YUCCA MOUNTAIN PROJECT

Studies

# Materials Research Program: Status and Changes

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Nuclear Waste Technical Review Board

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# Outline

- Role of Waste Package Materials Testing and Modeling
- Environment Assumptions for Testing
- Container Materials in Corrosion Test Program
- Waste Package Materials Test Strategy
- Waste Package Materials Program Summary and Recent Results
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- Summary

# Role of Waste Package Materials Testing and Modeling

**Provide the scientific basis for materials selection and performance for waste package and engineered barrier design and performance assessment**

- **Inputs include materials performance data on:**
  - **Inner and outer barrier materials**
  - **Basket criticality control materials**
  - **Ceramic coatings**
  - **Concrete invert and other EBS materials**
  - **Waste form alteration and release**
  - **Impacts of microbes and radiocolloids**
  - **Degraded materials state for criticality analysis**
  - **Model development and abstraction**

# Environment Assumptions for Waste Package Materials Testing

- **Assumed Water Contact Mode Scenario:**
  - **Early hot, dry conditions followed by cooler, more humid conditions with potential for dripping of concentrated groundwater onto waste packages**
- **Existing test conditions include water chemistry that ranges from 10X to 1000X J-13 and pH ranges from 2 to 12 (which encompasses design range of pH 4.5 to 10.5) and temperatures of 60 to 90$^{o}$C**
- **Higher water seepage flux may reduce concentration of ionic species of water contacting the packages**
  - **However corrosion degradation is more closely coupled to local conditions at the surface of the waste package**

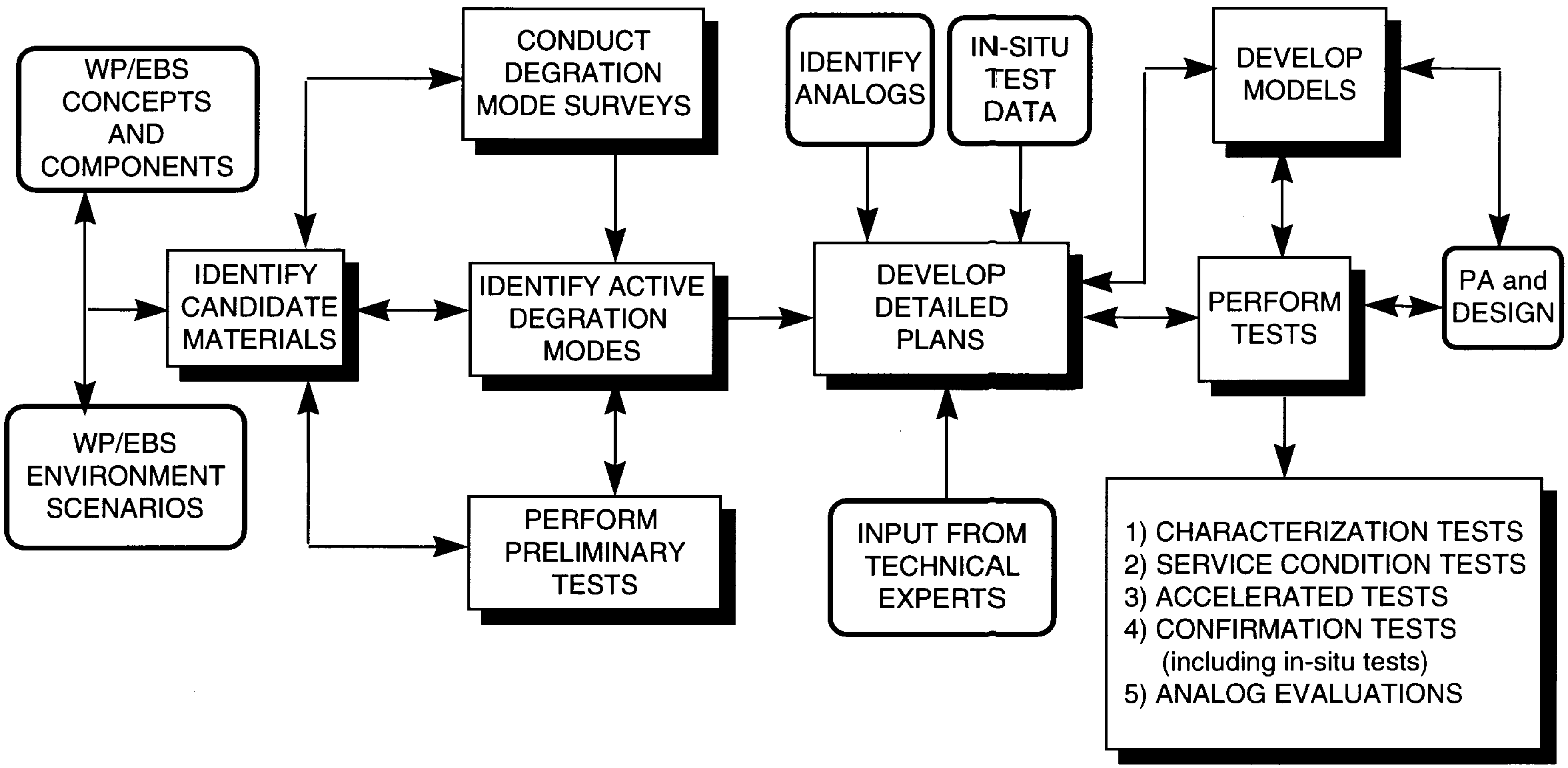
# Environment Assumptions for Waste Package Materials Testing
(continued)

- The corrosion test program follows the progression of environmental conditions from hot and dry to cool and moist:
  - Thermogravimetric analysis and relative humidity (RH) chamber tests expose coupon samples to determine the effect of low and high RH on corrosion-allowance materials and their surface conditions, such as clean, oxidized and salted
  - The long-term corrosion test facility exposes coupons, U-bend, and creviced specimens under a range of environmental conditions that examines the effect of vapor phase, waterline and full immersion for both corrosion-allowance and corrosion-resistant materials

# Container Materials in Corrosion Test Programs

- **Corrosion-Allowance Materials**
  - **Carbon steel - cast (ASTM A27) and wrought (ASTM A516)**
  - **Low alloy (2.25 Cr - 1 Mo) steel**
- **Intermediate Corrosion-Resistant Materials**
  - **Copper-nickel (70/30) alloy**
  - **Nickel-copper (70/30 - Monel 400) alloy**
  - **Corrosion-Resistant Materials**
  - **Nickel-rich alloys (Alloy G-3, G-30, 825)**
  - **Nickel-base alloys (Alloy 625, C-4, C-22)**
  - **Titanium alloys (Ti-Grade 12, Ti-Grade 16)**
- **Other Materials**
  - **Type 304/316 stainless steel with and without boron**
  - **Zircaloy (to be added to support Navy testing)**
  - **Ceramic coatings (alumina, titania, magnesia, zirconia, plus combinations of these oxides)**

# Waste Package Materials Test Strategy



# Waste Package Materials Studies

- **Engineered Barrier Materials**
  - Container materials testing
    - » Long-term corrosion
    - » Humid air corrosion
    - » Crack growth
    - » Electrochemical potential
    - » Microbiologically-influenced corrosion
  - Basket materials corrosion
  - Ceramic materials testing
  - Other engineered barrier materials testing
  - Degradation and abstraction modeling
- **Waste Form Materials**
  - Commercial spent fuel testing
  - High-level waste glass testing
  - Degradation and abstraction modeling
  - DOE spent fuel (planned)
  - Cladding and structural material (planned)

# Long-Term Corrosion Testing

- **Objective:**
  - **Determine long-term corrosion behavior to support material selection and performance prediction**
- **Status:**
  - **All 18 corrosion test vessels (Increments 1 and 2) operational**
  - **Six vessels each contain carbon and alloy steel, copper-nickel, and corrosion-resistant material (CRM) specimens**
  - **Environments include low pH, moderately high pH, and concrete modified pH at two test temperatures (60 and 90$^{o}$C)**
  - **Six galvanic test vessels (Increment 3) just underway**
- **Results:**
  - **First six-month tests completed for all specimens**
    - » **Copper-nickel alloys showed general corrosive attack**
    - » **CRMs were not attacked except for 825 under crevices**
    - » **Carbon and alloy steels showed aqueous corrosion in the range of expected values, 80-110 µm/yr (3-4 mpy)**

# Humid Air Corrosion

- **Objective:**
  - Determine corrosion rates of samples exposed to humid air with and without salt films
- **Status:**
  - Critical relative humidity (RH) determined in thermogravimetric apparatus (TGA) studies
  - Relative humidity chamber tests underway with carbon steel (and titanium alloy) at 50% RH
  - Additional RH chambers ordered
  - Six-month sample analysis initiated
- **Results:**
  - For clean surfaces, no corrosion evident for carbon steel or titanium alloy
  - For salted surfaces, reddish brown oxide corrosion evident for carbon steel, consistent with TGA tests, but no corrosion evident for titanium alloy

# Modifications to the Waste Package Materials Testing Program

- **Alternative Materials**
- **Carbon Steel Pitting**
  - **Coupon thickness increased to study pit propagation and geometry**
  - **Vessels started up with concrete modified pH**
- **Ceramic Testing Program**
- **Cladding Testing Program**
- **Galvanic Protection**
- **Microbiologically Influenced Corrosion**

# Modifications to the Waste Package Materials Testing Program

**(Continued)**

- **Alternative Materials**
  - WPDEE indicated that C-22 was preferred over Alloy 625 based on available short-term corrosion data
  - Current data from long-term corrosion testing are not able to differentiate between these two corrosion-resistant materials
  - Short-term tests under aggressive chemistries will be performed to differentiate the materials and obtain parameter values for the crevice corrosion model
  - Crevice corrosion probe will be developed to determine the pH (suppression) and chloride content (enhancement) in the crevice as corrosion proceeds as input to the model

# Modifications to the Waste Package Materials Testing Program

**(Continued)**

- **Ceramic Testing Program**
  - WPDEE concern for flaking or spalling of ceramic coating will be eliminated by the utilization of backfill prior to closure
  - Program modified to emphasize density of coatings and resistance to handling loads
  - Coating composition will be adjusted to match thermal expansion requirements
  - Coatings will be generated by several thermal spray methods including high velocity oxy-fuel and detonation gun

# Modifications to the Waste Package Materials Testing Program

**(Continued)**

- **Ceramic Testing Program (Continued)**
  – **Coatings will be tested to determine bond strength**
  – **Corrosion resistance will be determined for notched and un-notched specimens**

# Modifications to the Waste Package Materials Testing Program

**(Continued)**

- **Cladding Testing Program**
  - Several experts have suggested that credit be taken for cladding performance, however data under protypic conditions are needed
  - Fuel performance tests are being initiated at ANL to study restraint of cladding on fuel expansion as a result of humid air and dripping water alteration
  - Mechanical tests are being planned to evaluate the the response of rod segments to rock loads
  - Zircaloy corrosion tests will be started shortly in the long-term corrosion test facility (supported by the Navy)

# Modifications to the Waste Package Materials Testing Program

**(Continued)**

- **Galvanic Protection**
  - **WPDEE concern that pits in corrosion-allowance material will be wide and not offer much galvanic protection to the corrosion-resistant material**
  - **However, the experience base on thick-walled carbon steel vessels and pipes is not conclusive regarding pit geometry**
  - **Long-term experiments were recently initiated under several environmental conditions to determine the degree of galvanic protection**
  - **Throwing power and the corrosion geometry particularly the pit geometry, will be evaluated**

# Modifications to the Waste Package Materials Testing Program
**(Continued)**

- **Galvanic Protection (continued)**
  - Specimens are couples of corrosion-allowance and corrosion-resistant materials
  - Vessel chemistry includes the concentrated solutions previously tested and a concrete modified chemistry utilized for the corrosion-allowance material vessels

# Modifications to the Waste Package Materials Testing Program

(Continued)

- **Microbiologically Influenced Corrosion (MIC)**
  - **MIC may be possible when the repository cools (<80ºC) and the relative humidity increases (>60%)**
  - **Current experimental and analytical approach involves answers to an event tree of questions:**
    - **Are microbes present or can they enter later?**
    - **If they are present after 1,000 years, are there sufficient nutrients to permit microbial colonization?**
    - **Will they colonize on the corrosion-allowance material?**
    - **If they colonize, will they enhance corrosion rates?**
- **Answers to these questions and development of models are being done in cooperation with performance assessment**

# Summary

- **Long-term tests are underway**
  - **Six month data have been collected and one year data will be available shortly**
- **In response to WPDEE concerns, modifications to the testing program have been made which address these concerns and focus on:**
  - **Corrosion-resistant material selection**
  - **Pitting of carbon steel and the viability of galvanic protection**
  - **Viability of ceramic coatings**
  - **Cladding credit**