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Used Nuclear Fuel Disposal in the US Overview

Presented to:



Spent Fuel Policy Forum
Seoul, Korea

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Outline

- **The Used Fuel Disposition Campaign**
 - Our mission and goals
 - How we are organized
- **The R&D activities**
 - Cross-cutting activities
 - Disposal R&D
 - Storage and Transportation R&D

Used Fuel Disposition (UFD) Campaign Overview

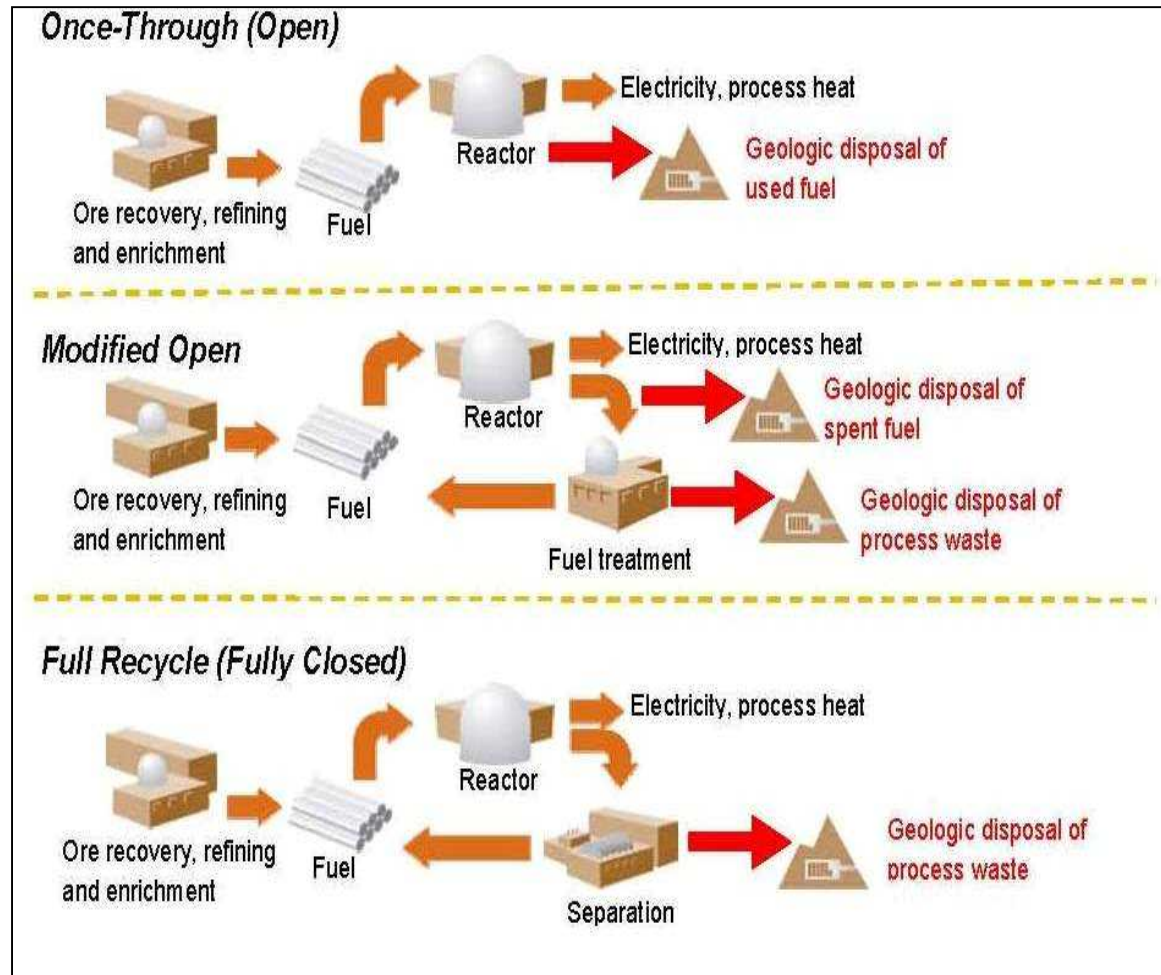
- **DOE Office of Nuclear Energy Mission**

... advance nuclear power as a resource capable of meeting the Nation's energy, environmental, and national security needs by resolving technical, cost, safety, proliferation resistance, and security barriers through research, development, and demonstration as appropriate.

- **Used Fuel Disposition Campaign Mission**

... 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.

Fuel Cycle Options



UFD Campaign 2009-Present

- **FY09: Planning meeting at Argonne National Laboratory, June 2009**
- **FY10: Relatively small program**
 - Disposal R&D, modest level of effort on Storage R&D, no Transportation R&D
- **FY11: Substantial increase in scope with termination of DOE Office of Radioactive Waste Management**
 - Nine national laboratories participating in UFD
 - Significant R&D program in Storage, including Transportation
 - Incorporation of DOE Office of Civilian Radioactive Waste Management science programs into Disposal R&D
- **FY12: Blue Ribbon Commission (BRC) on America's Nuclear Future final report provides guidance *specific to Disposal Research* (<http://brc.gov/>). DOE should:**
 - Undertake prompt efforts to develop a new geologic disposal facility and keep repository program moving through non-site specific activities
 - Develop RD&D plan and roadmap for deep borehole disposal concept including a licensed demonstration
 - Follow an adaptive, staged and consent-based approach to disposal facility siting, and ensure the process is informed by past experience
 - Display active leadership in international efforts to address safety, non-proliferation and security concerns

Used Fuel Disposition Campaign

External Collaborations

- **Nuclear Energy University Programs (NEUP)**
 - 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
- **Electric Power Research Institute (EPRI)**
 - Extended Storage Collaboration Program (ESCP) (with NRC and international groups)
- **US National Laboratory directed R&D programs**
 - E.g., deep borehole work at SNL
- **International activities**
 - Bilateral agreements on disposal R&D with Korea, Japan
 - Memorandum of Understanding for salt R&D with Germany
 - International Atomic Energy Agency (IAEA) working groups in storage and transportation
 - Significant effort proposed in FY12 to increase US presence in underground research laboratories in Europe (DECOVALEX, Mont Terri)

Used Fuel Disposition Campaign

Long-Term Disposal Research Goals

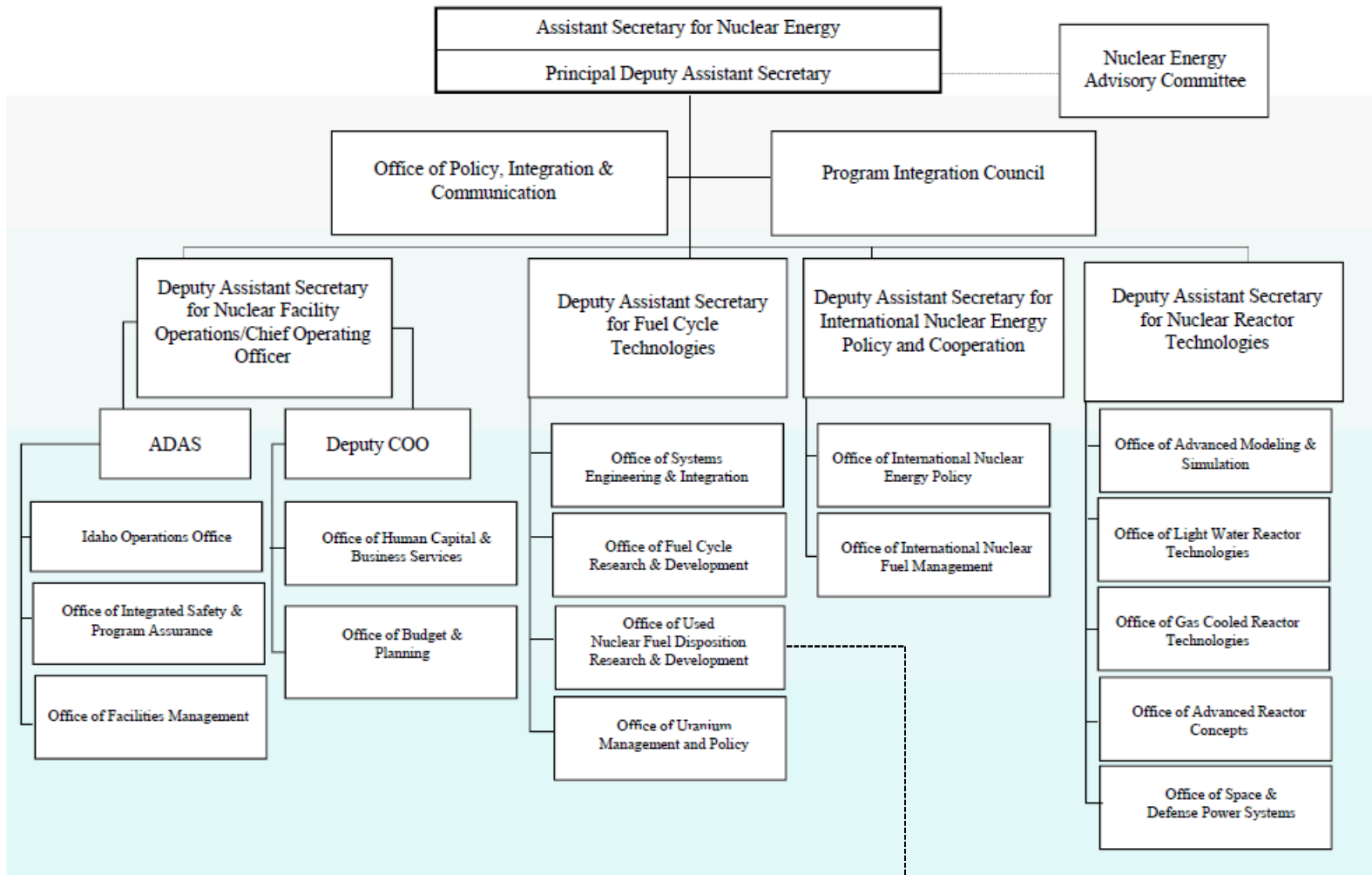
- **By 2015**

- 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**

- Robust modeling and experimental basis for evaluation of multiple disposal system options

DOE-NE Organization



Used Fuel Disposition Campaign

Used Fuel Disposition Campaign Structure

US DOE Office of Used Fuel Disposition R&D

William Boyle

Office Director

Jeff Williams

Deputy Office Director

Used Fuel Disposition Campaign

Peter Swift

National Technical Director

Sandia National Laboratories

Mark Nutt

Deputy National Technical Director

Argonne National Laboratory

Crosscut Activities

Mark Nutt

Campaign Lead

Argonne National Laboratories

Disposal Research

Kevin McMahon

Campaign Lead

Sandia National Laboratories

Storage & Transportation R&D

Ken Sorenson

Campaign Lead

Sandia National Laboratories

UFD Campaign R&D Participants...

9 US National Laboratories



PNNL



SRNL



LANL



SNL



ANL



LLNL



ORNL



INL



LBNL

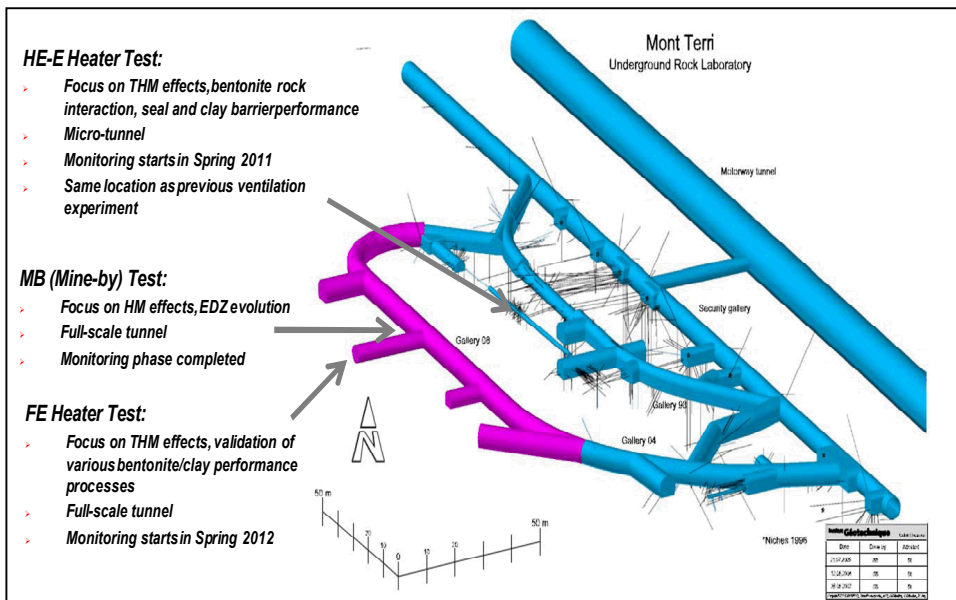
UFD Cross Cutting R&D Activities

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

KAERI Underground Research Tunnel (KURT)

R&D plan for experiments beginning in FY13

Nuclear Waste Management Perspectives

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

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

Public Beliefs about the Disposition of Used Nuclear Fuel In the USA**

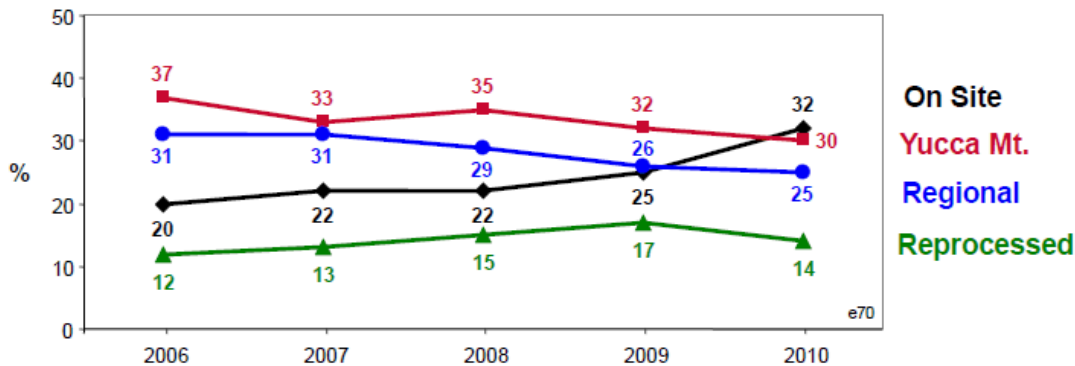


Figure 1 from H. C. Jenkins-Smith, 2011. Public Beliefs, Concerns, and Preferences Regarding the Management of Used Nuclear Fuel and High Level Radioactive Waste, report prepared for the Blue Ribbon Commission on America's Nuclear Future

** For comparison see "Assessment of Public Perception of Radioactive Waste Management in Korea," SAND2011-8529 (Available through Sandia National Laboratories)

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 Waste Isolation Pilot Plant (WIPP) to provide insight into dynamics of public acceptance
- Evaluate effects of fuel cycle alternatives on disposal system uncertainties

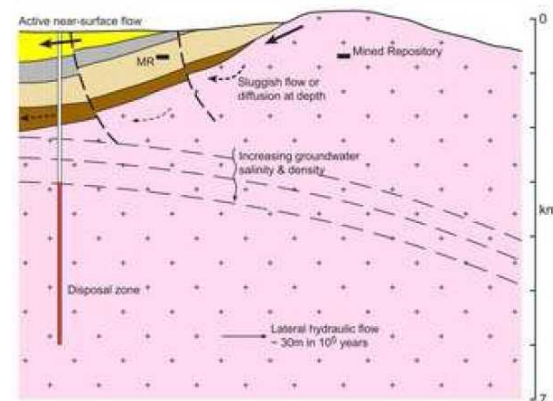
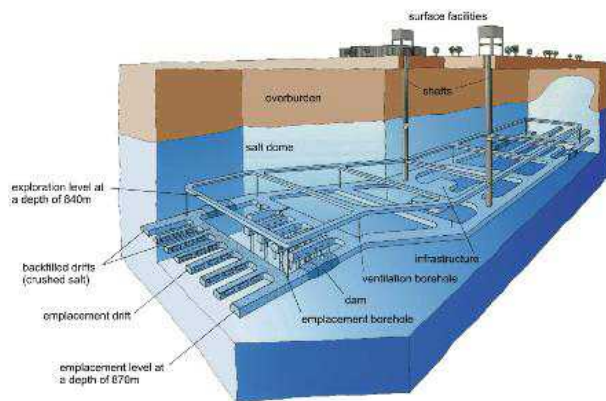
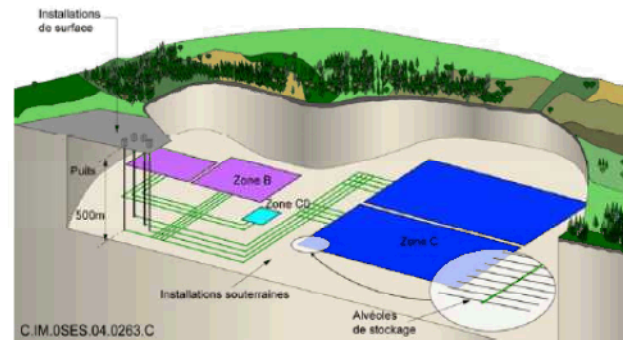
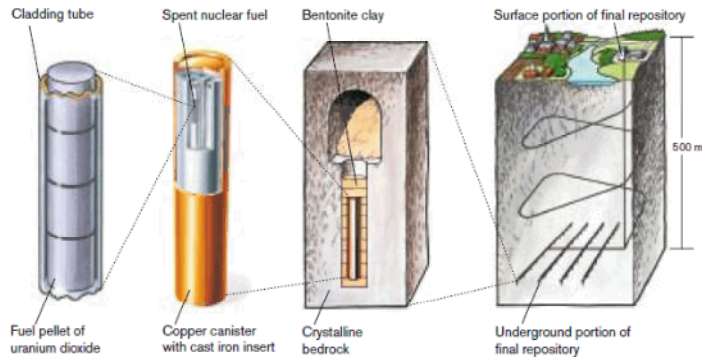
UFD Disposal R&D Activities

Role of Disposal R&D after Yucca Mountain

- **The US 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



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, ...)
- **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?

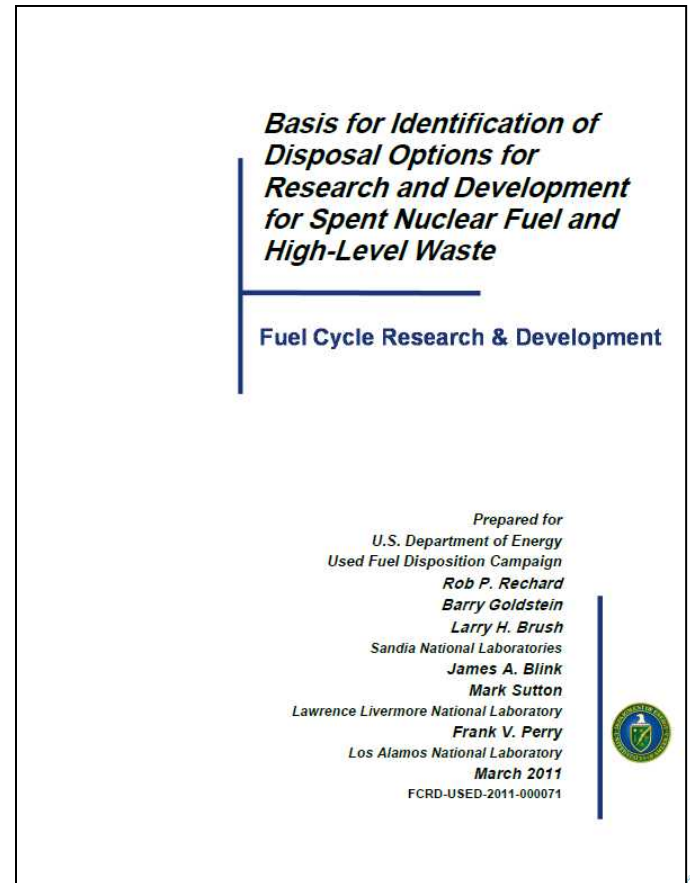
- Disposal options have been proposed and evaluated for 50+ years
- Consensus for at least thirty years, both in US and internationally, that deep geologic disposal is the preferred option,
 - Multiple in-depth reviews from the late 1950s to the present have noted the need for geologic disposal
 - **“Geological 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.)

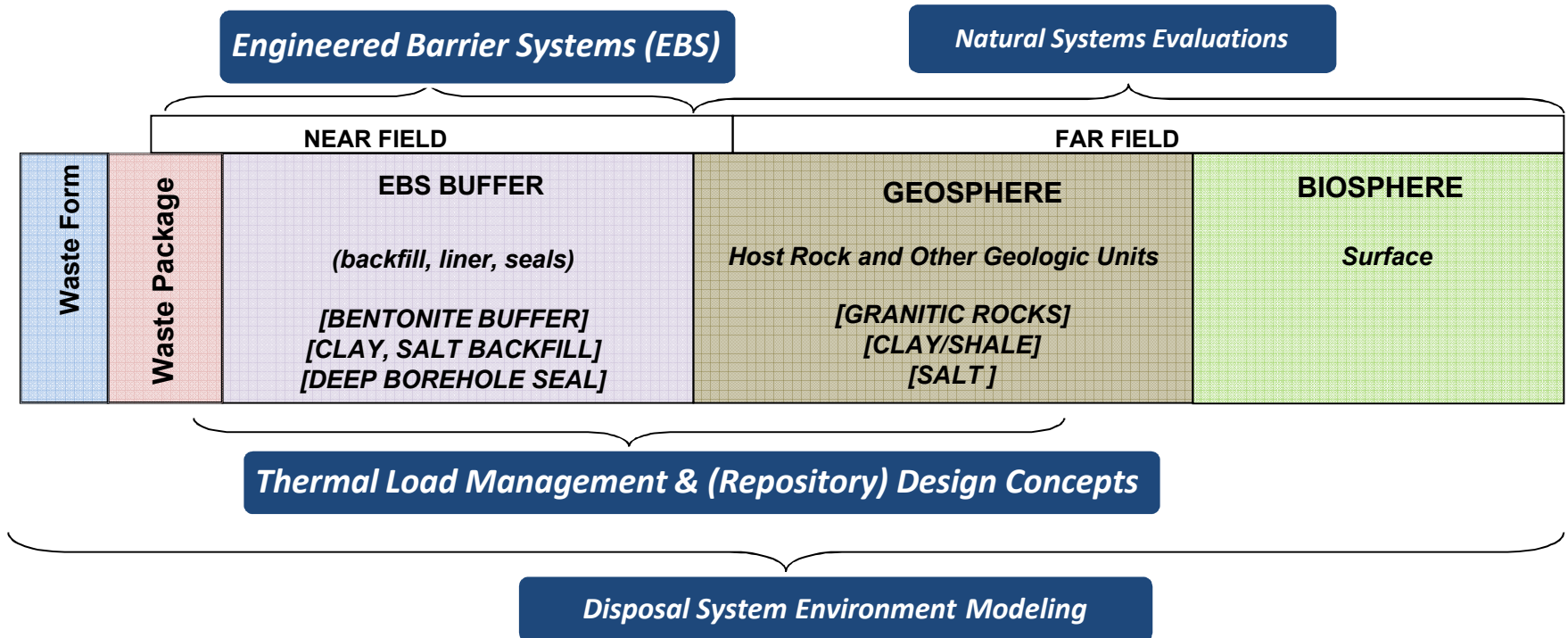
Alternatives summarized by Recharad et al., 2011

- 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

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



UFD Disposal R&D Activities



SUPPORT, ANALYSIS & EXPERIMENTAL ACTIVITIES

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

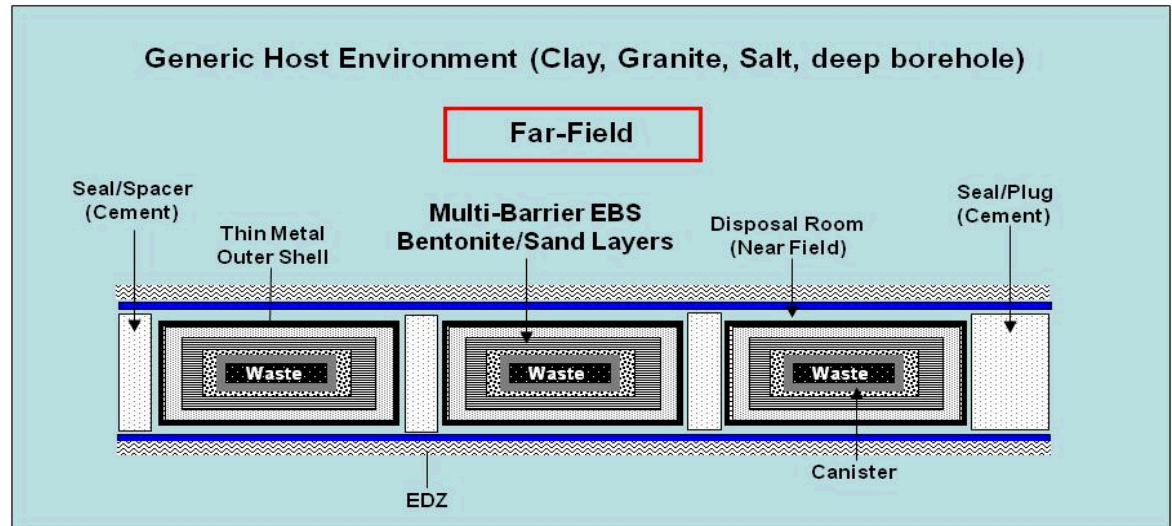
(corrosion, degradation studies)
(how R&D is organized and prioritized)
(part of total nuclear waste consideration)
(LLW/HLW, used fuel, open → closed fuel cycles)

Engineered Barrier Systems R&D

EBS and materials evaluation for multiple disposal environments (clay/shale, granite, 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

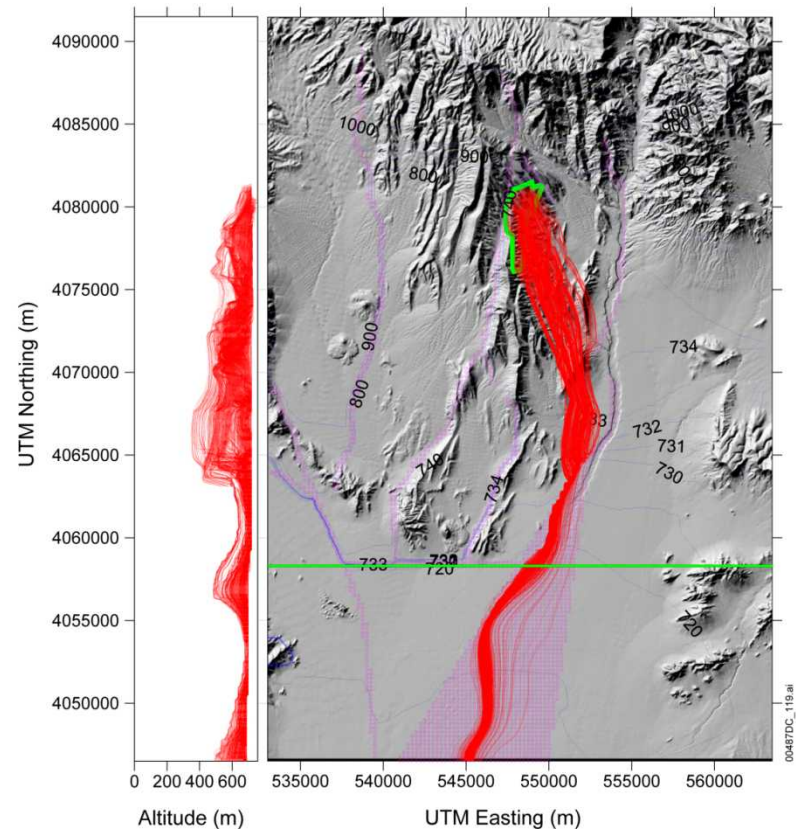


Natural Systems Evaluation R&D

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 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



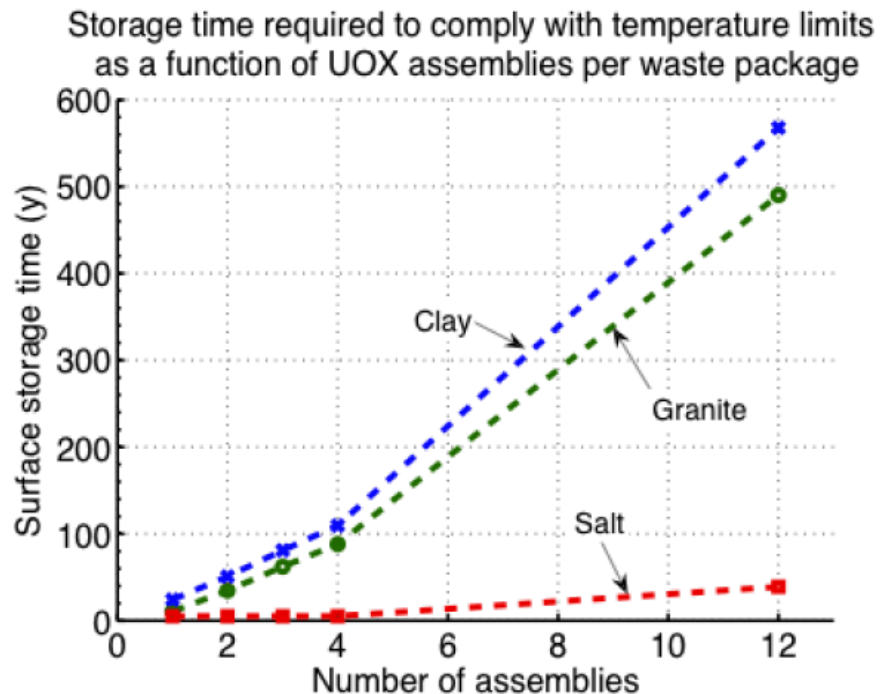
Simulated Flow Paths, Saturated Zone
FEHM. Yucca Mountain Project

Thermal Load Management & (Repository) 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



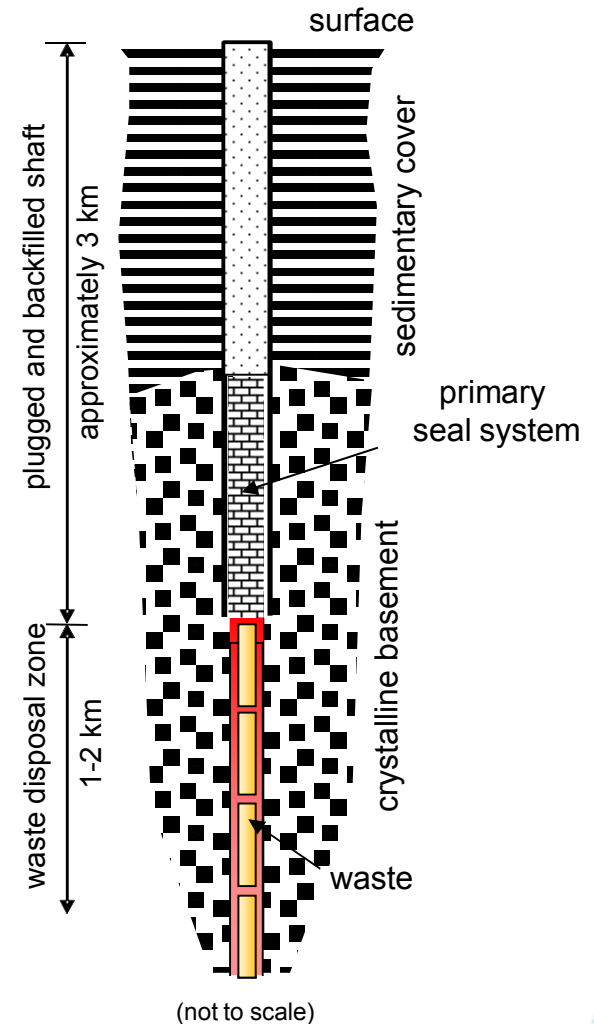
Minimum decay storage durations to limit peak PWR waste package surface temperature to 100°C (granite, clay) or 200°C (salt). (Hardin et al., 2011, Generic Repository Design Concepts and Thermal Analysis (FY11), FCRD-USED-2011-000143)

Generic Disposal System Modeling

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



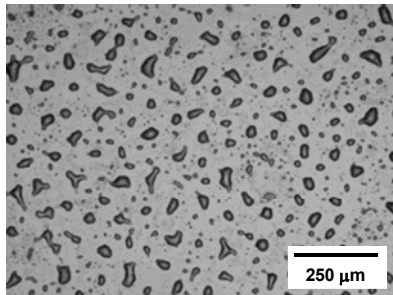
Source: modified from Brady et al., 2009, Deep Borehole Disposal of High-Level Radioactive Waste, SAND2009-4401

Engineered Materials Experimental

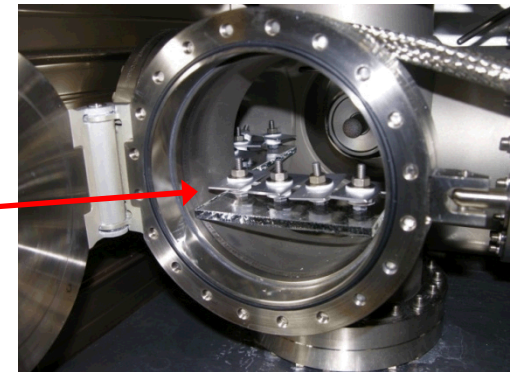
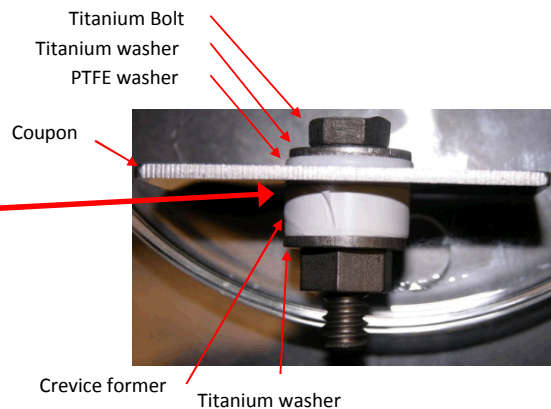
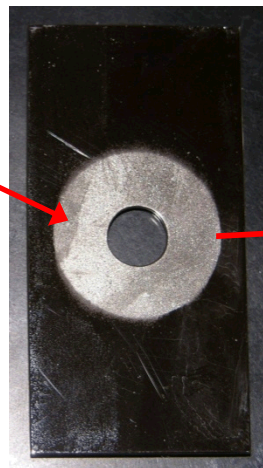
Experiments and model development for long-term performance of engineered materials in storage and repository environments

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

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 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

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 Argonne National Lab, Oak Ridge National Lab

- **Inventory Projections**

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

- **Low Level Waste (LLW) 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

Thank You

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Questions?