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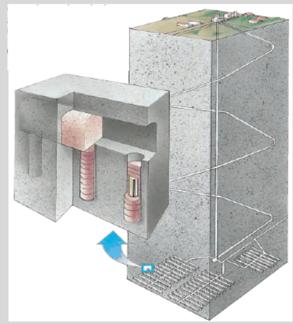

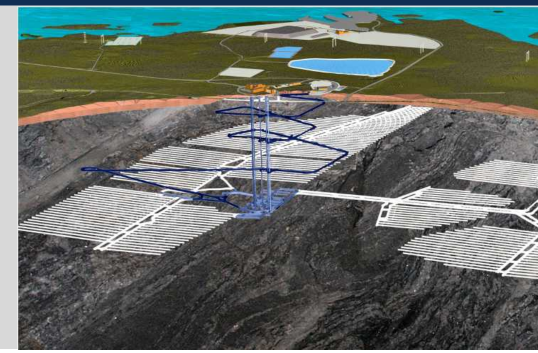

Overview of Concept Development for Geologic Disposal of Commercial Spent Nuclear Fuel

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Presentation to U.S. Department of Energy – U.K. Nuclear Decommissioning Authority
Videoconference on Opportunities to Cooperate in Radioactive Waste Management R&D – July 22, 2014

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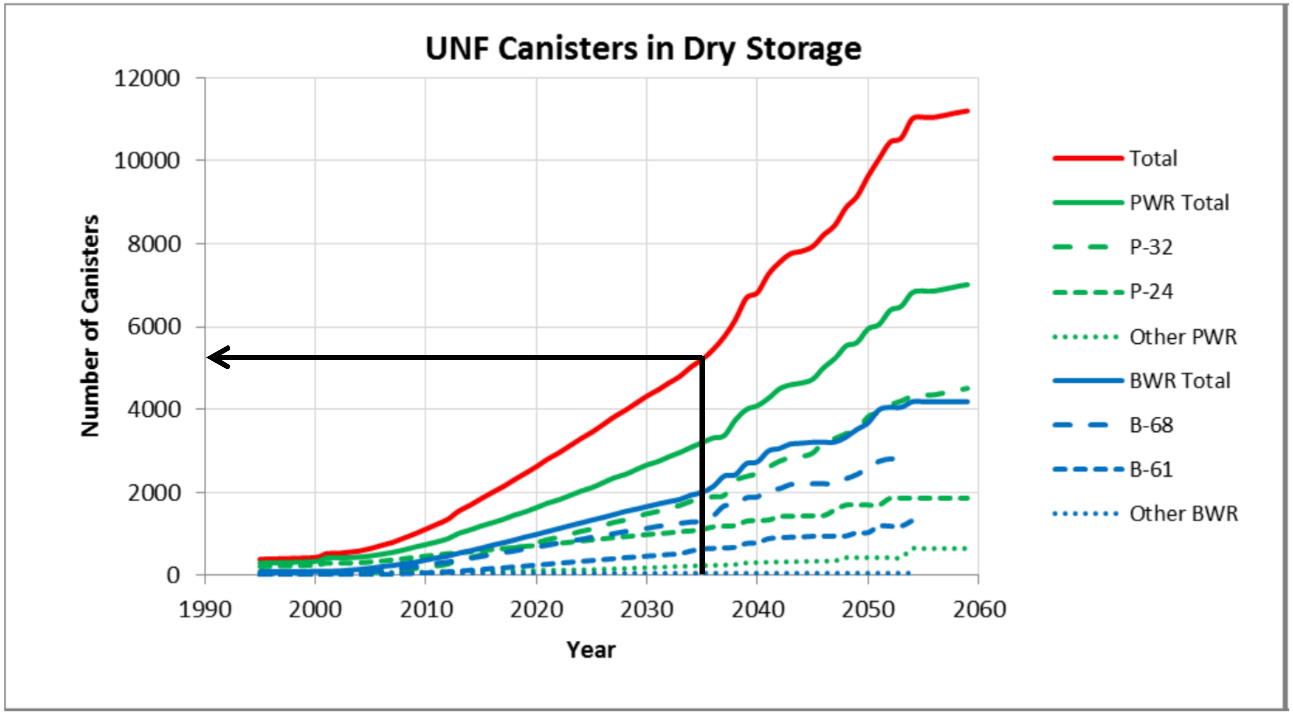
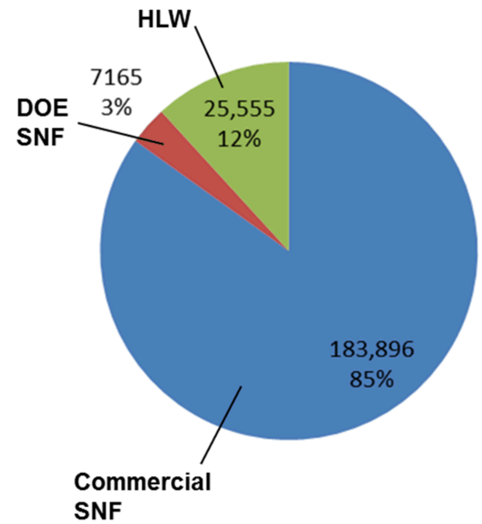
Projections of Future SNF and HLW



Historical and Projected Commercial SNF Loaded in Dry-Storage Canisters in the U.S.

Projected Volumes of SNF and HLW in 2048



Volumes shown in m^3, assuming constant rate of nuclear power generation

Largest, Recent DPC Designs

- Example: Magnastor DPC system (NAC International)
- Recently brought to market
- Capacity 37-PWR (or BWR equiv.)
- Thermal limits: 35.5 kW storage/24 kW transport
- Fuel cool time >4 yr OoR
- Size evolution (free market): burnup credit analysis, heat transfer features, transportation needs.

Pictures and data from NAC International website 31Mar2012

Mined Disposal Concepts:

Open vs. Enclosed Emplacement Modes

- **Enclosed**: Buffer, backfill or host rock material encloses and contacts waste packages immediately after emplacement
  - Thermal resistance → Increased temperature at the package and within the engineered barrier system
- **Open**: Openings persist around waste packages for 100 to $>10^4$ years
  - Can use larger waste packages, simple "in-drift" emplacement
  - Heat spread by thermal radiation
  - Pre-closure ventilation possible to remove heat
  - Backfilling may be necessary at closure

<u>Enclosed</u> Mode Thermal Analysis Summary & Effect of Varying 100°C or 200°C Limits

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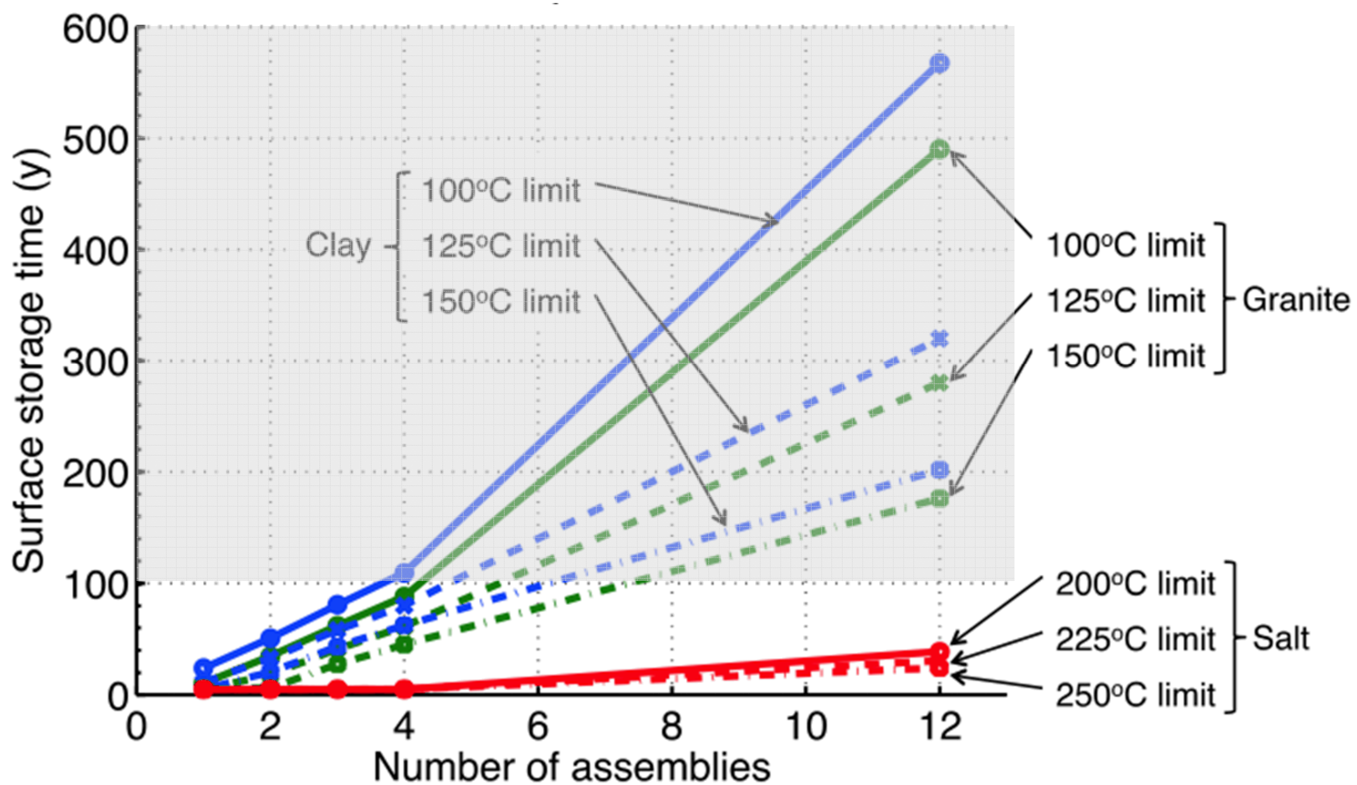
- **Temperature limits based on current international and previous U.S. concepts:**
  - **100°C for clay buffers and clay/shale media (e.g., SKB 2011)**
  - **200°C for salt (e.g., Salt Repository Project, Fluor 1986)**
- **Final temperature constraints will be site- and design-specific**
- **Waste packages for enclosed modes would be purpose-built, with design features controlling criticality.**

Decay Storage Needed to Meet WP Surface Temperature Limits vs. WP Capacity (PWR assemblies; 60 GW-d/MT burnup)



Thermal conductivity for all media selected at 100°C.

Source: Hardin, et al. 2012. FCRD-USED-2012-000219 Rev. 2.

Thermal Management for Larger/Hotter Packages

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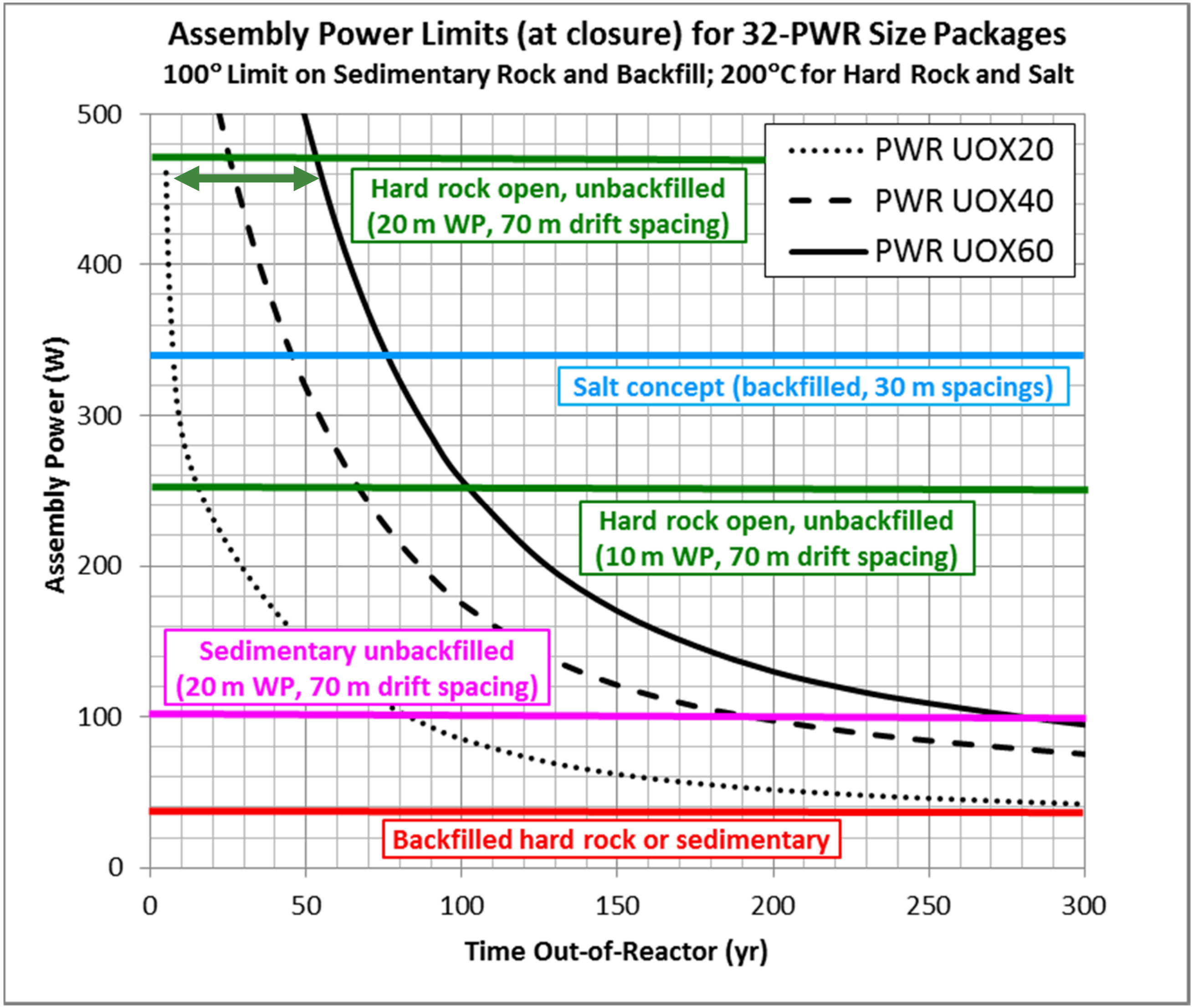
Example Results for 32-PWR Size Packages & Current Temperature Limits

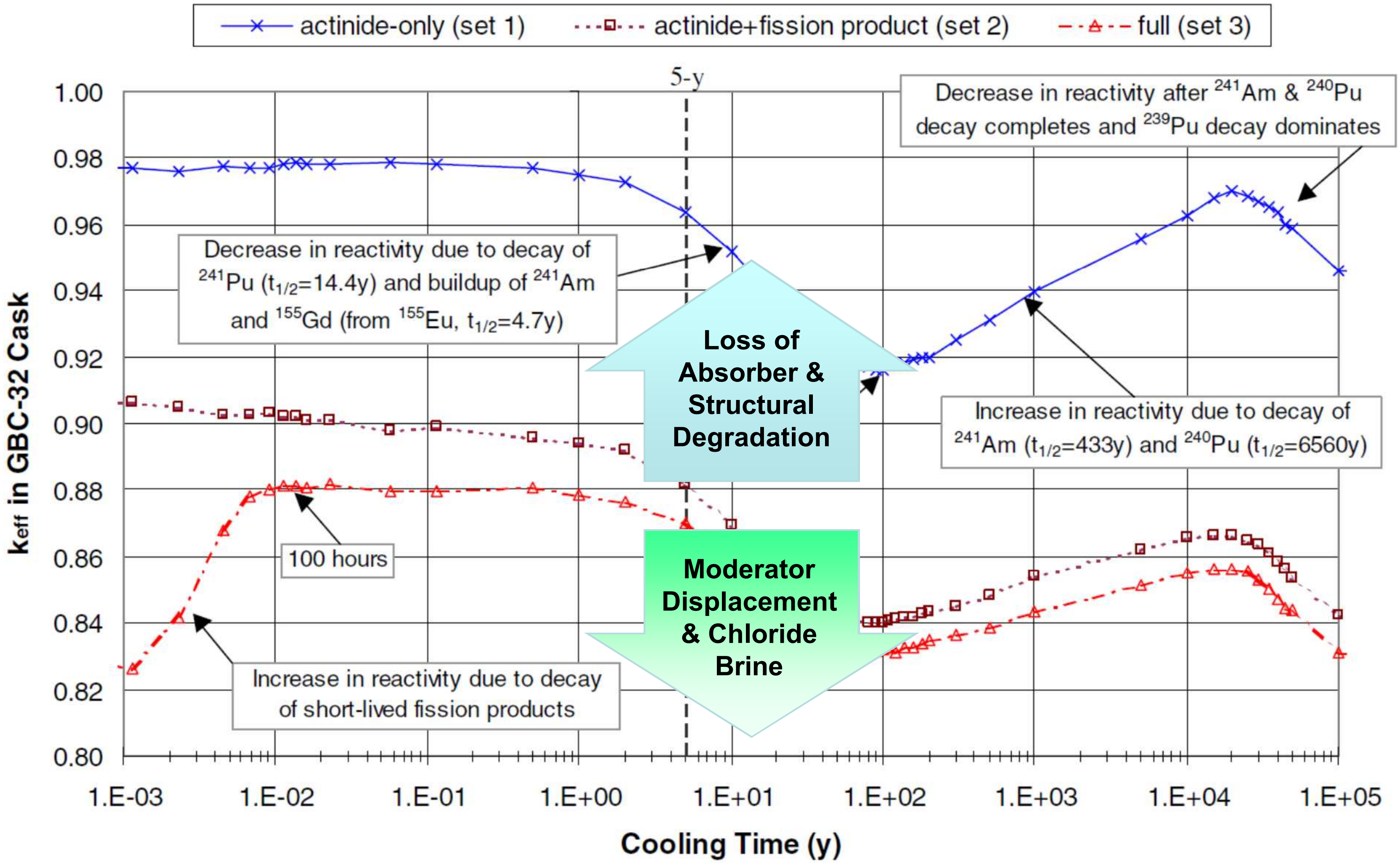
Time to Repository (or Panel) Closure for Representative Disposal Concepts

Thermal Mgmt. Degrees of Freedom:

- Package SNF capacity
- Burnup
- Age at emplacement
- Repository ventilation
- Host rock properties
- Spacings
- Use of backfill

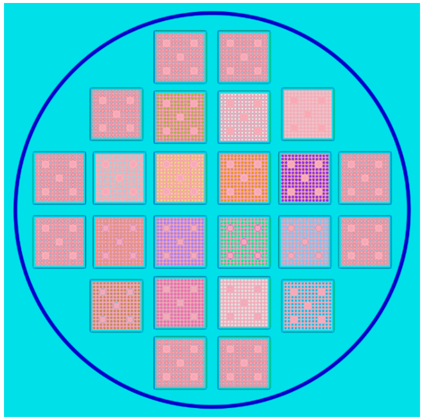


Analysis of Postclosure Criticality

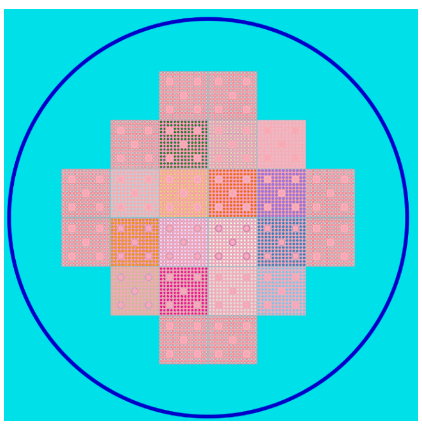


Generic burnup credit 32-PWR canister (cask) PWR fuel (4% enriched, 40 GW-d/MT burnup)
Original Figure: Wagner J.C. & C.V. Parks 2001. NUREG/CR-6781, Fig. 3.

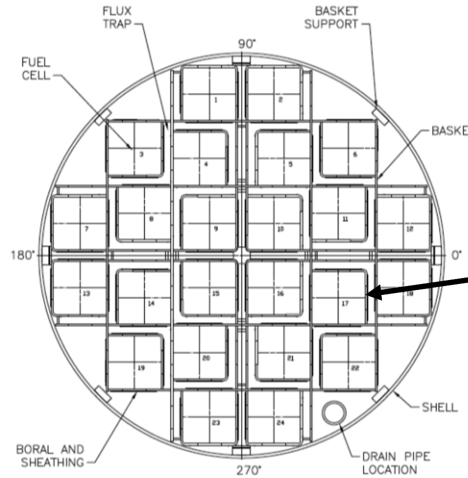
Loss-of-Absorber & Basket Degradation Cases for Large Waste Packages (DPC-based)



Intact Basket (as considered for preclosure safety analysis)

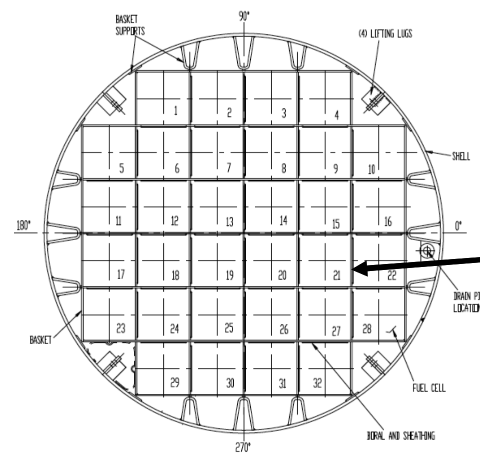


Degraded Configurations (neutron absorbers replaced by water, or entire basket removed and fuel assembly spacings minimized)



Fuel-tube type basket (e.g., Maine Yankee TSC-24)

Boral sheets attached with thin-gauge SS sheathing (welded)



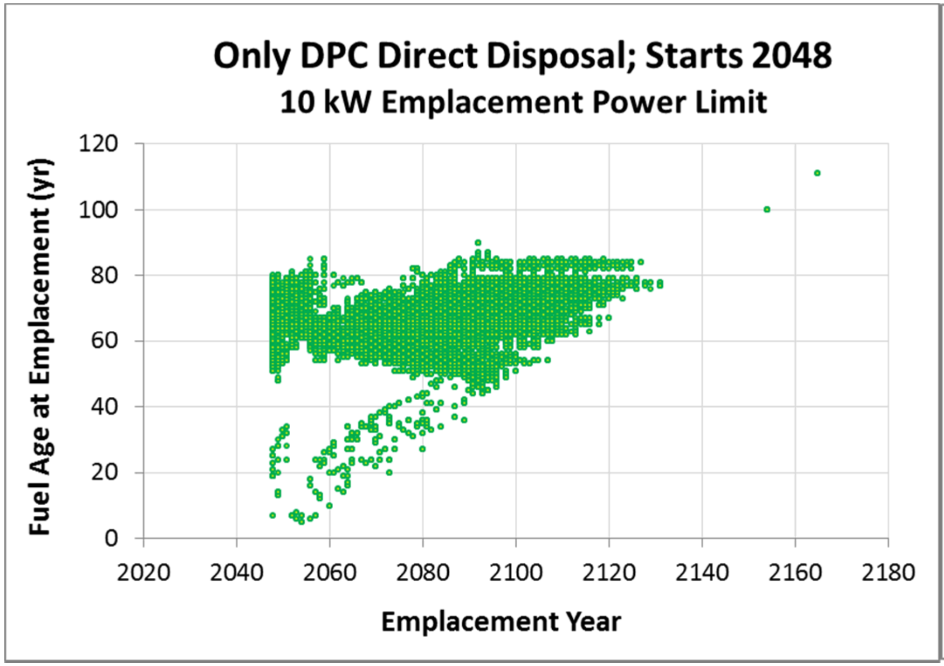
Egg-crate type basket (e.g., Sequoyah MPC-32)

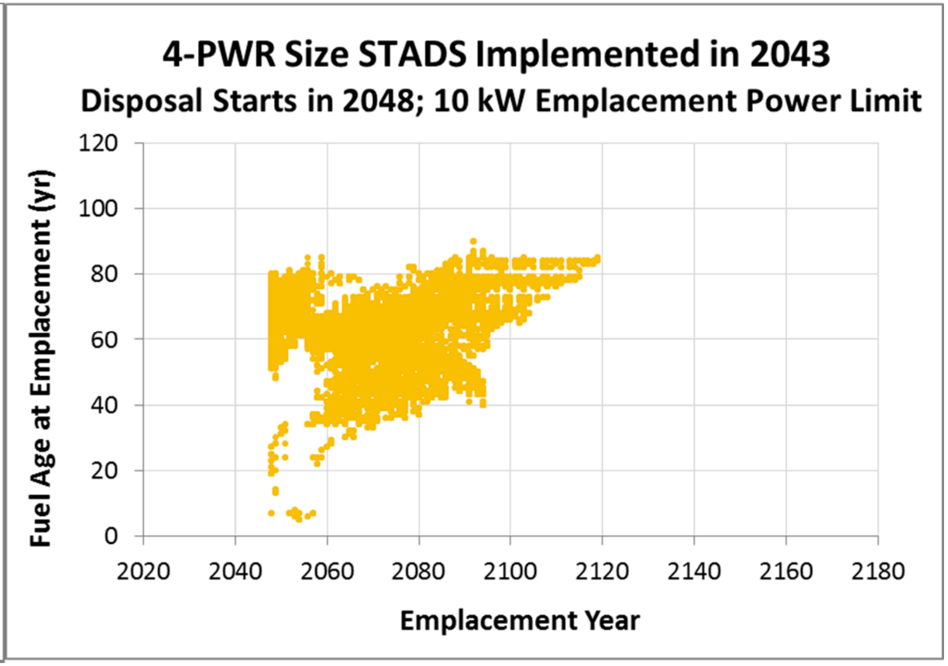
Boral sheets attached with thin-gauge SS sheathing (welded)

References:
Clarity, J.B. and J.M Scaglione 2013. ORNL/LTR-2013/213.
Hardin et al. 2012. FCRD-UFD-2012-000219 Rev. 2.

Fuel Age at Emplacement in a Repository

Compared to Re-Packaging in Small STADS



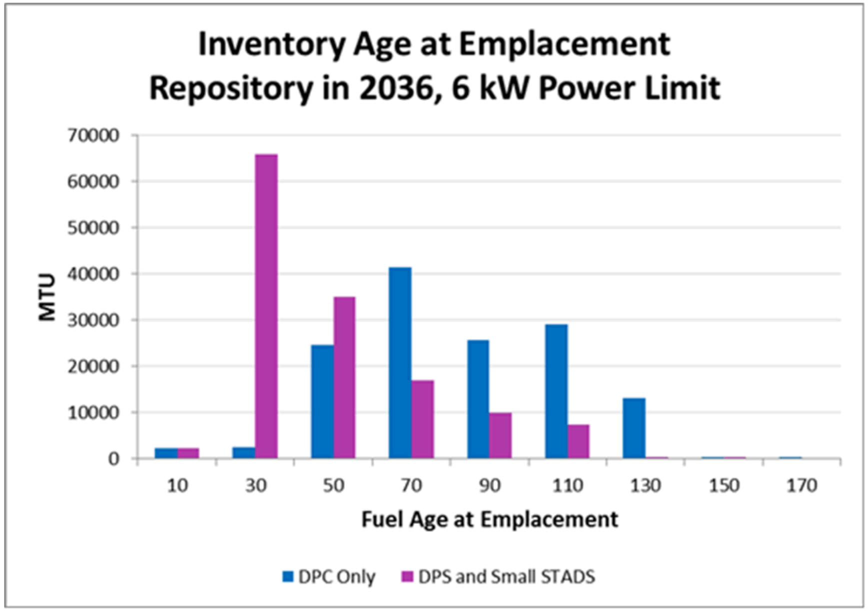


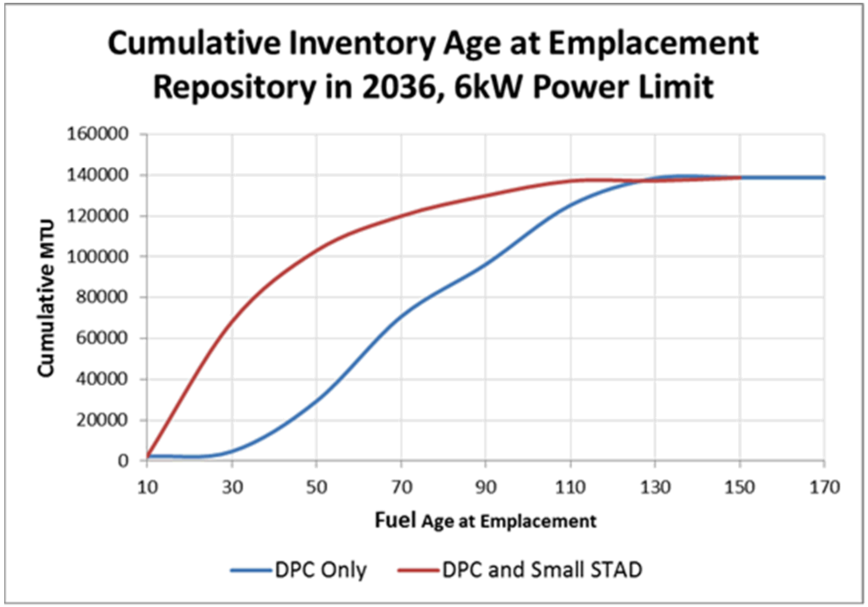
- **Plots show disposition of ~140,000 MTHM U.S. SNF**
  - For 10 kW limit, emplacement could be mostly complete by 2130
  - Smaller canisters accelerate disposal but SNF age at disposal is similar
- **Calculated using TSL-CALVIN**

Timing of DPC Direct Disposal

Compared to Re-Packaging in Small STADS

Sensitivity Case: Accelerate Repository Opening to 2036





- **Limiting Fuel Age at Disposal is Sensitive To:**
  - Smaller canisters for earlier cooling to emplacement limits
  - Earlier repository opening date to take advantage of earlier cooling
- **Calculated using TSL-CALVIN (DRAFT)**

Canister Disposability Framework

Group	Design Alternative	
Group 1 – Small canisters (up to 4 PWR assemblies or BWR equiv.) with no neutron absorbers	1.A Small capacity waste package	
	1.B Small capacity waste package combined with heavy insert	KBS-3
Group 2 – Larger canisters with bolted closures or bolted/welded combinations	2.A Bolted closures (both inner and outer canister lids)	
	2.B Bolted closure combined with welded closure	
	2.C Can-within-can arrangements using bolted or welded closures	
Group 3 – Existing DPC designs (welded closures) used for disposal without reopening	3.A High reliability (~10^{-12}/year/package) overpack performance	DPC Direct Disposal
	3.B Disposal in unsaturated conditions with multiple engineered and natural groundwater diversion/ exclusion barriers that prevent flooding for at least 10,000 years.	DPC Direct Disposal
	3.C Flooding possible only with chloride brine	DPC Direct Disposal
	3.D Disposal of existing DPCs so that packages are subcritical after flooding with dilute ground water and degradation of canister internals.	DPC Direct Disposal
Group 4 – Existing DPC designs (welded closure) used for disposal with modifications	4.A Reactivity control improvements	DPC Direct Disposal
	4.B Fillers for reactivity control	DPC Direct Disposal
Group 5 – Multi-purpose canisters with long-lived baskets and neutron absorbers	5.A Larger canisters, with basket and absorber materials selected for longevity in oxidizing environments	DOE 2008
	5.B Larger canisters, with basket and absorber materials selected for longevity in a range of chemically reducing and oxidizing environments	

Source: Hardin, E. 2013. Spent Fuel Canister Disposability Baseline Report. FCRD-UFD-2014-000330 Rev. 0.

Possible DPC Direct Disposal, Re-Packaging and STAD Canister Strategies

STAD Canister ≡ Storage, Transport and Disposal, "Multi-Purpose" Canister	Existing Canister Designs			New Design
	Storage-Only Canisters: Re-Package→ Disposal	DPCs: Re-Package→ Disposal	DPCs: Direct Disposal	Operational Switch to STAD Canister at Power Plants
1. No near-term changes→ Re-package (*current path*)	√	√		
2. No near-term changes→ Maximize direct disposal (*evaluate*)	?		√	
3. Multiple modes of disposal→ Minimize re-packaging (*evaluate*)	?		√	√
4. Re-package→STAD canister full implementation	√	√		√

Summary

- **Enclosed disposal concepts are probably too hot for SNF canisters larger than 4-PWR/12-BWR size**
- **If larger canisters are intentionally backfilled, peak backfill temperature will be >150°C unless decay storage duration is 100's of years**
- **Larger canisters may require long-life components to control post-closure criticality on exposure to ground water for thousands of years**
- **Salt repositories offer superior heat dissipation and neutron absorption**
- **R&D activities continue on small and large packages, canister design, and direct disposal of DPC-based packages**