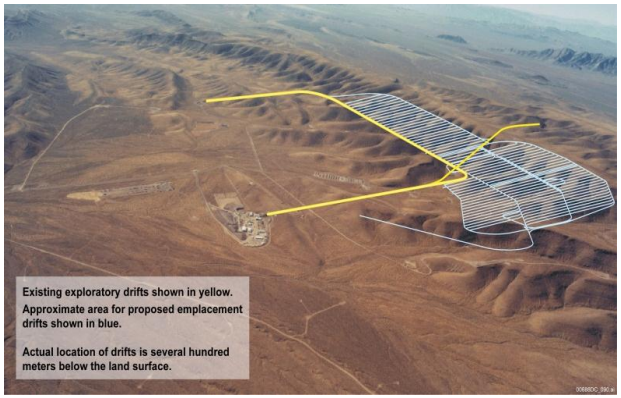
SAND2012-6969P

Exceptional service in the national interest

Sandia National Laboratories



Repository Science at Sandia:

WIPP, Yucca Mountain, and the Path Forward

Peter Swift

Presented to the Geoscience Research Foundation External Review Panel

August 31, 2012

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Status of the U.S. Repository Program

- "Yucca Mountain is not a workable option" (DOE licensing motion, March 3, 2010)
  - "the Secretary's judgment here is not that Yucca Mountain is unsafe or that there are flaws in the LA, but rather that it is not a workable option and that alternatives will better serve the public interest." (DOE filing to NRC Licensing Board, May 27, 2010, footnote 102)
- The Nuclear Waste Policy Act remains in effect and Yucca Mountain remains the only legally available option
- Yucca Mountain license hearings remain in suspension pending court action
  - August 3, 2012 ruling by the US Court of Appeals for the District of Columbia delays a decision until after December 14, 2012, pending Congressional action
- All current DOE activities related to disposal of spent nuclear fuel and high-level radioactive waste have moved to the DOE Office of Nuclear Energy

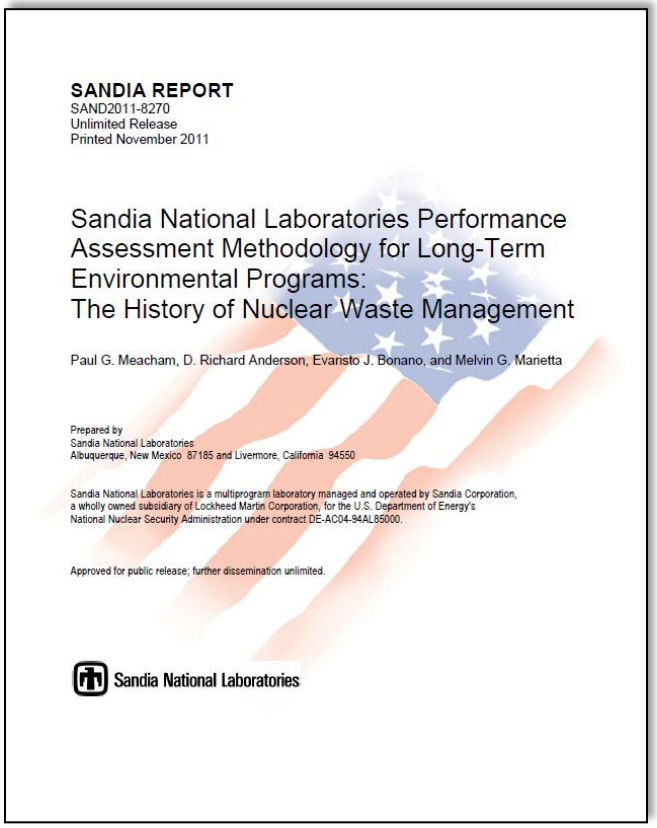
SNL Leadership in Repository Science

Sandia National Laboratories

- WIPP
  - Lead for science programs 1975-present
  - Site selection and characterization 1975-1993
  - Regulatory certification 1994-1998
  - Science in support of operations and recertification 1998-present
- Yucca Mountain
  - Contributor to site characterization 1978-2002
  - Major role in long-term performance assessment 1989-2010
  - DOE Office of Civilian Radioactive Waste Management (OCRWM) Lead Laboratory for repository science 2006-2010
  - Primary role in supporting the 2008 License Application to the NRC
- DOE Office of Nuclear Energy's Used Fuel Disposition Campaign
  - Leadership responsibility 2009-present

SNL Leadership in Repository Science (cont.)

- Other Significant Radioactive Waste Management Programs at SNL
  - Subseabed Disposal (1973-1987)
  - Nuclear Regulatory Commission Licensing Support (1976-1993)
  - DOE's Greater Confinement Disposal facility (1989-2001)
  - SNL Mixed Waste Landfill (1989-2007)



SANDIA REPORT
SAND2011-8270
Unlimited Release
Printed November 2011

Sandia National Laboratories Performance Assessment Methodology for Long-Term Environmental Programs:
The History of Nuclear Waste Management

Paul G. Meacham, D. Richard Anderson, Evaristo J. Bonano, and Melvin G. Marietta

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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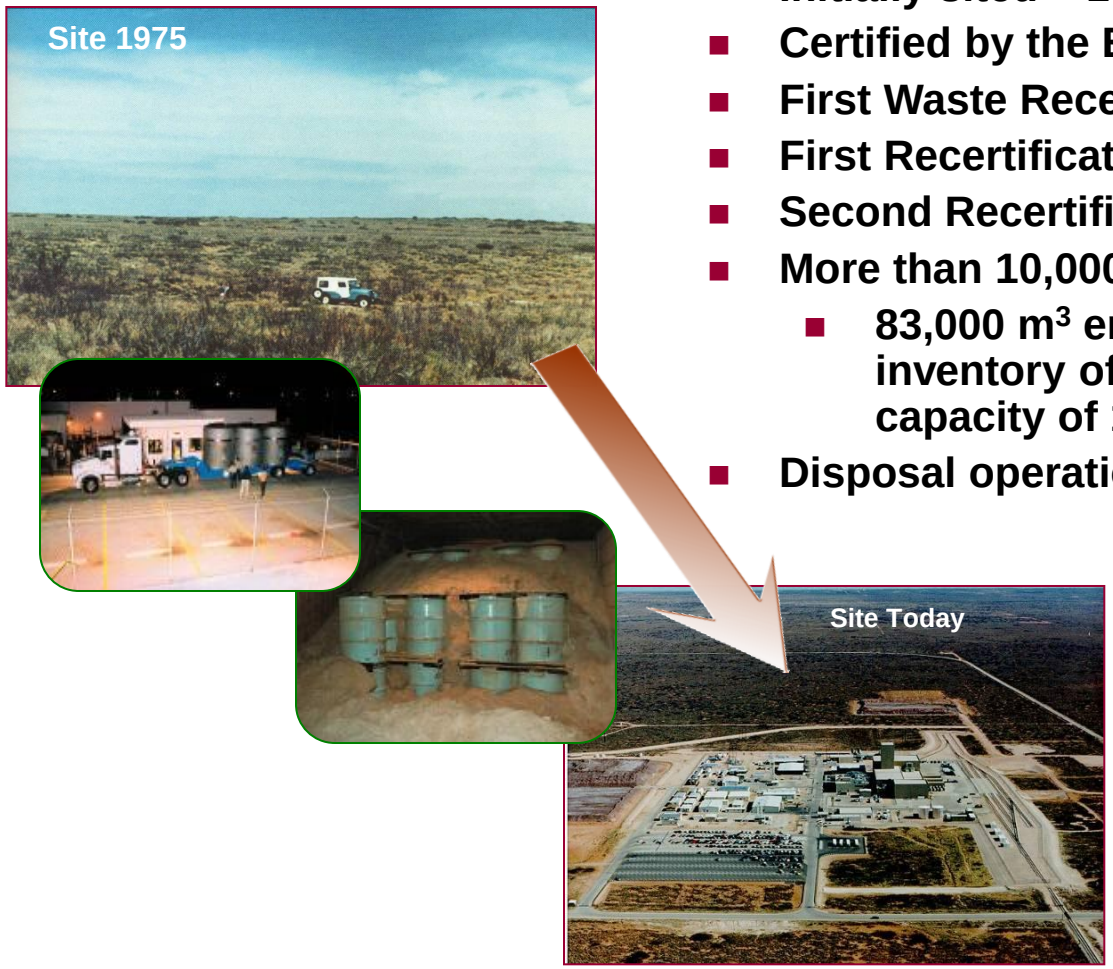
Sandia National Laboratories

Stages of Repository Science

- Site Selection
  - Identification of potentially suitable media, evaluation and screening of candidate sites
- Site Characterization
  - Experimental and field test programs to characterize long-term performance of engineered and natural components of the system
- Site Evaluation (Performance Assessment)
  - Modeling of future performance under a range of conditions at component and full-system level, with uncertainty
- Licensing
  - EPA regulations (40 CFR 191 and 40 CFR 194) for WIPP require probabilistic estimates of repository performance for 10,000 years
  - EPA (40 CFR 197) and NRC (10 CFR 63) regulations for Yucca Mountain require probabilistic estimates of repository performance for 1 million years
  - Regulatory requirements for future repositories remain uncertain

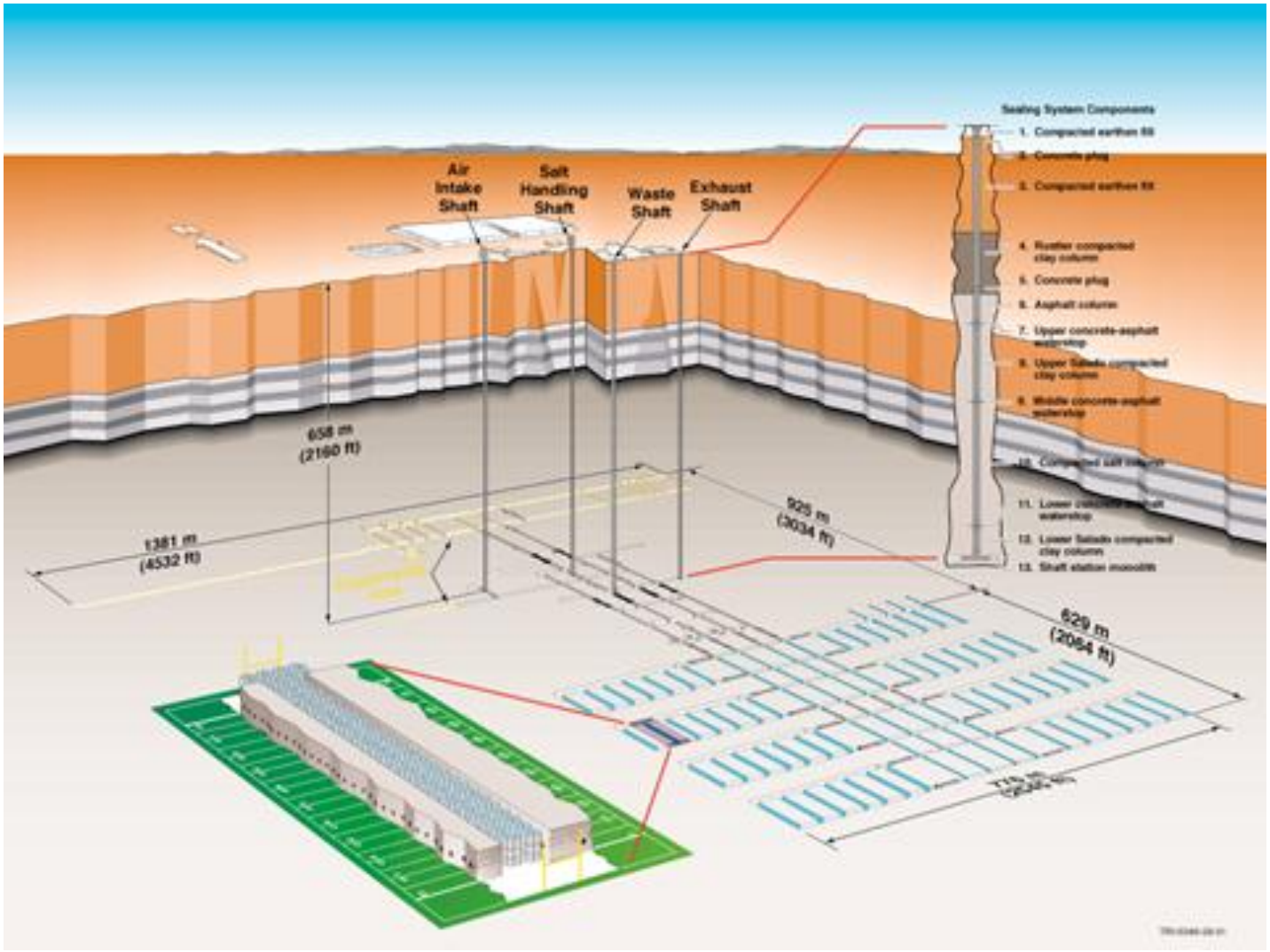
Waste Isolation Pilot Plant

Geologic Disposal of Transuranic Waste



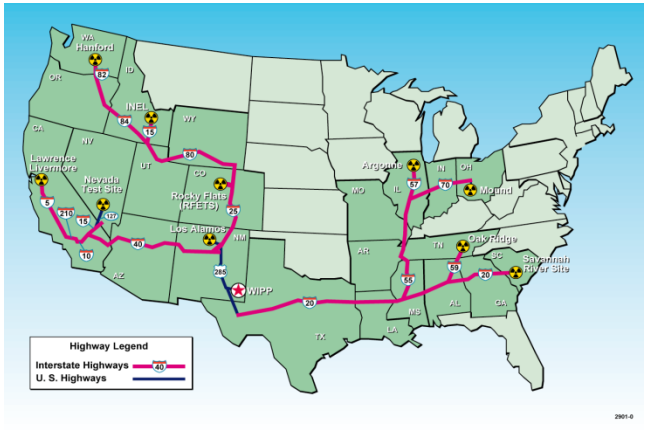
- Initially sited – 1975
- Certified by the EPA – 1998
- First Waste Receipt – March 26, 1999
- First Recertification – March 2006
- Second Recertification – November 2010
- More than 10,000 shipments to date
  - 83,000 m^3 emplaced, projected 2004 inventory of 145,000 m^3, allowable capacity of 175,000 m^3
- Disposal operations continue – 2008 → 2033?

WIPP Design


Air Intake Shaft
Salt Handling Shaft
Waste Shaft
Exhaust Shaft
Sealing System Components
658 m (2160 ft)
1381 m (4532 ft)
925 m (3034 ft)
629 m (2064 ft)

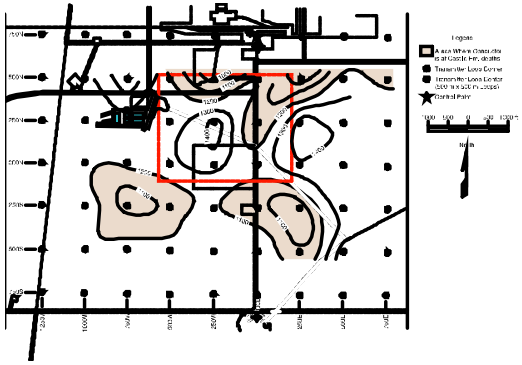
WIPP Transuranic Waste

- **Derived from defense-related activities**
  - **Laboratory and industrial trash contaminated with transuranic radionuclides**
  - **Primarily alpha-emitting radionuclides, relatively little gamma emission and low thermal power**



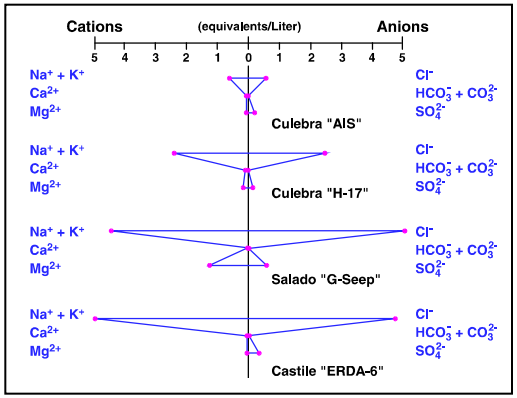
WIPP Site Characterization

Geologic studies



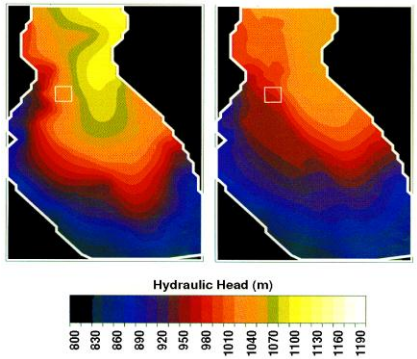
Geophysical surveys

Hydrologic testing



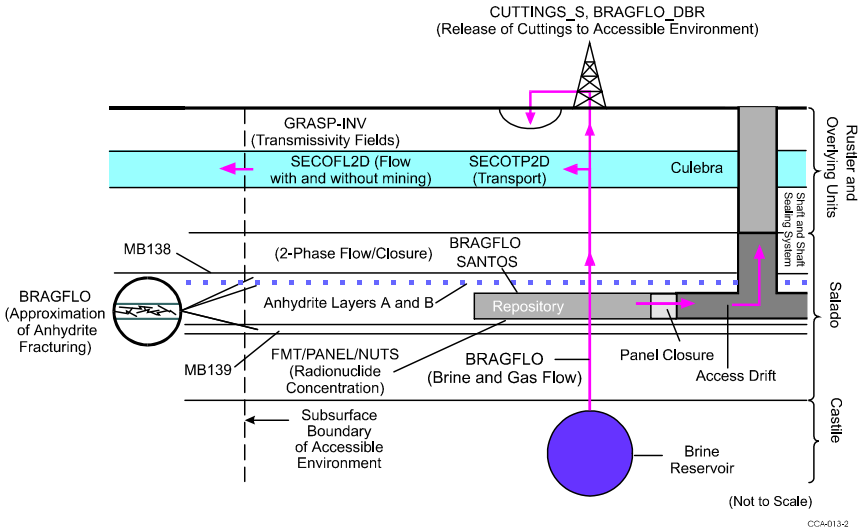
Geochemical sampling and analysis

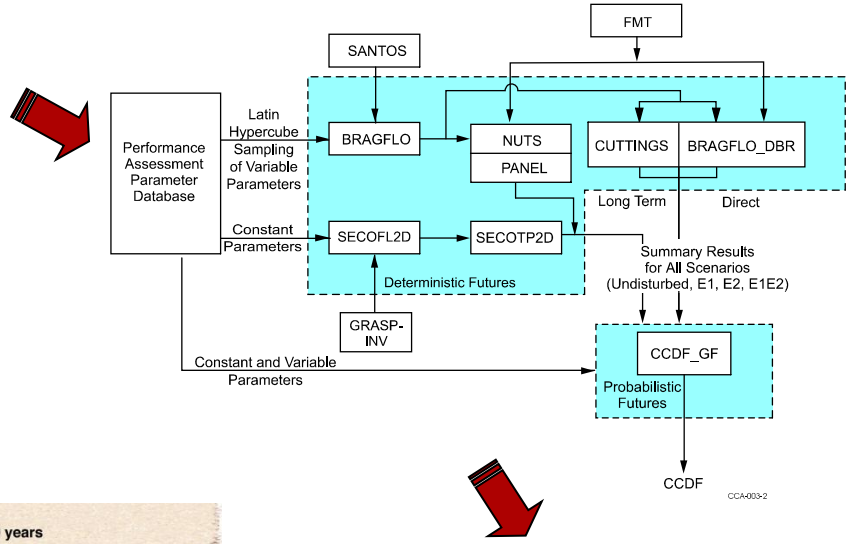
Geomechanical testing

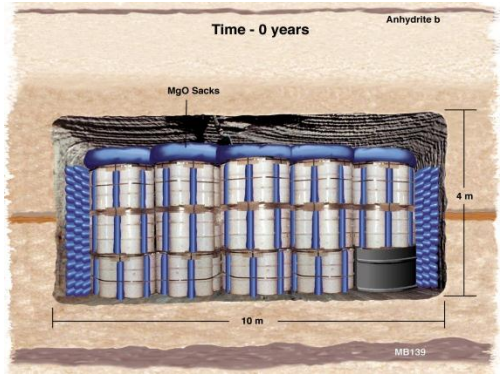


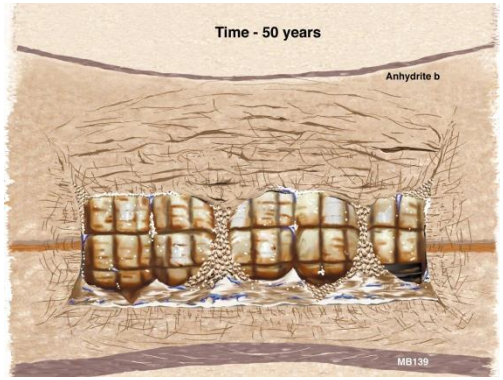
Numerical modeling

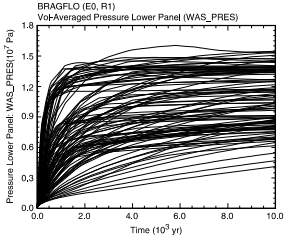
Performance Assessment for WIPP











Long-term Performance of the WIPP

- Geologic barriers provide long-term isolation
  - Dry climate
  - Very low permeability of salt
- No releases of radionuclides to the accessible environment occur during the 10,000-year performance period without human intrusion
- Hypothetical borehole intrusions as a result of future oil and gas exploration are evaluated as part of the long-term performance assessment
  - Releases due to multiple human intrusions are well below regulatory limits

The Yucca Mountain Mission

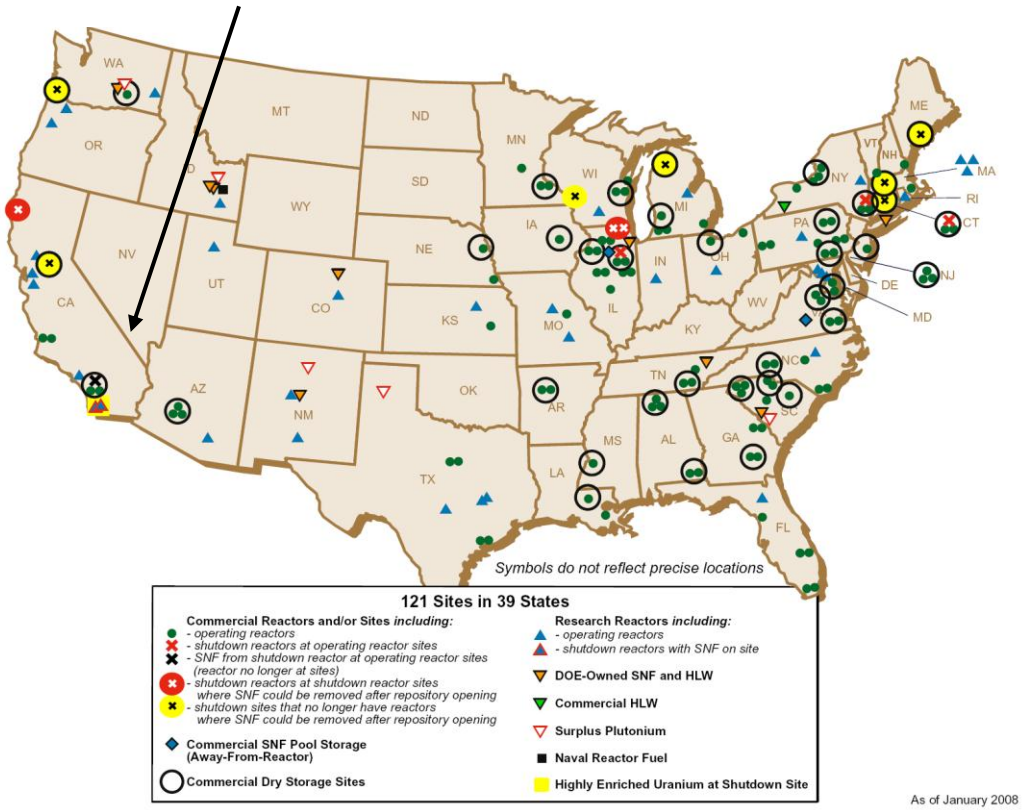
Current locations of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) destined for geologic disposal:

[121 sites in 39 states]

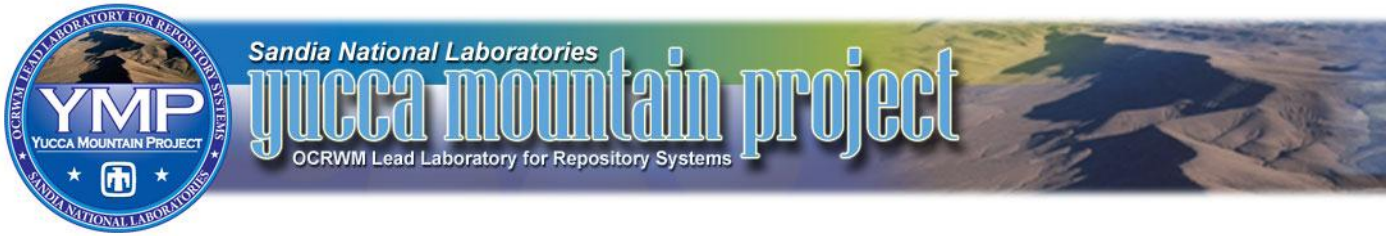
United States Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) Mission:

To manage and dispose of high-level radioactive waste and spent nuclear fuel in a manner that protects health, safety, and the environment; enhances national and energy security; and merits public confidence.

Proposed Yucca Mountain Repository



The Yucca Mountain Lead Laboratory



Sandia National Laboratories

Los Alamos National Laboratory

ornl Oak Ridge National Laboratory

Berkeley Lab

INL Idaho National Laboratory

Science in the National Interest
Lawrence Livermore National Laboratory

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

The University of Texas at Austin

Argonne National Laboratory

UNLV University of Nevada Las Vegas

The University of Nevada Reno

DRI Desert Research Institute

- Apogen / QinetiQ
- Areva
- Beckman & Associates
- Galson Sciences
- Geotrans
- Intera
- ISSI
- Itasca
- John Hart and Associates
- JKRA
- Kleinfelder
- Longenecker & Associates
- RESPEC
- RHYM
- SAIC
- Sala & Associates
- Stoller
- URS

Waste for Yucca Mountain

Sandia National Laboratories

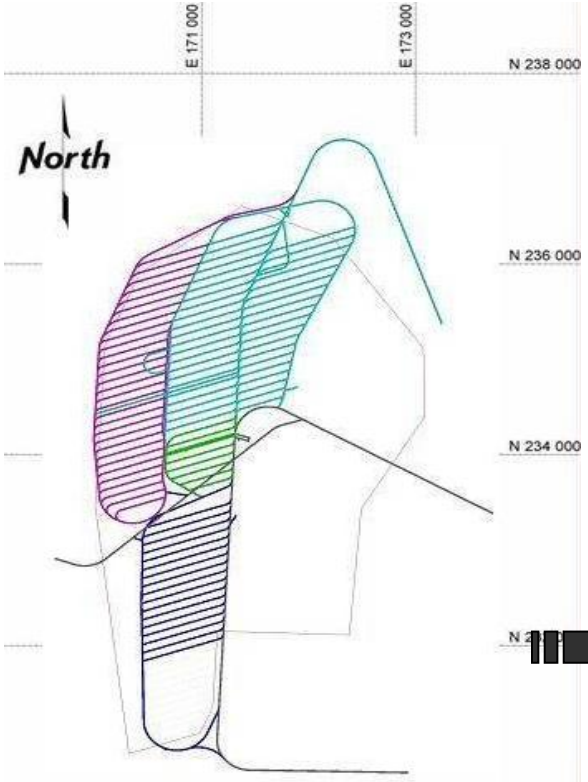
Commercial Spent Nuclear Fuel:
63,000 MTHM (~7500 waste packages)

DOE & Naval Spent Nuclear Fuel:
2,333 MTHM
(~400 naval waste packages)
(DSNF packaged with HLW)

DOE & Commercial High-Level Waste:
4,667 MTHM
(~3000 waste packages of co-disposed DSNF and HLW)

DSNF: Defense Spent Nuclear Fuel
HLW: High Level Radioactive Waste
MTHM: Metric Tons Heavy Metal

Yucca Mountain Subsurface Design



Emplacement drifts

5.5 m diameter

approx. 100 drifts, 600-800 m long

Waste packages

~11,000 packages

~ 5 m long, 2 m diameter

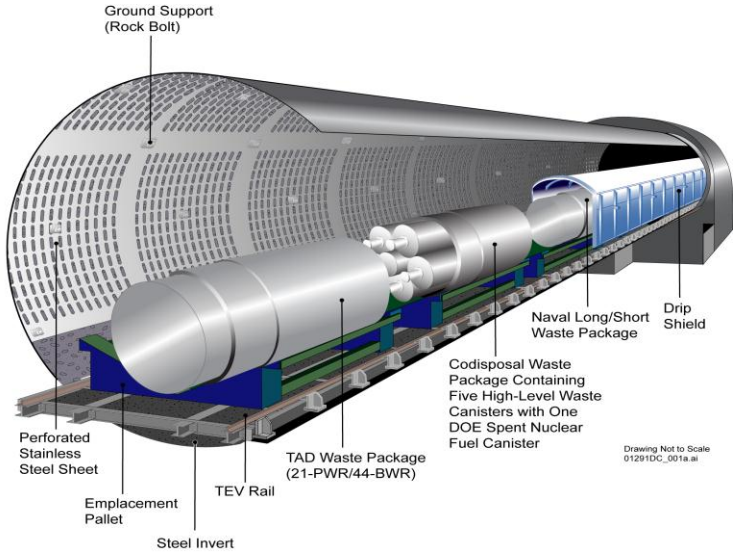
outer layer 2.5 cm Alloy 22 (Ni-Cr-Mo-V)

inner layer 5 cm stainless steel

Internal TAD (transportation, aging, and disposal) canisters for commercial spent fuel, 2.5 cm stainless steel

Drip shields

free-standing 1.5 cm Ti shell



Yucca Mountain Exploratory Studies Facility

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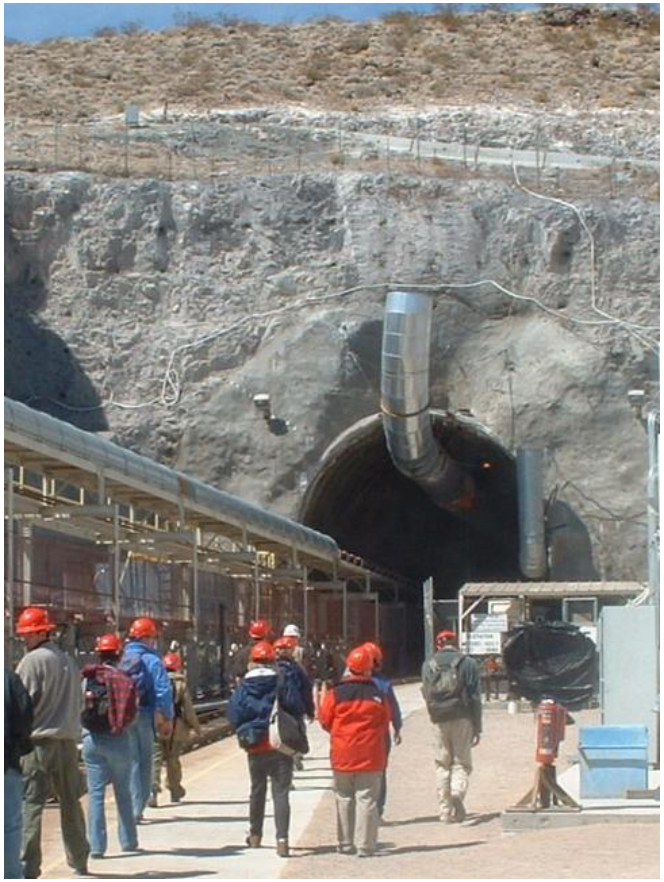
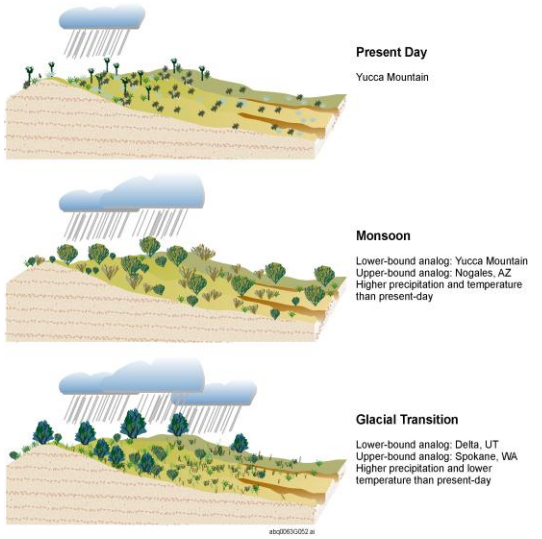
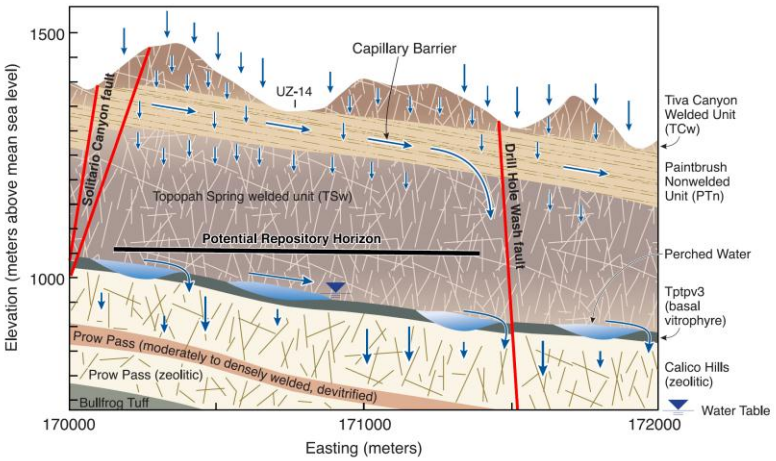
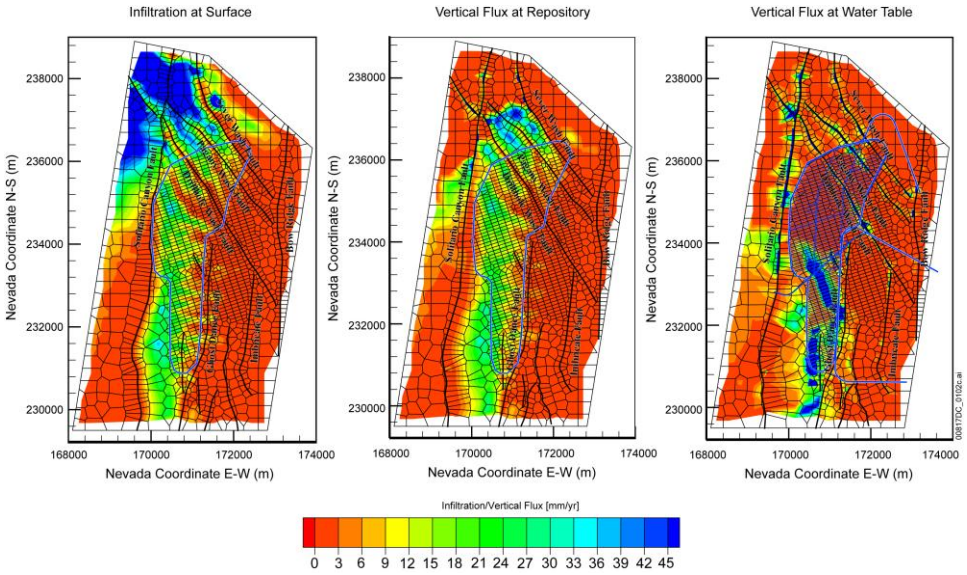


Groundwater Flow at Yucca Mountain

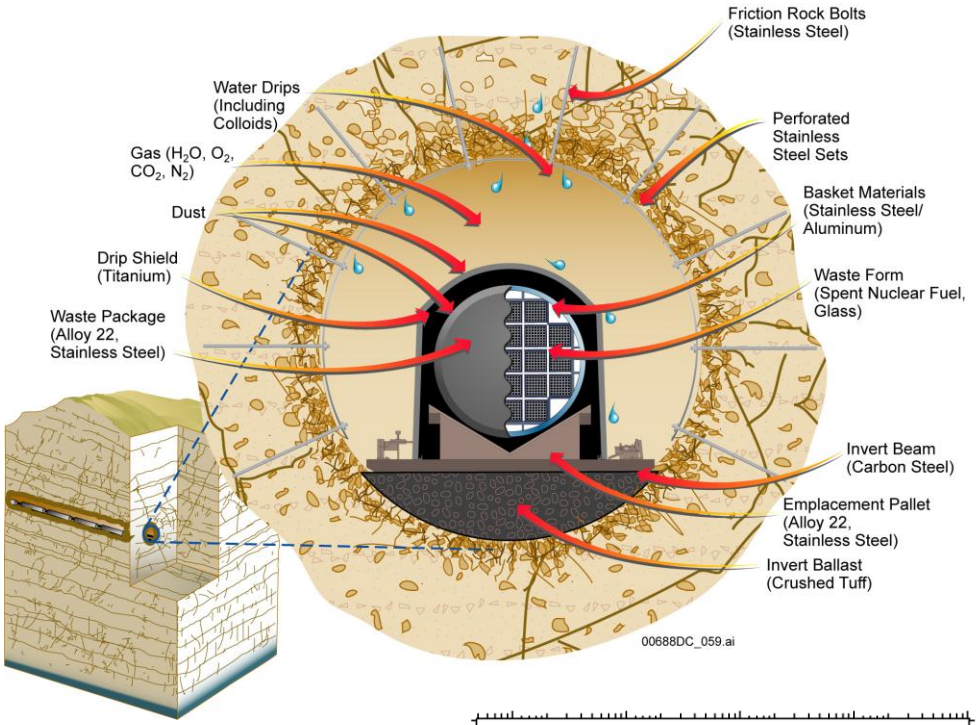


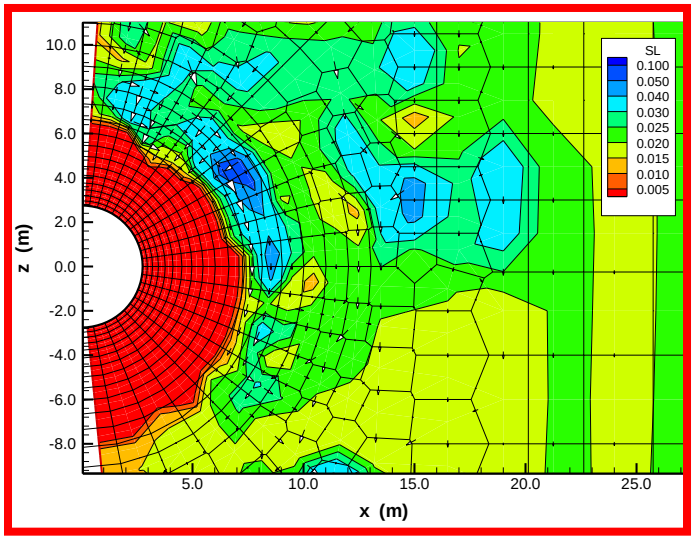




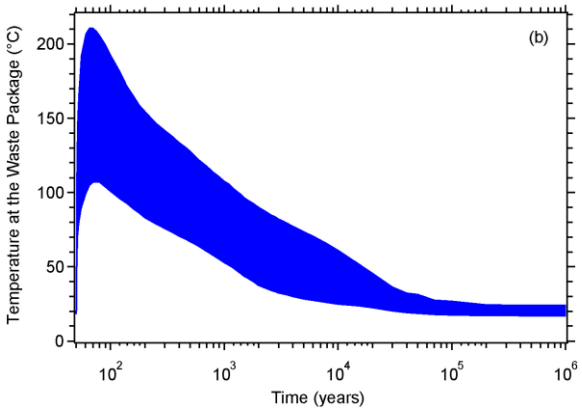
Field tests and models provide basis for understanding infiltration and flow in unsaturated rocks at Yucca Mountain

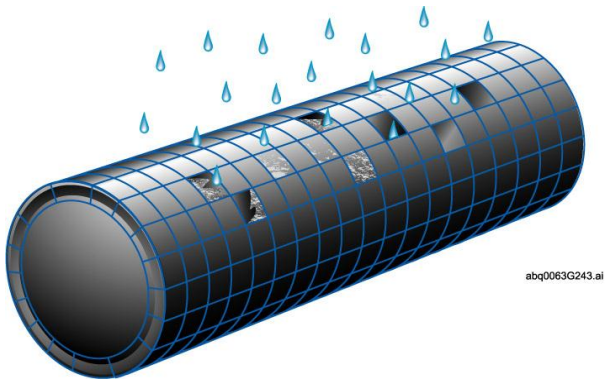
The Emplacement Environment at Yucca Mountain



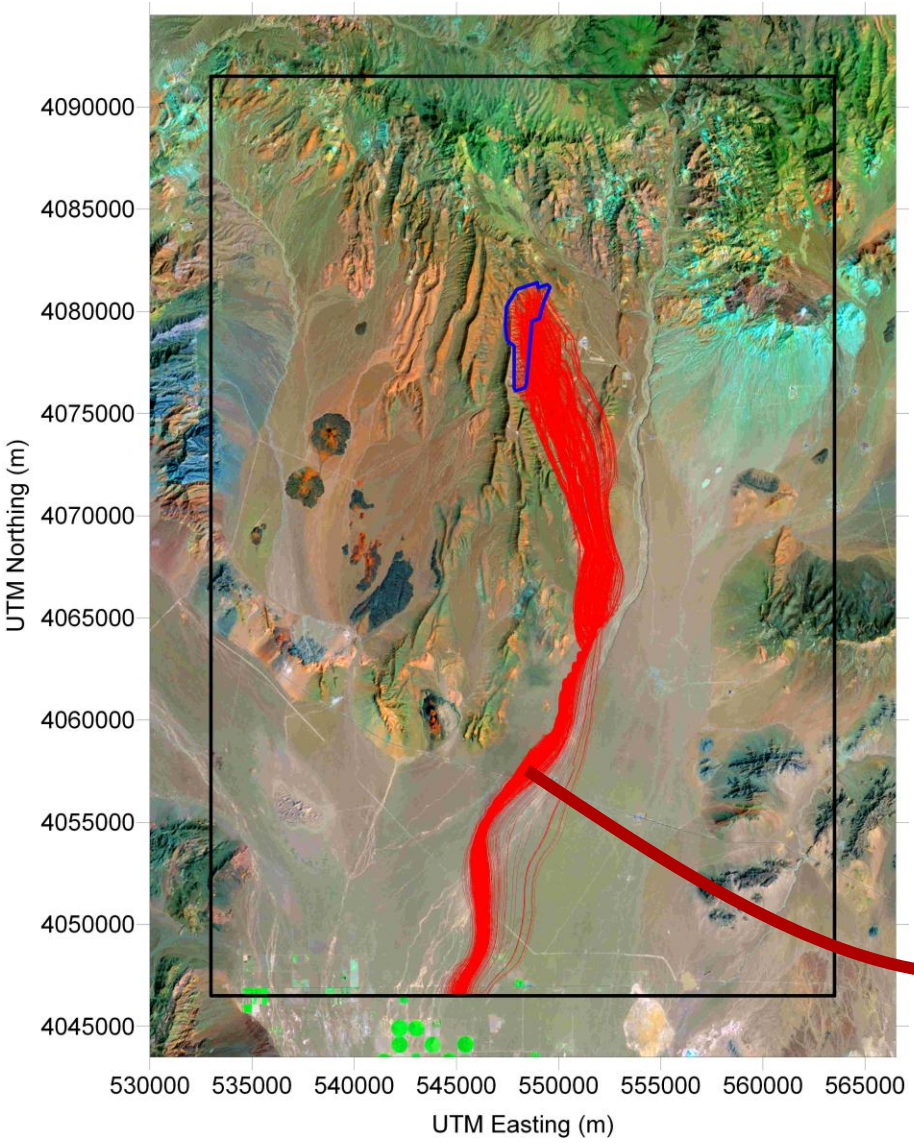


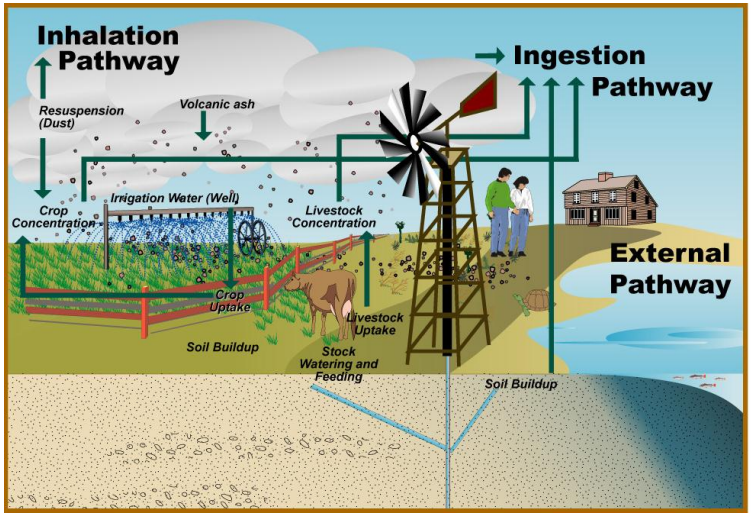
Material testing and models characterize performance of the engineered barriers





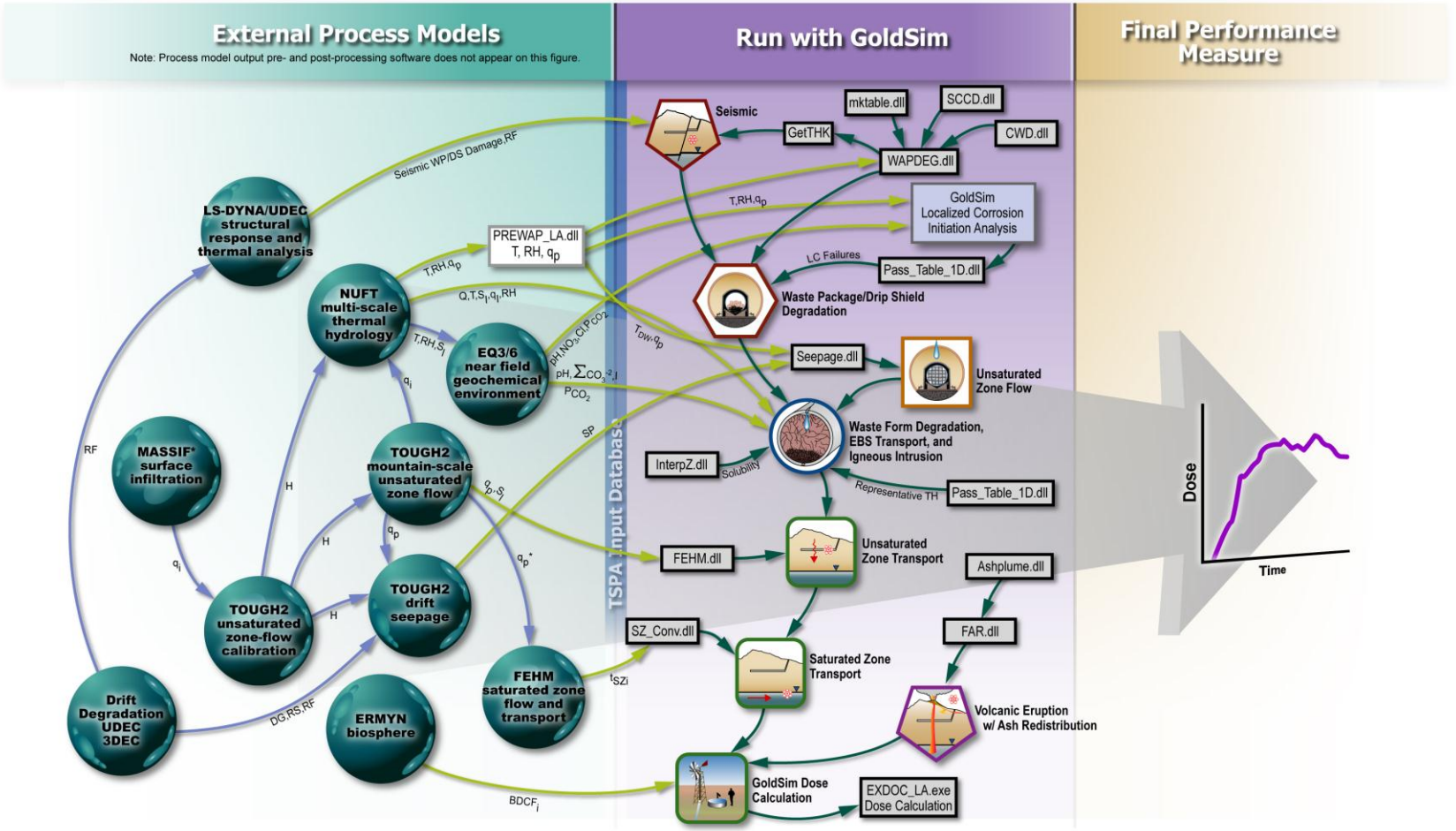
Estimating Dose to Hypothetical Future Humans





Modeled groundwater flow paths and hypothetical exposure pathways

Total System Performance Assessment Architecture



Output Parameters

f_S	Fraction of WPs with Seeps	q_p	Percolation Flux	q_l	Infiltration Flux	H	Hydrologic Properties
EBS	Engineered Barrier System	NO_3	Nitrate Concentration	DG	Drift Geometry	SP	Seepage Parameters
Q_S	Seep Flow Rate	T	Temperature	Cl	Chloride Concentration	RS	Rock Strength
Q	Evaporation Rate	RH	Relative Humidity	I	Ionic Strength	RF	Rockfall Size and Number
pH	pH	S_l	Liquid Saturation	t_{SZi}	Saturated Zone Transport Time		
ΣCO_3^{-2}	Carbonate Concentration	X_a	Air Mass Fraction	$BDCF_i$	Biosphere Dose Conversion Factor		
P_{CO_2}	Partial Pressure of CO_2	q_l	Liquid Flux	q_g	Gas Flux		

*Note: q_p derived from INFIL model

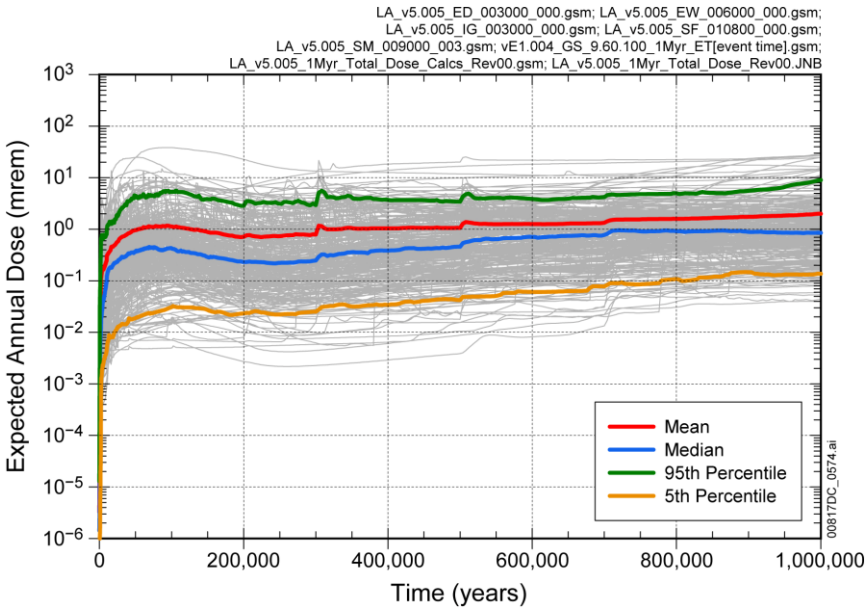
Legend

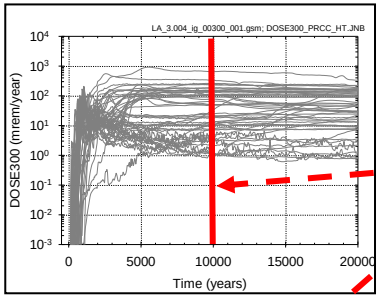
Response Surface between Process Models
Response Surface from Process Model to GoldSim
Connection in GoldSim
Preprocessor
TSPA Model DLL

00817DC_0093a.ai

Yucca Mountain Performance Assessment Results

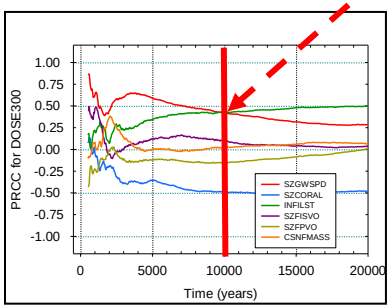
Monte Carlo estimates of overall performance
(Example dose histories from Yucca Mountain Total System Performance Assessment for the License Application, total expected dose from all scenarios)

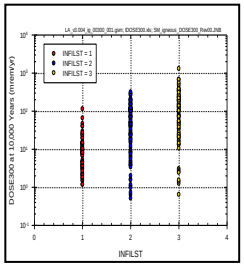


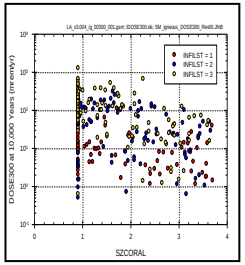


DOSE300: 10,000 yr

Variable	R^2	SRRC
INFILST	0.28	0.53
SZCORAL	0.40	-0.36
SZGWSPD	0.53	0.36
GTCPU239	0.61	0.27
IGPH	0.63	0.15
SZHAVO	0.64	0.09
EP1LOWU	0.65	0.10
EPSLOWPU	0.66	0.09
SZNVF7	0.66	0.08







Sensitivity and Uncertainty Analyses
Identify model inputs important to uncertainty in performance estimates

Long-Term Performance of Yucca Mountain

- No significant releases for many tens of thousands of years if the site is undisturbed
  - Dry climate, little groundwater flow
  - Corrosion-resistant waste packages
- Over hundreds of thousands of years, estimated mean and median annual doses are well below natural background
- Disruption by unlikely geologic processes could cause releases and doses to humans; probability-weighted consequences are evaluated
  - Site geology indicates probability of volcanism is on the order of one chance in 10 million to one chance in 1 billion per year (mean 1.7×10^{-8}/yr)
  - Disruption by seismic activity is reasonably likely over very long time periods; consequences are not severe
- All estimated radiation doses are within regulatory limits

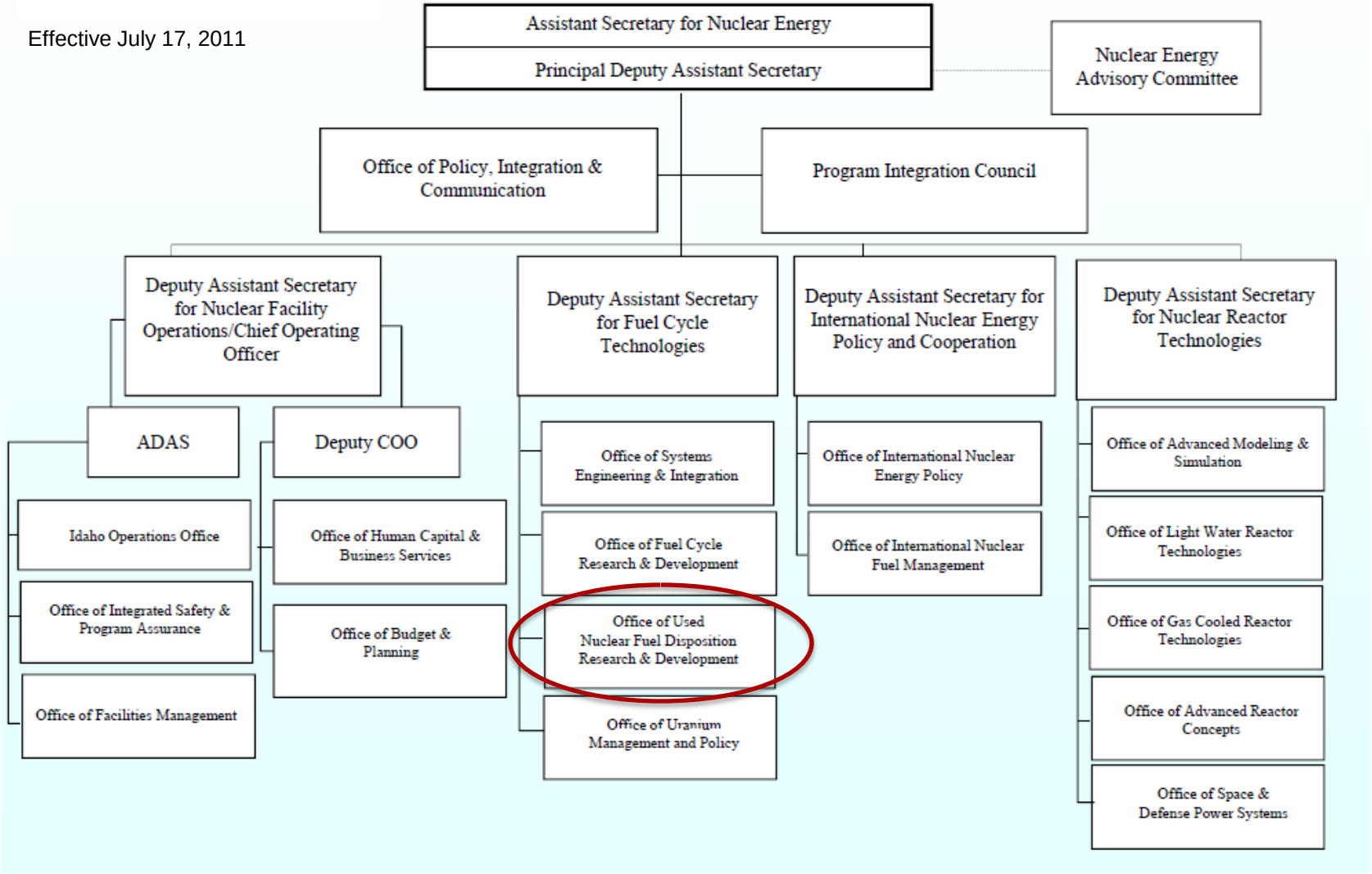
The US Repository Program After Yucca Mountain

Sandia National Laboratories

- With the suspension of Yucca Mountain Licensing and termination of funding for the DOE Office Civilian Radioactive Waste Management, the national mission has moved to the DOE Office of Nuclear Energy Office of Used Fuel Disposition (NE-53)
  - R&D within NE-53 is performed by the “Used Fuel Disposition Campaign”
  - The mission of the Used Fuel Disposition Campaign is to identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles.

DOE NE Organizational Chart

Sandia National Laboratories



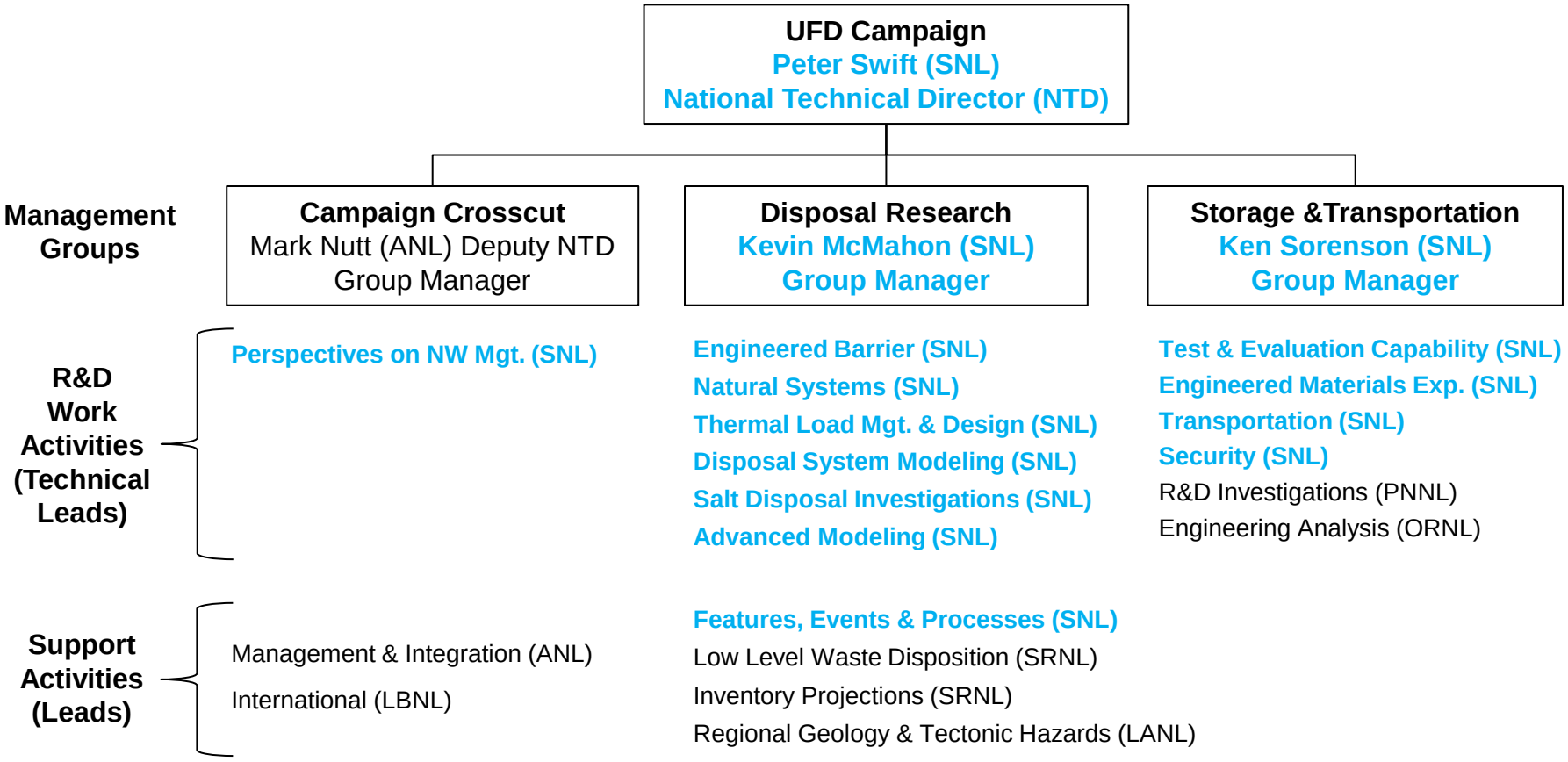
UFD Campaign 2009-Present

Sandia National Laboratories

- FY09 Planning meeting at Argonne National Laboratory, June 2009
- FY10 R&D funding at $7.1 M
  - Disposal R&D, modest level of effort on Storage R&D, no Transportation R&D
- FY11 R&D funding at $23.8 M
  - Nine national laboratories participating in UFD
  - Significant R&D program in Storage, including Transportation
  - Disposal R&D not site specific
- FY12 R&D budget baseline at $22.8M, end-of-year actual ~$37M
  - Some elements of FY12 work scope not established until fourth quarter
  - Programmatic uncertainties remain regarding national policy and Yucca Mountain litigation.
- FY13 R&D budget planning target at $26M

UFD Campaign R&D Participants…
9 US National Laboratories

Sandia's Role in the Used Fuel Disposition Campaign



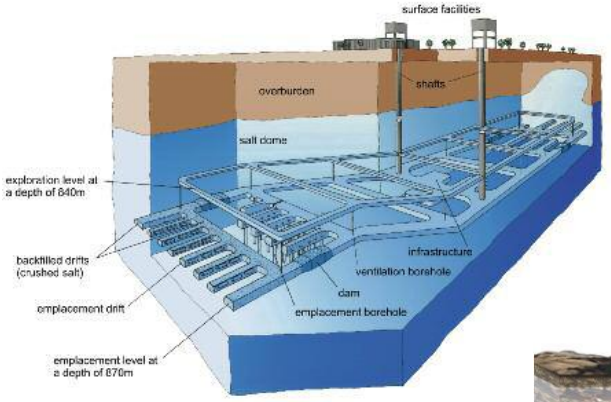
Generic Disposal R&D

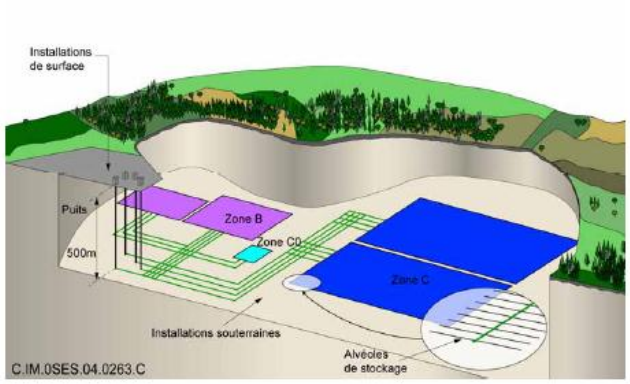
- The Nuclear Waste Policy Act precludes any and all site-specific repository investigations at locations other than Yucca Mountain
- All disposal research must be generic at this stage
- What can generic R&D accomplish?
  - Provide a sound technical basis for the assertion that the US has multiple viable disposal options that will be available when national policy is ready
  - Identify and research the generic sources of uncertainty that will challenge the viability of disposal concepts
  - Increase confidence in the robustness of generic disposal concepts to reduce the impact of unavoidable site-specific complexity
  - Develop the science and engineering tools required to address the goals above, through collaborations within NE and DOE, and with universities, industry, and international programs

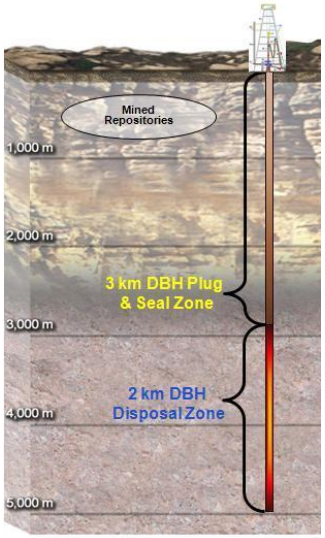
28

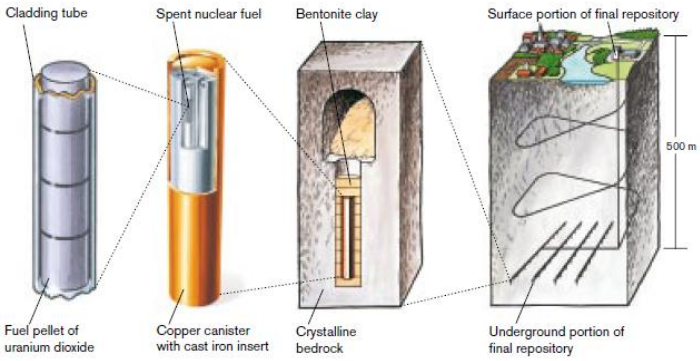
U.S. Disposal R&D Focuses on Four Options

- Three mined repository options (granitic rocks, clay/shale, and salt)
- One geologic disposal alternative: deep boreholes in crystalline rocks

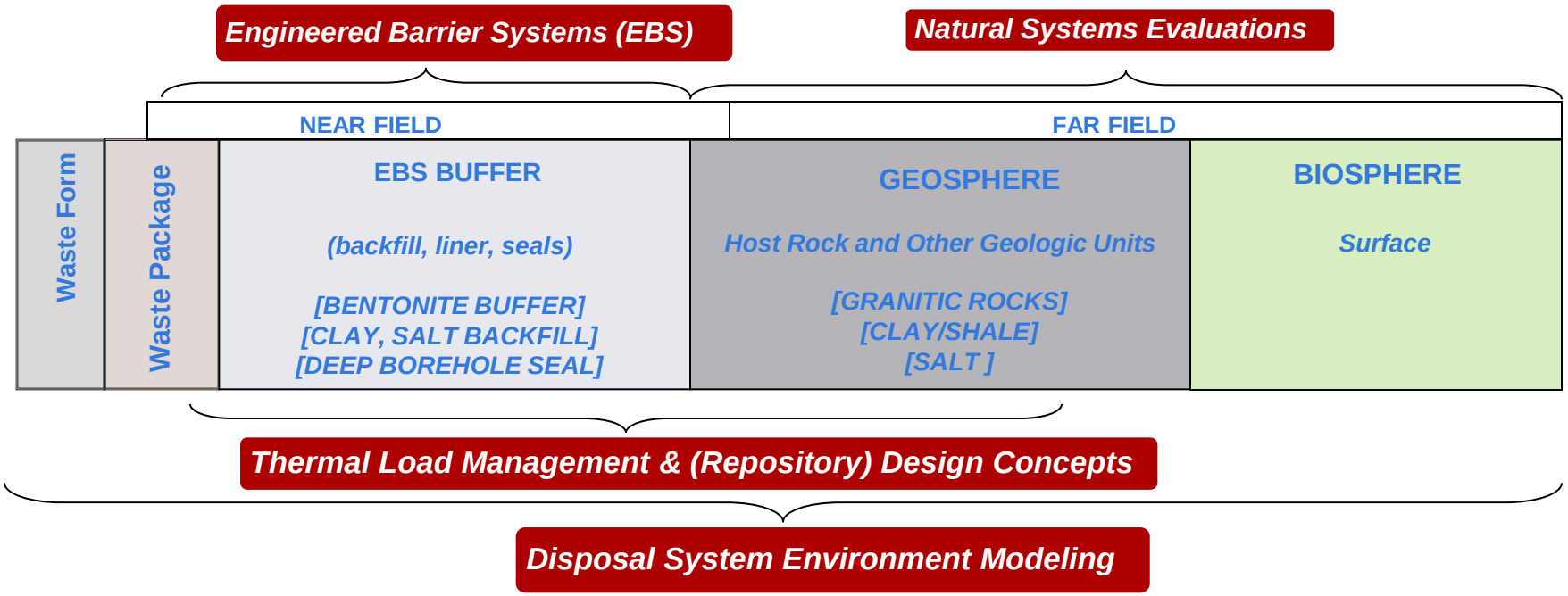








UFD Disposal Research Activities

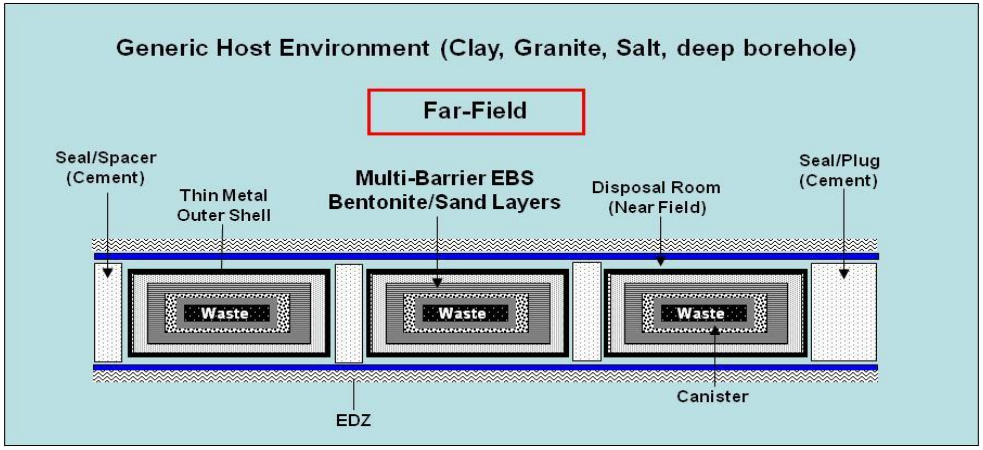


SUPPORT, ANALYSIS & EXPERIMENTAL ACTIVITIES

Engineered Materials Performance	*(corrosion, degradation studies)*
Features, Events & Processes	*(how R&D is organized and prioritized)*
Low Level Waste Disposition Issues	*(part of total nuclear waste consideration)*
Inventory Projections	*(LLW/HLW, used fuel, open → closed fuel cycles)*

Generic Engineered Barrier Systems R&D

EBS and materials evaluation for multiple disposal environments (clay/shale, granitic rocks, salt, deep borehole)



Representative activities

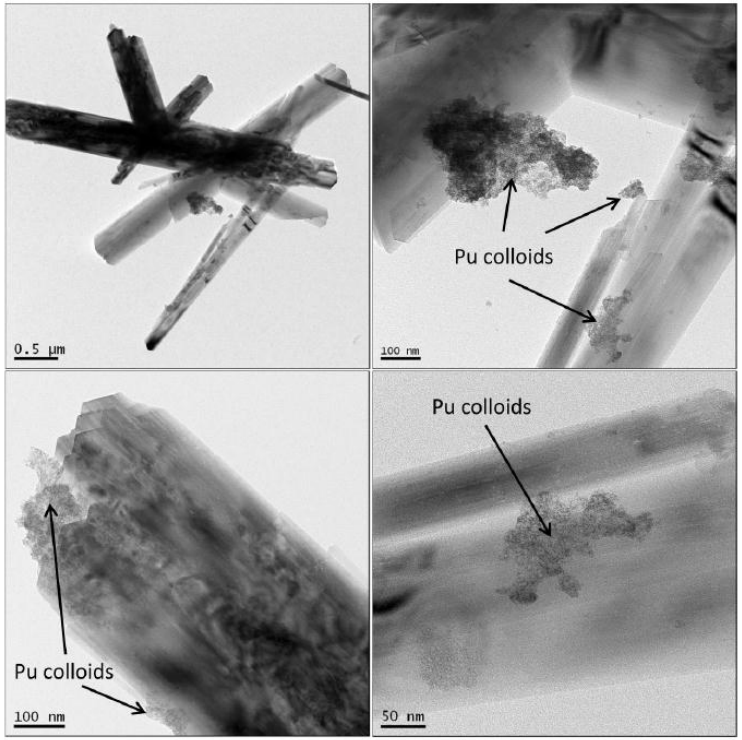
- Evaluation of EBS configurations and material properties: backfill and sealing material (clay and cement)
- Evaluation of clay / metal interactions at elevated temperatures and pressures: literature review, clay phase characterization, and experiments
- Expand THM constitutive and reactive diffusive transport modeling in bentonite
- Laboratory-scale crushed-salt consolidation experiments and modeling

Generic Natural Systems Evaluation R&D

Evaluation of key natural system attributes of multiple disposal system concepts to evaluate impacts on waste immobilization and isolation

Representative activities

- Regional geologic characterization
- Discrete fracture network simulation
- Effects of spatial heterogeneity in Kd on radionuclide transport
- Experimental work on Pu colloid behavior in the presence of goethite
- Geomechanical modeling of excavation damage zone in clay/shale and salt
- Experimental work on saturated and unsaturated flow through clay
- Experimental work related to direct disposal of e-chem salt in a salt repository



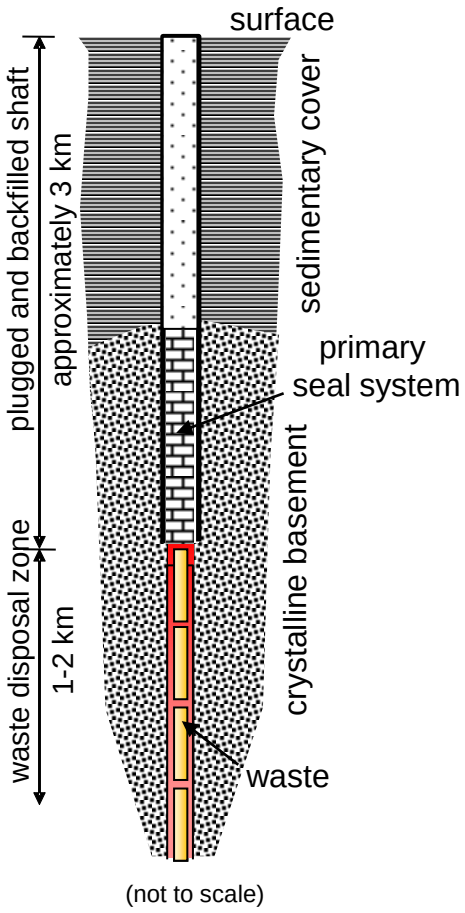
•TEM of intrinsic Pu(IV) nano-colloids sorbed to goethite at 25° C for 103 days

Generic Disposal System-Level Modeling R&D

Develop models to evaluate performance of multiple generic disposal systems

Representative activities

- Implement configuration management for the generic performance assessment (PA) models
- Document technical basis for treatment of Features, Events, and Processes for each generic PA model
- Develop preliminary generic PA models for repositories in clay/shale, granitic rock, salt, and deep borehole settings
  - Highly simplified geometries
  - Isothermal behavior except for deep borehole



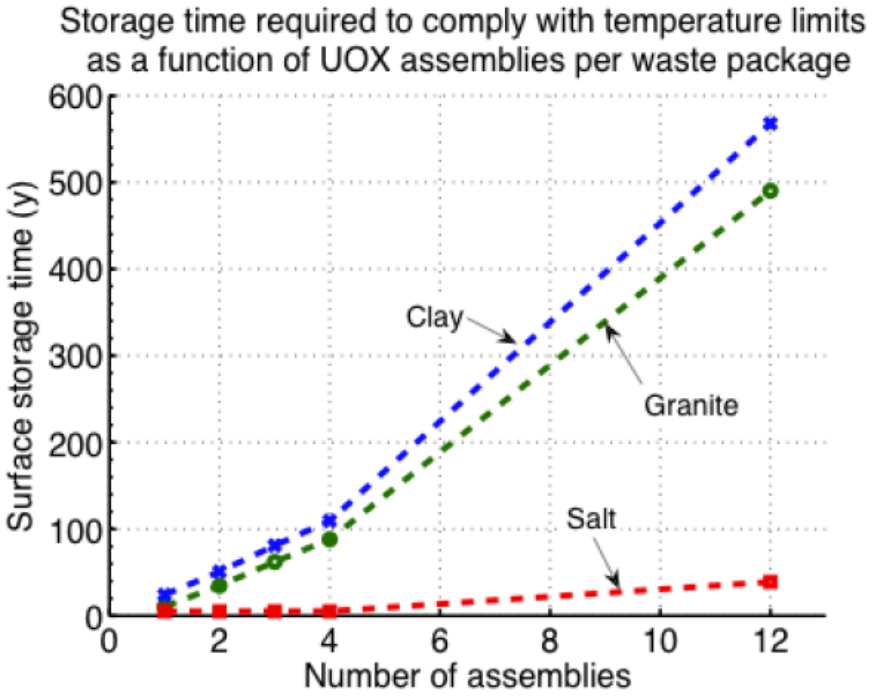
Source: modified from Brady et al., 2009, Deep Borehole Disposal of High-Level Radioactive Waste, SAND2009-4401

Thermal Load Management & Design Concepts R&D

Thermal modeling and testing to evaluate thermal loading options for multiple disposal concepts and alternative waste forms

Representative activities

- Develop representative design concepts for repositories in clay/shale, granite, salt, and deep borehole settings.
- Identify waste streams for thermal analysis
- Complete thermal loading analyses in representative design concepts for selected waste streams



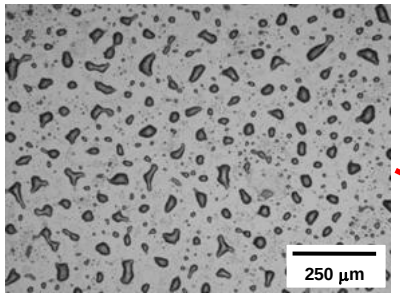
Minimum decay storage durations to limit peak PWR waste package surface temperature to 100° C (granite, clay) or 200° C (salt). (Hardin et al., 2011, Generic Repository Design Concepts and Thermal Analysis (FY11), FCRD-USED-2011-000143)

Engineered Materials Performance R&D

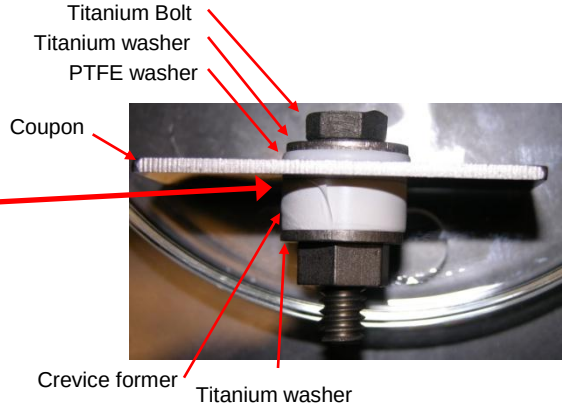
Experiments and model development for long-term performance of engineered materials in storage and repository environments

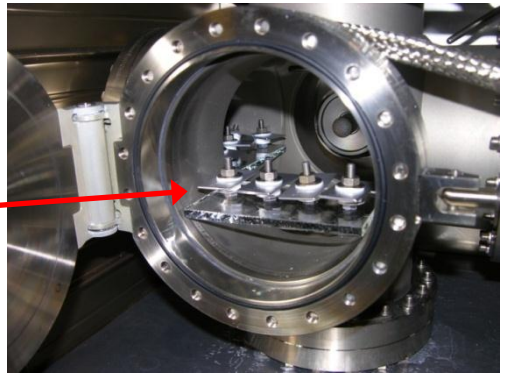
Representative activities (limited to repository environments in FY11, expanded to inlcude storage in FY12)

- Ongoing experiments (YMP initiated, continuing):
  - Immersion: Sampled after 9 months of exposure (12/10). Analysis of samples underway
  - Deliquescence: Corrosion initiation experiments with 2-,3-, and 4-salt assemblages completed
  - Dependence of extent of corrosion on quantity of salt present is now being investigated
- Literature survey/gap analysis for material performance in repository environments has been initiated



Salt mixture on an Alloy 22 Coupon



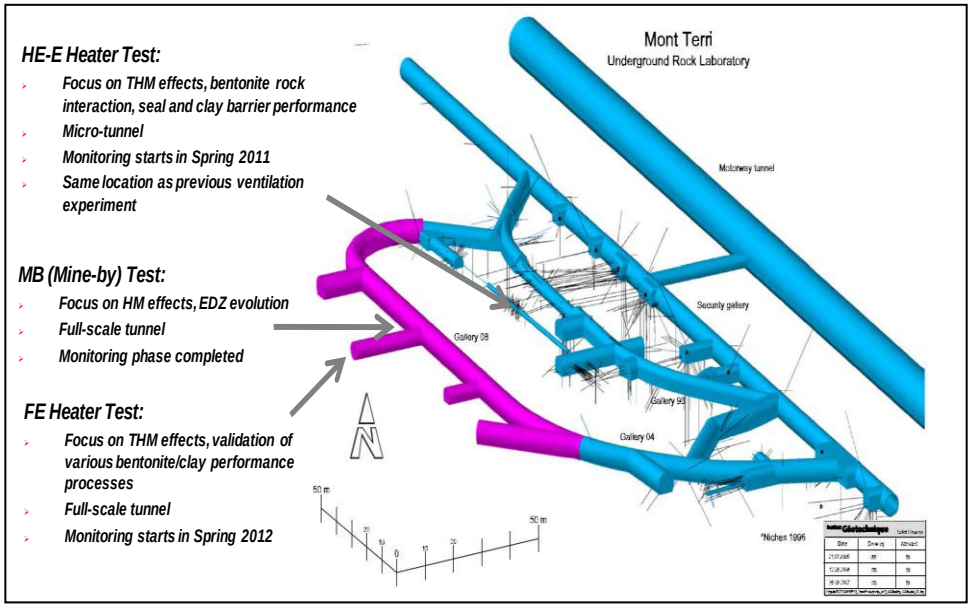

T, RH-Controlled Environmental Chamber

UFD Campaign International Activities

Primary new goal for Disposal R&D in FY12: Establish formal collaborative R&D arrangements ongoing international programs

Ongoing collaborations continue in multiple areas, including storage, transportation, and disposal

Major current or soon-to-be started experiments



Mont Terri: International underground research laboratory (URL) in clay in Switzerland

Joining the URL will give DOE access to data from all Mont Terri R&D, also the opportunity to conduct new experiments

Colloid Formation and Migration Project

Colloid research at Grimsel granite URL in Switzerland

DECOVALEX: (Development of Coupled Models and their Validation against Experiments)

DOE has participated in the past, new phase of project begins Spring 2012

KAERI Underground Research Tunnel (KURT)

R&D plan for experiments beginning in FY13

Sandia National Laboratories

Backup

The Blue Ribbon Commission

Sandia National Laboratories

- Recommendations from the BRC's Report to the Secretary of Energy, January 2012 (http://brc.gov/)
  - A new, consent-based approach to siting future nuclear waste management facilities.
  - A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed.
  - Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management.
  - Prompt efforts to develop one or more geologic disposal facilities.
  - Prompt efforts to develop one or more consolidated storage facilities.
  - Prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage and disposal facilities when such facilities become available.
  - Support for continued U.S. innovation in nuclear energy technology and for workforce development.
  - Active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns.