SAND2015-9337PE

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Used Nuclear Fuel Disposition R&D Campaign Overview

Peter Swift
National Technical Director
Used Fuel Disposition R&D Campaign

2015 Fuel Cycle Technologies Annual Review Meeting
November 3-5, 2015
Idaho Falls, ID

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Outline

- **The Campaign Overview**
  - Mission
  - Long-term Objectives (10-20 years)
  - Near-term Milestones (1-3 years)
  - Organization of the Current R&D Portfolio
  - Selected accomplishments for FY15
  - Summary of activities planned for FY16
  - Conclusion
- **Introduction to the following Used Fuel Disposition R&D presentations**
  - Nick Klymyshyn, PNNL: "Modeling Used Fuel under Transportation and Storage Loads"
  - Cliff Lissenden, Penn State University: "Multi-Sensor Inspection and Robotic Systems for Dry Storage Casks"
  - Jens Birkholzer, LBNL: "International Collaboration Activities in Disposal Research"
  - David Sassani, SNL: "Deep Borehole Field Test Overview"

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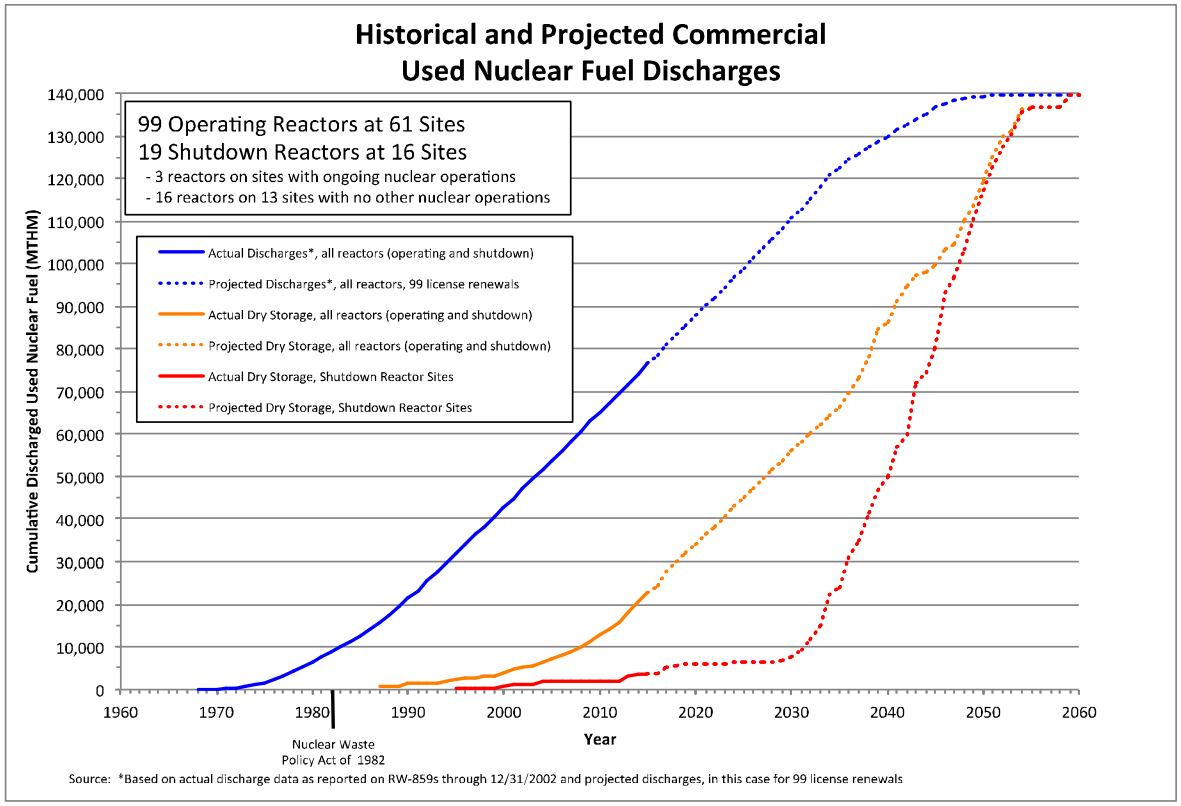
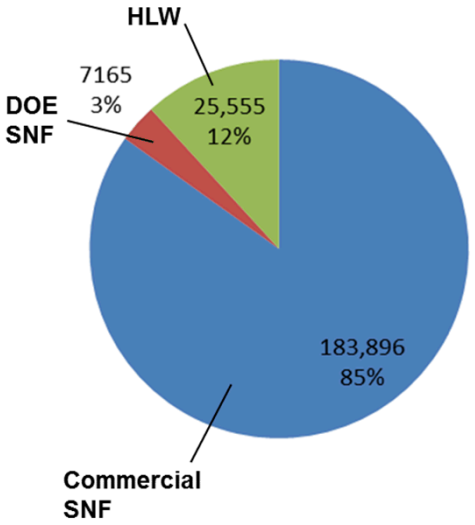
Historical and Projected Spent Nuclear Fuel (SNF) and High-Level Radioactive Waste (HLW) in the United States



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

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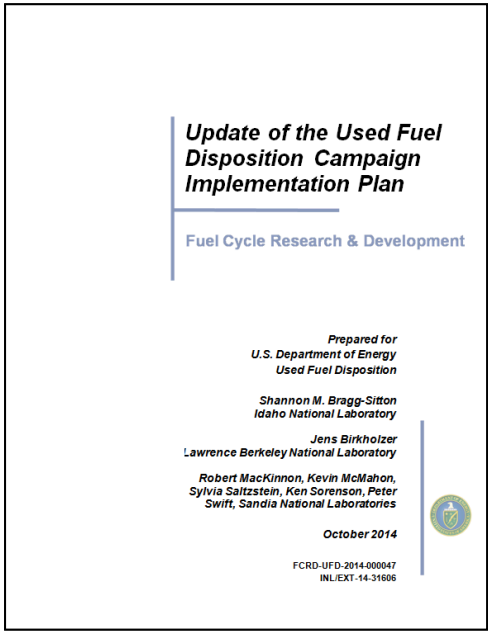
UFD Mission

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, including the identification and evaluation of safe and secure options for storage, transportation, and permanent disposal of radioactive wastes resulting from existing and future fuel cycles.



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

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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 basis for:**
  - Extended storage of used nuclear fuel
  - Fuel retrievability and transportation after extended storage
  - Transportation of high-burnup used nuclear fuel

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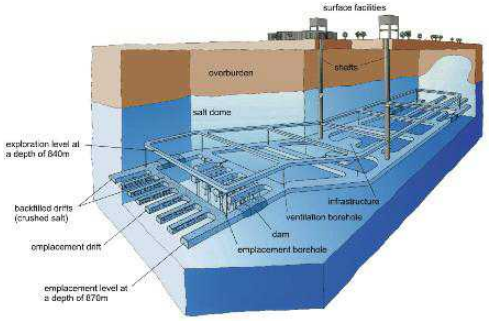
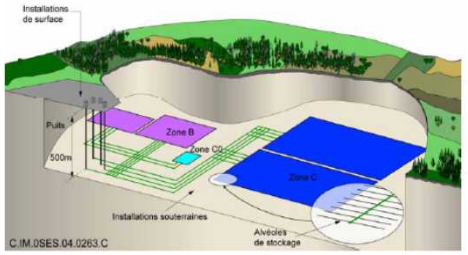
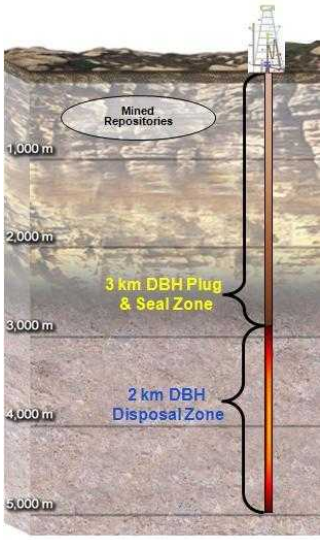
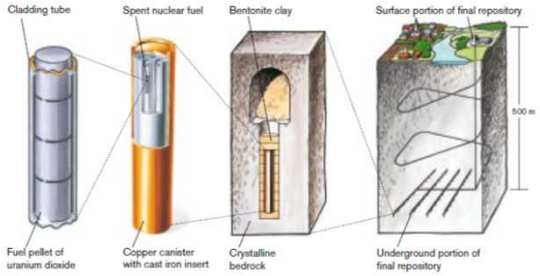
UFD Campaign Strategic Focus: Disposal R&D

- 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









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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 modeling work transitioning from MR/WF to UFD in FY14
- **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

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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)**

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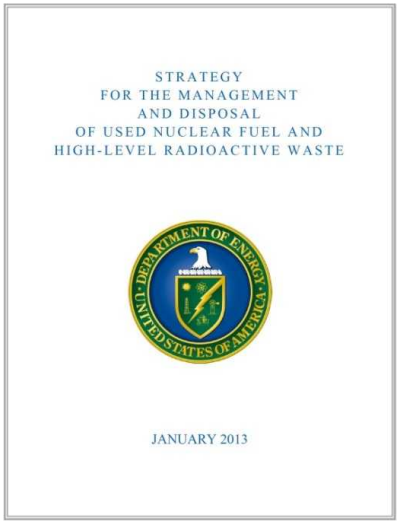
Long-Term UFD R&D Campaign Objectives

- 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*



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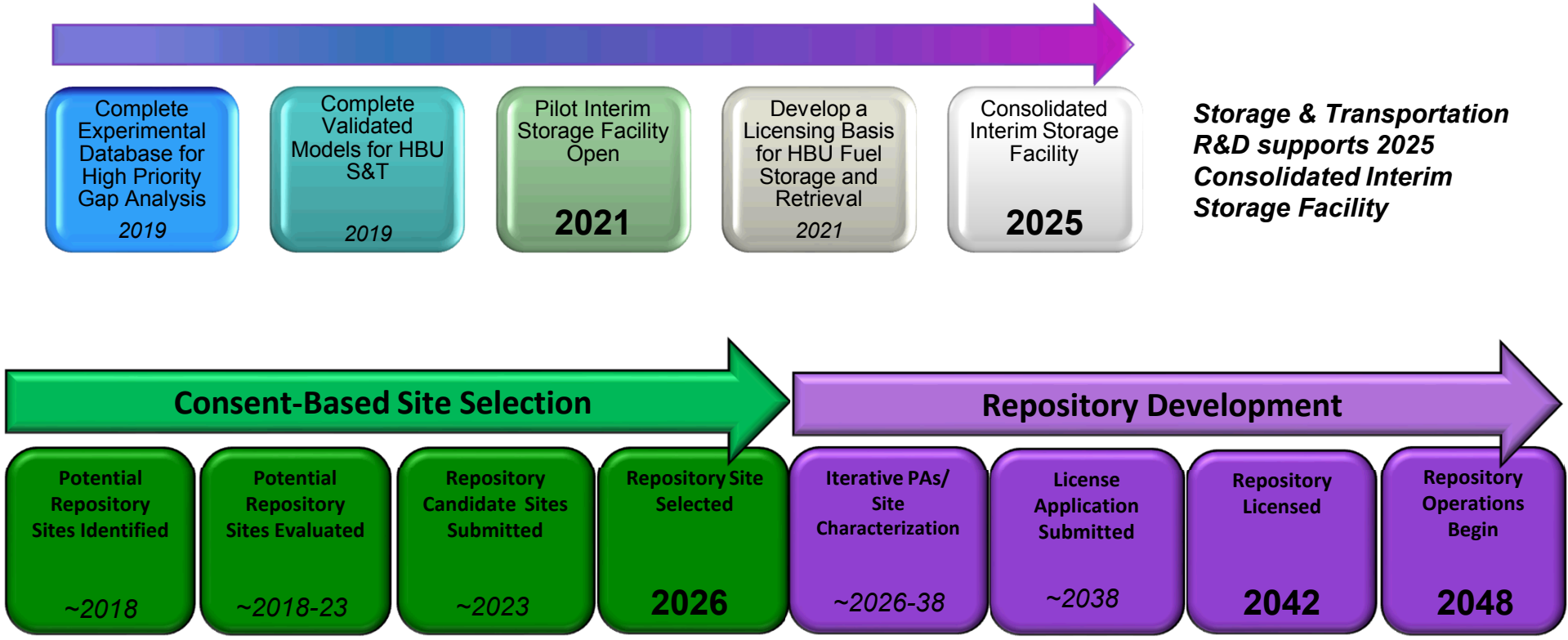
R&D Path to Support DOE Waste Management Strategy



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

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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

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FY2015 Organization of the Used Fuel Disposition Campaign R&D Portfolio

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 HLW and SNF Research

Field Demonstration Support
Experiments
Analysis
Transportation
Security

Major Activities	FY 2015 Funding
Management and Integration	$1,089,762
Storage and Transportation Research	$10,777,537
Disposal Research	$14,150,941
DOE-managed Deep Borehole Field Test	$655,000
DOE-managed Industry High-Burnup Data Project	$6,0000,000
DOE HLW and SNF Research	$455,000
Total	**$33,127,240**

UFD Storage and Transportation R&D Selected FY15 Accomplishments

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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

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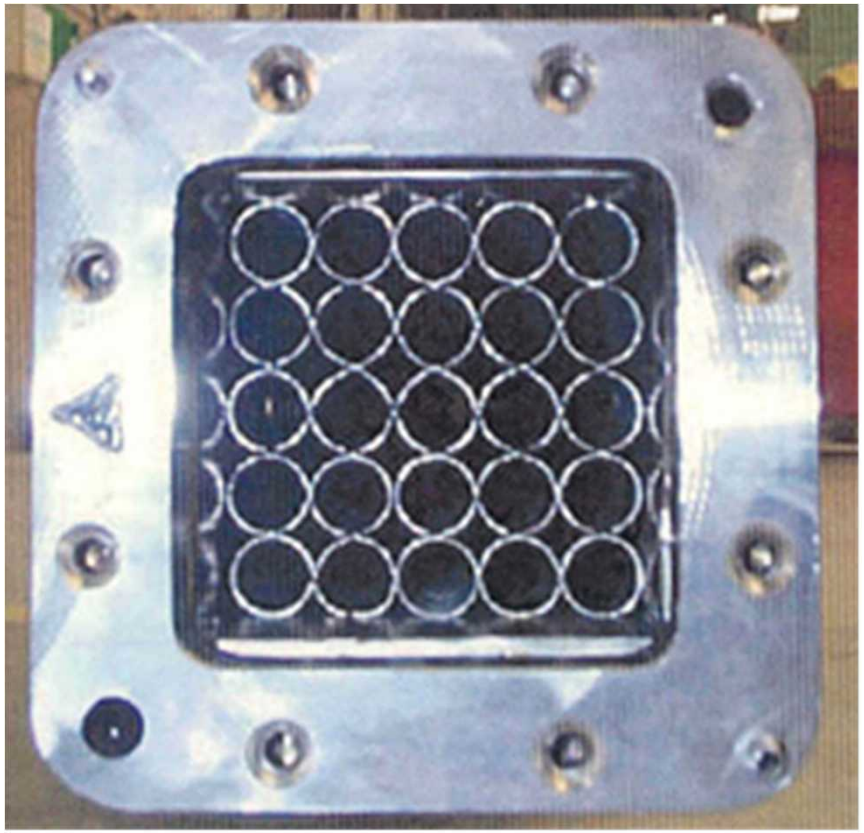
High Burnup Confirmatory Data Project - Highlights

- **Both INL and ORNL Transportation routes have been approved by NRC**
- **Areva rods pulled January 2015**
- **Westinghouse rods pulled June 2015**
  - Nine AREVA M5™ rods
  - Nine Westinghouse Zirlo™ rods
  - Four Westinghouse Low-tin Zircaloy-4 rods
  - Three Westinghouse standard Zircaloy-4 rods
- **Draft Sister Rod Test Plan has been completed and shared with others**
- **License Amendment was submitted to the NRC by Dominion in August, 2015**
- **NRC has docketed the LAR and is continuing to review the document. Draft SER is expected summer of 2016**



NAC LWT basket for shipping rods

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DOE-NEI PRIORITIES REVIEW
HIGHLIGHTS

DOE and the Nuclear Energy Institute (NEI) hold periodic meetings to discuss relative priorities associated with the DOE UFD ST R&D program and industry needs.

- **NEI partners include: EPRI, utilities**
- **DOE partners include: Lab team and NEUP**

There is good consistency relative to identified priorities in the UFD program based on our technical gaps and prioritization studies compared with industry needs.

The major priorities being addressed by both DOE industry are:

- **Closing the gaps on cladding behavior**
- **Addressing stress corrosion cracking in spent dry storage stainless steel canisters**

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NEI
NUCLEAR ENERGY INSTITUTE

January 8, 2015

Dr. John W. Herczeg
Deputy Assistant Secretary, Office of Fuel Cycle Technologies
U.S. Department of Energy
Office of Nuclear Energy
1000 Independence Ave., S.W.
Washington, DC 20585

Subject: Industry Research and Development (R&D) Priorities Specific to the Long-Term Dry Storage of Used Nuclear Fuel

Dear Dr. Herczeg:

The Nuclear Energy Institute (NEI)[1] greatly appreciates the U.S. Department of Energy's (DOE) essential research and development (R&D) role, administered through the your office's Used Nuclear Fuel Disposition (UFD) Program, in support of the long-term dry storage of used nuclear fuel. As we recently discussed, the industry is in the process of seeking dry storage license renewals that will benefit directly from these R&D activities. It is the purpose of this letter to describe the priority areas in which industry believes that the capabilities and resources of the UFD program would be of the greatest value.

Since 1986, the U.S. nuclear industry has been loading used fuel into dry cask storage systems in which the fuel can be safely stored until a repository for final disposal can be developed—with over 2,000 of these systems loaded to-date. Because the DOE's plans for removal of used nuclear fuel from reactor sites remain uncertain, reactor operators and the U.S. Nuclear Regulatory Commission (NRC) need to plan for the potential of on-site storage for several decades. As a result, the industry has placed a high priority on understanding potential aging effects on dry storage systems, as well as the fuel stored in those systems,

[1] The Nuclear Energy Institute (NEI) is the organization responsible for establishing unified industry policy on matters affecting the nuclear energy industry, including the regulatory aspects of generic operational and technical issues. NEI's members include all entities licensed to operate commercial nuclear power plants in the United States, nuclear plant designers, major architect/engineering firms, fuel cycle facilities, nuclear materials licensees, and other organizations and entities involved in the nuclear energy industry.

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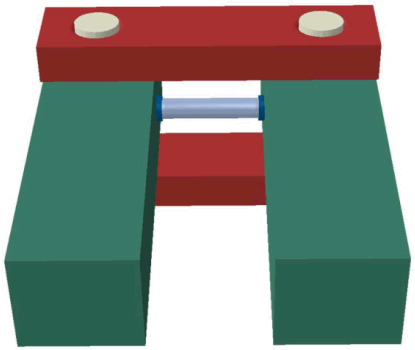
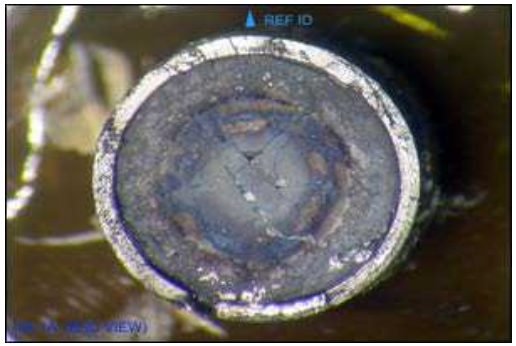
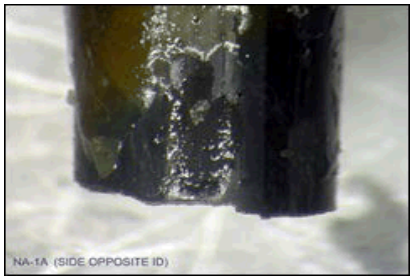
Storage and Transportation Research FY15 Highlights

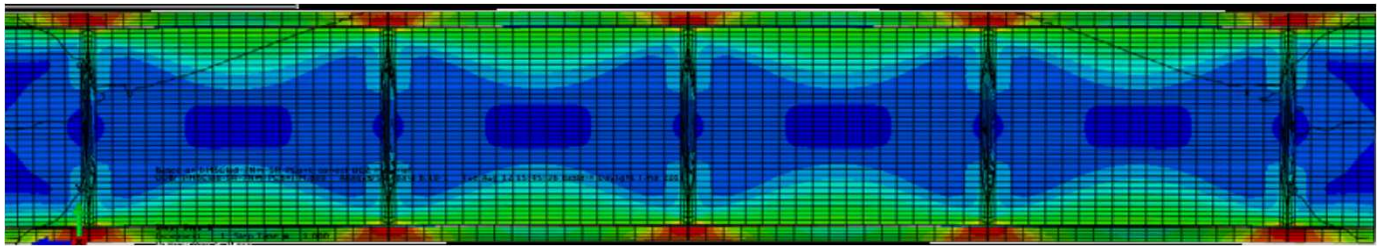
High-burnup cladding performance

- Ongoing testing and modeling (ORNL, ANL) to continue to provide information about cladding performance
- ORNL hot cell tests show importance of pellet-pellet and pellet-clad bonding, allowing rods to withstand greater bending fatigue than anticipated









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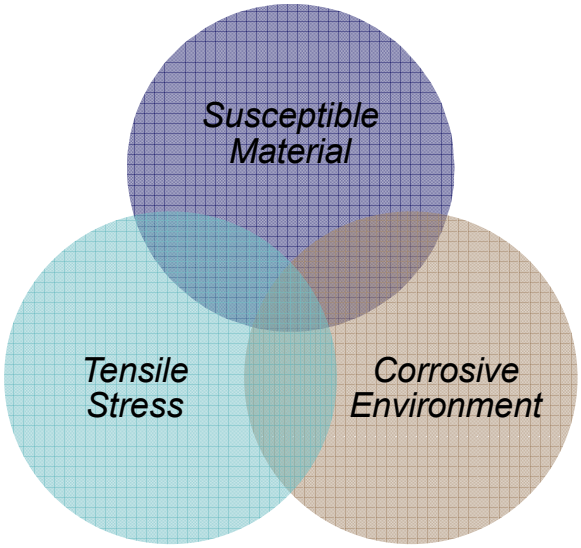
Storage and Transportation Research FY15 Highlights (cont.)

Stress Corrosion Cracking of Stainless Steel Storage Canisters

Questions to be answered:

1. Will a chloride bearing environment form on the surface of the containers?
2. Is the material of construction for fielded interim storage containers susceptible?
3. Is there a sufficiently large tensile stress to support crack initiation and propagation in fielded interim storage containers?



Preliminary Observations:

Be prepared to inspect the canister surfaces

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Storage and Transportation FY15 Highlights (cont.)

Is there a Corrosive Environment for Stress Corrosion Cracking?

Dust sampling at Calvert Cliffs, Hope Creek, and Diablo Canyon

Typical Calvert Cliffs Analytical Results

Ion	EPRI #1 filter	EPRI #1 pad	EPRI #4 filter	EPRI #4 pad
Na^{+}	19.2	14.8	n.d.	11.3
K^{+}	18.1	13.7	1.05	7.75
Ca^{+2}	77.1	20.6	24.1	153
Mg^{+2}	16.9	6.0	1.95	17.6
F^{-}	0.30	0.61	n.d.	n.d.
Cl^{-}	5.64	n.d.	n.d.	3.10
NO_3^{-}	21.3	9.09	4.34	14.2
SO_4^{-2}	89.7	51.5	48.0	291
PO_4^{-3}	6.68	2.05	0.45	n.d.
Total mass, µg	255	118	80	498

Data: Chloride bearing salts are likely in some locations

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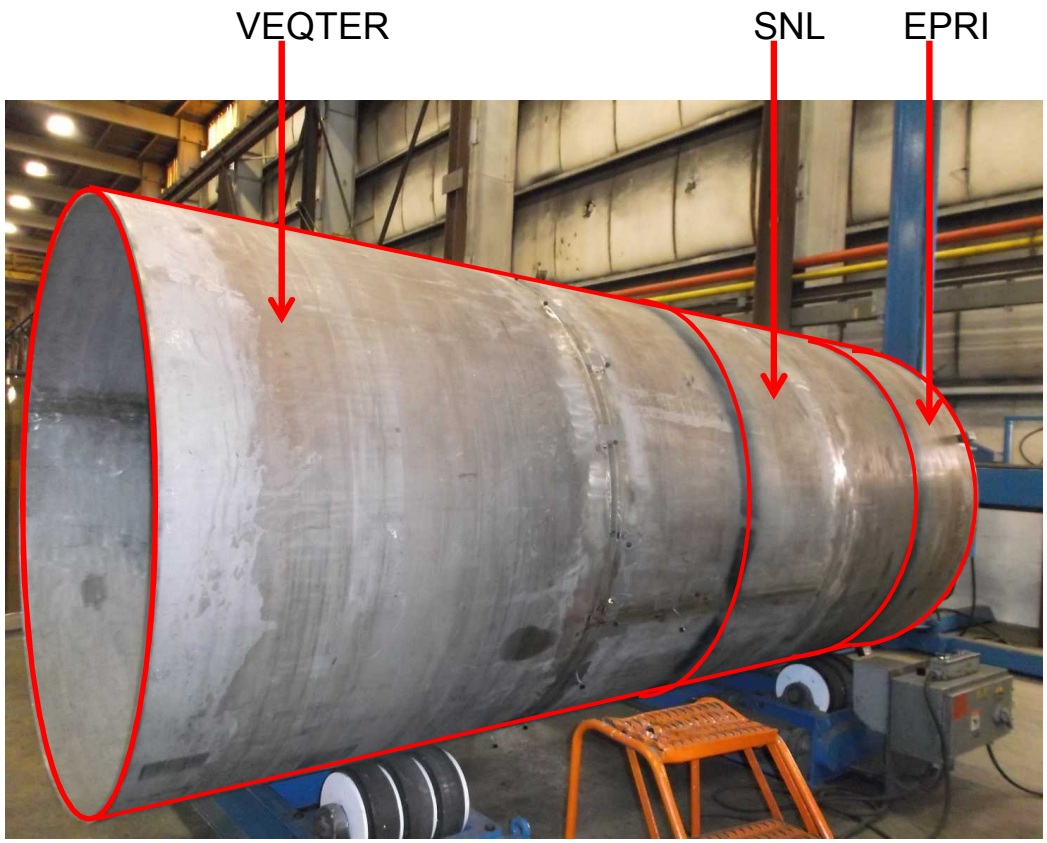
Storage and Transportation Research FY15 Highlights (cont.)

Are there Tensile Stress Conditions for Stress Corrosion Cracking?

Full-diameter canister mockup undergoing testing at VEQTER in the UK



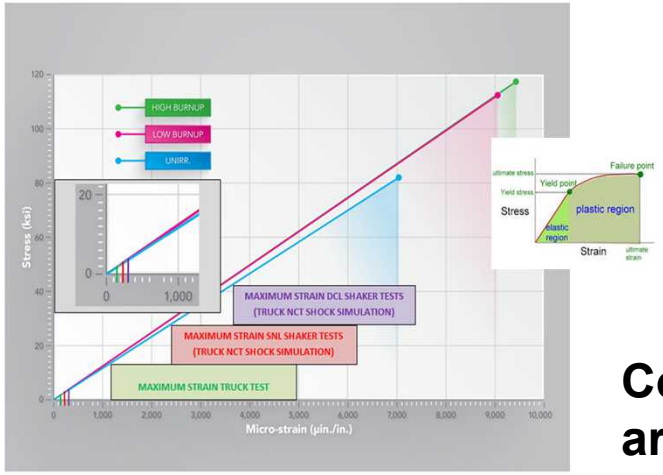
FY16 work will quantify residual stress at welds, weld repairs, heat affected zones, and away from welds.

Storage and Transportation FY15 Highlights (cont.)

Loading on Fuel Assemblies During Normal Conditions of Transport

Three series of tests using a surrogate PWR assembly

- Tests on a vertical acceleration shaker table at SNL
- Over-the-road truck test
- Tests on a commercial seismic shaker with six degrees of motion



Conclusions: strains during normal transport are far below yield and failure limits for cladding

UFD Disposal R&D
Selected FY15 Accomplishments

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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.

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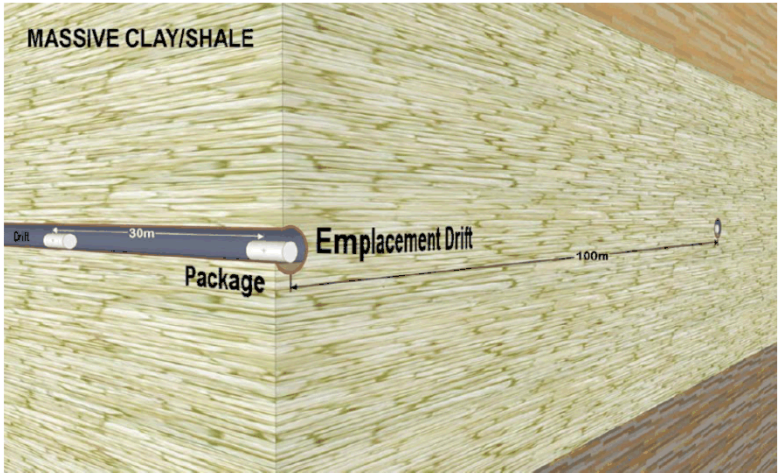
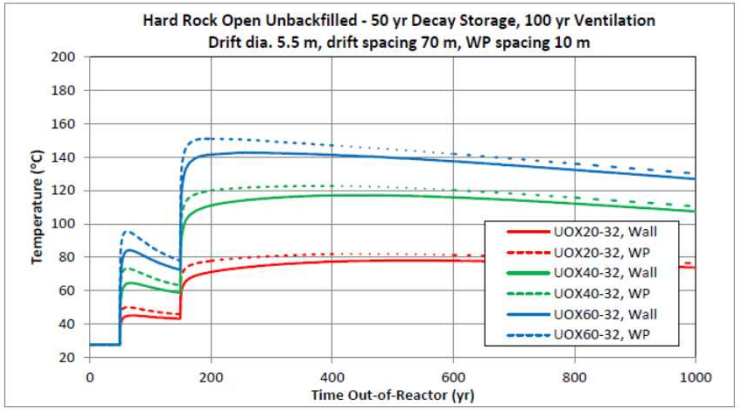
Disposal Research FY15 Highlights

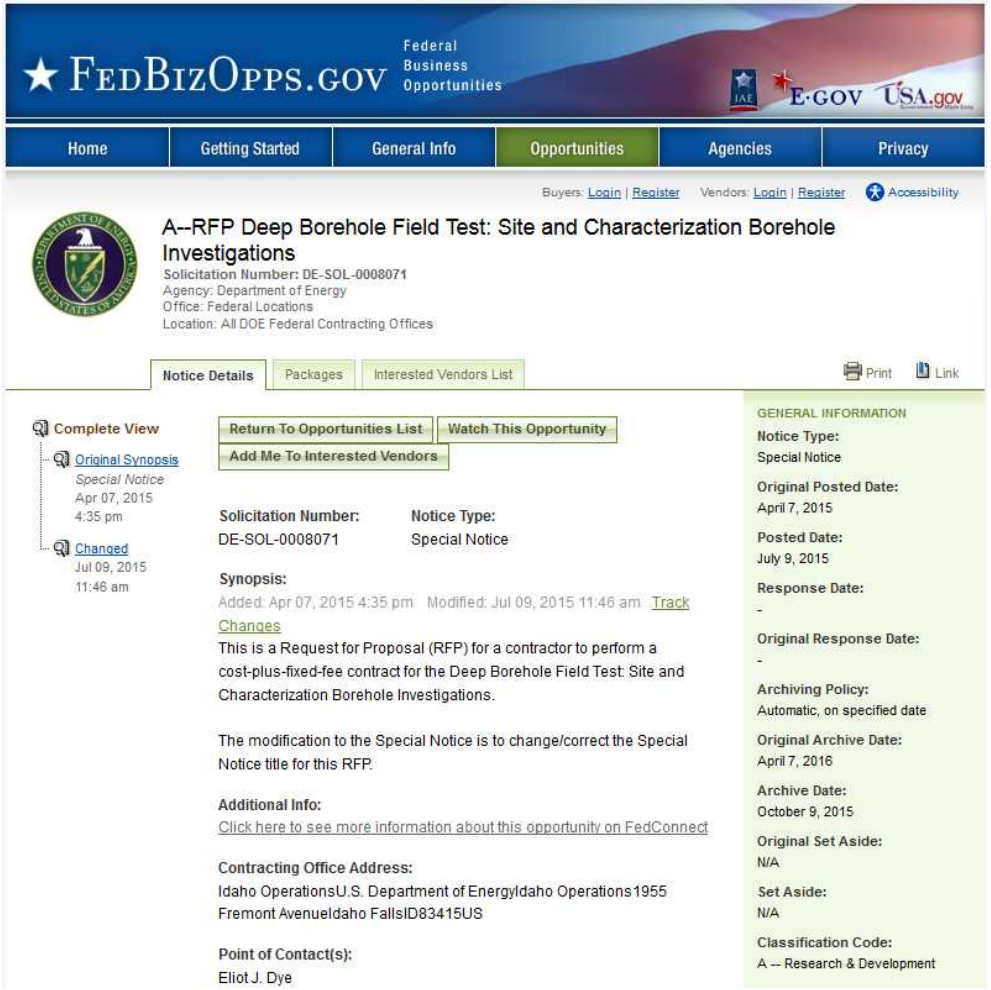
- **Evaluating Technical Feasibility of Direct Disposal of Dual Purpose Canisters (DPCs)**
  - Considerations
    - Operational challenges (size and mass)
    - Thermal management
    - Post-closure criticality control
- **Conclusions:**
  - Direct geologic disposal of some DPCs is feasible in some disposal 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 Plans

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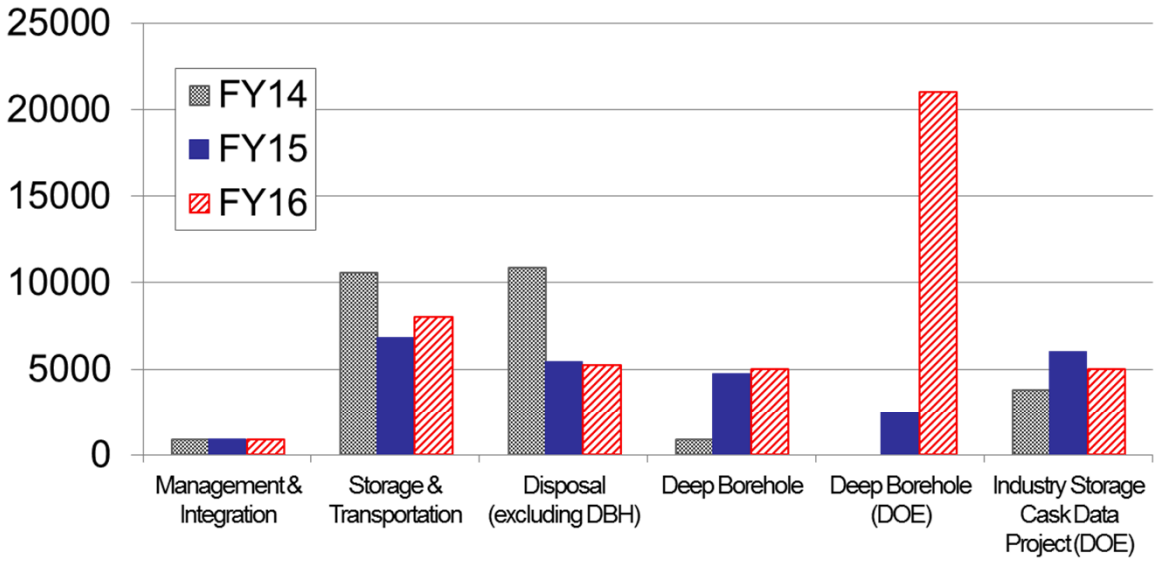
Implementing UFD R&D Priorities from FY14 to FY16

Overall planning basis for campaign funding increases from $26.4M in FY15 to $45.4M in FY16

Funding at National Laboratories increases from $17.9M to $19.2M



FY14*	900	10557	10845	860	0	3800
FY15*	900	6815	5455	4755	2500	6000
FY16**	900	8000	5225	5000	21000	5000

Does not include $3M for DOE HLW and SNF Research

* *Based on FY actuals, PICSNE targets not including carryover*
** *Based on FY16 US Senate Mark (7/13/15)*
*** *Does not include 275k in FY15 or 225k in FY16 held back by DOE NE to fund membership fees associated with international collaboration memberships.*

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Proposed FY16 UFD R&D Campaign Control Account Structure

Focus Area	Control Accounts	Proposed FY16 Funding
Campaign Management and Integration (CX)	Management and Integration	900k
Storage and Transportation Research (ST)		8000k
	Experiments	3500k
	Transportation	900k
	Analysis	1350k
	Field Demonstration Support	2100k
	Security	150k
Disposal Research (DR)		10275k
	Argillite Disposal R&D	1400k
	Crystalline Rock Disposal R&D	1400k
	Salt Disposal R&D	1250k
	Generic Disposal System Analysis	600k
	International Research Coordination	375k
	Dual Purpose Canister Disposal R&D	250k
	Deep Borehole Field Test	5000k
DOE-Managed HLW and SNF Research		3000k
	Inventory and Waste Characterization	450k
	Preliminary Design Concepts	430k
	Organizational and Procedural Frameworks	880k
	Safety Analysis and Technical Site Evaluation	1240k

Proposed Campaign Total for FY16 $22.2M

17 Control Accounts

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Selected UFD R&D 2016 Milestones

- Selected 2016 Milestones: Storage and Transportation
  - *Canister Mockup Weld Residual Stress Final Report (SNL, 8/15/2016)*
  - *High Heat Load Thermal Analysis (PNNL, 9/ 28/2016)*
  - *Sister Pin Test Plan (PNNL, 4/30/2016)*
  - *Stress Corrosion Cracking Investigations on Full Scale Stainless Steel Canister Mock-up (SNL, 8/21/2015)*
- Selected 2016 Milestones: Disposal
  - *Evaluation of Used Nuclear Fuel Disposition in Clay-bearing Rocks (SNL, 9/16/2016)*
  - *Evaluation of Used Nuclear Fuel Disposition in Crystalline Rocks (SNL, 9/21/2016)*
  - *Generic Disposal System Model Development and Reference Case Applications (SNL, 9/22/2016)*
  - *International Collaboration Activities in Different Geologic Disposal Environments (LBNL, 9/27/2016)*
  - *Deep Borehole Field Test Conceptual Design Report (SNL, 8/15/2016)*
  - *Strategy for Downhole and Laboratory Testing (SNL, 9/01/2016)*
- Selected 2016 Milestones: DOE 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, 04/29/2016)*
  - *Generic Organizational and Procedural Framework for DOE Managed HLW and SNF Licensing (SNL, 9/16/2016)*

21 proposed Level 2 Milestones for UFD R&D Campaign in FY16

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Used Fuel Disposition R&D Concluding Remarks and Issues

- **Will the current R&D Portfolio achieve near-term objectives?**
  - For Storage and Transportation R&D: Yes
    - Storage demonstration project is still in very early stages
    - Uncertainty remains about where sister rods will be shipped and tested
  - For Disposal R&D: yes, but only for generic concepts
    - Significant accomplishments are within reach in disposal R&D
      - E.g., increased confidence in engineered barrier designs and robust natural system performance, improved system-level modeling framework
    - Field demonstration of deep borehole disposal is achievable
- **Will the current R&D Portfolio achieve the long-term strategic goals?**
  - For Storage and Transportation R&D: uncertain
    - Commitment to storage demonstration and RD&D must be sustained for many years
  - For Disposal R&D: yes, but only with resolution of national policy issues
    - R&D is needed, but is not sufficient to address disposal issues

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