SAND2013-8826C

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

# Preliminary Evaluation of Dual-Purpose Canister Disposal Alternatives (FY13)

**Ernest L. Hardin, Ph.D.**
Applied Systems Analysis & Research (06224)
Sandia National Laboratories
Albuquerque, New Mexico

**DOE/NE Fuel Cycle Technologies Annual Meeting**
Argonne National Laboratory

**November 5-6, 2013**

SAND2013-8676A (Unclassified Unlimited Release)

# Context

**This is a technical presentation that does not take into account the contractual limitations under the Standard Contract. Under the provisions of the Standard Contract, DOE does not consider spent fuel in canisters to be an acceptable waste form, absent a mutually agreed to contract modification. To ensure the ability to transfer the spent fuel to the government under the Standard Contract, the individual spent fuel assemblies must be retrievable for packaging into a DOE-supplied transportation cask.**

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

# Acknowledgments


**Ernest Hardin, Dan Clayton, Payton Gardner & Andrew Miller – Sandia National Laboratories**

**Rob Howard, John Scaglione, Justin Clarity & Bob Jubin – Oak Ridge National Laboratory**

**Jim Blink, Max Fratoni, Harris Greenberg, Montu Sharma & Mark Sutton – Lawrence Livermore National Laboratory**

**Joe Carter & Tom Severynse – Savannah River National Laboratory**

**Michael Voegele & Tom Cotton– Complex Systems Group, LLC**

**Charles Fairhurst – University of Minnesota**

**Bill Spezialetti & Bob Clark – U.S. DOE Office of Used Nuclear Fuel Disposition**

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

# Technical Evaluation of DPC Direct Disposal Feasibility

## Q: Why evaluate technical feasibility of direct disposal of large dual-purpose canisters?

## A: Potential for

- Less fuel handling
- Potentially simpler spent nuclear fuel (SNF) management
- Lower cost
  - Re-packaging cost (operations, new canister hardware)
  - 10,000 waste packages for U.S. SNF vs. up to 9X that many for smaller packages
- Lower worker dose
- Less secondary waste (e.g., no separate disposal of existing DPC hardware)

# Preliminary Technical Evaluation of DPC Direct Disposal Alternatives: Outline

- **Approach and Assumptions**
- **Design Options**
  - Thermal
  - Criticality control
  - Engineering challenges
- **Example Disposal Concepts**
- **Thermal Management Analysis**
- **Criticality Scoping Analysis**
- **Preliminary Logistical Analysis**
- **Summary and Conclusion**

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

# Technical Evaluation of DPC Direct Disposal Feasibility

## Scope

- Multi-year project (FY12→) to evaluate potential technical issues
  - **Safety (preclosure and postclosure)**
  - **Engineering feasibility**
  - **Thermal management**
  - **Criticality control**

## Approach

- Goal: "Map" disposal concepts to existing DPC inventory
- Focus R&D activities
- Iteratively evaluate technical feasibility (e.g., decision to continue)

## Technical Participants

- ORNL, SNL, SRNL, ANL, LANL, LBNL, and other labs
- External interactions and reviews will continue

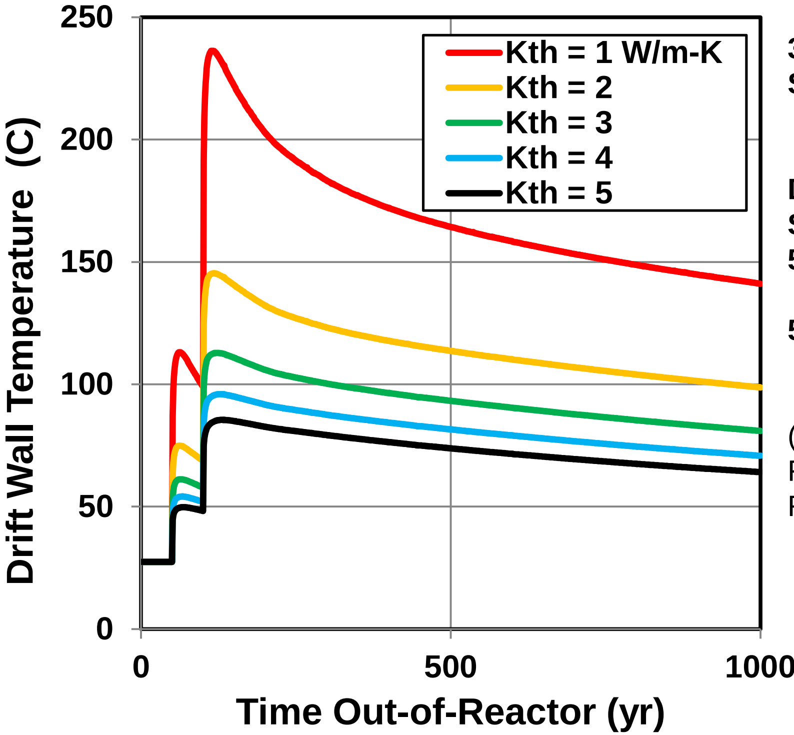
# DPC Direct Disposal Study Assumptions and Conditions

## Key Technical Assumptions for This Analysis

- Completion of disposal operations (i.e., panel closure) is desired at/before fuel age of 150 years out-of-reactor
  - 50 to 100 years of surface storage, and up to 50 years of repository operations
- Fuel and canister condition will be suitable for transport and disposal, for up to 100 years from reactor discharge
- Canistered SNF will be placed in disposal overpacks
- Technical analyses will be conducted with a regulatory context, similar to 40CFR197 and 10CFR63 (e.g., probabilistic treatment of features, events & processes)
- Low probability and low consequence arguments may both be used to evaluate criticality.

# Design Options (1/3)
# Thermal Management

- **Design options for a given waste package capacity and SNF burnup:**
  - **Choice of host rock**
    - Salt (up to 5 W/m-K)
    - Hard rock (2.5 W/m-K)
    - Sedimentary (1.75 W/m-K)
  - **Repository spacings**
  - **Surface decay storage duration**
  - **Ventilation**
  - **Use of backfill**




**32-PWR size packages**
**Spacings**
**Package: 20 m**
**Drift 70: m**
**Drift diameter 5.5 m**
**SNF burnup 60 GW-d/MT**
**50-yr surface decay storage**
**50-yr repository ventilation**

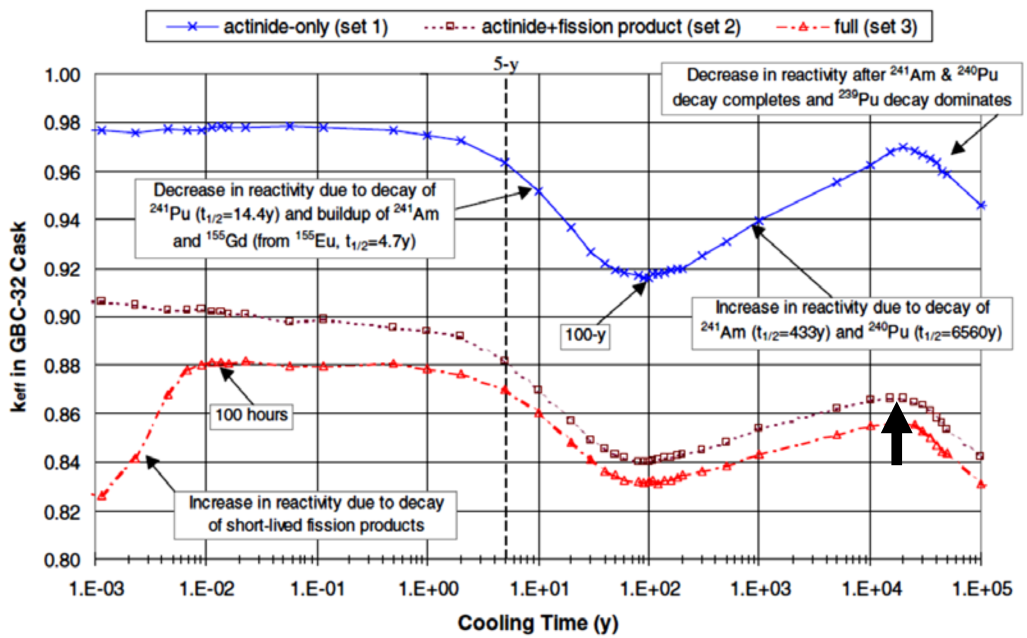
(after Hardin et al. 2012. FCRD-UFD-2012-000219 Rev.2)

**Example: Effect of rock $K_{th}$ on drift wall temperature for a 32-PWR, high-burnup case.**

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

# Design Options (2/3)
# Nuclear Criticality Control

- **Disposal Environment**
  - Groundwater availability
  - Chloride in groundwater
  - Package (overpack) integrity
- **Moderator Exclusion**
  - Package integrity
- **Moderator Displacement**
  - Fillers (e.g., boron carbide loaded grout)
- **Criticality Analysis Methodology**
  - Burnup credit, as-loaded, degradation cases
  - Peak reactivity occurs at ~25,000 years




**$k_{eff}$ vs. Time**

**Generic burnup credit 32-PWR cask PWR fuel (4% enriched, 40 GW-d/MT burnup)**

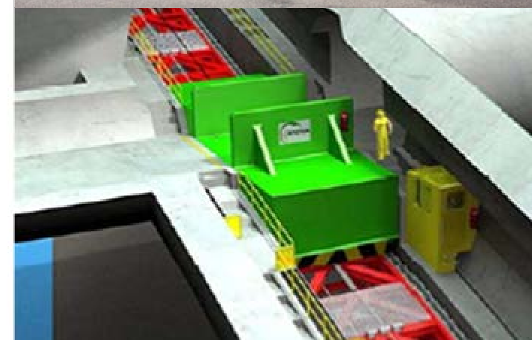
Wagner and Parks 2001. NUREG/CR-6781.(Fig. 3)
Note: Set #2 burnup credit reactivity results correspond to criticality scoping analysis of Clarity & Scaglione (2013).

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

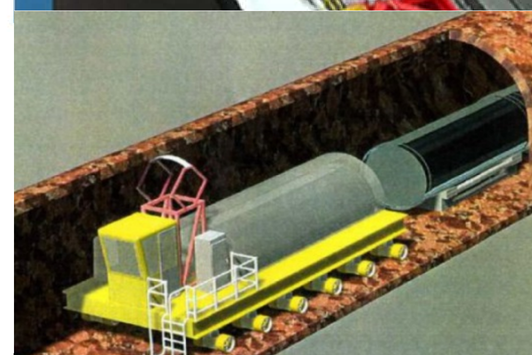
# Design Options (3/3) Engineering Challenges

- **Handling/Packaging (current practices)**
- **Surface-to-Underground Transport**
  - Heavy shaft hoist
  - Spiral ramp (≤10% grade for rubber-tires)
  - Linear ramp (>10% grade with funicular)
  - Shallow ramp (≤ 2.5% for standard rail)
- **Opening Stability Constraints**
  - Salt (a few years with minimal maintenance)
  - Hard rock (50 years or longer)
  - Sedimentary (50 years or longer may be feasible in some geologic settings)

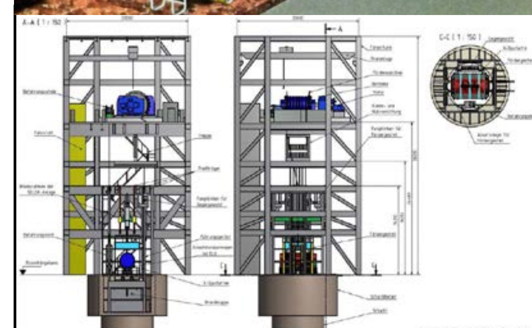
**SKB Demo (90 MT), Äspö**



**Andra Funicular Concept**



**Wheelift® Transport-Emplacement Vehicle Concept**

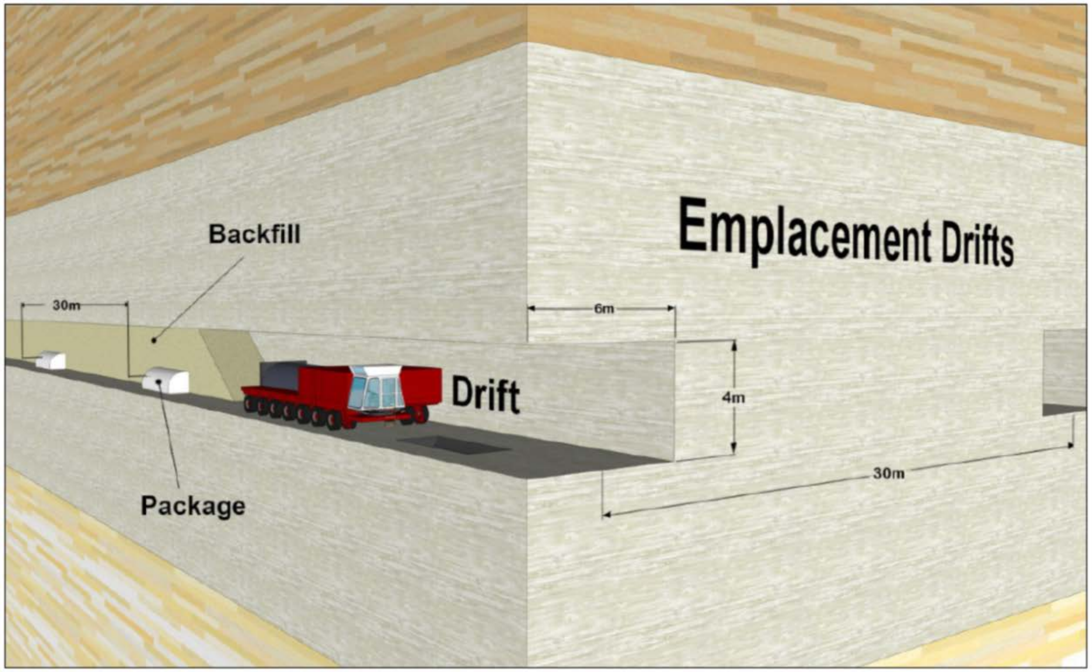


**DBE Shaft Hoist Concept (85 MT)**

Sources: Fairhurst (2012); www.wheelift.com; Nieder-Westermann et al. (2013).

# Example: Salt Concept for SNF Disposal in DPC-Based Packages

- Emplace SNF at 50 to 70 years out-of-reactor (OoR)
- Crushed salt backfill at emplacement
- Bedded or domal salt
- ~175 MT transport payload with shielding
- Simple “corrosion allowance” overpack



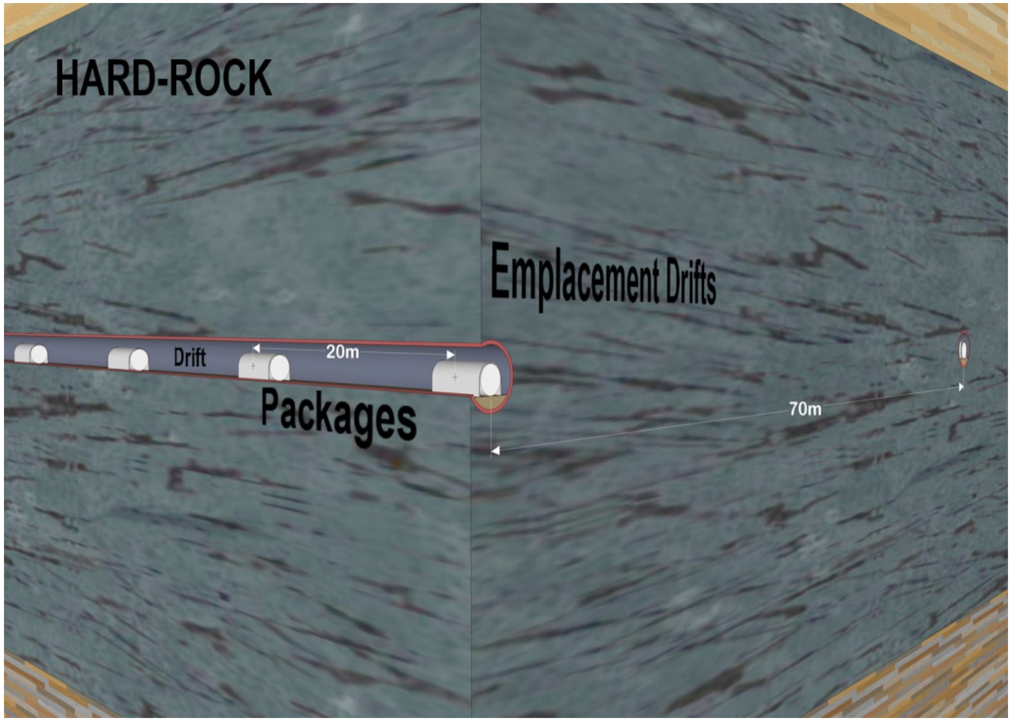

Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0)

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

# Example: Hard-Rock Open, Unbackfilled Concept

- Emplace SNF at 50 to 100 years OoR
- Ventilate up to 50 yr, close at ≤150 years OoR
- Flexible: combine functions of storage and disposal
- Unbackfilled for unsaturated settings (or include backfill for saturated settings)
- Corrosion resistant overpack
- Additional engineered barriers may be installed (e.g., drip shields)
- Long-term opening stability



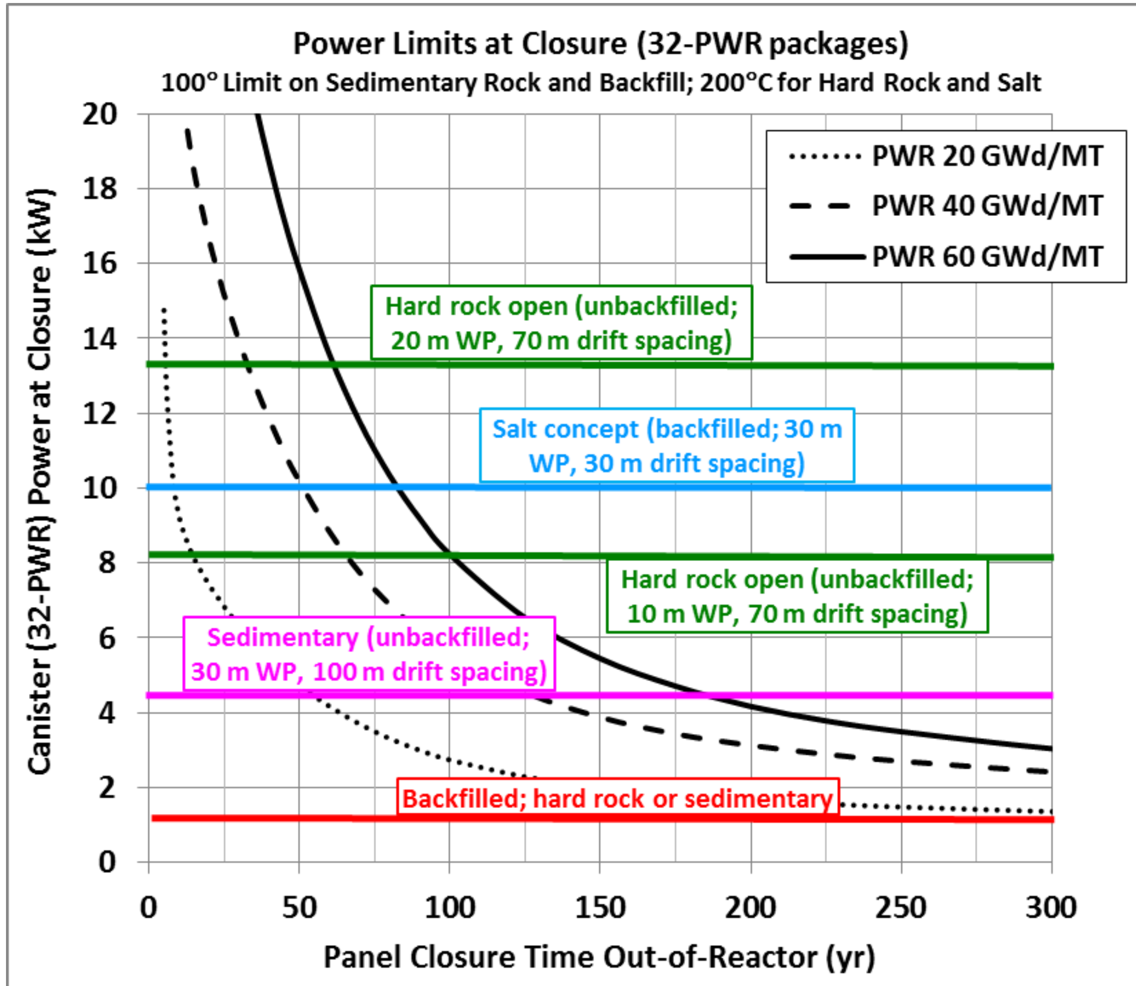

Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0.

# Thermal Management Summary: Time to Repository Panel Closure for Representative Disposal Concepts

## 32-PWR size packages

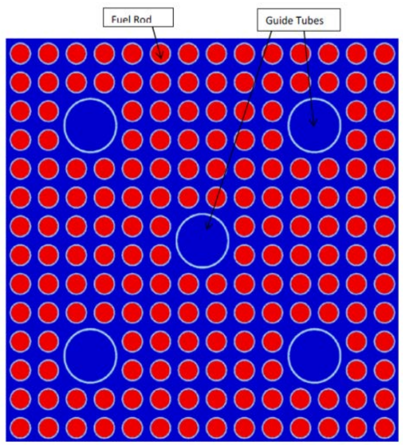
Hard rock open, unsaturated concept (small and large spacings)

Sedimentary concept and backfill require much more aging, for higher burnup.




Based on: Hardin et al. 2013. *Collaborative Report on Disposal Concepts.* FCRD-UFD-2013-000170 Rev. 0.

# Criticality Scoping Analysis Results, “Site A” (1/3)




- **Numerical Model of TSC-24 Canisters (37 analyzed)**
- **ORNL Database SNF-ST&DARDS**
- **Software/Data**
  - SCALE code system (ORNL 2011)
  - Details: see Clarity and Scaglione (2013)
- **Also Analyzed: “Site B” (MPC-32)**

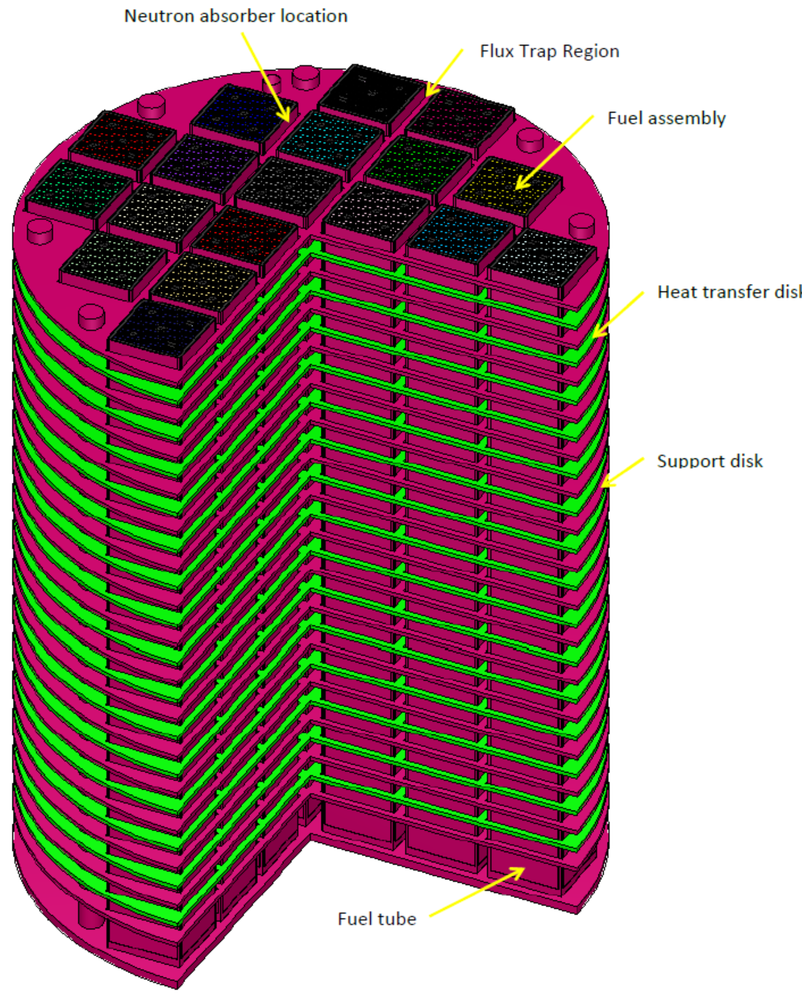
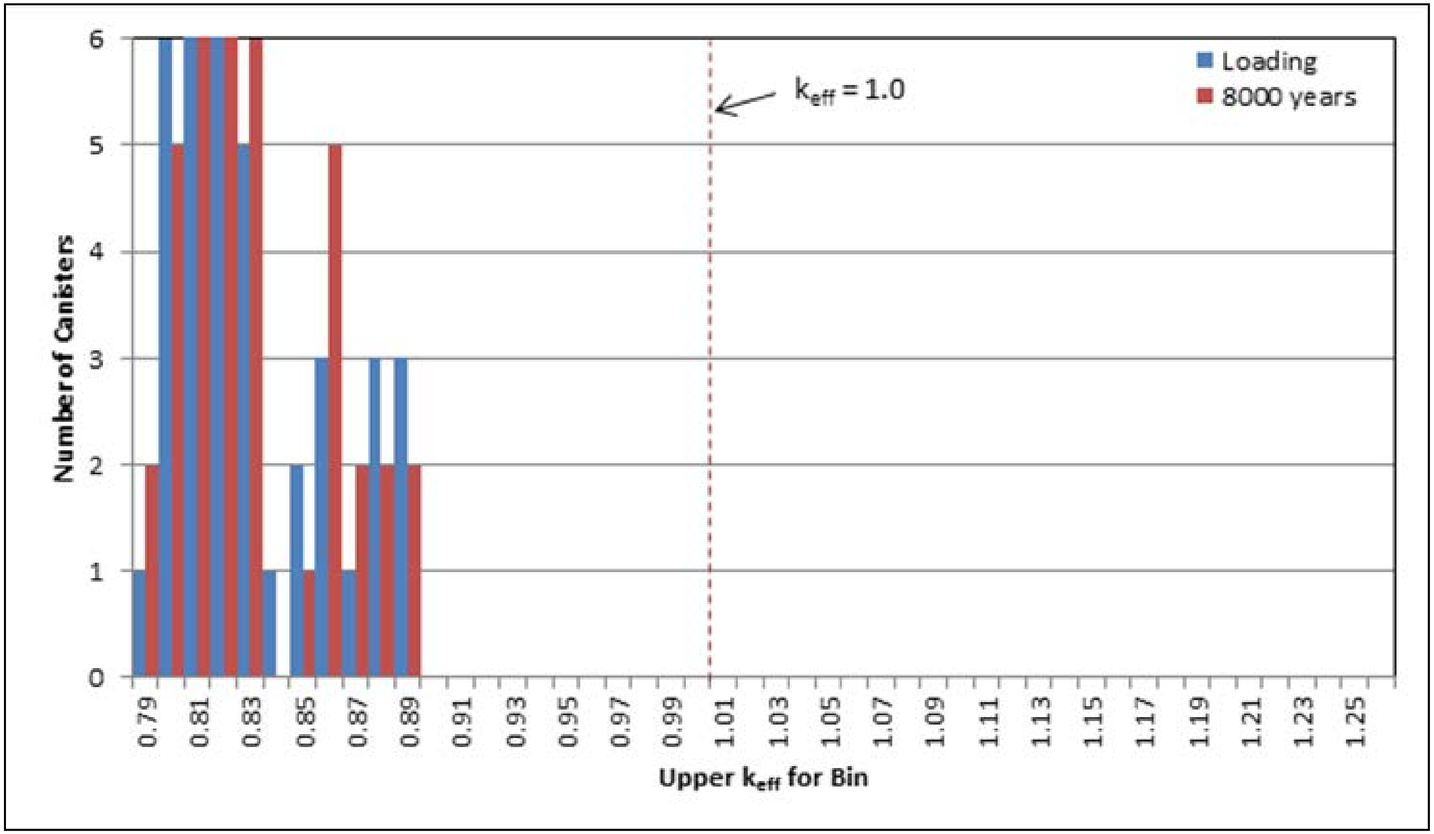



Figure 8-3. Cut-away view of the TSC-24 design basis KENO model

# Criticality Scoping Analysis Results, "Site A" (2/3)

- **Loss-of-absorber case, <u>flooded with low-salinity groundwater</u>**
- **PWR dry storage canisters, analyzed as-loaded, with burnup credit**

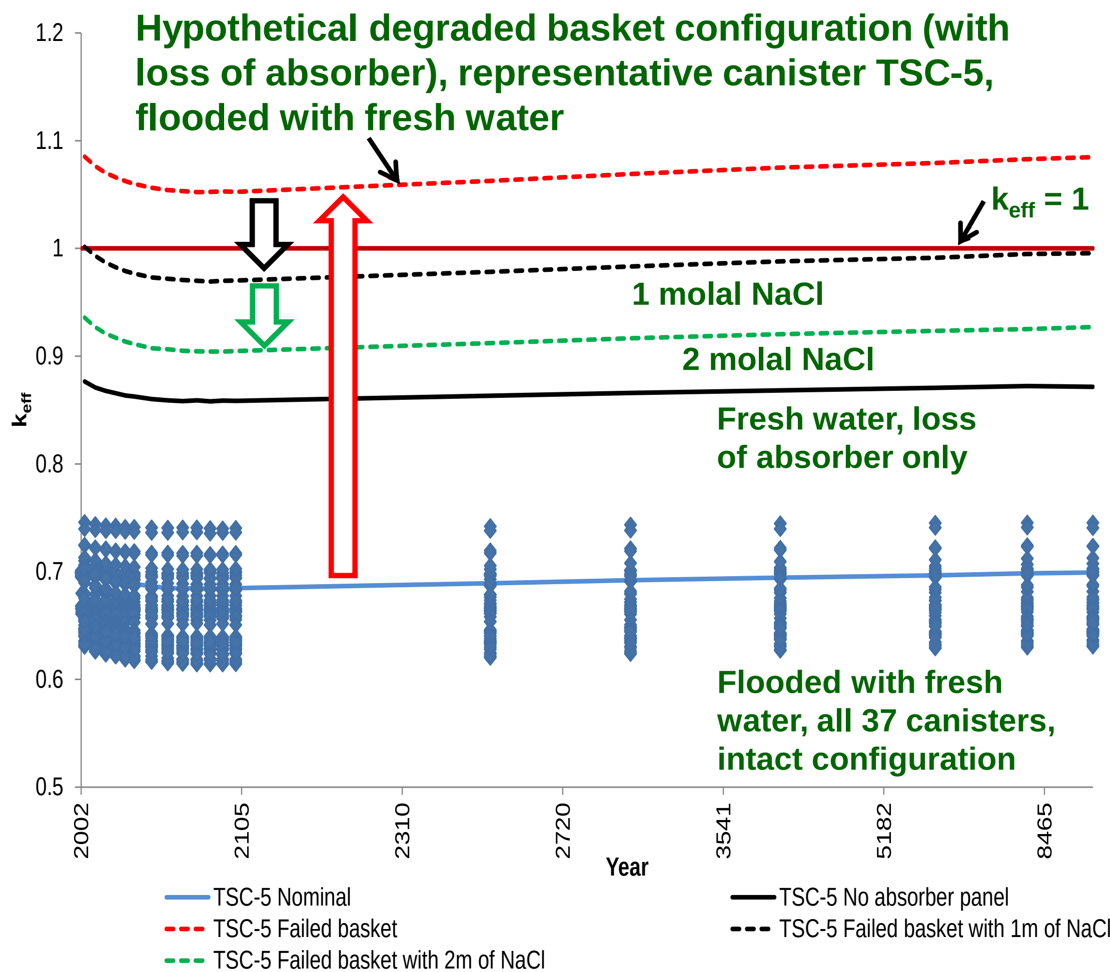



Source: Clarity, J. and J. Scaglione 2013. ORNL/LTR-2013/213.

# Criticality Scoping Analysis Results ("Site A") (3/3)

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

- Analyzed as-loaded, with burnup credit
- Higher chloride brine strength → less reactivity (saturated NaCl ≈ 6 molal)
- Note: $k_{eff}$>1 results signify DPCs for which other control measures might be used, e.g., corrosion resistant overpack, or re-packaging




Source: Clarity, J. and J. Scaglione 2013. ORNL/LTR-2013/213.

# Preliminary Logistical Analysis of DPC Direct Disposal Scenarios (1/2)

## Objectives

- Forecast when DPCs could be emplaced in a repository, and throughput rates.
- Estimate incremental decay storage costs for DPCs, and compare with the cost to re-package the SNF into smaller canisters for disposal

## Assumptions (modeling from now until repository closure)

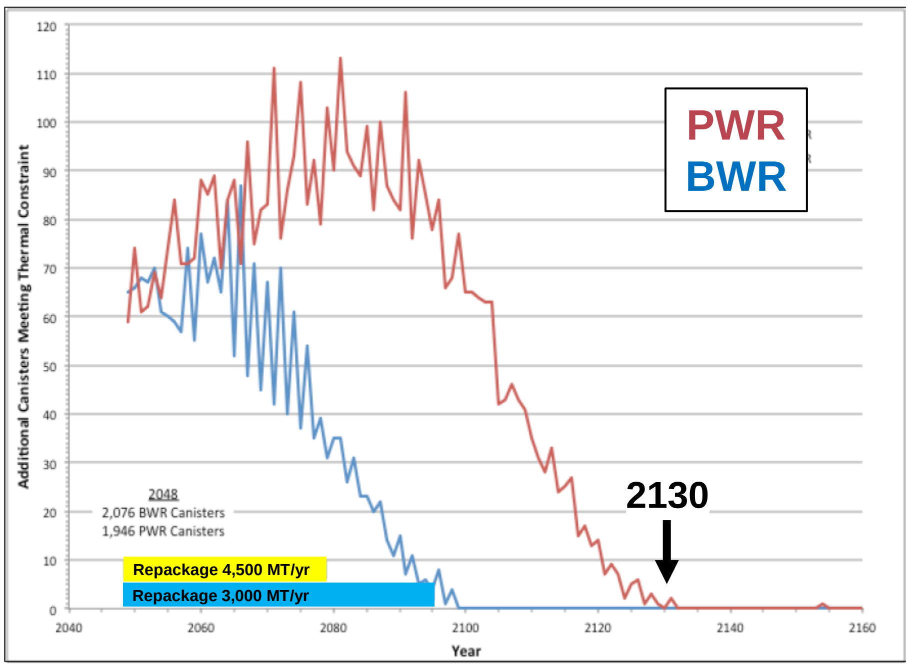
- SNF will be generated at currently operating plants, with 20-year life extensions.
- All SNF would be put in dry storage in DPCs as plants are decommissioned.
- DPC shipments to the CSF would begin in 2025.
- A repository would begin to package and emplace DPCs underground in 2048.
- Once the repository is operating, DPCs cool enough for disposal (here 4, 6, 8 10 or 12 kW) would be shipped first from reactors or from the CSF.

**Use TSL-CALVIN code, developed originally for Yucca Mountain repository studies, adapted to generic studies with additional features (Nutt et al. 2012).**

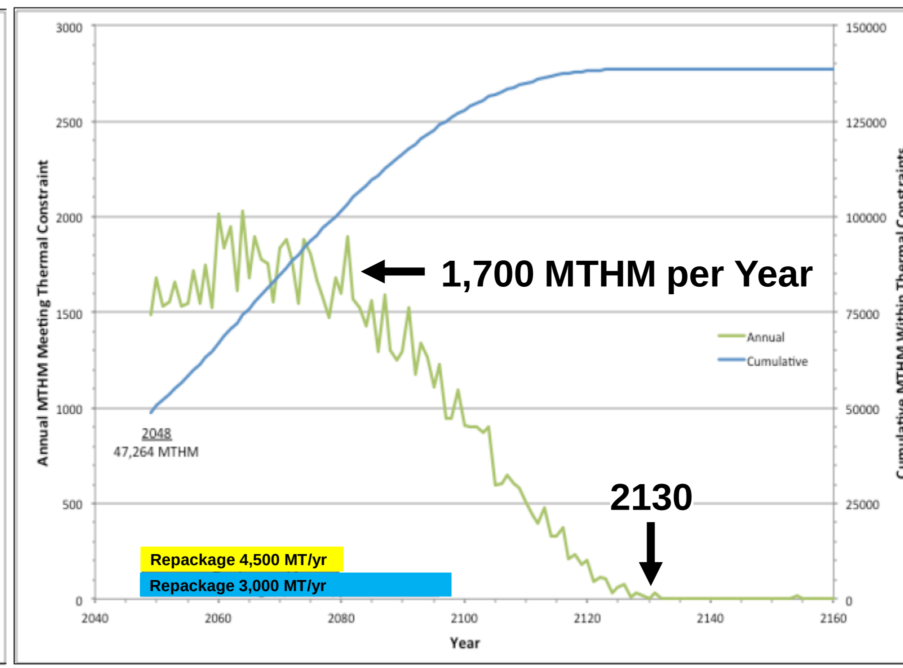
Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0.

# Preliminary Logistical Analysis of DPC Direct Disposal Scenarios (2/2)

- 10 kW limit typical for salt disposal; substantially done by 2130
- Color bars show re-packaging (and re-blending) durations for 4,500 and 3,000 MT/yr throughput




Number of canisters per year, vs. calendar year




SNF emplaced per year (MTHM), vs. calendar year

Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0.

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

# Preliminary Evaluation of DPC Disposal Feasibility: Summary and Conclusion

- **Disposal Alternatives**
  - Technical challenges are identified for disposal concepts in various rock types
- **Thermal Results**
  - Repository panel closure <150 yr fuel age out-of-reactor (salt and hard rock)
  - Backfill temperature potentially >> 100°C (if used)
- **Criticality Scoping Results**
  - Margin is available with burnup credit analysis and as-loaded information
  - Some, but not all, existing DPCs could be sub-critical for the cases defined
  - Saline water ($^{35}Cl$) provides significant absorption
- **Preliminary Logistical Result**
  - Emplacement mostly complete by 2130, at 1,700 MTHM/yr (10 kW limit)

***Preliminary results indicate DPC direct disposal could be technically feasible, for certain concepts. They also suggest cost savings compared to re-packaging, although further analysis is needed. Feasibility evaluation and related R&D are planned to continue.***

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

# References


- Clarity, J.B. and J.M Scaglione 2013. *Feasibility of Direct Disposal of Dual-Purpose Canisters-Criticality Evaluations*. ORNL/LTR-2013/213. Oak Ridge National Laboratory, Oak Ridge, TN. June, 2013.
- Fairhurst, C. 2012. *Current Approaches to Surface-Underground Transfer of High-Level Nuclear Waste*. Itasca Consulting Group, Minneapolis, MN.
- 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. November, 2012. U.S. Department of Energy, Used Fuel Disposition R&D Campaign.
- Hardin, E., D. Clayton, R. Howard, J. Scaglione, E. Pierce, K. Banerjee, M.D. Voegele, H. Greenberg, J. Wen, T. Buscheck, J. Carter and T. Severynse 2013. *Preliminary Report on Dual-Purpose Canister Disposal Alternatives*. FCRD-UFD-2013-000171 Rev. 0. U.S. Department of Energy, Used Fuel Disposition R&D Campaign. August, 2013.
- Nieder-Westermann, G.H., P. Herold and W. Filbert 2013. *Hoisting of Very Large Payloads for a Generic Waste Repository for Used Nuclear Fuel – Final Report*. TEC-06-2013-Z. DBE TECHNOLOGY GmbH, Peine, Germany.
- Nutt, M., E. Morris, F. Puig, E. Kalinina and S. Gillespie 2012. *Transportation Storage Logistics Model – CALVIN (TSL-CALVIN).* FCRD-NFST-2012-000424. U.S. Department of Energy, Nuclear Fuel Storage and Transportation Planning Project. Washington, D.C. October, 2012.
- ORNL (Oak Ridge National Laboratory) 2011*. Scale: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design*. ORNL/TM-2005/39 Version 6.1. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-785. June, 2011.
- Wagner, J. and C. Parks 2001. *Recommendations on the Credit for Cooling Time in PWR Burnup Credit Analyses*. NUREG/CR-6781. Oak Ridge National Laboratory, Oak Ridge, TN. ORNL/TM-2001/272.