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A Framework for the Analysis of Localized Corrosion at the Proposed Yucca Mountain Repository

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Presented by:
Dr. Joe H. Payer
Thrust Lead-OST&I Materials Performance
Case Western Reserve University

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- Co-Authors: Joe H. Payer[1], Susan A. Carroll[2], Gregory E. Gdowski[2] and Raul B. Rebak[2]
  - [1]Case Western Reserve University
  - [2]Lawrence Livermore National Laboratory
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Introduction

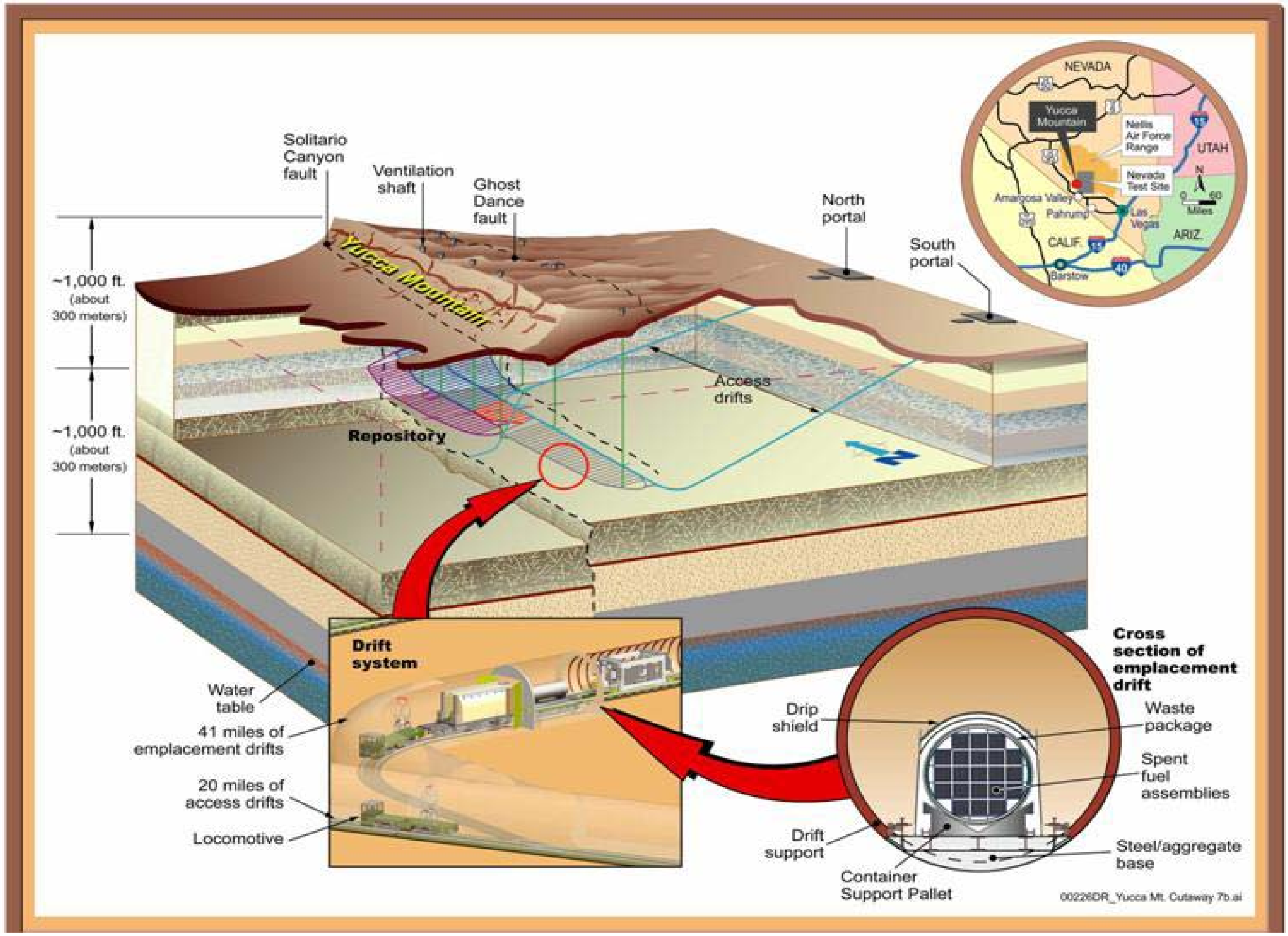
- **Corrosion is a primary determinant of waste package performance at the proposed Yucca Mountain Repository**
  - **The most likely degradation process**
  - **Controls the delay time for radionuclide transport from the waste package**
  - **Determines when packages will be penetrated and the shape size and distribution of those penetrations**
- **In this presentation a framework for the analysis of localized corrosion is presented and demonstrated for a scenario**
  - **Water chemistry of mixed salt solutions (sodium chloride-potassium nitrate)**
  - **Time-temperature-relative humidity profiles for a hot, mid and cool temperature waste package**

Methodology for Determination of Materials Performance

- Materials performance at the proposed Yucca Mountain Repository is amenable to a familiar and effective analytical methodology
  - Widely accepted in the energy, transportation and other industries
- Three components comprise the analysis
  - Definition of the performance requirements
  - Determination of the operating conditions to which materials will be exposed
  - Selection of materials of construction that perform well in those conditions
- A special feature of the proposed Repository is the extremely long time frame of interest, i.e. 10,000's of years and longer
  - Time evolution of the environment in contact with waste package surfaces
  - Time evolution of corrosion damage that may result

The Proposed Yucca Mountain Repository

Repository Reference Design Concept



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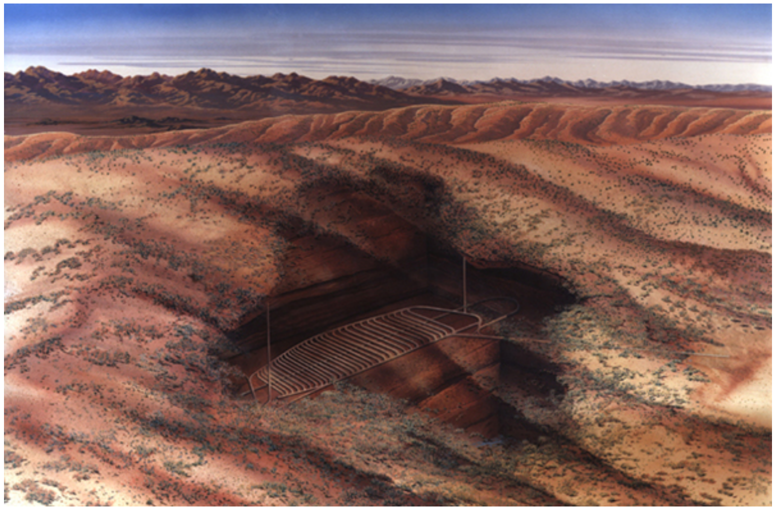
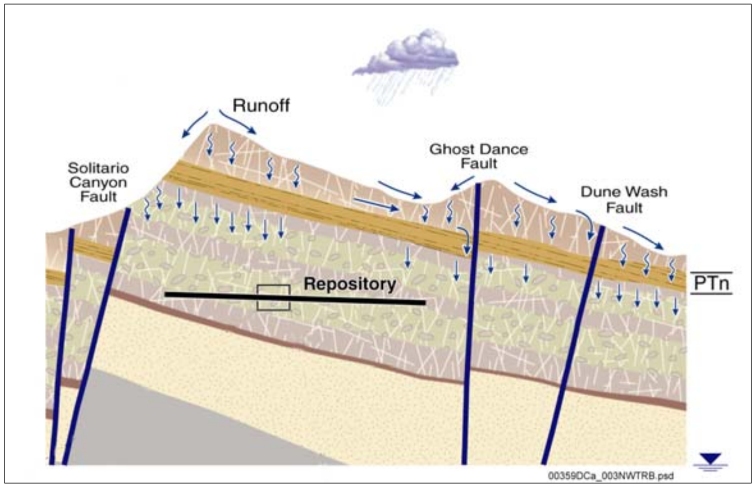
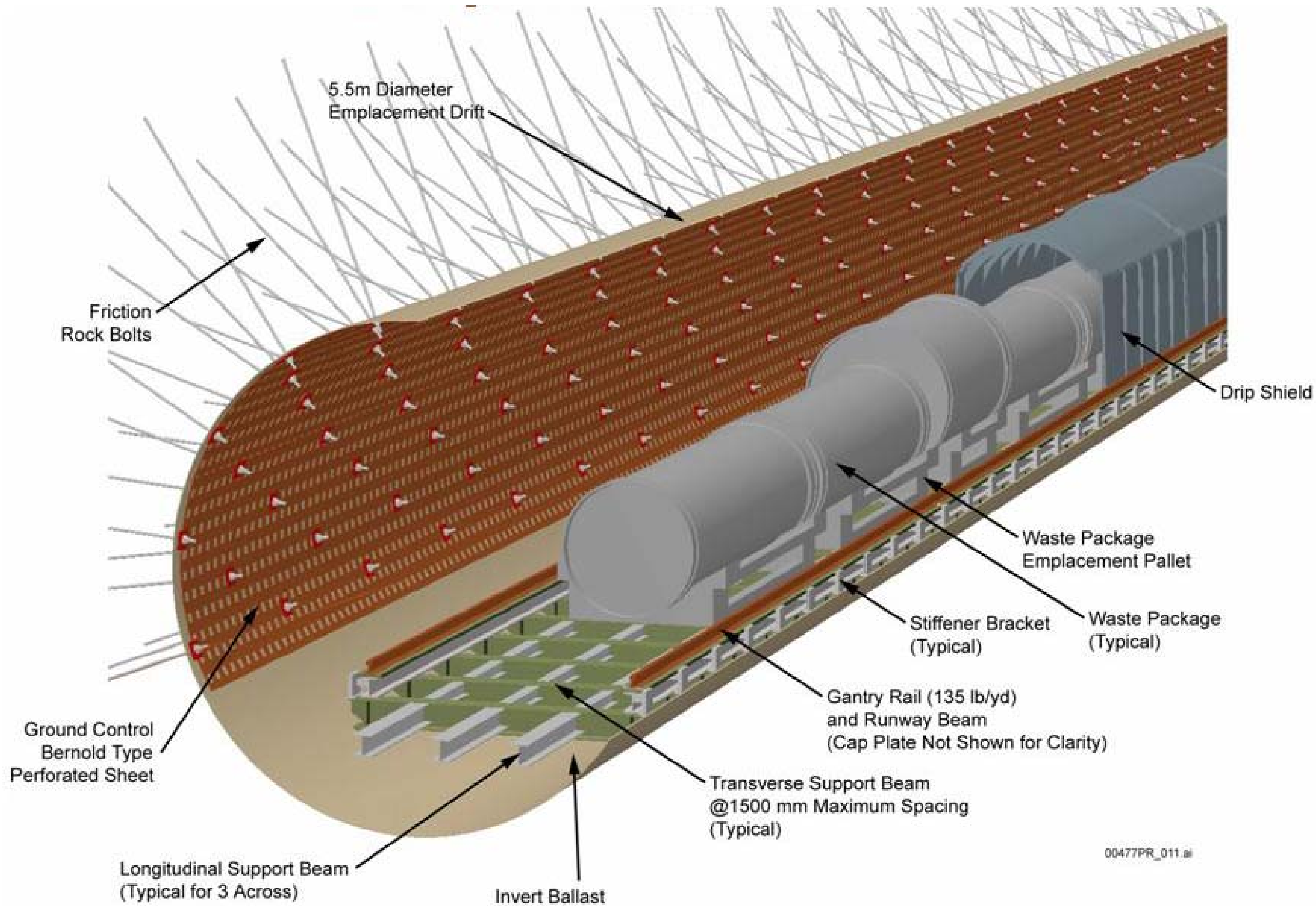
The Proposed Yucca Mountain Repository





- Proposed Repository is about 300 m below the surface and 300 m above the water table
- Unsaturated zone, i.e. fractures and pores in rock are partially filled with water
- Desert area with about 18 cm of rain per year
- Atmospheric pressure
- Ambient waters are dilute and near neutral pH
- Concentrated waters can form by condensation, deliquescence and evaporation

Proposed Emplacement Drift



Background on Ni-Cr-Mo Alloys

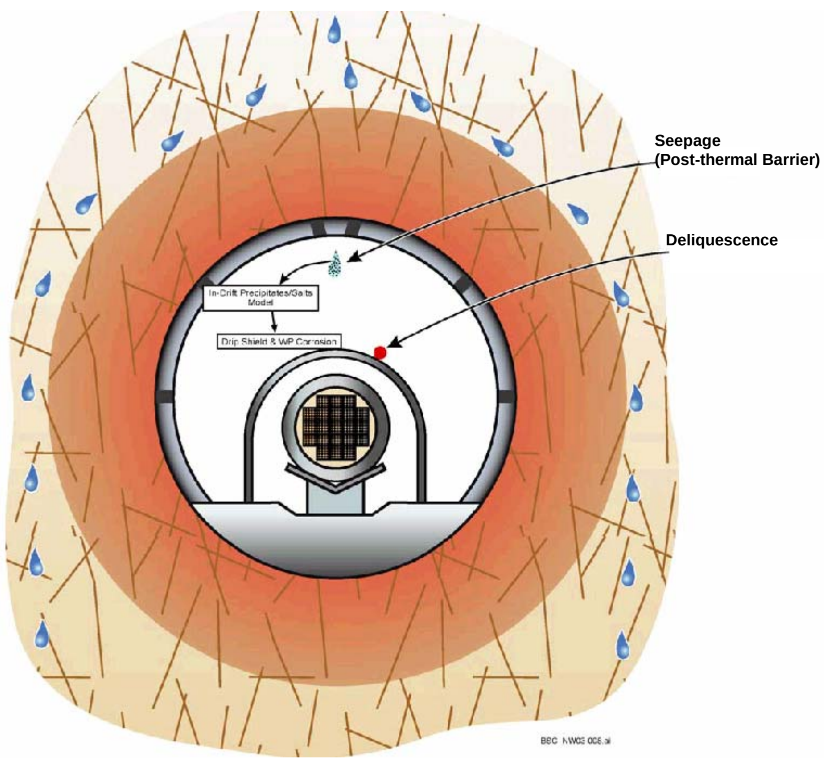
- **Alloy 22 belongs to a family of Ni-Cr-Mo alloys**
  - **Earlier alloys include C-276 and C-4 and later alloys include Inconel 686, Alloy 59, Hastelloy C-2000 and MAT-21**
  - **Alloy 22 (N06022) is a solid solution of Ni, Cr, Mo and W as the main alloying elements**
  - **Cr-Mo-W in Alloy 22 act synergistically to provide resistance to localized corrosion such as crevice corrosion**
- **Large industrial equipment in service for many years in harsh environments without corrosion**
  - **Alloy 22 has great toughness and over 50% elongation before failure**
  - **Can be hot or cold formed and is weldable by many methods**
  - **Can be fabricated into large structures and components**

Corrosion Resistance is Crucial to Waste Package Performance

- **Radionuclides are fully isolated if there are no penetrations**
  - **Even penetrated package can limit radionuclide movement**
- **Corrosion rates of passive metals are extremely low**
  - **Realistic rates are less than 1 μm/yr (a millionth of a meter per year) and much less**
  - **Alloy 22 layer is 2-cm thick (a stack of 12 U.S. quarters)**
- **Corrosion rates of approximately 0.01 μm/year are measured in exposures of over 5-years at the Long Term Test Facility at Lawrence Livermore National Laboratory**

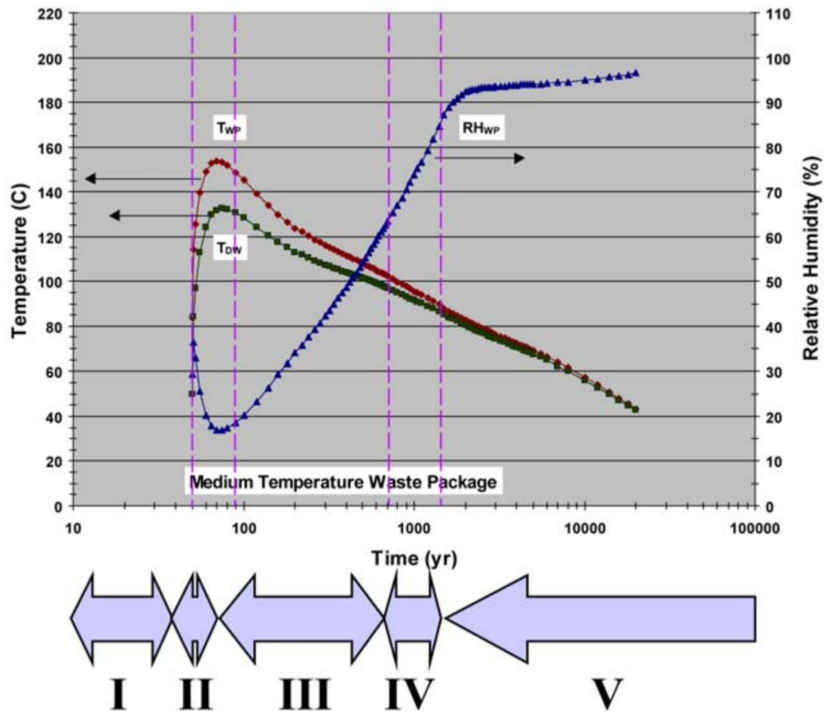
16,000 to 160,000 years to penetrate the thickness of one U.S. quarter for a corrosion rate of 0.1 to 0.01 μm/yr

Attributes of the Proposed Yucca Mountain Repository



- One long, slow heating/cooling cycle
  - Packages cool to ambient over several thousands of years
- Waste packages on support pallets
  - No immersion in waters
- No moving parts
- Low heat fluxes, slow heating and cooling, and modest thermal gradients
- Radiation effects at waste package surface negligible after a few hundred years
- Limited amount of water moving through the rock
- Limited salts and minerals carried into drifts by incoming water and dust

Relevant Time Periods for Corrosion



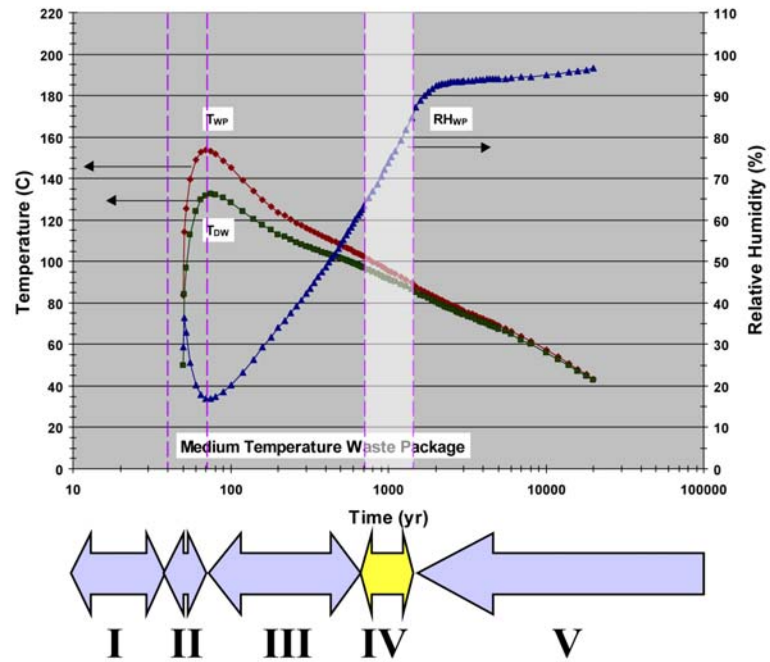
- I - Emplacement of waste packages and preclosure
  - Start to Year 50
- II - Heat Up after closure
  - Year 50 to ~65
- III - Cool down/Thermal Barrier (drift wall above boiling temperature)
  - Year ~65 to 750
- IV - Cool Down/Dripping and Seepage Possible
  - Year 750 to 1375
- V - Waste Packages below Critical Temp for Corrosion
  - Year 1375 and beyond

- This scenario is for Temp-RH shown above
  - Waste Package at 101°C when Drift Wall cooled to 96°C
  - Critical Corrosion Temp 90°C

- Periods are determined by
  - Temperature-RH conditions
  - Time when drift wall reaches 96°C
  - Critical Corrosion Temp for Alloy 22

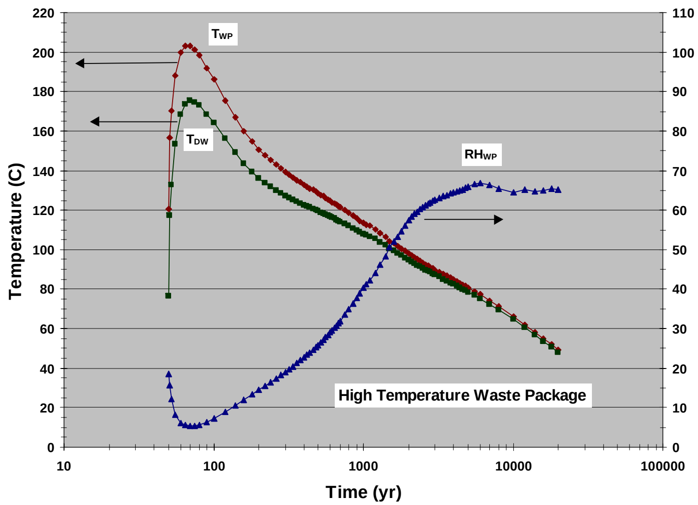
Period IV-Dripping and Seepage Possible

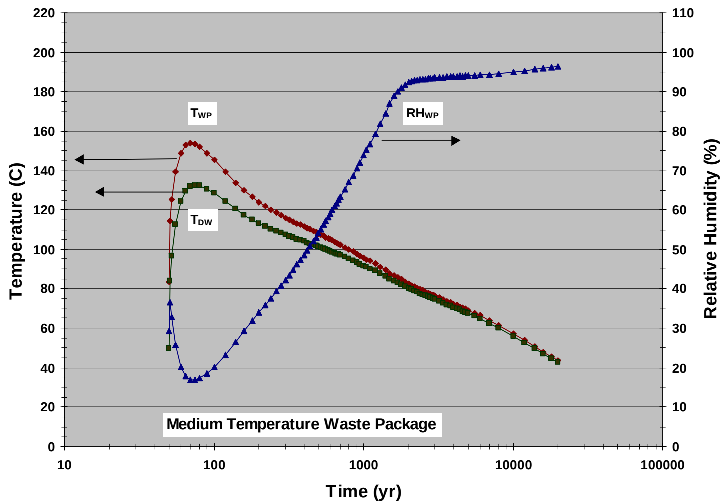
- When drift wall is below boiling temperature (96°C), dripping/seepage can occur
- Dripping/seepage can contact waste package surface
  - Where both capillary barrier and drip shield are inoperative
  - And dripping location is in aligned with drip shield penetration
- When these conditions are met
  - If waste package temperature above critical corrosion temperature
  - Then follow decision-tree analysis for local corrosion damage evolution

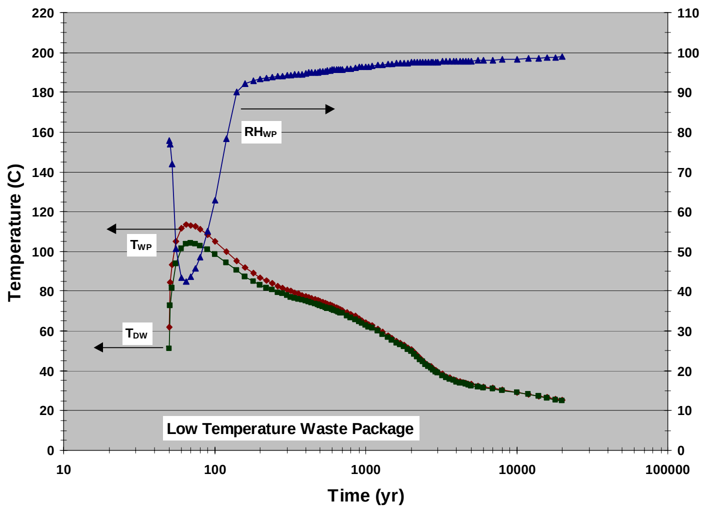


- Drift wall is below boiling at year 750
  - Waste Package at 101°C
  - Relative humidity 65%
- Waste Package is at 90°C at year 1375
  - Relative Humidity 84%

Period IV Conditions for Mid, Hot and Cool Waste Packages

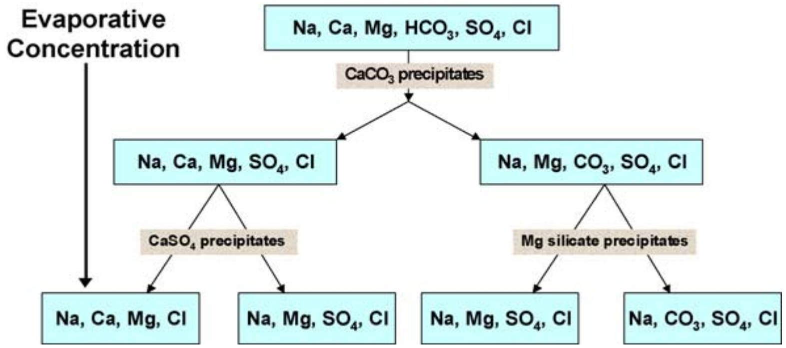


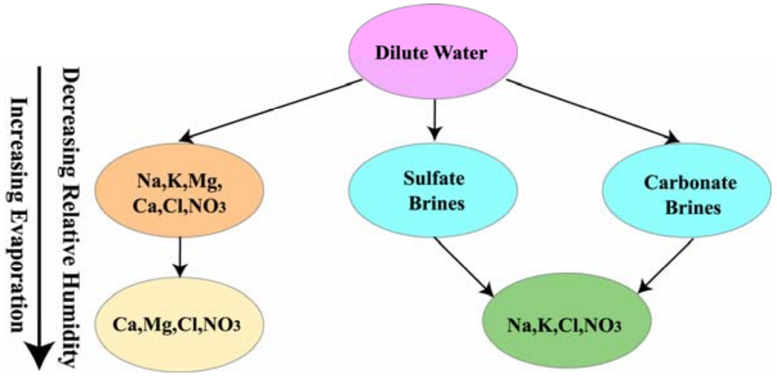




Drift Wall 96°C	Year	Waste Package Temp °C	Relative Humidity	Waste Package at 90°C
Mid WP	700	101	65	1325
Hot WP	1850	99	56	3000
Cool WP	62	102	72	125

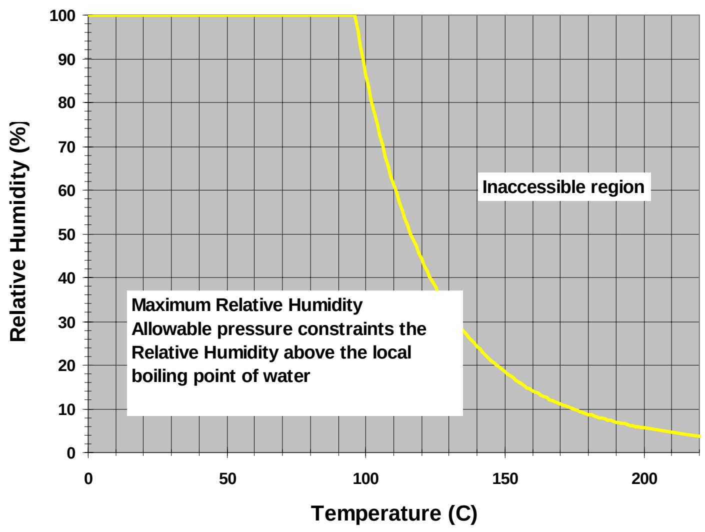
Chemical Divide Processes Determine the Categories of Waters

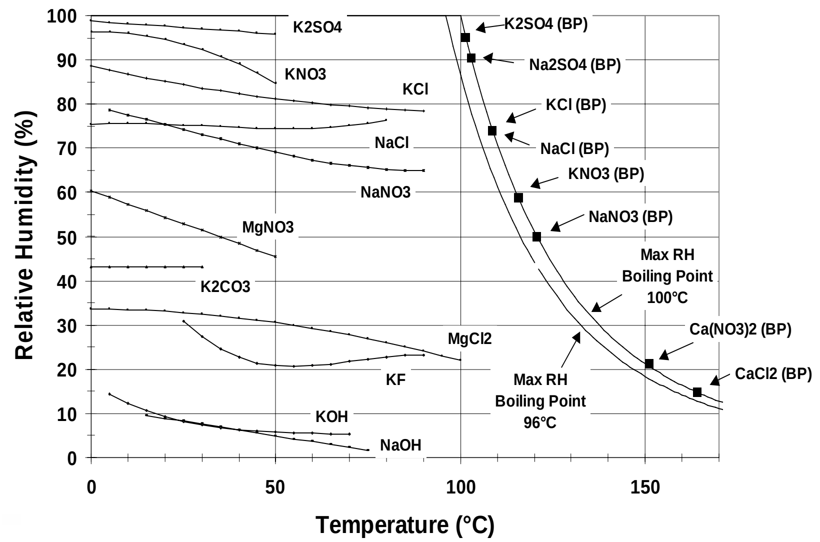


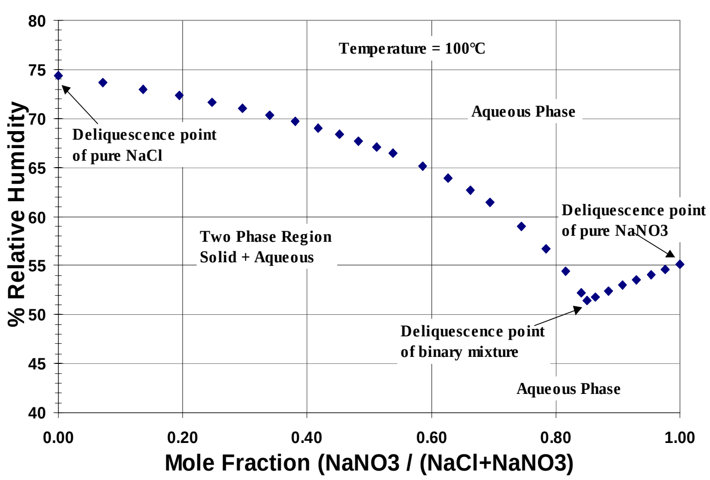


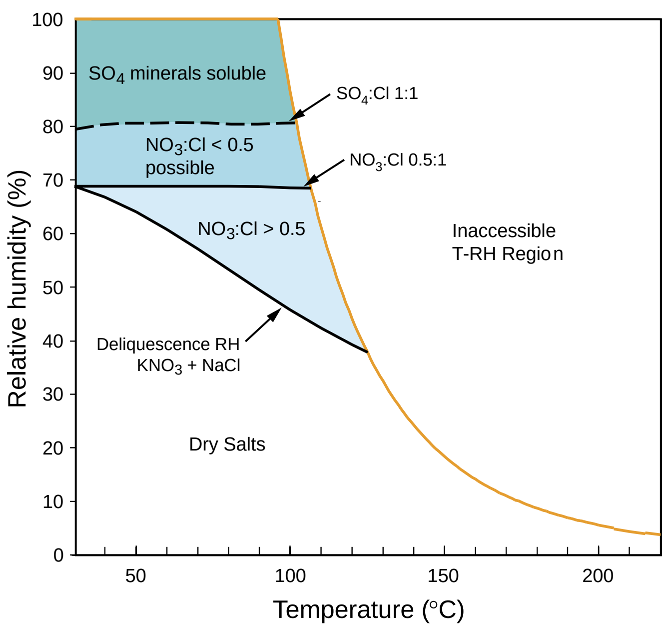
- Ambient Waters:
  - Dilute solutions
  - Na-Ca-Mg-HCO_3-CO_3-Cl-NO_3-SO_4
  - Near neutral pH
- Waters can be concentrated
  - Modified during movement
  - Thermal-chemical processes
- Modifications on waste package surface
- Chemical and electrochemical processes

Solution Chemistry Principles

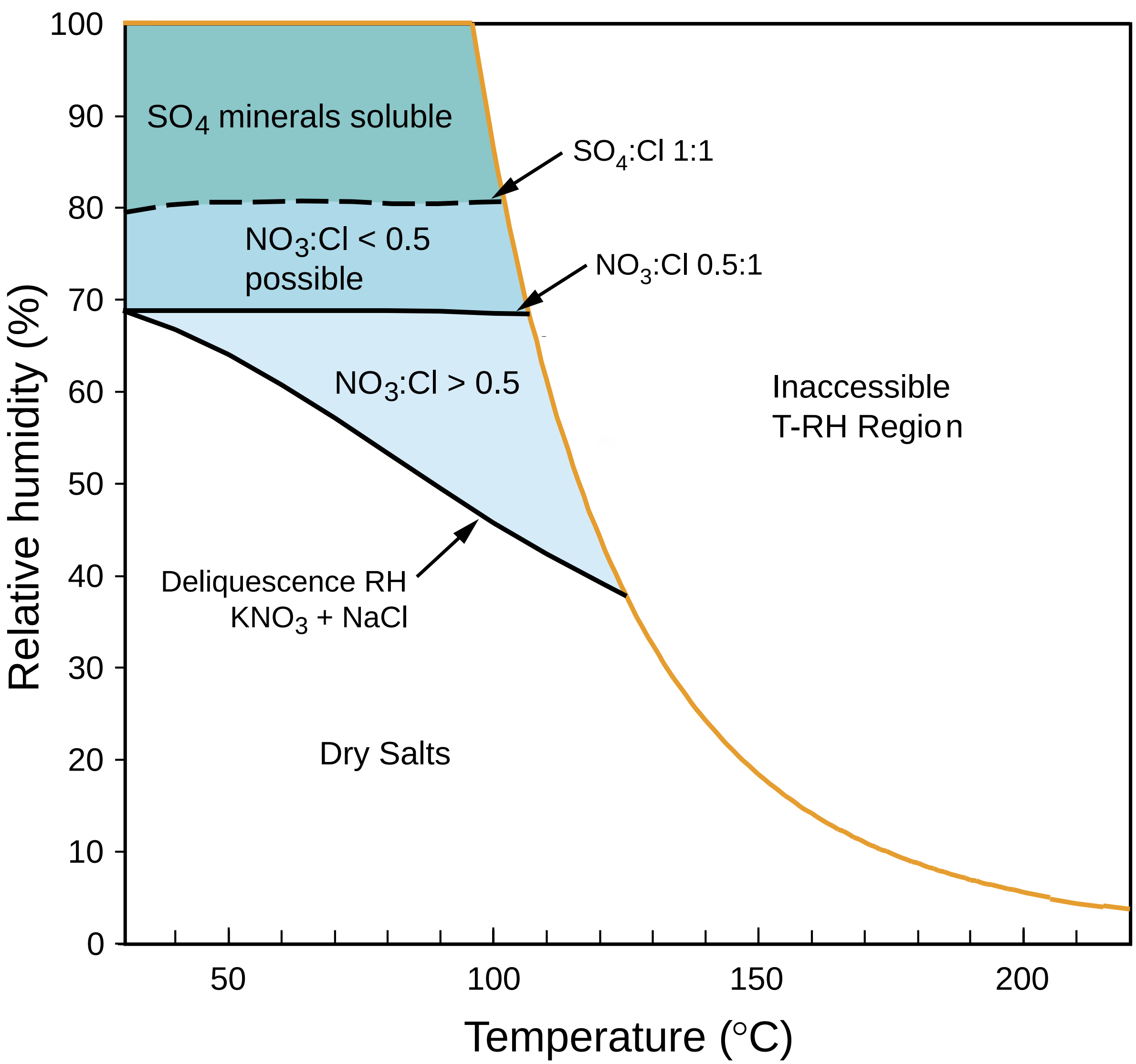








Constraints on Water Compositions for Sodium and Potassium Salts



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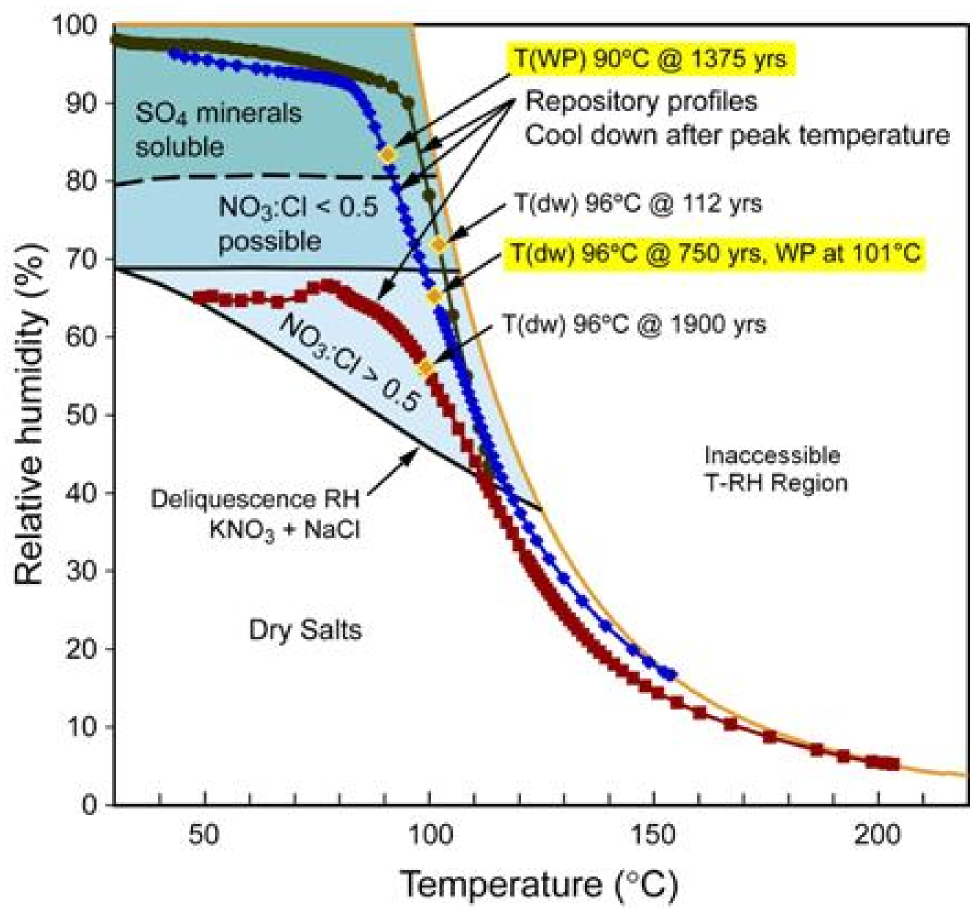
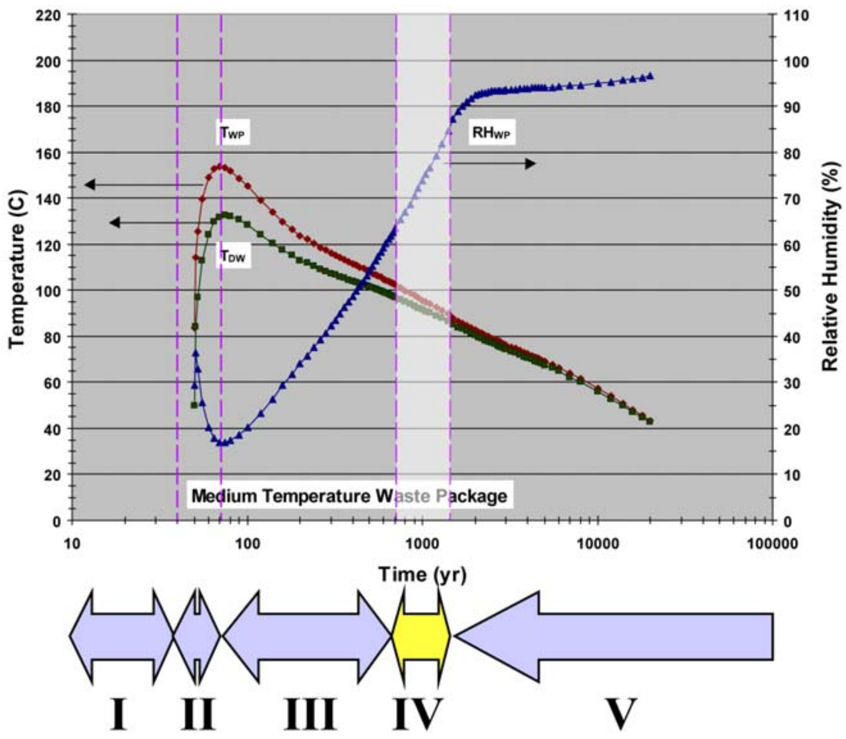
Water Chemistry Scenarios for Waste Package

- **T-RH Profiles Related to Brine Solution Compositions for Sodium and Potassium Base Salts**

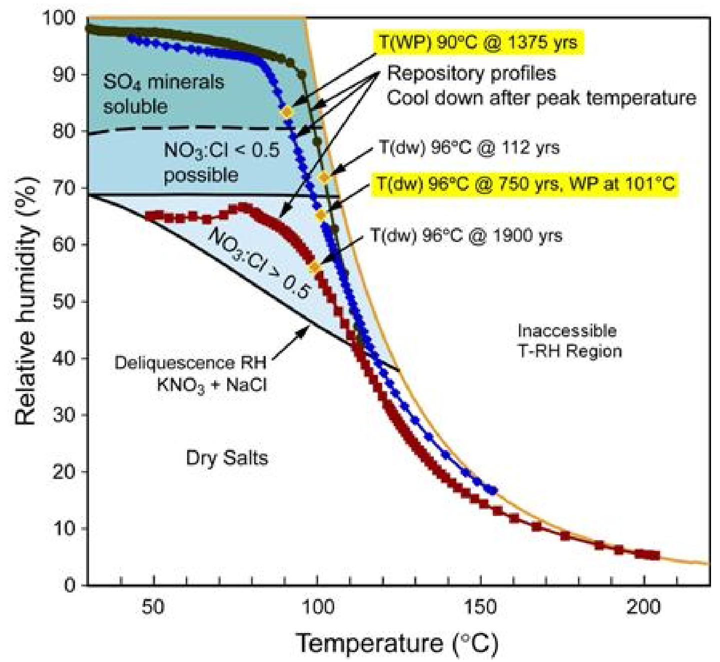


Period IV Analysis of T-RH-Solution Composition



Drift wall 96°C at 750 years;
Waste Package at 101°C;
Relative Humidity 65%

Critical Corrosion Temp 90°C
at year 1375; Relative Humidity 85%



The Temp-RH at any time fixes the possible waters. Can follow the trajectory with time

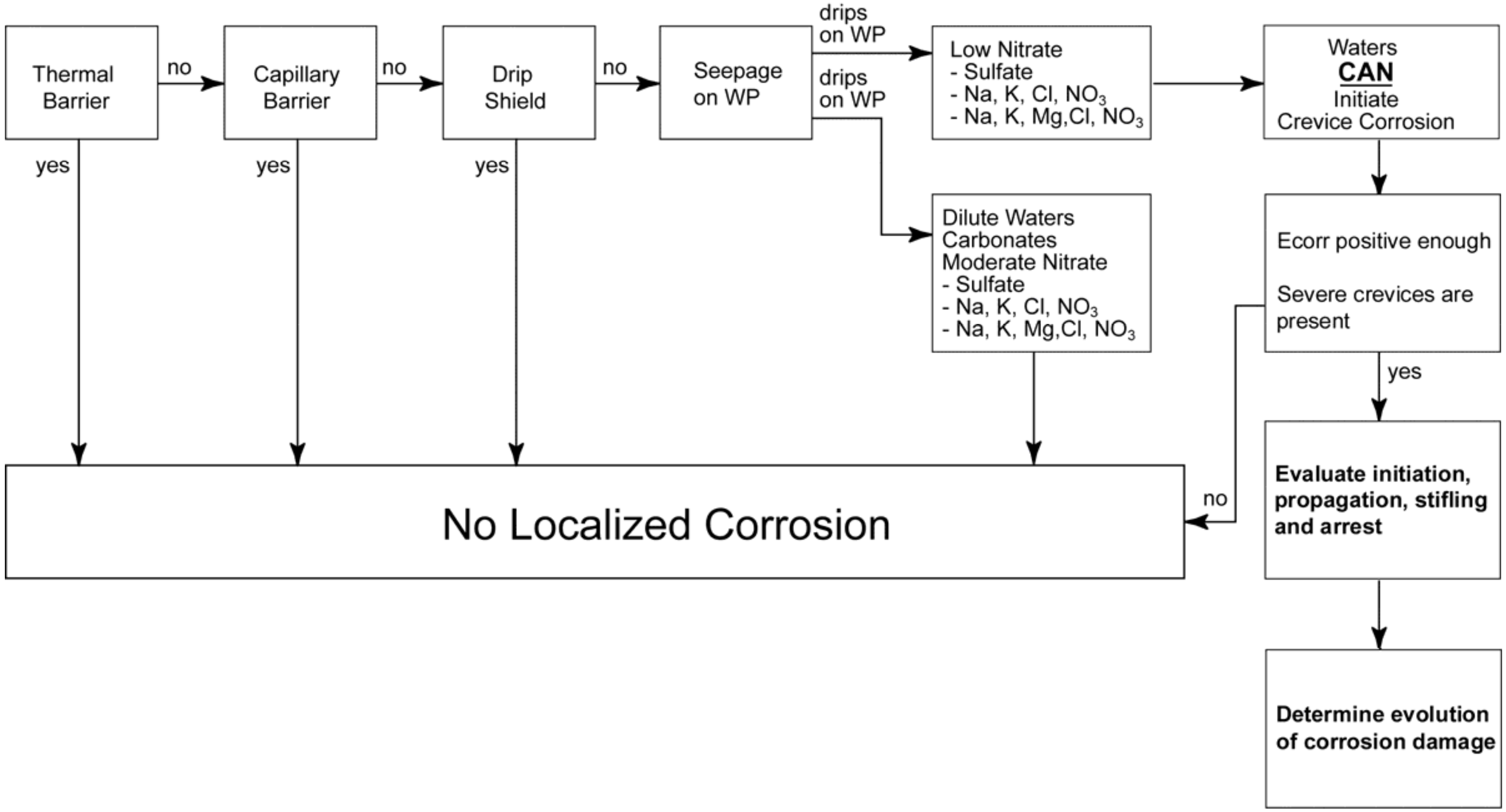
Number of non-corrosive solutions; Sodium chloride with low nitrate solutions can be corrosive

Decision-Tree Analysis

- **A decision-tree for localized corrosion**
  - **Are environments and crevices present to induce localized corrosion?**
    - **Consider conditions in moist layers of particulate and deposits**
  - **If localized corrosion initiates, will it persist?**
    - **Consider stifling and arrest processes as the corrosion proceeds**
  - **What amount of metal penetration occurs?**
  - **What is the size and distribution of corrosion sites?**

Decision-Tree Analysis

- **A decision-tree for localized corrosion**



Summary

- Presented a framework for the analysis of localized corrosion
- Demonstrated the analysis for a scenario
  - Water chemistry of mixed salt solutions
  - Time-temperature-relative humidity profiles for waste packages
- Localized corrosion on waste packages is restricted to finite time periods
  - Corrosion conditions at key time periods in proposed Repository
  - Corrosion analysis during period IV-cool down/dripping and seepage
- Decision-tree analysis for corrosion damage evolution
  - For those time periods when localized corrosion can be supported
  - Based upon the temperature and possible water chemistries
  - Apply decision-tree analysis to determine the evolution of corrosion damage