Testing and Analysis for Site Recommendation

Presentation to:
Nuclear Waste Technical Review Board (NWTRB)

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Yucca Mountain Project

Testing and Analysis for Site Recommendation

Objectives

- Build confidence in technical basis for TSPA-SR
  - » Defensible process models
    - ¤ Reasonable representations
    - ¤ Bounded representations
  - » Alternative interpretations considered
- Characterize process model uncertainties to support sensitivity studies

Testing and Analysis for Site Recommendation: Focus on Process Models Representing Principal Factors

Key Attributes of System	Factors for Enhanced System Design
Water Contacting Waste Package	Climate
	Net infiltration into the mountain
	UZ flow above repository
	Seepage into drifts
	Coupled processes - effects on UZ flow
	Coupled processes - effects on seepage
	Environments on drip shield
	Performance of drip shield
Waste Package Lifetime	Environments on waste package
	Performance of waste package barriers
Radionuclide Mobilization and Release from the Engineered Barrier System	Environments within waste package
	CSNF waste form performance performance
	DSNF, Navy fuel, Pu disposition waste form performance
	DHLW glass waste form performance
	Solubility limits of dissolved radionuclide
	Colloid-associated radionuclide concentrations
	In-package radionuclide transport
	Transport through the drift invert
Transport Away from the Engineered Barrier System	Advective pathways in the UZ
	Retardation of radionuclide migration in UZ
	Colloid-facilitated transport in the UZ
	Coupled processes--effects on UZ transport
	Advective pathways in SZ
	Retardation of radionuclide migration in SZ
	Colloid-facilitated transport in SZ
	Dilution of radionuclide concentration in UZ and SZ
	Biosphere transport and uptake

Principal Factors

- Seepage into drifts
- Performance of drip shield
- Performance of waste package barriers
- Solubility limits of dissolved radionuclides
- Retardation of radionuclide migration in UZ
- Retardation of radionuclide migration in SZ
- Dilution of radionuclide concentration in UZ and SZ

Testing and Analysis for Site Recommendation

- **Natural System at Yucca Mountain**
- **Waste Package and Waste Form**
- **Engineered Barrier System**
  - **Drip shield**
  - **Backfill**

Expected Improvements in Principal Factors/Process Models

Seepage into Drifts

- 3-D Dual continuum model using conservative parameters verified by discrete fracture model
- Calibration with test data from ESF and Cross Drift

Unsaturated Zone Flow and Transport

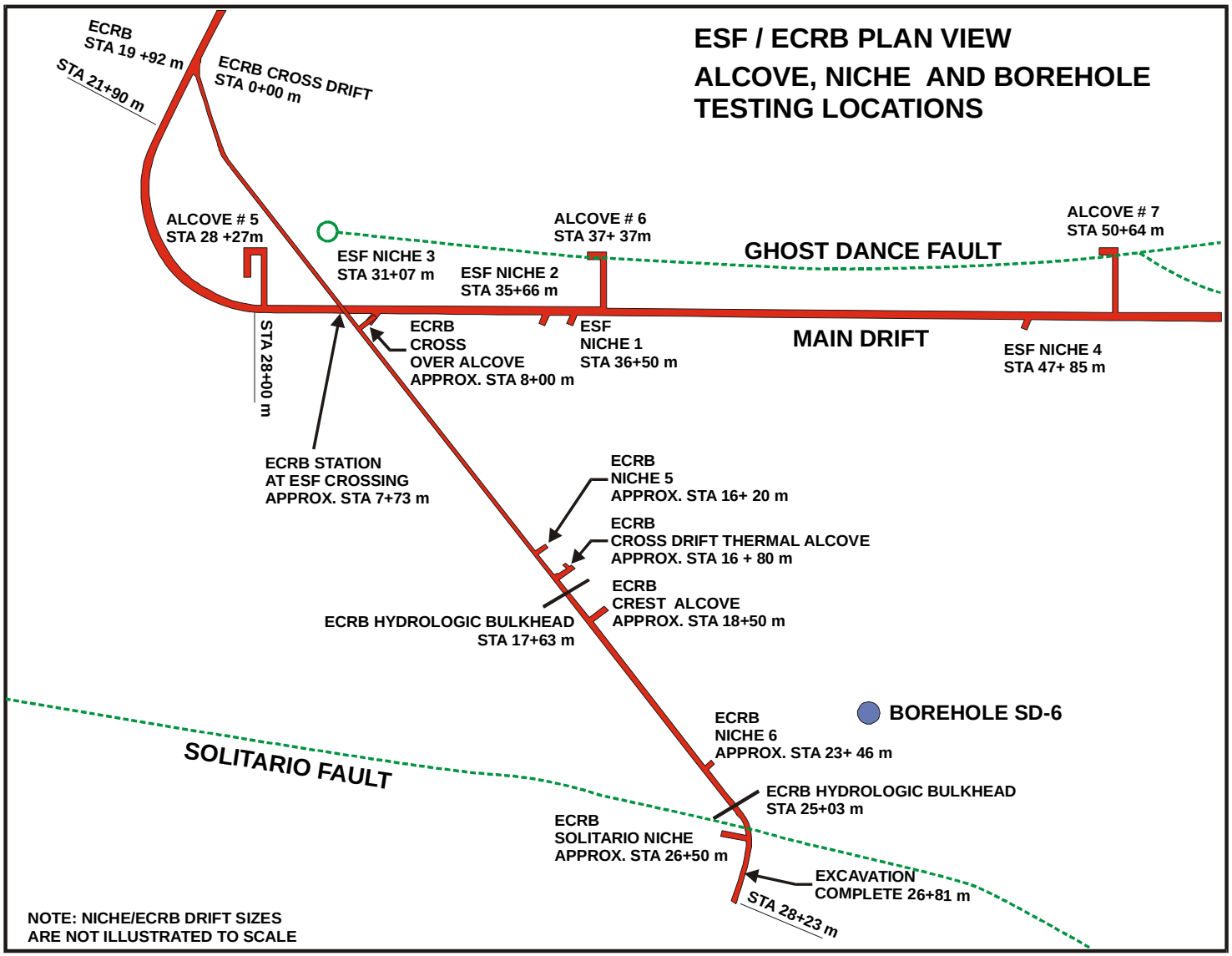
- Realistic 3-D flow fields, realistic sorption parameters for vitric Calico Hills, conservative estimates for matrix diffusion and sorption in zeolitic Calico Hills and Prow Pass
- Calibration with test results from Busted Butte and various geochemical observations

Expected Improvements in Principal Factors/Process Models

Saturated Zone Flow and Transport

- Realistic 3-D flow fields, conservative estimates for sorption and matrix diffusion in alluvial and volcanic aquifers
- Calibration with test data from C-wells and cooperative program with Nye County

Exploratory Studies Facility and Cross Drift



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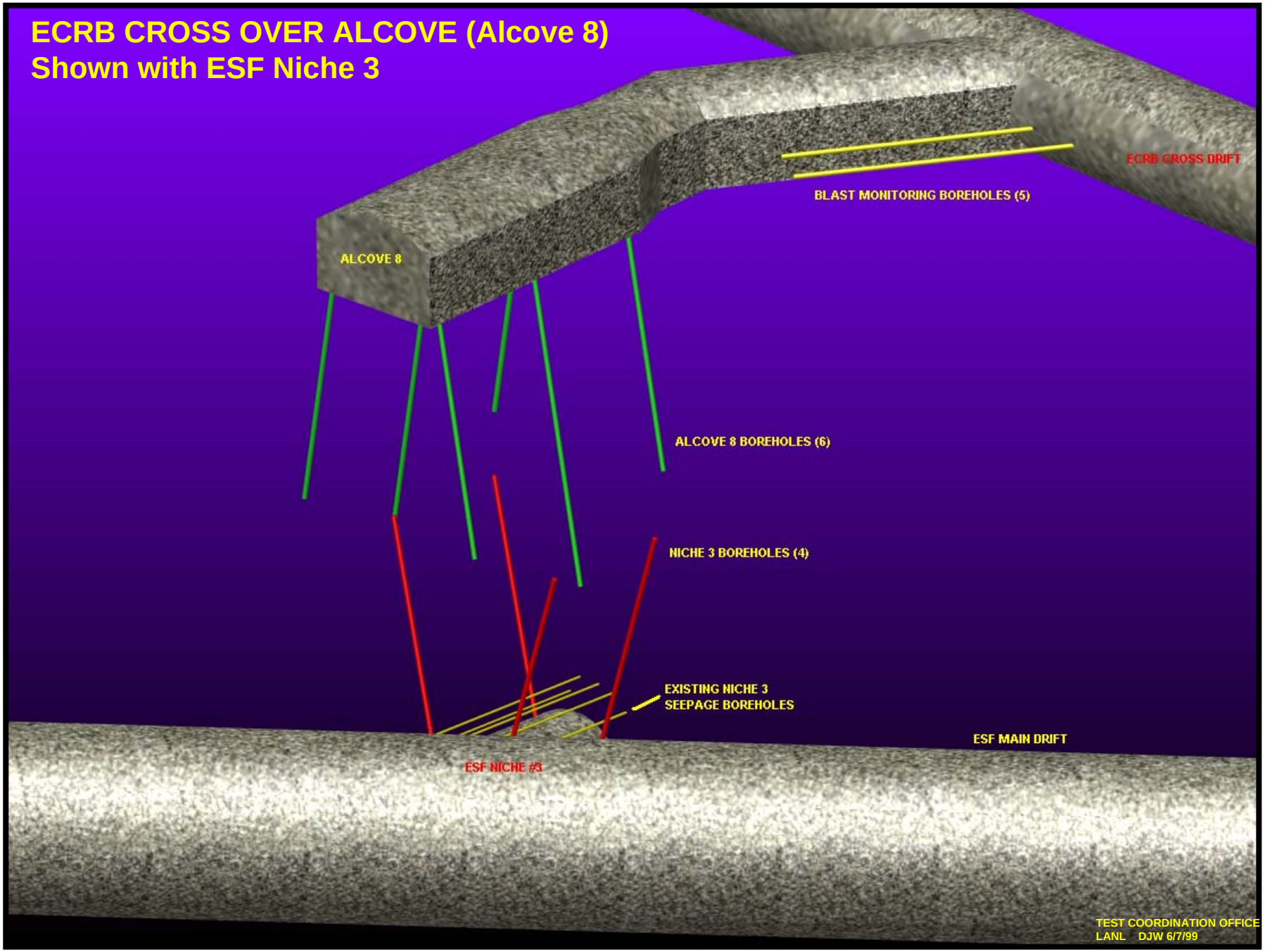
Testing/Analyses Addressing Seepage into Drifts

- **Cross Drift Bulkhead Studies**
  - **Moisture and seepage studies in Topopah Spring Lower Lithophysal and Lower Nonlithophysal Units and Solitario Canyon Fault zone**
- **Cross Drift Alcove and Niche Studies**
  - **Crossover Alcove 8**
    - » **Conduct flow and seepage testing between the Cross Drift and ESF Niche 3 in repository host rock**
    - » **Will provide field-scale data for UZ flow, seepage, and matrix diffusion over scale of tens of meters**

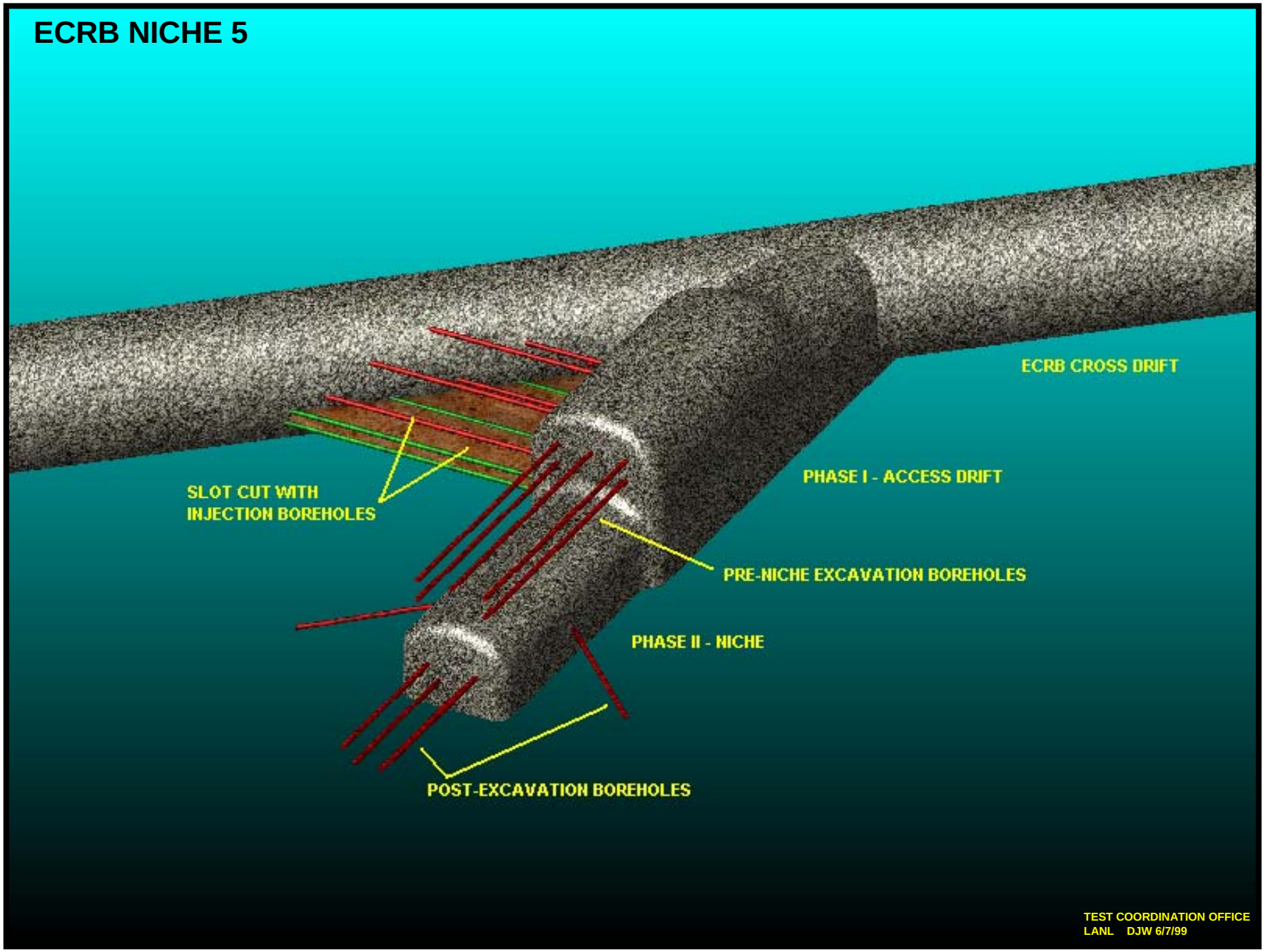
Seepage into Drifts
(continued)

- **Systematic Hydrologic Characterization: Niche 5**
  - **Measure air permeability and conduct seepage testing in systematic boreholes in Topopah Spring Lower Lithophysal Unit**
    - **Improve seepage process data and data on variability in hydrologic parameters in repository host rock**

ECRB CROSS OVER ALCOVE (Alcove 8)
Shown with ESF Niche 3

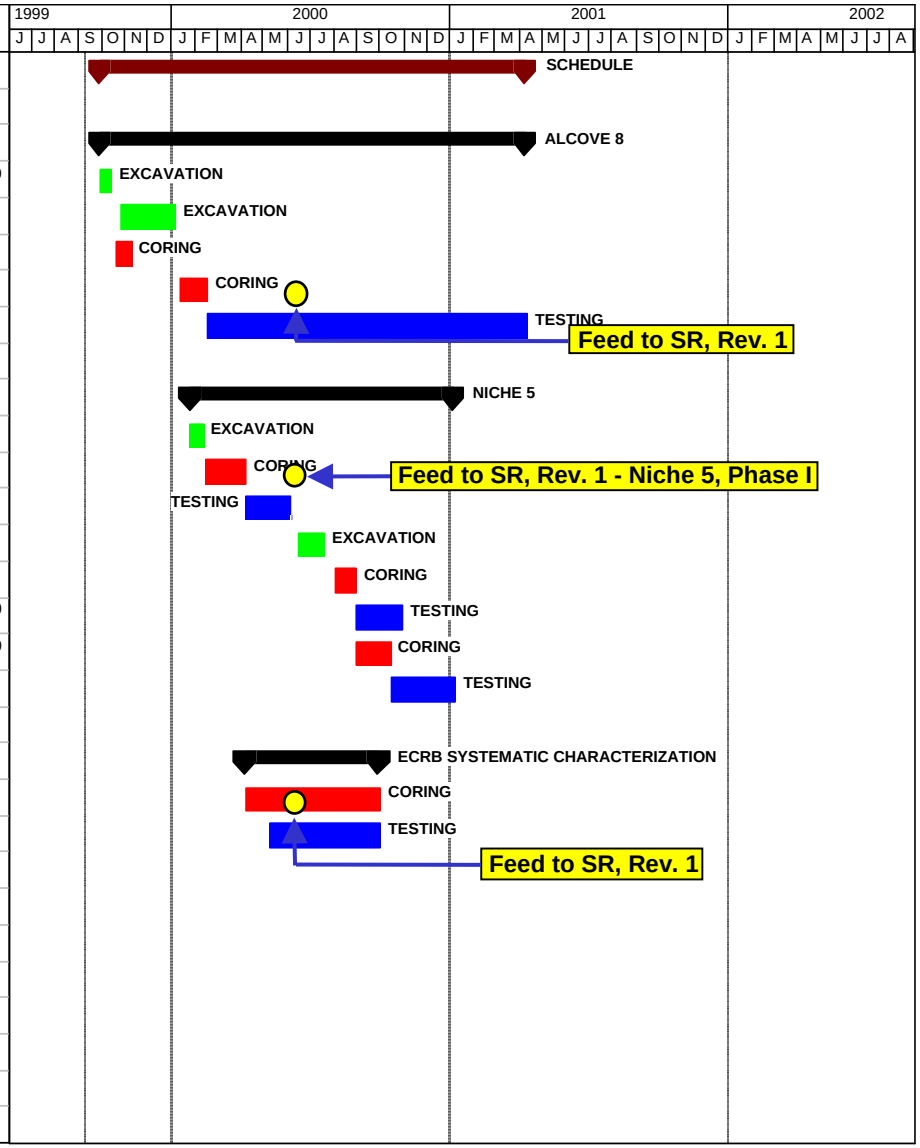


ECRB NICHE 5


ECRB CROSS DRIFT
PHASE I - ACCESS DRIFT
SLOT CUT WITH
INJECTION BOREHOLES
PRE-NICHE EXCAVATION BOREHOLES
PHASE II - NICHE
POST-EXCAVATION BOREHOLES
TEST COORDINATION OFFICE
LANL DJW 6/7/99

CONCEPTUAL ECRB SCHEDULE WITH FEED TO THE SITE RECOMMENDATION

ID	Task Name	Start	Finish
1	**SCHEDULE**	**9/27/99**	**4/10/01**
2			
3	**ALCOVE 8**	**9/27/99**	**4/10/01**
4	Excavation: D&B Access Drift	9/27/99	10/12/99
5	Excavation: Roadheader	10/26/99	1/5/00
6	Coring: 4 Seepage Holes - Upward from Niche 3	10/18/99	11/8/99
7	Coring: 6x15 m Seepage Holes - Alcove 8	1/11/00	2/15/00
8	Testing	2/16/00	4/10/01
9			
10	**NICHE 5**	**1/25/00**	**1/5/01**
11	Excavation: D&B Access Drift	1/25/00	2/10/00
12	Coring: Pre-Niche Coring	2/15/00	4/5/00
13	Testing - Phase I Seepage	4/6/00	6/4/00
14	Excavation: Roadheader	6/15/00	7/17/00
15	Coring: Post Niche	8/3/00	8/29/00
16	Testing - Phase II Seepage and Air-K	8/30/00	10/28/00
17	Coring: Fracture Matrix	8/29/00	10/13/00
18	Slot Cut and Testing	10/16/00	1/5/01
19			
20	**ECRB SYSTEMATIC CHARACTERIZATION**	**4/6/00**	**9/29/00**
21	Coring - Systematic Characterizaton Holes	4/6/00	9/29/00
22	Install and Test- Systematic Characterization Holes	5/8/00	9/29/00



Current Schedule for Cross Drift

Alcove 8

Excavation start - D&B	27 Sept 99
Excavation start - Roadheader	26 Oct 99
Coring start from within Alcove 8	11 Jan 00
Testing set-up - Alcove 8	16 Feb 00

Niche 5

Excavation start - D&B	25 Jan 00
Coring start from within Niche 5	15 Feb 00
Testing set-up - Niche 5	06 Apr 00
Excavation start - Roadheader	15 Jun 00
Coring start - Phase II	03 Aug 00
Testing set-up - Phase II	30 Aug 00

Systematic Characterization Holes

Drilling start	06 Apr 00
Testing set-up and start	08 May 00

Seepage into Drifts

- **ESF Alcove 1 and Niche Studies**
  - **Flow and seepage testing and "El Nino" studies in fractured, welded tuffs of the Tiva Canyon and repository host rock**
    - » **Improves confidence in seepage and matrix diffusion representation**
    - » **Expanded basis for climate effects on UZ infiltration rates - boundary condition for the UZ Flow and Transport Model**
- **ESF Alcove 7 Moisture Monitoring**
  - **Continue monitoring to assess impact of Ghost Dance Fault zone on seepage**

Seepage into Drifts
(continued)

- **ESF Cl, ^{36}Cl Validation Studies**
  - **Complete ^{36}Cl and Cl mass balance studies at two ESF "bomb pulse" locations : Sundance Fault and Drillhole Wash Fault zones**
    - » **Increase understanding of potential for preferential pathways**
    - » **Use Cl distribution to calibrate UZ flow and transport model**
  - **Complete ^{36}Cl and Cl mass balance studies on systematic and feature-based samples from Cross Drift**

Testing/Analyses Addressing Retardation of Radionuclide Migration in Unsaturated Zone

- **Busted Butte Test Facility**
  - **Continue data analysis, modeling, and interpretation of Phase I results and complete Phase II studies**
    - » **Provides matrix diffusion and sorption data in the nonwelded Calico Hills beneath the potential repository**

Testing/Analyses Addressing Thermal Effects on Seepage into Drifts

- **ESF Drift-Scale Thermal Test**
  - **Heating continues for 4 years; cool down for 4 years followed by post-test characterization**
    - » **Large-scale thermal effects on seepage**
      - ¤ **Place bounds on chemistry and amount of water contacting EBS and waste package**
    - » **Addresses issues related to lower repository thermal loads**
- **ECRB Cross Drift Thermal Test**
  - **Thermal test in the Topopah Spring Lower Lithophysal Unit (majority of repository host rock)**
    - » **Expand data for thermal effects on seepage and performance of drip shield/waste package barriers**
    - » **Increase confidence in process models based on results of ESF Thermal Tests**

Retardation of Radionuclide Migration in the Saturated Zone

- **Collaborate with Nye County Saturated Zone Drilling Program and Conduct Future Hydraulic and Tracer Testing in Alluvial Aquifer**
  - **Role of alluvial aquifer**
  - **Interactions between tuff and carbonate rocks/alluvial aquifers**
  - **field-scale radionuclide transport in the saturated zone**
  - **Eh-pH of far-field water**

Gaining Confidence Through Natural Analogs

Pena Blanca Site

- **Analog for transport of uranium and daughter products over long timescales**
- **Past work has focused on open vs. closed system behavior of U, Th, and Pa in fracture-filling material**
- **Results suggest stability for U, Th, and Pa - should extend to Pu, Np, and rare earth elements**
- **Planned drilling will provide rock and water samples for analysis/modeling**

Testing and Analysis for Site Recommendation

- **Natural System at Yucca Mountain**
- **Waste Package and Waste Form**
  - **Includes materials testing for drip shield**
- **Engineered Barrier System**
  - **Drip shield**
  - **Backfill**

Expected Improvements in Principal Factors/Process Models

Performance of Waste Package

- **Mechanistic analysis of manufacturing defects**
- **Additional corrosion mechanisms included**
  - **Stress corrosion cracking**
  - **Long term phase stability**
  - **Thermal aging**
- **Incorporating new lab data on corrosion rates**

Expected Improvements in Principal Factors/Process Models

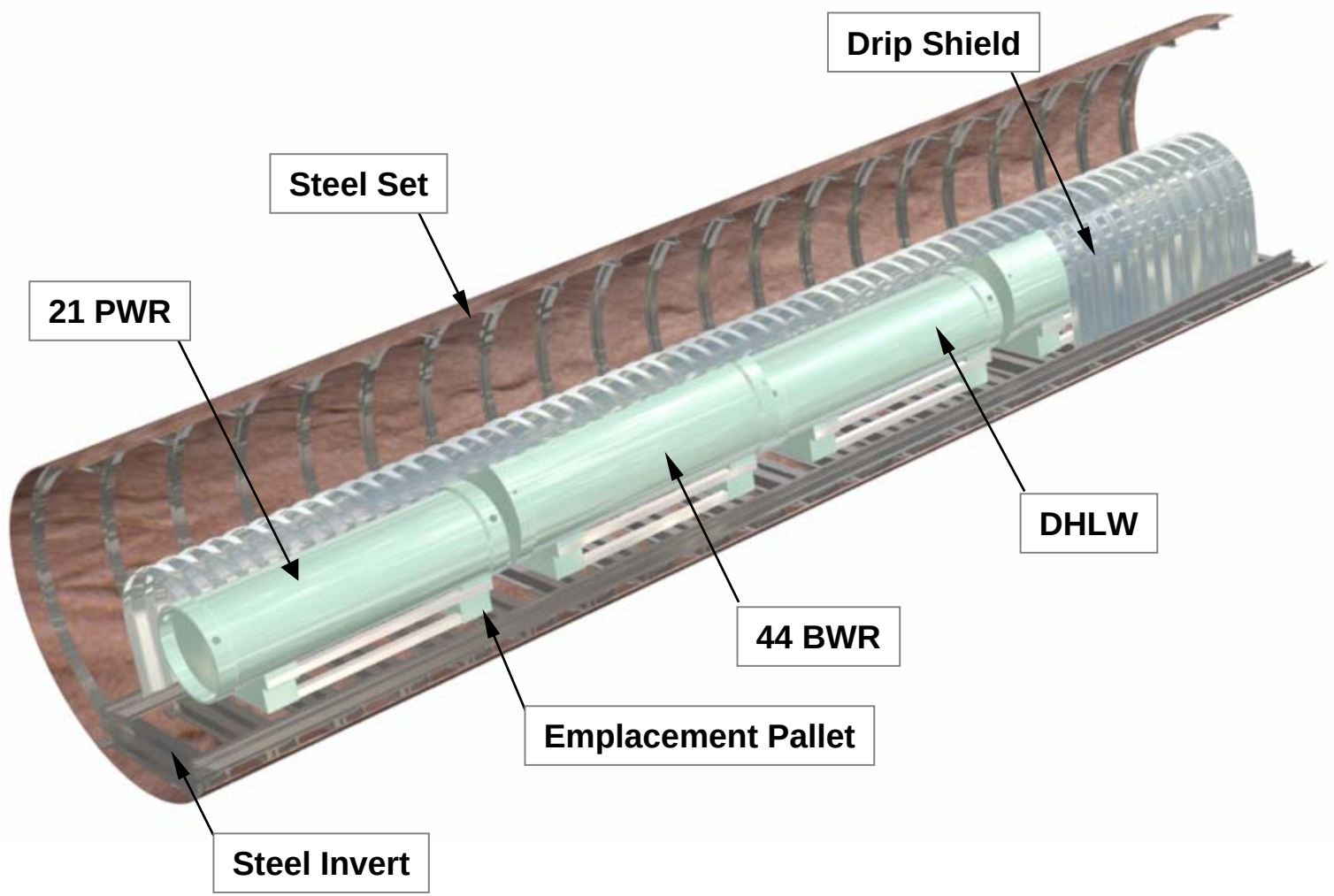
Solubility Limits of Dissolved Radionuclides

- Reasonably bounded representation for SR
- Incorporating new data on relatively immobile radionuclides

Improvements in Related Factors

- **Colloid-associated radionuclide concentrations**
  - Improved colloid formation model with new data on sorption/desorption
  - Americium colloid data added
- **Cladding Degradation Model**
  - Direct evaluation of clad unzipping
  - Conservative bounds on initial defects

Schematic of Waste Packages with Drip Shield



Performance of Waste Package Barriers

- **Fabrication and non-destructive testing techniques will reduce probability of early failure**
  - **Sound basis for early failure assumption for SR**
- **Upgrading process model with additional degradation modes**
  - **Localized and general corrosion tests in progress at range of concentrations, pH and temperatures**
    - » **General corrosion rates are low (<1 micron/year)**
    - » **Pitting corrosion demonstrated to not be a significant factor - additional testing underway**

Performance of Waste Package Barriers

- **Improved data for stress corrosion cracking (SCC) of Alloy 22, Ti 7 and SS 316**
  - » **Industry experience and test results on SCC and crack growth under repository relevant conditions**
  - » **Data will be adequate to benchmark model and determine susceptibility by SR**
  - » **Will bound remaining uncertainties**
- **Long term phase stability and thermal aging**
  - » **Potential for precipitation of intermetallic phases leading to increased corrosion, embrittlement and stress corrosion susceptibility**
    - ¤ **Accelerated testing will provide basis for SR models**
    - ¤ **Probability of phase changes causing problems is considered low**

Performance of Waste Package Barriers

- Stability of passive corrosion films on Alloy 22 and Ti 7
  - » Stability of Alloy 22 and Ti 12 and 16 demonstrated after one year exposure
  - » Alloy C (similar to Alloy 22) exposed for 60 years in marine environment (Kure Beach, NC)
    - ¤ Original condition
  - » A natural analog Josephinite (Ni/Fe) exposed in stream beds for many millennia show no film breakdown
  - » Corrosion under oxide deposit on waste package and cyclic polarization tests initiated

Performance of Waste Package Barriers

Improved Definition of Waste Package Surface Environments

- New data indicate boiling point and pH can be higher than previously assumed
  - Maximum boiling point ~115-125ºC
  - pH can be $\geq$12
- Experimental/modeling effort will provide expected range of environments
- Models will be benchmarked and uncertainties bounded by SR

Solubility Limits of Dissolved Radionuclides: Waste-Form Related Testing

- **Solubility of Immobile Radionuclides, e.g., plutonium, uranium and neptunium**
  - **Key solubilities being re-evaluated for SR**
  - **Uncertainties bounded in models for SR**
- **Colloidal Radionuclides**
  - **Potential mechanism for transport of low solubility, strongly sorbed radionuclides**
  - **Bounded uncertainty for SR**

Solubility Limits of Dissolved Radionuclides: Waste-Form Related Testing/Analyses

- **Cladding Performance**
  - **Models with bounded uncertainties being developed for SR**
    - » **Initial state defined -Fraction breached at receipt**
    - » **Degradation rates - Fraction breached with time**
    - » **Unzipping Rate - Surface area for dissolution, transport resistance**
- **Waste Form Degradation Rates (Commercial Fuel, HLW Glass)**
  - **Bounding rates being used for SR**

Testing and Analysis for Site Recommendation

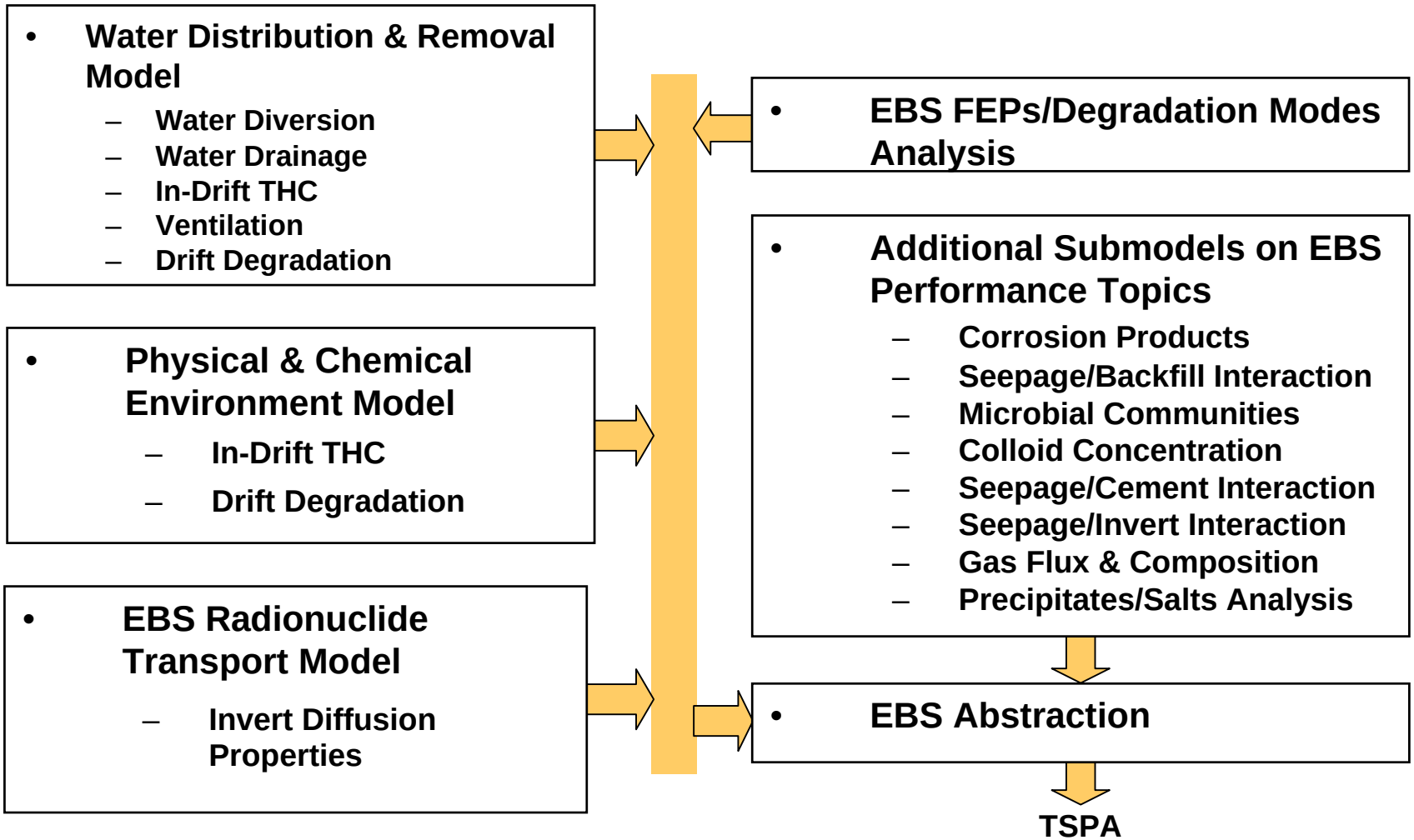
- Natural System at Yucca Mountain
- Waste Package and Waste Form
- Engineered Barrier System
  - Drip Shield
  - Backfill

Expected Improvements in Principal Factors/Process Models

Performance of Drip Shield

- New drip shield degradation model
  - Mechanistic analysis of manufacturing defects
  - Include hydrogen induced cracking
    - » Design will isolate Ti from H sources to limit potential problem
  - Include rock fall and seismic loading effects

Engineered Barrier System Models: Linkage to TSPA



Performance of Drip Shield

- **Performance depends on water exclusion**
  - **Backfill-drip shield flow processes**
  - **Thermal effects on flow, and changes in EBS materials**
  - **Drip shield degradation modes (e.g., shifting) and performance of partially failed drip shield (e.g., gaps or cracks)**
- **Testing/modeling to improve process model**
  - **Pilot-Scale Testing and EBS column tests**
  - **Water distribution and removal model (EBS hydrology)**
  - **In-drift THC (changes in EBS materials)**

EBS: Impacts on Seepage into Drifts

- **Seepage into drifts is affected by their geometry**
  - **Drift Degradation Model**
    - » **Considers rockfall frequency, block size, total extent, timing, and other characteristics**

Testing Results Being Used to Develop Defensible EBS Model for Site Recommendation

- **Completed in FY99**
  - **Pilot-scale Test - Richards Barrier**
  - **Pilot-scale Test - Single-Backfill**
  - **Laboratory Flow Visualization Test to evaluate Richards Barrier**
  - **Laboratory THC coupled effects tests, and thermal, hydrologic, and chemical properties of materials**
  - **Laboratory diffusion coefficient test for crushed tuff and silica sand**

EBS Testing and Analysis to Improve Basis for SR: Pilot-scale Test #4 - Drip Shield With Backfill

Purpose

- Validate models of moisture and chemical responses for EDA II configuration with backfill
- Verify conditions that control condensation under drip shield

Test Design

- Overton sand (fine) as backfill
- Crushed tuff invert
- Scale-model drip shield
- Simulated waste package at 80°C; drift wall at 60°C
- Inflow rate varied to relate seepage with in-drift conditions

EBS Testing and Analysis to Improve Basis for SR: Pilot-scale Test #5 - Drip Shield With Coarse Backfill

Purpose

- Verify conditions that control condensation under DS
- Validate models for moisture and chemical response

Test Design

- Coarse sand backfill
- Crushed tuff invert
- Scale-model drip shield
- Simulated waste package at 80°C; drift wall at 60°C
- Inflow rate varied to relate seepage with in-drift conditions

EBS Testing and Analysis to Improve Basis for SR: EBS Column Tests

- **Saturated Alteration Tests**
  - **Plugging of backfill and invert materials**
  - **Calibrate THC models to alteration of backfill/invert materials in extreme conditions**
- **Unsaturated Thermal-Hydrologic-Chemical (THC) Column Tests**
  - **Behavior of precipitates and salts in backfill**
  - **Validate THC models for backfill response under expected conditions**

Summary

- **Testing has been expanded to include new/revised SR design: improved waste package, backfill, drip shield**
- **Testing/analyses program designed to focus on improvements to key process models supporting TSPA-SR**
  - **Provide sound technical basis for reasonable and bounded representations, and alternative models where necessary**
  - **Define process model uncertainties to support sensitivity studies**