NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: WASTE PACKAGE DEGRADATION MODELING AND ABSTRACTION FOR TSPA-1995

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Objectives

- Assimilate relevant corrosion degradation data for similar containment barrier materials in similar environments
- Develop corrosion models for the containment barrier materials
- Implement the corrosion models and their uncertainties to develop detailed waste package degradation simulation model
- Develop abstractions for waste package degradation for TSPA model
  - Use drift-scale thermal-hydrology results
  - Determine distribution of initial pit penetrating waste container
  - Determine distribution of pits penetrating waste container
Objectives
(continued)

- Investigate the sensitivity of waste package performance to different conceptual models
  - Cathodic protection
    - Delay the inner barrier pitting until the corrosion-allowance outer barrier thickness reduced by 75 %
  - Alternative thermal-hydrologic models
    - This study vs Buscheck’s model (LLNL)
  - Thermal load
  - Corrosion initiation
  - Infiltration rate
  - Backfill
## Waste Disposal Container Design

<table>
<thead>
<tr>
<th></th>
<th>Large MPC</th>
<th>HLW Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>21 PWR or 40 BWR Spent Fuel Assemblies</td>
<td>4 Pour Canisters</td>
</tr>
<tr>
<td><strong>High-Thermal Load</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner Barrier</td>
<td>Alloy 825 (20 mm)</td>
<td>Alloy 825 (20 mm)</td>
</tr>
<tr>
<td>Outer Barrier</td>
<td>Carbon Steel (100 mm)</td>
<td>70/30 Cu-Ni Alloy (50 mm)</td>
</tr>
<tr>
<td><strong>Low-Thermal Load</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inner Barrier</td>
<td>Alloy 825 (20 mm)</td>
<td>Alloy 825 (20 mm)</td>
</tr>
<tr>
<td>Middle Barrier</td>
<td>Carbon Steel (100 mm)</td>
<td>70/30 Cu-Ni Alloy (50 mm)</td>
</tr>
<tr>
<td>Outer Barrier</td>
<td>Monel 400 (1)</td>
<td>Monel 400 (1)</td>
</tr>
</tbody>
</table>

Alloy 825: Corrosion Resistant Material (CRM)
Carbon Steel: Corrosion Allowance Material (CAM)
Monel 400 and 70/30 Cu-Ni Alloy: Moderately Corrosion Resistant Materials (MCRM)
Sources: Controlled Design Assumption Document, Rev. 1 (M&O, 1995)
Doering (M&O IOC LV.WP.TWD.5/95.182, 1995)

(1) Recommended that the third barrier not be included in waste package performance analysis (Doering, 1995).
Stochastic Waste Package Performance Simulation Model

General Corrosion Model

Pitting Corrosion Model

CAM Humid-Air Corrosion Models Including Uncertainty

Drift-Scale Temperature & RH History

Stochastic Waste Package Degradation Simulation Module

Waste Package "Failure"

Waste Package Degradation History

EBS Radionuclide Transport Model

General Corrosion Model

Pitting Corrosion Model

CAM Aqueous Corrosion Models Including Uncertainty

CRM Aqueous Pitting Corrosion Model Including Uncertainty
Approach to Waste Package Degradation Simulation

- General Corrosion
- Humid-Air Corrosion of CAM
- Pitting Corrosion of CAM
  - Aqueous Pitting Corrosion of CRM
  - Cathodic Protection
- Waste Package "Failure" Time
  - Waste Form Alteration
  - Radionuclide Mobilization
  - Radionuclide Release
- Substantially Complete Containment
- Controlled Release
- Waste Package Degradation History

Controlled Waste Package : Release Degradation History

Complete Waste Package : Waste Form Alteration

Radionuclide Mobilization
Development of **Humid-Air** Corrosion Models for Corrosion-Allowance Barrier Material

- Develop general corrosion model as a function of time, humidity, and temperature

\[
\ln D_g = a_0 + a_1 \ln t + a_2/RH + a_3/T + a_4[\text{SO}_2]
\]

- 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 from marine test locations not included
- Data reduced to define “active” corrosion time and the relative humidity and temperature during which \(RH \geq 70\%\)
Development of **Humid-Air** Corrosion Models for Corrosion-Allowance Barrier Material

(Continued)

- Develop pitting corrosion model

\[ D_p = f_p \cdot D_g = \text{normal}(4,1) \cdot D_g \]

- Assume the pitting factor 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

- Corrosion Depth (μm)
- Exposure Time (years)

- Model Prediction for 15 °C; 84 % RH; 90 μg SO₂/m³

- SO₂ ≤ 70 μg/m³
- SO₂ > 70 μg/m³

± 2 s.d.
Predicted Pit Depth Distribution of Corrosion-Allowance Material in Constant Humid-Air Condition Using Expected Values of Model Parameters

Temperature = 60 °C
RH = 90%

- 100 years
- 500 years
- 1000 years
- 3000 years

Pit Depth (mm)
Development of **Aqueous** Corrosion Models for Corrosion-Allowance Barrier Material

- Develop general corrosion model as a function of time and temperature
  \[ \ln D_g = a_0 + a_1 \ln t + \frac{a_2}{T} + a_3 T^2 \]
  - 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

- Develop pitting corrosion model
  \[ D_p = f_p \cdot D_g = \text{normal}(4,1) \cdot D_g \]
  - Assume the pitting factor 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

![Graph showing corrosion depth vs exposure time for Tropical Lake Water, River Water, and model prediction. The graph includes data points and lines indicating the model's fit at 29 °C.](image-url)
General Corrosion Depth vs Temperature of Corrosion-Allowance Material in Water and the Model Fit

Exposure Time: 0.27 year
- Mild Steel in Distilled Water
- Model Prediction
- ± 2 s.d.
Predicted Pit Depth Distribution of Corrosion-Allowance Material in Constant \textit{Aqueous} Condition Using Expected Values of Model Parameters

![Graph showing predicted pit depth distribution with various temperature and time conditions, indicating the impact of temperature and time on pit depth distribution.](JOONTRB15.125.NWTRB.PPT4/10-17-95)
Development of Aqueous Pitting Corrosion Model for Corrosion-Resistant Barrier Material

- Incorporate “constant” pit growth rate model for corrosion-resistant barrier (Alloy 825)
  - The same model as in TSPA-1993 (developed from expert elicitation)
  - Pit growth rate varies with temperature and is log-normally distributed
Pit Growth Rate vs Temperature of Corrosion-Resistant Inner Barrier in *Aqueous* Condition

![Graph showing pit growth rate vs temperature with different percentile growth rates and exposure temperature scales.](image-url)
Major Assumptions in Stochastic Waste Package Degradation Simulation

- Initiate humid-air corrosion of corrosion-allowance outer barrier at relative humidity between 65 and 75 percent (uniformly distributed)
- Start aqueous corrosion at relative humidity between 85 and 95 percent (uniformly distributed)
- Corrosion-resistant inner barrier subjected to aqueous pitting corrosion only
- Represent pit-to-pit variability and WP-to-WP variability by equally splitting the uncertainties in the corrosion models
Waste Package Performance vs Cathodic Protection
RH & T Switch for Corrosion Initiation; 83 MTU/acre; No Backfill; High Infiltration Rate

Cumulative Fraction of WPs with 1st Pit Penetration vs Exposure Time (years)
Waste Package Performance vs Alternative Thermal-Hydrologic Models

This Study: 25 MTU/acre; No Backfill; High Infiltration Rate
Buscheck's Model: 24 MTU/acre; No Backfill; No Infiltration

Cum. Fraction of WPs with 1st Pit Penetration vs Exposure Time (years)
Representative Pitting Histories of 25 Waste Packages
RH & T Switch for Corrosion Initiation; Without Cathodic Protection;
83 MTU/acre; No Backfill; High Infiltration Rate

Exposure Time (years)

Fraction of Pits Through Container Wall

10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6}

JOONTRB21.125.NWTRB.PPT4/10-17-95
Summary and Conclusions

• The current waste package design appears to meet the substantially complete containment requirement within the conditions of the degradation modes, assumptions and near-field environments considered in the simulation.

• Cathodic protection of the inner barrier by the outer barrier has significant impacts on waste package performance.

• In future TSPA
  – Substantiate the inner barrier pitting model and cathodic protection model
  – Include stress-corrosion cracking of the inner barrier
  – Include potential effects of microbiologically influenced corrosion