NRC'S APPROACH TO WASTE PACKAGE DEGRADATION MODELING

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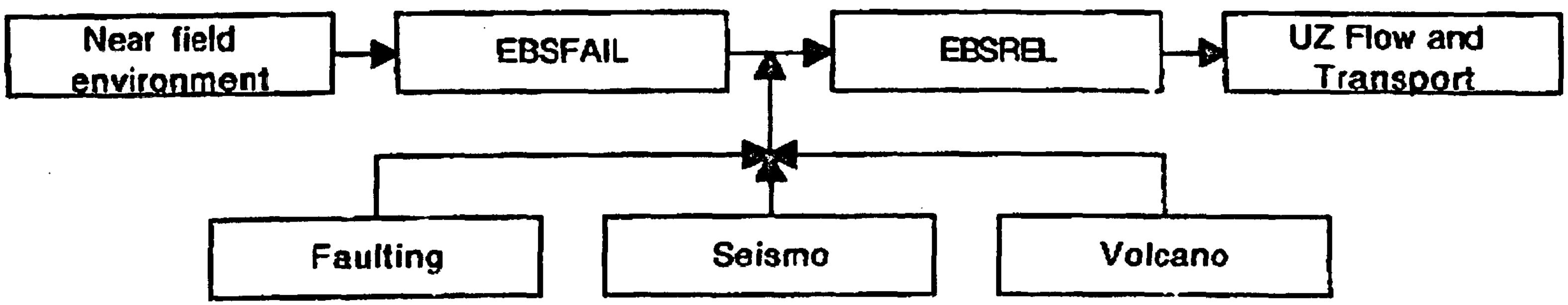
h/m- rd

ENGINEERED BARRIER SYSTEM FAILURE (EBSFAIL) MODULE

- **A consequence module of TPA Version 3.1 code**



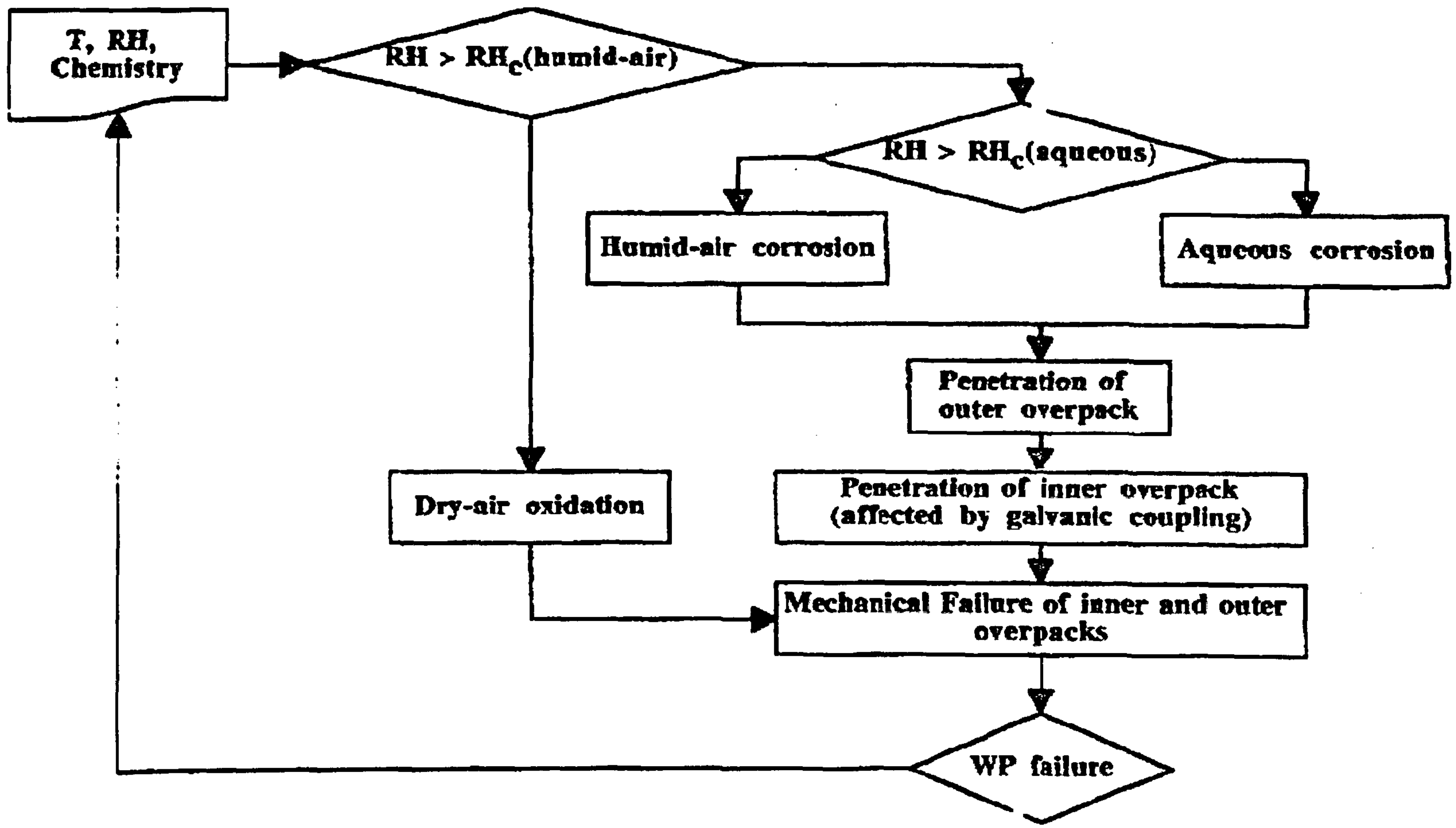
- **A part of Engineering Barrier System Performance Assessment Code (EBSPAC) Version 1.1**

- **Calculates failure time of waste packages (WPs) due to various degradation modes including corrosion and mechanical processes**

FAILURE OF WASTE PACKAGE IN EBSFAIL

- WP failure by corrosion is defined as through-wall penetration of outer and inner overpacks by a single pit or by uniform dissolution
- Modes of WP corrosion:
  - Outer overpack: air oxidation, uniform humid-air and uniform aqueous corrosion, and localized (pitting and crevice) aqueous corrosion
  - Inner overpack: uniform and localized aqueous corrosion
- WP failure can occur by brittle failure due to mechanically dominated processes resulting from fabrication stress
- WP failure can also occur from events modeled outside of EBSFAIL such as fault movement, seismic events, and volcanic events

PROCESS FLOW CHART FOR EBSFAIL



CONCEPTUAL MODEL APPROACHES

- WP corrosion affected by temperature, RH, and water chemistry at WP surface and evaluated using a combination of mechanistic modeling and experimentally measured parameters
  - Temperature based on a heat conduction model
  - RH calculated from water vapor pressure considering temperature difference between the WP surface and drift wall
  - Initiation of humid-air and aqueous corrosion determined by critical values of RH
  - Chemical composition of the aqueous phase with NaCl as the 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

EVALUATION OF LOCALIZED AQUEOUS CORROSION

- **Corrosion potential:** $E_{corr} = f(T, pH, C_{O_2}, \ldots)$

- **Localized corrosion:** $E_{crit} = f(T, C_{Cl}, material)$

- **Galvanic coupling:** $E_{wp}^{825} = (1 - \eta)\, E_{corr}^{825} + \eta\, E_{couple} \qquad 0 \leq \eta \leq 1$

- **Conditions for Localized Corrosion**
  - **Outer overpack:** $E_{corr}^{A516} > E_{crit}^{A516} \qquad at\ pH > 9.0$
  - **Inner overpack:** $E_{wp}^{825} > E_{crit}^{825}$

LOCALIZED CORROSION PENETRATION RATES

- **Maximum pit penetration rate for A516 steel [Marsh & Taylor. Corrosion Science. 28,289-320 (1988)]**

$$\frac{dP}{dt}(mm/yr) = 3.897\ t^{-0.55}$$

- **Pit penetration rate for Alloy 825**

$$\frac{dP}{dt} = 0.18\ \ mm/yr$$

EVALUATION OF WP MECHANICAL FAILURE

- **Stress intensity defined as**

$$K_I = Y \sigma (\pi a)^{1/2}$$

where

Y = **geometry factor, depends on crack shape and load configuration and incorporates a safety factor of 1.4**

σ = **applied stress, assumed to be equal to yield strength for residual stresses in welds**

a = **depth of the crack, assumed to be equal to pit depth**

- **Condition for mechanical failure**

$$K_I > K_{IC}$$

where K_{IC} is the fracture toughness

DIFFERENCES BETWEEN EBSFAIL AND WAPDEG APPROACHES

EBSFAIL	WAPDEG
Combinations of mechanistic models and experimentally measured parameters using laboratory generated database	Empirical models for humid air and aqueous corrosion using parametric equations based on a limited field database (rural and urban atmospheres, lake and river waters)
Near-field chemistry considered	No consideration of near-field environment (except for T and RH)
Penetration by dry oxidation is continued through uniform or localized corrosion under wet conditions	Dry oxidation considered negligible
Mechanical failure of outer overpack by fracture	No mechanical failure considered

DIFFERENCES BETWEEN EBSFAIL AND WAPDEG APPROACHES

EBSPAC	WAPDEG
Penetration of a representative pit through both containers constitutes failure of the WP. No degradation history beyond the penetration of the representative pit	Penetration of the deepest pit from multiple pits, initiated simultaneously but grown stochastically, constitutes WP failure, but degradation continues
Empirical or process-based model for pitting corrosion based on experimentally measured or estimated growth rates	Pitting rate of outer overpack is calculated by multiplying uniform corrosion rate by a sampled factor. Pitting of the inner overpack is calculated from a temperature-dependent equation.
Corrosion failure of all WP in a subarea (SA) occur at the same time	Failure time distribution is due to variations in hydrothermal conditions at various locations.

UNCERTAINTIES IN EBSFAIL

- WP corrosion
  - Temperature of WP and critical relative humidity
  - Water chemistry (Chloride concentration, pH, Oxygen partial pressure)
  - Dissolution rate of alloys under passive and localized corrosion conditions
  - Effectiveness of galvanic protection

- Mechanical disruption of WP
  - Magnitude and location of stress/deformation fields
  - Changes in fracture toughness due to thermal embrittlement

ACTIVITIES FOR ASSESSING EFFECTIVENESS OF GALVANIC COUPLING

- **Improve mechanistic understanding of galvanic coupling**
- **Develop methodology to estimate galvanic coupling efficiency**
- **Simplified modeling used in "An Analysis of Galvanic Coupling Effects on the Performance of High-Level Nuclear Waste Container Material", CNWRA 97-010, August 1997.**
  - **Geometry of galvanic couple defined by pit penetrating outer A516 steel container and exposing alloy 825 to local, acidified environment**
  - **Evaluation of the influence of environmental and electrochemical parameters, in addition to the effect of area ratio, on the efficiency of galvanic coupling**
- **Galvanic corrosion potential for alloy 825 as a function of galvanic coupling efficiency compared with critical potential to determine propensity to localized corrosion**