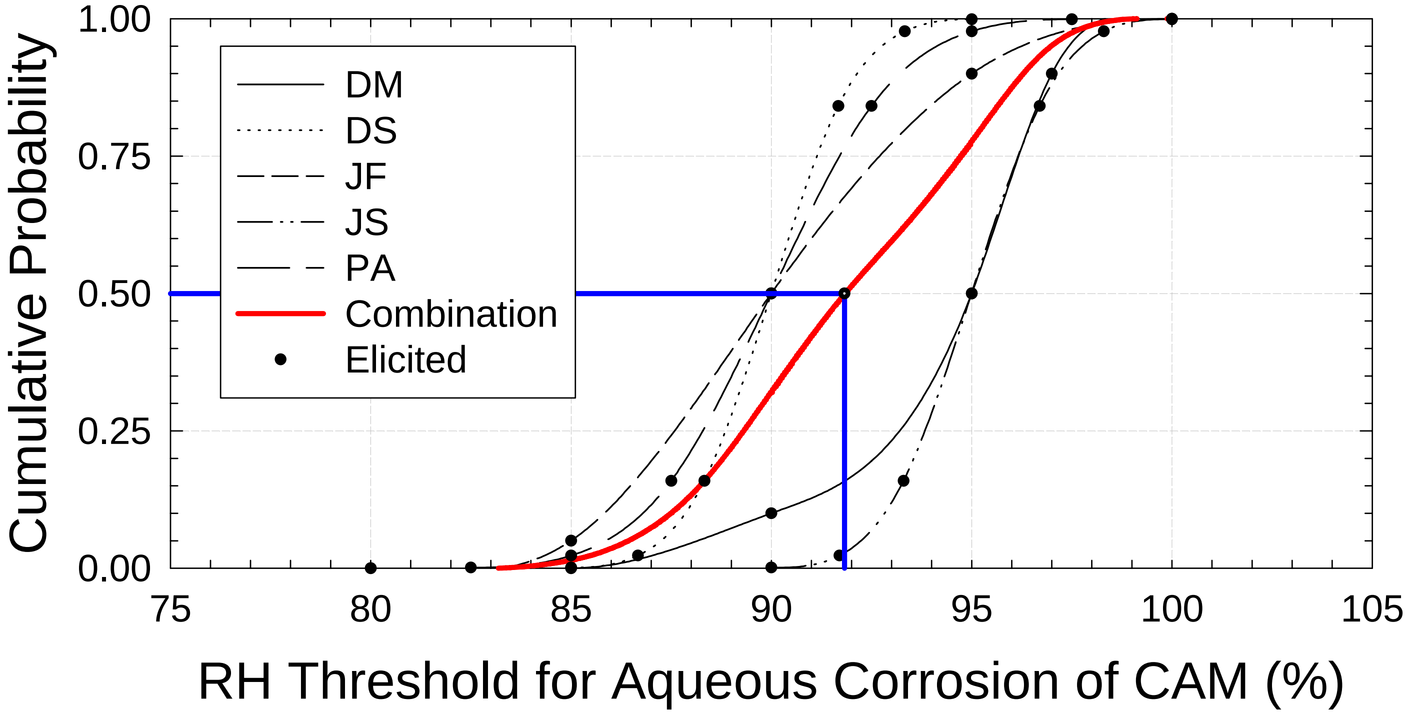
Distribution for RH Threshold for CAM Aqueous Corrosion Initiation



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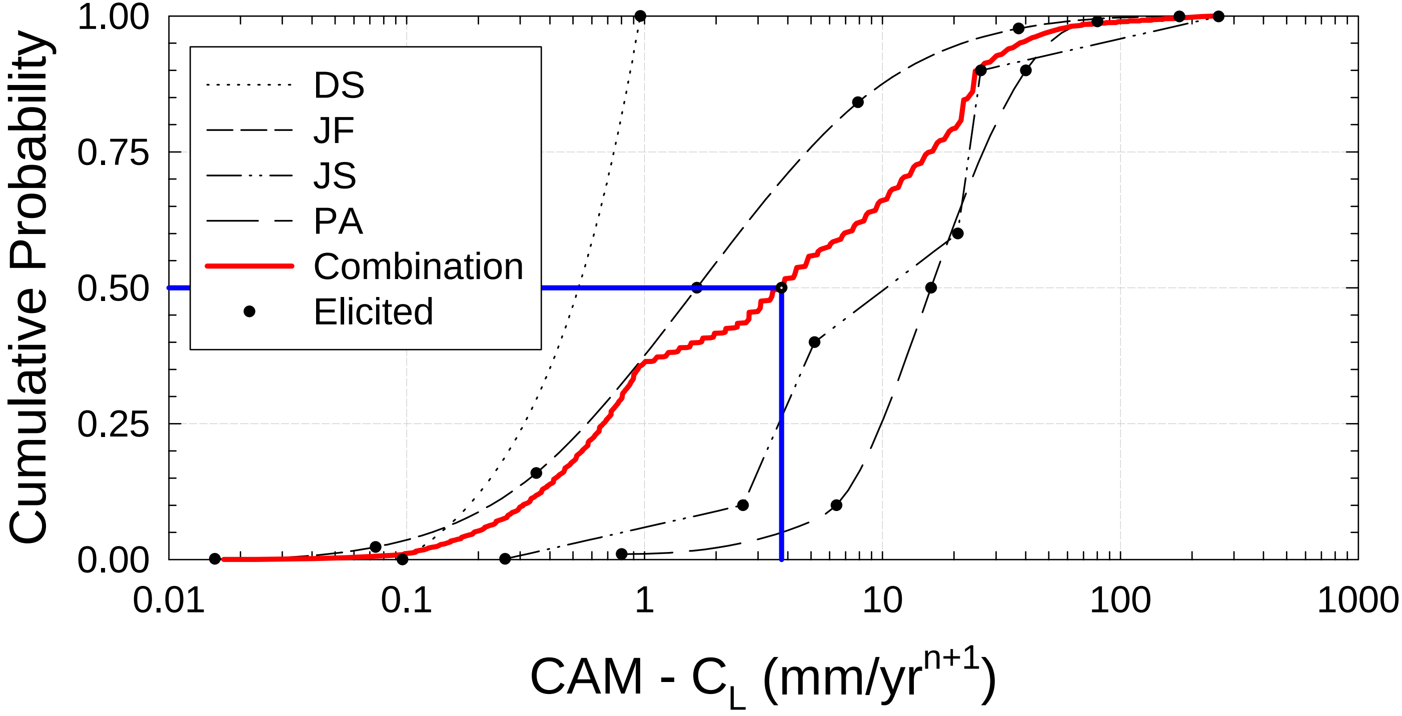
Key Parameters for the TSPA-VA Base Case Waste Package Degradation Model

(continued)

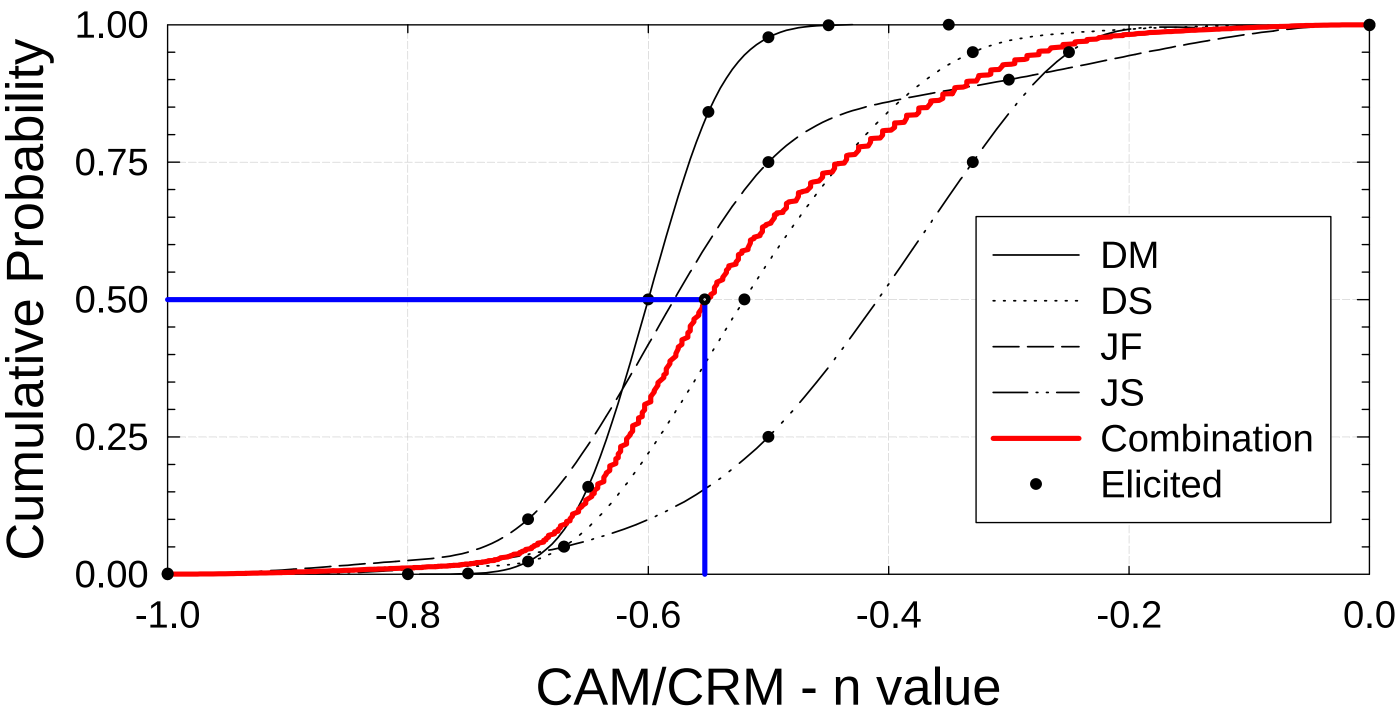
- **CAM corrosion modes**
  - **humid-air or neutral pH (4 to 10) aqueous condition**
    - » **use TSPA-95 model for neutral pH aqueous general corrosion**
    - » **use TSPA-95 model for humid-air general corrosion**
    - » **general (uniform) corrosion with low localized variations**
  - **alkaline (pH≥10) aqueous condition**
    - » **high aspect ratio pitting model**
    - » **use pit growth law, rate = $C_G(t) + C_L\ t^n$**
    - » **use "modified" TSPA-95 model for $C_G(t)$ = fn (T, pH)**
    - » **pit density**

Distribution for Constant 'C_L' of Pit Growth Rate (= $C_G + C_L\ t^n$) for CAM Pitting Corrosion in Alkaline Conditions (pH≥10)



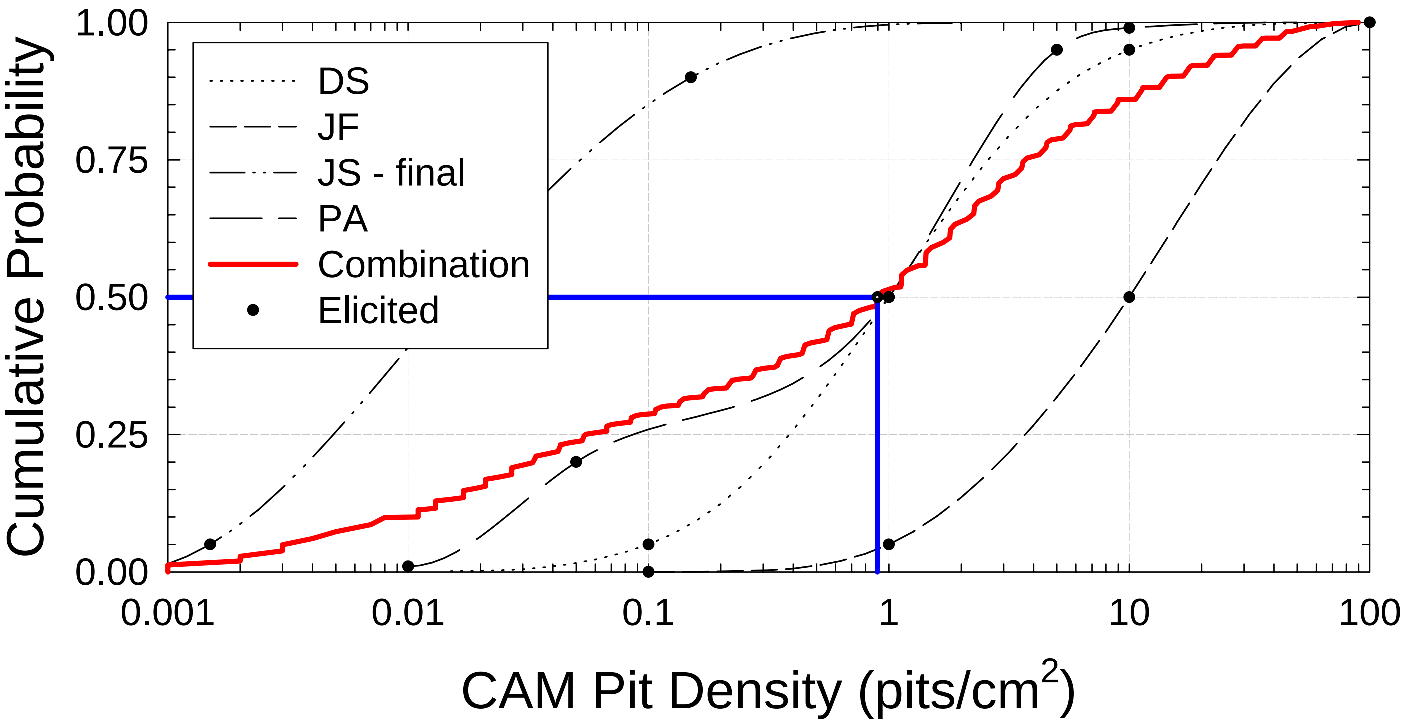
"Preliminary Draft"

Distribution for Constant 'n' of Pit Growth Rate (= $C_G + C_L t^n$) for CAM Pitting Corrosion in Alkaline Conditions (pH≥10)



"Preliminary Draft"

Distribution for Pit Density of CAM in Alkaline Conditions (pH≥10)



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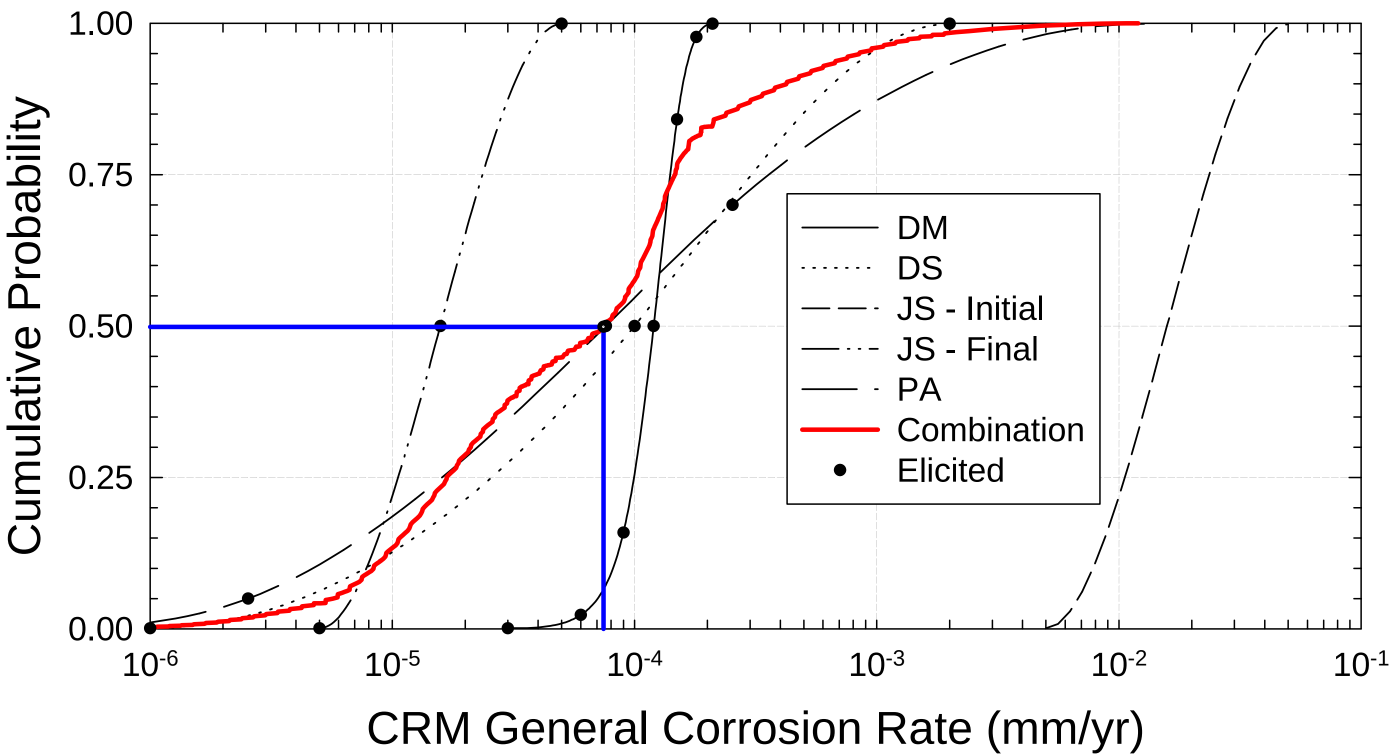
Key Parameters for the TSPA-VA Base Case Waste Package Degradation Model

(continued)

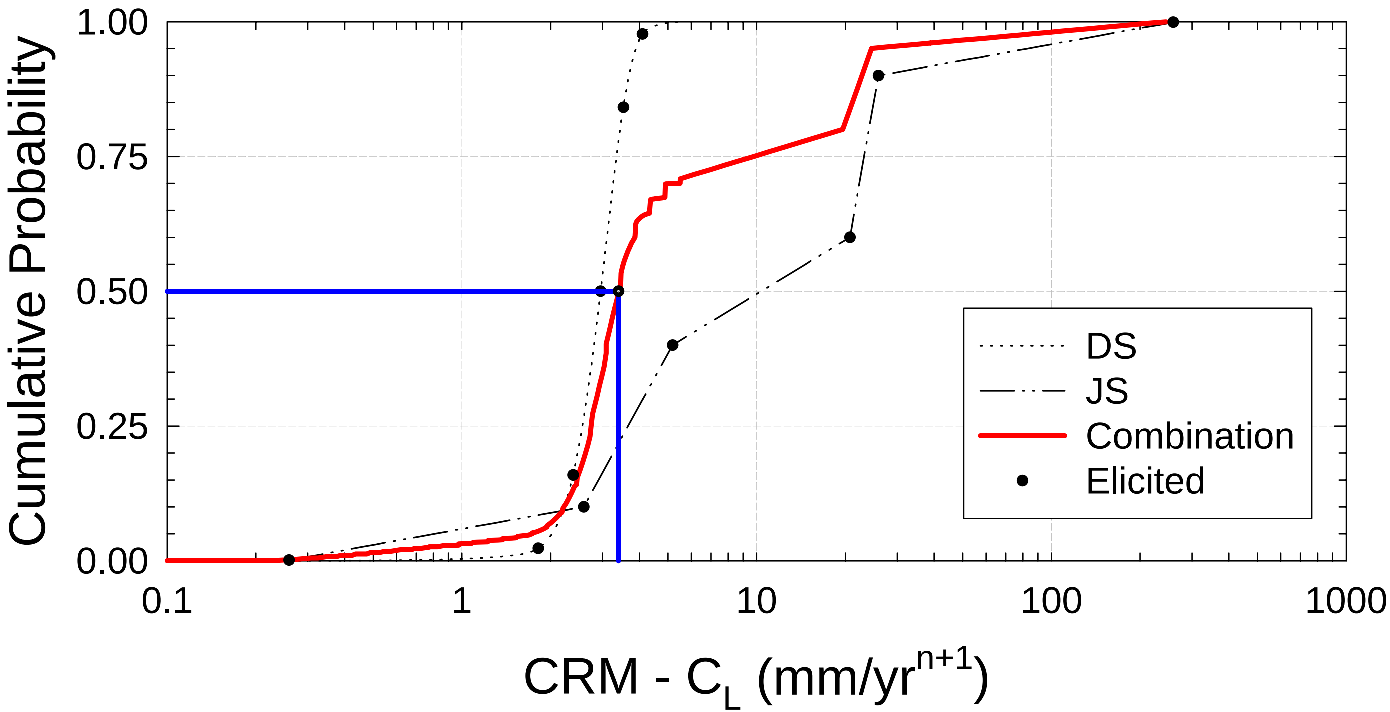
- **CRM corrosion mode**
  - **general corrosion of CRM under humid-air or "non-dripping" aqueous condition**
  - **marginal galvanic protection of CRM (a few 100 years at most)**
  - **localized (pitting/crevice) corrosion requires drips with elevated Cl^- and low pH within a crevice and pit**
  - **use pit growth law for pitting and crevice corrosion**
    - » **pit growth rate = $C_G(t) + C_L\ t^n$**
    - » **pit density and pit diameter**

Distribution for Constant ‘C_G’ of Pit Growth Rate (= $C_G + C_L t^n$) for CRM Pitting/Crevice Corrosion



“Preliminary Draft”

Distribution for Constant ‘C_L’ of Pit Growth Rate (= $C_G + C_L t^n$) for CRM Pitting/Crevice Corrosion



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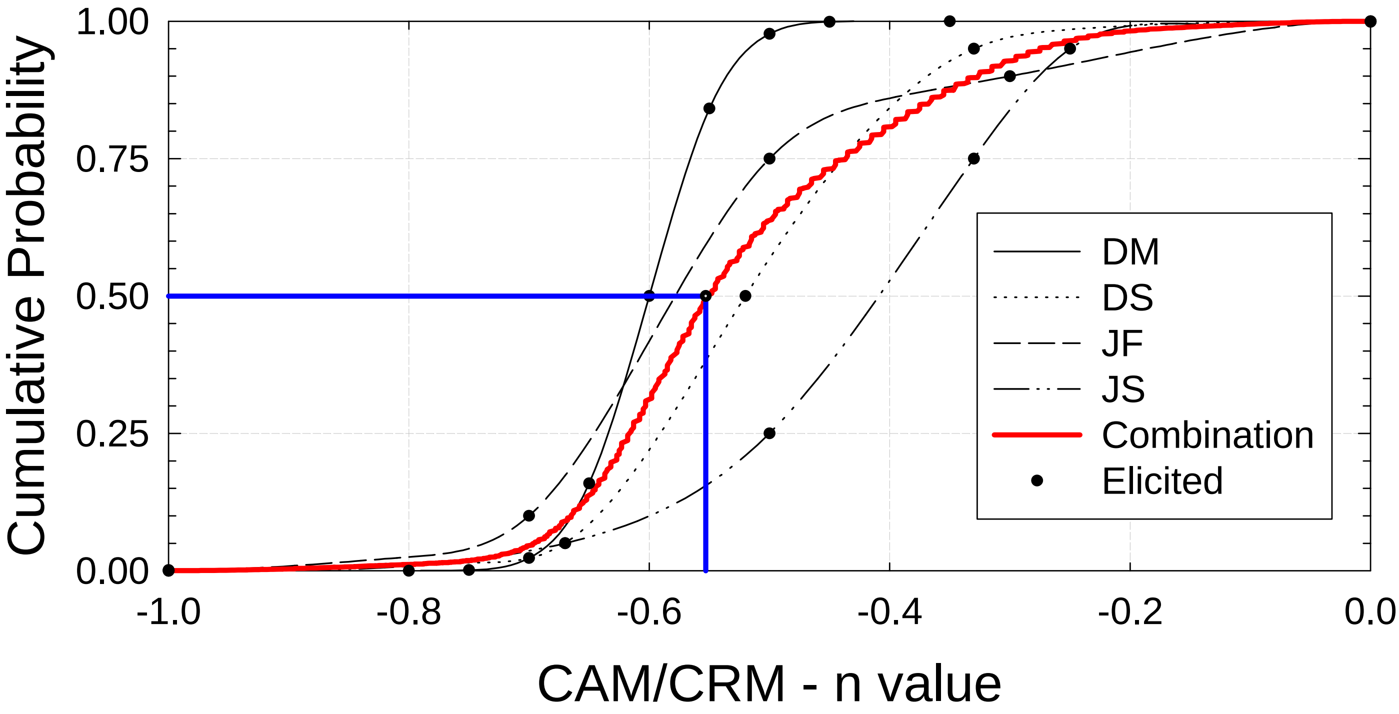
Distribution for Time Constant ‘n’ of Pit Growth Rate (= $C_G + C_L t^n$) for CRM Pitting/Crevice Corrosion



“Preliminary Draft”

Concluding Remarks

- The WPDEE results will be incorporated extensively in the TSPA-VA base case and sensitivity analyses
  - develop scenarios for the base case and sensitivity analysis
  - develop/derive key model parameters
- The base case and sensitivity analyses of waste package degradation modeling in TSPA-VA will be focused to evaluate the effect of waste package performance
  - waste containment and isolation
    - » time-history of waste package failure (first pit perforation)
    - » time-histories of waste package perforations
  - alternative options for waste package design
  - effects of alternative EBS designs

BACKUP

Aspects of Waste Package Performance That Impact Total System Performance

- **Waste containment - time of waste package failure**
  - waste package failure defined as the first perforation (pit penetration or crack propagation) through the container wall
  - corresponds to the initiation of waste form degradation inside the failed waste package

Aspects of Waste Package Performance That Impact Total System Performance

(Continued)

- **Controlled/gradual release of radionuclides - waste package failure rate, and subsequent perforation rate of failed waste container**
  – **waste package failure rate provides the rate of waste inventories that become available for release**
  – **subsequent perforation rate of failed waste container provides the area in the waste container available for radionuclide transport by diffusion and/or advection**

Waste Package Degradation Modeling in TSPA-1991 (SNL)

- **Container failure based on a predetermined distribution**
  - **no container failure during an initial dry-out period of 300 years**
  - **a maximum container failure time sampled from a log-uniform distribution from 500 to 10,000 years**

Waste Package Degradation Modeling in TSPA-1993

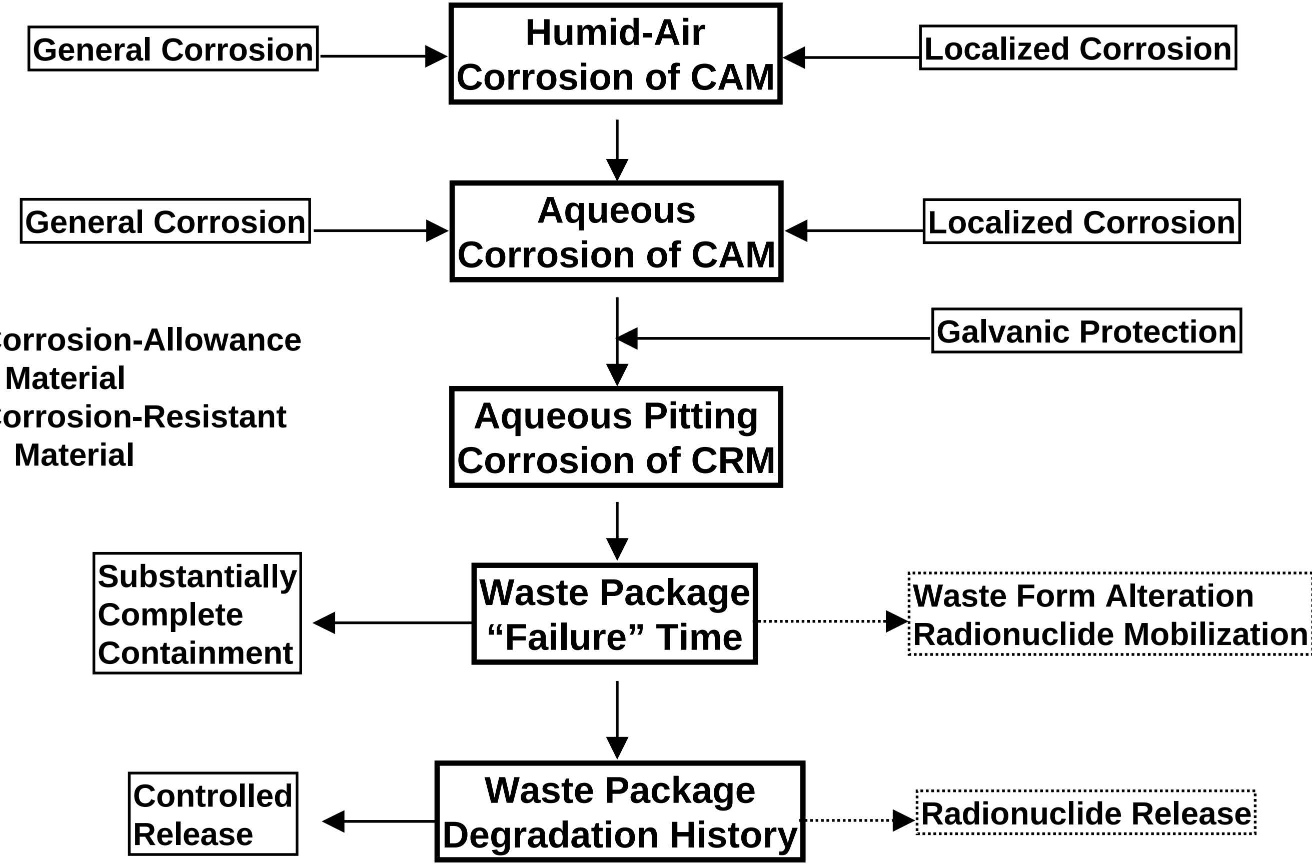
- **SNL**
  - **carbon-steel outer barrier**
    - » **dry-oxidation active when no liquid water present**
      - **modeled with the oxidation rate equation following an Arrhenius relationship**
    - » **aqueous general corrosion active when liquid water present**
      - **modeled with the temperature-dependent parabolic function rate equation**
      - **pitting factor of either 1 or 4 employed**
  - **alloy-825 inner barrier**
    - » **probabilistic approach based on expert elicitation on pit growth rate distribution for high-nickel alloy (McCright and Henshall)**
      - **“constant” pit growth rate distributions given at 70 and 100°C**
      - **pitting corrosion active at temperatures less than 100°C**
      - **calculated the “deepest” pit penetration**

Waste Package Degradation Modeling in TSPA-1993

(continued)

- **M&O**
  - **carbon-steel outer barrier**
    - » **dry-oxidation considered**
      - **not included in container failure calculation due to negligible corrosion by this corrosion mode**
    - » **aqueous general corrosion modeled as a function of time and temperature**
      - **two thresholds used for the initiation of aqueous general corrosion**
        - **temperature less than 100°C**
        - **liquid saturation greater than the residual saturation**
      - **a pitting factor of 4 employed**
  - **alloy-825 inner barrier**
    - » **used the median growth rate of the model used in SNL TSPA-1993**
      - **calculated the “deepest” pit penetration**

Approach to WP Degradation Modeling in TSPA-1995

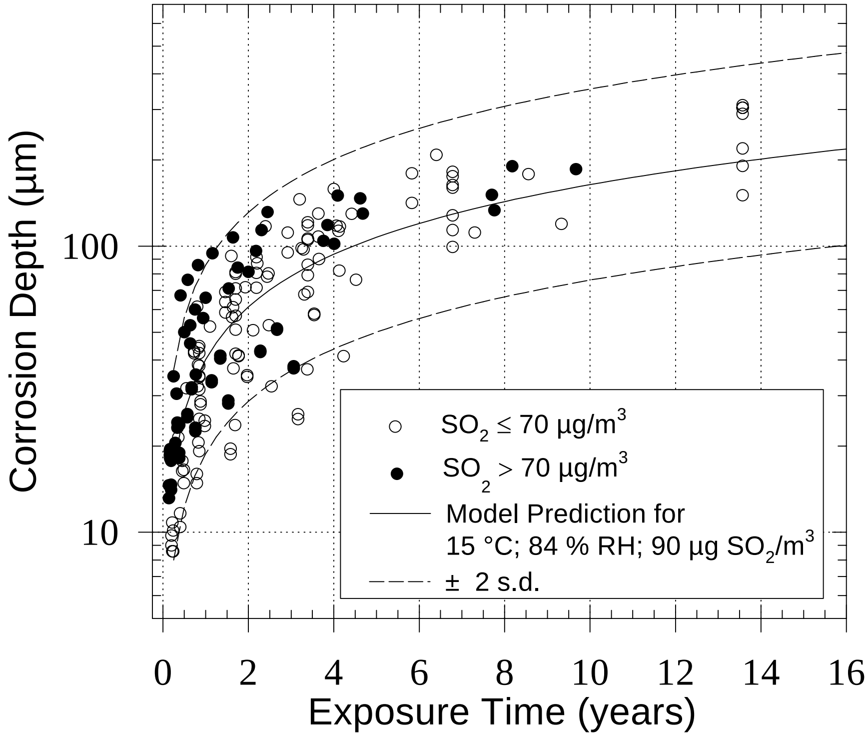


CAM = Corrosion-Allowance Material
CRM = Corrosion-Resistant Material

Waste Package Degradation Modeling in TSPA-1995

- **Humid-air corrosion of carbon steel outer barrier**
  - **humid-air general corrosion modeled as a function of time, humidity and temperature**
    - » **a total of 166 atmospheric corrosion data points (up to 16 years) from 10 sources**
    - » **included data from tropical, rural, urban and industrial test locations**
    - » **data reduced to define "active" corrosion time and the relative humidity and temperature, during which RH $\geq$ 70 %**
  - **localized corrosion modeled with a pitting factor**
    - » **assumed the pitting factor (fp) normally distributed with a mean of 4 and a standard deviation of 1**

General Corrosion Depth vs Time of Corrosion-Allowance Material in Humid-Air and the Model Fit (TSPA-1995)

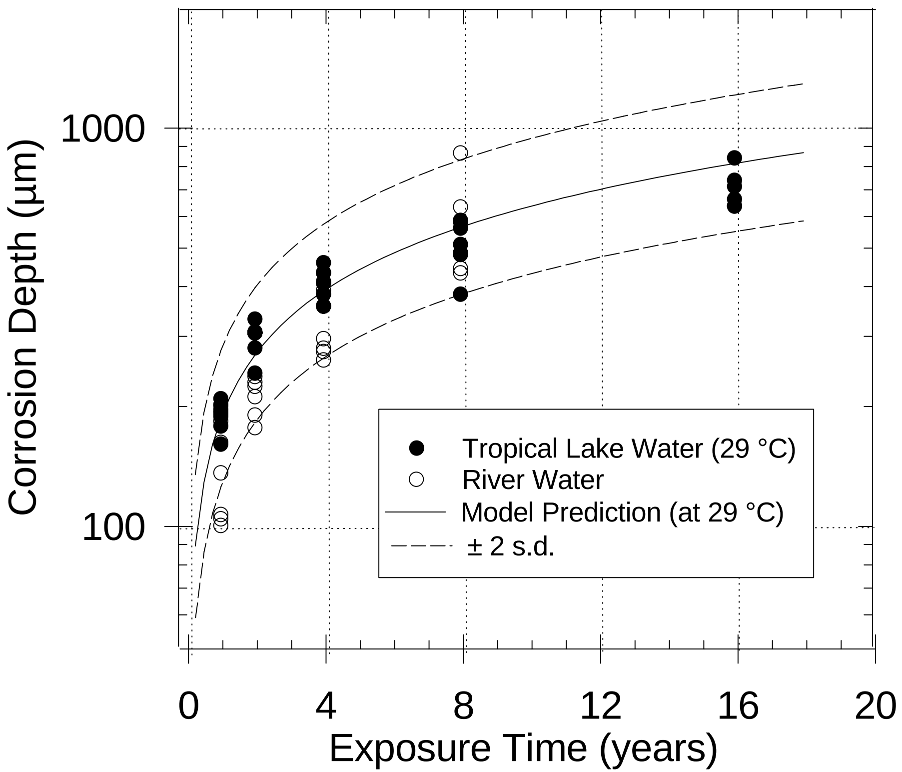


Waste Package Degradation Modeling in TSPA-1995

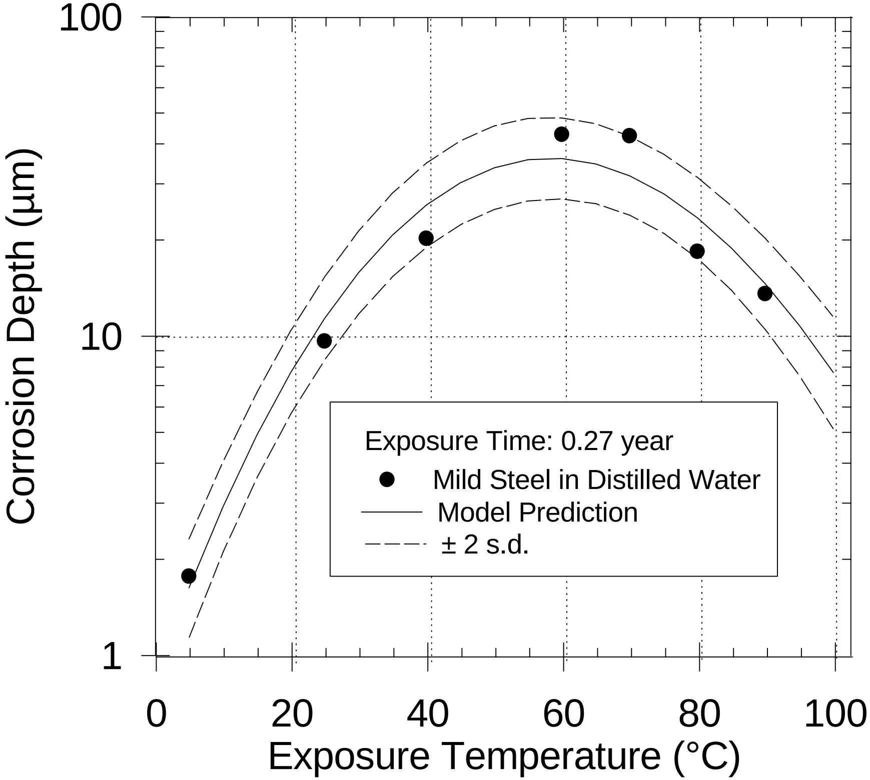
(continued)

- **Aqueous corrosion of carbon steel outer barrier**
  - **aqueous general corrosion modeled as a function of time and temperature**
    - » **included data from tropical lake water and polluted river water (up to 16 years)**
    - » **Included short-term laboratory data in distilled ('clean') water for temperature-dependency**
  - **localized corrosion modeled with a pitting factor**
    - » **assumed the pitting factor (fp) normally distributed with a mean of 4 and a standard deviation of 1**

General Corrosion Depth vs Time of Corrosion-Allowance Material in Water and the Model Fit (TSPA-1995)



General Corrosion Depth vs Temperature of Corrosion-Allowance Material in Water and the Model Fit (TSPA-1995)

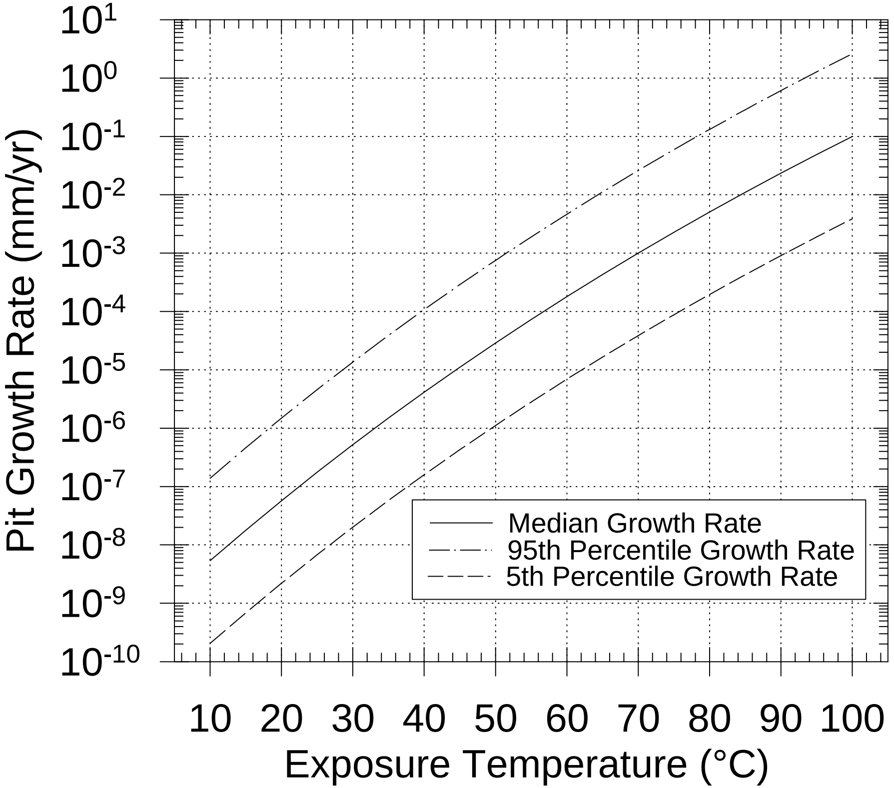


Waste Package Degradation Modeling in TSPA-1995

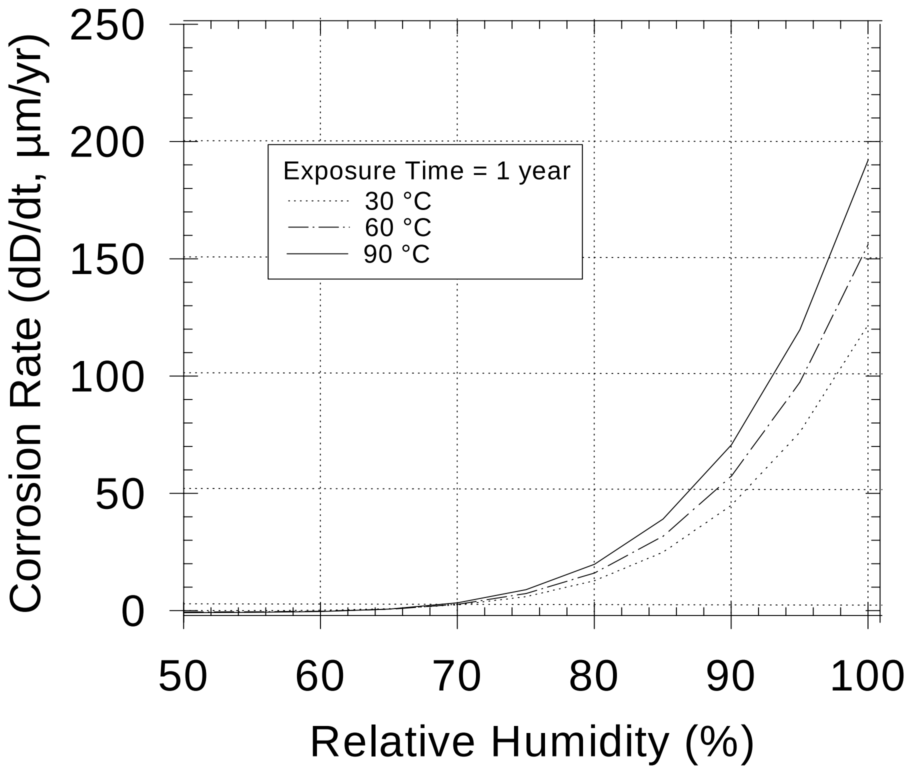
(continued)

- **Corrosion-resistant Alloy-825 inner barrier**
  - **aqueous pitting corrosion modeled with "constant" pit growth rate model**
    - » **the pit growth rate model developed from the same expert elicitation employed in TSPA-1993**
    - » **pit growth rate varies with temperature and is log-normally distributed**
  - **modeled galvanic protection of inner barrier with the model elicited from the project expert (D. McCright)**
    - » **delay the inner-barrier pitting corrosion until the thickness of corrosion-allowance outer barrier reduced by 75%**

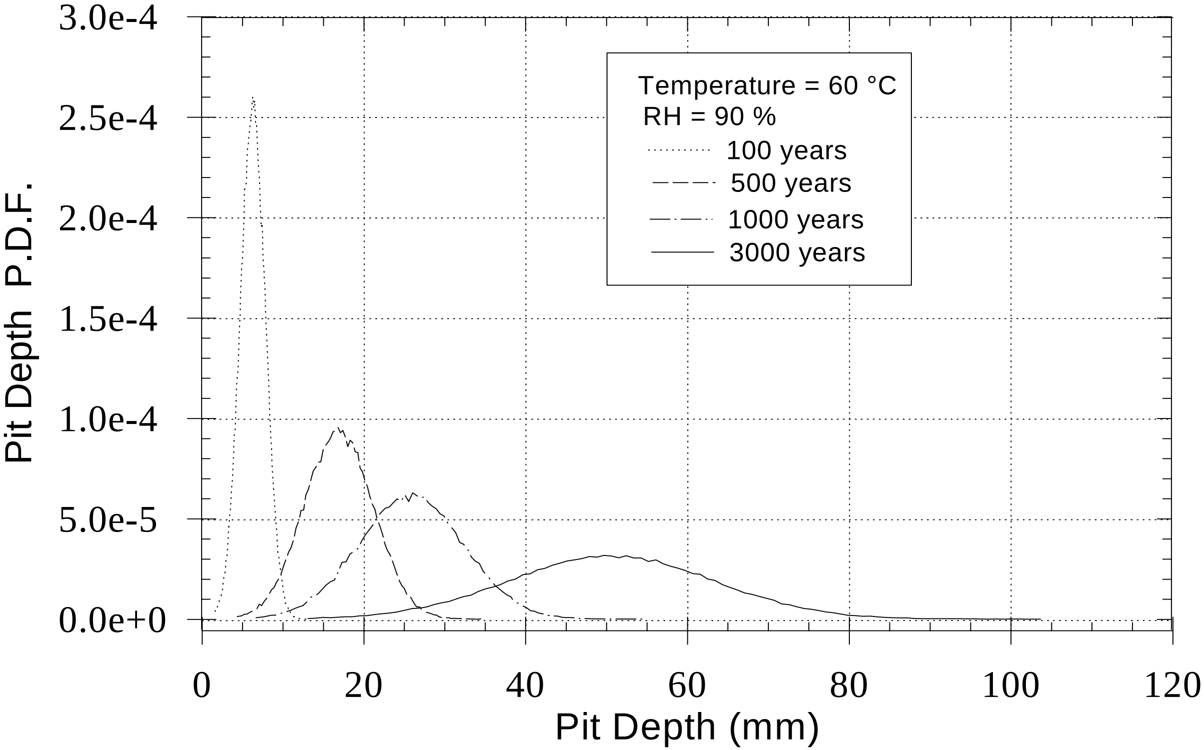
Pit Growth Rate vs Temperature of Corrosion-Resistant Inner Barrier in Aqueous Condition (TSPA-1995)



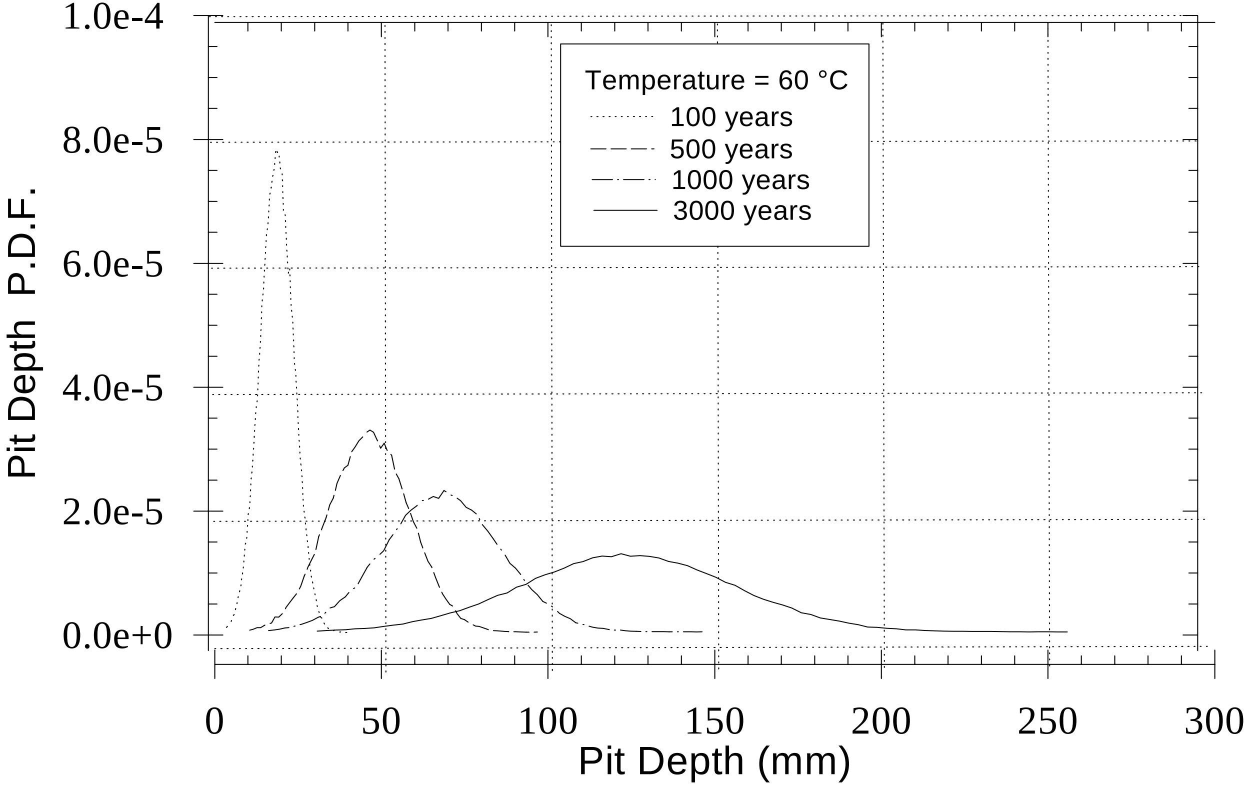
Predicted General Corrosion Rates of Corrosion-Allowance Material in Humid-Air vs Relative Humidity and Temperature (TSPA-1995)



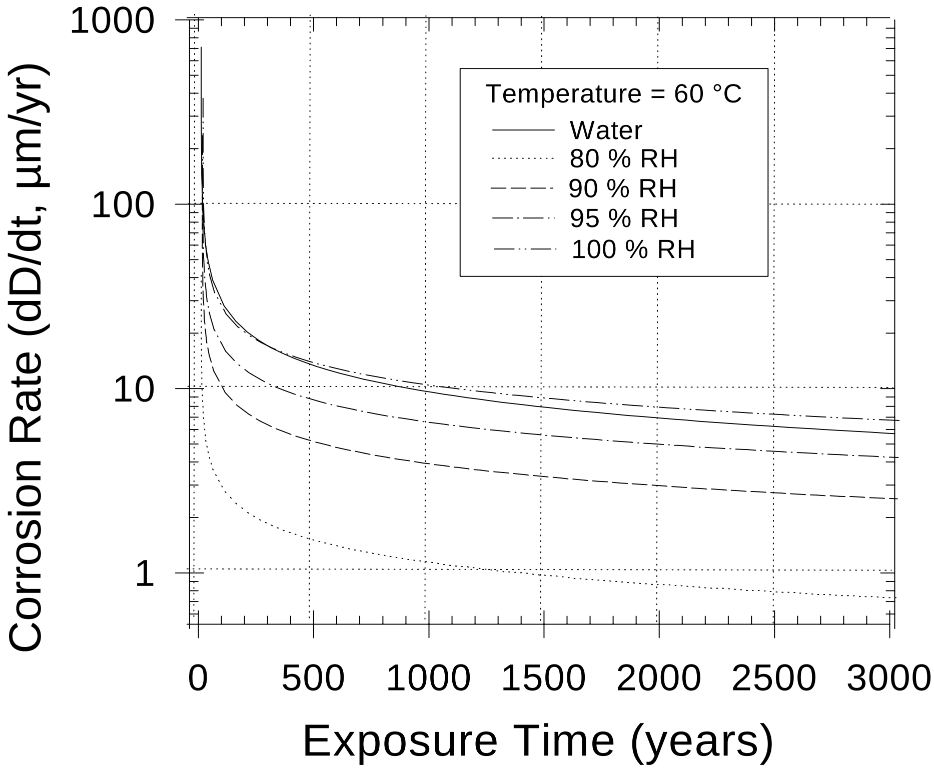
Predicted Pit Depth Distribution of Corrosion-Allowance Material in Constant Humid-Air Condition Using Expected Values of Model Parameters (TSPA-1995)



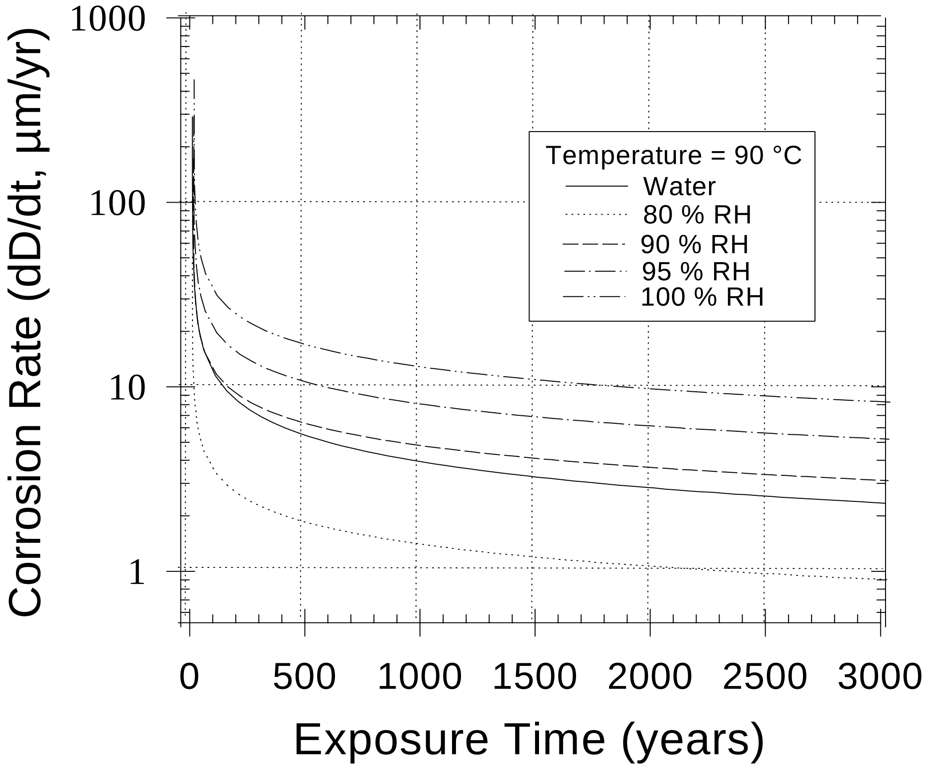
Predicted Pit Depth Distribution of Corrosion-Allowance Material in Constant Aqueous Condition Using Expected Values of Model Parameters (TSPA-1995)



Comparison of Predicted General Corrosion Rates of Corrosion-Allowance Material in Humid-Air and Aqueous Conditions (TSPA-1995)



Comparison of Predicted General Corrosion Rates of Corrosion-Allowance Material in Humid-Air and Aqueous Conditions (TSPA-1995)



Representation of Uncertainty and Variability in Waste Package Degradation in TSPA-1995

- About 12,000 waste packages across the repository
  - variability in exposure conditions (T, RH, water dripping, water chemistry) across the repository (WP-to-WP variability)
  - variability in exposure conditions (T, RH, water dripping, water chemistry) within a single waste package (pit-to-pit variability)
  - uncertainty in the conceptual model of waste package degradation and individual corrosion models

Representation of Uncertainty and Variability in Waste Package Degradation in TSPA-1995

(Continued)

- **Represented WP-to-WP variability and pit-to-pit variability by equally splitting the variability in the individual corrosion models**
  - **humid-air corrosion model for carbon steel outer barrier**
  - **aqueous corrosion model for carbon steel outer barrier**
  - **aqueous pitting model for Alloy 825 inner barrier**

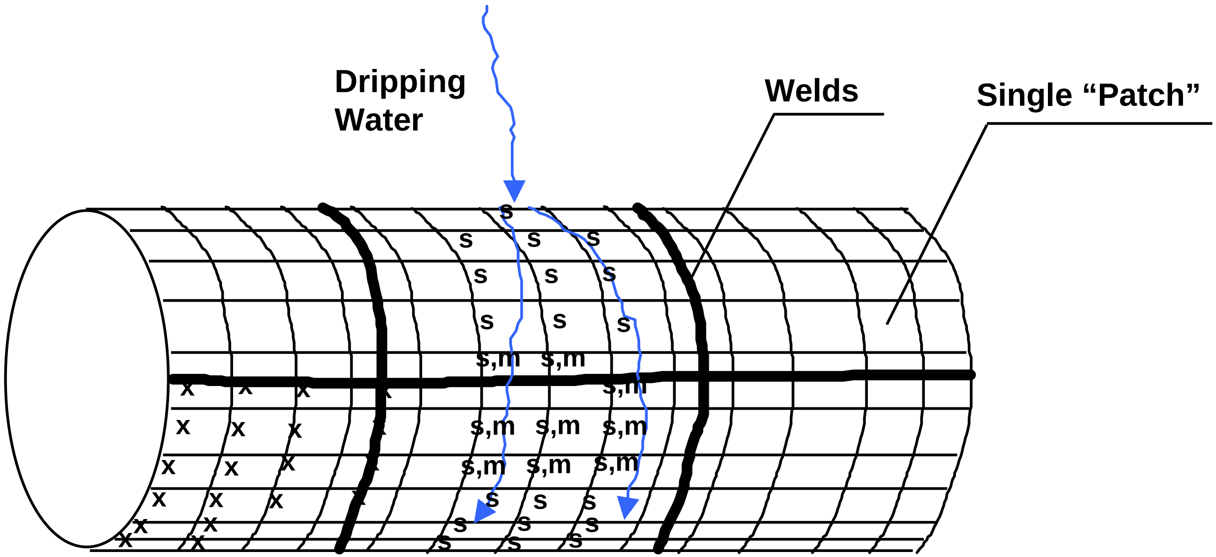
Major Assumptions in Stochastic Waste Package Degradation Modeling in TSPA-1995

- Initiate corrosion at temperature below 100 °C
- Initiate humid-air corrosion of carbon-steel outer barrier at relative humidity between 65 and 75% (uniformly distributed)
- Start aqueous corrosion at relative humidity between 85 and 95% (uniformly distributed)
- Corrosion-resistant inner barrier subjected to aqueous pitting corrosion only
- A pit density of 10 pits/cm^2 assumed for both the outer and inner barriers

Schematic of the Conceptual Model for WP Degradation Modeling and Abstraction for TSPA-VA

* T, RH, in-drift water dripping across repository from drift-scale T-H model

* pH, [Cl$^-$] of dripping water, P(O_2), across repository from NFE model



s - Patches w/ drips

x - Patches w/o Galvanic Protection

m - Patches w/ MIC

Patches w/ welds