Issues in the Licensing Review of the Potential Yucca Mountain Repository: Container, Cladding and Waste Form

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Objectives

- Review potential technical issues concerning a waste package (WP - container, cladding and waste form) associated with the U.S. Department of Energy's potential license application for disposal of high-level waste at the proposed Yucca Mountain repository

  - operational safety during the preclosure period and

  - waste isolation during the postclosure period

- Present potential collaboration work with European Commission (EC)

Outline

- Process for Preclosure Safety Analysis
- Processes for Total System Performance Assessment
- Repository Temperature and Waste Package
- Operational Safety (Preclosure)
- Waste Isolation (Postclosure)

Process for Preclosure Safety Analysis

- Areas of Conseideration:
  Engineered Barriers, Waste Package Emplacement, Ventilation,
  Waste Package Transportation, Waste Handling,
  North Portal Surface Facilities, Performance Confirmation
- Event Sequence Analysis
- Normal and Accident Conditions
- Worker Dose
- Public Dose
- Preclosure Safety Analysis (PCSA)

Processes for Total System Performance Assessment

- Normal Processes:

  Climate, Unsaturated Zone Flow, Effects of Decay Heat on Water Movement, In-Drift Physical and Chemical Environment, Water Diversion Performance of the Engineered Barriers, Waste Package and Drip Shield Degradation, Waste Form Degradation and Radionuclide Release, Engineered Barrier System Transport, Unsaturated Zone Transport, Saturated Zone Transport, Biosphere

- Feature, Event and Process (FEP) Analysis

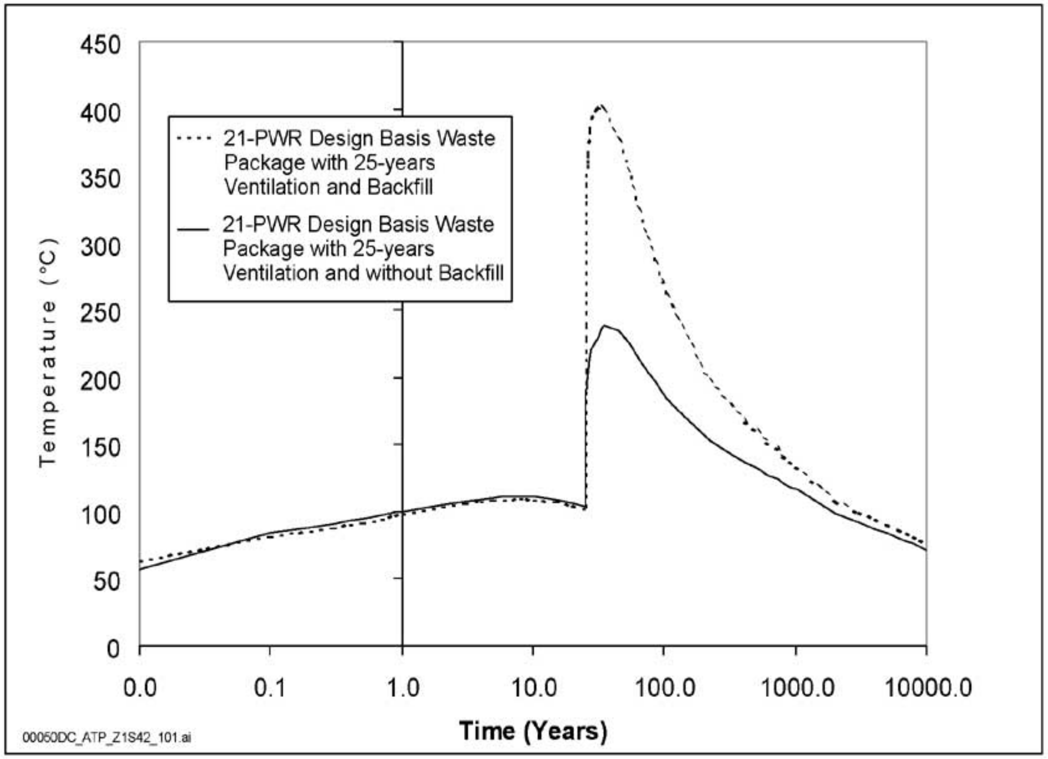
- Nominal and Disruptive Scenarios

- Public Dose: individual, groundwater, human intrusion

- Total-system Performance Assessment (TPA)

Repository Temperature and Waste Package

DOE (2002)



100, 200, 300, 400 °C [212, 393, 572, 752 °F]

- Alloy 22 (w/o):
  Cr (20.0 – 22.5),
  Mo (12.5 – 14.5),
  Co (2.50 max),
  W (2.5 – 3.5),
  V (0.35 max),
  Fe (2.0 – 6.0), Ni (Bal.)

- Ti – 7 (w/o):
  Pd (0.12 – 0.25), Ti (Bal.)

- Ti – 24 (w/o):
  Al (6.0), V (4.0),
  Pd (0.04 – 0.08)

Operational Safety (Preclosure)

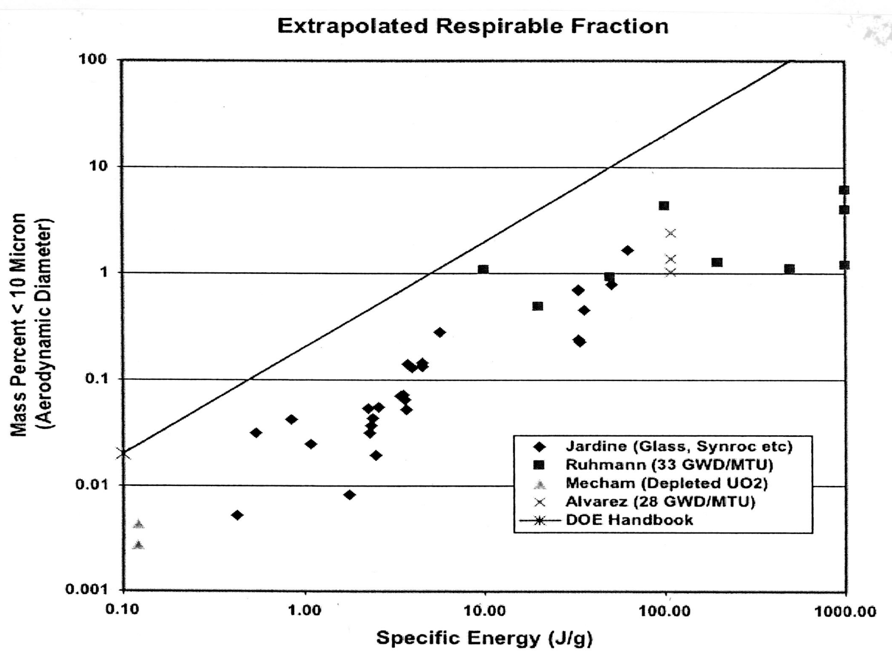
Canister Drop

- Transport, Aging and Disposal (TAD) canister is being considered
- Canister inside canister handling building may need to be sufficiently robust to withstand drop
- Drop height, fabrication defects, canister and internal materials may be important parameters
- For Part 63 (disposal) safety analysis, canister may be partly credited in the PCSA compliance assessment
- Safety of cask (with canister) during transportation and interim storage is reviewed under 10 CFR Part 71 and 72, respectively

Operational Safety (Preclosure)

Source Term

Sanders et al. (1992)



Comparison of the DOE Handbook Respirable Fraction Equation to Experimental Values of the Specific Energy Input into the Brittle Material

- Release Fraction - impact energy, oxidation from UO_2 to U_3O_8, high-burnup
- Leak Path Factor – HEPA efficiency, stack height, building leakage

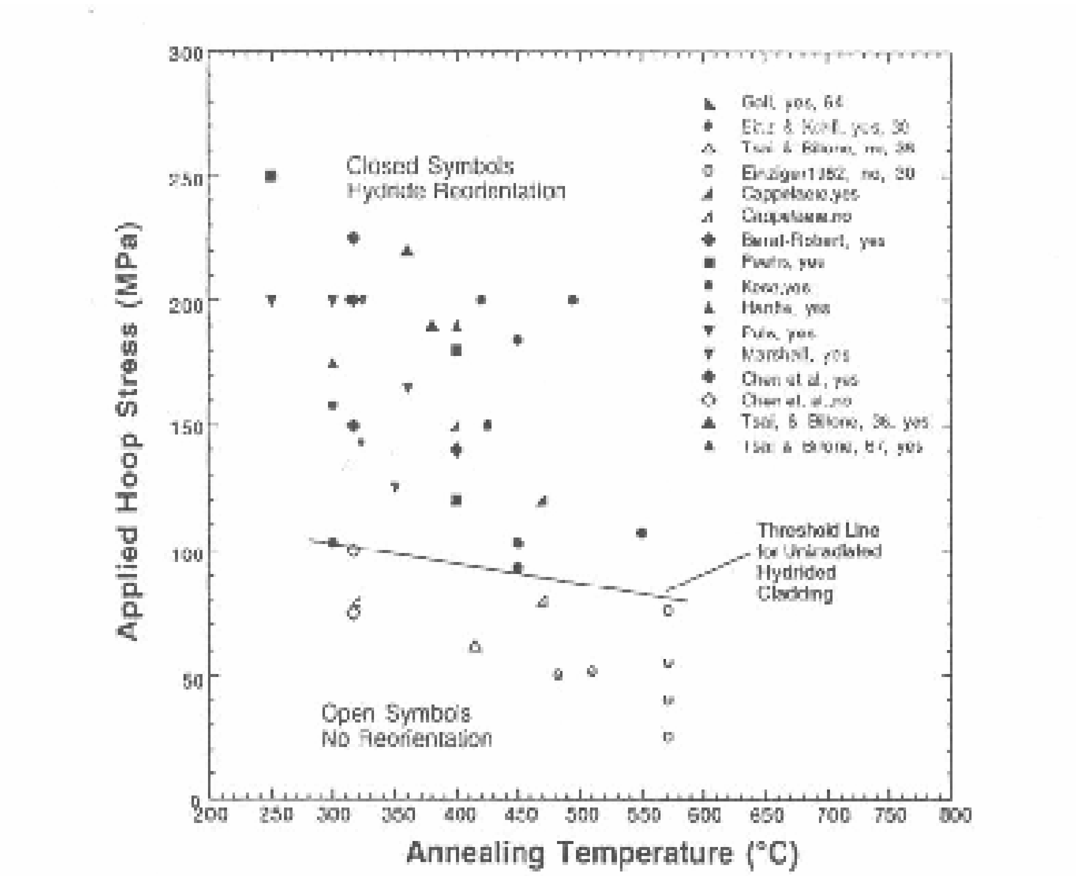
10 μm [$3.9x10^{-4}$ in]

1 J/g [$1.1x10^{2}$ cal/lb]

Operational Safety (Preclosure)

Cladding Integrity

Chung (2004, copyright by the American Nuclear Society, La Grange Park, Illinois)

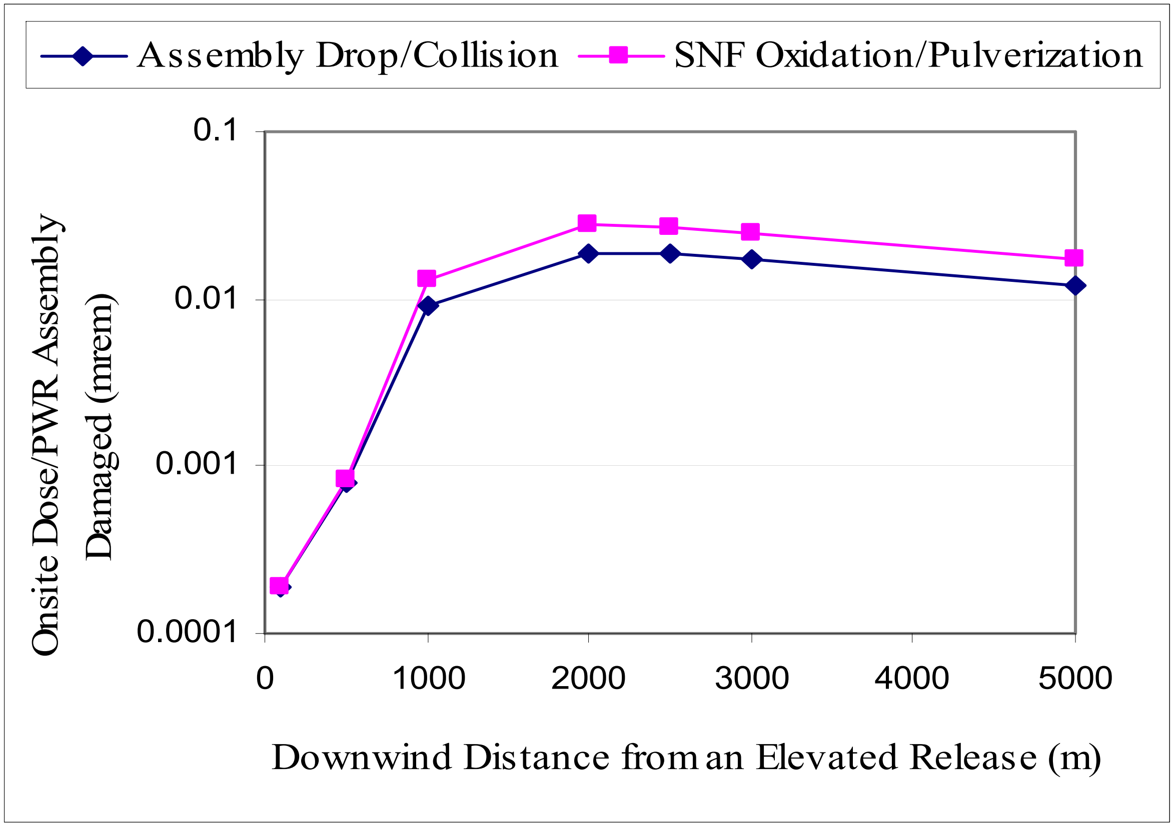


- Detection of pinholes and hairline cracks
- Mechanical vibration - transportation
- Hydride effects – reorientation and delayed hydride cracking (DHC): localized stress by temperature gradient, swelling and Zr/UO_2 interaction

100 MPa [14.5 KSI]

Operational Safety (Preclosure)

PCSA Exercise Results



1000 m [3281 ft]; 1 mrem [10 μSv]

Waste Isolation (Postclosure)

Dust Deliquescence Corrosion of Waste Package

Environments:

- Temperature: 130 to 220 °C [234 to 428 °F] for mixed salts of NaCl, $NaNO_3$ and $NaNO_3$
- Representative drift conditions: ambient pressure, no deaeration

Corrosion Test Results (Yang et al., 2006):

- General corrosion was the major mode of attack for Alloy 22
- General corrosion rate was from 1 to 10 μm/yr [0.39 – 3.9 x 10^{-4} in/yr] at 150 to 180 °C [270 to 356 °F]
- Uncertainties exist in susceptibility to localized corrosion

Waste Isolation (Postclosure)

Persistency in Passive Film

- Accelerated corrosion by passivity breakdown related to localized corrosion, assurance of extremely low general corrosion rates

  - Structural change – micro-structure (crystalline or amorphous), various defects, compact/porous, void

  - Change of chemical compositions

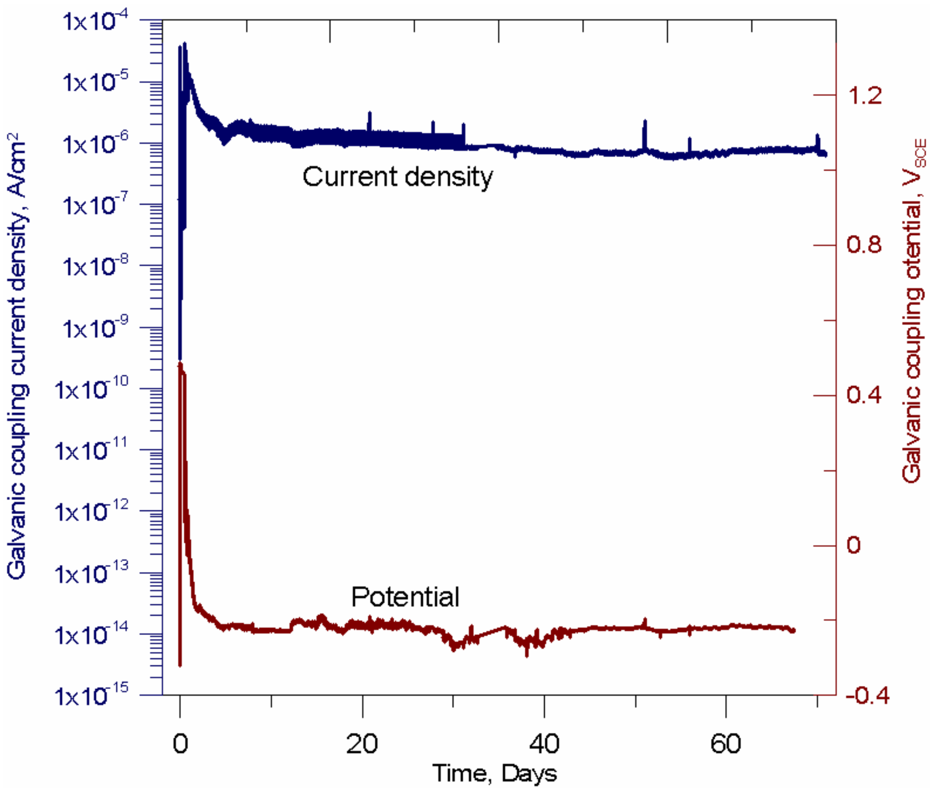
  - Thickness change with time

  - Examples:
    (i) transpassive dissolution
    (ii) anodic sulfur segregation
    (iii) development of porous structure
    (iv) mechanical spallation by void formation at film interface
    (v) development of large cathodic surface area
    (vi) anion selective sorption

Waste Isolation (Postclosure)

Localized Corrosion

Ahn, Pan and others (2006)



- Initiation: corrosion potential > repassivation potential
- Propagation: decrease with time
- Stifling or Arrest
- Restricted Opening Area

1 A/cm^2 [0.5 A/in^2]

Waste Isolation (Postclosure)

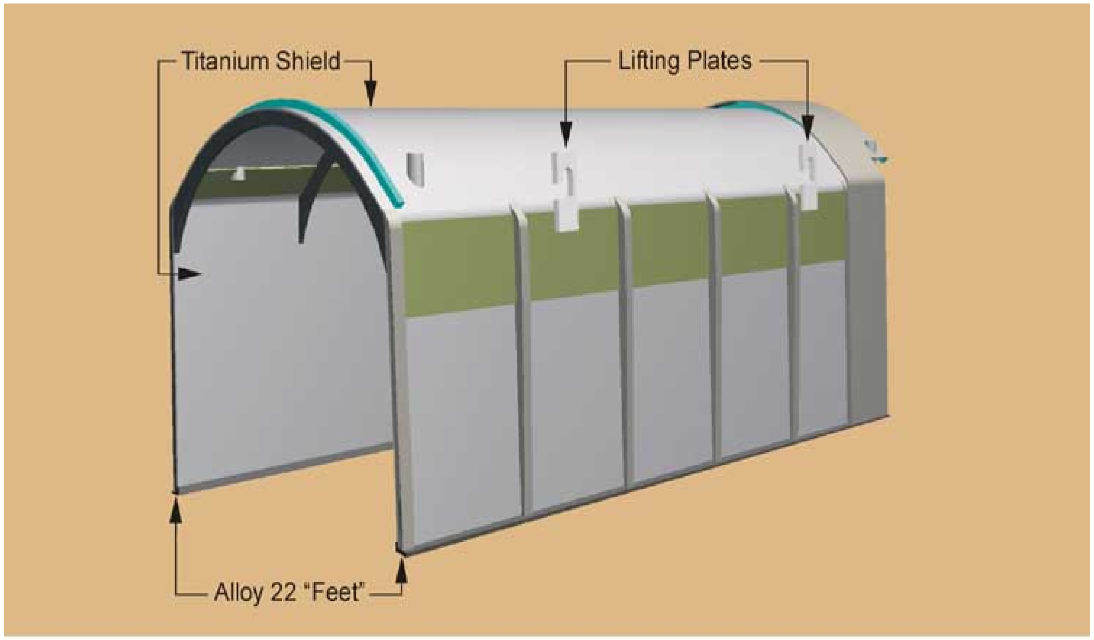
Stress Corrosion Cracking

- Unlikely to happen
- Long-term effects: threshold potential model or K_{ISCC} model
- Screening by crack plugging: corrosion products and mineral precipitation

Waste Isolation (Postclosure)

Titanium Drip Shield

DOE (2002)



Drawing Not To Scale
00033DC_ATP_Z1S24_Fig-03a.cdr

- Uphill hydrogen effects in welds
- Mechanical buckling
- Low temperature creep: twinning and slip
- Dust deliquescence corrosion

Waste Isolation (Postclosure)

Spent Nuclear Fuel (SNF) Dissolution

- Major release modes of Tc-99 and I-129

- Factors affecting SNF Dissolution:

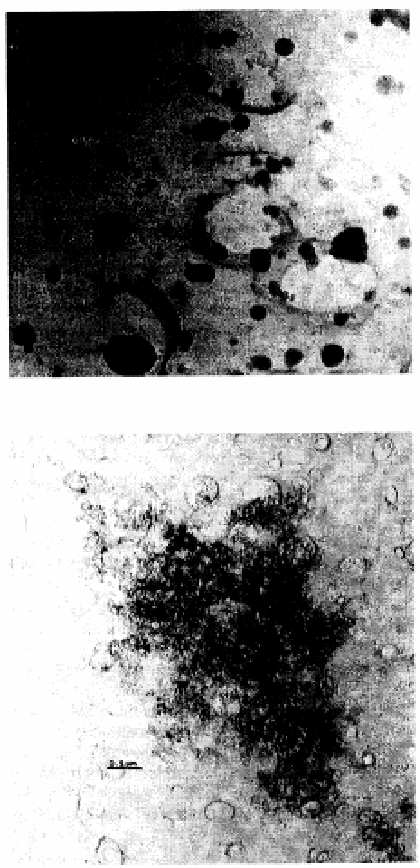
  pH, T, [CO_3/HCO_3], [O_2], [cation, Ca and Si], failed cladding, alteration during dry periods (e.g., hydration and oxidation)

- Important issue: radionuclide (RN) release measurements may include large amount of grain boundary inventory of RNs

Waste Isolation (Postclosure)

Colloids

Bates et al. (1992)



(a)

(b)

- Major carrier of Pu-(239 + 240)

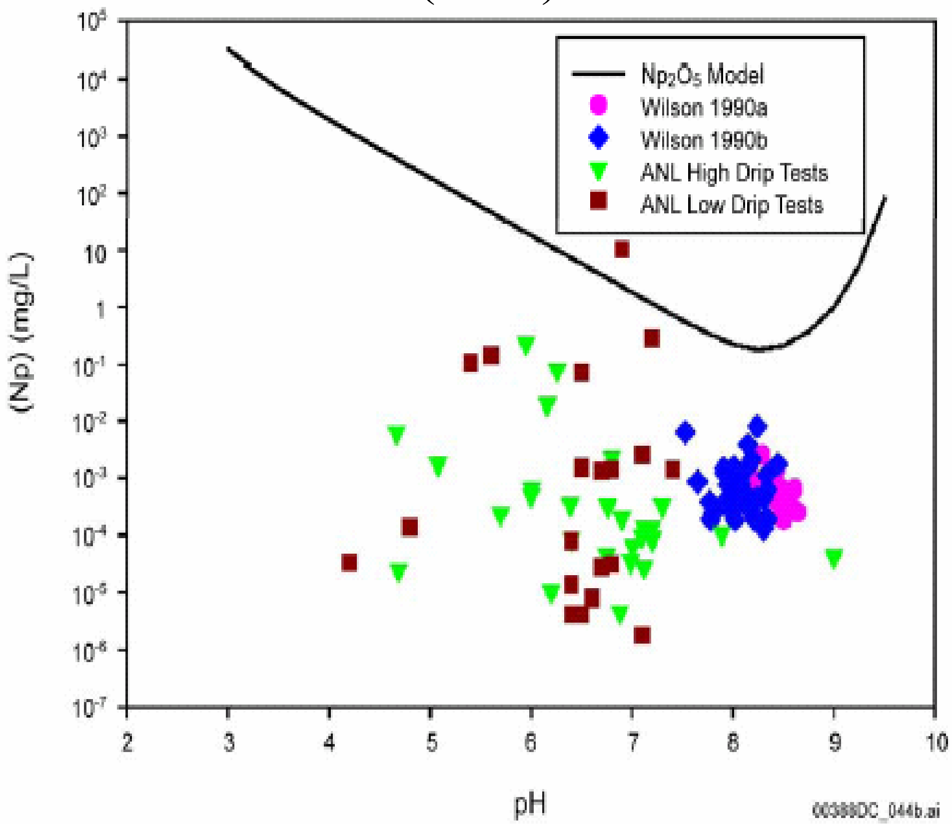
- Types:

  - Waste form: radioactive alteration product colloids, true colloids
  - Pseudo-colloids: reversible and irreversible sorption on nonradioactive colloids
  - Nonradioactive colloids: groundwater colloids, iron colloids from WP internal corrosion

Waste Isolation (Postclosure)

Solubility Limits

DOE (2004)



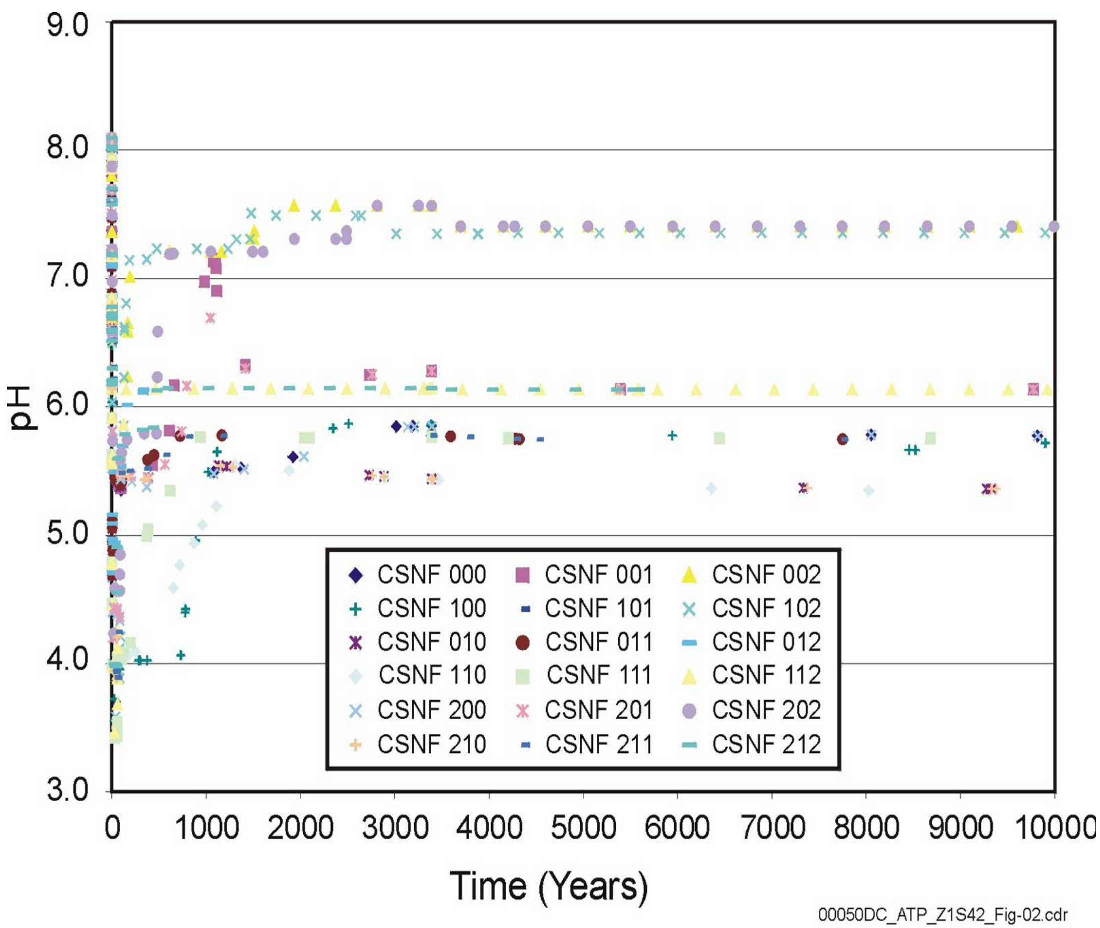
1 mg/L [3.6x10^{-5} lb/in^{3}]

- Major release mode of Np-237
- Controlling factors: pH, T, secondary phase
  - Incorporation of Np-237 in Schoepite or Uranosilicates may substantially decrease the solubility limit

Waste Isolation (Postclosure)

In-Package Chemistry

DOE (2002)

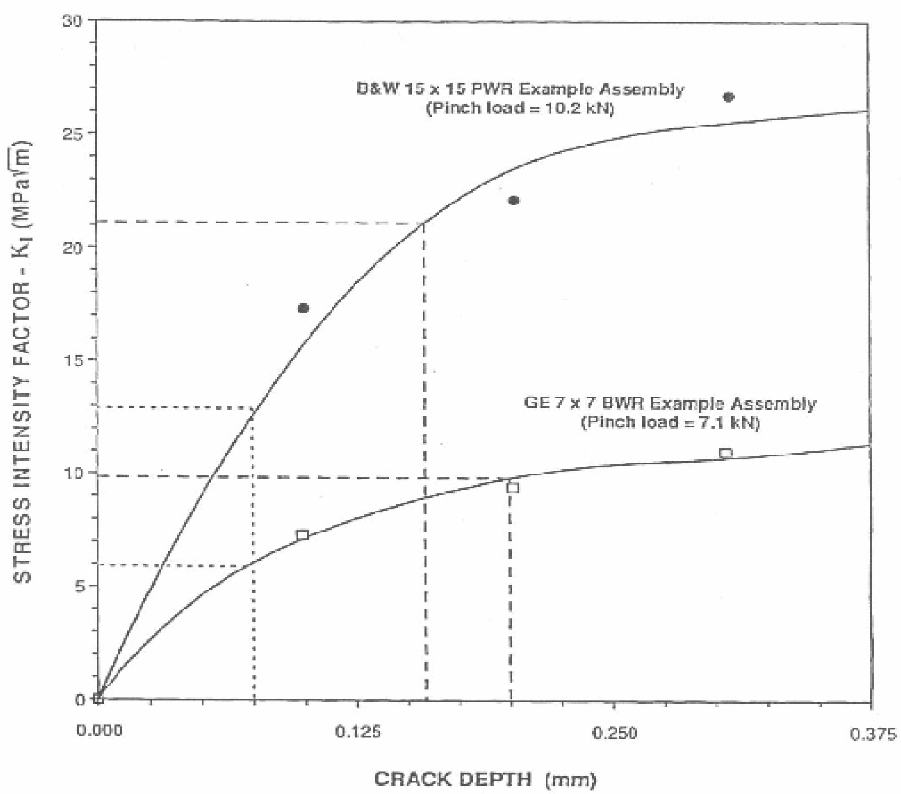


- Affects the dissolution rates of the SNF matrix
- Affects colloid stability
- Affects the solubility limits of radionuclides
- Controlling components: waste form, basket structure, TAD canister, neutron poison

Waste Isolation (Postclosure)

Cladding Performance

Sanders, Seager et al. (1992)

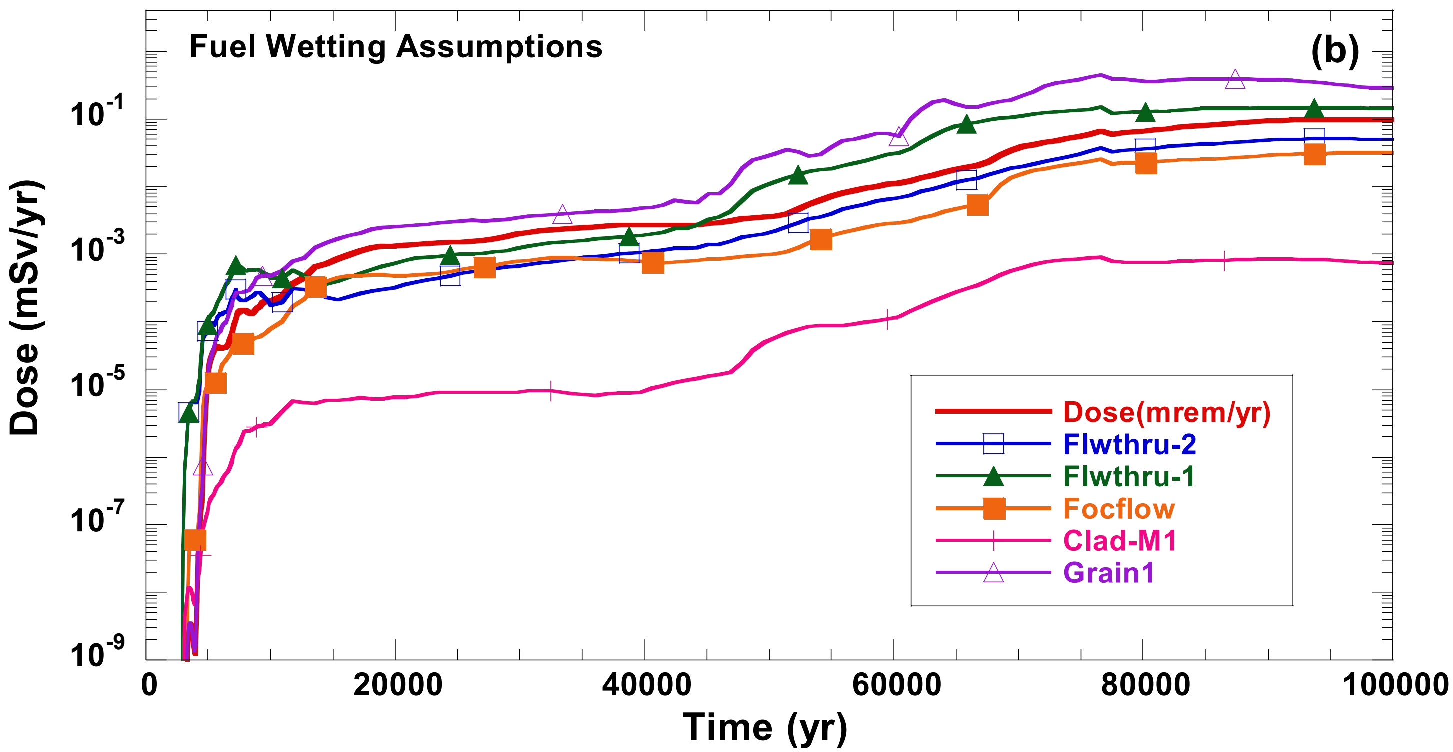


- Hydride effects
  - Cooling rates during postclosure period are much slower than preclosure operation: more susceptible to hydride reorientation
  - Repository may be subject to seismic shaking: more susceptible to delayed hydride cracking

Waste Isolation (Postclosure)

TPA Exercise Results

(Mohanty et al., 2002)



Groundwater Dose from the Basecase and the Fuel-Wetting Alternative Conceptual Models for 100,000 Years, Using the Mean Value Data Set

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Disclaimer

The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of a license application for a geological repository at Yucca Mountain.