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Preliminary Technical Evaluation of Dual-Purpose Canister Direct Disposal Alternatives

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U.S. Nuclear Waste Technical Review Board

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SAND2013-9261C (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.

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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**

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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)

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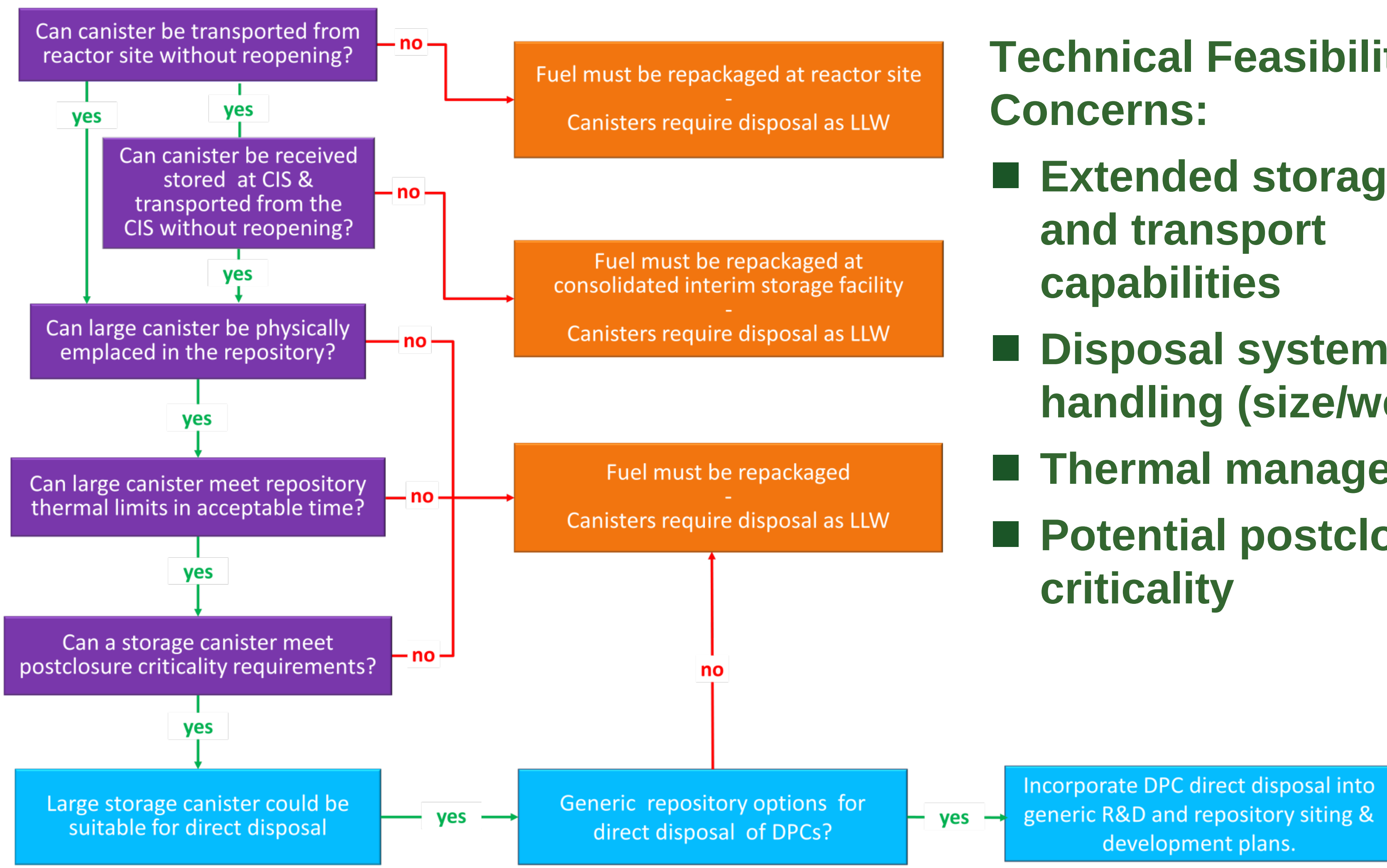
Path to Direct Disposal of SNF in Dual-Purpose Canisters



Technical Feasibility Concerns:

- Extended storage and transport capabilities
- Disposal system handling (size/weight)
- Thermal management
- Potential postclosure criticality

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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

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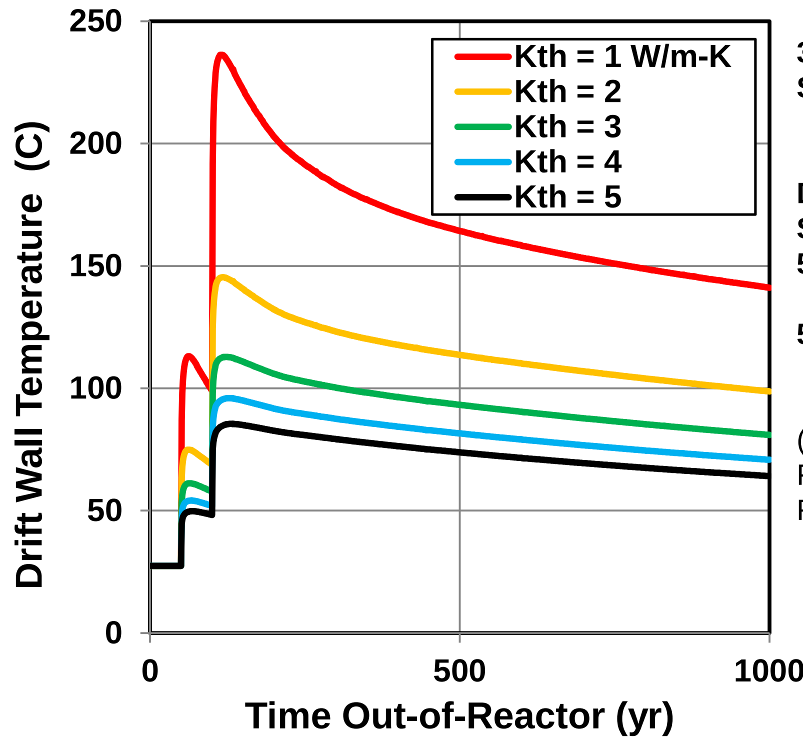
Key Technical Assumptions for This Analysis

- 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**



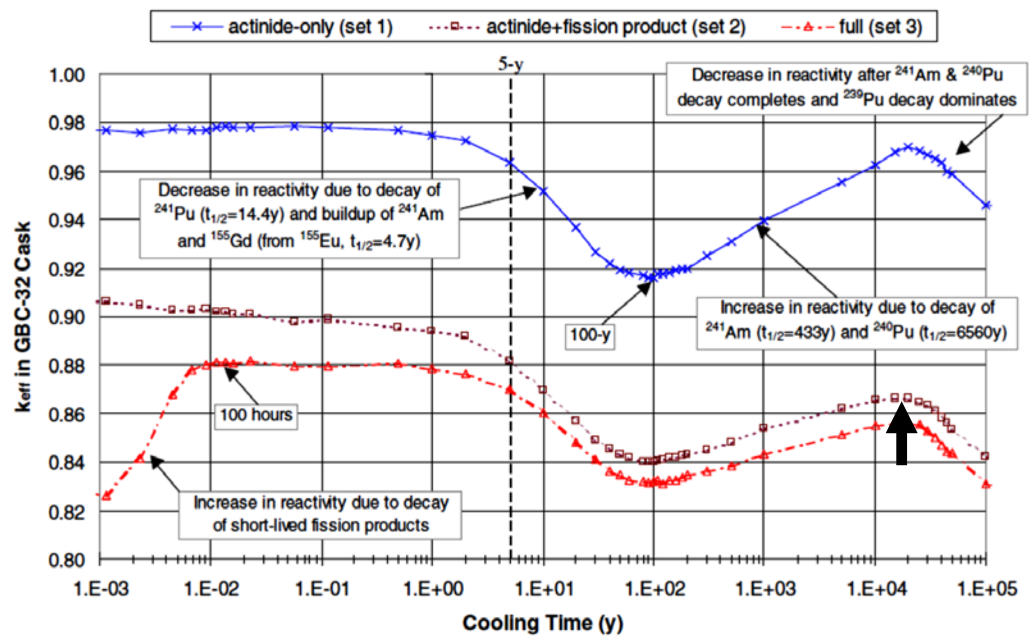
32-PWR size packages
Spacings
Package: 20 m
Drift 70: m
Drift diameter 5.5 m
SNF burnup 60 GW-d/MT
50-yr surface decay storage
50-yr repository ventilation

(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.

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).

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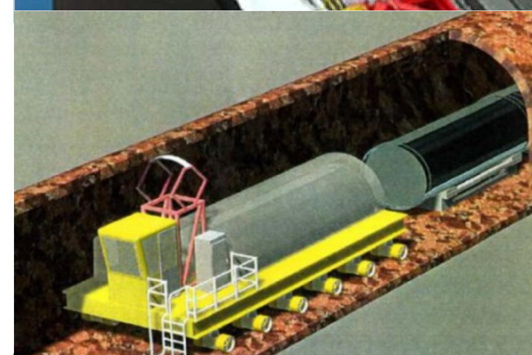
Design Options (3/3) Engineering Challenges

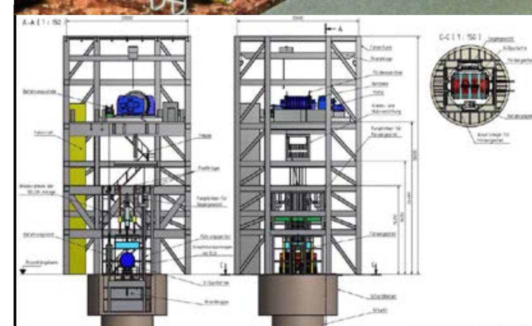
- **Handling/Packaging (current practices)**
- **Surface-to-Underground Transport**
  - Heavy shaft hoist
  - Spiral ramp (≤10% grade for rubber-tires)
  - Linear ramp (>10% grade with funicular)
  - Shallow ramp (≤ 2.5% for standard rail)
- **Opening Stability Constraints**
  - Salt (a few years with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

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).

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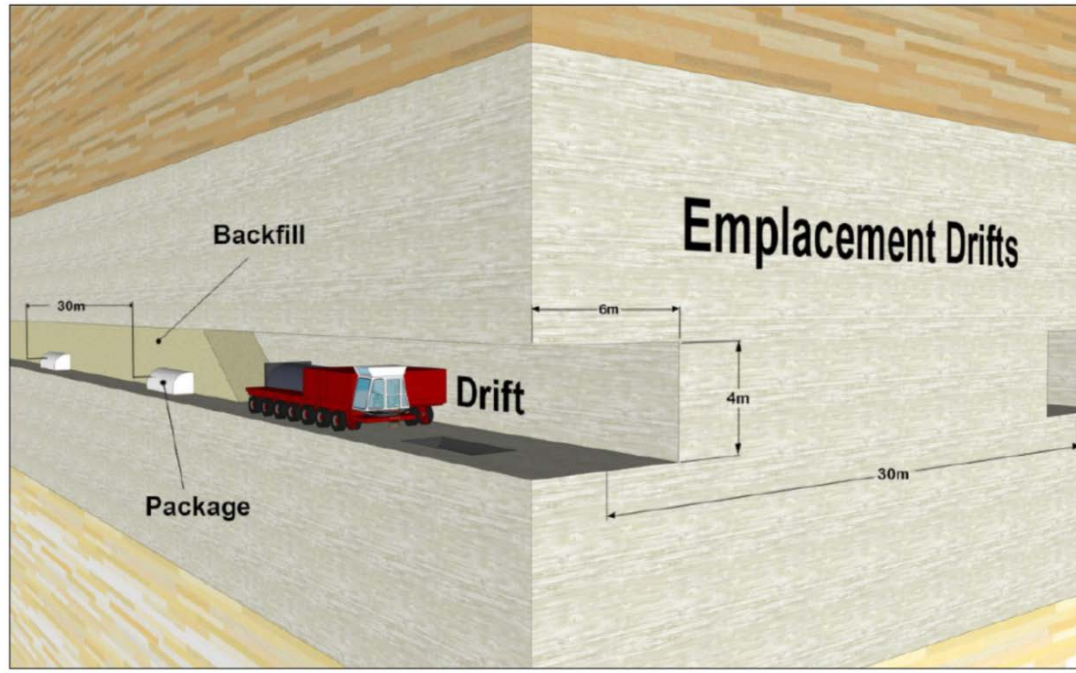
Example: Salt Concept for SNF Disposal in DPC-Based Packages

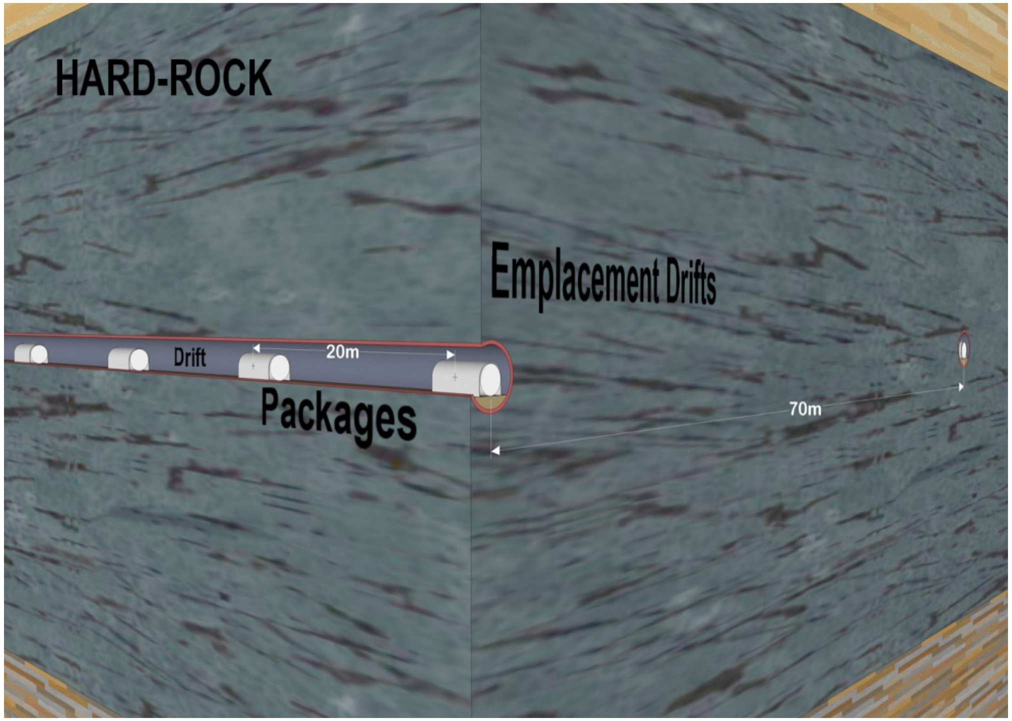
- **Emplace SNF at 50 to 70 years out-of-reactor (OoR)**
- **Crushed salt backfill at emplacement**
- **Bedded or domal salt**
- **~175 MT transport payload with shielding**
- **Simple "corrosion allowance" overpack**



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

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.

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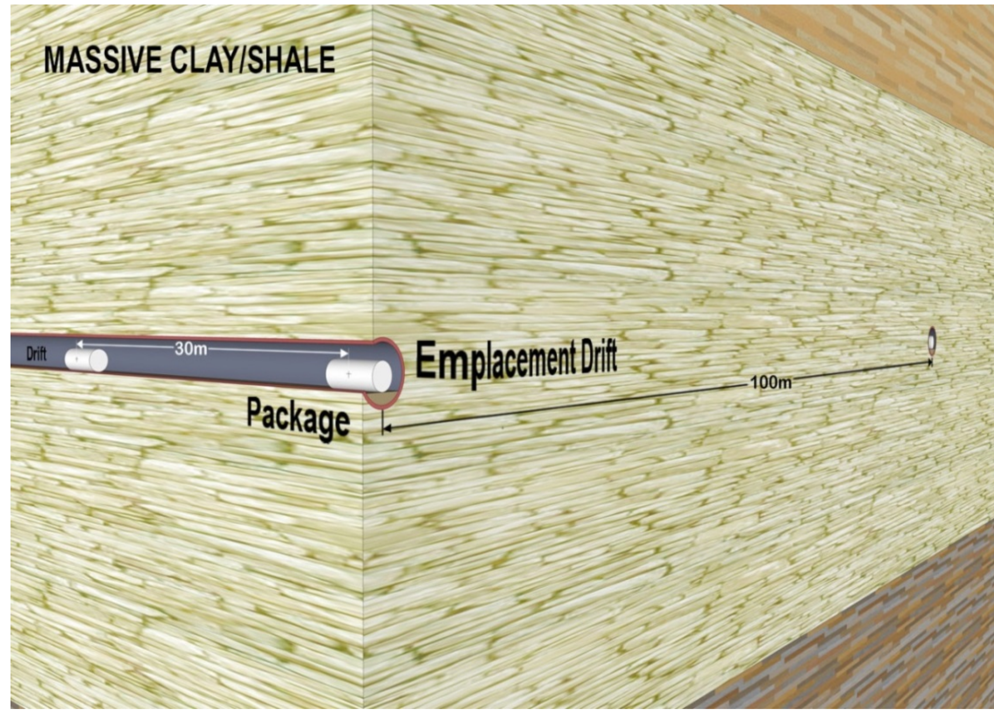
Example: Sedimentary Open, Backfilled Concept

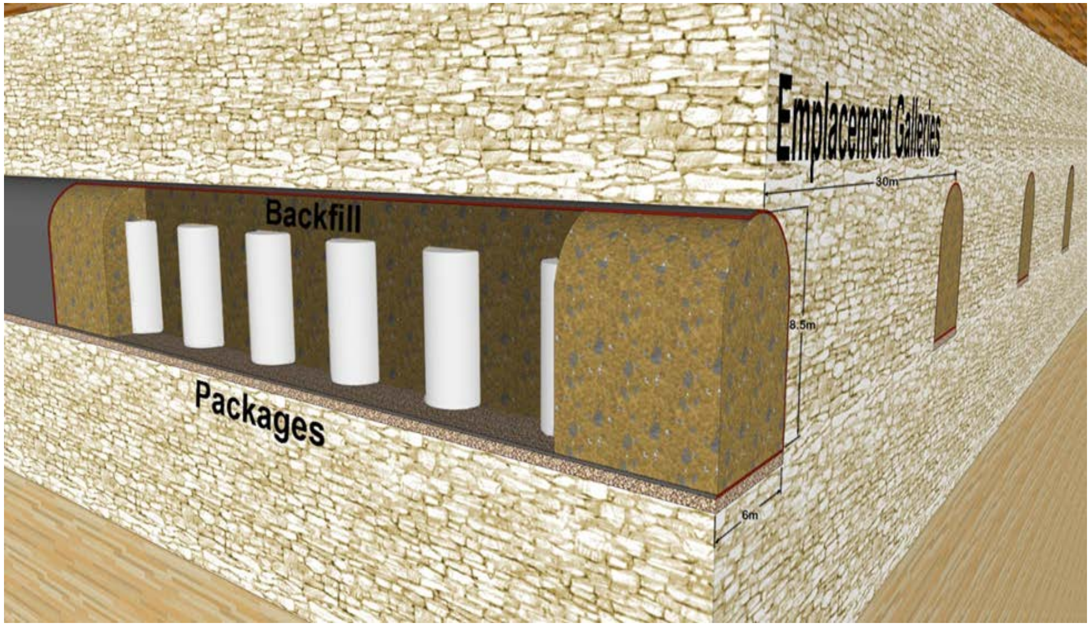
- Emplace SNF at 50 to 100 years OoR
- Flexible: combine functions of storage and disposal
- Backfill at closure (peak backfill T >> 100°C)
- Close at 100 to >200 years OoR depending on SNF burnup (limited by host rock peak temperature)
- Corrosion allowance or resistant overpack as needed



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

Example: Cavern-Retrievable Storage/Disposal Concept

- **Use existing dry storage canisters, with**
  - Existing storage casks, or
  - Purpose-built vaults
- **Large galleries**
- **Extended storage with ventilation (≥100 yr)**
- **Unsaturated settings preferred (but not required)**
- **Engineered barrier(s) installed at closure: development needed**



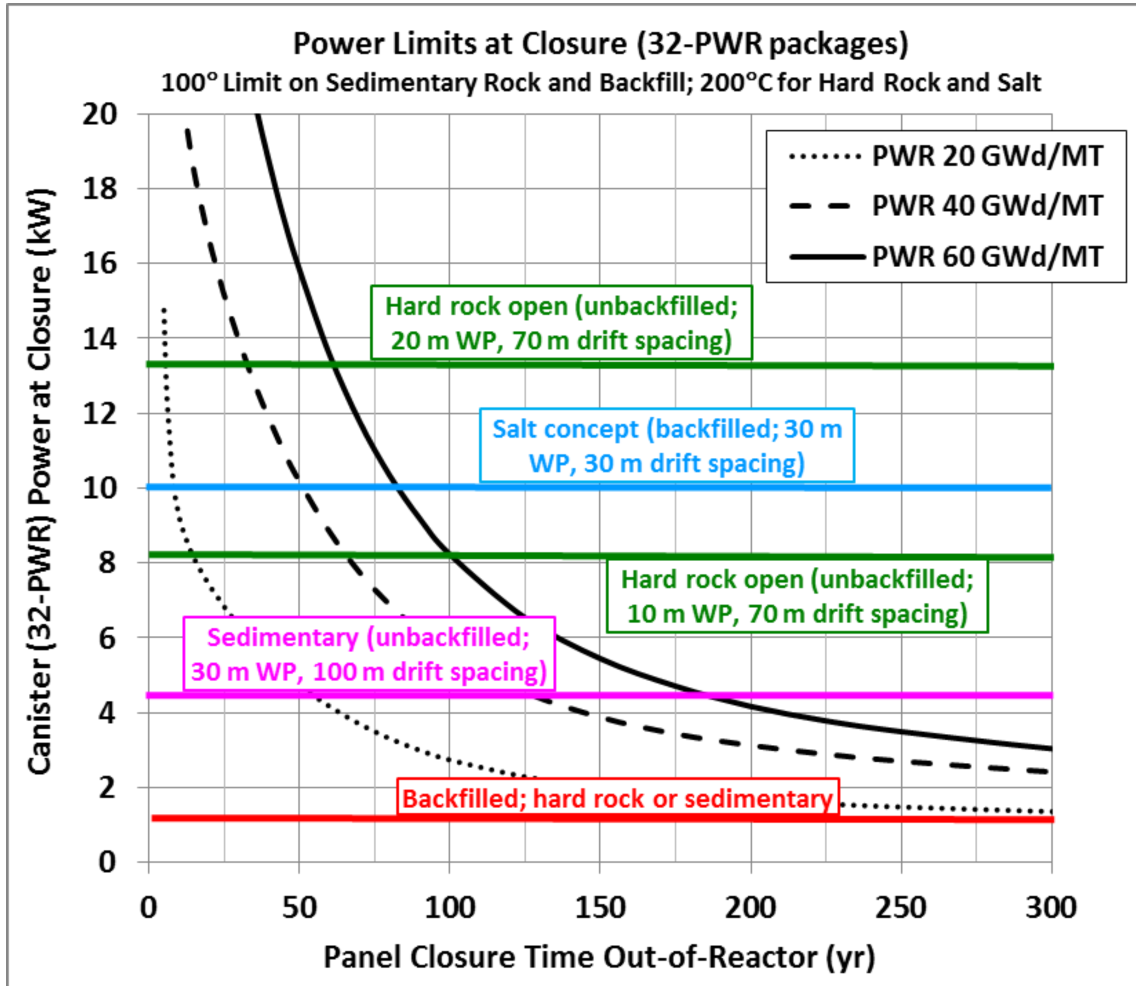
Concept from McKinley, Apted et al. 2008; figure from Hardin et al. 2013.

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.



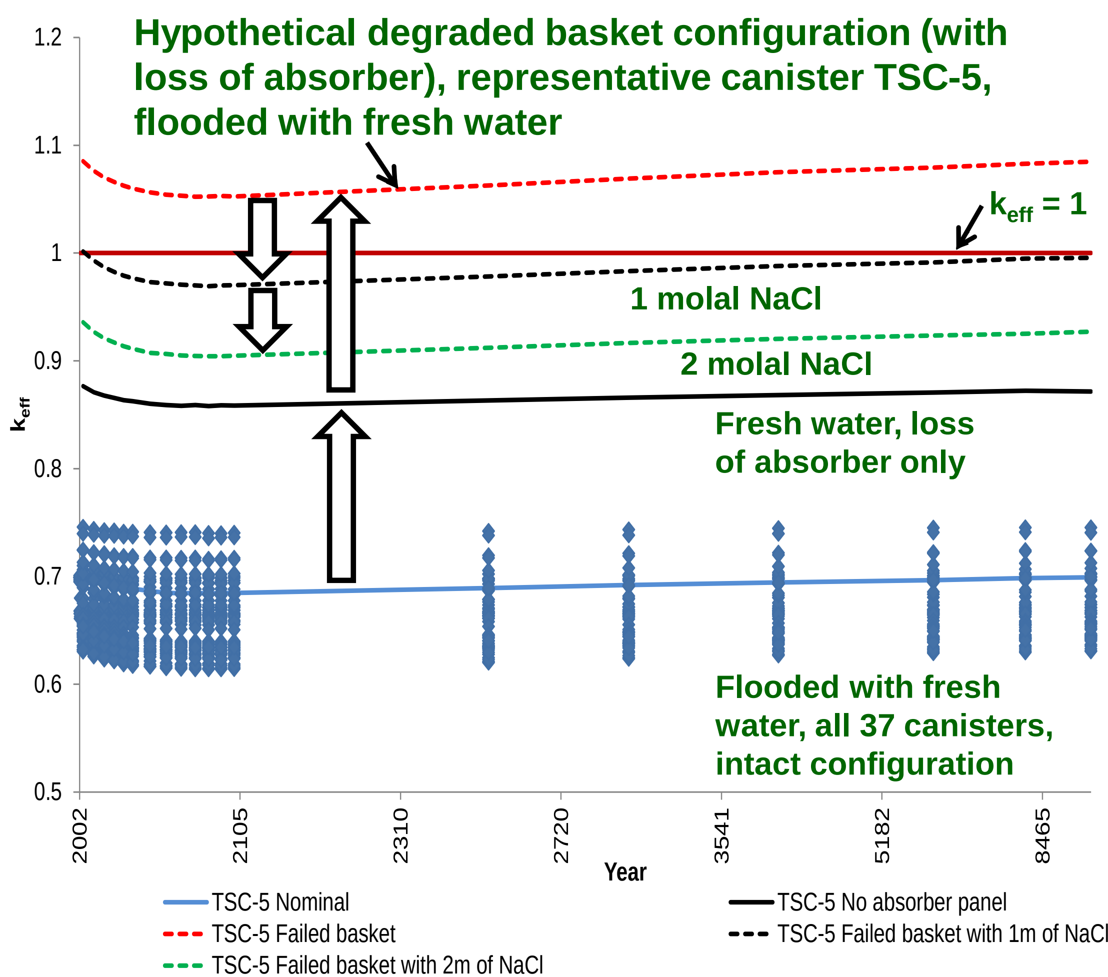
Based on: Hardin et al. 2013. *Collaborative Report on Disposal Concepts.* FCRD-UFD-2013-000170 Rev. 0.

Approach to Postclosure Criticality Analysis for DPC Direct Disposal

- **Criticality cannot occur without flooding**
  - Moderator exclusion by disposal overpack integrity is important
  - Moisture is scarce in some disposal environments
  - Groundwater has dissolved species that may absorb neutrons or displace H_2O
- **DPC neutron absorbers will be chemically and mechanically degraded on long-term exposure to groundwater**
- **Absorber and basket degradation cases**
  - Loss-of-absorber
  - Basket-degradation

Criticality Scoping Analysis Results (“Site A”) (2/2)

- 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.

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Preliminary Logistical Analysis of DPC Direct Disposal Scenarios

Objectives:

- Forecast when DPCs could be emplaced in a repository, for thermal power limits of 4, 6, 8, 10, and 12 kW/canister
- Project repository acceptance (throughput) rates
- Estimate the incremental costs that would be required to store DPCs at a centralized storage facility (CFS) facility for cooling
- Compare with estimates of the cost to re-package the SNF into purpose-built canisters for disposal

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

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

Preliminary Logistical Analysis: Assumptions

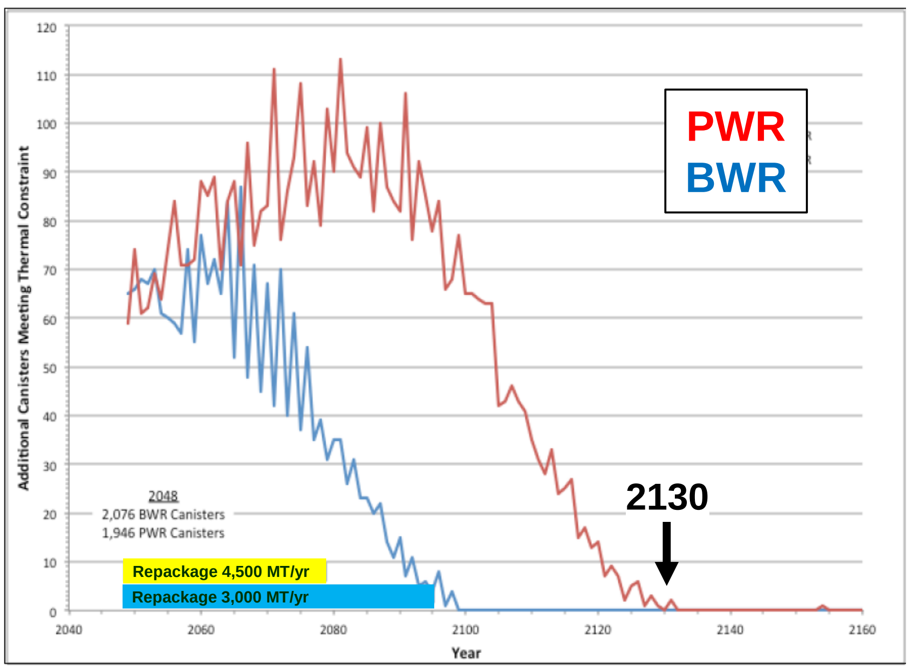
Modeling from the Present Until Repository Closure:

- SNF will be generated at all currently operating power plants, with 20-year life extensions, and gradual increases in burnup.
- All SNF would be put in dry storage as plants are decommissioned.
- Shipment of DPCs from reactor sites to the CSF would begin in 2025.
- A repository would begin to emplace DPCs underground in 2048.
- Once the repository is operating, DPCs cool enough for disposal would be shipped from reactor sites or from the CSF.

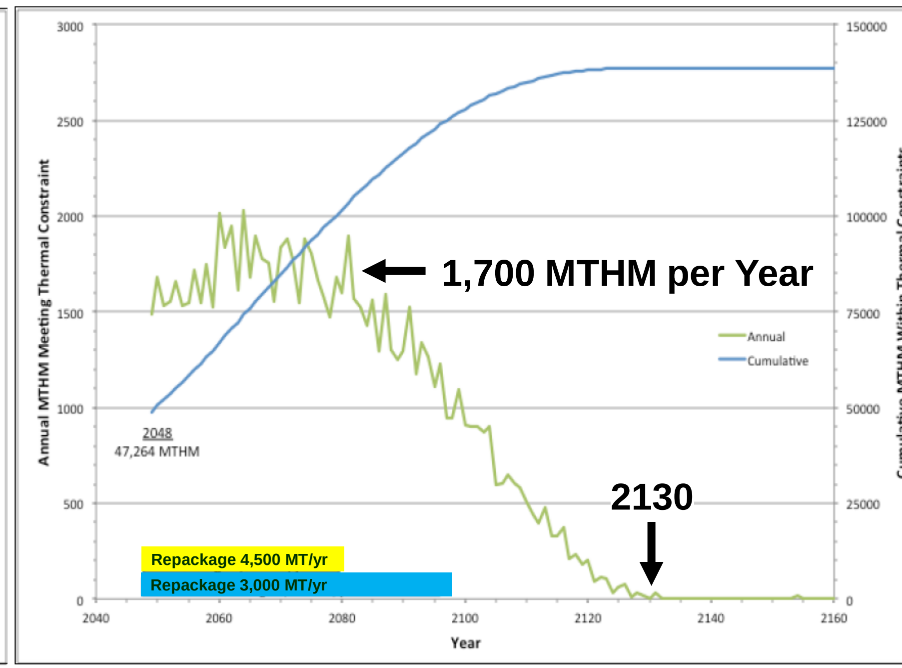
Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0

Preliminary Logistical Analysis: 10 kW Emplacement Power Limit

- 10 kW is limit would be 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

Preliminary Technical Evaluation of DPC Direct Disposal Alternatives: Summary and Conclusions

Disposal Alternatives

- Thermal, criticality, and engineering challenges have been identified for disposal concepts in crystalline, argillaceous, and salt rock types

Example Disposal Concepts for DPC-Based Waste Packages

- Salt (backfilled at emplacement)
- Hard rock (unsaturated/unbackfilled or saturated/backfilled)
- Sedimentary (clay-rich)

Thermal Results

- Repository panel closure <150 yr fuel age out-of-reactor (salt and hard rock, and low-to-moderate burnup SNF in sedimentary)
- For sedimentary settings and higher burnup SNF: need some combination of longer repository operations, local heating of host rock > 100°C, and larger repository spacings
- Backfill temperature potentially >> 100°C (if used)

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Preliminary Technical Evaluation of DPC Direct Disposal Alternatives: Summary and Conclusions, cont.

Criticality Scoping Results

- Reactivity margin available with burnup credit analysis, as-loaded assembly information
- Preliminary results show some, but not all, DPCs could be sub-critical for the degraded cases as defined
- Saline water (^{35}Cl) can provide significant neutron absorption
- Other options (e.g., fillers) are being investigated

Preliminary Logistics Result

- At 10 kW power limit, emplacement could be complete at 2130, with average emplacement rate of 1,700 MTHM/yr

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

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