



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

Fuel Cycle Technologies

**Basis for Identification of Disposal
Options for Research and Development**

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DOE-NE Used Fuel Disposition Campaign

Presented to the

Nuclear Waste Technical Review Board

Fall 2011 Board Meeting

Salt Lake City, Utah

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Outline

- **The role of disposal R&D within the DOE's Fuel Cycle Technology Program**
- **What disposal options are being carried forward for R&D?**
- **How did we identify these options? What were the alternatives?**
- **What disposal R&D are we doing relevant to these options?**
 - Examples of disposal R&D covered in detail in later presentations
- **Where does the disposal R&D program go from here?**



Role of Disposal R&D within the Fuel Cycle Technology Program

■ **The Disposal R&D Program is not starting over**

- There is an international consensus that deep geologic disposal is a robust and necessary solution for permanent isolation of high-level radioactive waste and used nuclear fuel
- Internationally, mature safety assessments indicate that granite and clay sites are viable
- DOE concluded in 2008 that the technical basis for Yucca Mountain was sufficient to submit a license application

■ **We have an opportunity to rethink disposal concepts: nearly all options are back on the table**

■ **We are limited to generic disposal concepts**

- No site specific investigations

■ **Goals of disposal R&D at this stage**

- 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

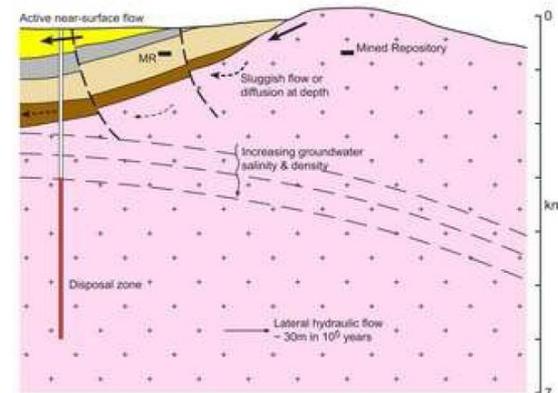
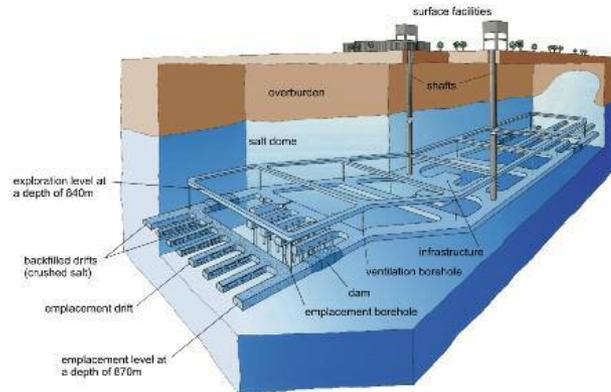
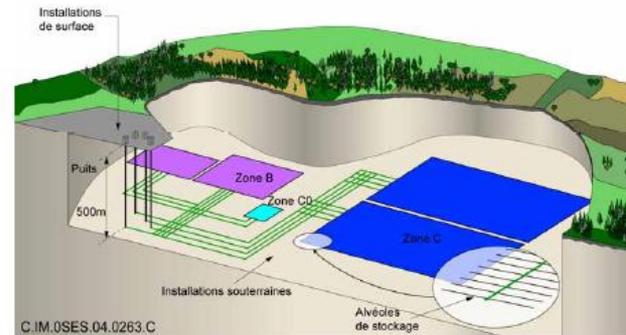
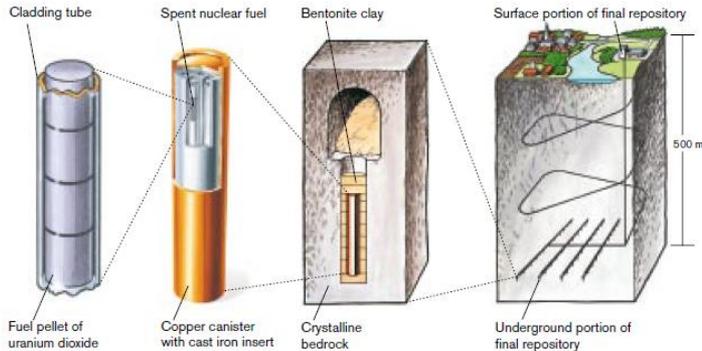


Disposal Options Included for R&D

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■ The short answer: 4 basic disposal options

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





Disposal Options Included for R&D (cont.)

- **The long answer: 48 combinations of environments and waste forms**
 - Eight Preliminary Repository Environmental Settings
 - Surface Storage
 - Near Surface Disposal
 - Mined Geologic Disposal (Hard Rock, Unsaturated)
 - Mined Geologic Disposal (Hard Rock, Saturated)
 - Mined Geologic Disposal (Clay/Shale, Saturated)
 - Mined Geologic Disposal (Salt, Saturated)
 - Deep Borehole Disposal
 - Other (sub-seabed, carbonate, ...)
 - Six Preliminary Waste Form / Inventory Categories
 - Used Fuel
 - Glass
 - Ceramic / Glass Ceramic
 - Metal Alloy
 - Lower than HLW
 - Other (molten salt, future WFs,)

- **Not all of these are the subject of active R&D; some are listed for completeness**

- **Total set of combinations of potential interest is very large because of potential design alternatives, thermal loading strategies, and alternative fuel cycle options**



How Did UFD Identify These Options?

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- Disposal options have been proposed and evaluated for 50+ years
- Consensus for at least thirty years, both in US and internationally, that deep geologic disposal is the preferred option,
 - Multiple in-depth reviews from the late 1950s to the present have noted the need for geologic disposal
 - **“Geological disposal remains the only-long-term solution available”**, National Research Council Board on Radioactive Waste Management, 2001, *Disposition of High-Level Waste and Spent Nuclear Fuel; the Continuing Social and Technical Challenges*, p. 3
 - **“One or more geologic repositories eventually will be needed in the United States”**, Nuclear Waste Technical Review Board, June 2011, *Technical Advancements and Issues Associated with the Permanent Disposal of High-Activity Wastes, Lessons Learned from Yucca Mountain and Other Programs*, p.1.
 - **“Every nation that is developing permanent disposal capacity plans to use a deep, mined geologic repository for this purpose. Other disposal options (i.e., deep boreholes) have been considered and may hold promise in the long-term but are at a much earlier stage of development.”** Blue Ribbon Commission on America’s Nuclear Future Draft Report to the Secretary of Energy, July 29, 2011, page 12.
 - Definitive US work on disposal options dates from the 1970s, summarized in the 1980 *Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste*, DOE/EIS-0046F.



How Did UFD Identify These Options? (cont.)

■ Alternatives summarized by Recharad et al., 2011

- Potential media for mined geologic disposal
 - Salt
 - Clay/shale
 - Carbonate rocks and chalk
 - Granitic rocks
 - Basalt
 - Volcanic Tuff
- Alternative settings for geologic disposal
 - Saturated zone versus unsaturated zone
 - Continent interior
 - Coastal areas
 - Islands
- Alternatives to mined disposal
 - Deep boreholes in igneous/metamorphic basement rock
 - Shallow boreholes in alluvium
 - Sub-seabed
 - Well injection
 - Rock Melt
- Alternatives to geologic disposal
 - Engineered Mountain/Mausoleum
 - Ice-Sheet Disposal
 - Space Disposal

*Basis for Identification of
Disposal Options for
Research and Development
for Spent Nuclear Fuel and
High-Level Waste*

Fuel Cycle Research & Development

Prepared for
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FCRD-USED-2011-000071



http://www.ne.doe.gov/FuelCycle/neFuelCycle_UsedNuclearFuelDispositionReports.html

Observations on Alternatives

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■ Potential media for geologic disposal

- Clay/shale and granitic rock: international experience supports generic viability of disposal concepts, detailed safety assessments have been completed in France, Sweden, Finland, and elsewhere; further R&D needed to support US program.
- Salt: WIPP experience demonstrates disposal of transuranic waste; international experience (i.e., Germany) supports viability of generic disposal concepts for high-activity waste, further R&D needed to support US program
- Volcanic tuff: additional R&D is a low priority; current technical basis is sufficient to support submittal of a license application
- Carbonate rocks and chalk: less international experience than other media; much of what is learned from R&D in other fractured saturated rock (e.g., granites) will be relevant should carbonate sites warrant additional consideration
- Basalt: little experience outside the Hanford site in the US; limited geographic distribution of thick deposits; fracturing and vertical heterogeneity are common; much of what is learned from R&D in other fractured saturated rock (e.g., granites) will be relevant should basalt sites warrant additional consideration



Observations on Alternatives (cont.)

■ Alternative settings for geologic disposal

- Saturated zone versus unsaturated zone
 - *Extensive R&D has been conducted in the US in unsaturated rocks at Yucca Mountain*
 - *Current R&D focuses on saturated rocks*
- Continental interior versus coastal areas or islands
 - *Past work provides some insight into potential differences among interior, coastal, and island locations*
 - *No R&D is currently addressing generic questions associated specifically with geographic location; these alternative settings are primarily variants of the various mined repository options*

■ Alternatives to mined disposal

- Deep boreholes in igneous/metamorphic basement rock
 - *Identified in multiple studies as the primary viable alternative to mined repositories*
 - *Topic of ongoing R&D*
- Shallow boreholes in alluvium
 - *Can provide excellent isolation in arid climates; implemented on the Nevada Test Site for relatively small volumes of transuranic waste at the Greater Confinement Disposal (GCD) facility*
 - *Shallow burial depths (approximately 30 m) appear to be incompatible with the requirement in the Nuclear Waste Policy Act for deep geologic disposal*
- Sub-seabed disposal
 - *Extensive R&D in the 1980s indicates a technically viable option*
 - *May be precluded by international treaty, no current R&D activities*



Observations on Alternatives (cont.)

■ Alternatives to mined disposal (cont.)

- Well injection
 - *Implemented in both the US (prior to 1975 for low-level and transuranic wastes) and in Russia*
 - *Well injection of HLW would be inconsistent with NRC requirements at 10 CFR part 50 for solidification of processing liquids prior to disposal*
- Rock melt
 - *Various options were proposed in the 1970s that relied on waste-generated heat to melt host rock; none carried forward beyond the 1980 EIS due to unresolved technical complexity*
 - *More recently, rock melt has been proposed as a component of deep borehole disposal; not currently a topic for UFD campaign R&D because deep borehole disposal performance appears likely to be robust without additional barriers created by rock melt.*

■ Alternatives to geologic disposal

- Engineered mountain/mausoleum
 - *Casual references date from the 1970s; there have been no proposals with substantive design concepts*
- Ice sheet disposal in Greenland or Antarctica
 - *Proposed in the late 1950s, various concepts evaluated in the 1970s, summarized in 1980 EIS*
 - *Precluded in Antarctica by international treaty; also subject to operational concerns and uncertainty about long-term isolation*
- Space disposal
 - *Evaluated in the 1970s and summarized in the 1980 EIS, economic cost and technical risk make it an improbable option*

Current Disposal R&D Activities



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Used Fuel Disposition Campaign R&D Participants





FY12 UFD Campaign Structure

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Management Group

Crosscut activities

Disposal Research

Storage and Transportation
Research

R&D Activities

Campaign Management and Integration
International
Perspectives on Nuclear Waste Management
UFD Science Competition

Thermal Load Management and Design Concepts
Generic EBS Evaluation
Generic Natural Systems Evaluation
Generic Disposal System-Level Modeling
Features, Events, and Processes
Inventory
LLW Disposition

Test and Evaluation Capability Development
Storage R&D Investigations
Transportation
Security
Engineering Analysis
Engineered Materials -- Experimental

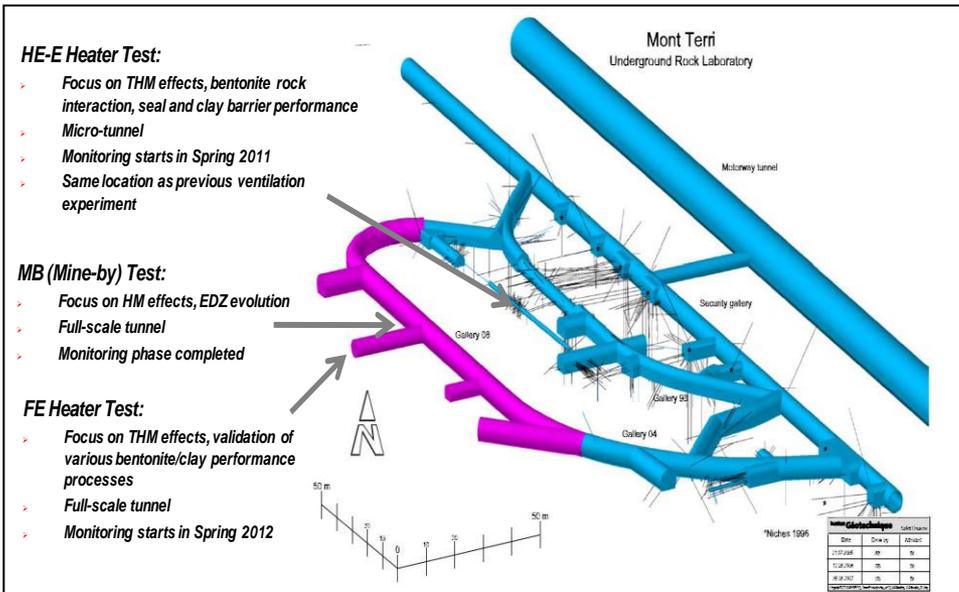


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Collaboration continues in multiple areas, including storage, transportation, and disposal

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

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



Nuclear Waste Management Perspectives

Three primary topics of research that affect storage, transportation, and disposal

- Analyses of the interface between storage and disposal
- Support for analysis of fuel cycle options
- Social science: e.g., public opinion surveys

Public Beliefs about the Disposition of Used Nuclear Fuel

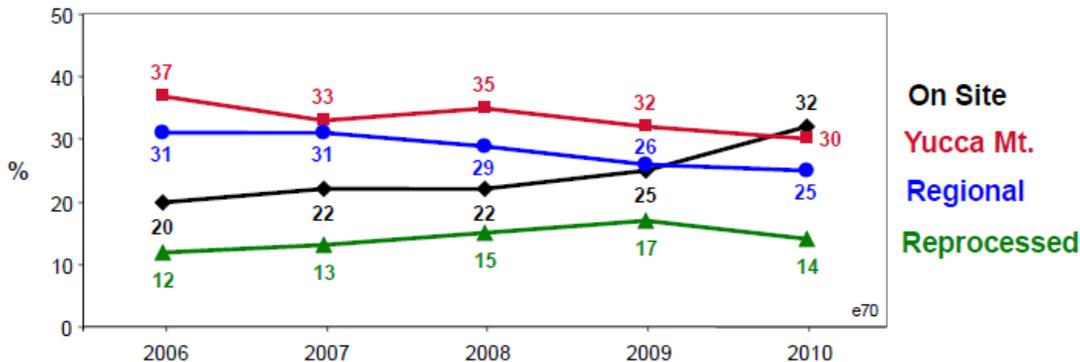


Figure 1 from H. C. Jenkins-Smith, 2011. *Public Beliefs, Concerns, and Preferences Regarding the Management of Used Nuclear Fuel and High Level Radioactive Waste*, report prepared for the Blue Ribbon Commission on America's Nuclear Future

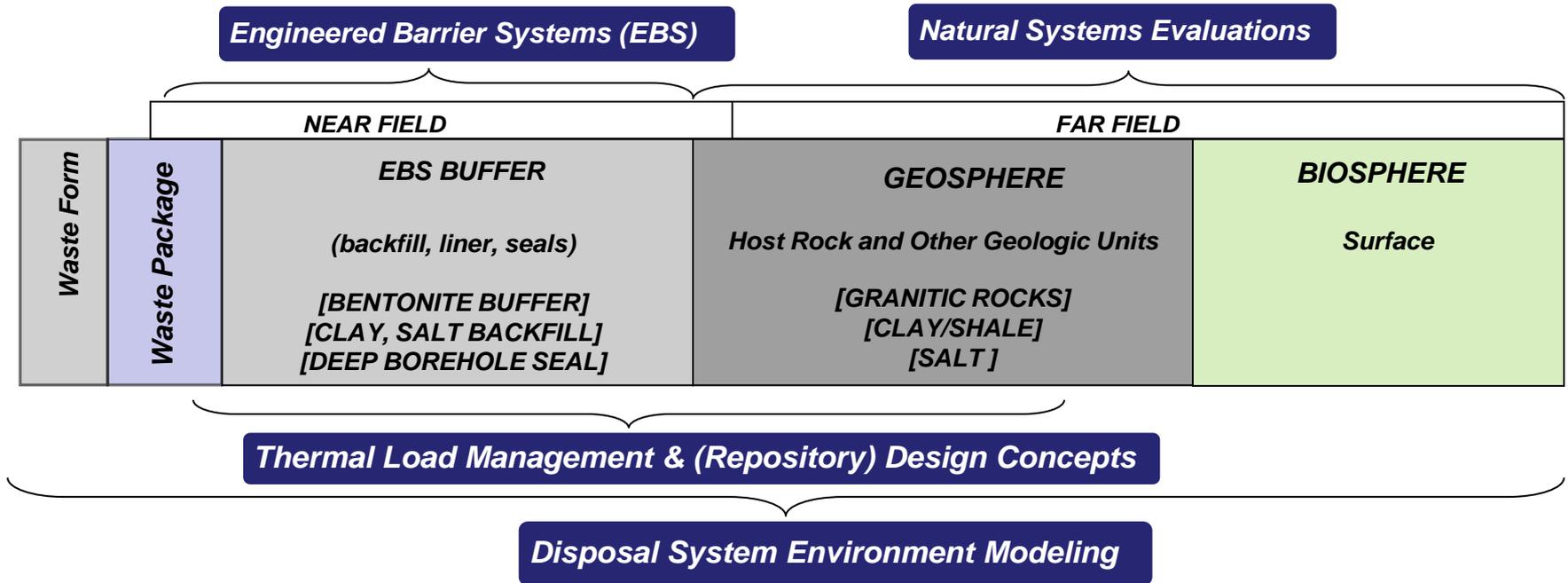
Representative FY11 activities

- Completed report on basis of decision for UFD to focus on salt, clay/shale, and granite for mined and deep borehole disposal
- Continued work identifying spatial distribution of geologic media and attributes potentially relevant to site selection
- Worked with the Center for Applied Social Research at the University of Oklahoma to develop and field public opinion survey related to nuclear waste disposal



UFD Disposal Research Activities

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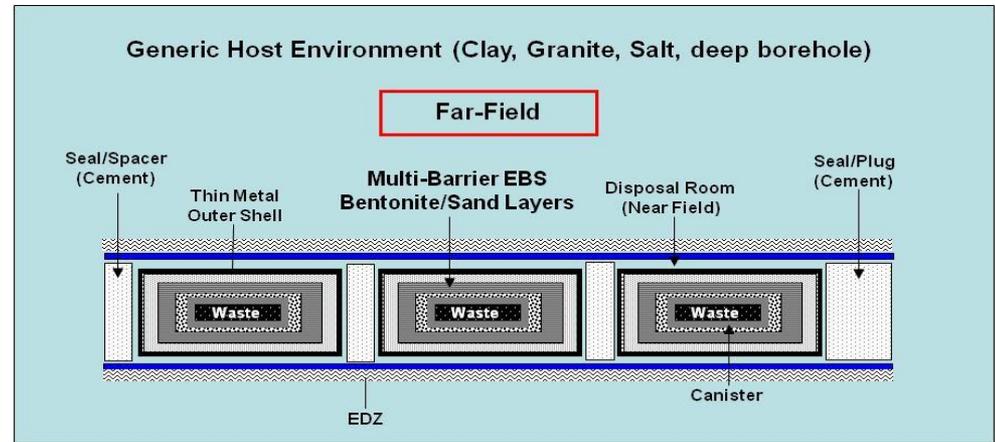
SUPPORT, ANALYSIS & EXPERIMENTAL ACTIVITIES

*Engineered Materials Performance
 Features, Events & Processes
 Low Level Waste Disposition Issues
 Inventory Projections*

*(corrosion, degradation studies)
 (how R&D is organized and prioritized)
 (part of total nuclear waste consideration)
 (LLW/HLW, used fuel, open → closed fuel cycles)*



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



Representative FY11 activities

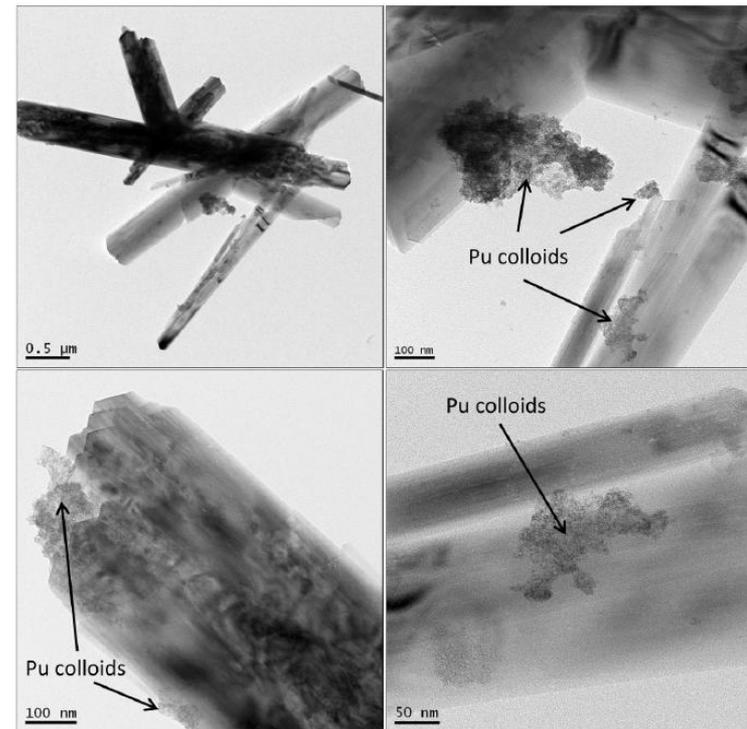
- Evaluation of EBS configurations and material properties: backfill and sealing material (clay and cement)
- Evaluated clay / metal interactions at elevated temperatures and pressures: literature review, clay phase characterization, and experiments
- Expanded and validated THM constitutive and reactive diffusive transport modeling in bentonite
- Disposal System Evaluation Framework (DSEF): developed EBS heat transport model and catalog of thermal properties for various repository environments
- Completion of test plan for laboratory-scale crushed-salt consolidation experiments



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

Representative FY11 activities

- Progress in discrete fracture network simulation
- Effects of spatial heterogeneity in K_d on radionuclide transport
- Experimental work on Pu colloid behavior in the presence of goethite
- Geomechanical modeling of excavation damage zone in clay/shale
- 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 (Wang et al., 2011; Natural System Evaluation and Tool Development—FY11 Progress Report, FCRD-USED-2011-000223)**

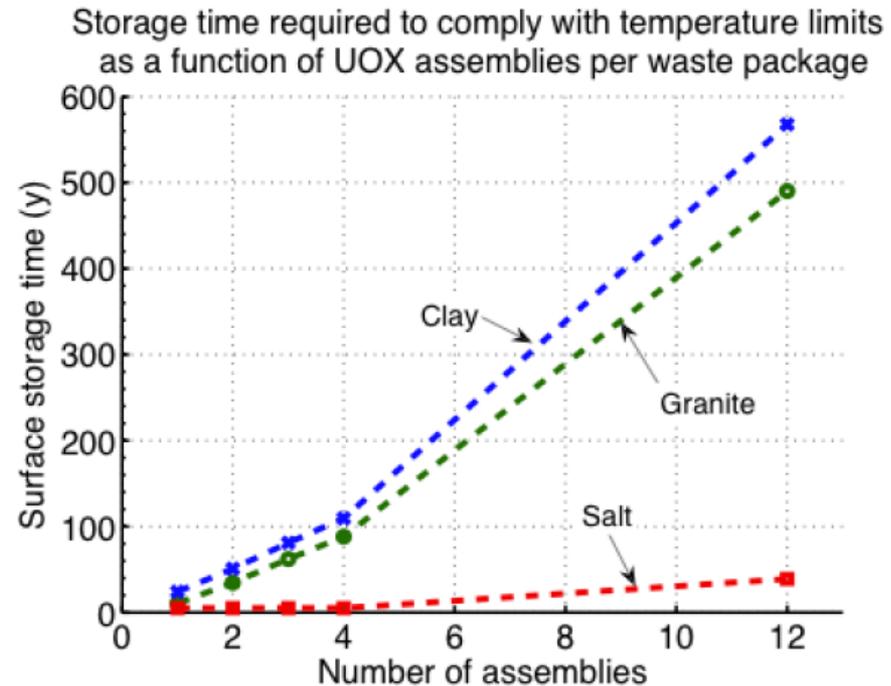


Thermal Load Management & Design Concepts R&D

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

Representative FY11 activities

- Developed representative design concepts for repositories in clay/shale, granite, salt, and deep borehole settings.
- Identified waste streams for thermal analysis
- Completed 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)

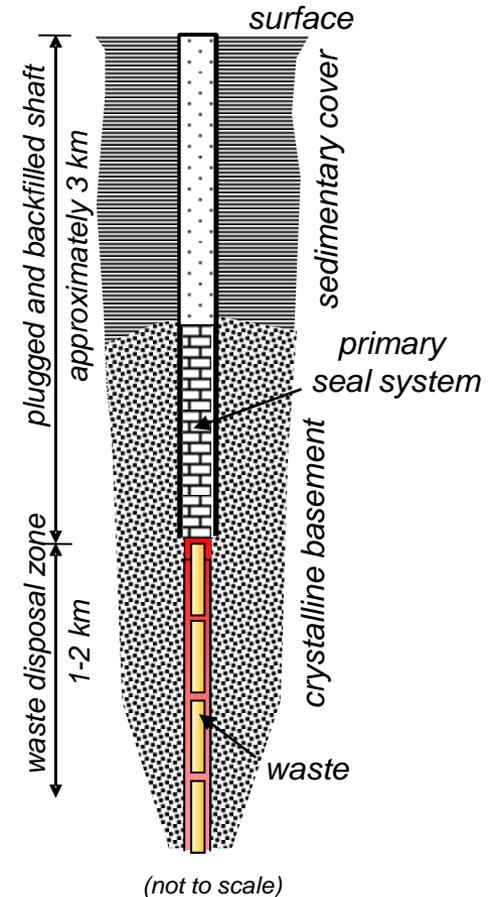


Disposal System Environment Modeling R&D

Develop models to evaluate performance of multiple generic disposal systems

Representative FY11 activities

- Implemented configuration management for the generic performance assessment (PA) models
- Documented technical basis for treatment of Features, Events, and Processes for each generic PA model
- Developed 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



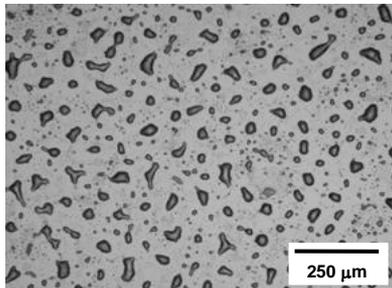
Source: modified from Brady et al., 2009, Deep Borehole Disposal of High-Level Radioactive Waste, SAND2009-4401



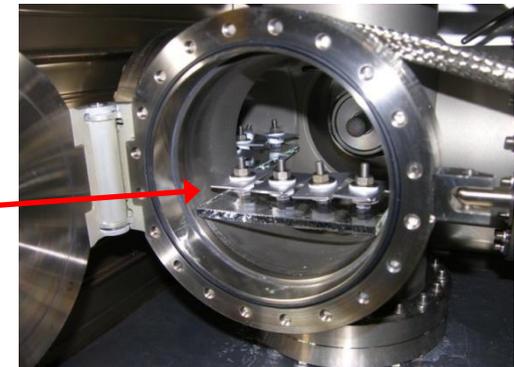
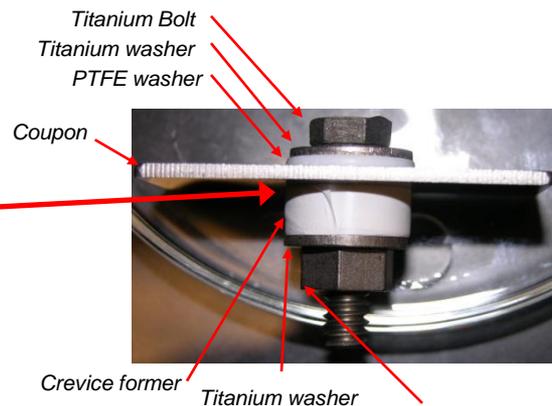
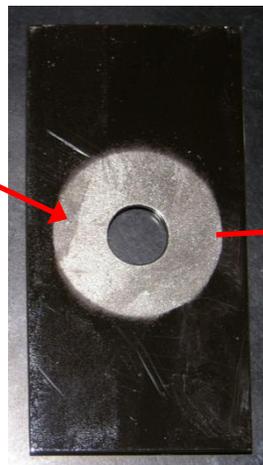
Experiments and model development for long-term performance of engineered materials in storage and repository environments

Representative FY11 activities (limited to repository environments, will include 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

Future Disposal R&D Activities



- ***Used Fuel Disposition Campaign Disposal Research and Development Roadmap***
 - “an initial evaluation of prioritization of R&D opportunities that could be pursued by the campaign”
 - Completed March 2011
 - Used to inform prioritization decisions for disposal research in FY12 and beyond
- **Described in detail in the following presentation**

http://www.ne.doe.gov/FuelCycle/neFuelCycle_UsedNuclearFuelDispositionReports.html

■ Engineered Barrier Systems

- Barrier phase mineralogy (cement and clay)
- Thermal-hydrologic-chemical-mechanical coupled process modeling in crushed salt and clay
- Radionuclide transport in clay
- Radiolysis effects on used fuel degradation
- Laboratory studies of crushed salt consolidation, salt thermal conductivity as a function of porosity, chemical and material properties of salt relevant to brine mobility

■ Natural Systems

- Modeling hydrologic flow in representative geologic media; e.g., discrete fracture network modeling
- Radionuclide transport in the far field; radionuclide speciation, sorption, and colloid-facilitated transport
- Continued documentation of spatial distributions of geologic media and related properties
- Develop and maintain archive of generic disposal system material properties

■ Thermal Load Management and Design Concepts

- Refine/expand design concepts for evaluation, include “open” emplacement mode for comparison
- Develop generic cost estimates, including surface facilities
- Expand range of waste streams to include advanced fuel cycles, develop uncertainty ranges

■ **Generic Disposal System Modeling**

- Migrate generic disposal system models (clay, granite, salt, deep borehole) to a common architecture (generic performance assessment model, GPAM, implemented in GoldSim)
- Use GPAM models to support Fuel Cycle Options analyses; identify appropriate disposal metrics for fuel cycle prioritization study
- Use GPAM to support generic safety case studies for disposal concepts
- Evaluate framework assessment tools for advanced disposal system modeling

■ **Engineered Materials Performance**

- Expand existing work scope to include testing on canister materials under storage conditions
- Initiate testing on cladding at ANL, ORNL

■ **Features, Events, and Processes**

- Continue generic FEP analyses for selected disposal concepts
- One-year goal to confirm stability of generic FEP list (currently 208 FEPs), document preliminary screening information for 75%. Complete 100% of generic evaluations in 3 years

■ **Inventory Projections**

- Work with Fuel Cycle Options study to define inventories for alternative fuel cycles



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■ Low Level Waste Disposition

- Continue development of generic LLW disposal models to evaluate options for LLW waste forms from alternative fuel cycles
- Develop LLW inventory estimates for alternative fuel cycles

■ International

- Engage formally as a participant in disposal underground research laboratories (URLs) at Mont Terri and Grimsel, rejoin the DECOVALEX modeling and experimental activities in Europe

■ Nuclear Waste Perspectives

- Evaluate interface between storage, transportation, and disposal; develop modeling tools to inform an integrated approach to waste management
- Continue public opinion surveys; examine post-Fukushima changes in public preference; update New Mexico perceptions of WIPP to provide insight into dynamics of public acceptance
- Others
 - *Knowledge management, develop a database of past YMP and WIPP personnel*
 - *Analyze impacts of fuel cycle alternatives on disposal performance uncertainty*
 - *Update Disposal R&D roadmap*

■ Science Competition

- Initiate internal call for R&D proposals

Questions?