Nuclear Waste R&D in the Earth Sciences Division (ESD) at Lawrence Berkeley National Laboratory (LBNL)

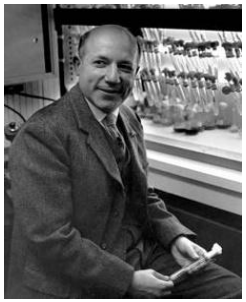
May 2010

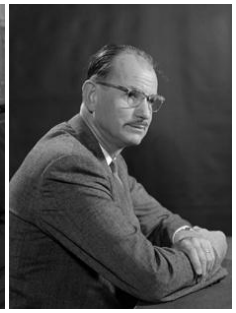
Don DePaolo, Division Director
Jens Birkholzer, Nuclear Energy and Waste Program Lead

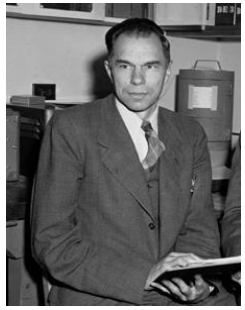
Outline

- **Introduction to LBNL and ESD**
- **LBNL's Expertise in Disposal R&D**
  - **LBNL's Core Expertise in Yucca Mountain R&D**
  - **Yucca Mountain License Application**
  - **OCRWM S&T Program**
  - **International Projects**
- **LBNL's (Potential) Role in UFD Disposal R&D**
  - **Some Thoughts on UFD Disposal R&D**
  - **LBNL's Current Focus**
  - **Next Steps**

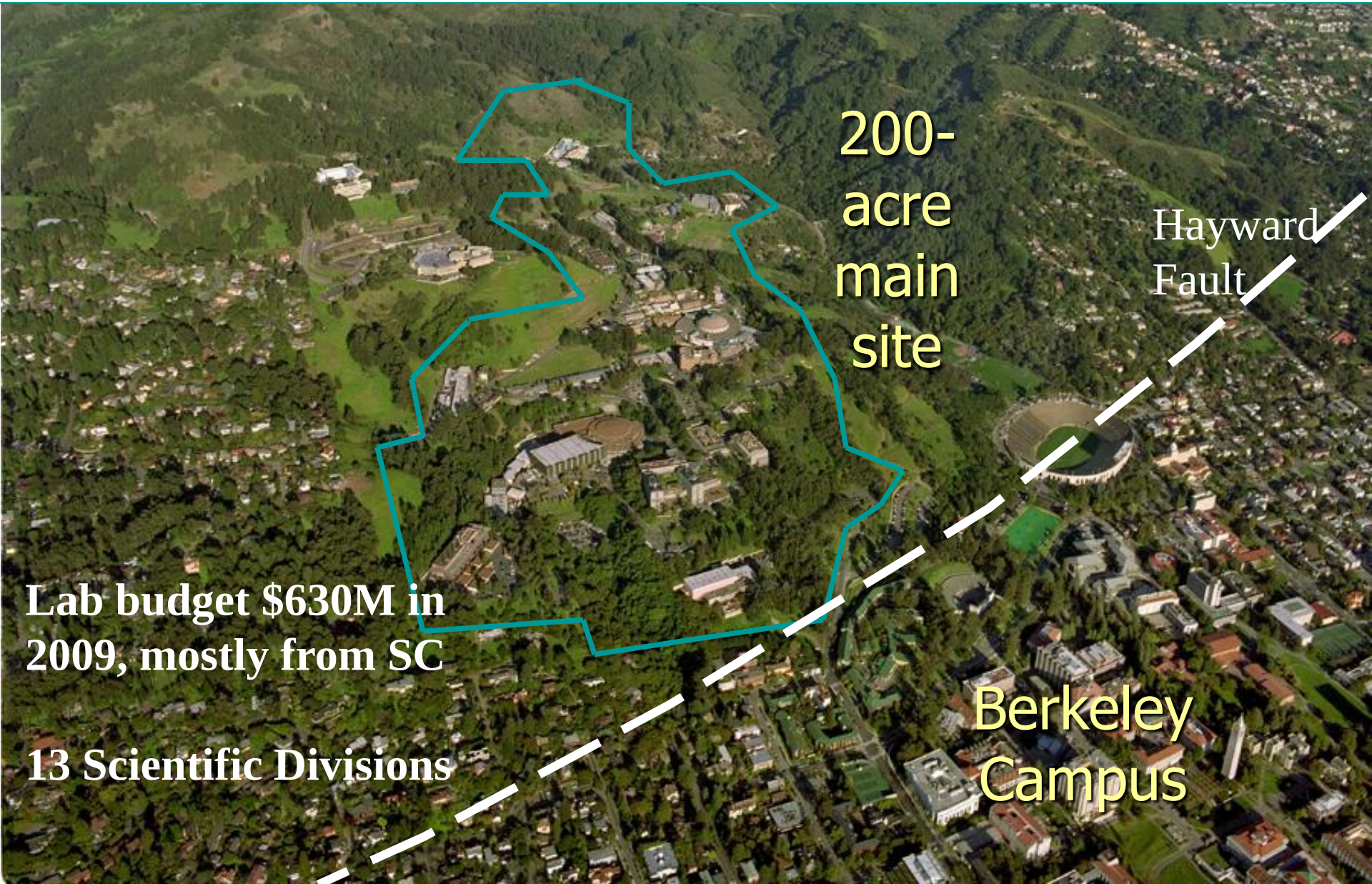
Ernest Orlando Lawrence Berkeley National Laboratory 1931 - 2010







A National Laboratory Next to a University Campus



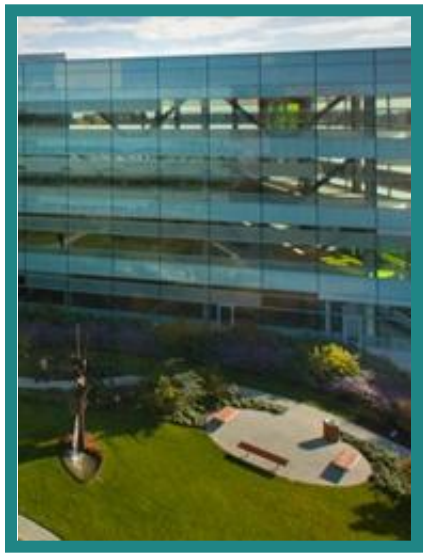
Lab budget $630M in 2009, mostly from SC

13 Scientific Divisions

LBNL Scientific Facilities

Advanced Light Source

National Energy Research Scientific Computing Center



Joint Bio-Energy Institute

Molecular Foundry

Joint Genome Institute

National Center for Electron Microscopy

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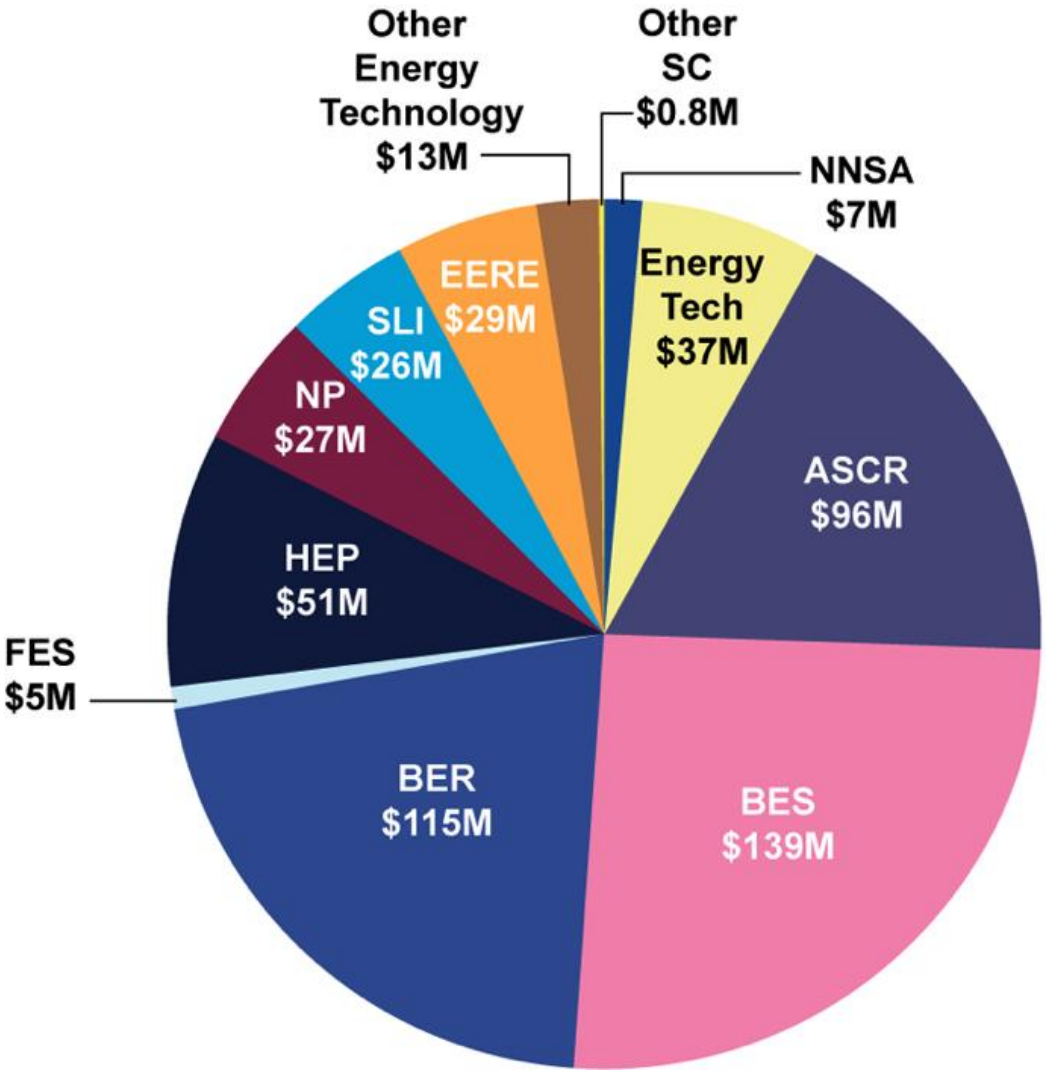
Berkeley Lab Funding Profile

- **FY 2009 Total DOE Funding: $516.2M**
- **FY 2009 Non-DOE Funding: $108.8M (17%)**
- **FY 2009 Dept. Homeland Security: $4.8M**
- **FY 2009 ARRA Funding: $211.9M**



LBNL Earth Sciences Division

… create new knowledge and understanding of Earth sciences to significantly impact national and global energy and environmental problems.

Climate Change

Climate system modeling and prediction of impacts
Carbon Sequestration
Ecosystem response
Biosequestration

Fundamental Science:
-Earth Materials and Processes/ Geochemistry
-Observing and imaging the Earth at nm to km scales
-Environmental biology
-Computational Geoscience

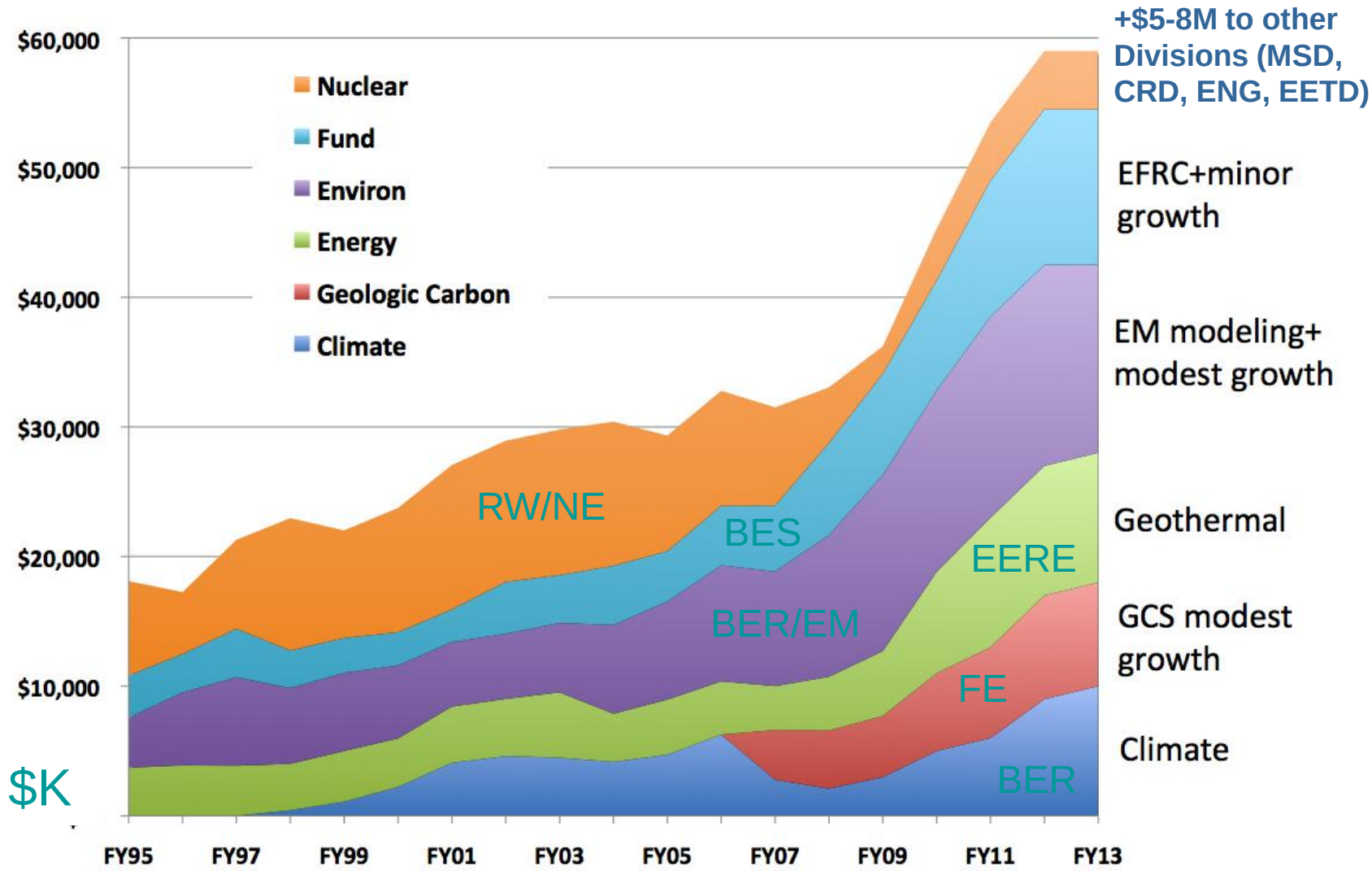
Energy Resources

Enhanced hydrocarbon recovery; methane hydrates
Alternative fuels
Geothermal energy
Nuclear fuel cycle & waste

Water Resources & Environment

Groundwater remediation science
Hydrologic response to climate change
Ensuring adequate water supplies

ESD Total Spending by Program



LBNL's Expertise in Disposal R&D

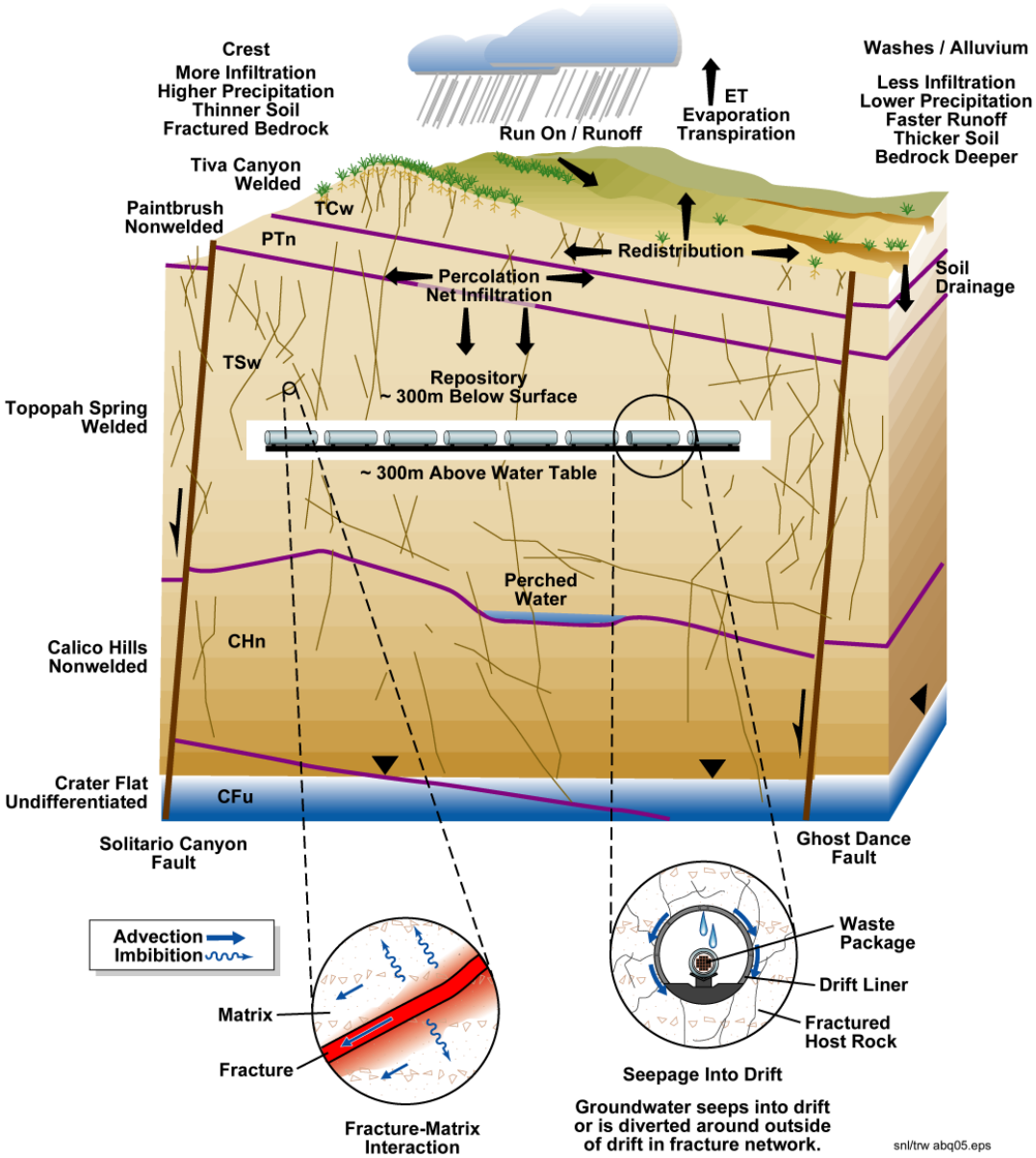
LBNL Expertise in Yucca Mountain R&D

- Characterize the geologic repository sites with novel instrumentation and interpretation methods
- Measure and monitor flow and transport processes in complex field and laboratory experiments
- Evaluate and predict the behavior and performance of geologic disposal systems with multi-physics computer models

- **Focus on characterization and understanding of fractured rock systems**
- **Focus on coupled thermal-hydrological-mechanical and chemical (THMC) processes**

Key R&D Issues Addressed by LBNL

- Ambient Infiltration and Percolation
- RN Transport
- Fracture/Matrix Flow
- Matrix Diffusion
- Faults as Potential Fast Flow Pathways
- Seepage into Drifts
- Drift Shadow Effect
- Coupled Processes (TH, THC, THM)
- Natural Analogs
- Impact of repository environment on waste form



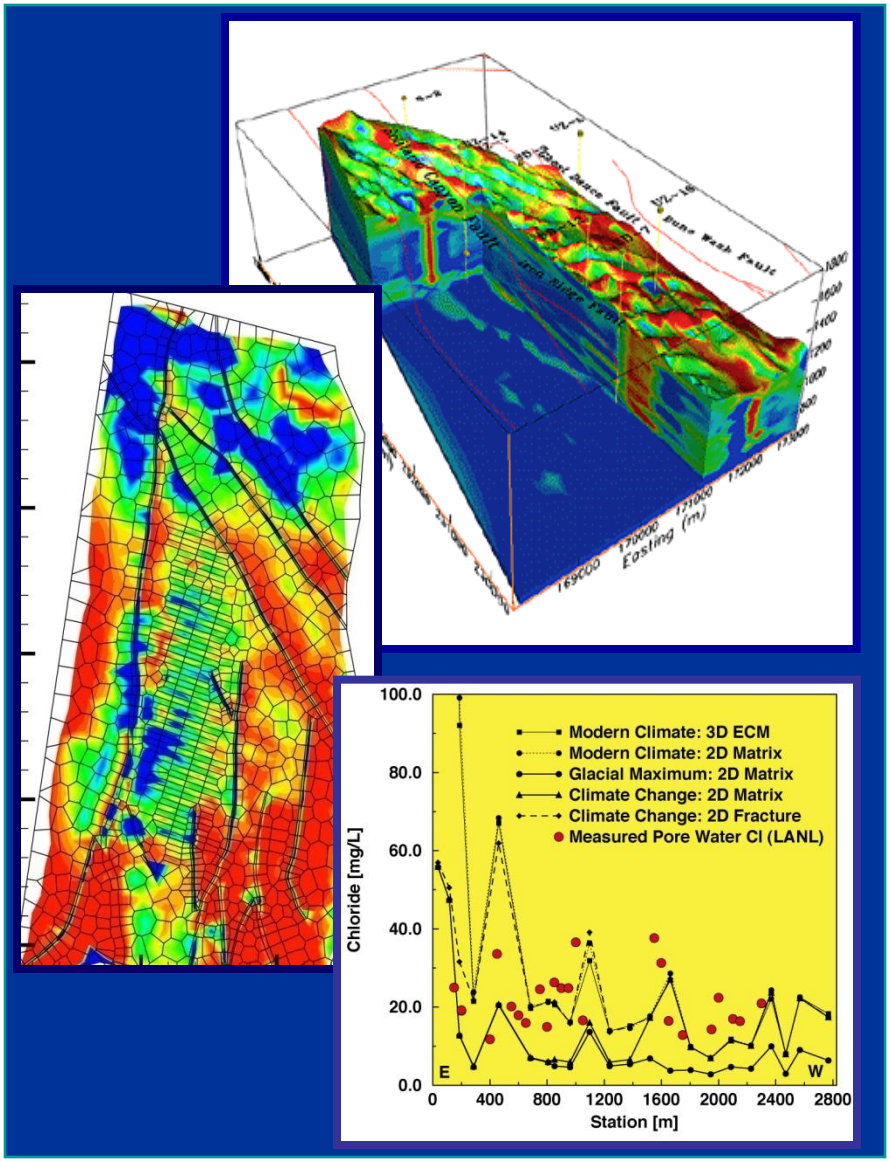
Mountain-Scale Flow and Transport Model

Main Purpose

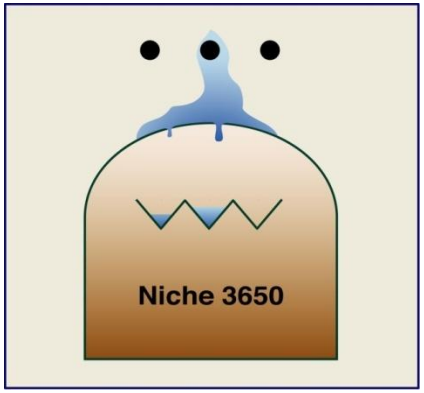
- Integrate all data collected for site characterization
- Predict UZ flow and RN transport
- Validate predictive models against geochemical data

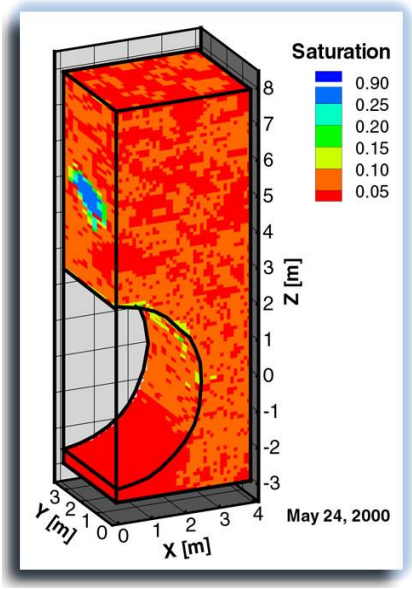
Modeling Approach

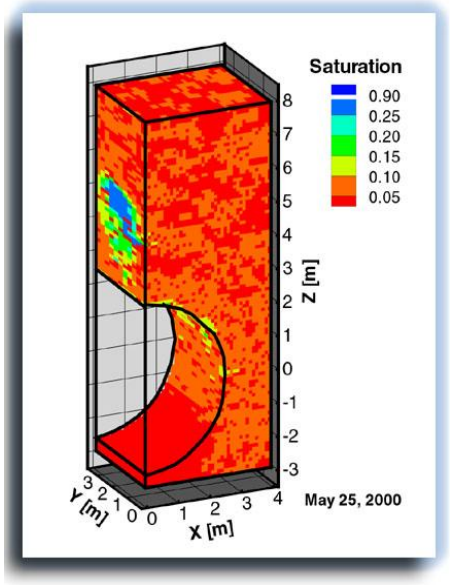
- 3D dual-permeability model
- Coupled, nonisothermal flow and reactive transport
- Variable infiltration and capillary-barrier effect
- Mineral-water-gas kinetic and equilibrium reactions

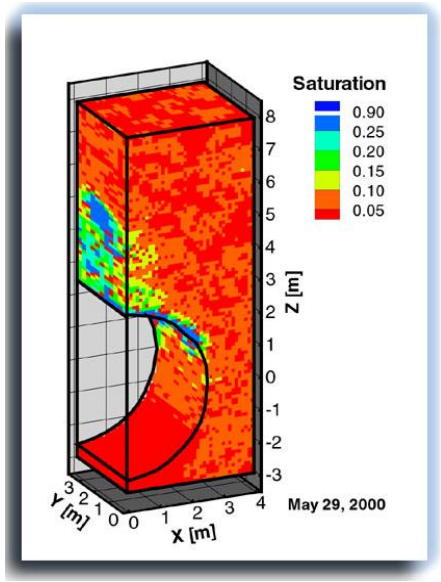


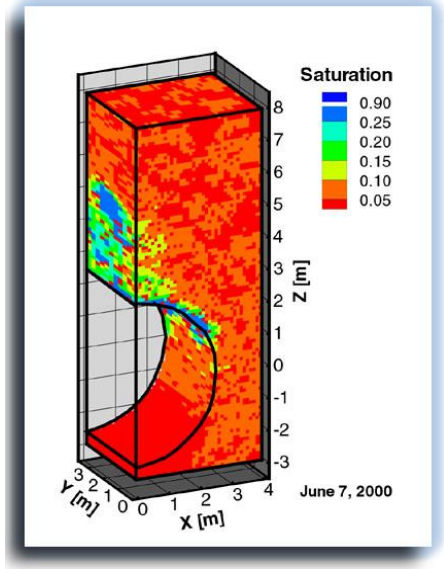
Ambient Seepage Testing/Modeling



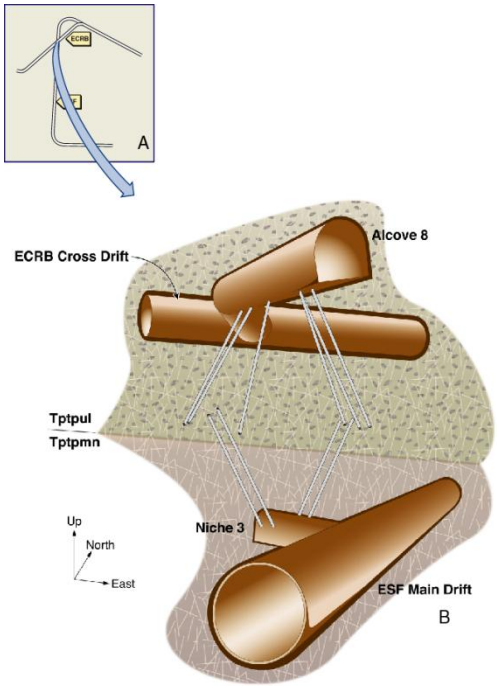






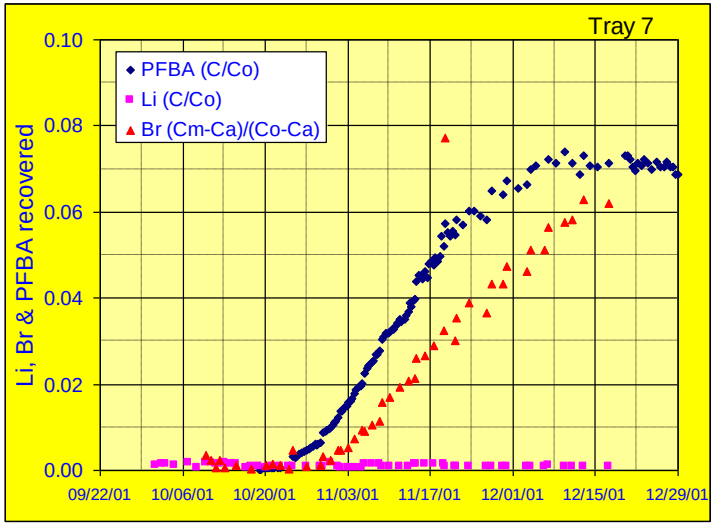


RN Transport Testing/Modeling



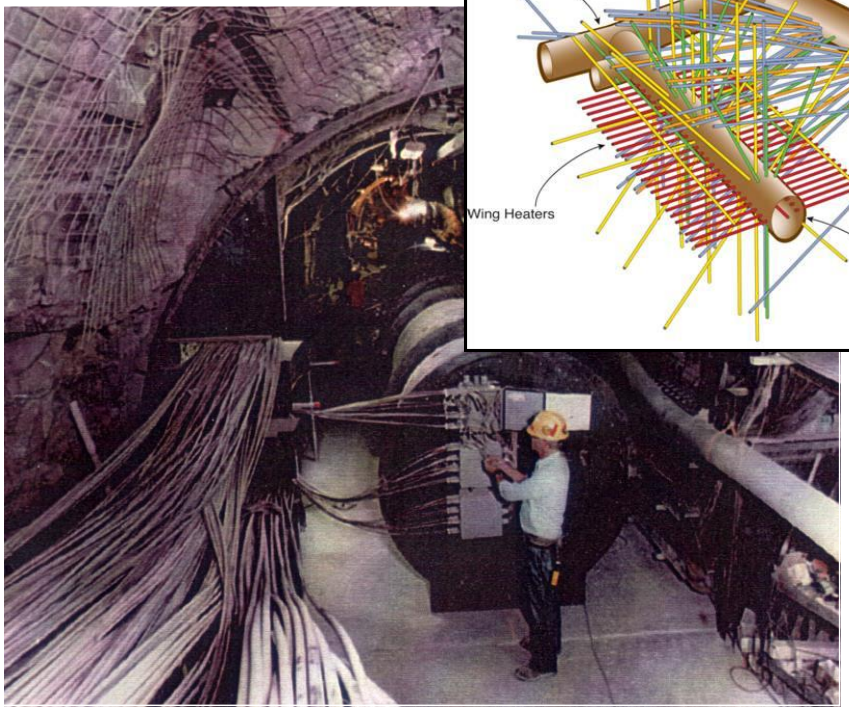
Alcove 8: Infiltration Along Fault

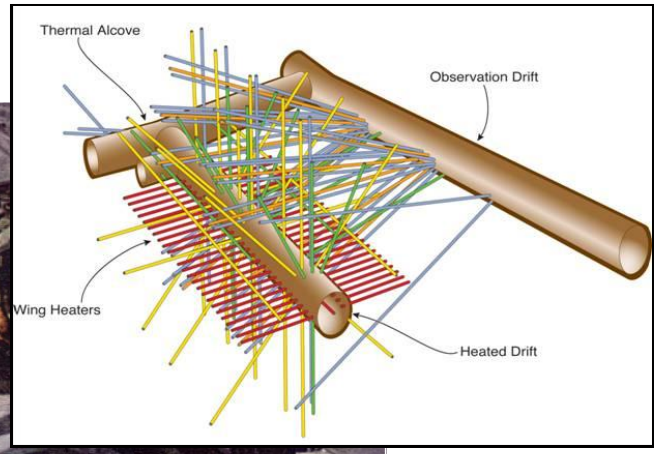
Niche 3: Seepage/Tracer Monitoring

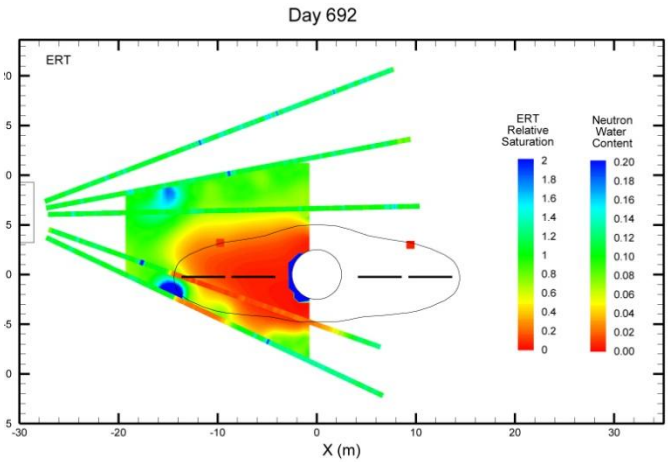


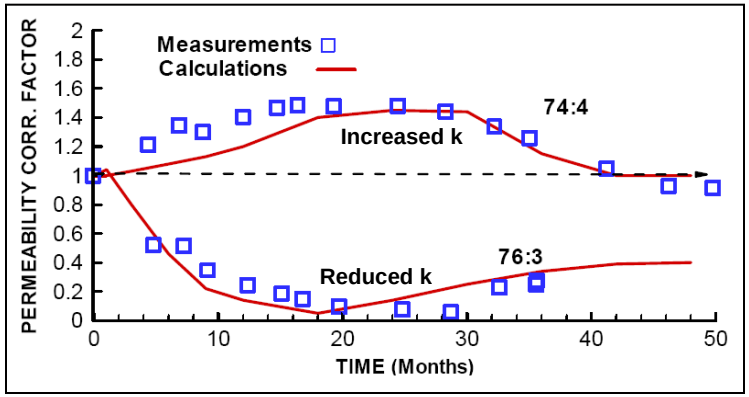
Coupled Processes Testing/Modeling

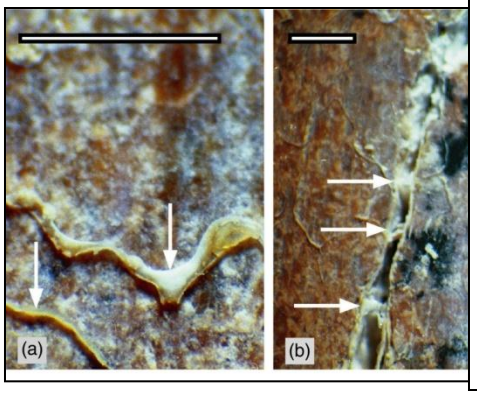
Drift Scale Heater Test

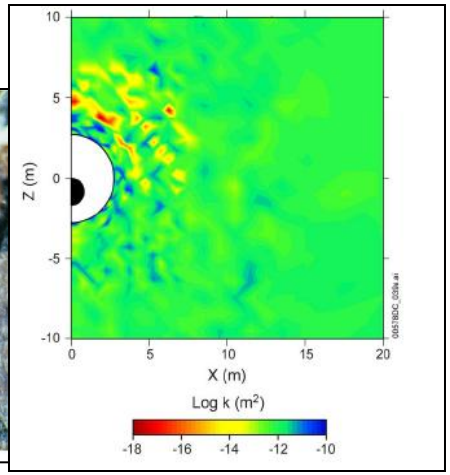




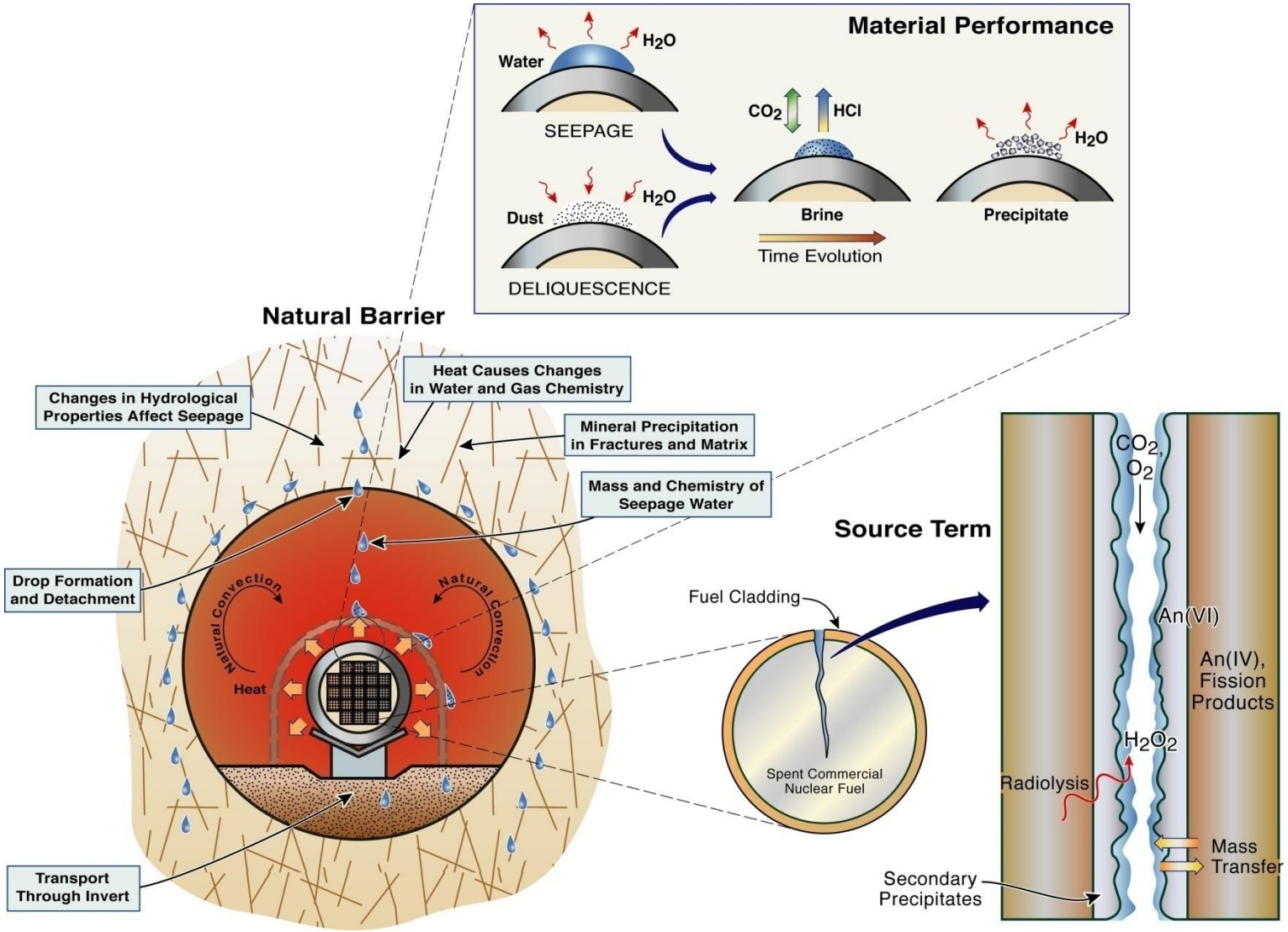








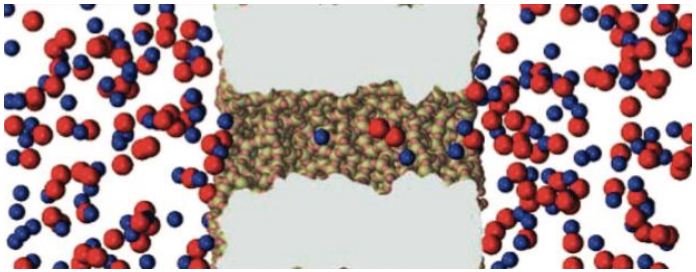
Coupling Waste Form, In-Drift and Near-Field Models



Current LBNL R&D on Waste Forms Behavior

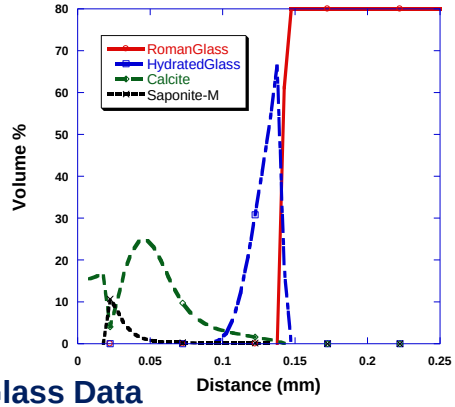
- Sub-continuum molecular scale and microscopic continuum scale models for borosilicate glass corrosion (with application to other waste forms such as ceramics)
- Determine corrosion controls
  - Hydration of glass and subsequent leaching of sodium and boron
  - Gradual formation of more stable silicate and carbonate phases
  - Interaction with near-field via diffusion/sorption, controlled by interfacial precipitates
- Funded by NEAMS

Molecular Modeling



Cruz-Chu et al. (2009) J. Phys. Chem. C

Microscopic Continuum Modeling



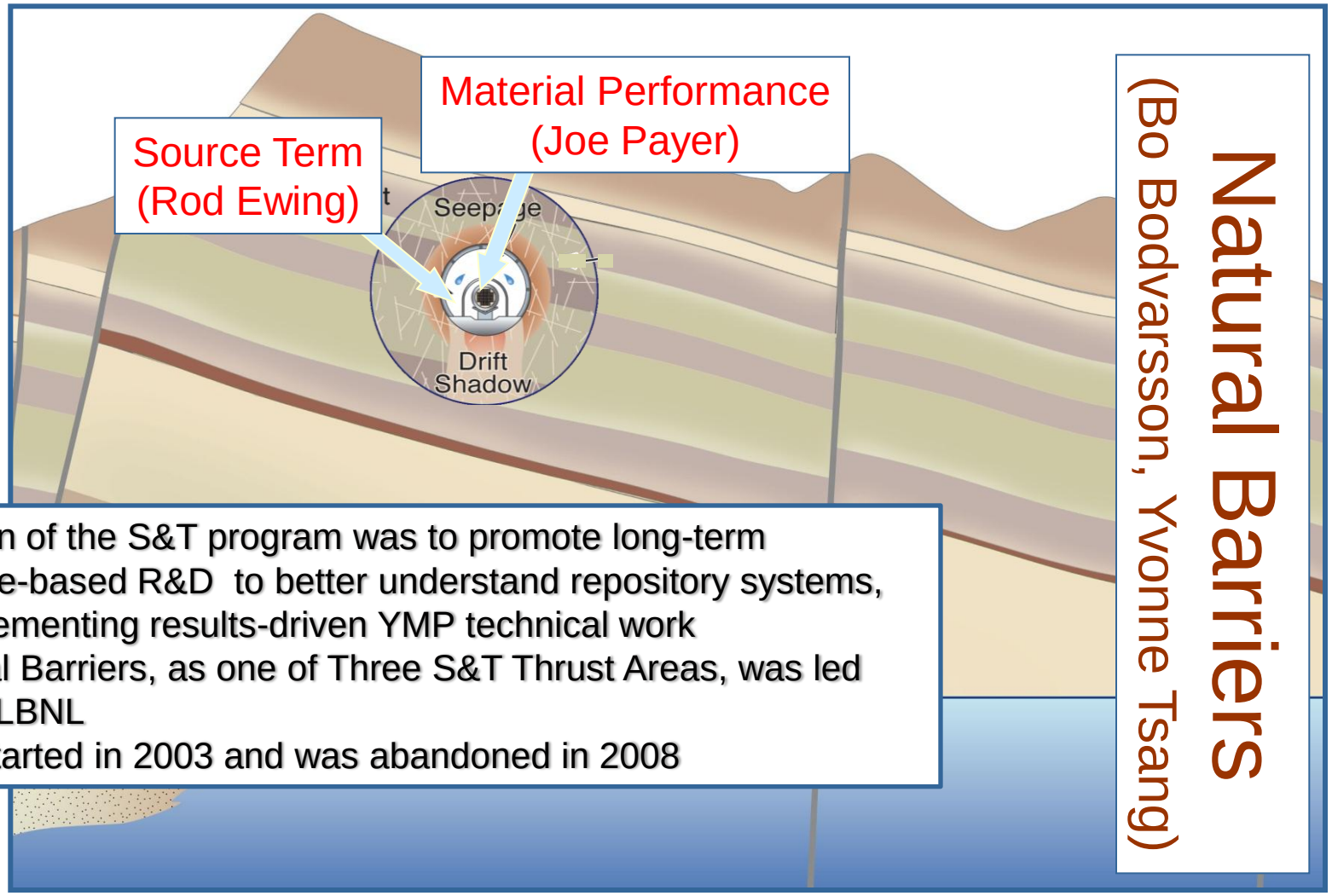
Roman Glass Data

YMP License Application and Defense

- LBNL's research covered many aspects of the technical basis for the License Application
  - Authored two main Safety Analysis Report (SAR) sections, and contributed significantly to several other
  - Authored more than 20 underlying science reports
- LBNL led license defense activities in several technical areas (NRC requests for additional information, contentions)
- LBNL staff were designated as key expert witnesses in UZ flow and transport, seepage, and coupled processes

June 2008

OCRWM Science and Technology Program (S&T)



- Mission of the S&T program was to promote long-term science-based R&D to better understand repository systems, complementing results-driven YMP technical work
- Natural Barriers, as one of Three S&T Thrust Areas, was led out of LBNL
- S&T started in 2003 and was abandoned in 2008

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Natural Barriers Thrust Objectives

- Enhance understanding of the natural system
  - Represent natural system more realistically
  - Remove conservatisms in a defensible manner
  - Significantly reduce uncertainty
- Provide data, process understanding and new models to enhance defensibility of the license application
- Demonstrate natural system *alone* meets regulatory standard
  - Supporting the foundation of multiple barrier concept
  - Dispelling the notion of over reliance on the engineered barrier
- Reduce costs
  - Provide scientific basis for reliance on natural system
  - Provide guideline for replacing redundant engineered components

- **Innovative R&D (high risk, high benefit)**
- **Transparent campaign with open RFPs and peer review of proposals**

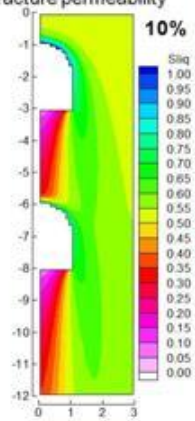
Natural Barriers Projects

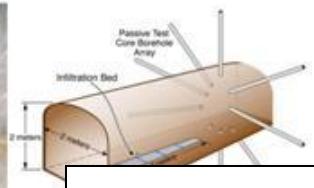
- **Seepage, near- and in-drift environment**
  - Coupled In-drift, Near-Field, and Mountain-Scale Fluid and Heat Flow Processes
  - Integrated Assessment of Critical Chemical and Mechanical Processes Affecting Drift Performance: Laboratory and Modeling Studies
  - An Integrated In-Drift/Near Field Flow and Transport Model with Reactive Chemistry
- **Drift shadow**
  - **Nature of Drift Shadows at Analog Sites**
  - **Testing the Concept of Drift Shadow with Isotope Data**
  - **Testing the Concept of Drift Shadow with X-ray Absorption Imaging**
- **Unsaturated Zone (UZ) transport**
  - Enhanced Retardation of Radionuclide Transport in Fractured Rock
  - Peña Blanca Natural Analogue
  - Matrix/Fracture Flow in Subrepository Units
  - Pore Connectivity, Episodic Flow, and Unsaturated Diffusion
- **Saturated Zone (SZ) transport**
  - Determining the Redox Properties of Yucca Mountain-Related Groundwater, Using Trace Element Speciation for Predicting the Mobility of Nuclear Waste
  - Field Studies for the Determination of Transport Properties of Radioactive Solutes and Colloids, Using Chemical Analogues
  - Improved Characterization of Radionuclide Retardation in Volcanics and Alluvium
  - Carbon-14 Groundwater Analysis
  - Saturated Zone Plumes in Volcanic Rocks
  - Large-Scale (2 km) Natural Gradient Tracer Test

Drift Shadow Coordinated R&D

Black Diamond Mine Analog (LBNL)

Seepage simulation for percolation to be 10% of saturated fracture permeability





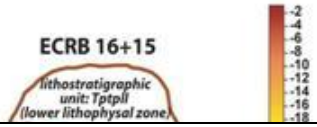
- Double drifts can be a possible design criteria
- Drift shadows in the upper drifts mitigate seepage into the lower waste emplacement drift

Testing Drift Shadow Concept (USGS)

- Collect rock samples around lithophysal cavities in ESF and ECRB
- Identify isotopic and chemical differences around lithophysal cavities

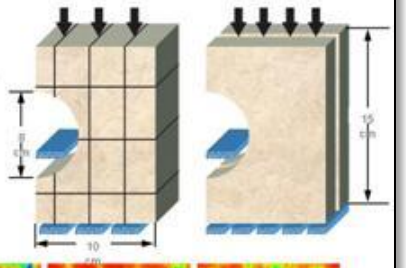
Conceptual Model

Patterns of Activity Ratio (AR) $^{234}U/^{238}U$ are different for samples collected from different sites

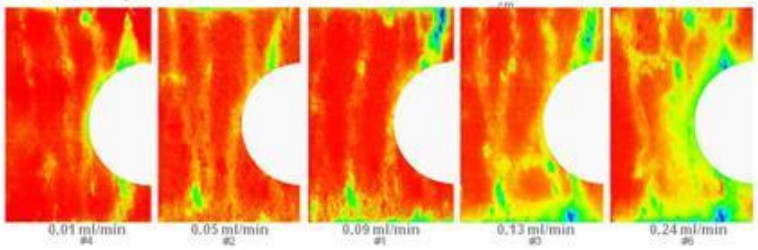


Small-Scale Studies (SNL)

- Design for multi- and in-plane fracture system
- Tracer being diverted around the drift
- Tracer shedding off the drift and not under the drift
- Capillary fringe at the bottom of the test cell for tests with higher flow rates (experimental design needs to be improved)



250 μm aperture fracture



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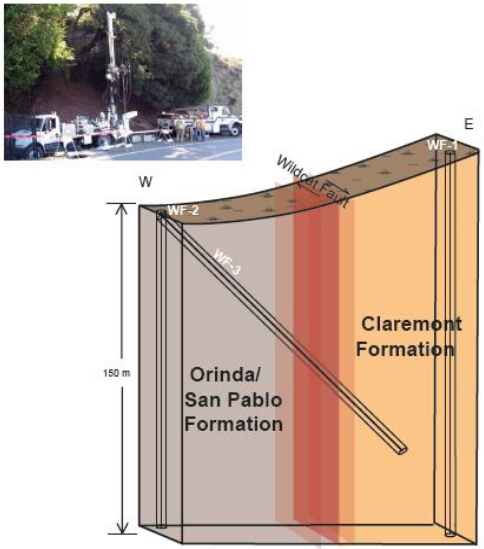
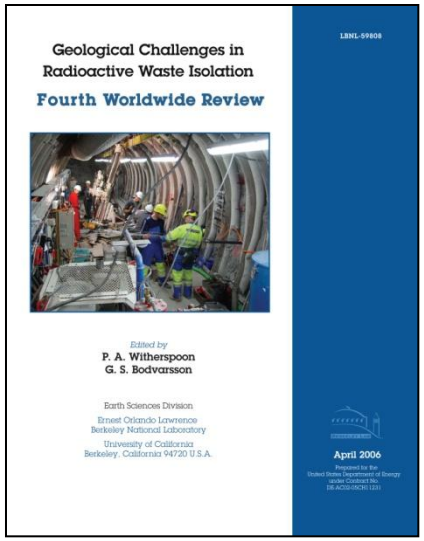
LBNL's R&D in International Programs

- Current R&D Supporting International Disposal Agencies
  - Fault zone characterization and testing (NUMO, Japan)
  - Gas generation and pressure buildup in a clay repository (NAGRA, Switzerland)
  - **DECOVALEX** (NDA, UK; SKB, Sweden)
- Software Support for TOUGH Codes
  - Various programs including ANDRA, NAGRA, ONDRA, JAEA, NUMO, KAERI, SKB,…
- IAEA Technology Transfer and Outreach
  - LBNL organized and hosted week-long training courses for less advanced programs to provide training on methodologies for geologic disposal
  - LBNL scientists participate in IAEA's Coordinated Research Project on Numerical Modeling to support site characterization and performance assessment
- World Wide Reviews



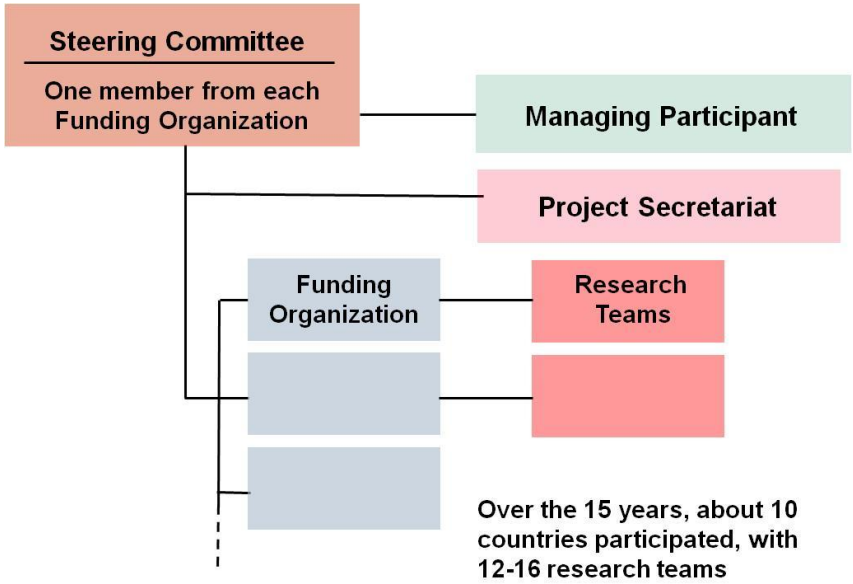


Worldwide Reviews on "Geologic Challenges in Waste Isolation", Four editions, 1991, 1996, 2002, 2006

DECOVALEX – An International Collaboration on Waste Disposal

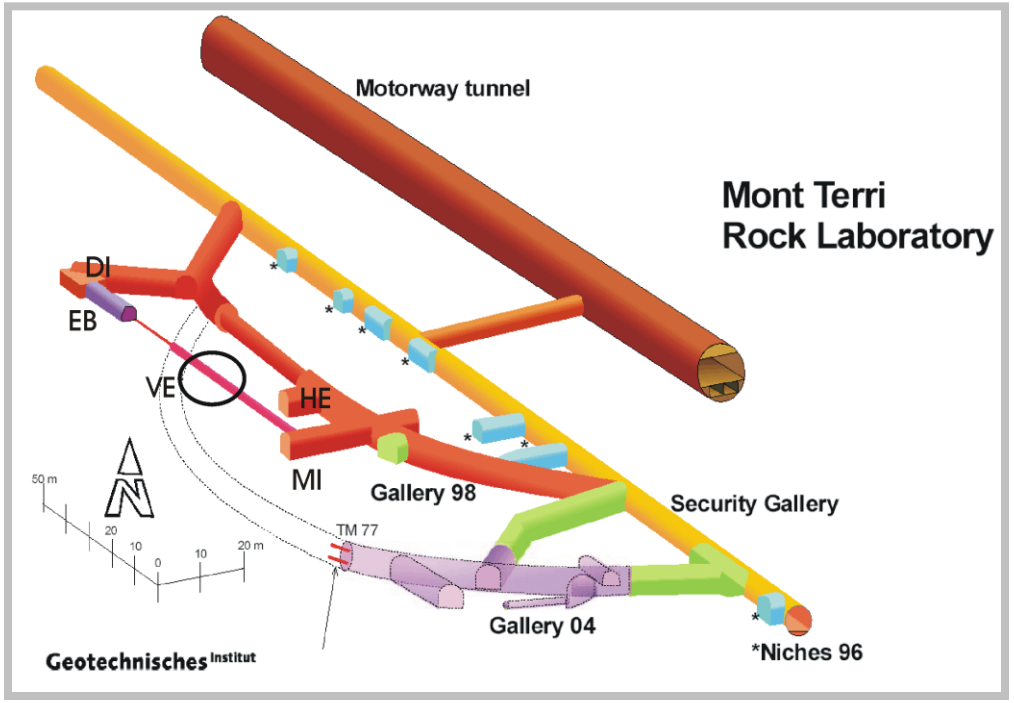
- DECOVALEX (acronym for DEvelopment of Coupled models and their VALidation against EXperiments) was established in 1992, and has been active since, in several project stages
- The objective is to achieve a better understanding and improved modeling of the effects of coupled (T-H-M-C) processes in nuclear waste repositories
- Past and current DECOVALEX activities include several international programs and research tasks with focus on clay and granite repositories

- **LBNL's Chin-Fu Tsang was a founding member and chaired the steering committee**
- **Up to 2007, LBNL modeling teams participated in several DECOVALEX tasks**
- **During DECOVALEX-THMC (2003-2007), LBNL organized DOE's DECOVALEX participation and led DOE's research tasks**



Example of a Current Task: Mont Terri Ventilation Test

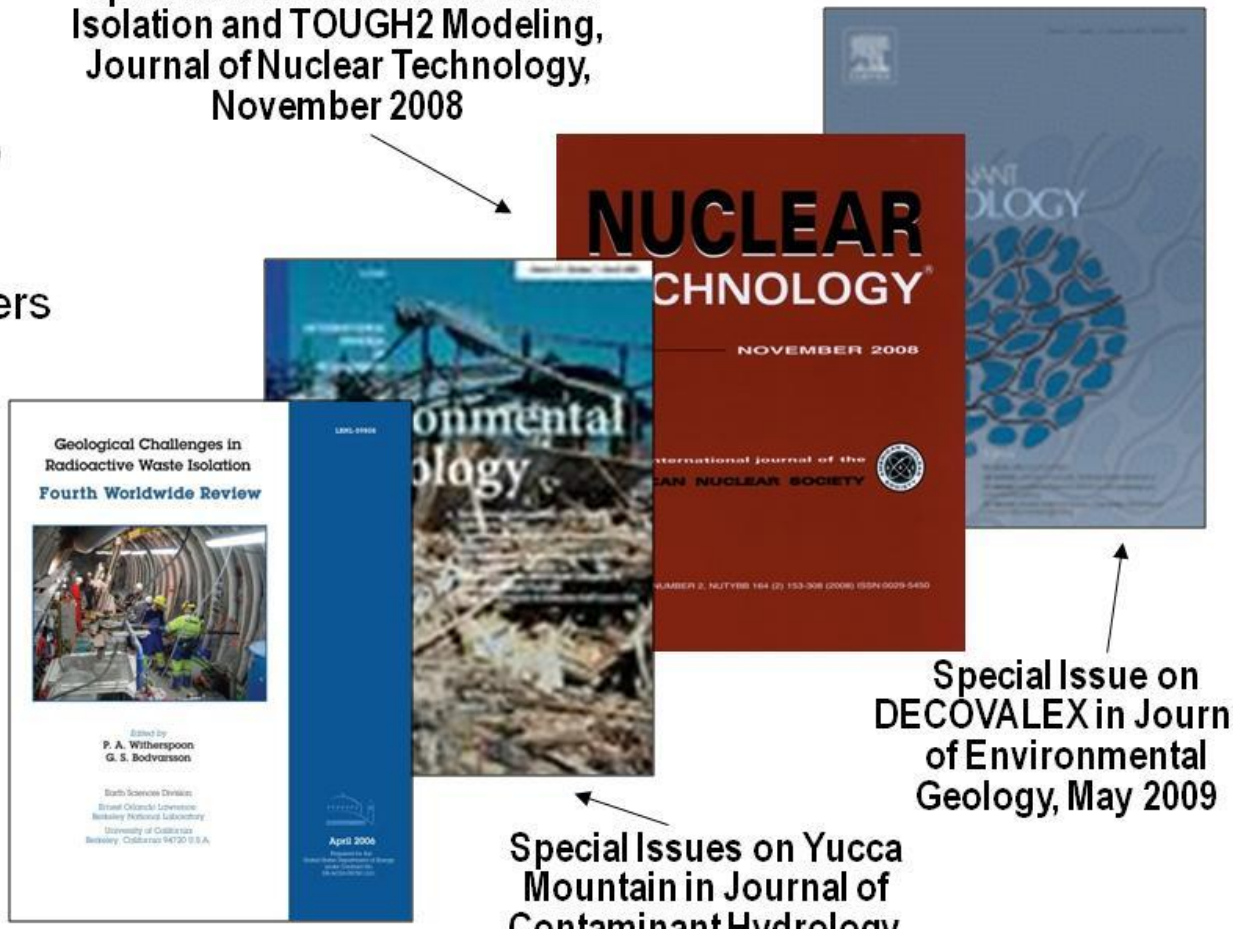
- Goal is to examine the HM and C changes that may occur in clay rocks, in relation to the ventilation of disposal drifts during the construction and operational phases of a geological repository
- Experiment is conducted in a micro-tunnel of 1.3 m diameter and 10 m long, with several de-saturation and resaturation cycles
- Issues involved in this subtask:
  - Desaturation/resaturation of the rock
  - Sealing
  - Damage/microcracking
  - Evolution of the EDZ



LBNL Contributions to Disposal Science

- Journal articles (>60 during 2007-2010)
- Special Issues
- Books and Book Chapters
- Conferences

Special Issue on Nuclear Waste Isolation and TOUGH2 Modeling, Journal of Nuclear Technology, November 2008



Special Issue on DECOVALEX in Journal of Environmental Geology, May 2009

Worldwide Reviews on "Geologic Challenges in Waste Isolation", Four editions, 1991, 1996, 2002, 2006

Special Issues on Yucca Mountain in Journal of Contaminant Hydrology, May 1999, May 2003

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LBNL's core R&D capabilities and experiences align well with DOE NE research needs regarding alternative disposal options

Site characterization

Complex experiments

Multi-physics modeling

Coupled processes

Fractured rock

Science focus

International connections

R&D Coordination