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Fuel Cycle Technologies

Used Fuel Disposition Overview

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DOE-NE Used Fuel Disposition Campaign

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Chicago, Illinois
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Outline

- **The Campaign**
  - Our mission and goals
  - How we are organized
- **The R&D activities**
  - Cross-cutting activities
  - Disposal R&D
  - Storage and Transportation R&D (see following talk)
- **Introduction to the following presentations**
  - Review of Used Fuel Disposition Storage and Transportation Activities (Ken Sorenson, SNL)
  - Generic Repository Concepts and Thermal Analysis for Advanced Fuel Cycles (Massimiliano Fratoni, LLNL)
  - Integrated Research Project: Fuel Aging in Storage and Transportation (FAST): Accelerated Characterization and Performance Assessment for Nuclear Fuel Storage Systems (Sean McDeavitt, Texas A&M University)

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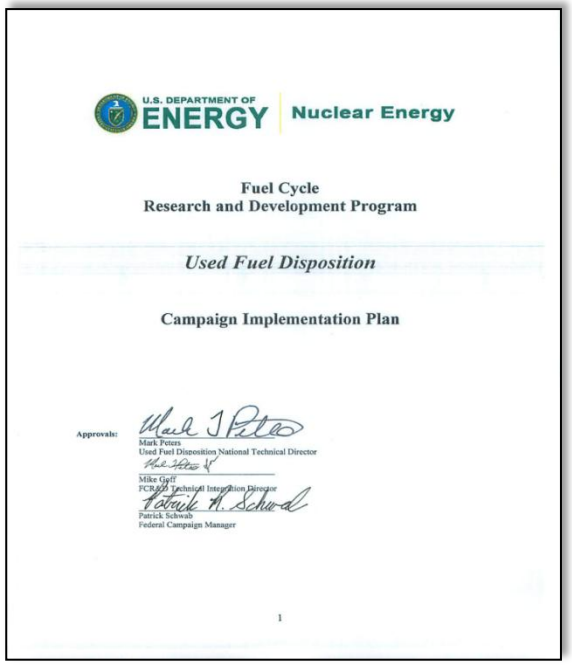
UFD Mission

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.

Used Fuel Disposition Campaign Implementation Plan
M1508010102, March 29, 2010

Proposed for update March 30, 2012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Fuel Cycle
Research and Development Program

Used Fuel Disposition

Campaign Implementation Plan

Approvals:

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Used Fuel Disposition National Technical Director

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Federal Campaign Manager

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UFD Campaign 2009-Present

HISTORY OF THE CAMPAIGN

- 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 proposed R&D budget $22.8 M
  - Uncertainties remain regarding national policy, Yucca Mountain litigation, and budget

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Used Fuel Disposition Campaign External Collaborations

- **University Programs**
  - 2010: one NEUP grant relevant to used fuel storage (U. of Michigan)
  - 2011: two NEUP grants relevant to storage, one relevant to disposal; integrated research project in storage R&D
- **Other university collaborations (U. of Wisconsin, MIT, U. of Oklahoma)**
- **Industry (Advisory and Assistance Contracts)**
  - Areva, Shaw/Westinghouse, GE Hitachi, EnergySolutions, Enercon, CH2M Hill
- **EPRI**
  - Extended Storage Collaboration Program (ESCP) (with NRC and international groups)
- **National Laboratory LDRD programs**
  - E.g., deep borehole work at SNL
- **International activities**
  - Bilateral agreements on disposal R&D with Korea, Japan
  - MOU for salt R&D with Germany
  - IAEA working groups in storage and transportation
  - Significant effort proposed in FY12 to increase US presence in underground research laboratories in Europe
- **Collaboration among Fuel Cycle Technology Campaigns**
  - Support for Fuel Cycle Options Campaign
  - Close interactions with Waste Form Campaign, NEAMs storage and waste form modeling

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UFD Long-term Goals
(from the 2010 Campaign Implementation Plan)

- **By 2015**
  - Develop the licensing basis for extended storage systems for existing LWR fuels
  - Develop a plan for a test and validation complex for high burnup and advanced fuels
  - Develop the licensing basis for transport of high burnup fuels
  - Develop advanced computational models for damage and dispersal events during storage and transportation
  - Develop a framework of advanced computational models for disposal system performance
  - Conduct experiments to fill data needs and confirm advanced modeling approaches
  - Develop a database catalog of potential disposal systems that could be used

- **By 2020**
  - Construction of a test and validation complex for high burnup and advanced fuels
  - Development of a plan to field a commercial-scale long-term interim storage facility for high burnup and advanced fuels
  - Robust modeling and experimental basis for evaluation of multiple disposal system options

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FY12 UFD Campaign Structure

Management Group	R&D Activities
Crosscut activities (3095 k)	
	Campaign Management and Integration
	International
	Perspectives on Nuclear Waste Management
Disposal Research (11,440 k)	
	Generic EBS Evaluation
	Generic Natural Systems Evaluation
	Generic Disposal System-Level Modeling
	Thermal Load Management and Design Concepts
	Inventory
	LLW Disposition
Storage and Transportation Research (8250 k)	
	Test and Evaluation Capability Development
	Storage R&D Investigations
	Transportation
	Security
	Engineering Analysis
	Engineered Materials -- Experimental

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Used Fuel Disposition Management Team

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Used Fuel Disposition Campaign
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Kevin McMahon
Campaign Lead

Storage & Transportation Research
Ned Larson
Federal Program Manager

Ken Sorenson
Campaign Lead

UFD Cross Cutting R&D Activities

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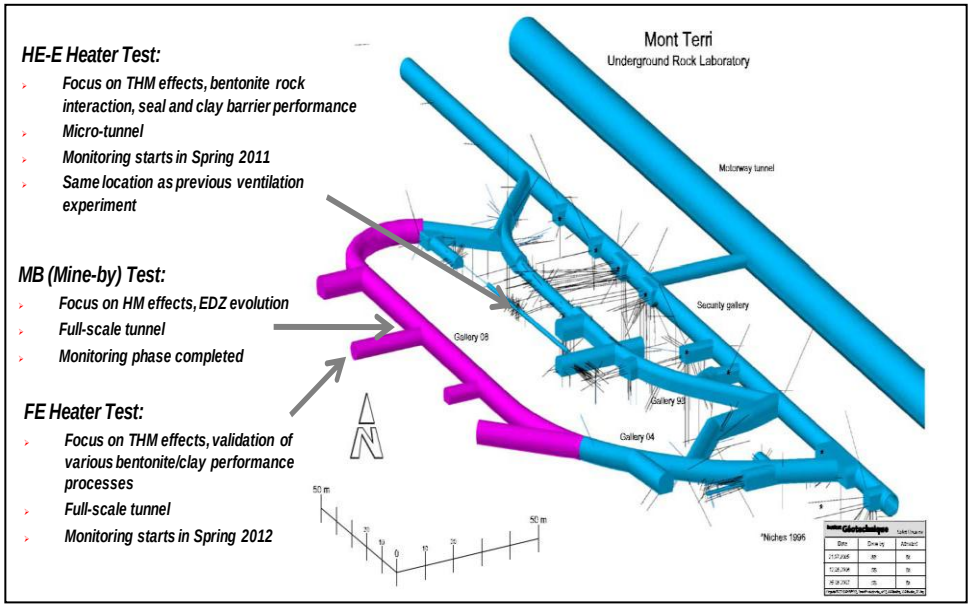
UFD Campaign International Activities

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

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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

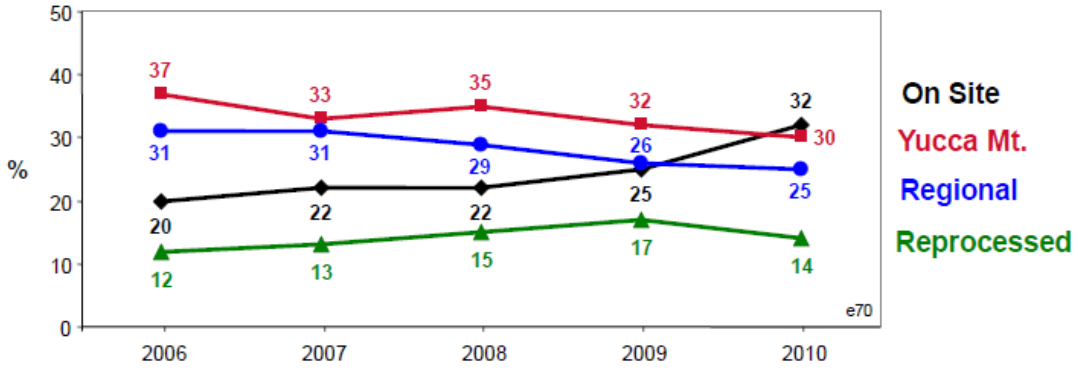

Figure 1 from H. C. Jenkins-Smith, 2011. *Public Beliefs, Concerns, and Preferences Regarding the Management of Used Nuclear Fuel and High Level Radioactive Waste,* report prepared for the Blue Ribbon Commission on America's Nuclear Future

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

Planned Cross-Cutting R&D

- **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
  - Continue bilateral cooperative R&D activities with Japan and Korea
  - Initiate cooperative R&D on salt disposal with Germany (MOU signed Sept. 2011, workshop in November in Peine, Germany)
  - Continue engagement in international storage and transportation activities, e.g., EPRI Extended Storage Collaboration Program (ESCP)
- **Nuclear Waste Perspectives**
  - Evaluate interface between storage, transportation, and disposal; develop modeling tools to inform an integrated approach to waste management
  - Support for Fuel Cycle Evaluation/Screening and Systems Integration activities
  - 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
  - Evaluate effects of fuel cycle alternatives on disposal system uncertainties

UFD Disposal R&D Activities

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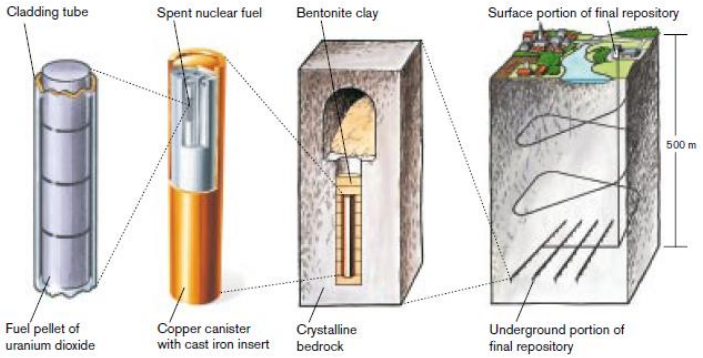
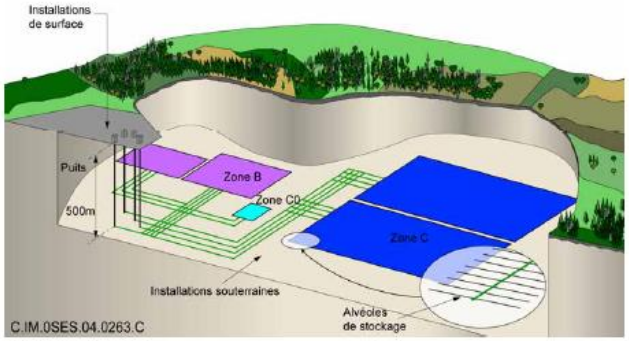
Role of Disposal R&D after Yucca Mountain

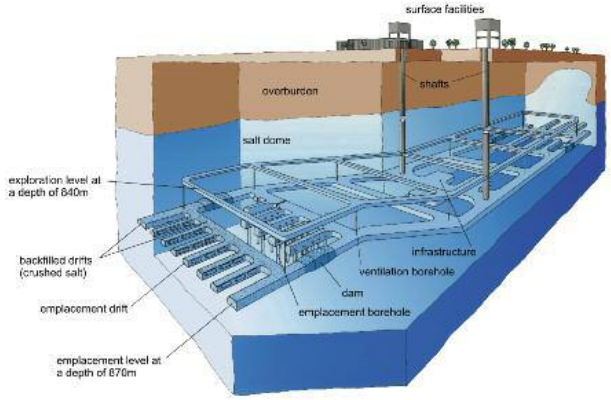
- **The Disposal R&D Program is not starting over**
  - There is an international consensus that deep geologic disposal is a robust and necessary solution for permanent isolation of high-level radioactive waste and used nuclear fuel
  - Internationally, mature safety assessments indicate that granite 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

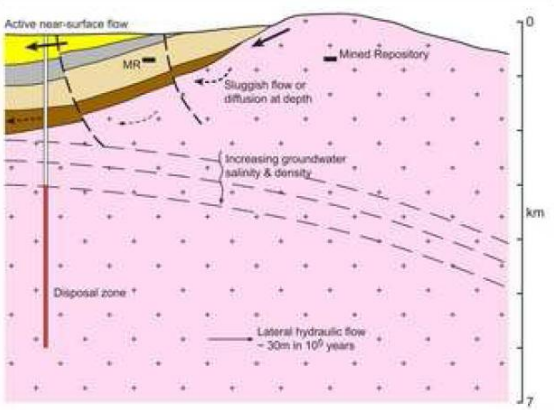
Disposal Options Included for R&D

- **Disposal R&D is focusing on four basic disposal options**
  - Three mined repository options (granitic rocks, clay/shale, and salt)
  - One geologic disposal alternative: deep boreholes in crystalline rocks









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Disposal Options Included for R&D (cont.)

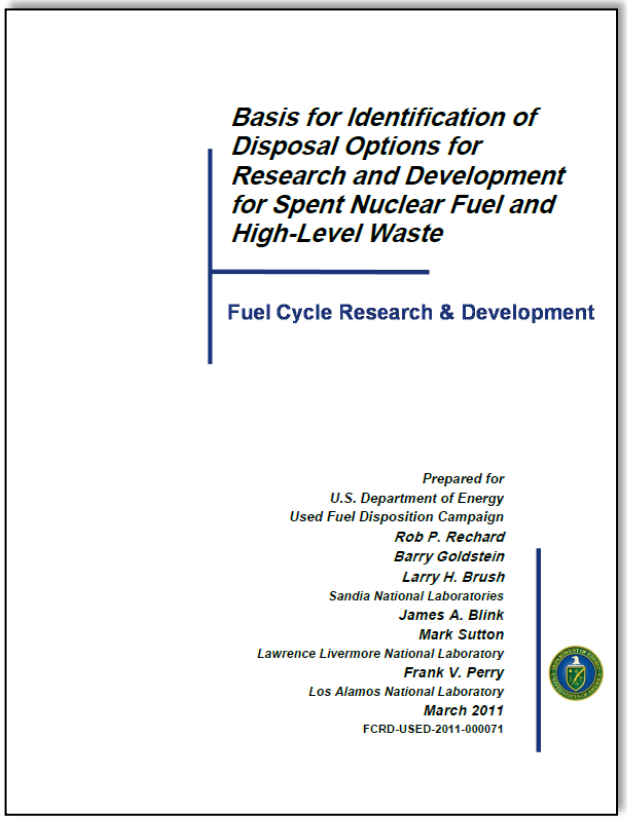
- **A longer list of disposal options: 48 combinations of environments and waste forms**
  - Eight Preliminary Repository Environmental Settings
    - Surface Storage
    - Near Surface Disposal
    - Mined Geologic Disposal (Hard Rock, Unsaturated)
    - Mined Geologic Disposal (Hard Rock, Saturated)
    - 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?

- **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 Rechard 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*



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

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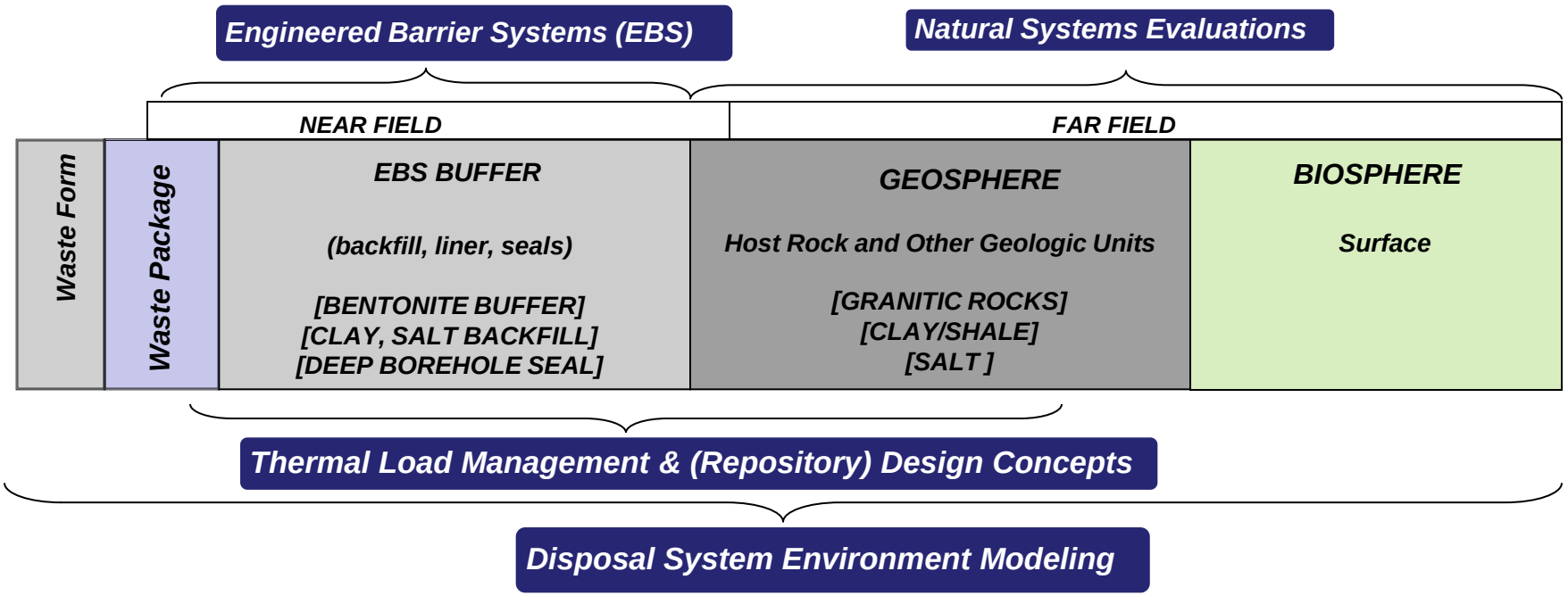
UFD Disposal Research Activities



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)

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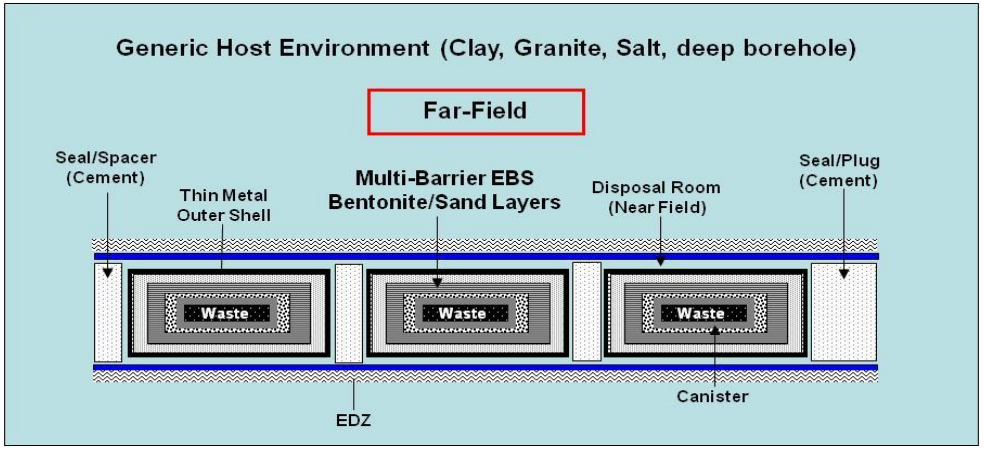
Generic Engineered Barrier Systems R&D

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

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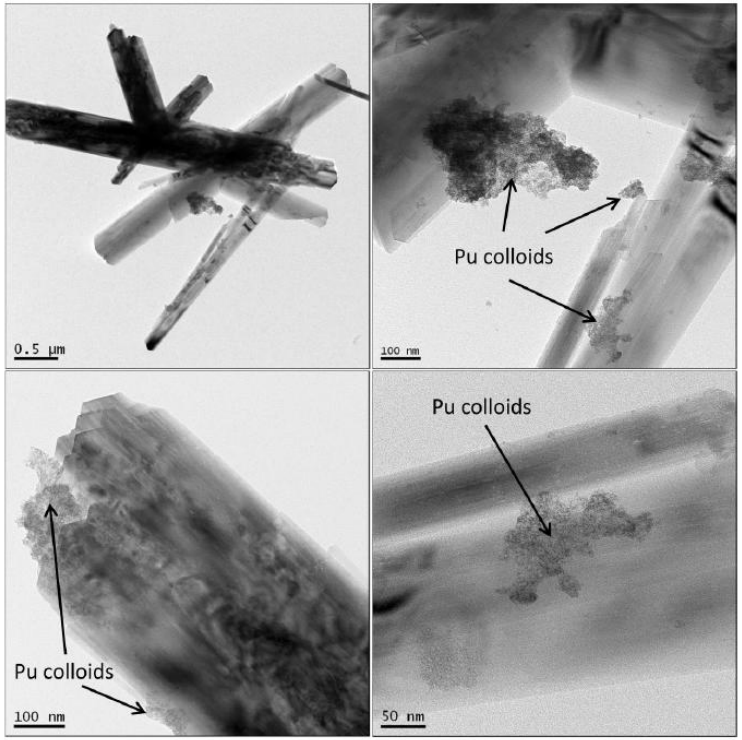
Generic Natural Systems Evaluation R&D

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

Representative FY11 activities

- Progress in 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
- 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)

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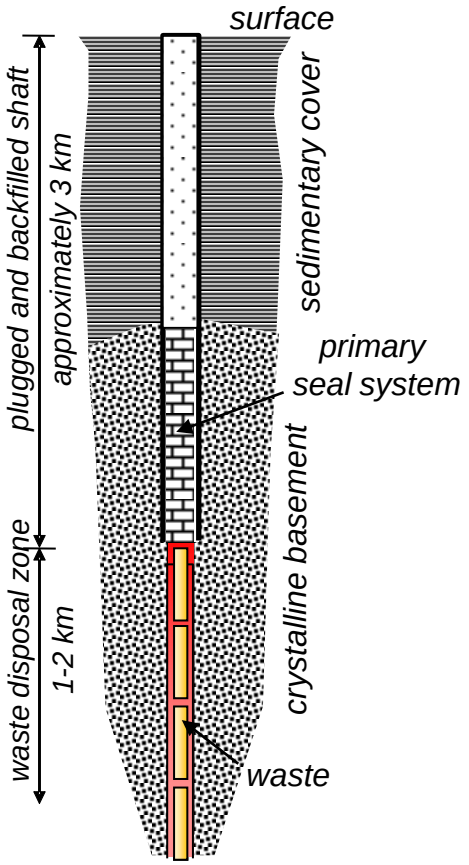
Generic Disposal System-Level Modeling R&D

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



(not to scale)

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

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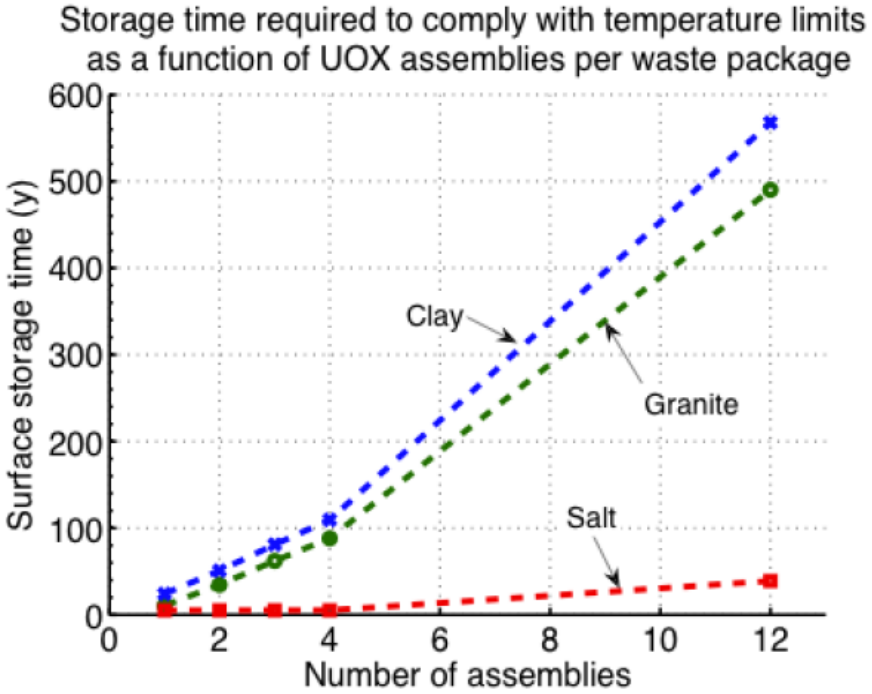
Thermal Load Management & Design Concepts R&D

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



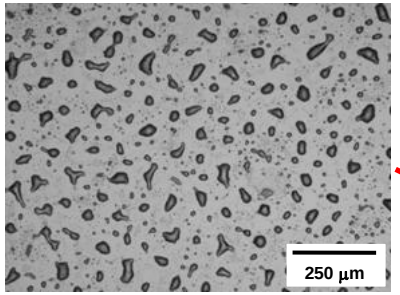
Minimum decay storage durations to limit peak PWR waste package surface temperature to 100˚ C (granite, clay) or 200˚ C (salt). (Hardin et al., 2011, Generic Repository Design Concepts and Thermal Analysis (FY11), FCRD-USED-2011-000143)

Engineered Materials Performance R&D

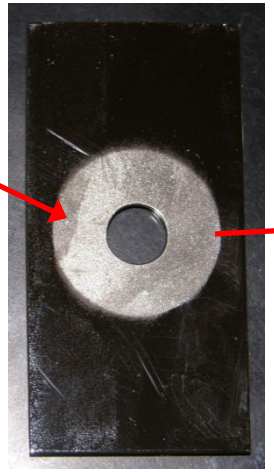
Experiments and model development for long-term performance of engineered materials in storage and repository environments

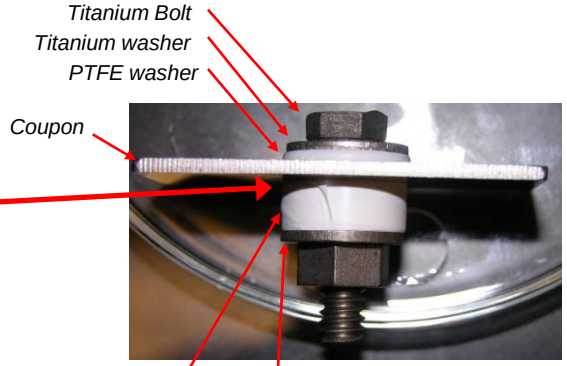
Representative FY11 activities (limited to repository environments, will include storage in FY12)

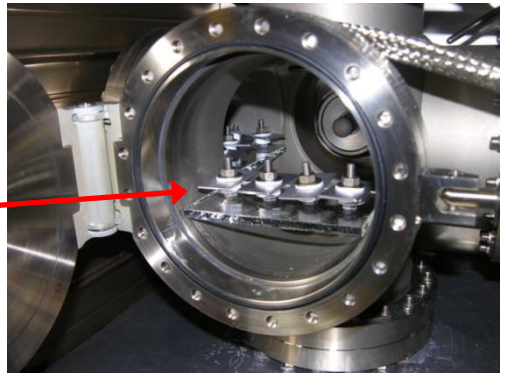
- Ongoing experiments (YMP initiated, continuing):
  - Immersion: Sampled after 9 months of exposure (12/10). Analysis of samples underway
  - Deliquescence: Corrosion initiation experiments with 2-,3-, and 4-salt assemblages completed
  - Dependence of extent of corrosion on quantity of salt present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



Salt mixture on an Alloy 22 Coupon







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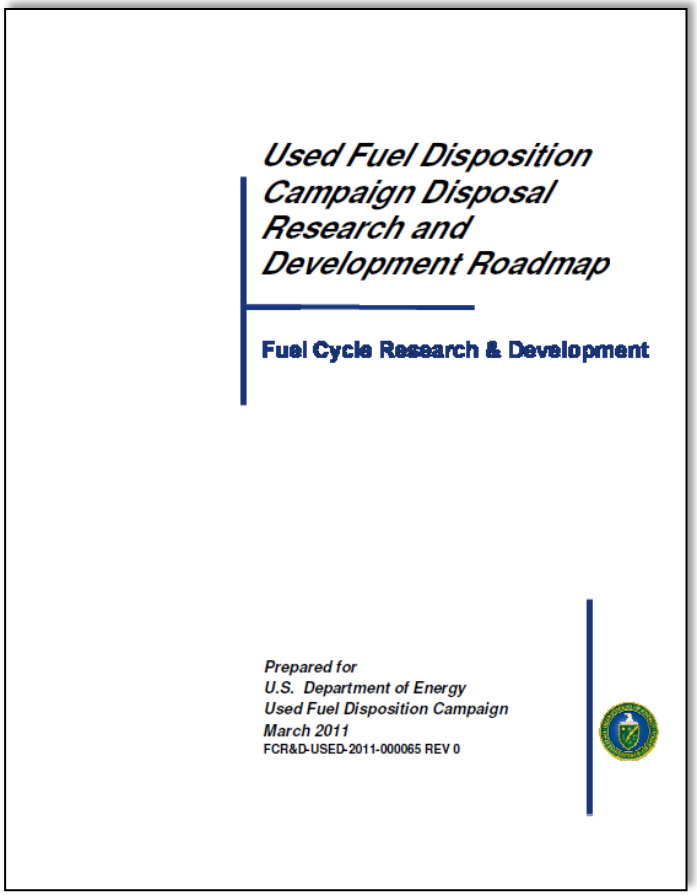
The Disposal R&D Roadmap



- ***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
- **Planned for update Sept. 2012**

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

Planned and Proposed Disposal R&D

- **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

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Planned and Proposed Disposal R&D

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

UFD Storage and Transportation R&D Activities

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UFD Storage and Transportation Objectives

- **UFD Storage and Transportation objectives roll up to three points:**
  - **Develop the technical basis for extended storage of used nuclear fuel**
  - **Develop the technical basis for fuel retrievability and transportation after extended storage**
  - **Develop the technical basis for transportation of high burnup used nuclear fuel**

UFD develops these bases through four groups of activities:

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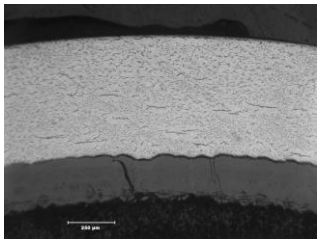
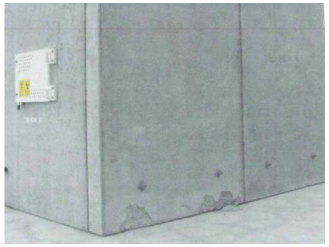
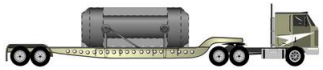
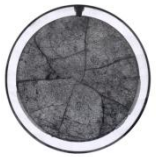
Storage and Transportation Work Package Structure

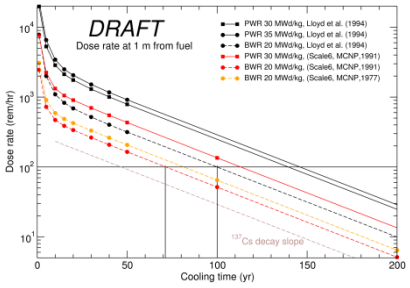
- **Storage R&D Investigations**
  - Data gap analyses
  - Plan to address gaps
  - Development of technical basis
- **Conceptual Evaluation**
  - Evaluate scenarios for accomplishing development of technical basis
  - Develop a systems framework for decision-making
- **Transportation**
  - High burnup fuels
  - Transportation of all fuels after storage
- **Security**
  - Regulatory assessment
  - Identify issues for long-term storage and subsequent transportation
  - Evaluate methods for security assessment over long-term storage











Questions?