6

NRC INSIGHTS ON DESIGN AND WASTE PACKAGE FAILURE

Sitakanta Mohanty
(210)522-5185 (smohanty@swri.org)
Center for Nuclear Waste Regulatory Analyses

Contributors: G. Cragnolino, O. Pensado, S. Brossia (CNWRA)
M. Rahimi (NRC)

May 25-27, 1999
San Antonio, Texas

NRC/DOE Technical Exchange on
Total System Performance Assessments for Yucca Mountain

OBJECTIVES

- Determine
  - Time of Failure of Waste Packages (WPs) Containing Spent Fuel
  - Number of WPs Degraded As a Function of Time
  - Spatial Distribution of Degraded WPs in the Repository
  - Geometry of Failure Due to Degradation That Will Dictate Quantity of Water Contacting SF

FEATURES OF DOE EBS PRELIMINARY DESIGN CONCEPT FOR VA

- WPs Based on Double Wall Over-pack Design Composed of Concentric Containers of Different Materials in a Horizontal Drift Emplacement
- ASTM A516, Grade 55 Steel for Outer Over-pack (100 mm Thick)
- Alloy 22 Material for Inner Over-pack (20 mm Thick)
- Uncanistered WP Containing 21 PWR or 40 BWR Spent Fuel Assemblies With Zircaloy Fuel Cladding
- Possible Use of Drip Shield, Ceramic Coating and Backfill Upon Closure

PRESENTATION OUTLINE

- WP Degradation Modes
  - Initially Defective Failures
  - WP Corrosion - Principal Factor Leading to WP Degradation Mechanical Disruption of Waste Package
    - Fracture of the Outer Overpack Due to Thermal Embrittlement (Treated As a Part of Mechanical Failure Model in TPA)
    - Direct Disruption Due to Faulting and Igneous Activity (Treated Only As a Part of Disruptive Event Scenarios)
    - Rupture Due to Rock Falls Induced by Seismicity in an Unbackfilled Repository
- Process-level Presentations With Technical Basis by
  - N. Sridhar (Initially Defective Failure)
  - G. Cragnolino (WP Corrosion)
  - S. Hsiung (Failure Due to Rock fall)

SYSTEM-LEVEL CONSIDERATIONS

- Implementation of the Models
  - Similar Between TPA and TSPA-VA (Both Use a Stochastic Modeling Approach Inside the PA Code)

- Spatial Distribution of Degraded WPs in the Repository
  - TSPA-VA: Divided Into 6 Subareas (SA), Considers Inter- and Intra-SA Variations
  - TPA:
    - Divided Into 7 Subareas (Not Limited to Seven);
    - Uses Only Inter SA Variations, I.E., Representative WPs Are Evaluated for Each Subarea
    - Variation in Rock Characteristics, Rock Temperature, and Humidity

SYSTEM-LEVEL CONSIDERATIONS (Cont.d)

- Geometry of Failure
  - Geometry Determines Quantity of Water Entering WPs
  - TSPA-VA Primarily Considers a Flow-through Model
  - TPA Considers Bathtub (i.e., Distinct Water Retention Capacity for Each Failure Mode
    - Corrosion: SA-to-SA Variation for Bathtub Height
    - Initially Defective Failure and Rock Fall:- Same Height for All SAs but Variation From Realization to Realization

TPA CONCEPTUAL MODEL APPROACHES

- Corrosion Modes:
  - Dry Air Oxidation (Carbon Steel)
  - Humid Air and Aqueous General Corrosion (Carbon Steel)
  - Aqueous Localized Corrosion (Carbon Steel)
  - Aqueous General and Localized Corrosion (Alloy 22)
- WP Corrosion Affected by Temperature, Humidity and Water Chemistry at Waste Package Surface and Evaluated Using a Combination of Mechanistic Modeling and Experimentally Measured Parameters
  - Temperature Based on Heat Conduction Model
  - Initiation of Humid Air Corrosion and Aqueous Corrosion Determined by Critical Values of RH
  - Chemical Composition of the Aqueous Phase With NaCl As Predominant Soluble Salt, Including pH (As Determined by $[HCO^-_3]$) and Assuming a Constant Value Equal to Partial Pressure of O_2 in Air
- Mechanical Failure of WP Evaluated Using a Fracture Mechanics Approach

TPA CONCEPTUAL MODEL APPROACH FOR CORROSION

- **Corrosion Potential:** $E_{corr} = f(T, pH, C_{O_2}, ...)$
- **Localized Corrosion:** $E_{rp} = f(T, C_{Cl^-}, material)$
- **Condition for Localized Corrosion**
  - **Outer Overpack:** $E_{corr}^{A516} > E_{rp}^{A516}$ **at pH > 9 and [Cl⁻] > 3E-4 mol/L**
  - **Inner Overpack:** $E_{WP}^{C-22} > E_{rp}^{C-22}$ **[Cl⁻] > 1 mol/L**
- **Maximum Pit Penetration Rate for CAM:** $\frac{dP}{dt}(mm/yr) = 3.897t^{-.55}$
- **Pit Penetration Rate for Alloy 22:** $\frac{dP}{dt}(mm/yr) = 2.5E-1$

MAJOR DIFFERENCES BETWEEN TSPA-VA AND TPA MODELING

- Corrosion in the Absence of Water
  - TSPA-VA Considers Insignificant, i.e., Appreciable Corrosion Requires Presence of Water As Either Liquid or Vapor
  - TPA Computes Dry-air Corrosion but the Effect Is Small

- Corrosion in the Presence of Water
  - In TPA, Models Are Based to a Greater Degree on Fundamentals of Electrochemical Corrosion and Experiment Data
    - TPA Model Considers Environmental Factors to a Greater Degree Such As Temperature, Oxygen Partial Pressure, pH and Chloride Ion Concentration.

MAJOR DIFFERENCES BETWEEN DOE AND NRC MODELING

- TSPA-VA Models Include Processes That Are Not Included in TPA Models Such As
  - Dripping on WP
  - Modeling of Pit and Patch Failure Modes (TPA Model Has More Simplistic Failure Modes).
- In TPA, Chemistry is Incorporated Through pH (for Aqueous Corrosion Only) and Chloride Concentration
- In TSPA-VA, for the CAM, Both Humid Air and Aqueous Corrosions Are Functions of Exposure Time and Temperature Whereas Only Aqueous Corrosion Is Modeled As a Function of RH
- In TSPA-VA, Pitting Corrosion Is Incorporated Through a Time Dependent Penetration Rate

TSPA-VA PARAMETERS

- Humid Air Corrosion at 70% <= RH <= 85%
- Aqueous Corrosion at RH >= 85% (Irrespective of the Presence or Absence of the Liquid Water by Dripping or Any Other Mechanism)
- Effect of Elevated pH (>10) and Chloride Ion Not(?) Considered in the TSPA-VA Base Case
- When No Dripping, CRM Undergoes Only Generalized Corrosion
- General Corrosion of CRM Is Essentially Neglected in Humid Air Environment
- Parameter Differences Exist Between NRC and DOE for Those Aspects of Models That Are Similar
  - Corrosion Rates for Corrosion Allowance Material and Corrosion Resistant Material Are Different Than the NRC Values
  - DOE Ranges Sufficiently Wide to Include Alternate Conceptual Models.
  - DOE Relies on Expert Elicitation Based on Sparse Data for Corrosion Rates

carbon steel only

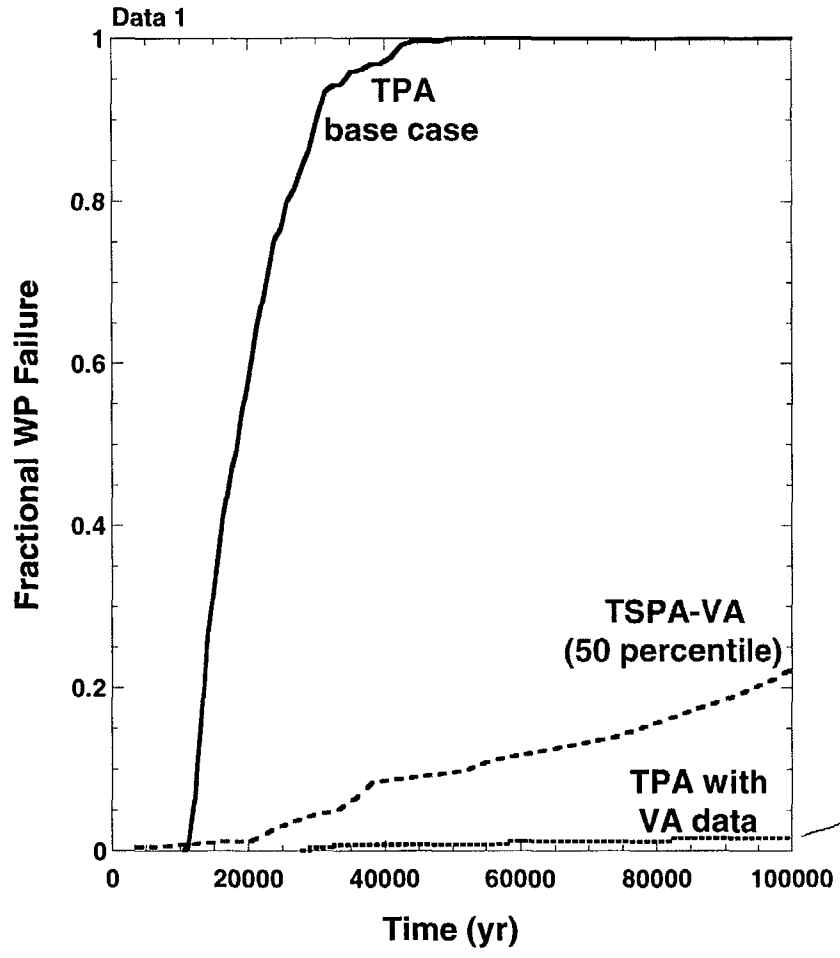
alloy 22 will corrode even without dripping

COMPARISON OF TSPA-VA AND TPA VALUES

Parameters	Emulated Values to Represent TSPA-VA	TPA 3.2 Base Case
Defective Fraction of WPs/subarea	Uniform: 10^{-5} - 10^{-3} (0.06- 6.4 WPs)	Uniform: 10^{-4} - 10^{-2} (0.6 - 64 WPs)
Coefficient for localized corrosion rate of outer overpack	Lognormal: 7.9×10^{-7} - 5.6×10^{-1} (TSPA_VA, Tech. Bas. Doc. Fig. 5-20, P. F5-13)	Uniform: 8.66×10^{-4} - 8.66×10^{-3}
Corrosion rate of C-22 at 100°C and no dripping (AA_2_1)	Lognormal: 4.6 - 6.0×10^{4} C/m^2/yr (1.4×10^{-7} – 1.84×10^{-3} mm/yr) (TSPA_VA, Tech. Bas. Doc. Fig. 5-23, P. F5-14)	Uniform: 2.0×10^{4} - 6.3×10^{4} C/m^2/yr (6.2×10^{-4} – 2.0×10^{-3} mm/yr)

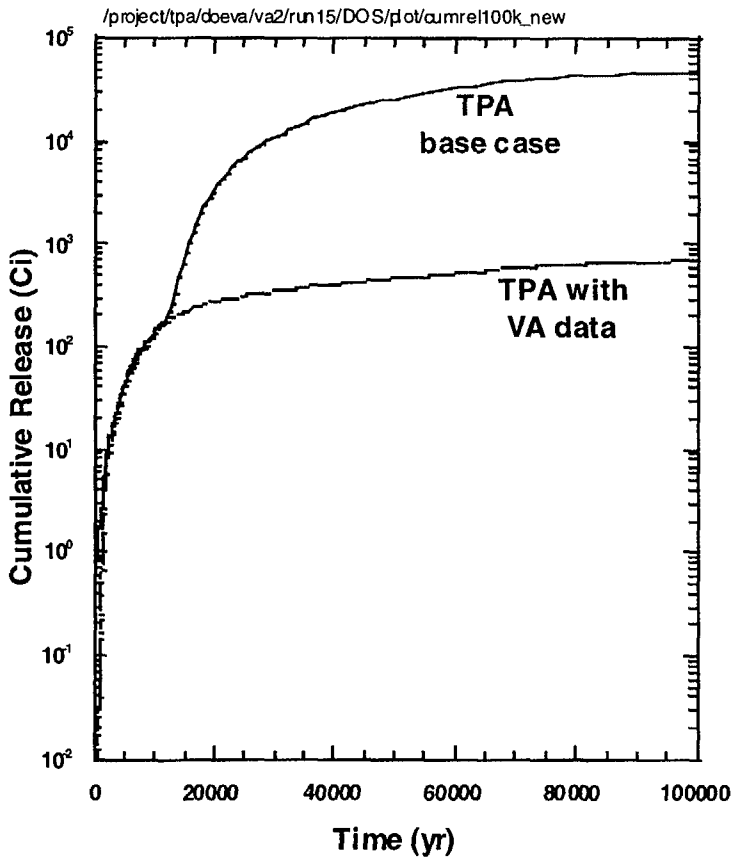
NRC has no mechanism for dripping

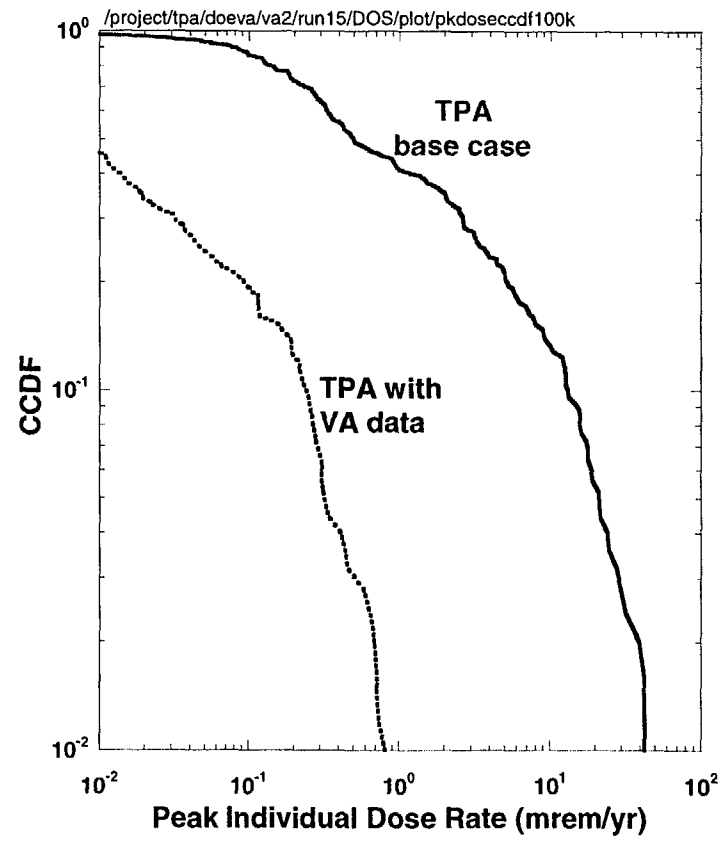
WASTE PACKAGE FAILURE



→ used no dripping condition

CCDF OF PEAK DOSE





SUMMARY

- For Long-lived WPs, Processes Not Included in TSPA-VA and TPA Could Accelerate Corrosion/failure (i.e., Stress Corrosion Cracking, Microbial Activity, Exposure to WP Wet/dry Cycle)

- Both NRC and DOE Acknowledge the Importance of Assessing the Propensity to Corrode the CAM by Exposing to Liquid Water

- Infiltrating Water or Re-circulating Water That Could Penetrate the Boiling Isotherm Could Be Highly Concentrated With Salt That Could Deposit on the WP Surface, Thus Leading to Higher Corrosion Rate

- Both Dripping and Temperature Between 80-100 Degree C Required for Localized Corrosion of the CRM, a Non-conservative Assumption. DOE Recognizes the Possibility of Dripping at RH Under 85%

- Negligible Aqueous Corrosion of C-22 in the Absence of Drip