SAND2016-4707PE

Used Fuel Disposition R&D Campaign

Used Fuel Disposition R&D Campaign Overview

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Used Fuel Disposition R&D Campaign

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Berkeley, California, USA

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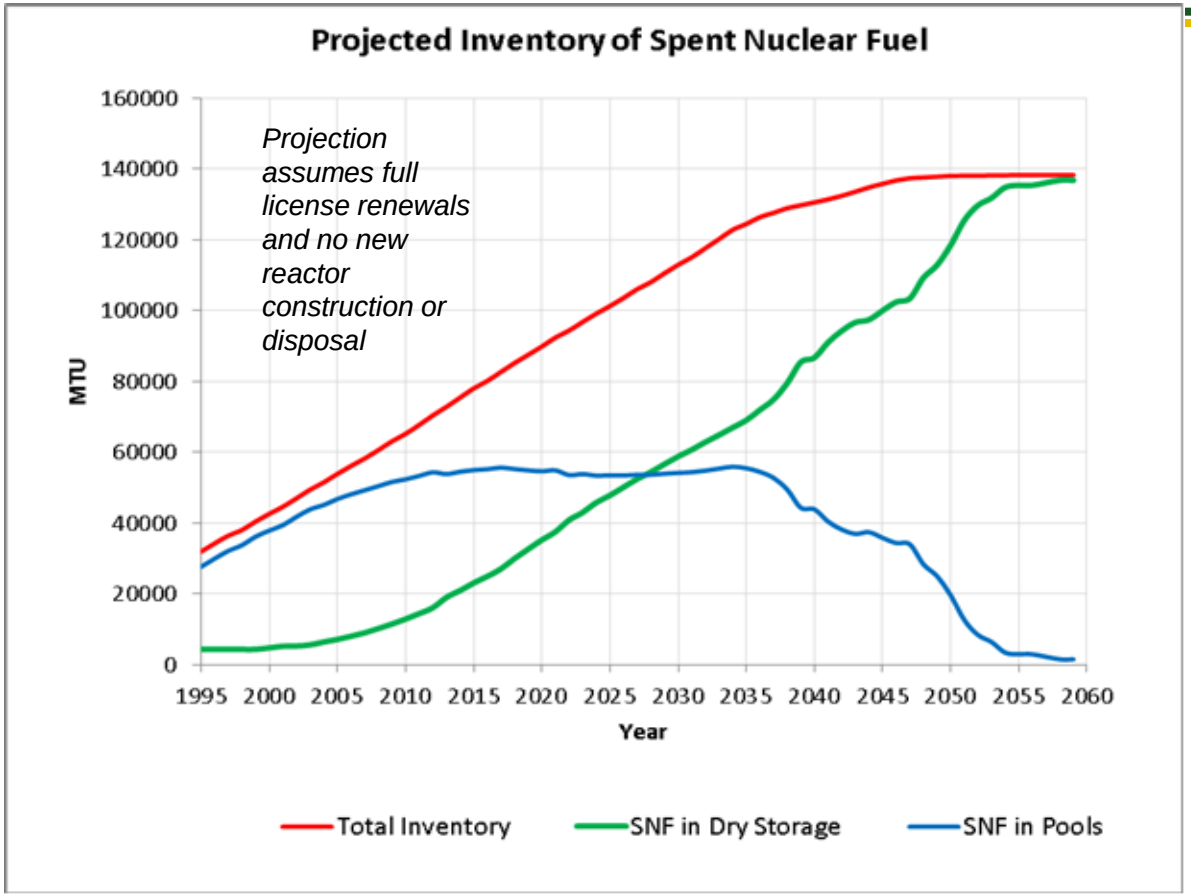
Used Fuel Disposition

Used Nuclear Fuel Disposition Research and Development Campaign Overview

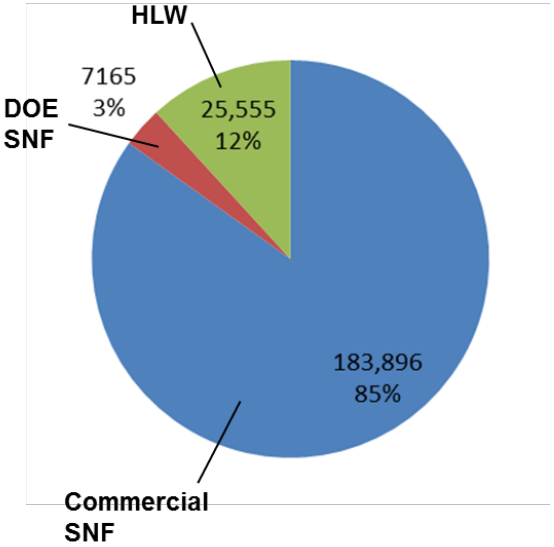
- **Background**
  - US Spent Fuel (SNF/UNF) and High-Level Waste (HLW) Inventories
  - Administration Strategy for UNF and HLW
  - US DOE Nuclear Energy Overview
- **UFD R&D Campaign (UFDC) Focus Areas and Structure**
  - Mission and Participants
  - External Collaborations
  - Objectives of the UFD Campaign
- **Long-term R&D Path and Conclusions**

Used Fuel Disposition

Historical and Projected Commercial Spent Nuclear Fuel (SNF) Discharges and High-Level Radioactive Waste (HLW) in the United States



Projected Volumes of SNF and HLW in 2048



Volumes shown in m^3, assuming constant rate of nuclear power generation and packaging of future commercial SNF in existing designs of dual-purpose canisters

Approx. 80,150 MTHM (metric tons heavy metal) of SNF in storage in the US today

- 25,400 MTHM in dry storage at reactor sites, in approximately 2,080 cask/canister systems
- Balance in pools, mainly at reactors

Approx. 2200 MTHM of SNF generated nationwide each year

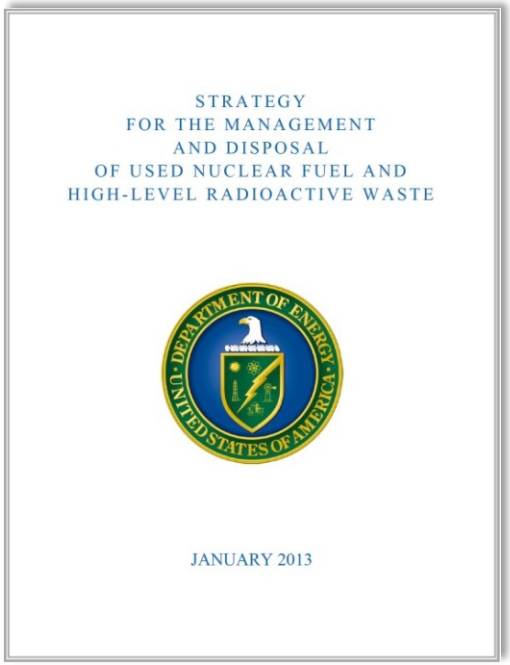
- Approximately 160 new DPCs are loaded each year because reactor pools are essentially at capacity

Summary of the Administration's UNF and HLW Strategy

Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste **issued January 2013**

The Strategy is:

- **A statement of Administration policy regarding the importance of addressing the disposition of used nuclear fuel and high-level radioactive waste**
- **The response to the final report and recommendations made by the *Blue Ribbon Commission on America's Nuclear Future***
- **The initial basis for discussions among the Administration, Congress and other stakeholders**

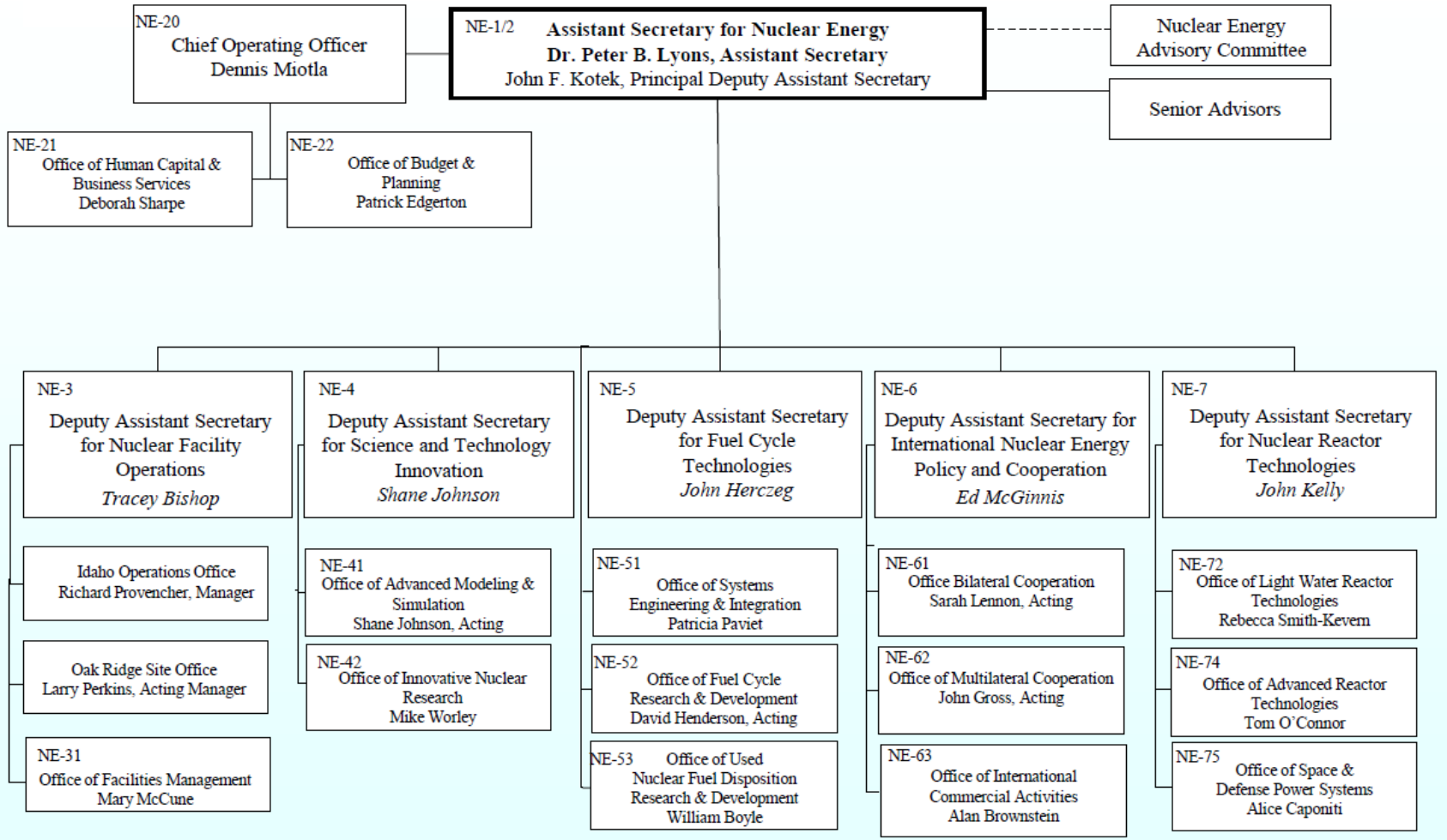


The Strategy outlines a 10-year program of work that:

- Sites, designs, licenses, constructs and begins operations of a pilot interim storage facility (operating 2021)
- Advances toward the siting and licensing of a larger interim storage facility (operating 2025)
- Makes demonstrable progress on the siting and characterization of repository sites (repository sited 2026, licensed 2042, operating 2048)

Used Fuel Disposition

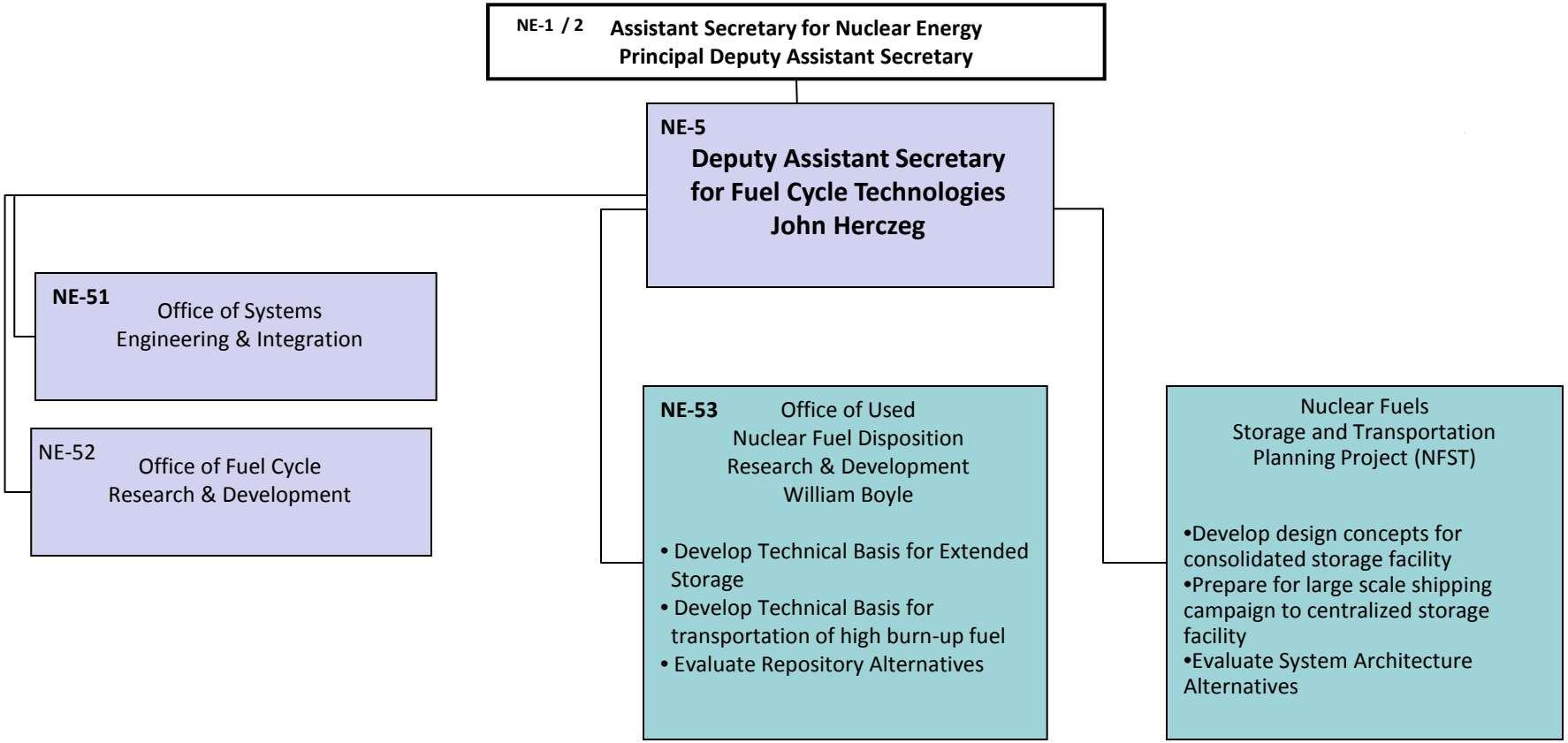
DOE-NE Organization Chart



Note: for latest see: http://energy.gov/ne/office-nuclear-energy

Used Fuel Disposition

DOE Office of Nuclear Energy Office of Fuel Cycle Technologies (NE-5)



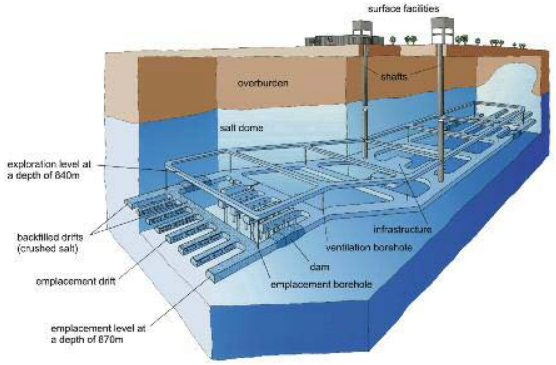
Campaign Strategic Focus: Storage and Transportation R&D

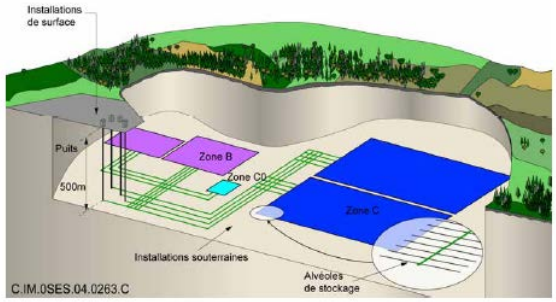
Prepare for extended storage and eventual large-scale transport of used nuclear fuel (UNF) and high-level waste

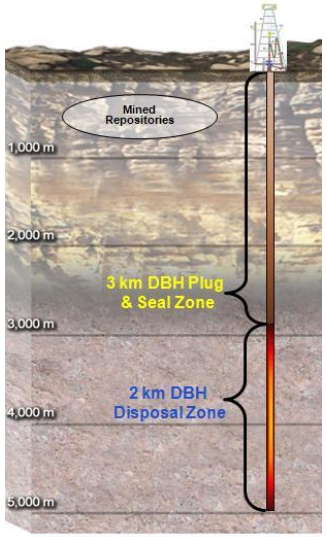
- **Develop the technical bases for:**
  - Extended storage of used nuclear fuel
  - Fuel retrievability and transportation after extended storage
  - Transportation of high-burnup used nuclear fuel

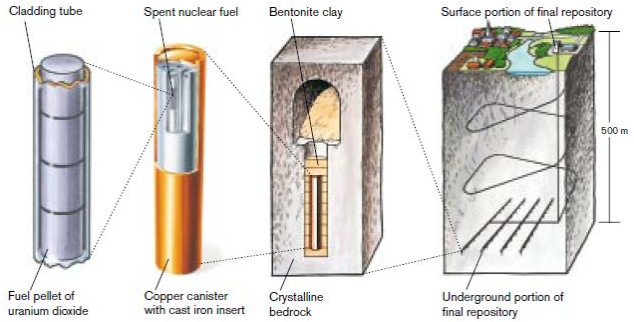
DOE's R&D Focus for UNF and HLW Disposal

- **Provide a sound technical basis for multiple viable disposal options in the US**
- **Increase confidence in the robustness of generic disposal concepts**
- **Develop the science and engineering tools needed to support disposal concept implementation**









Used Fuel Disposition

Used Fuel Disposition R&D National Laboratories and Campaign Mission

The DOE Office of Used Nuclear Fuel Disposition Research and Development and ***nine national laboratories*** participate in the DOE Office of Nuclear Energy's "Used Fuel Disposition Campaign"

Campaign Mission: 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

Campaign challenge: to provide a sound technical basis for supporting the current DOE strategy for managing the back end of the nuclear fuel cycle…

Update of the *Used Fuel Disposition Campaign Implementation Plan, FCRD-UFD-2014-0000474, October 2014*

Used Fuel Disposition

FY2016 Organization of the Used Fuel Disposition Campaign

UFD Campaign
Peter Swift
National Technical Director (NTD)

Disposal Research
Kevin McMahon
Bob MacKinnon

Storage &Transportation
Ken Sorenson
Sylvia Saltzstein

Host Rock Research: Argillite
Host Rock Research: Crystalline
Host Rock Research: Salt
Generic Disposal System Analysis
International Collaborations
Deep Borehole Disposal
Disposal of Dual Purpose Canisters
DOE Managed HLW and SNF Research

Deep Borehole Field Test (procurement managed directly by DOE)

Field Demonstration Support
Experiments
Analysis
Transportation
Security

High-burnup Confirmatory Data Project (industry-led, managed directly by DOE)

Used Fuel Disposition Campaign External Collaborations

- **Collaboration among Fuel Cycle Technology Campaigns**
  - Full collaboration and shared resources with Nuclear Fuels Storage and Transportation Planning Project (NFST)
  - Support for Fuel Cycle Options Campaign
  - Close interactions with Material Recovery/Waste Form Campaign
    - *Waste form degradation modeling integration*
- **Collaboration with DOE-EM**
  - Canister concepts for deep borehole disposal
- **Industry (Advisory and Assistance Contracts)**
  - E.g., Areva; engineering services task for deep borehole field test
- **DOE/Industry Storage High-Burnup Data Project initiated FY13**
  - Dominion, Areva, Westinghouse
- **EPRI**
  - Extended Storage Collaboration Program (ESCP) (with NRC, utilities, vendors, and international organizations)
- **NEI**
  - Meetings to coordinate prioritization of funded activities

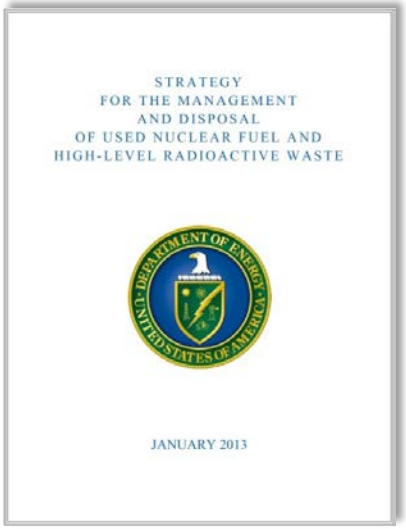
Used Fuel Disposition Campaign External Collaborations (cont.)

- **International Collaborations**
  - Participation in international Underground Research Laboratories in Europe and Korea and in multi-national disposal research activities
  - Bilateral agreements on storage and disposal R&D with Korea, Japan, China
  - MOU for salt disposal R&D with Germany
  - IAEA working groups in storage and transportation
  - Collaboration with Germany and Japan on extended performance of bolts and seals for bolted storage casks and on SS canister stress corrosion cracking
- **DOE NE University Programs**
  - UFD R&D is affiliated with 22 active NEUP research projects (not including FY15 awards)
    - *11 projects in Storage R&D*
    - *2 projects in Transportation R&D*
    - *6 projects in Disposal R&D*
    - *3 Integrated Research Projects in Storage R&D*
- **Other university collaborations (MIT, U. of Oklahoma, University of Sheffield UK)**

Long-Term UFD R&D Campaign Objectives

- Support the implementation of a full-scale NRC-licensed confirmatory storage demonstration facility, in collaboration with industry
- Develop the technical basis necessary to support eventual transportation of used nuclear fuel, including high-burnup fuel
- Support the Nuclear Fuel Storage and Transportation Planning Project with implementation of integrated storage, transportation, and disposal concepts

Support the Administration's 2013 *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*



Used Fuel Disposition

Three-Year UFD Campaign Objectives (2016-2019)

Storage and Transportation

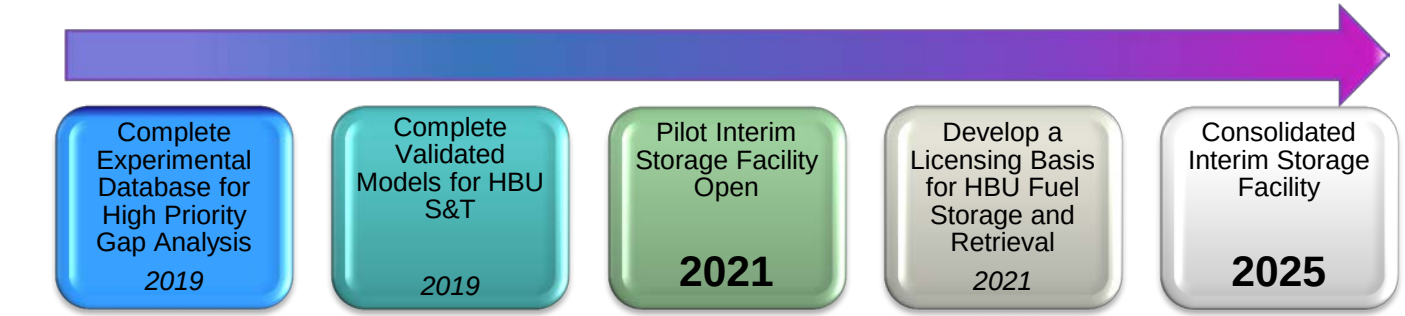
- Support the high burn-up fuel full-scale storage demonstration project
- Develop understanding of how temperature and pressure affect cladding integrity in high-burnup UNF
  - *Predictive modeling*
  - *Experimentation*
- Develop understanding of how corrosion and stress corrosion cracking affect performance of stainless steel dry storage canisters
  - *Material and environmental data; predictive modeling*
- Characterize external loadings on UNF during normal conditions of transport

Disposal Research

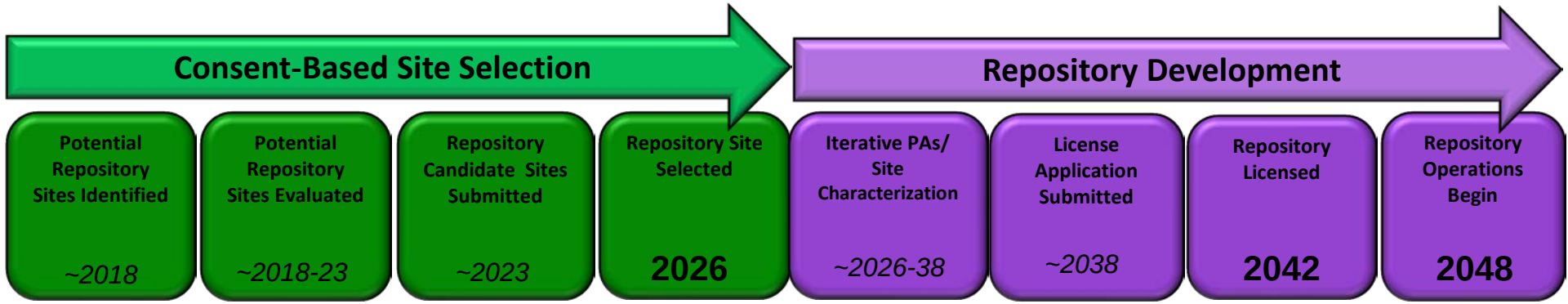
- Field a deep borehole test
  - *Initiate drilling in 2016, complete testing in 2019*
- Complete evaluation of the direct disposal of dual-purpose canisters
- Develop experimental and modeling basis for understanding long-term performance of disposal systems in argillaceous rock, salt, crystalline rock, and deep boreholes
  - *Leverage international disposal R&D*
- Develop reference cases for generic disposal concepts
  - *Initiate DOE-managed waste repository approach*

Used Fuel Disposition

R&D Path to Support DOE Waste Management Strategy



Storage & Transportation R&D supports 2025 Consolidated Interim Storage Facility



Approximate target dates (in *italics*) needed to meet milestones (in bold) set out in the 2013 DOE *Strategy*

Disposal R&D supports 2026 Repository Site Selection and 2042 Repository Licensing

Used Fuel Disposition

Contact Information

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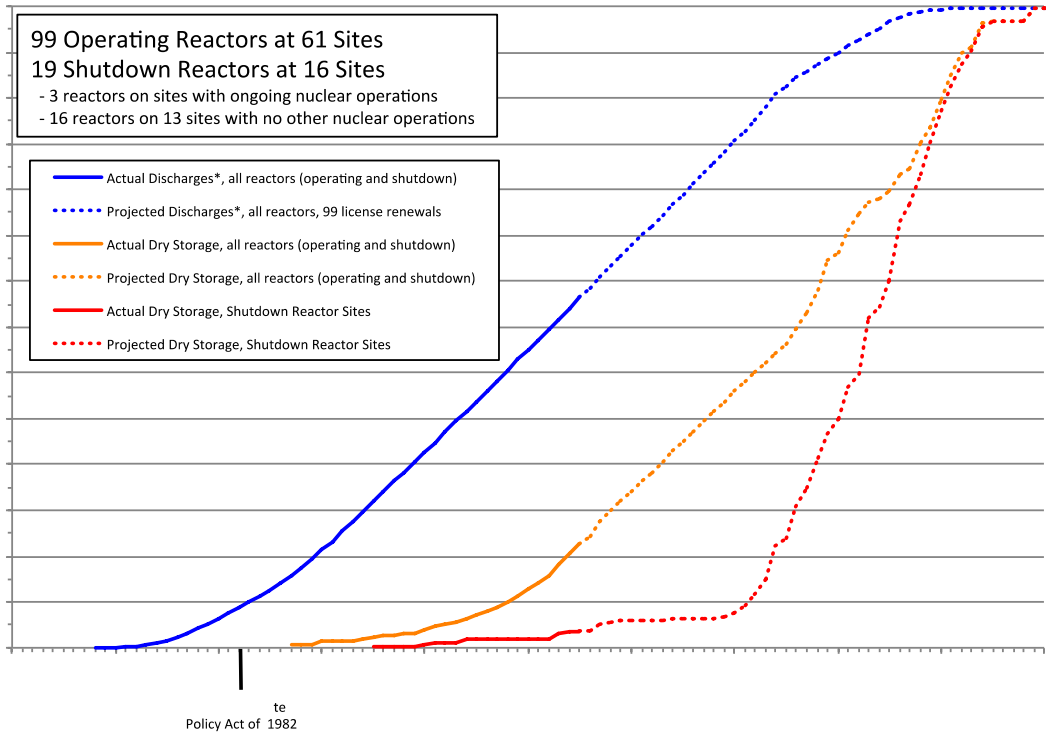
Backup Slides

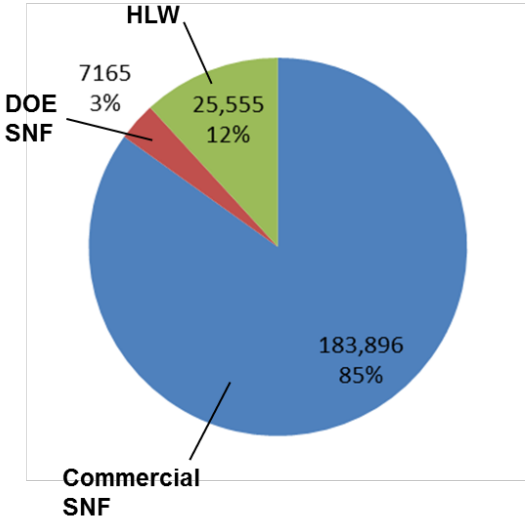
Used Fuel Disposition

Historical and Projected Spent Nuclear Fuel (SNF) and High-Level Radioactive Waste (HLW) in the United States



Historical and Projected Commercial SNF Discharges

Projected Volumes of SNF and HLW in 2048



Volumes shown in m^3, assuming constant rate of nuclear power generation and packaging of future commercial SNF in existing designs of dual-purpose canisters

UFD Storage and Transportation R&D Selected FY15 Accomplishments

Selected Storage and Transportation FY15 Deliverables

- Test Plan for Sister Rod Characterization and Testing, M2FT-15IN08020111, March 2015
- Evaluate the Frequency for Gas Sampling for the High Burn-up Storage Demonstration Project, M2FT-15IN0802013, April 2015
- Conduct ring compression tests on HBU PWR cladding alloys at 350 C. M2FT-15AN0805011, September 2015
- Conduct cyclic bend tests of used nuclear fuel. M2FT-15OR0805031, September 2015.
- Stress Corrosion Cracking Investigation on a Full Scale Stainless Steel Canister Mock-up. M2FT-15SN0805051, August 2015.
- Thermal profile analyses of in-situ industry storage systems identified for inspection. M2FT-15PN0810049. September 2015.
- Development of Uncertainty Quantification Methodology as Applied to Storage and Transportation R&D. M2FT-15SN0810051. July 2015

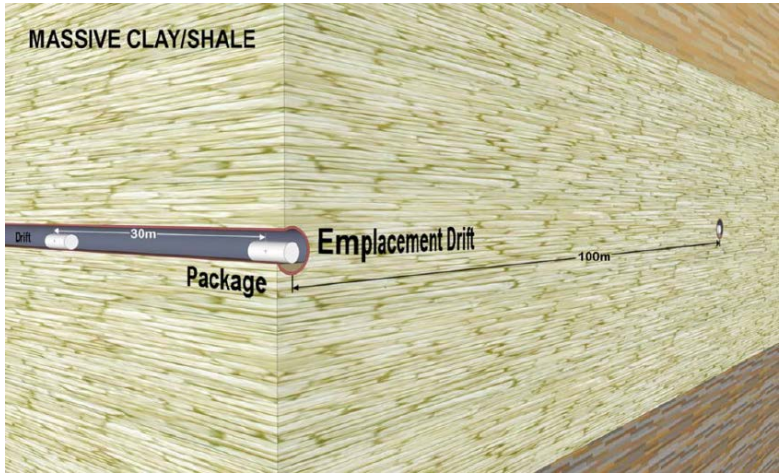
UFD Disposal R&D
Selected FY15 Accomplishments

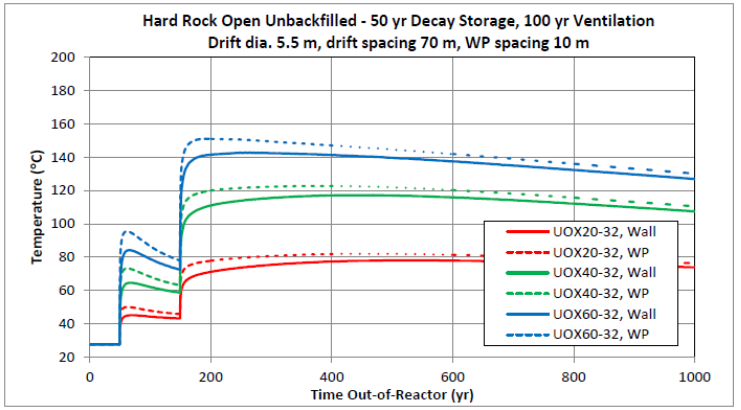
Selected Disposal Research FY15 Deliverables

- Evaluation of Used Nuclear Fuel Disposition in Clay-bearing Rocks, M2FT-15SN0806071, September 2015.
- Evaluation of Used Nuclear Fuel Disposition in Crystalline Rocks, M2FT-15SN0807071, September 2015.
- Application of Generic Disposal System Models. M2FT-15SN0808011, September 2015.
- International Collaboration Activities in Different Geologic Disposal Environments. M2FT-15LB0811012. September 2015.
- Investigations on Technical Feasibility of Direct Disposal of Dual-Purpose Canisters. M2FT-15SN0816021. May 2015.
- Site Evaluation for Deep Borehole Field Test. M2FT-15SN0817061. June 2015.
- Conceptual Design and Requirements for Characterization and Field Test Boreholes. M2FT-15SN0817081. September 2015.
- Deep Borehole Field Test Specifications. M2FT-15SN0817091. September 2015.
- Draft Test Plan for Phased Large-Scale Thermal Testing. M2FT-15LA0819016. April 2015.

Disposal Research FY15 Highlights

- **Evaluating Technical Feasibility of Direct Disposal of Dual Purpose Canisters (DPCs)**
  - Considerations
    - *Operational challenges (size and mass)*
    - *Thermal management*
    - *Post-closure criticality control*
- **Conclusions:**
  - Direct geologic disposal of some DPCs is feasible in some disposal concepts
    - *Operational challenges can be met*
    - *Thermal management can be achieved through aging, ventilation, and spacing*
    - *Post-closure criticality control may need to be addressed individually for each DPC*
  - *DPC disposal is not an all-or-nothing choice*





Disposal Research
FY15 Highlights (cont.)

- **Deep Borehole Field Test**

  Request for Proposals Issued
  July 9, 2015

  DE-SOL-0008071

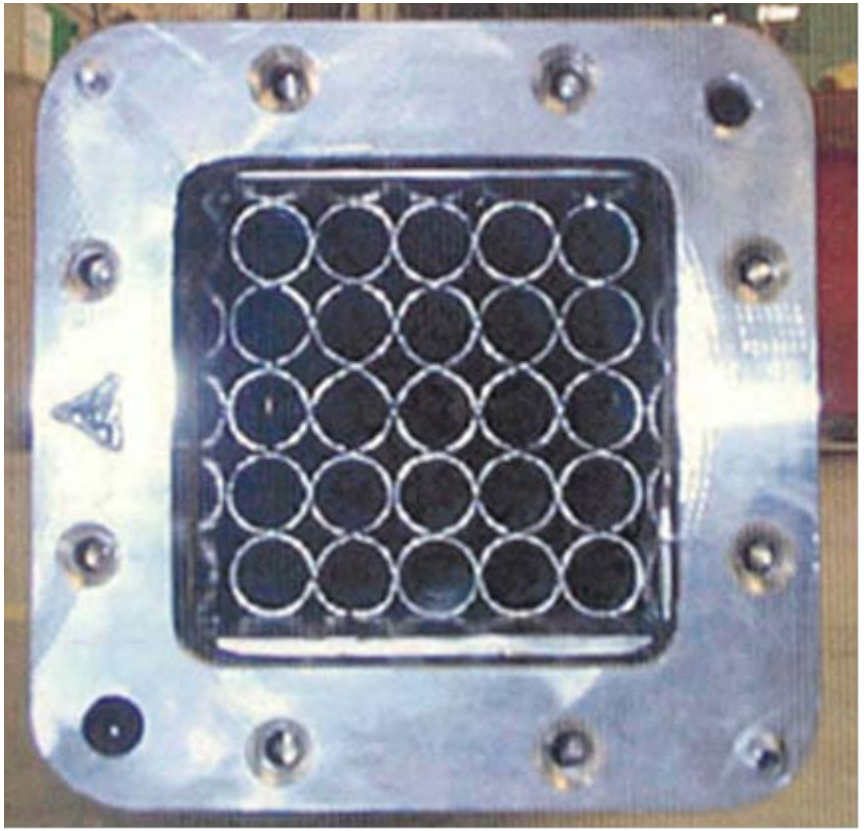
UFD R&D Campaign FY16 Activities

Selected UFD R&D 2016 Milestones

- **Selected 2016 Milestones: Storage and Transportation**
  - *Canister Mockup Weld Residual Stress Final Report (SNL, 6/30/2016)*
  - *High Heat Load Thermal Analysis (PNNL, 9/29/2016)*
  - *Sister Pin Test Plan (PNNL, 4/29/2016)*
  - *Documentation of Data Collection of CIRFT Tests on Rod Ends (ORNL, 9/15/2016)*
- **Selected 2016 Milestones: Disposal**
  - *Evaluation of Used Nuclear Fuel Disposition in Clay-bearing Rocks (SNL, 9/15/2016)*
  - *Evaluation of Used Nuclear Fuel Disposition in Crystalline Rocks (SNL, 9/21/2016)*
  - *International Collaboration Activities in Different Geologic Disposal Environments (LBNL, 9/23/2016)*
  - *Deep Borehole Field Test Conceptual Design Report (SNL, 6/30/2016)*
  - *Deep Borehole Field Test Laboratory and Borehole Testing Strategy (SNL, 8/31/2016)*
- **Selected 2016 Milestones: DOE Managed HLW and SNF Research**
  - *Draft Program Plan for the Permanent Disposal of High-Level Radioactive Waste and Spent Nuclear Fuel from Defense and Department of Energy Research and Development Activities (SNL, 07/29/2016)*
  - *Generic Organizational and Procedural Framework for DOE Managed HLW and SNF Licensing (SNL, 9/16/2016)*
- **There are a total of 20 Level 2 Milestones for UFD R&D Campaign in FY16 (one completed at this time)**

High Burnup Confirmatory Data Project - Highlights

- **Both INL and ORNL Transportation routes have been approved by NRC**
- **Areva rods pulled January 2015**
- **Westinghouse rods pulled June 2015**
  - AREVA M5™ rods
  - Westinghouse Zirlo™ rods
  - Westinghouse Low-tin Zircaloy-4 rods
  - Westinghouse standard Zircaloy-4 rods
- **Draft Sister Rod Test Plan has been completed and shared with others**
- **ORNL received 25 high burnup SNF rods from Dominions North Anna nuclear power plant**
  - Fuel rods extracted from 7 different fuel assemblies



NAC LWT basket for shipping rods

Observations from Current Storage and Transportation R&D

1. *Spent fuel integrity*

- Current test and analyses indicate that spent fuel is ***more*** robust than was previously thought.
- The *DOE/EPRI High Burnup Confirmatory Data Project* will obtain data after 10 years of dry storage to confirm current test and analysis results.

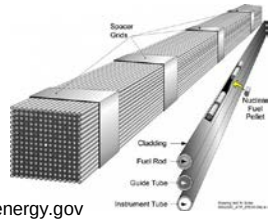


Photo: energy.gov

2. *Storage system integrity*

- *Stress corrosion cracking of canisters may be a concern in some parts of the country. More work is needed in analysis and detection.*
- *Monitoring and Aging Management practices at storage sites will be important to confirm storage system performance during extended service.*

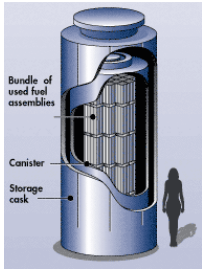
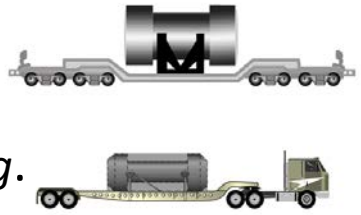


Photo: nrc.gov

3. *Spent fuel transportability following extended storage*

- *The realistic stresses fuel experiences due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding.*



Energy.gov/pictures

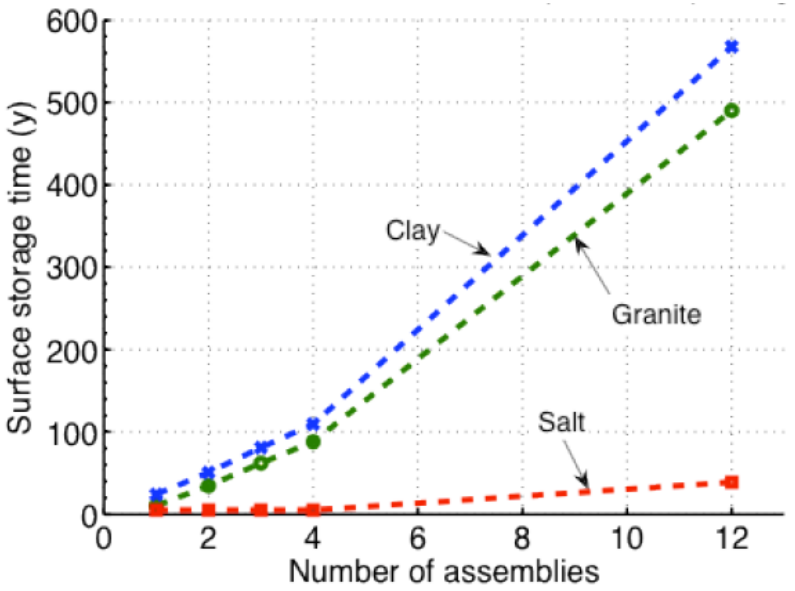
Repository Considerations: Thermal Management

Temperature limits based on current international and previous US concepts:

- 100°C for clay buffers and clay/shale media (e.g., SKB 2006)
- 200°C for salt (e.g., Salt Repository Project, Fluor 1986)

Final temperature constraints will be site- and design-specific

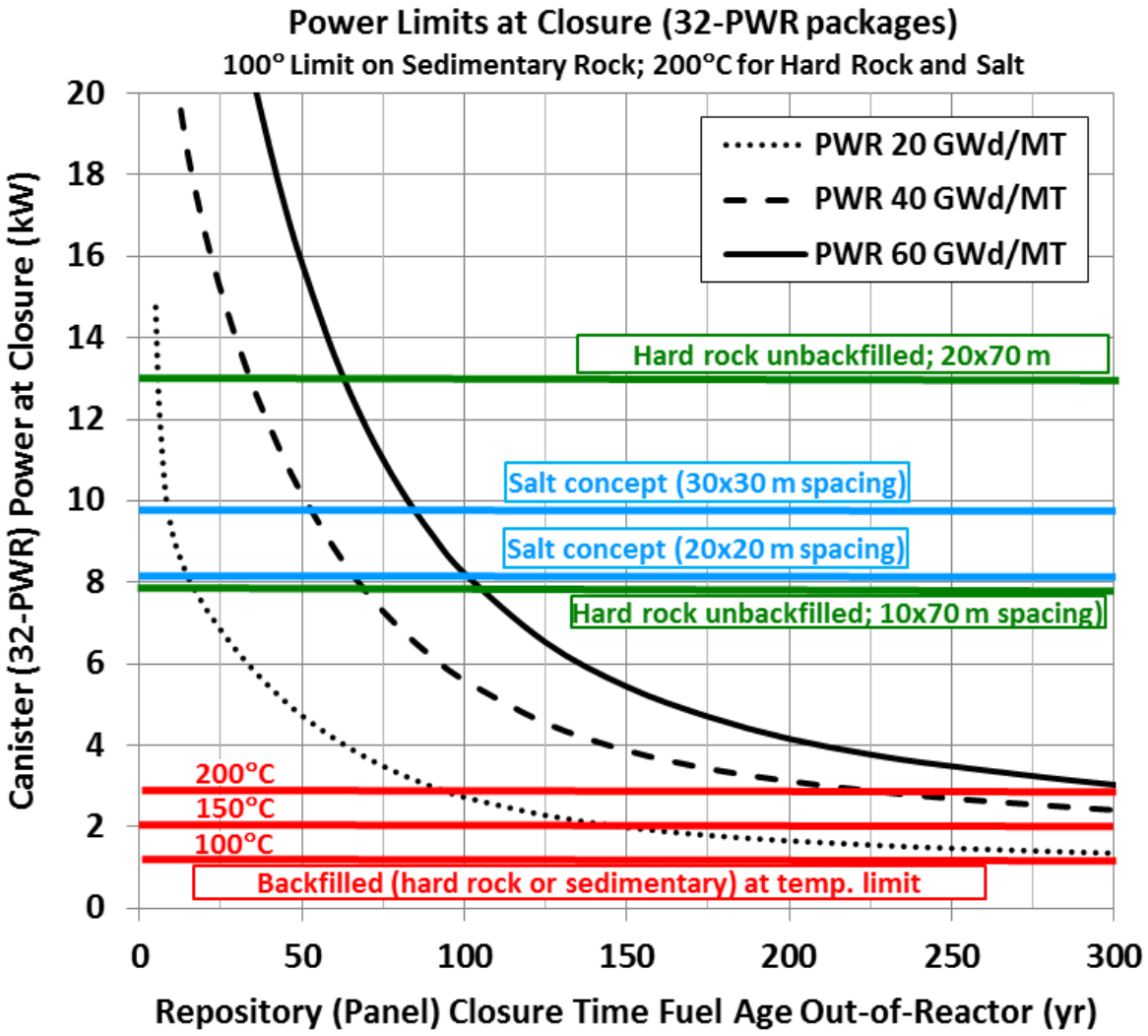
Decay Storage Needed to Meet WP Surface Temperature Limits vs. WP Size or Capacity (PWR Assemblies; 60 GWd/MT Burnup)



Repository thermal constraints can be met by

1) Aging
2) Ventilation in the repository
3) Decreasing package thermal output (size and burn-up)
4) Increasing package and drift spacing in the repository

Thermal Load Management (cont.)



Source: Hardin et al. 2015, FCRD-UFD-2015-000129 Rev 0 Figure 2-29

Higher burnup fuels require longer preclosure cooling times

Repository designs without backfill or in high-thermal-conductivity salt will need relatively shorter preclosure cooling times to accommodate large packages; underground spacing can have a large impact

Repository designs with thermal constraints on backfill will need long preclosure cooling times to accommodate large packages

Deep Borehole Disposal Concept: Why Deep Borehole Disposal?

- **Potential for robust isolation**
- **Gives DOE the flexibility to consider options for disposal of smaller waste forms in deep boreholes**
  - Potentially earlier disposal of some wastes than might be possible in a mined repository
  - Possible reduced costs associated with projected treatments of some wastes
- **Several DOE-managed small waste forms are potential candidates for deep borehole disposal (SNL 2014)**
  - Cesium and strontium capsules. 1,936 cesium and strontium capsules stored at the Hanford Site
  - Untreated calcine HLW currently stored at INL in sets of stainless steel bins within concrete vaults
  - Salt wastes from electrometallurgical treatment of sodium-bonded fuels could be packaged in small canisters as they are produced
  - Some DOE-managed SNF currently stored in pools at INL and SRS

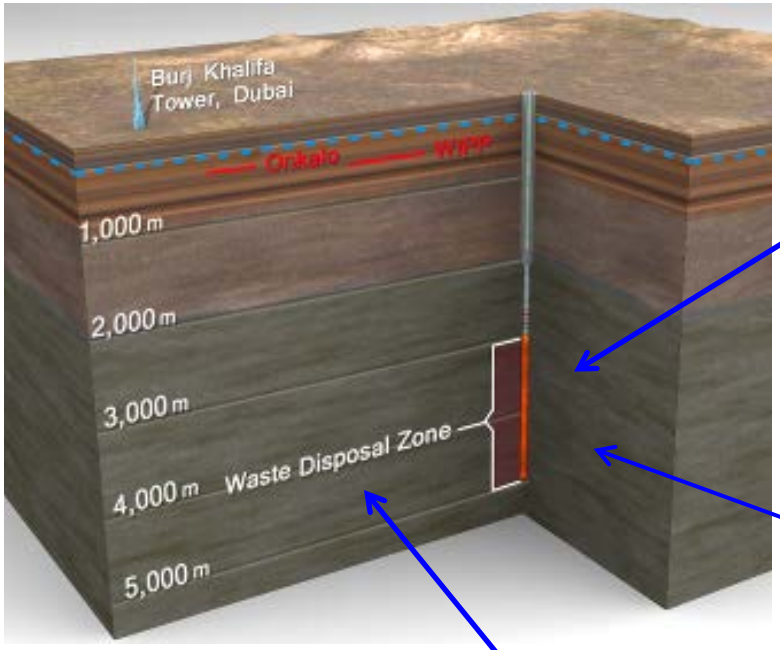
Possible Options for an Integrated System

- Introduce a standardized canister to be loaded at reactors in the future
  - Selection of a standardized transportation, aging, and disposal (STAD) canister is repository-design and regulation specific
  - Loading STADs directly from reactor pools (as proposed for Yucca Mountain) is unlikely to happen before perhaps 2030, by which time more than 50,000 MTHM of SNF will be in DPCs
    - Later dates for repository and STAD selection will mean more fuel in DPCs
  - Lack of present incentive for utilities to use standardized canister
- Repackaging of SNF from DPCs to STADs at a consolidated storage facility
  - Cost and schedule of repackaging
  - Management of additional LLW stream (used DPCs)
- Repository design options to handle multiple packaging systems
  - Plan now for disposal of some DPCs, repackaging of others
- Cost considerations–number of handling operations, number of packages, repository design, and complexity of licensing

Note: the DOE has relevant work in progress in each of these areas

Deep Borehole Disposal Concept – Safety and Feasibility Considerations

Long-Term Waste Isolation (hydrogeochemical characteristics)



Waste emplacement is deep in crystalline basement

- At least 1,000 m of crystalline rock (seal zone) overlying the waste disposal zone
- Crystalline basement within 2,000 m of the surface is common in many stable continental regions

Crystalline basement can have very low permeability

- limits flow and transport

Deep groundwater in the crystalline basement:

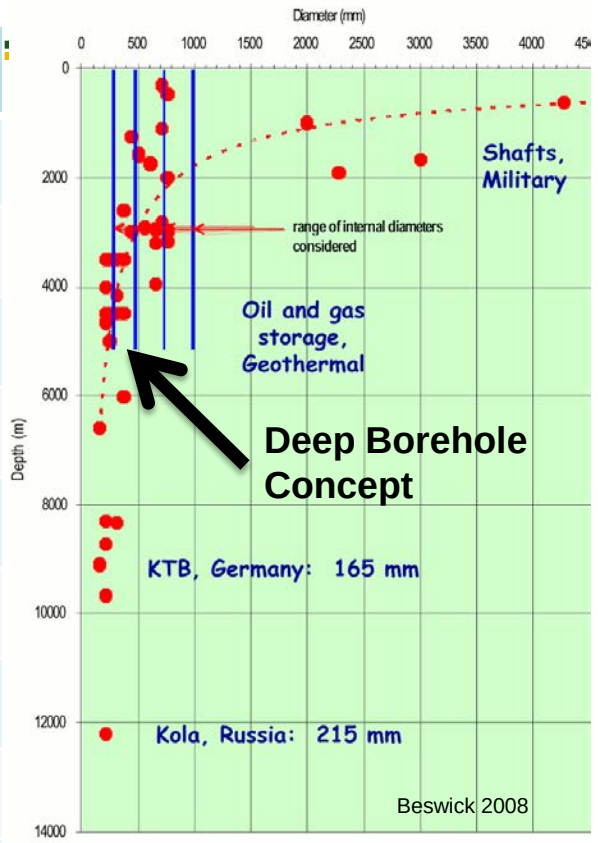
- Can have very long residence times – isolated from shallow groundwater
- Can be highly saline and geochemically reducing – enhances the sorption and limits solubility of many radionuclides
- Can have density stratification (saline groundwater underlying fresh groundwater) – opposes thermally-induced upward groundwater convection

Used Fuel Disposition

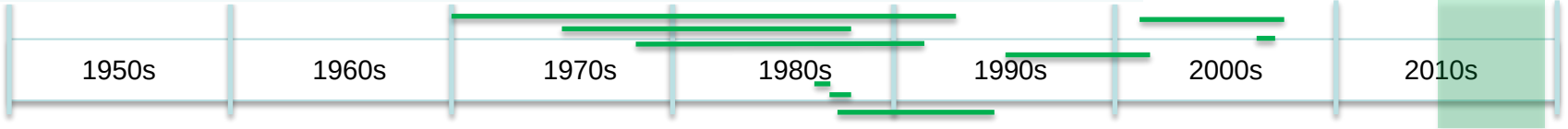
Deep Crystalline Drilling

Site	Bores	Location	Years	Depth [km]	Diam* [in]	Purpose
Kola SG-3	1	NW USSR	1970-1992	12.2	8½	Geologic Exploration + Technology Development
Fenton Hill	3	New Mexico	1975-1987	3, 4.2, 4.6	8¾, 9⅞	Enhanced Geothermal
Urach-3	1	SW Germany	1978-1992	4.4	5½	Enhanced Geothermal
Gravberg	1	Central Sweden	1986-1987	6.6	6½	Gas Wildcat in Siljan Impact Structure
Cajon Pass	1	California	1987-1988	3.5	6¼	San Andreas Fault Exploration
KTB	2	SE Germany	1987-1994	4, 9.1	6, 6½	Geologic Exploration + Technology Development
Soultz-sous-Forêts GPK	3	NE France	1995-2003	5.1, 5.1, 5.3	9⅝	Enhanced Geothermal
SAFOD	2	Central California	2002-2007	2.2, 4	8½, 8¾	San Andreas Fault Exploration
Basel-1	1	Switzerland	2006	5	8½	Enhanced Geothermal

*borehole diameter at total depth



Deep Borehole Field Test DBFT



Used Fuel Disposition

Objectives of the Deep Borehole Field Test

Synthesize field test activities, test results, and analyses into a comprehensive evaluation of concept feasibility

Evaluate site

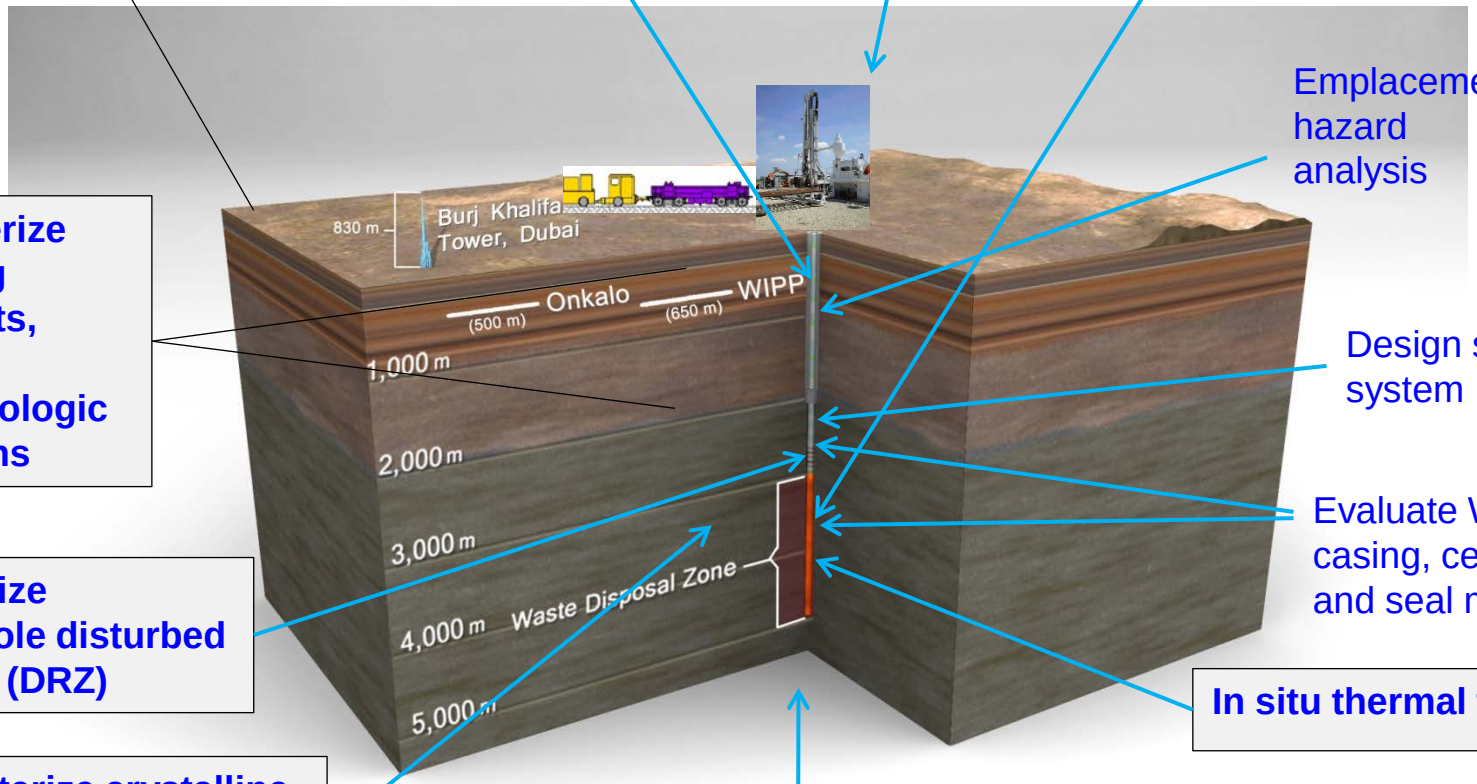
Design and construct characterization borehole then field test borehole

Develop and test systems for handling, emplacing, and retrieving WPs

Design and test WPs

Emplacement hazard analysis

Characterize overlying sediments, fluids, and hydrologic conditions



Design seal system

Evaluate WP, WF, casing, cement, and seal materials

In situ thermal test

Characterize the borehole disturbed rock zone (DRZ)

Characterize crystalline basement, fluids, and hydrologic conditions

Assess post-closure safety

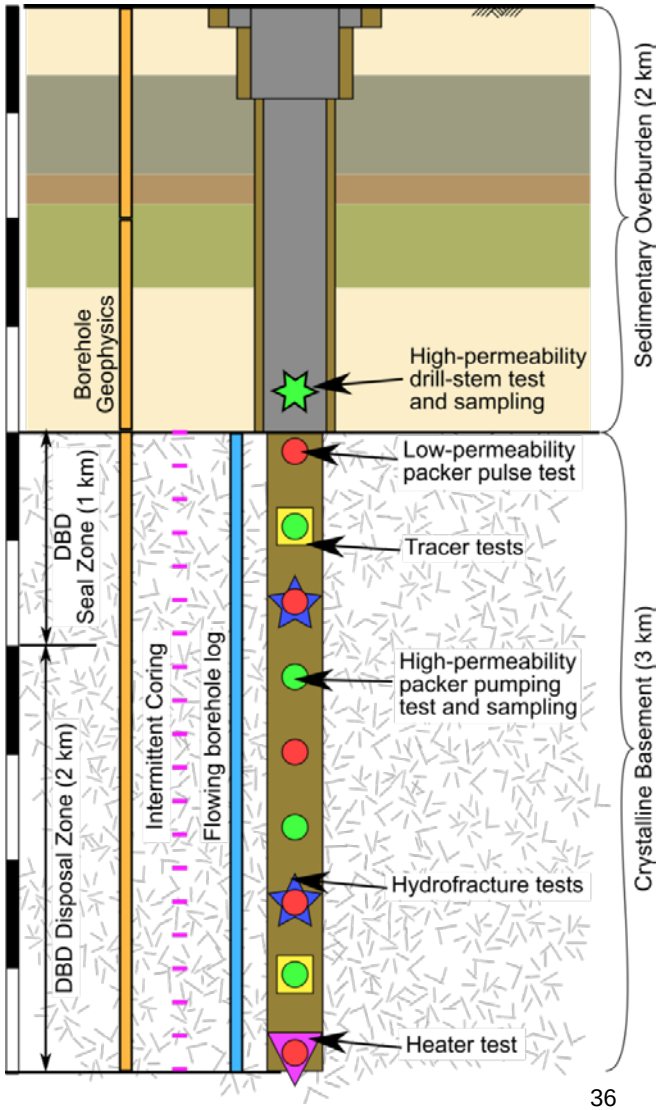
In no case will the US Government place or otherwise have nuclear material, waste, or other waste disposal material on the property (RFP 2015).

Used Fuel Disposition

Characterization Borehole (CB)

- Not all Char. Methods Included
  - Surface geophysics
  - Testing sedimentary sequence
  - No need to demonstrate in DBFT
- 8.5” diam. ~geothermal experience
- Core 150 m of Bedrock Section
- Testing/Sampling After Completion
  - Packer tool via work-over rig
  - At limits of current technology

Borehole designed to maximize likelihood of good samples

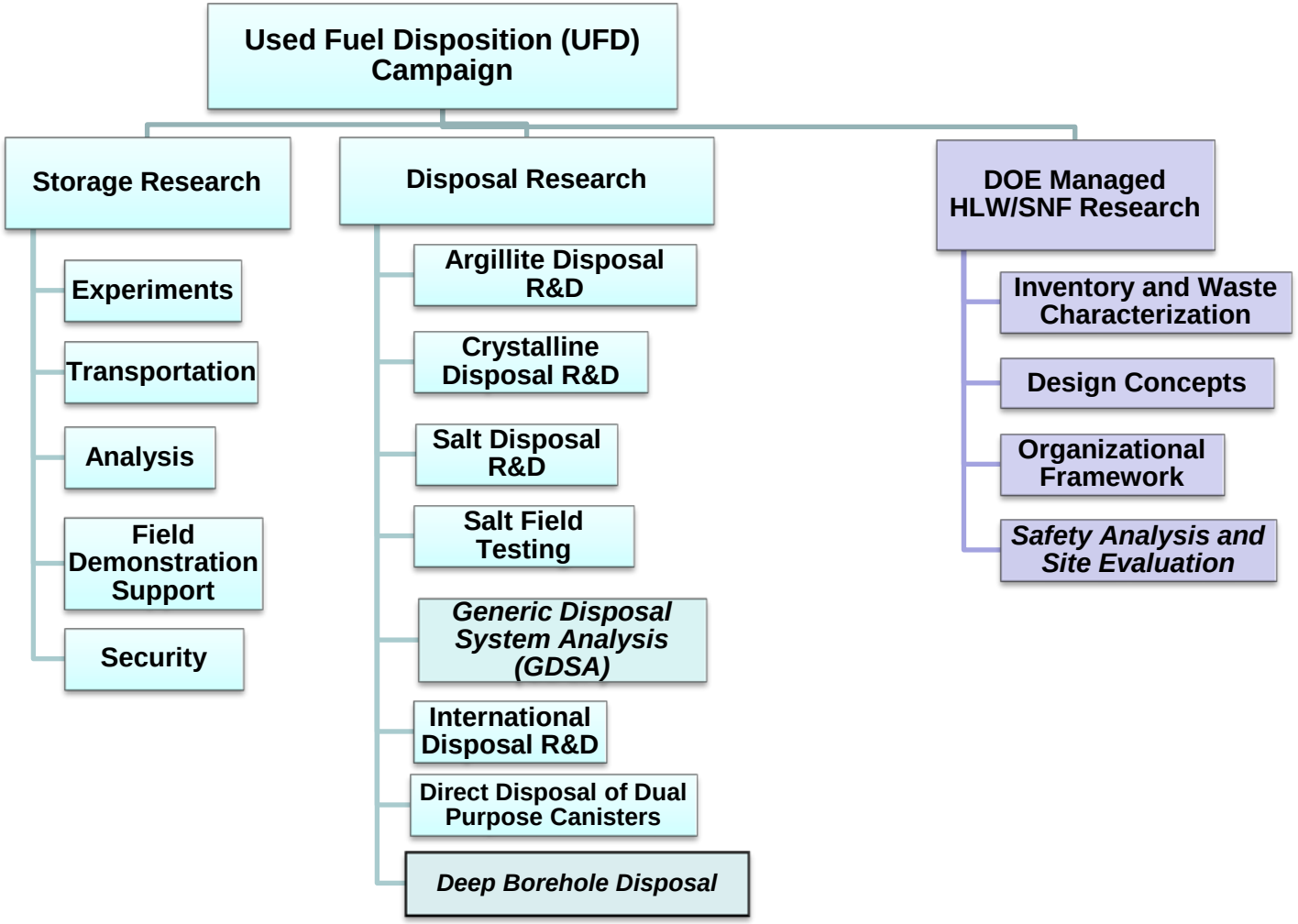


Deep Borehole Field Test
Acquisition of Site and Services

- **Request for Information solicited input and interest from States, local communities, individuals, private groups, academia, or any other stakeholders who were willing to host a DBH Field Test**
  - Posted to via Federal Business Opportunities (FedBizOps, www.fbo.gov) on October 24, 2014
  - Responses received on December 8, 2014 (45 days)
- **Sources Sought and Draft Request For Proposal (RFP)**
  - Posted on FedBizOps on April 7, 2015
  - Feedback received on May 5, 2015
- **Final RFP (Solicitation Number DE-SOL-0008071)**
  - Pre-solicitation notice posted on June 22, 2015
  - Final RFP posted on FedBizOps on July 9, 2015
  - Proposals due and received September 23, 2015
- **The DOE Awarded Contract to the team led by Battelle Memorial Institute**
  - Early January 2016
  - Local ND community opposed the DBFT being sited there
  - DOE and Battelle team are in process of finding a new site

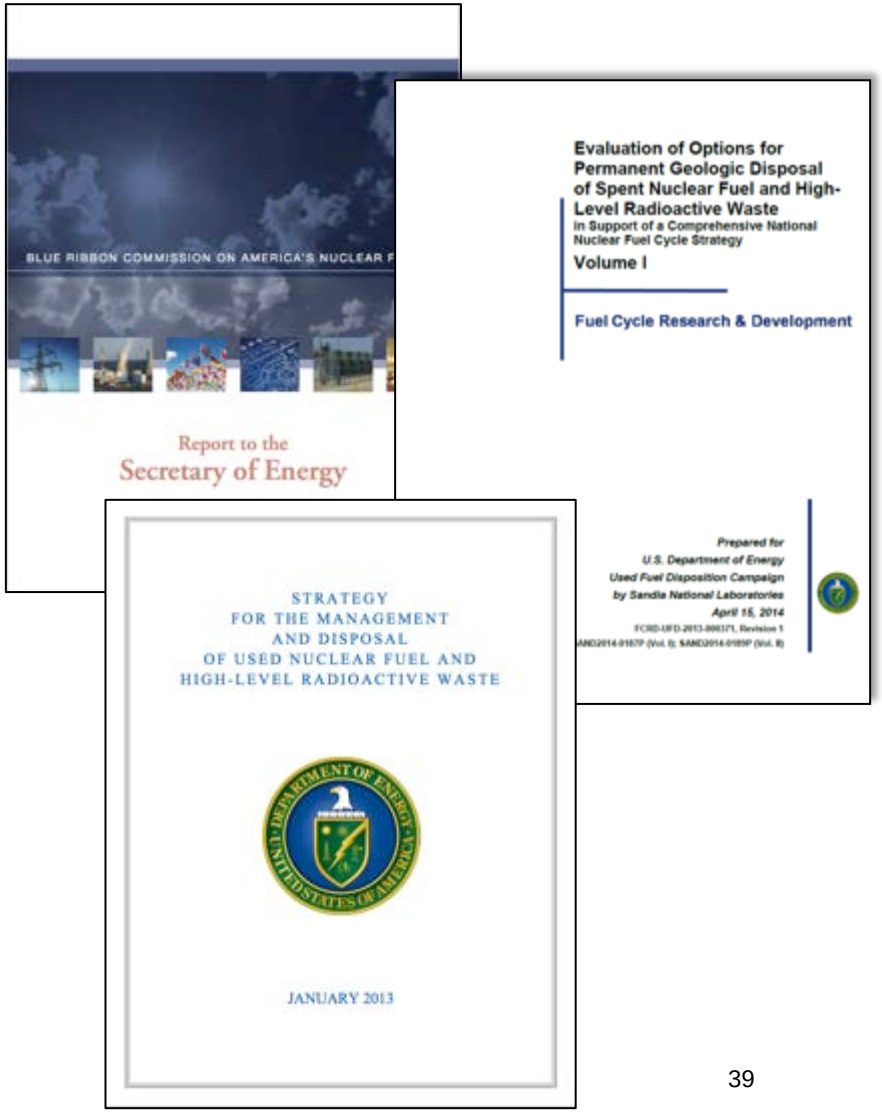
Used Fuel Disposition

DOE-Managed Spent Nuclear Fuel and High Level Waste Research Integration



Underlying Documents

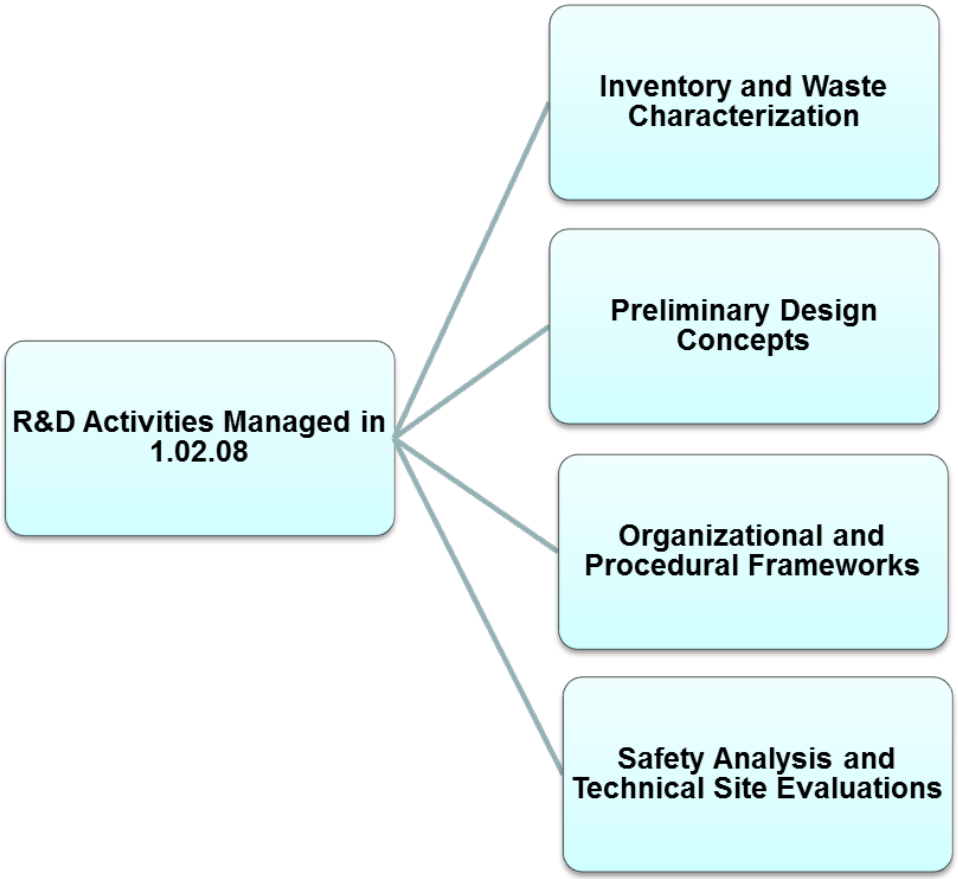
- **January 2012 Blue Ribbon Commission (BRC) on America's Nuclear Future report to the Secretary of Energy**
  - Recommends review of "single repository" policy, whereby defense-related and commercial wastes are co-mingled
- **2013 Administration releases "Strategy for the Management and Disposal of Used Nuclear and High-Level Radioactive Waste"**
  - Follows the BRC Report's recommendation to review repository policy
- **April 2014 UFD report "Evaluation of Options for Disposal…"**
  - Concludes that both commingled and separate repositories are technically feasible



Underlying Documents

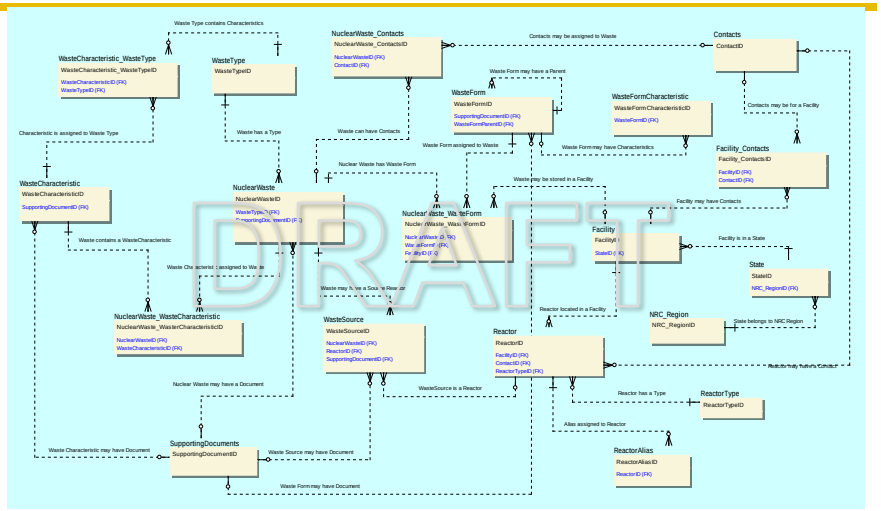
- **October 2014 DOE report "Assessment of Disposal Options…"**
  - Recommends that the DOE begin implementation of a phased, adaptive, and consent-based strategy with development of a separate repository for some DOE-managed HLW and SNF
  - Also recommends the DOE retain flexibility to consider deep borehole disposal of some smaller DOE-managed waste forms
- **March 2015 DOE report "…Separate Disposal of Defense High-Level Radioactive Waste"**
  - Presents the basis for a decision in the context of the Nuclear Waste Policy Act

Structure of Technical Work Areas



Used Fuel Disposition

Inventory and Waste Characterization: Complete & Populate Online Waste Library (OWL)

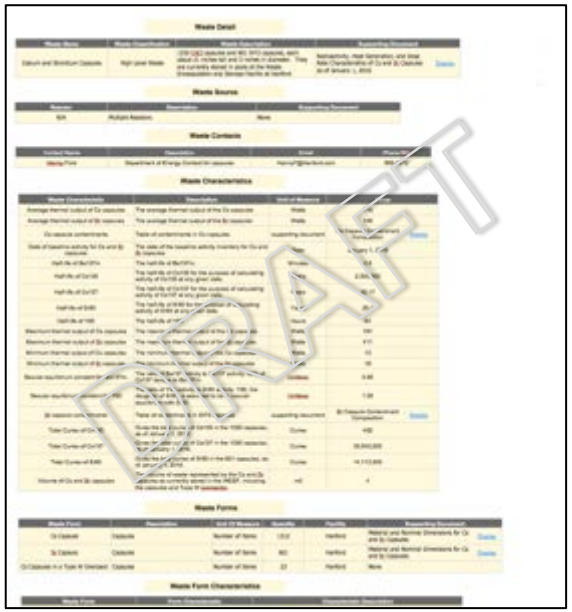


SCOPE:

The on-line waste library (OWL) will be implemented to contain detailed **cross-linked information**, both **technical** and **organizationa**l, regarding DOE-managed high-level waste (HLW) and spent nuclear fuel (SNF) (D-wastes), and other DOE-managed radioactive wastes that are likely candidates for deep geologic disposal, with **links to the current supporting documents** for the data (where possible).

OBJECTIVES:

- Finalize the initial design of the information system that implements the database
- Implement the database onto a platform with account access available to a prototype group (i.e., DOE and National Laboratory participants)
- Populate the database with at least a portion of the primary technical data for the waste types/forms.

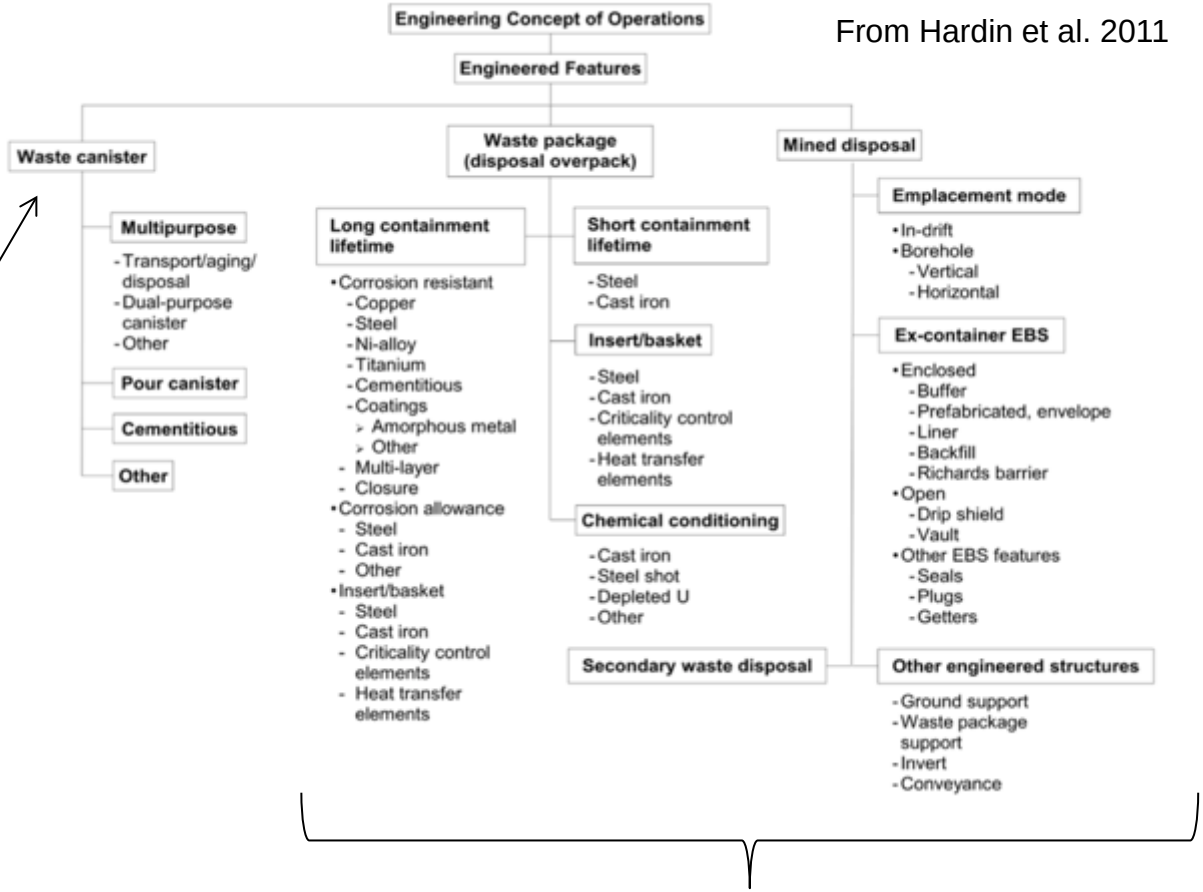


Creating a Design Concept

Inventory
- Dimensions
- Quantity
- Thermal output

Design Concepts
- Packing spacing

From Hardin et al. 2011



Used Fuel Disposition

Integration Linkages