YUCCA MOUNTAIN PROJECT

Studies

Waste Package Degradation Expert Elicitation: Process and Summary of Results

Presented to:
Nuclear Waste Technical Review Board

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Waste Package Degradation Expert Elicitation (WPDEE)

OBJECTIVES

- **To quantify uncertainties in key aspects of waste package degradation process model**
- **Use panel of experts to provide perspective and experience**
- **Provides a ‘snapshot’ of uncertainties; not a replacement for data**
- **Part of series of expert elicitations being conducted for TSPA-VA**

Members Of The Expert Panel

Dr. Peter L. Andresen, GE Corporate R&D

Dr. Joseph C. Farmer, Lawrence Livermore National Laboratory

Dr. Brenda J. Little, Naval Research Laboratory, Stannis Space Center

Dr. R. Daniel McCright, Lawrence Livermore National Laboratory

Dr. John R. Scully, University of Virginia

Dr. David W. Shoesmith, Atomic Energy of Canada Limited

Waste Package Degradation Expert Elicitation (WPDEE) Process

STEPS FOLLOWED:

- **Expert Selection**
- **Data Workshop #1: Issues and Available Data**
- **Data Dissemination**
- **Workshop #2: Alternative Models and Interpretations**
- **Field trip to ESF**
- **Elicitation Training**
- **Workshop #3: Preliminary Expert Interpretations**
- **Elicitation Interviews**
- **Feedback**
- **Documentation**

Summary of Key Assessments

Corrosion Allowance Material (CAM)

- Dry oxidation (thickness of layer, spalling potential)
- Relative thresholds for humid air corrosion and aqueous corrosion
- Importance of drips
- Corrosion modes (general vs. high-aspect ratio pitting)
- Geometry of corrosion processes
- Pit density and pit diameter
- Corrosion rates

Corrosion Resistant Material (CRM)

- Galvanic protection
- Pit density, pit diameter
- Pit/crevice growth rates

Other Issues

- MIC: conditions required, mechanisms, impact
- Ceramic coating
- Stress corrosion cracking

Recommendations for Additional Work to Reduce Uncertainties

Assumed Environmental and Design Conditions

ENVIRONMENTAL CONDITIONS

- **Temperature**
- **Relative Humidity**
- **Water Seepage Flux**
- **Water Chemistry**
  - Chloride concentration
  - pH
  - Oxygen and carbon dioxide fugacities

DESIGN CONDITIONS

- **Waste Package**
- **Materials/Alloys**
  - CAM: carbon steel, or Monel 400
  - CRM: alloy 625, or C-22
- **Mechanical Loads**
- **Fabrication and Assembly**
- **Radiation/Waste Package Shielding**

Summary of Key Assessments Corrosion Allowance Material (CAM)

1. Dry oxidation of carbon steel

- Most experts expect a very thin oxide layer to develop during dry, hot period
- Differences of opinion regarding spalling potential
- Oxygen depletion may be significant

2.Temperature threshold for corrosion of CAM

3.Relative humidity thresholds for humid air corrosion and aqueous corrosion

4.Importance of drips

- Location, frequency, persistence of drips is very important
- Drips on hot package will evaporate and leave salts/saturated solutions
- Alkaline solutions from dripping through concrete liner

5.Corrosion modes

- Neutral pH (4-9): general corrosion
- High pH ($\geq$10): high-aspect ratio pits

6.Geometry of corrosion processes

- Top of package (upper 90-180°) subject to drips, high pH, salts
- Bottom of package may experience bulk water conditions

Summary of Key Assessments Corrosion Allowance Material (CAM)

(cont'd.)

7. Pit density and pit diameter

8. Corrosion rates (general corrosion and pits)

- **Corrosion rates follow this form**:

  $$\textbf{Rate} = C_G + C_L\, t^n$$

where C_G is the general corrosion (passive dissolution) rate, C_L is the rate of localized growth, n specifies the nature of decay with time

  – **C_G for CAM from TSPA-95, includes temperature dependence and RH**

Summary Of Key Assessments
Alternative CAM: Monel 400

1. Corrosion Modes

- General corrosion without deep pits

2. Pros and Cons

- General corrosion rates lower than carbon steel
- Passive in most environments, including high pH

* Resistant to SCC and hydrogen embrittlement

* May undergo dealloying in presence of MIC

* Fewer data to establish rates than carbon steel

Summary Of Key Assessments Corrosion Resistant Material (CRM)

1. Galvanic Protection
    - Extent determined by throwing power, function of ion conductivity and geometry of CAM penetration
    - Throwing distance: millimeters to few centimeters
    - Neutral conditions: expose large CRM surfaces, galvanic protection for tens of years
    - High pH, CAM pits: few hundreds of years for expected aspect ratios
2. Corrosion Modes
    - General corrosion under expected bulk environmental conditions
    - Expected localized corrosion mode is crevice corrosion, perhaps pitting
    - Localized corrosion function of Cl^-, pH, Fe^{+3}, T, O_2, other anions, and drips
    - Gap between CAM and CRM may serve as pathway for moisture
3. Pit Density, Pit Diameter
4. Corrosion Rates

Summary Of Key Assessments
Other Issues

1. Microbiologically Influenced Corrosion (MIC)

- Controlled by availability of nutrients, water, and electron acceptors
- <80°C, RH>60% potential for MIC begins
- Iron-reducing bacteria most important organisms for carbon steel
- For CRM, drips are required
- Importance of MIC is in probability of initiation of localized corrosion and pit/crevice density, rather than affect the corrosion rate

2. Welds

- Enhanced potential for SCC can be mitigated by full stress relief anneal
- Don't expect enhanced potential for localized corrosion or MIC

3. Ceramic Coating

- Ceramic coatings subject to cracking and spalling due to mechanical loads
- Volume expansion of carbon steel corrosion products will lead to cracking
- Not recommended

Summary of Key Assessments

Other Issues

(cont'd.)

4. Stress Corrosion Cracking

- Residual stresses due to shrink-fit may lead to SCC; mitigate with larger gap
- Mitigate weld stresses with narrow-gap welding and full stress anneal

5. Radiolysis

- Radioactive decay will have lowered dose by the time conditions reach 100°C and RH 65%

6. Recommendations for Additional Work to Reduce Uncertainties

- Establish near-field environments: drip frequency, volume, and distribution; pH of drips, T, RH
- Testing of carbon steel in high pH conditions to establish pit density, passive dissolution, and growth rate
- Experiments to evaluate localized corrosion initiation and potential for stifling crevices/pits in CRM as function of temperature and materials
- Conduct mass-balance inventory to assess potential for MIC