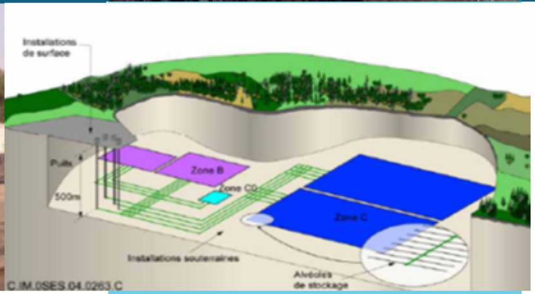
SAND2018-11342C

Current Status of US SNF Management: Addressing the Growing Inventory



PRESENTED BY

Evaristo J. (Tito) Bonano, Senior Manager

Fall 2018 Conference of Korea Radioactive Waste Society

October 31- November 2, 2018

Jeju Island, ROK

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2018-XXXX C

Introduction

- Due to the lack of an operating repository for the final disposal of spent nuclear fuel (SNF) from commercial and defense-related activities as well as high-level radioactive waste, nuclear utilities have been storing SNF on site.
- As of December 2017, ~2/3 of the SNF inventory is stored in pools with the remaining in dry-storage casks.
- By ~2022 it is projected that the majority of the SNF inventory will be in dry-storage casks, and by mid-century 100% will be in dry-storage casks.
- Ten years ago the SNF management system in the US was based on bare fuel assemblies being loaded into Transportation, Aging and Disposal (TAD) casks and disposed of at the proposed Yucca Mountain Repository.
- There are several possible alternatives to address the current situation.
- This presentation examines the potential direct disposal of the dry-storage casks.

Timeline of U.S. Spent Nuclear Fuel Management

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

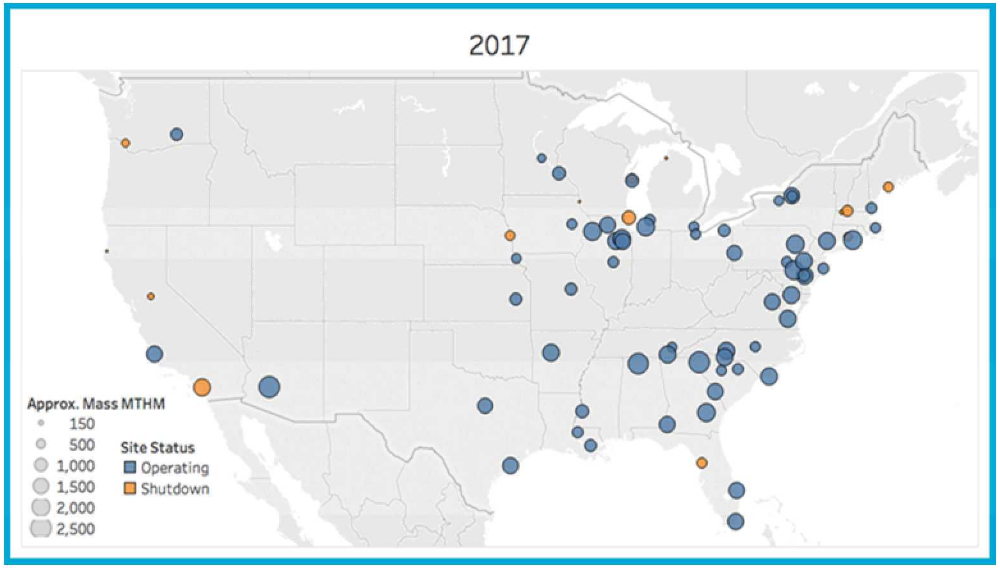
Today

SNF Management in the US: The Reality

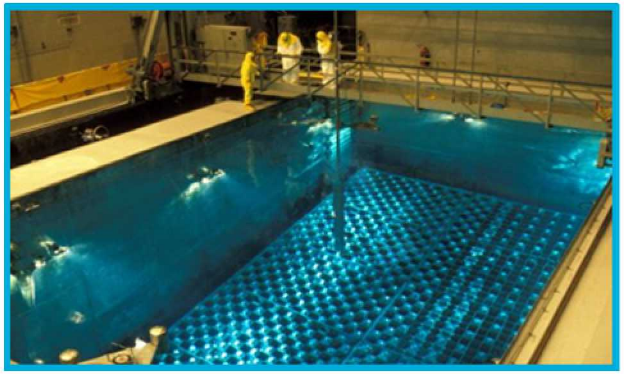
Sandia National Laboratories

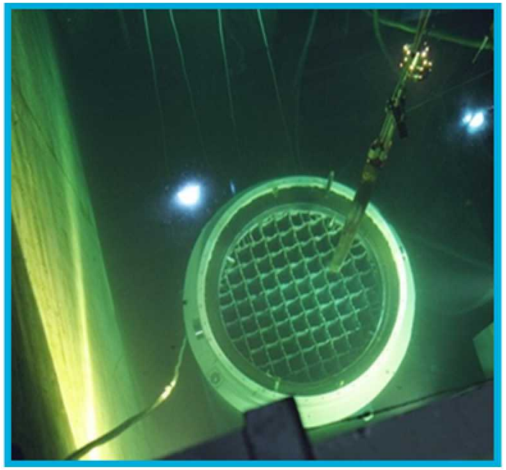
Commercial SNF is in Temporary Storage at 75 Reactor Sites in 33 States

- 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

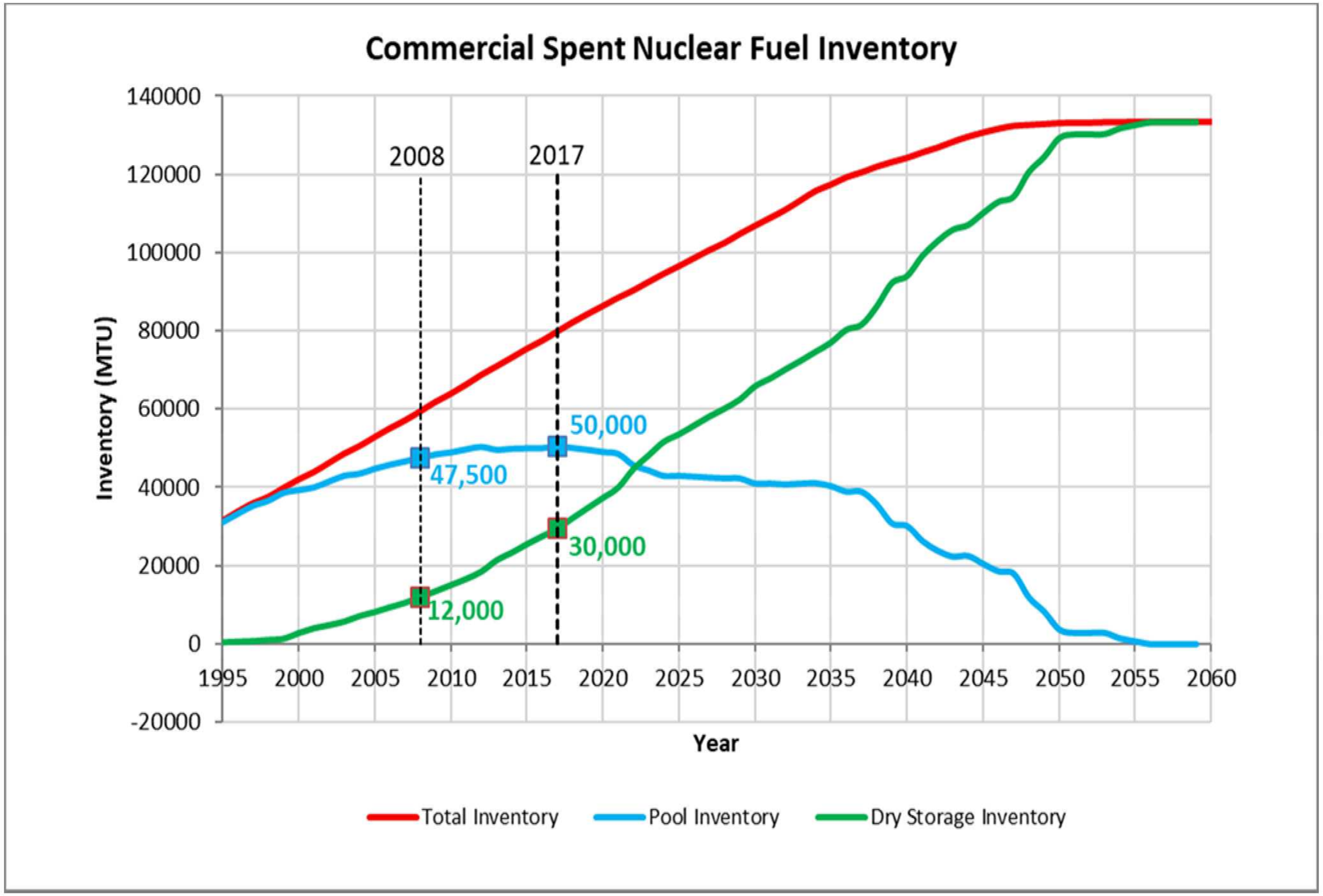


Map of the US commercial SNF storage from Bonano et al. 2018





US Projections of SNF Inventory



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

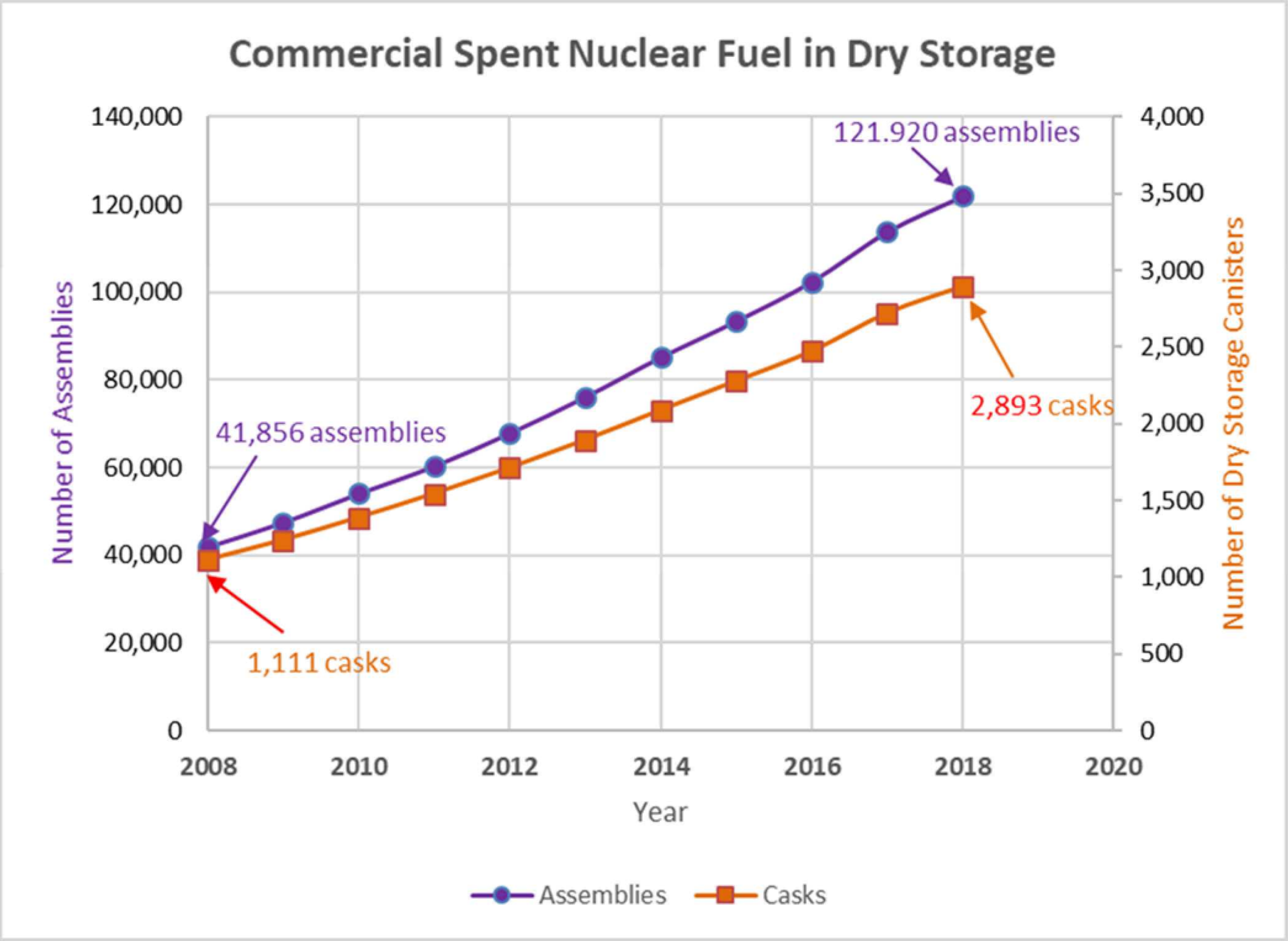
Approx. 80,000 MTHM (metric tons heavy metal) of commercial SNF in storage in the US as of Dec. 2017

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.

Dry Storage Systems for Spent Nuclear Fuel

Dual purpose canister (DPC)

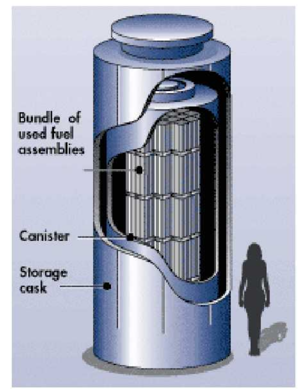
- A canister that is certified for both storage and transportation of spent nuclear fuel

Dry cask/canister storage systems

- The most common type of dry storage cask systems is the vertical cask/canister system shown to the right, in which the inner stainless steel canister is removed from the storage overpack before being placed in a shielded transportation cask for transport
- Can be constructed both above and below grade
- Horizontal bunker-type systems and vaults are also in use

Some older fuel is also stored as "bare fuel" in casks with bolted lids; few sites continue to load these systems

Multiple vendors provide NRC-certified dry storage systems to utilities



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, and criticality control

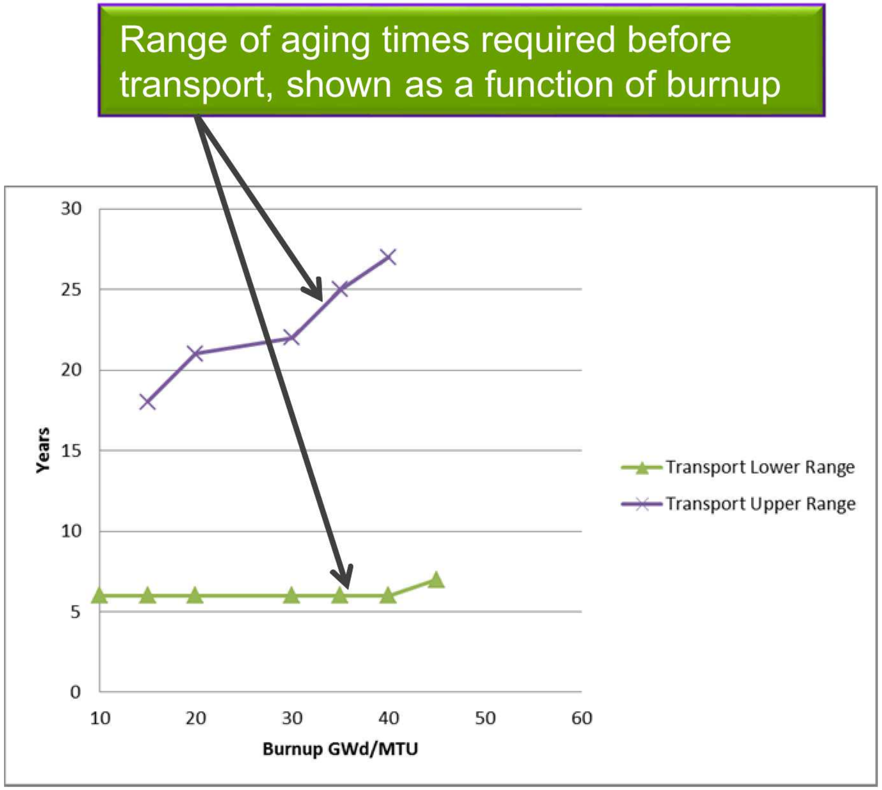
Placing spent fuel in dry storage in dual purpose canisters (DPCs) commits the US to some combination of three options

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

Transportation Considerations

- Some DPCs may require decades of aging to cool spent fuel before they can be transported
  - High-burnup fuels may require longer aging
  - Cooling times are design-specific (in general, larger DPCs require longer cooling times)
- Transportation casks remain to be certified for some DPC systems

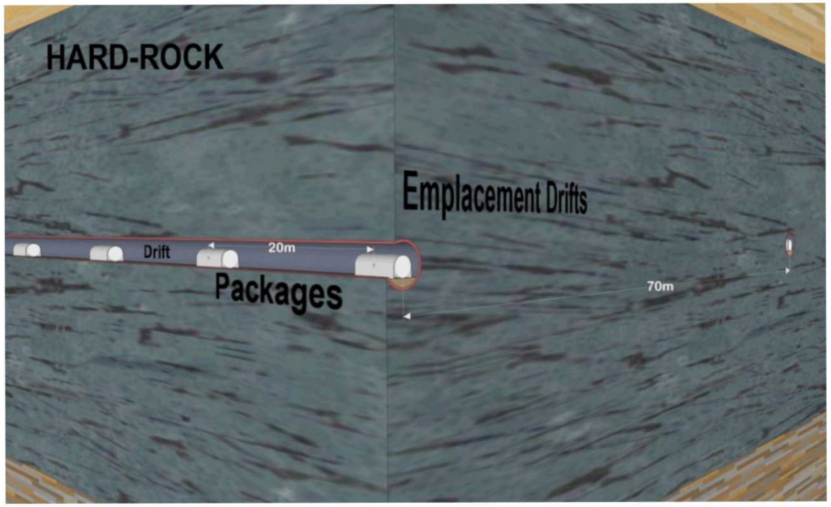


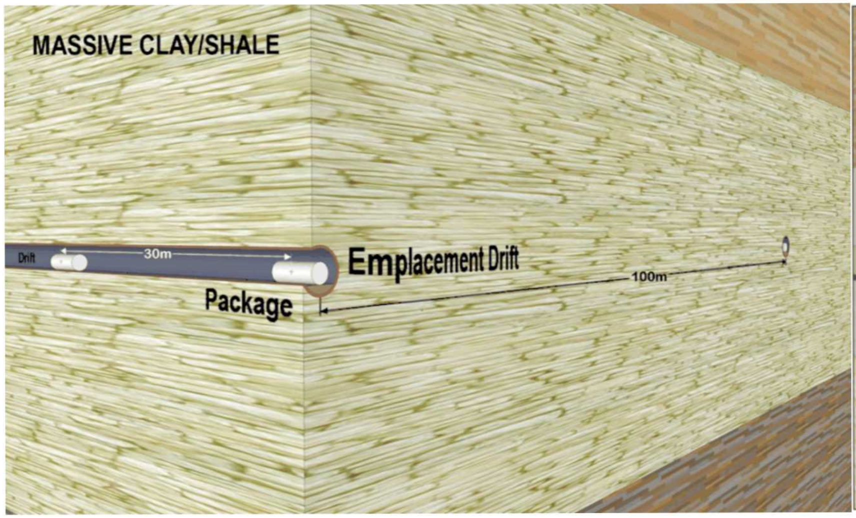
Source: Adapted from Stockman and Kalinina, SAND2013-2013P

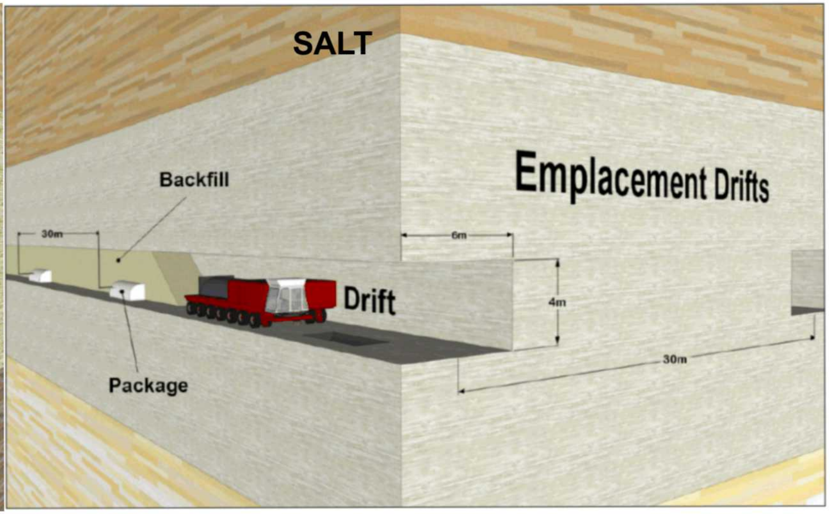
Minimum cooling times for multiple cask/canister systems, based on NRC certificates of compliance for specific designs as of 2013. Variation in times is due to the diversity of the current inventory, dominated by DPC size and heat transfer capabilities.

DPC Direct Disposal Concepts: Engineering

- **Engineering challenges are feasible**
- **Shaft or ramp transport**
- **In-drift emplacement**
- **Repository ventilation (except salt)**
- **Backfill before closure (except unsat.)**
- **Degradation of Al-based materials in ground water ⇒ Postclosure criticality control problem**







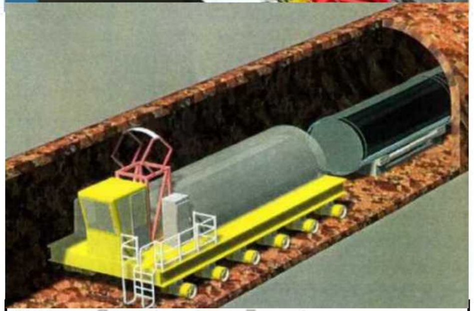
Sandia National Laboratories

Disposal Considerations: Waste Package Size

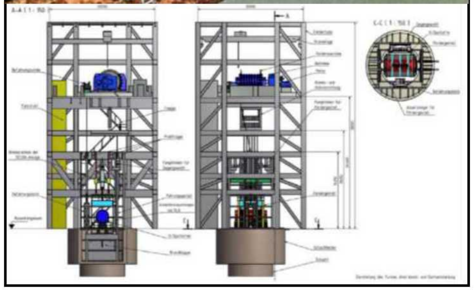
- DPCs are massive, but not unprecedented
  - Transportation, aging, and disposal canisters proposed for Yucca Mountain were in the range of sizes of existing DPCs
  - With disposal overpack and transport shielding, total mass could be on the order of 150 metric tons
- Size poses engineering challenges for handling during both transportation and disposal, but options are available

SKB Demo (90 MT), Äspö

Andra Funicular Concept



Wheelift® Transport-Emplacement Vehicle Concept



DBE Shaft Hoist Concept (85 MT)

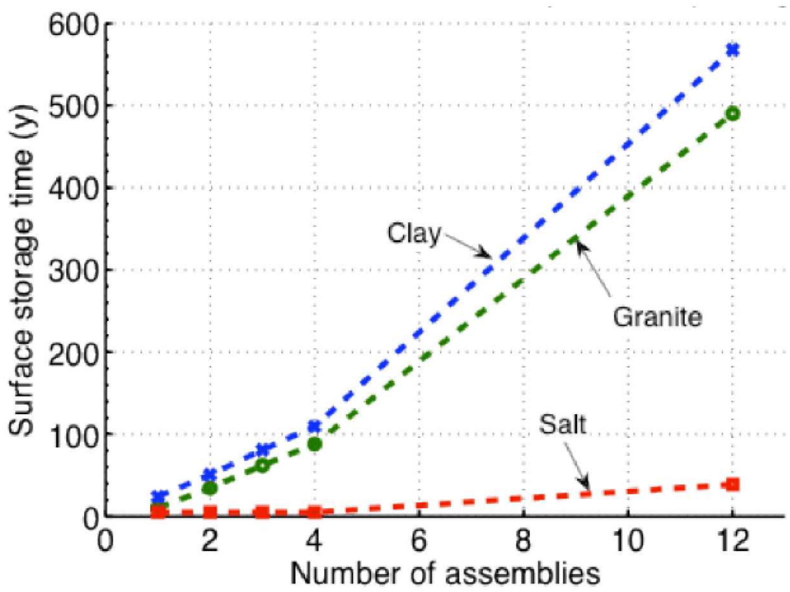
Disposal Considerations: Thermal Management

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)

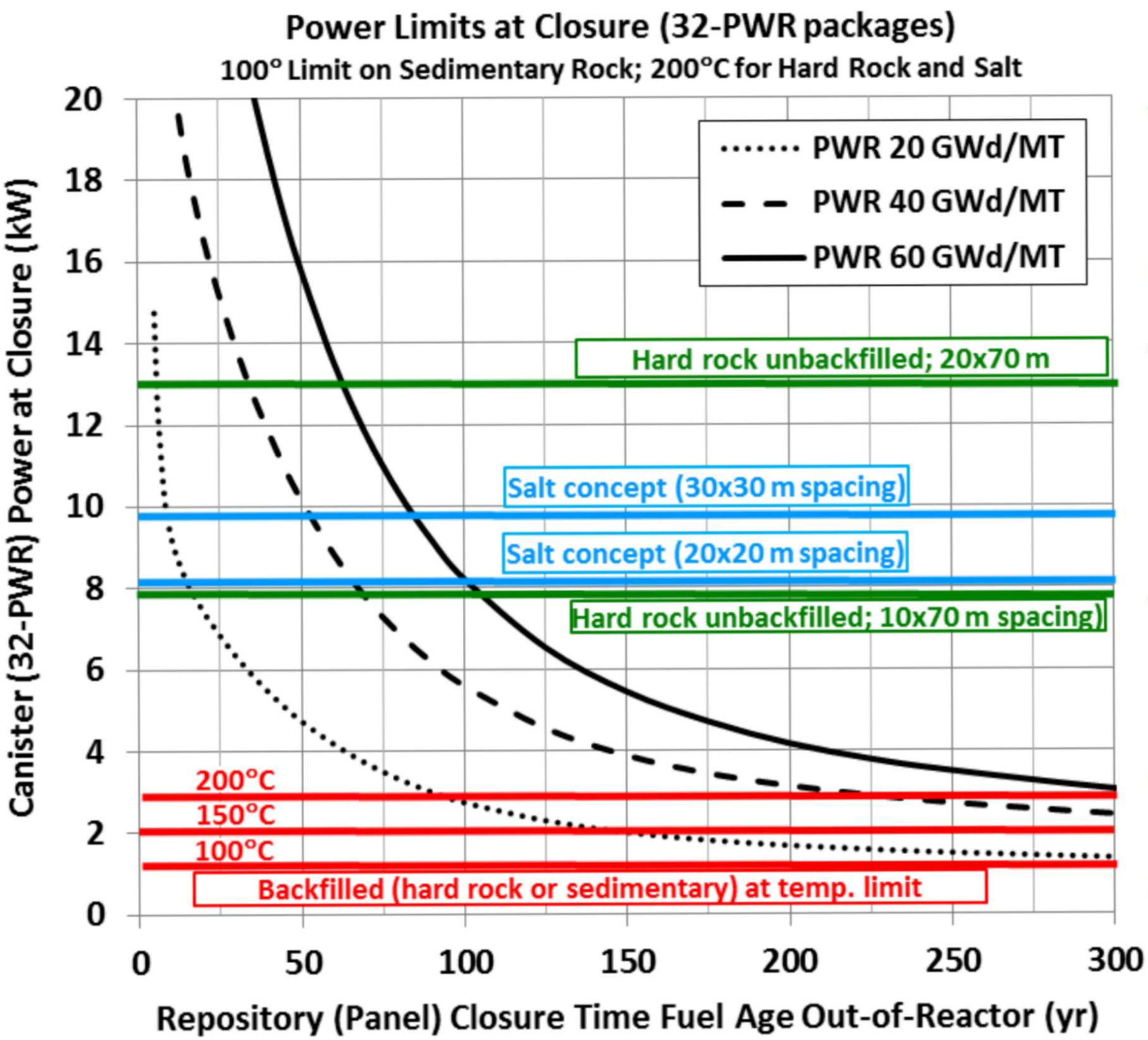


Source: Hardin et al. FCRD-USED-2011-000143 Rev. 2, 2011

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

Disposal Considerations: Thermal 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

Disposal Considerations: Criticality Control

- Some already-loaded DPCs pose complications for licensing analyses of post closure criticality control
  - Flooding by groundwater following canister degradation is a pre-requisite for criticality in any waste package
  - Al-based neutron absorbers used in some DPCs will degrade in water
  - Resulting reactivity increase can be offset by
    - High-reliability disposal overpacks to exclude moderators
    - Uncredited high-burn up margin in SNF configurations
    - High chloride content in groundwater (e.g., in salt)
  - Other options include
    - Open DPCs before disposal to add criticality controls (fillers, disposal control rods)
  - Case-by-case analysis of individual DPCs may be needed for licensing (function of enrichment and burn-up)

Direct Disposal of DPCs: 2018- 2019 Planned Activities & Outcomes

- Planned Activities:
  - Technical/Programmatic Solutions for Direct Disposal of SNF in DPCs
  - Probabilistic Post-Closure DPC Criticality Consequence Analysis
  - DPC Filler and Neutron Absorber Degradation R&D
  - Multi-Physics Simulation of DPC Criticality
- Expected Outcomes:
  - DPC disposition alternatives, R&D and resource needs
  - Generic (non-site specific) preliminary PRA
  - Preliminary multi-physics coupled models
    - Model benchmarks
  - Feasibility of thermal-setting phosphate cement as filler

Concluding Remarks

- The lack of an operating geologic disposal in the US for commercial SNF has resulted in utilities needing to store the growing inventory on site.
- While today ~2/3 of the inventory is still in pools, by ~2022 the majority of the inventory will be in dual-purpose canisters, and by mid-century 100% will be in DPCs.
- One potential alternative being researched in the US program is the direct disposal of DPCs in a geologic repository.
- Implementing this alternative will require resolving several challenges: package size and design, thermal loading and criticality control.
- Our ongoing research is addressing these challenges

References

- Bonano, E.J., E.A. Kalinina, P.N. Swift 2018. "The Need for Integrating the Back End of the Nuclear Fuel Cycle in the United States of America," *MRS Advances*, DOI: 10.1557/adv.2018.231
- Hardin, E., J. Blink, H. Greenberg M. Sutton, M. Fratoni, J. Carter, M. Dupont, R. Howard. 2011*. Generic Repository Design Concepts and Thermal Analysis (FY11)*. FCRD-USED-2011-0002143 Rev. 2. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, December, 2011.
- Hardin, E., T. Hadgu, D. Clayton, R. Howard, H. Greenberg, J. Blink, M. Sharma, M. Sutton, J. Carter, M. Dupont and P. Rodwell 2012*. Repository Reference Disposal Concepts and Thermal Management Analysis*. FCRD-USED-2012-000219 Rev. 2. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition. November, 2012.
- Hardin, E., D. Clayton, M. Martinez, G. Nieder-Westermann, R. Howard, H. Greenberg, J. Blink and T. Buscheck 2013. *Collaborative Report on Disposal Concepts*. FCRD-UFD-2013-000170 Rev. 0. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition. September, 2013.
- Hardin, E., L. Price, E. Kalinina, T. Hadgu, A. Ilgen, C Bryan, J. Scaglione, K. Banerjee, J. Clarity, R. Jubin, V. Sobes, R. Howard, J. Carter, T. Severynse, and F. Perry, 2015. *Summary of Investigations on Technical Feasibility of Direct Disposal of Dual-Purpose Canisters,* FCRD-UFD-2015-000129 Rev 0, U.S. Department of Energy, Office of Used Nuclear Fuel Disposition, May 2015.
- International Energy Agency, 2015. *Potential Interface Issues in Spent Fuel Management*, IAEA-TECDOC-1774, October 2015.
- Stockman, C. and E. Kalinina, 2013. *Cooling Times for Storage and Transportation of Spent Nuclear Fuel*. SAND NO. 2013-2013P.

THANK YOU!

Contact Information:

Dr. Evaristo J. (Tito) Bonano,
Nuclear Energy Fuel Cycle Program
Sandia National Laboratories
Albuquerque, NM 87185 USA
ejbonan@sandia.gov