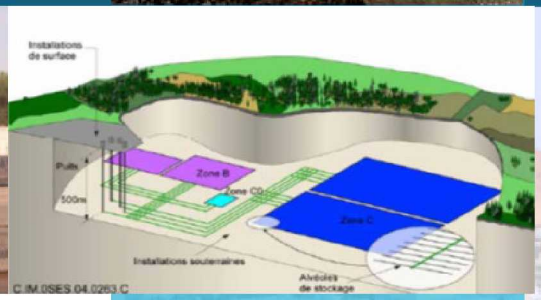
SAND2019-11235PE

Sandia National Laboratories

Status of Back End of the Nuclear Fuel Cycle in the United States of America: Current R&D Program



PRESENTED BY

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Korea International Nuclear Graduate School

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U.S. DEPARTMENT OF ENERGY NNSA

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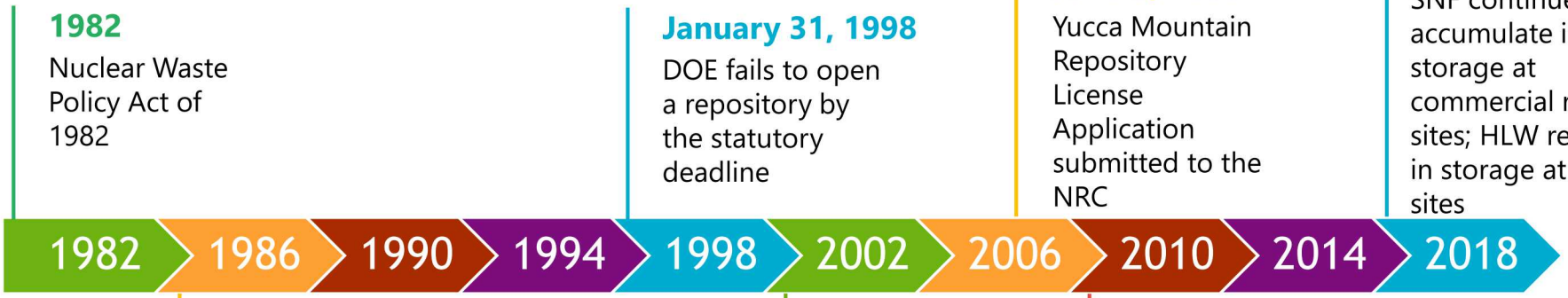
Outline

Status of Current System
- Timeline of US Repository Program
- Actions over the last decade
- Accumulation of SNF Inventory
- Future Options

Current R&D Program and Priorities
- Storage & Transportation
- Disposal

Concluding Remarks

Timeline of the U.S. Repository Program



1982
Nuclear Waste Policy Act of 1982

1987
Nuclear Waste Policy Amendments Act selects Yucca Mountain as sole site for further characterization

January 31, 1998
DOE fails to open a repository by the statutory deadline

February 2002
Yucca Mountain Site Recommendation Site is designated by DOE and President G.W. Bush as suitable for repository development and licensing

June 3, 2008
Yucca Mountain Repository License Application submitted to the NRC

2010
Obama Administration decides Yucca Mountain is not workable; Project suspended

Spent nuclear fuel continues to be generated at ~2,200 MTHM/yr.

Present Day
Repository program remains suspended, but law is unchanged

SNF continues to accumulate in dry storage at commercial reactor sites; HLW remains in storage at DOE sites

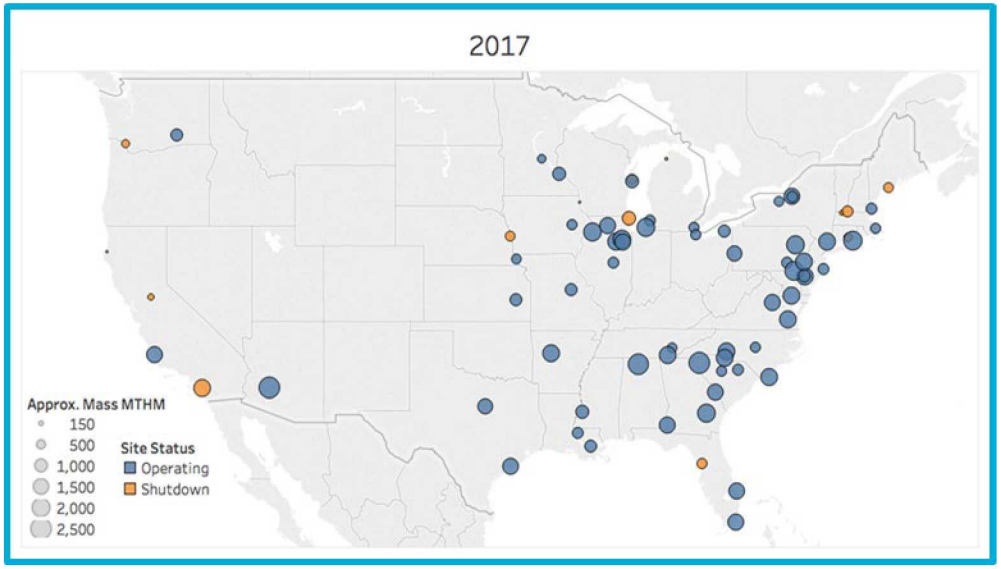
Current Status of the US Program

2008	Yucca Mountain Repository License Application submitted
2009	Department of Energy (DOE) determines Yucca Mountain to be unworkable
2010	Last year of funding for Yucca Mountain project
2012	Blue Ribbon Commission on America's Nuclear Future completes its recommendations, including a call for a consent-based process to identify alternative storage and disposal sites
2013	Federal Court of Appeals orders Nuclear Regulatory Commission (NRC) to complete its staff review of the Yucca Mountain application with remaining funds
2015	NRC staff completes Yucca Mountain review, finds that "the DOE has demonstrated compliance with the NRC regulatory requirements" for both preclosure and postclosure safety
2015	DOE begins consideration of a separate repository for defense high-level wastes and initiates first phase of public interactions planning for a consent-based siting process for both storage and disposal facilities. (Both activities terminated 2017.)
2016-18	Private sector applications to the NRC for consolidated interim storage (Waste Control Specialists [now Interim Storage Partners] in Andrews, TX and Holtec in Eddy/Lea Counties, NM)
2019	Yucca Mountain licensing process remains suspended, and approximately 300 technical contentions remain to be heard before a licensing board can reach a decision

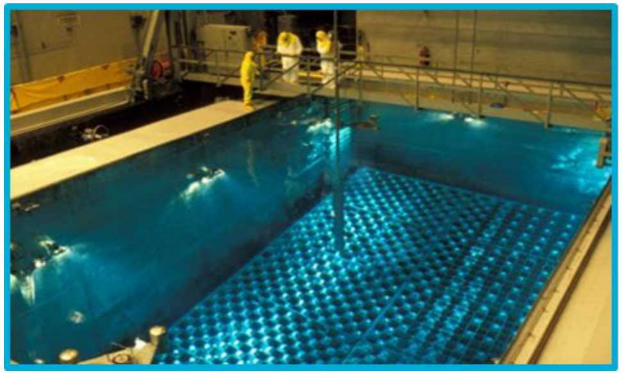
SNF Management in the US: The Reality

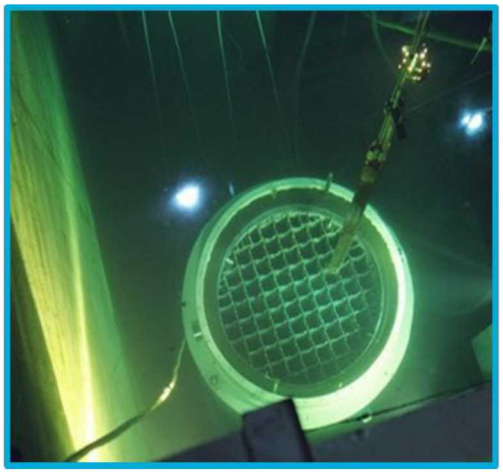
Commercial SNF is in Temporary Storage at 75 Reactor Sites in 33 States

- Pool storage provides cooling and shielding of radiation
  - Primary risks for spent fuel pools are associated with loss of the cooling and shielding water
- US pools have reached capacity limits and utilities have implemented dry storage
- Some facilities have shutdown and all that remains is "stranded" fuel at an independent spent fuel storage installation (ISFSI)



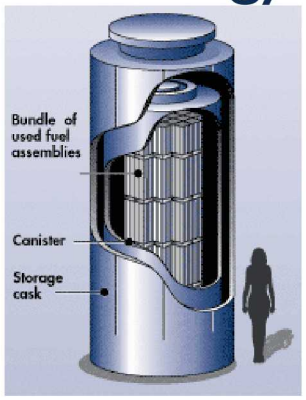
Map of the US commercial SNF storage from Bonano et al. 2018

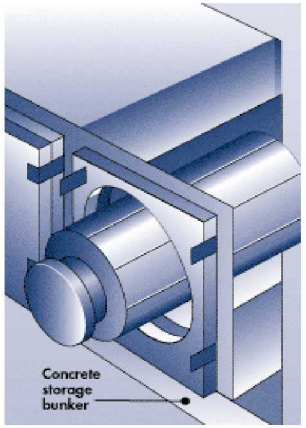




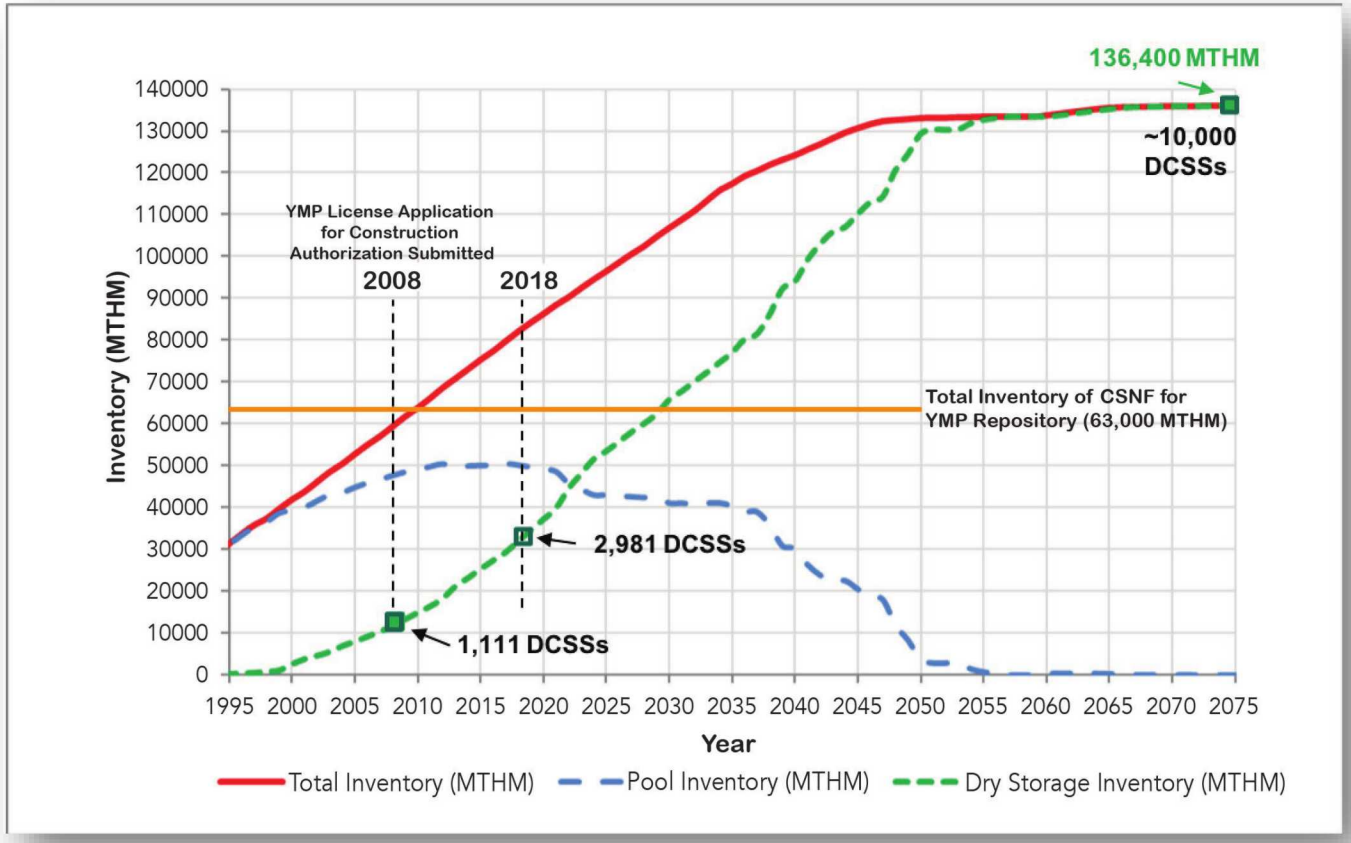
Dry Cask Storage System Terminology

- Dry Cask Storage Systems (DCSSs) include:
  - Dry cask/canister storage systems using dual purpose canisters (DPCs) that are certified for both storage and transportation (right-hand photographs)
  - The welded stainless steel DPC is placed in a concrete and steel overpack (vertical cask or horizontal bunker) for shielding and protection during storage. The DPC is removed from the storage overpack and placed in a shielded transportation cask for transport.
  - Vertical DPC designs can be above or below grade.
  - Horizontal systems are also in use.
- "Bare fuel" casks with bolted lids, integral shielding and no overpack, available in cast iron and forged steel designs (bottom left photograph). Few sites in the U.S. continue to load these systems.
- Multiple vendors provide NRC-certified dry storage systems to utilities. About 30 basic DPC designs.





US Projections of Commercial SNF Inventory



Projection assumes full license renewals and no new reactor construction or disposal (updated from Bonano et al., 2018)

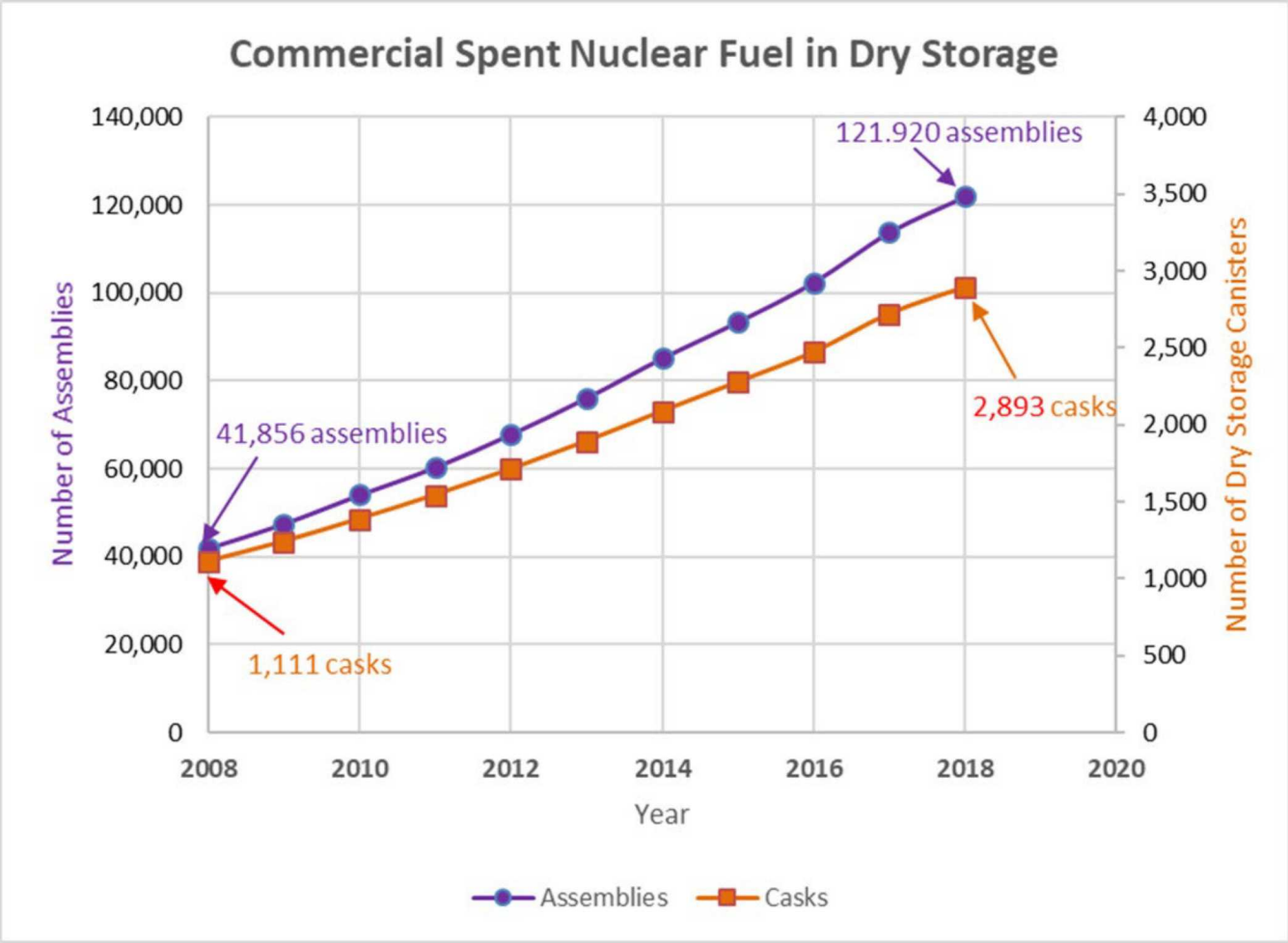
Approx. 80,000 MTHM (metric tons heavy metal) of commercial SNF in storage in the US as of Dec. 2017

Approx. 30,000 MTHM in dry storage at reactor sites, in approximately 2,900 cask/canister systems

- Balance in pools, mainly at reactors

Approx. 2200 MTHM of SNF generated nationwide each year

SNF Inventory in Dry Storage



- Approximately 160 new dry storage canisters are loaded each year in the US
- By mid-century ~10,000 DPCs are expected to be in service.

Observations on Current Practice

- Current practice is safe and secure
  - Extending current practice raises data needs; e.g., canister integrity, fuel integrity, aging management practices
- Current practice is optimized for reactor site operations
  - Occupational dose
  - Operational efficiency of the reactor
  - Cost-effective on-site safety
- Current practice is not optimized for transportation or disposal
  - Thermal load, package size, and package design

Placing spent fuel in dry storage in dual purpose canisters (DPCs) commits the US to some combination of three options

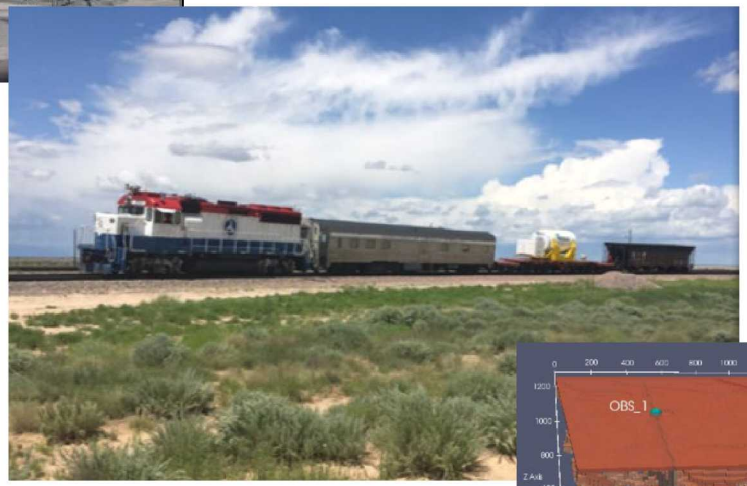
1) Repackaging spent fuel in the future

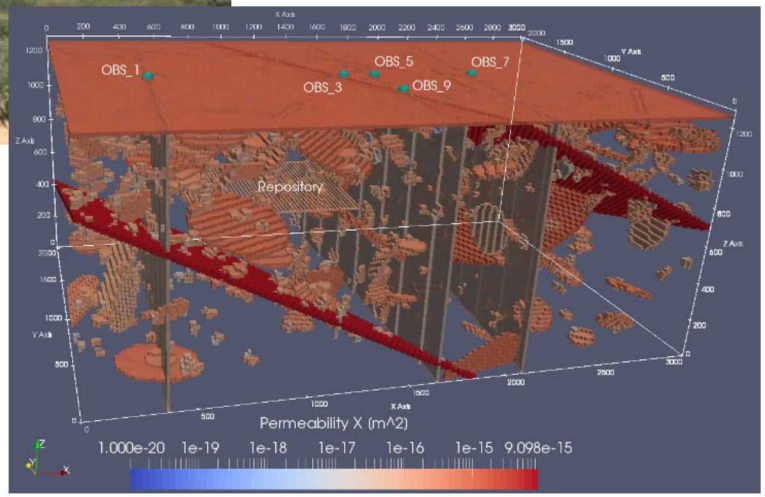
2) Constructing one or more repositories that can accommodate DPCs

3) Storing spent fuel at surface facilities indefinitely, repackaging as needed

Each option is technically feasible, but none is what was originally planned

U.S. Department of Energy Office of Nuclear Energy
Spent Fuel & Waste Science & Technology R&D Campaign





Spent Fuel and Waste Science and Technology Campaign

- Managed by the NE Office of Spent Fuel and Waste Science and Technology (SFWST)
- Formerly referred to as the "Used Fuel Disposition" Campaign
- Nine national laboratories support the campaign

Argonne NATIONAL LABORATORY

BERKELEY LAB

INL Idaho National Laboratory

Science in the National Interest
Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

ornl OAK RIDGE NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

Sandia National Laboratories

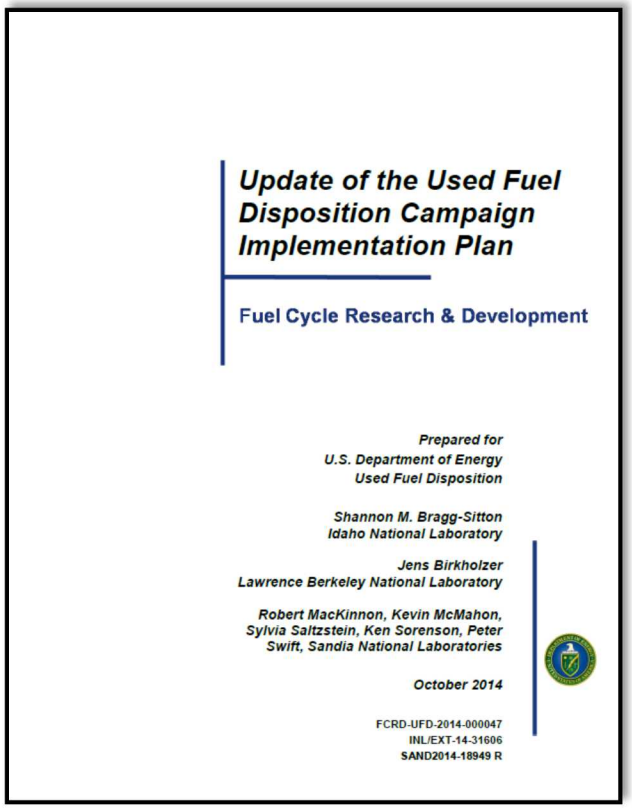
SRNL SAVANNAH RIVER NATIONAL LABORATORY

SFWST R&D Mission

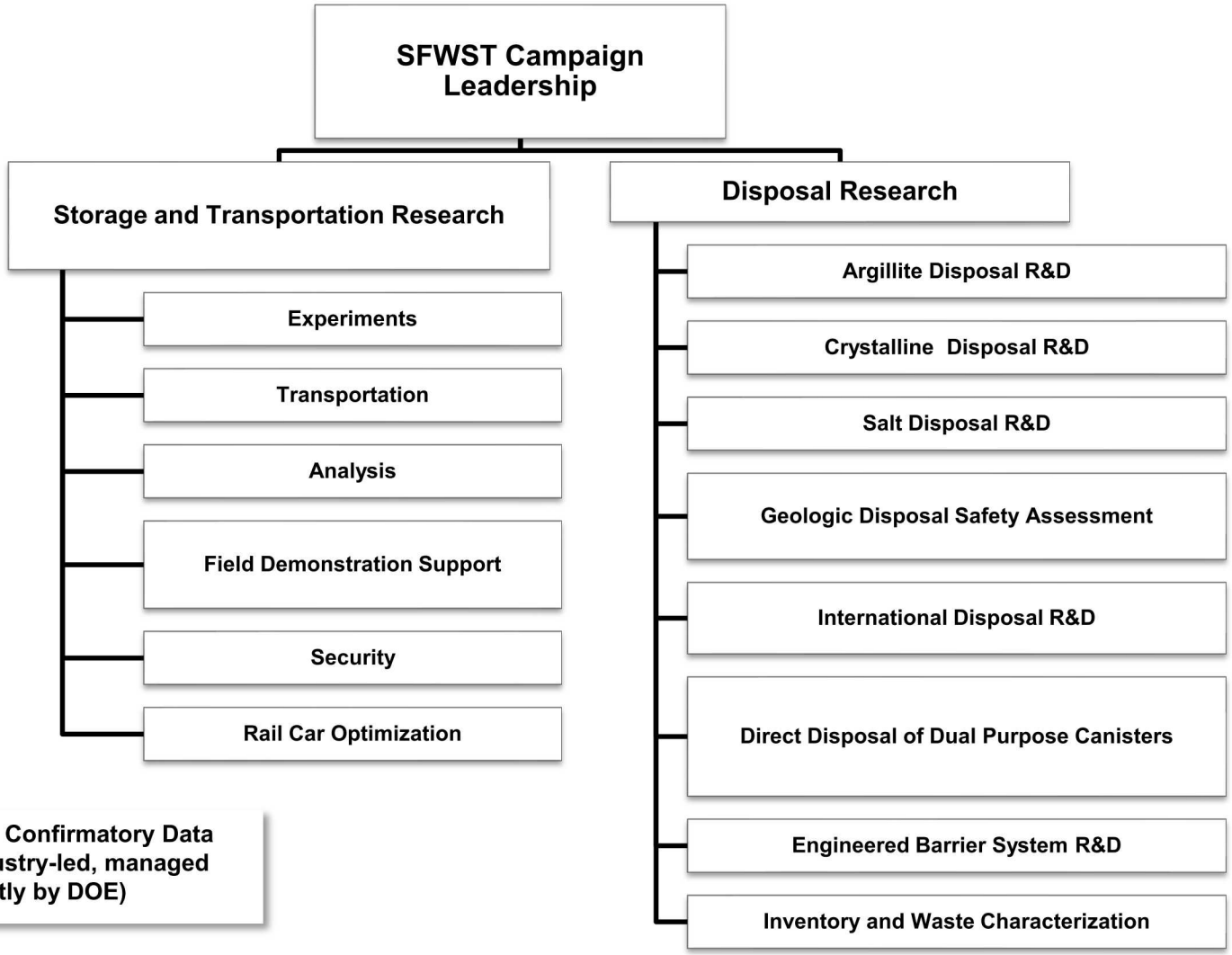
The mission of the Spent Fuel and Waste Science and Technology Disposition Campaign is to identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles.

Update of the Used Fuel Disposition Campaign Implementation Plan

FCRD-UFD-2014-000047, October 2014



SFWST R&D Campaign Structure



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

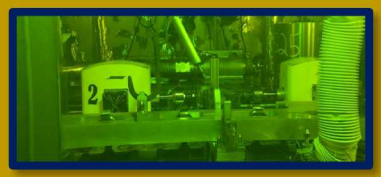
Campaign Strategic Focus: Storage and Transportation R&D

Prepare for extended storage and eventual large-scale transport of spent nuclear fuel and high-level waste

- Support the technical basis for evaluating:
  - Extended storage of spent nuclear fuel
  - Fuel retrievability and transportation after extended storage
  - Transportation of high-burnup spent nuclear fuel

S&T R&D is Driven by the 2017 Internal Gap Analysis & NEI R&D Priorities and Is Enhanced by the Demo Data

We have fuel in hot cells.

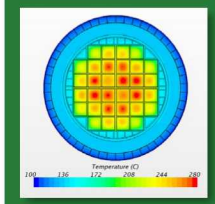


We completed non-destructive tests.

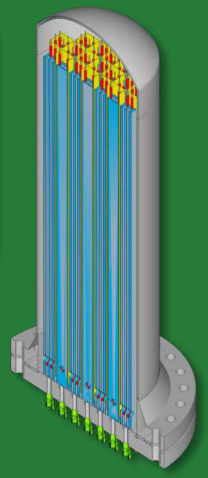
We are starting destructive analysis.

SISTER ROD MECHANICAL TESTING DATA

We have thermal models.



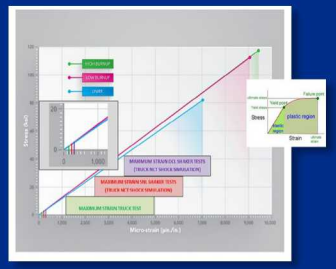
We are getting new thermal data from the Demo.



We will build a test apparatus to identify thermal conservatisms & develop more realistic assumptions.

THERMAL BEHAVIOR

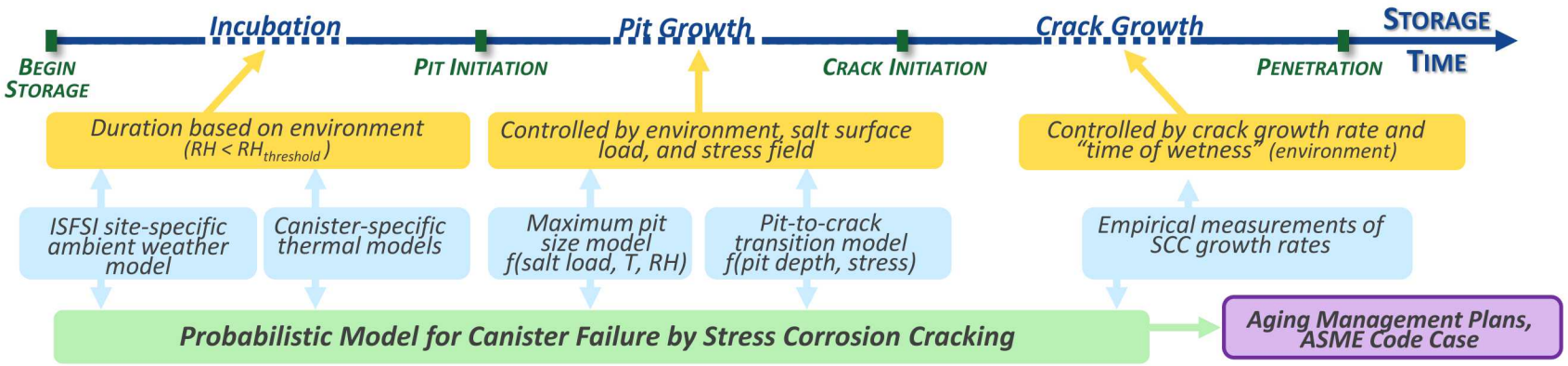
PROVIDES KNOWLEDGE ABOUT SPENT FUEL INTEGRITY WHICH IS COMPARED TO DATA FROM THE TRANSPORTATION TESTS



SPENT FUEL TRIATHLON:
QUANTIFICATION OF NORMAL TRANSPORT SHOCKS & VIBRATIONS

Stress Corrosion Cracking R&D

Evaluate Time Dry Storage Canisters Can Be Safely Stored as a Function of ISFSI Location



CURRENT AND FUTURE WORK IN EACH OF THE ABOVE AREAS

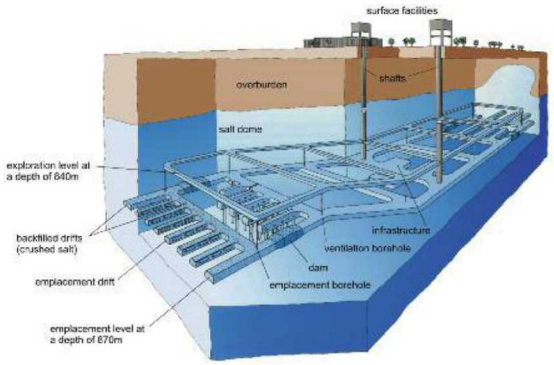
- *SNL — Surface environment, brine stability*
- *SNL/Ohio State Univ. — Pitting initiation/growth, pit-to-crack transition*
- *CO School of Mines (CSM)/SNL — Pitting initiation/growth (effect of stress)*
- *SNL/LANL — mockup pitting/cracking*
- *CSM — Pit-to-crack transition (modeling)*
- *NC State U (SNL) — SCC growth rates*
- *Ohio State Univ. (SNL) — SCC growth rates*
- *SRNL — SCC growth rates*

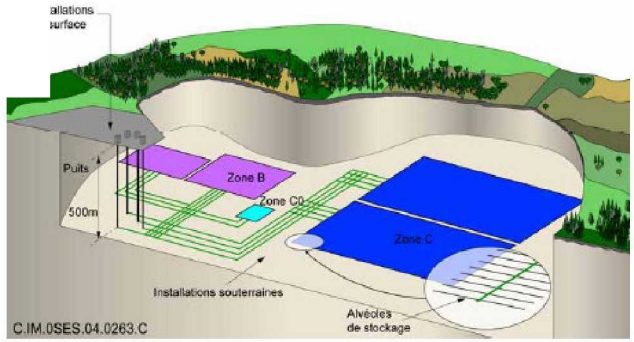
Major Activities in the Last Year Storage and Transportation R&D

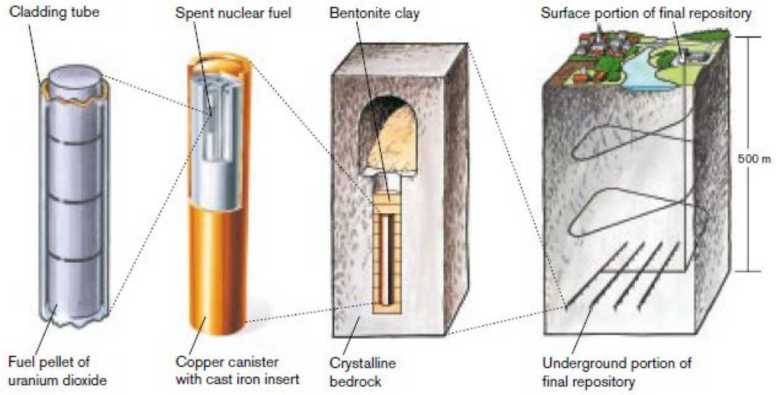
- High burnup fuel testing to support storage demonstration project
  - Non-destructive testing is complete
  - ORNL and PNNL are starting destructive testing
  - ANL has received samples and will test soon
- Corrosion
  - Improved understanding of salt deposition and decomposition rates, incubation times, pitting progression, and crack initiation and growth rates
  - Crack consequence experimental work and modeling has begun
  - Initiated repair and mitigation studies
- Transportation Handling Tests
  - Completion of 30 cm drop test; analyses of stress on fuel in progress
  - Designing a 9 m drop to get data on viability of pinch loads
- Residual Water After Drying
  - Analyzed gas samples from storage demonstration test and working to get more gas samples
  - Planning for experimental set up
  - Initiated consequence analysis
- Thermal Work
  - Vertical BWR experiments complete and horizontal test set up has begun
  - Blind round-robin modeling will continue

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
- Conduct R&D on the direct disposal of existing dual purpose (storage and transportation) canisters
- Leverage international collaboration





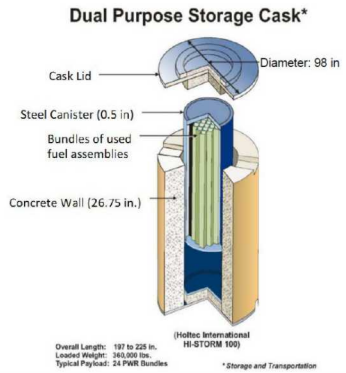


Major Activities in the Last Year
Disposal R&D

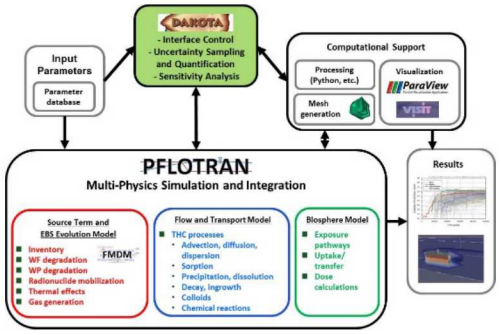
- Argillite, Crystalline, and Salt Research
  - Experimental data and modeling of bentonite performance at elevated temperatures
  - Improved techniques for modeling fracture flow and transport
  - Borehole heater test in progress at WIPP
- Geologic Disposal Safety Assessment
  - PFLOTRAN modeling capability expands
  - Uncertainty and sensitivity analysis capability expands
  - Re-assessment of 2012 Disposal R&D Roadmap priorities in progress
- International Disposal R&D
  - Collaborations continue on multiple fronts
  - Leadership role in DECOVALEX
  - Planning role in HotBENT test
  - Support for Nuclear Waste Technical Review Board
- Direct Disposal of Dual Purpose Canisters
  - Work continues on analyses of the potential for postclosure criticality events
  - Work initiated on fillers for criticality control
  - Cost analyses and multi-year planning in progress

Emphasis for FY19 Disposal R&D

- Options for Dual Purpose Canisters
  - Continue analysis of potential for postclosure criticality
    - Conduct post closure criticality consequence analysis
    - Analyses of DPC fillers for criticality control
    - Modeling of DPC postclosure performance including fillers
    - Design enhancement options for existing and future DPCs
  - Geotechnical considerations for postclosure performanc
- Geological Disposal Safety Assessment (GDSA)
  - High performance computing of system performance (PFLOTRAN)
  - Uncertainty Quantification and Sensitivity Analysis tools
  - Performance assessment inventory of DOE-managed wastes
- Enhanced R&D and International Collaborations to support disposal concepts in multiple geologic media
  - Heated borehole field test in salt at WIPP
  - Experimental and modeling activities in salt, argillite, and crystalline rock



Example of a dual-purpose canister inside a storage overpack (cask) (modified from Easton 2011).



Concluding Remarks

- Because there is not an operational deep geologic repository for SNF and HLW in the US at present, the SNF inventory is storage at NPPs continues to grow.
- The current practice of dry storage at the NPPs is not optimized for transportation or disposal, leaving the US with three options or combinations, thereof:
  - Repackage the fuel
  - Directly dispose of the SNF in the DPCs
  - Indefinite storage with potential repacking every 100 years or so
- Current R&D efforts in the US are focused on
  - Extended storage and eventual large-scale transport of spent nuclear fuel and high-level waste
  - Geologic disposal in different geologic media, including international collaborations; direct disposal of DPCs; and development of advanced modeling and simulation capabilities.

Thank you!

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