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Geologic Disposal Concepts for HLW and Spent *Nuclear Fuel*

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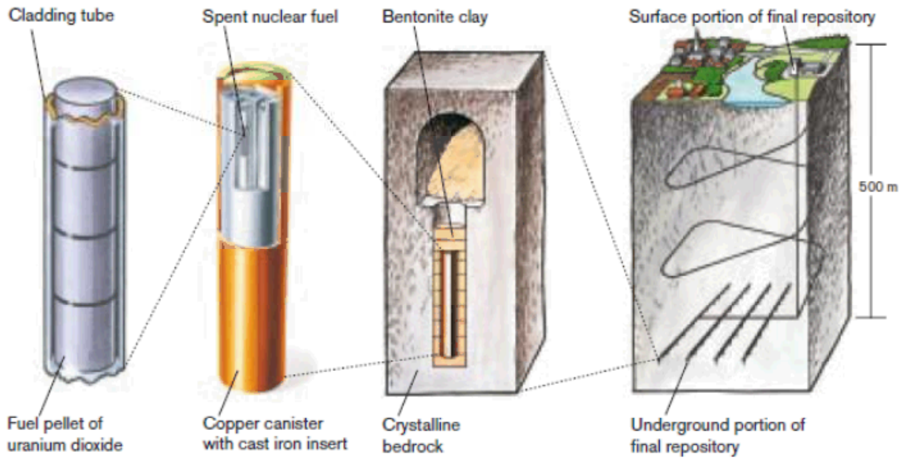
Outline

- Introduction, disposal concepts, waste forms, SNF projections
- Enclosed-mode disposal concepts (international)
- WIPP disposal mission
- Temperature limits and thermal analysis for enclosed modes
- Open-mode disposal concepts for larger, hotter packages (U.S.)
- Direct disposal (open-mode) of SNF in existing dual-purpose canisters
  - DPC designs
  - Projected SNF storage in DPCs
  - Engineering challenges
  - Thermal analysis
  - Nuclear reactivity scoping analysis
- Summary

The Used Fuel Disposition Campaign

- **Scope**: Identify alternatives and conduct research and development to enable storage, transportation and disposal of spent nuclear fuel (SNF) and high level waste (HLW) generated by existing and future nuclear fuel cycles.



- The UFDC developed a set of reference geologic disposal concepts in FY11-13, that provide context for ongoing research and development activities.

Hardin, E.L., Geologic Disposal Concepts for HLW and Spent Nuclear Fuel

Disposal Concept Definition: Three Elements

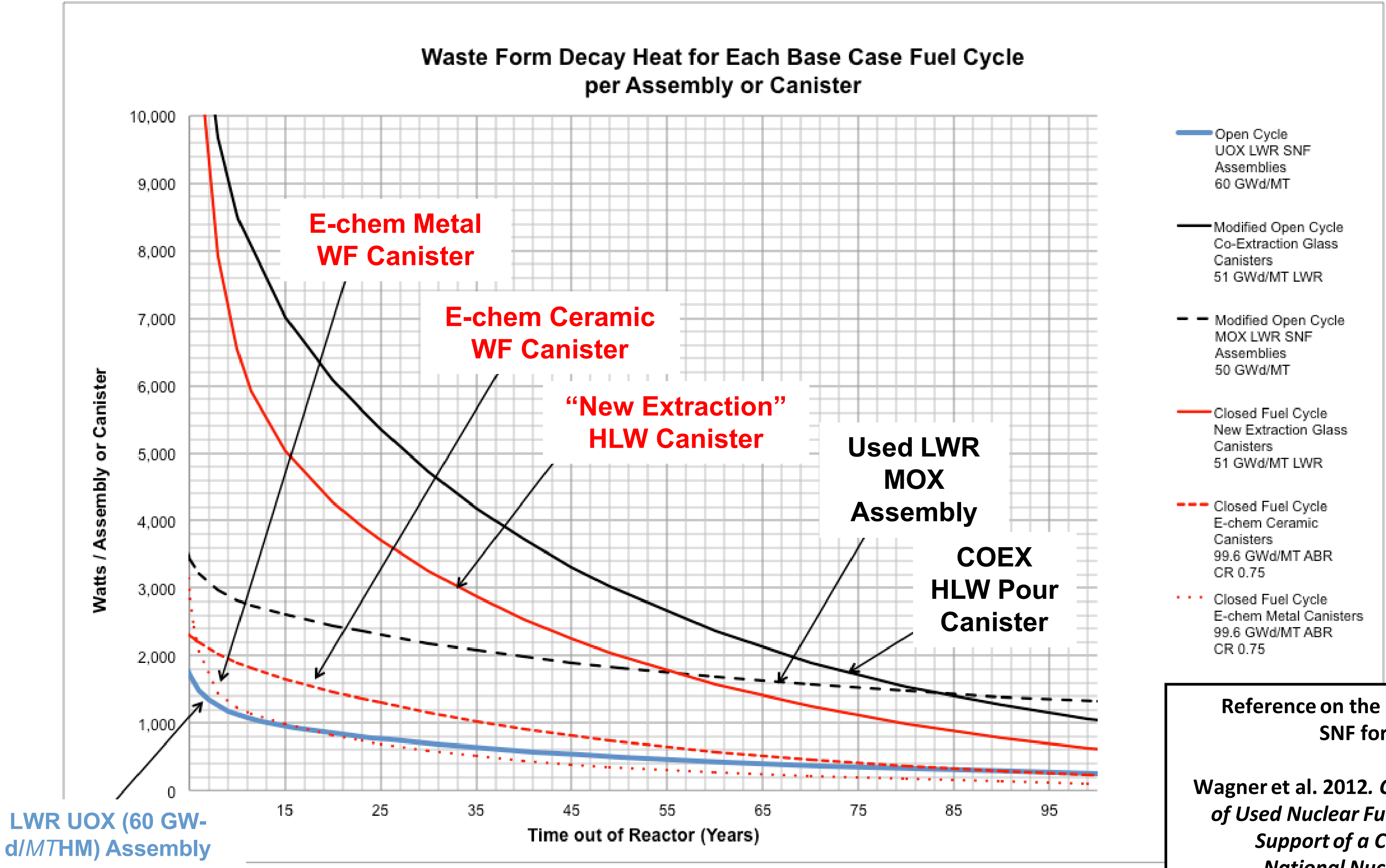
1. **Waste inventory**
   - Waste types from a sample of possible future commercial fuel cycles (Carter et al. 2012)
2. **Geologic setting**
   - Clay/shale, crystalline rock, bedded salt, and deep crystalline basement
3. **Engineering concept of operation**
   - Examples:
     - Clay/shale repository (Andra, Dossier 2005)
     - KBS-3 (vertical) disposal (SKB, SR-Site 2011)
     - Deep borehole concept (Brady et al. 2009)
     - Generic salt repository (Carter et al. 2011)

Six Heat-Generating Reference Waste Types

Strategy Sampled	Description	Waste Types (Carter et al. 2012)	Example Source
Once-Through	Direct disposal of high-burnup (60 GW-d/tHM) LWR UOX SNF	• UOX SNF (burnup range 20, 40 & 60 GW-d/MT)	• Generation III+ LWRs
Modified-Open	Reprocessing of LWR UOX used fuel (51 GW-d/tHM) to produce MOX fuel, which is used once (50 GW-d/tHM) then disposed of directly	• MOX SNF • Co-Extraction HLW borosilicate glass	• "Transitional" variation of the French strategy with direct disposal of MOX SNF • Irradiated MOX fuel from Pu-disposition program (~500 MTHM)
Closed	Reprocessing of LWR UOX used fuel (51 GW-d/tHM) to produce U-TRU metal fuel for SFRs (0.75 conversion ratio), and repeated recycle of the SFR used fuel (99.6 GW-d/tHM)	• "New-Extraction" HLW borosilicate glass • Electrochemical ceramic HLW • Electrochemical fission-product metal HLW	• "Transitional" fast-spectrum burner strategy with TRU recycling (e.g., Sevougian et al. 2011)

Sevougian S. D. et al. 2011. *Initial Screening of Fuel Cycle Options*. FCRD-SYSE-2011-000040 Rev. 0.

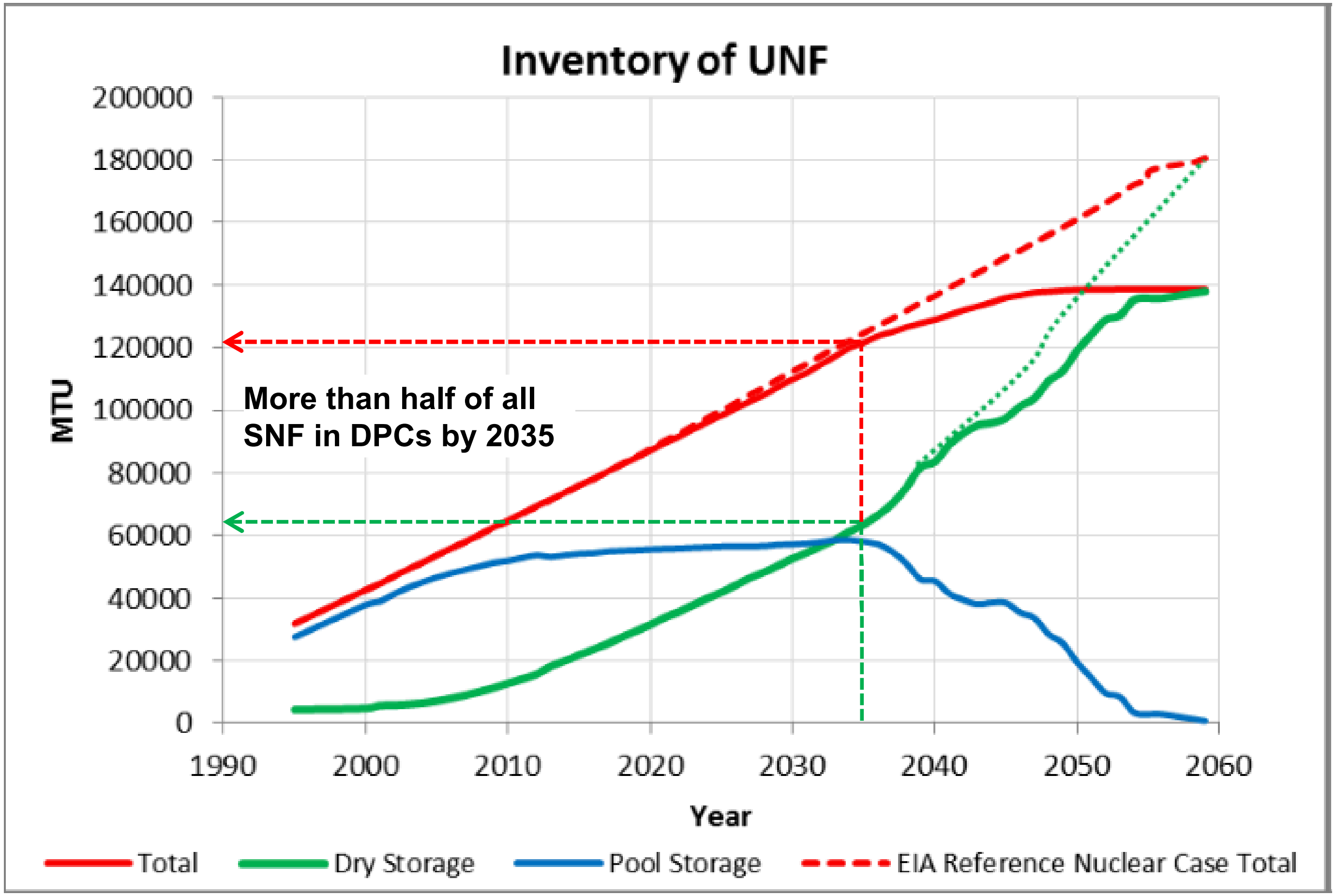
Heat Output for Reference Waste Forms, by Assembly or Canister (Carter et al. 2012)



Reference on the need to retain SNF for reprocessing:

Wagner et al. 2012. *Categorization of Used Nuclear Fuel Inventory in Support of a Comprehensive National Nuclear Fuel Cycle Strategy*. FCRD-FCT-2012-000232.

Spent Fuel Projection – TSL-CALVIN* Accumulation of Heavy Metal (MTHM)

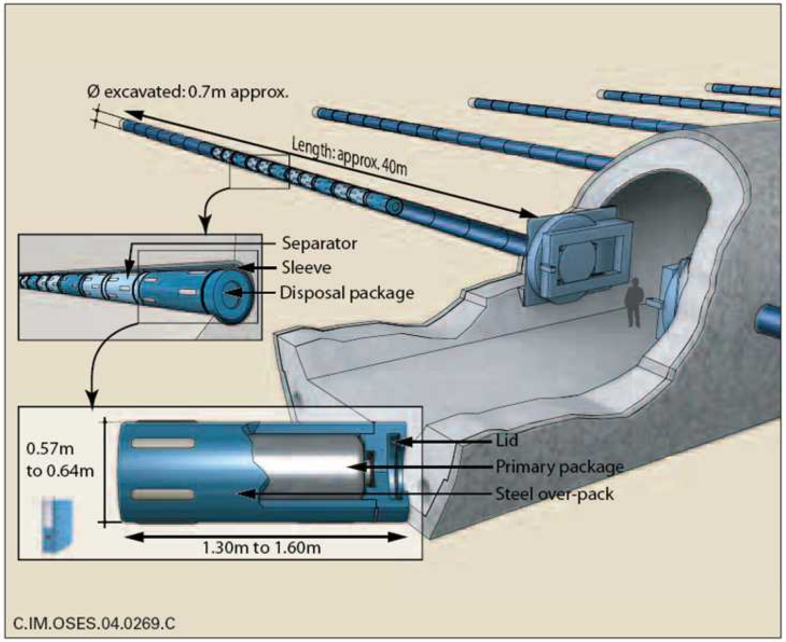


Assume 20-yr Life Extensions for the Currently Operating Reactor Fleet.

* Nutt et al. 2012. *Transportation Storage Logistics Model – CALVIN (TSL-CALVIN).* FCRD-NFST-2012-000424.

Reference Disposal Concepts:
Mined Clay/Shale with Horizontal Emplacement

- Ref.: Based on Andra 2005
- Depth: ~500 m
- Hydrologic setting: Saturated
- Near-field temp. limit: 100°C
- # of 4-PWR size packages for U.S. SNF: 86,049 *



Disposal Characteristic	SNF	HLW
Emplacement mode	Horizontal, in drift	Horizontal, boreholes
Overpack material	Steel	Steel
Package spacing, m	10	6
Drift (borehole) spacing, m	30	30
Borehole liner material	Steel	Steel
Buffer material	Bentonite clay	-
Backfill material	Crushed clay/shale	Crushed clay/shale

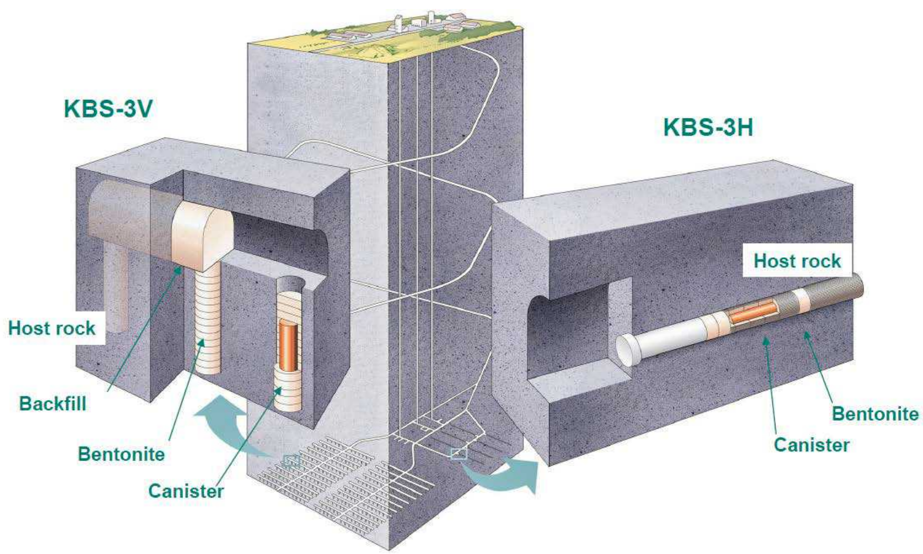
(left) Andra HLW disposal concept (no buffer).

Andra 2005. *Dossier 2005 argile – architecture and management of a geological disposal system.* December, 2005.

* Kalinina, E. and E. Hardin 2012. SAND2012-8109. Sandia National Laboratories.

Reference Disposal Concepts:
Mined Crystalline Rock with Vertical Borehole Emplacement

- Ref.: Based on KBS-3 (SKB 2011)
- Depth: ~500 m
- Hydrologic setting: Saturated
- Buffer temperature limit: 100°C
- # of 4-PWR size packages for U.S. SNF: 86,049 *



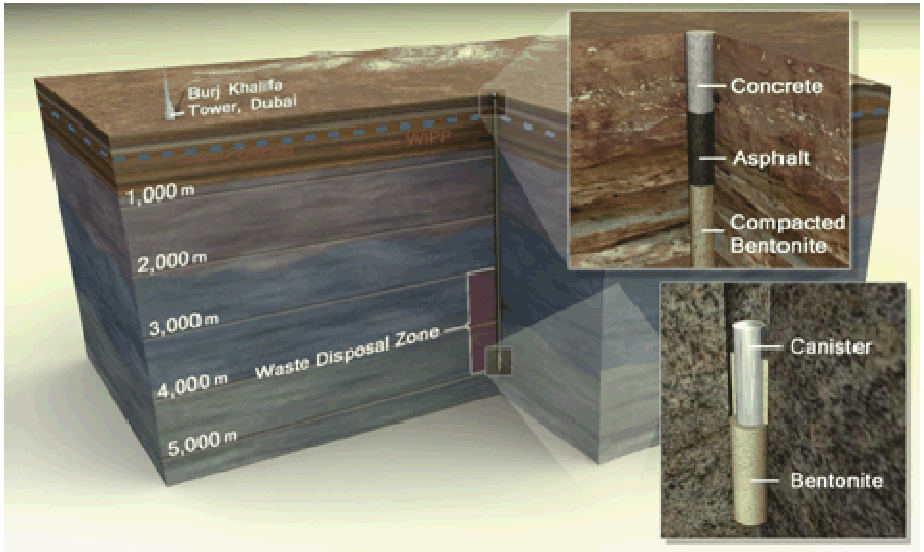
Disposal Characteristic	SNF	HLW
Emplacement mode	Vertical boreholes	Vertical boreholes
Overpack material	Copper or steel	Steel
Borehole spacing, m	10	10
Drift spacing, m	20	20
Borehole liner material	-	-
Buffer material	Bentonite clay	Bentonite clay
Backfill material	Clay/sand mixture	Clay/sand mixture

SKB (Swedish Nuclear Fuel and Waste Management Co.) 2011. *Long-term safety for the final repository for spent nuclear fuel at Forsmark: Main report of the SR-Site project, Volume* I. TR-11-01.

* Kalinina, E. and E. Hardin 2012. SAND2012-8109. Sandia National Laboratories.

Reference Disposal Concepts: Deep Borehole Disposal

- Ref.: SNL and MIT studies
- Depth: 3 to 5 km
- Hydrologic setting: Saturated
- Temperature constraint: None

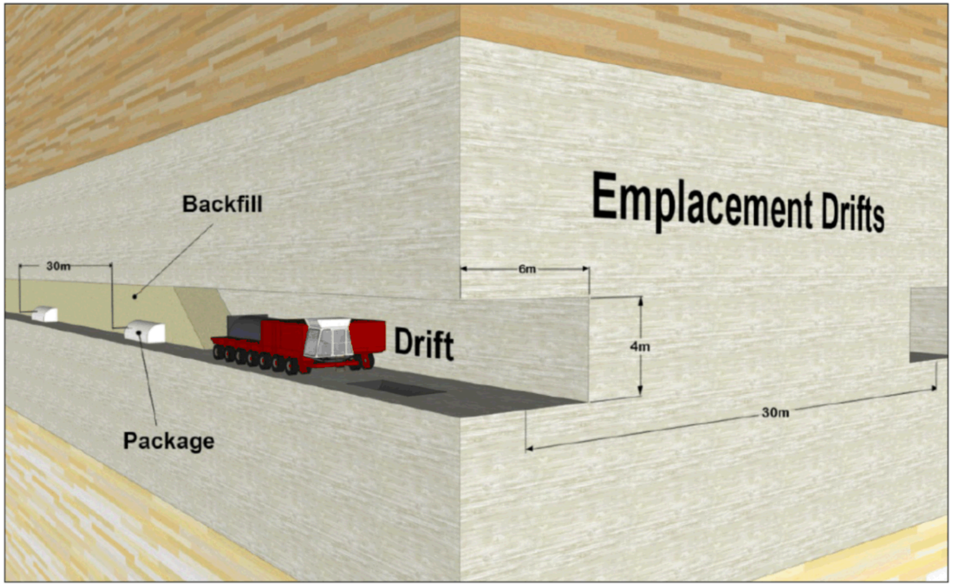


Disposal Characteristic	SNF	HLW
Emplacement mode	Vertical, stacked	Vertical, stacked
Overpack material	Steel	Steel
Package spacing, m	6	6
Borehole spacing, m	200	200
Borehole liner material	Steel	Steel
Buffer material	Water/mud	Water/mud
Backfill material	-	-

Reference: Brady, P.V. et al. 2009. *Deep borehole disposal of high-level radioactive waste*. SAND2009-4401. Sandia National Laboratories.

Reference Disposal Concepts:
Generic Salt Repository with In-Drift Emplacement

- Ref.: Generic salt repository (Carter et al. 2011; Hardin et al. 2013)
- Depth: ~500 m
- Hydrologic setting: Saturated
- Salt temperature limit: 200°C
- # of 21-PWR size packages for U.S. SNF: 28,648 *



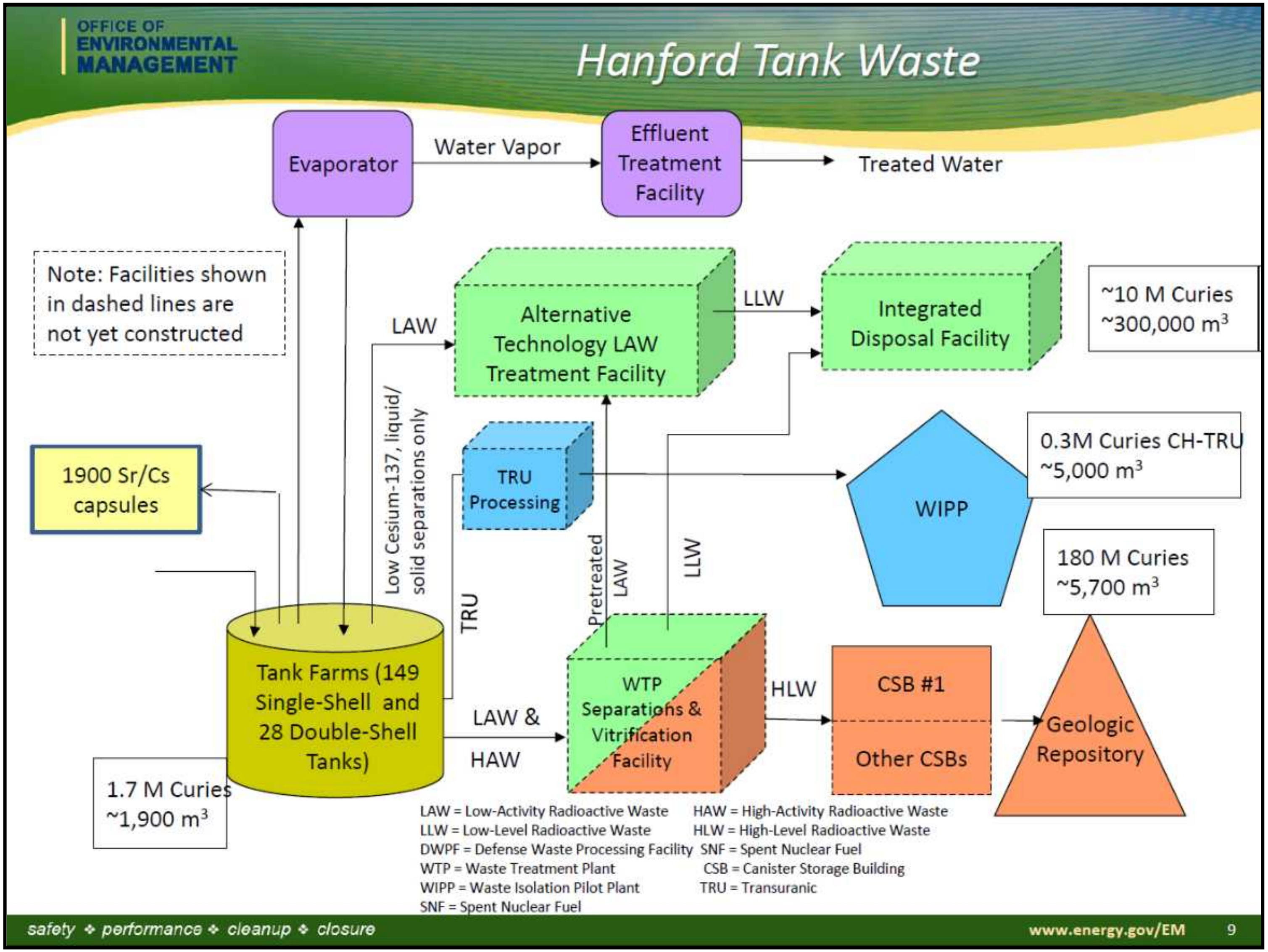
Disposal characteristic	SNF	HLW
Emplacement mode	Horizontal, in-drift (axial)	Horizontal, in drifts or alcoves (transverse)
Overpack material	Steel	Steel
Package spacing, m	Up to 30 m	2 m (in-drift) to 20 m (alcove)
Borehole liner material	-	-
Buffer material	-	-
Backfill material	Crushed salt	Crushed salt

Carter et al. 2011. *A generic salt repository for disposal of waste from a spent nuclear fuel recycle facility*. SRNL-RP-2011-00149 Rev. 0.

Hardin et al. 2013. *Preliminary Report on Dual-Purpose Canister Disposal Alternatives*. FCRD-UFD-2013-000171 Rev. 0.

* Kalinina, E. and E. Hardin 2012. SAND2012-8109. Sandia National Laboratories.

WIPP Disposal Mission in Context



TRU waste ≡ >100 nCi/gm (3700 Bq/gm) as α-emitting TRU nuclides with half-life >20 yr (without regard to form or origin).

TRU waste may be contact handled (steel containers) or remote handled (up to 10 Sv/hr surface dose rate)

Slide from: Picha, K. 2013. *Nuclear Waste Technical Review Board Overview: Office of Environmental Management*. Presentation April 16, 2013. (www.nwtrb.gov)

Disposal Concept for Canistered Defense Waste in a Salt Repository

- In-drift, transverse emplacement
- No overpacks
- Low heat output defense waste

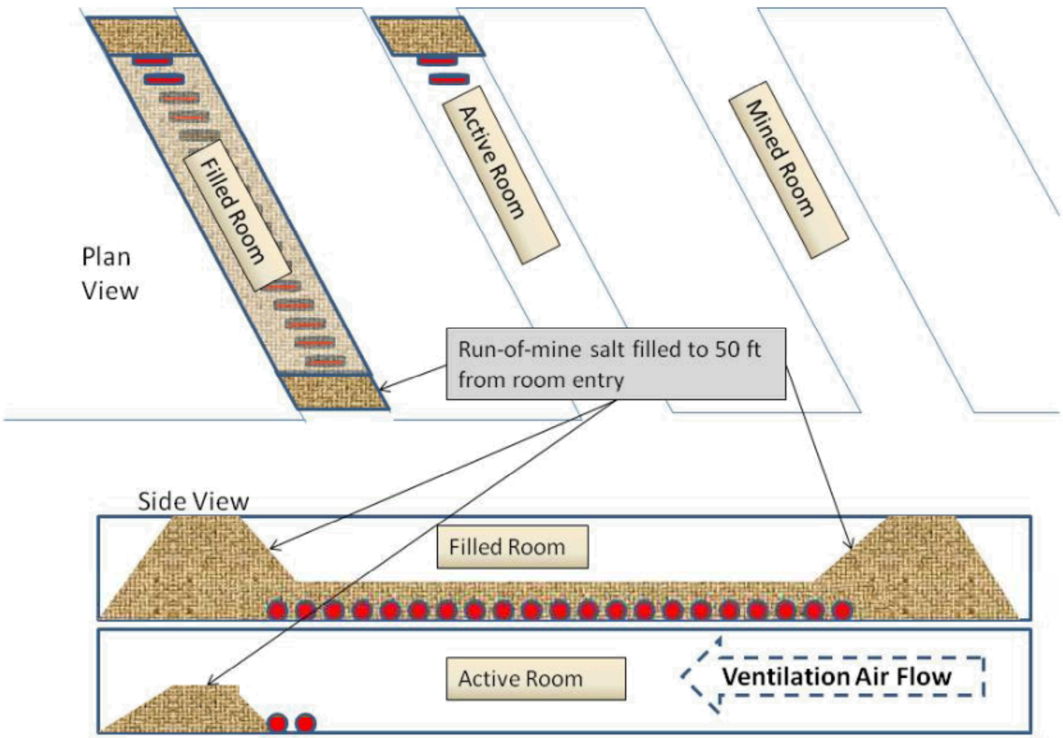


Figure source:
Carter et al. 2012. *Defense Waste Salt Repository Study*. FCRD-UFD-2012-000113.

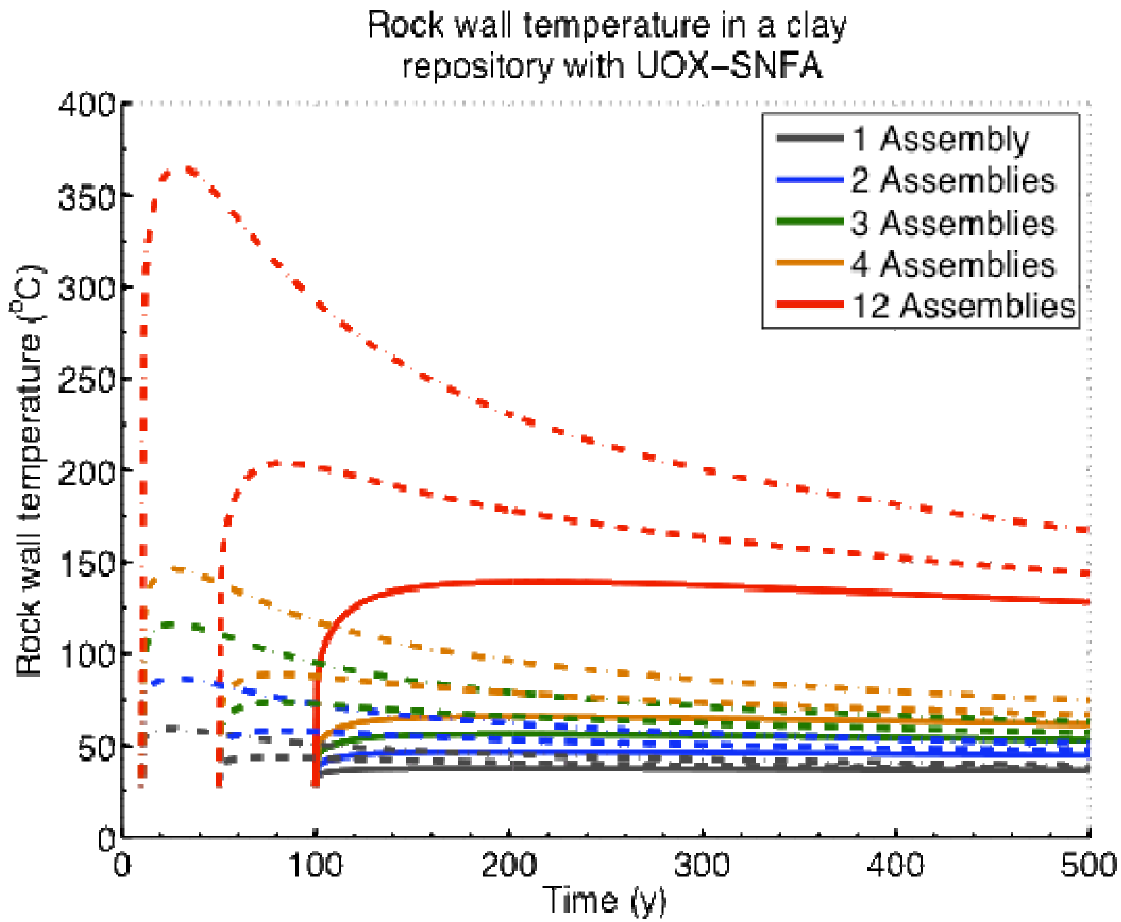
Reference Mined Disposal Concepts: Temperature Limits (Targets)

- **Temperature limits selected for this analysis are based on material degradation properties**
  - 100°C for clay/shale media and swelling clay-based buffer material (e.g., SKB and Andra programs)
    - Multiphase-moisture reactive transport processes
  - 200°C for salt (e.g., Salt Repository Project 1986, current German work)
    - Polyhalite decomposition (~200°C) and salt decrepitation (~270°C)
  - 200°C for hard rock (granite, gneiss, tuff, etc.)
    - Thermal expansion microfracture damage*
  - No limit identified for deep crystalline basement rock
- **Differences between concepts >> uncertainty in temperature limits**
- **Final temperature constraints will be site- and design-specific**

* Hardin, E.L. et al. 1997. *Synthesis Report on Thermally Driven Coupled Processes*. UCRL-ID-128495. Lawrence Livermore National Laboratory.

Thermal Analysis – Example Temperature Histories

- **Example: clay/shale repository**
  - **Host rock temperature (at rock wall)**
  - **LWR UOX SNF (60 GW-d/MTHM)**
  - **Calculate for different package size/capacity**

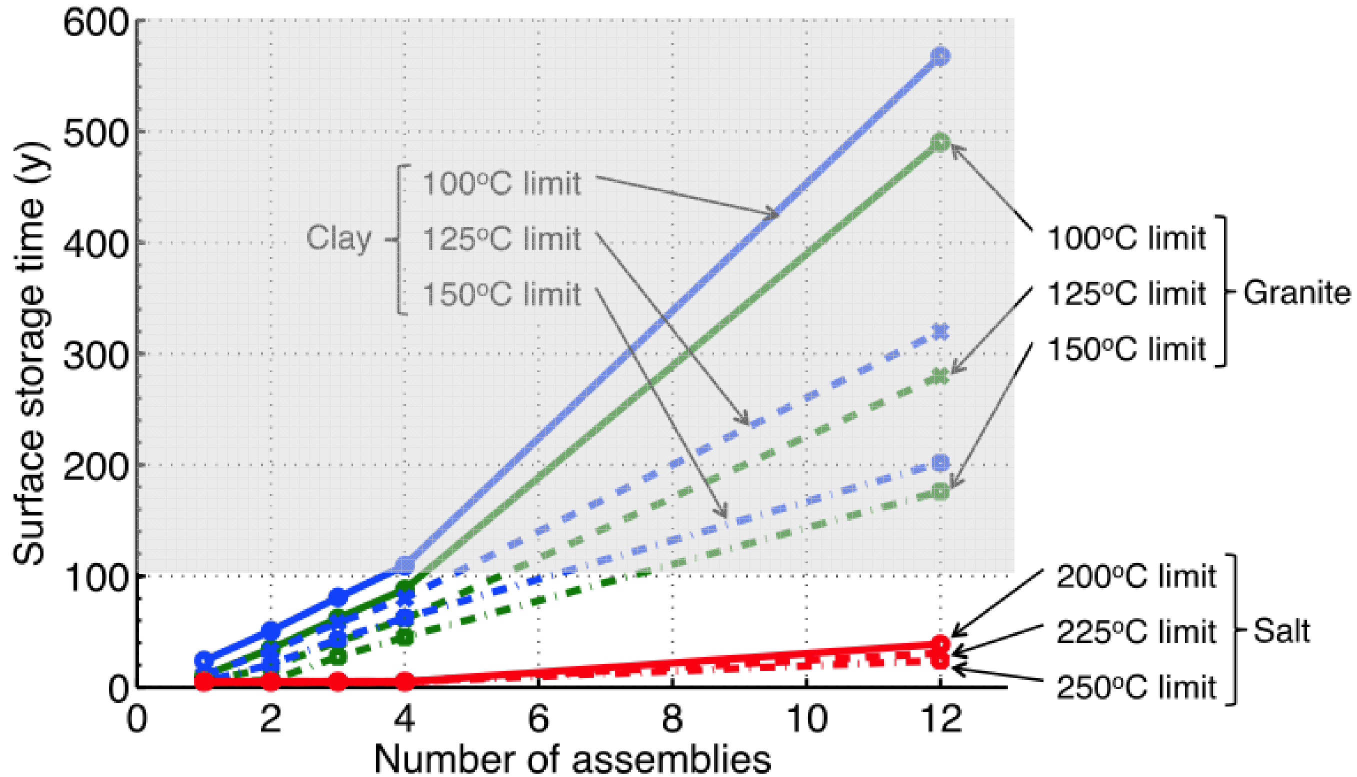


Source: Hardin, et al. 2012. FCRD-USED-2012-000219 Rev. 2.

Enclosed Mode Thermal Analysis Summary & Effect of Varying 100°C or 200°C Limits

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

- **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.**



Thermal conductivity for all media selected at 100°C.

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

Where do we go from here?

Open vs. Enclosed Emplacement Modes for Mined Disposal

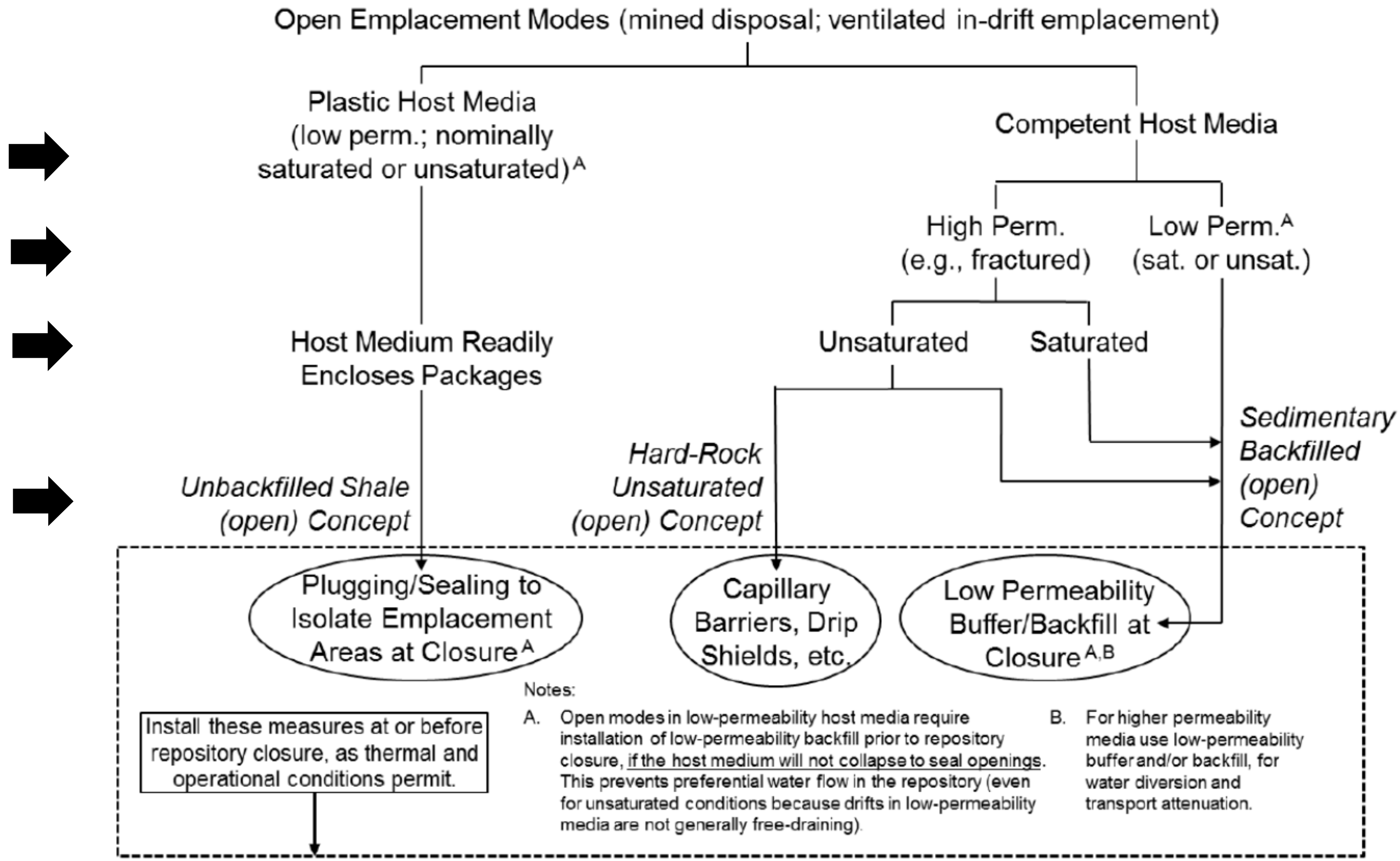
Mined Disposal Concepts:
Open vs. Enclosed Emplacement Modes

- **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: Emplacement openings around waste packages persist for ~10^2 to >10^4 years**
  - Simple "in-drift" emplacement
  - Heat spread by thermal radiation across air gaps
  - Pre-closure ventilation possible to remove heat

Open Emplacement Mode Rationale

- **System Operation**
  - Potential to decrease the scope and duration of interim storage
  - Emplace (and ventilate) larger, hotter waste packages
  - Enable direct disposal of existing dry storage/transport canisters
    - Potential to minimize repackaging and associated worker dose, cost, and LLW
  - Readily reversible or reusable
- **System Economics**
  - Earlier investment in disposal facilities (inter-generational equity)
  - Reduce life-cycle cost, but with extended repository operations

Open Emplacement Mode "Taxonomy"



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

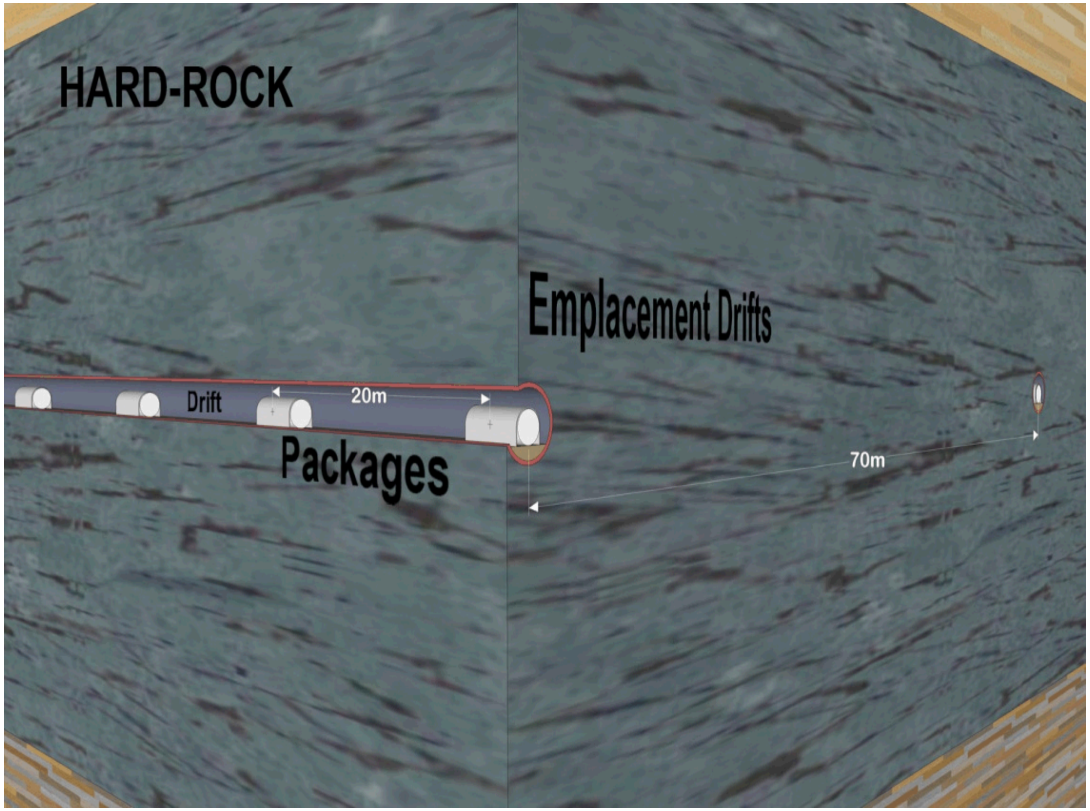
Reference Disposal Concepts

1. Clay/Shale Repository (enclosed)
2. KBS-3 (vertical) Repository Concept (enclosed)
3. *Generic Salt Repository (enclosed)**
4. Deep Borehole
5. ***Hard-Rock Unsaturated Unbackfilled Open Mode Concept****
6. ***Sedimentary Backfilled Open Mode****
7. ***Cavern-Retrievable Concept****

** Concepts suitable for larger, hotter waste packages*

Hard-Rock Unbackfilled Open Concept

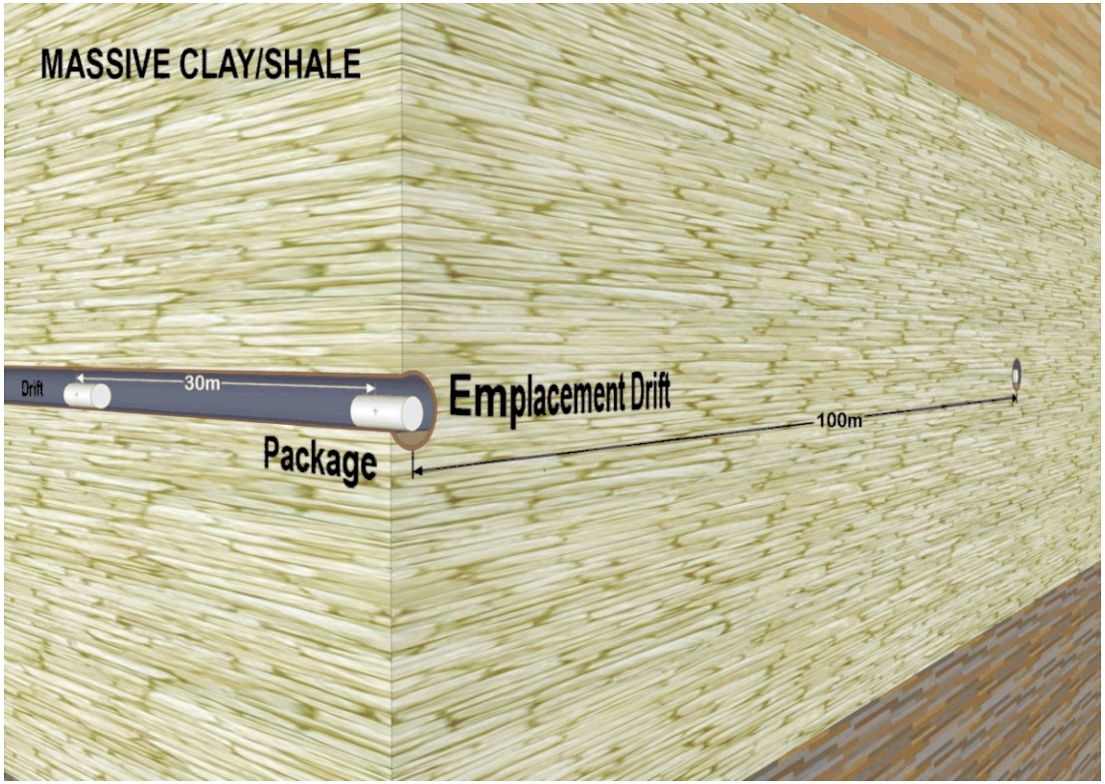
- Up to 32-PWR size or larger
- In-drift emplacement
- Emplace SNF at 50 to 100 years OoR
- Ventilate up to 50 years, closure at ≤150 years OoR
- Unbackfilled, for unsaturated settings
- Corrosion resistant waste packaging
- Additional engineered barriers may be installed at closure
- Long-term opening stability can be expected



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

Sedimentary Backfilled Open Concept

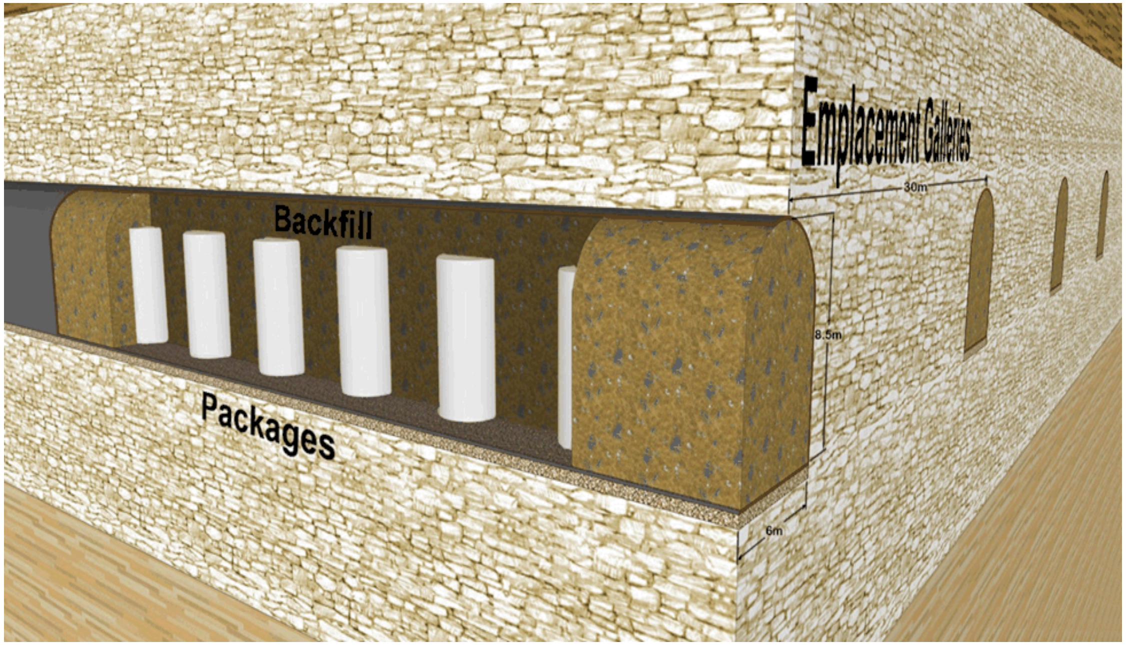
- Massive, soft clay/shale
- 32-PWR size or larger
- In-drift emplacement
- Emplace SNF at 50 to 100 years OoR
- Backfilling at closure (peak backfill T >> 100°C)
- Closure at 100 to >200 years OoR (limited by host rock)
- Possible local heating of host rock >100°C
- Steel or corrosion resistant waste packaging as needed



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

Cavern-Retrievable Storage-Disposal Concept

- Use existing dry storage systems
- Large galleries
- Extended ventilation (>100 yr)
- Unsaturated settings preferred
- Engineered barrier(s) installed at closure: development needed



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

Reference Concept Comparison
SNF Disposal Duration and Cost

- **Stylized depiction of disposal timing based on SNF age out-of-reactor**
- **Disposal of 140,000 MT SNF**
- **Concepts and cost estimates (Hardin et al. 2012; Kalinina & Hardin 2012)**
- **Shading indicates range of possible age at emplacement (e.g., burnup)**

Mined Repository Operational Duration with Range of Projected Burnup		Imposed T_{lmt} (°C)	Spent Fuel Age in yr Out-of-Reactor (10 … 100 … 200 … 300)	Disposal Cost $B (20 40 60 80 100)
Clay/Shale Enclosed	**4-PWR**[A]	100[C]		
Crystalline Enclosed	**4-PWR**[A]	100[C]		
Generic Salt Repository	4-PWR[B]	90		X
	12-PWR[A,B]	150		X
	21-PWR	200[C]		n/a
	32-PWR			n/a
Shale/Unbackfilled Open	**21-PWR**[A]	~130[D]		
		100[C]		n/a
Sedimentary/Backfilled Open	**21-PWR**[A]	~130[D]		
		100[C]		n/a
Hard-Rock Unbackfilled Open[E]	**21-PWR**[A]	200[C]		
	32-PWR			n/a

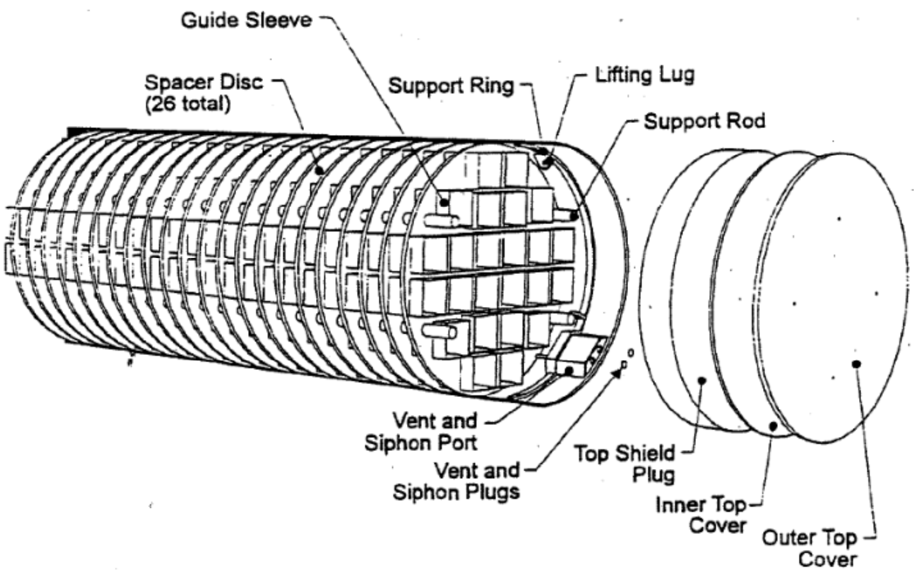
[A] Bold type indicates reference concepts (Ref. 2). Temp. limits are at the waste package surface except as noted.
[B] Independent estimates of cost (Ref. 8). [C] Material temp. limit. [D] These cases heat the near-field sedimentary host rock >100°C exceeding the assumed temp. limit. [E] Includes site char. and canister costs not included in other estimates.

Addl. estimation uncert. approx. ±$5B
n/a = not analyzed

Direct Disposal of SNF in Dual Purpose (Storage-Transportation) Canisters

Preliminary Feasibility Study

Typical DPC Canister/Cask System - NUHOMS



- **NUHOMS® (TransNuclear/Areva)**
- **~1/3 of existing U.S. DPC fleet**
- **NUHOMS®–24P, –24PHB, –24PTH, –32PT, –32PTH1, –52B, –61BT,–61BTH, and –69BTH**
- **Welded SS304 construction typical (fuel pool compatibility)**

- **Over 50% of U.S. UNF is stored in Transnuclear (TN) designed systems (part of Areva Group)**
- **>650 TN storage casks**
- **>23,000 assemblies**
- **31 U.S. sites at the end of 2010**

NUHOMS DPC Canister/Cask System, cont.

- Vertical loading & sealing
- Removable trunnions
- Horizontal storage vaults: only system stored horizontally
- Ribs in vault to promote sliding

- Use TN-MP197HB transportation overpack
- Horizontal xfer to transport cask
- Horizontal transport

Some Terminology

- **Canister** ≡ Sealed, unshielded vessel for storing, transporting and possibly disposing of spent fuel (using different overpacks). Also, a sealed vessel containing HLW. Typically welded closure (NRC annual inspection requirements for bolted closures). Example tradenames: NUHOMS, TSC, MPC, Magnastor, etc. (3 major vendors Transnuclear/Areva, Holtec, NAC International).
- **Storage Cask** ≡ Shielded (possibly self-shielded as with CASTOR) container for stationary storage. Typically bolted closure. Examples: Licensed storage systems for canisters listed above.
- **Transportation Cask** ≡ Shielded (possibly self-shielded as with CASTOR) container for transporting SNF in canisters, or as “bare” fuel assemblies. Typically bolted closure. Examples: Licensed transportation systems for canisters listed above.
- **Transfer Cask** ≡ Used locally to transfer unshielded canisters from fuel pools to storage casks, or from storage to any other system, e.g., for transport or disposal.

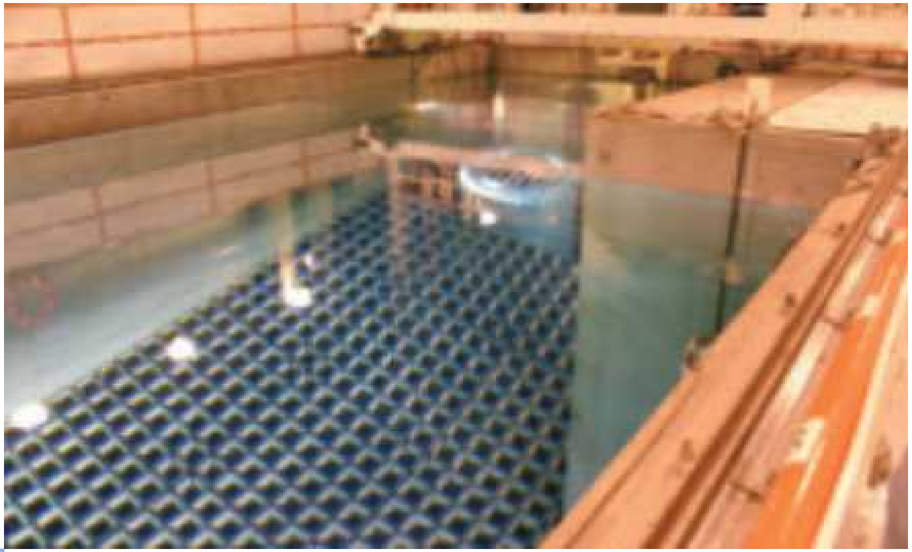
Largest, Recent DPC Designs


- Example: Magnastor DPC system (NAC International)
- Recently brought to market
- Capacity 37-PWR (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

U.S. Spent Fuel Inventory

- **CSNF Projection**
  - Extend all operating reactors→ 60 yr
  - Last shutdown 2055 (140,000 MTHM total)
  - Avg. burnup ~45 GWd/MT



- **Pool Storage**
  - ~60,000 MTHM capacity
- **Dry Cask Storage**
  - ~20,000 MTHM current
  - +2,000 MTHM/yr
  - 1/2 of all SNF by ~2035

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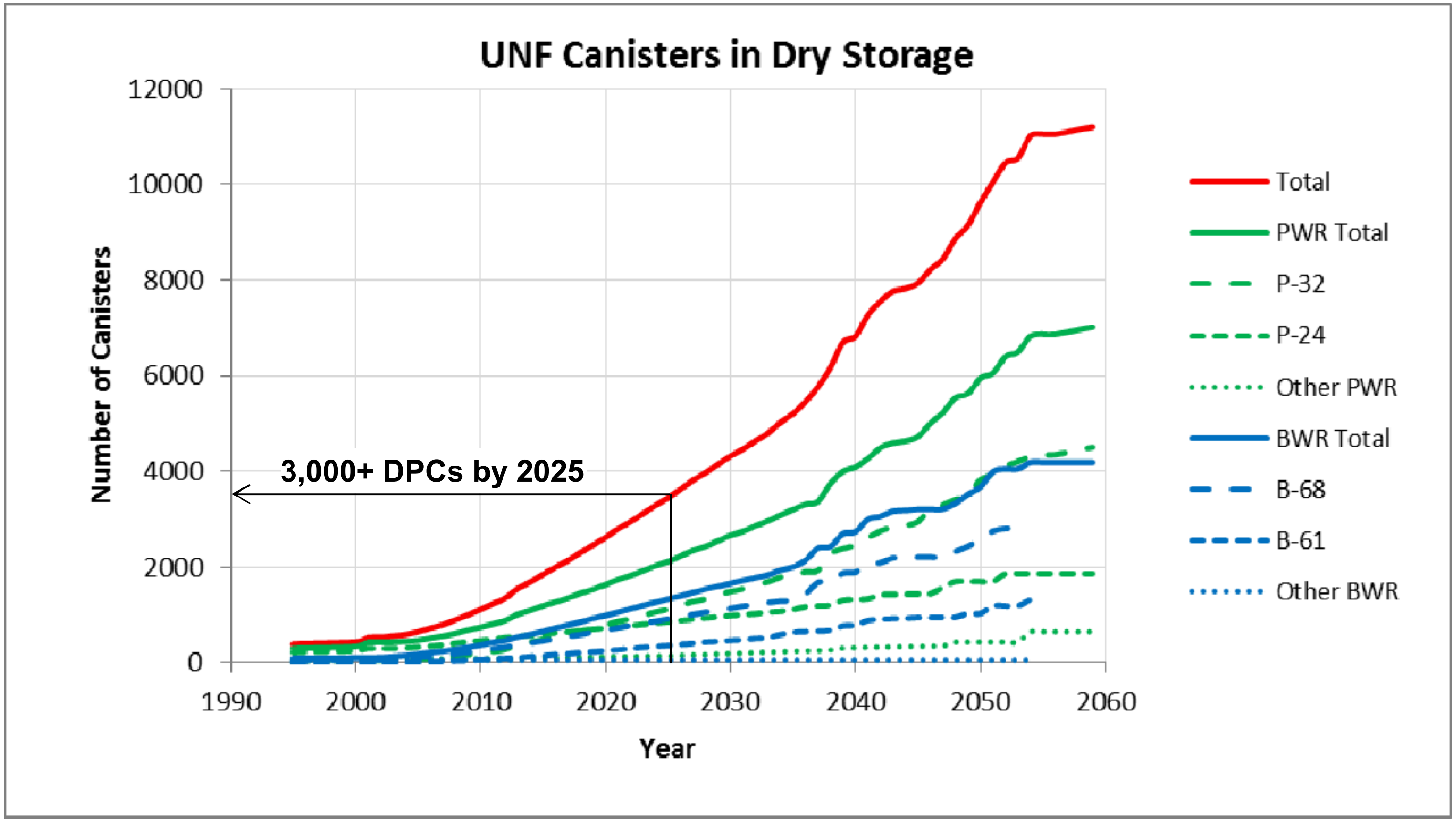
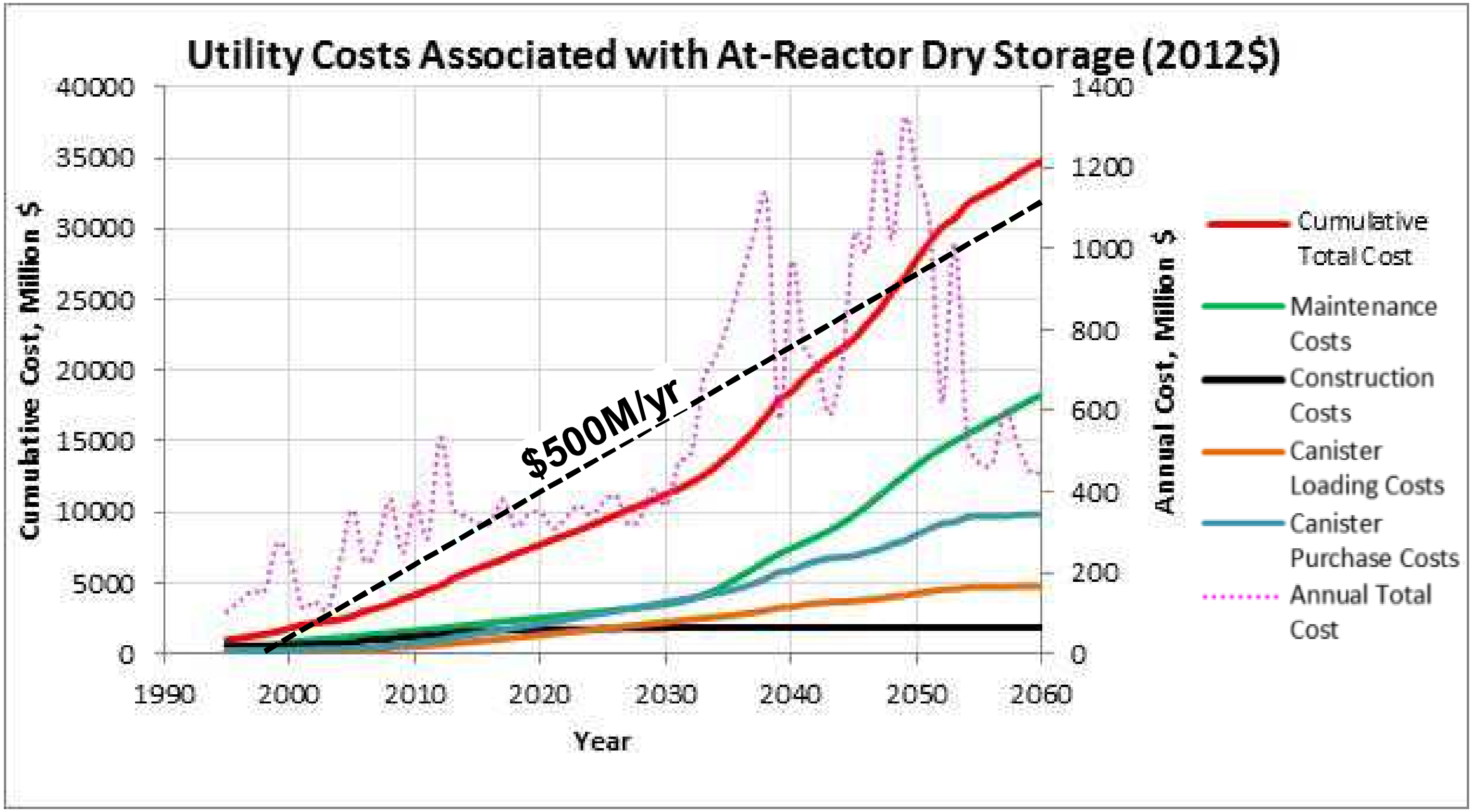
Dry Storage Projection – TSL-CALVIN Accumulation of Canisters



Assume Presently Used DPC Types, No Fuel Shipments from Existing ISFSIs, and 20-yr Life Extensions for the Currently Operating Reactor Fleet.

Dry Storage Projection – TSL-CALVIN Utility SNF Management Costs

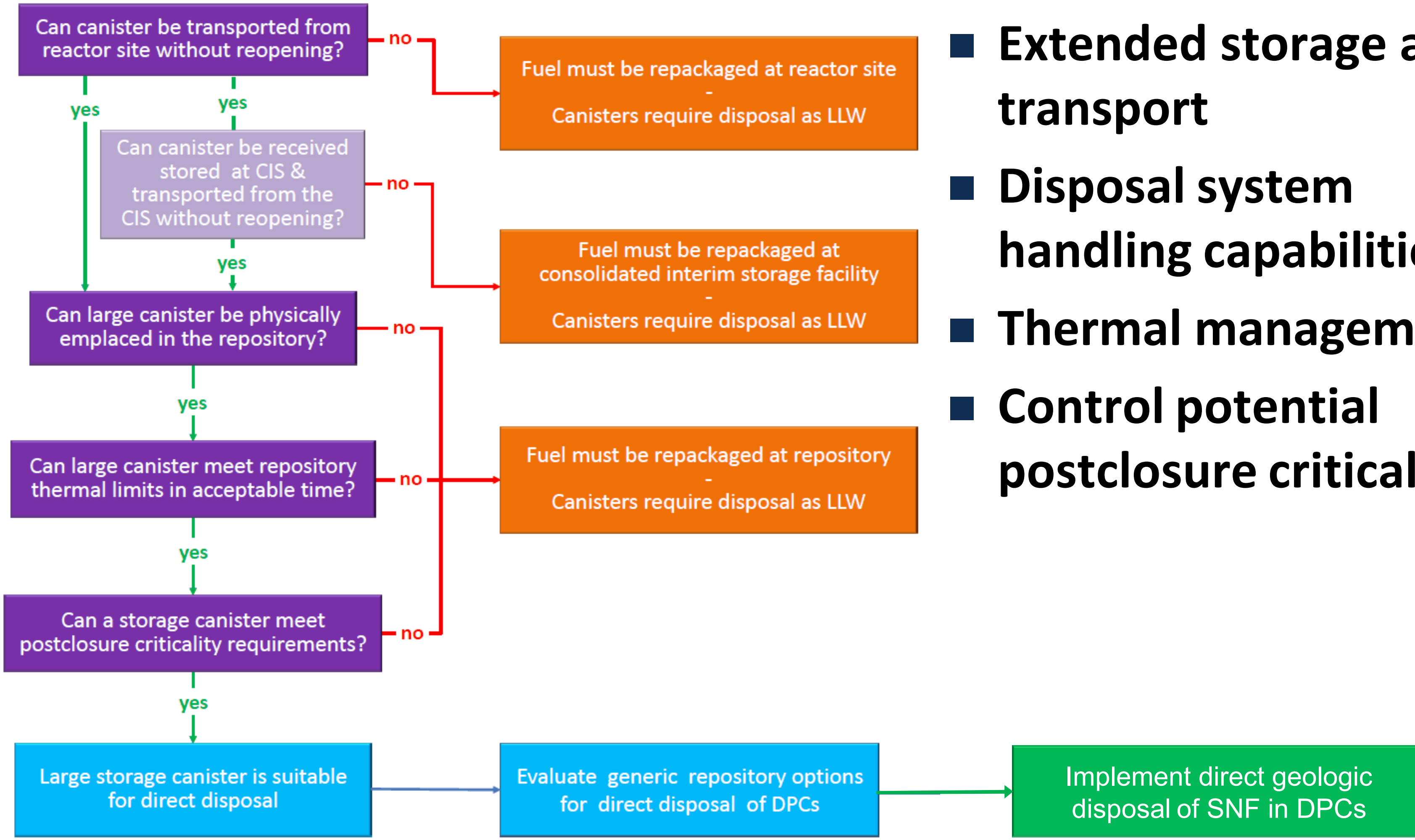


Assume Presently Used DPC Types, No Fuel Shipments from Existing ISFSIs, and 20-yr Life Extensions for the Currently Operating Reactor Fleet.

Direct Disposal of DPCs as "Multi-Purpose Canisters"

- Proposition: Licensed DPC functions + disposal function = "MPC"
- Pros: Avoid re-packaging, which produces more LLW
  - Cost to re-package any SNF is $100k to $200k per MTHM
  - Worker dose is associated with canister loading, drying, welding, etc.
- Con: MPCs will be large (DPCs have typ. 32-PWR capacity, or BWR equiv.)
  - 2 m dia. × 5 m long
  - Canister loaded 50 MT
    Disposal overpack (e.g., 2-in. steel wall) 15 MT
    Shielding 75 MT
    Cart or vehicle 20 to 100 MT
    → Total mass for surface-underground transport 160 to 240 MT
    (compare with heaviest package for a Yucca Mtn. repository = naval SNF, loaded canister weight 44.5 MT; waste package 74 MT; loaded transport-emplacement vehicle >250 MT)
- Con: DPCs are not designed for disposal
  - Principal technical issue is criticality control
- Added complication: Some dry storage-only canisters are also in use

Path to Direct Disposal of SNF in DPCs



- **Extended storage and transport**
- **Disposal system handling capabilities**
- **Thermal management**
- **Control potential postclosure criticality**

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Direct Disposal of Large, Multi-Purpose Canisters

- **Engineering Challenges**
  - Conveyance (shaft or ramp?) and emplacement (in-drift)
  - Thermal management (preclosure handling as well as postclosure)
  - Underground structures (e.g., invert, ground support, large openings)
  - Plugging and/or backfilling at closure, in radiation environment
- **Postclosure Safety Case Challenges**
  - Package containment longevity strategy (balance cost, waste isolation performance, and regulatory risk)
  - Modeling groundwater flow and radionuclide transport
    - Waste package size vs. # of packages vs. scale of natural variability
    - Repository drift plug and/or backfill performance
    - Groundwater control (e.g., ramps)
  - Modeling cementitious materials (e.g., shotcrete and concrete; plumes)
  - Criticality analysis (absorber fate, moderator exclusion)
  - Related to pre-closure ventilation (feasibility, deliquescence, etc.)

Design Options for Engineering Challenges

- **Handling/Packaging: Use Current Practices**
- **Surface-Underground Transport**
  - **Spiral ramp (10% grade)**
  - **Linear ramp (>10% grade)**
  - **Shallow ramp (≤ 2.5% grade)**
  - **Heavy shaft hoist**
- **Opening Stability Constraints**
  - **Salt (a few years with minimal maintenance)**
  - **Hard rock (50 years or longer)**
  - **Sedimentary (50 years may be feasible; longer may require special geologic settings)**

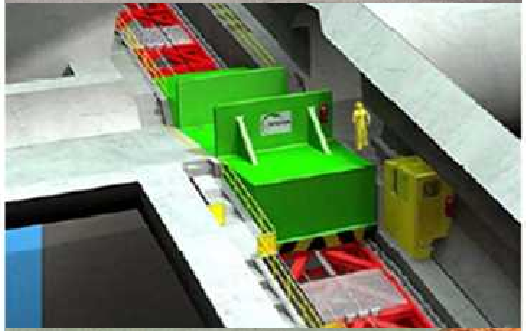
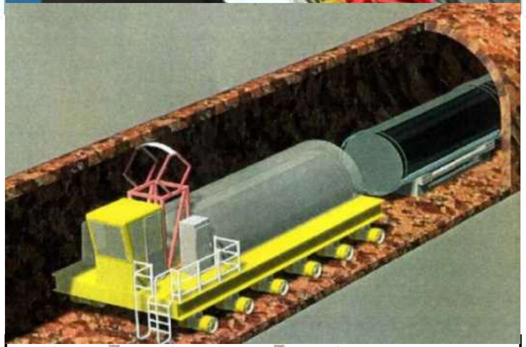
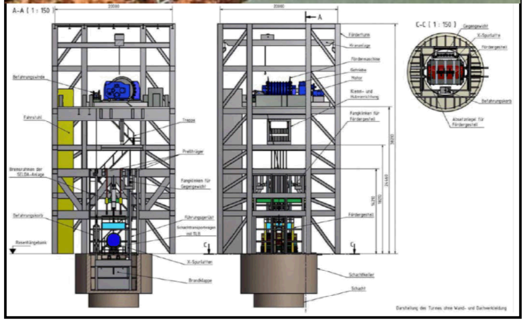
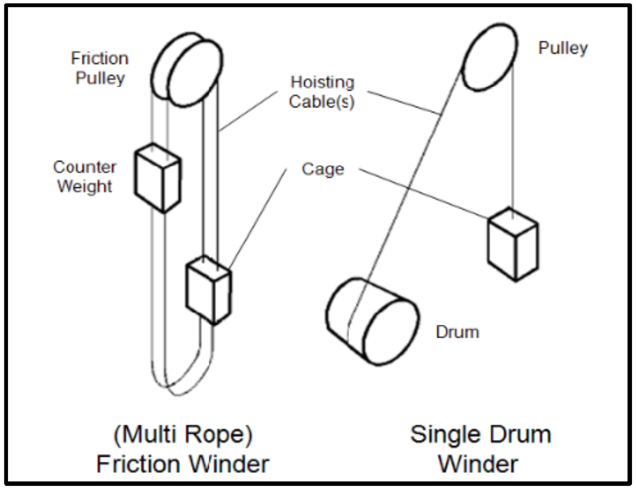
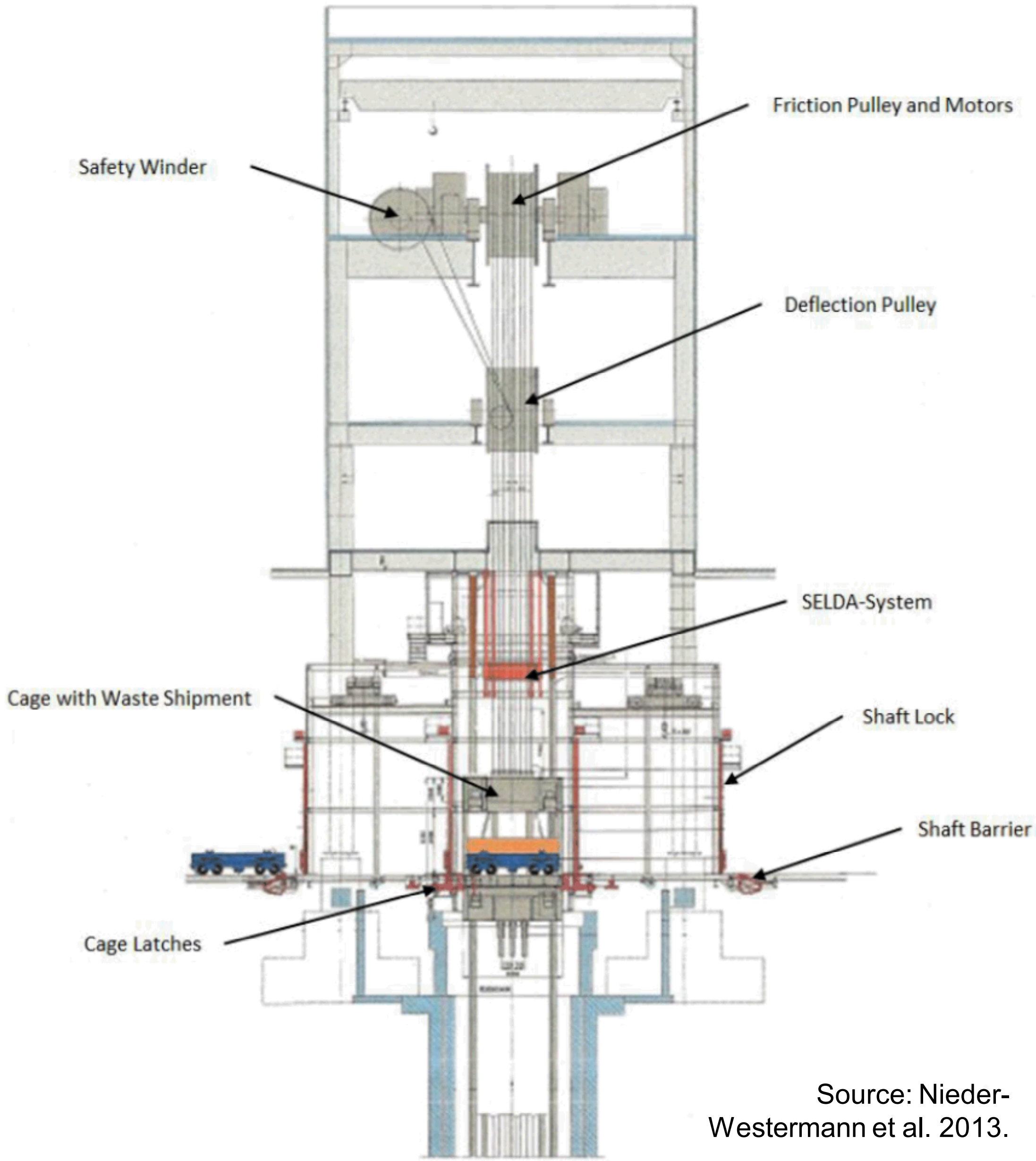





Image sources:
Fairhurst 2012
www.wheelift.com
Nieder-Westermann et al. 2013

Heavy Shaft Hoist Technology

- Gorleben, Germany design and DEAB test (85 MT)
- Payload extension to 175 MT for DPC package, shielding & cart
  - Friction hoist, 6 cables (66 mm) plus 6 balance cables
  - Counterweight 133 MT
  - 1 m/sec hoist speed
  - 2.8 m drive pulley, 800 kW winder
  - Equipment cost ~$30M

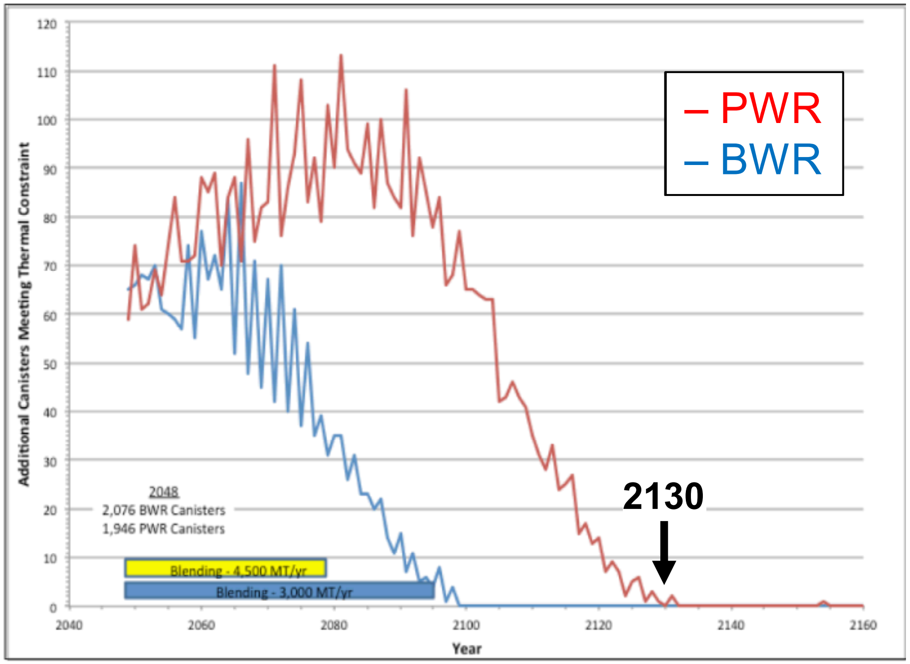




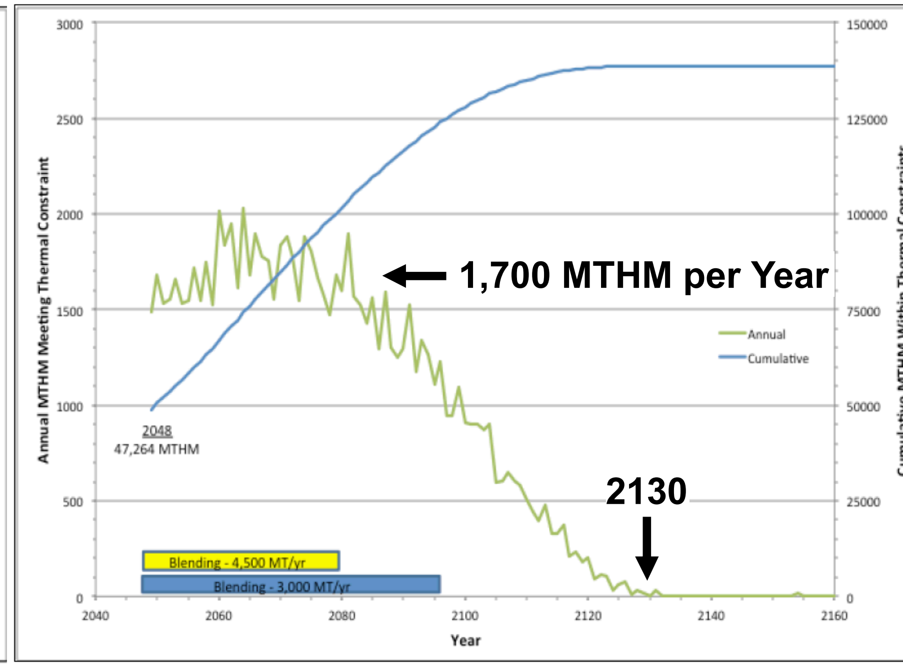
Source: Nieder-Westermann et al. 2013.

Cooling Time for DPC Direct Disposal

- **Example Results (10 kW power limit, typical for salt):**
  - Emplacement operations would be substantially done by 2130
  - Additional ventilation time would be needed for hard rock (up to 50 yr) and sedimentary (100 to >200 yr) concepts



# of Canisters per Year Cooling to 10 kW

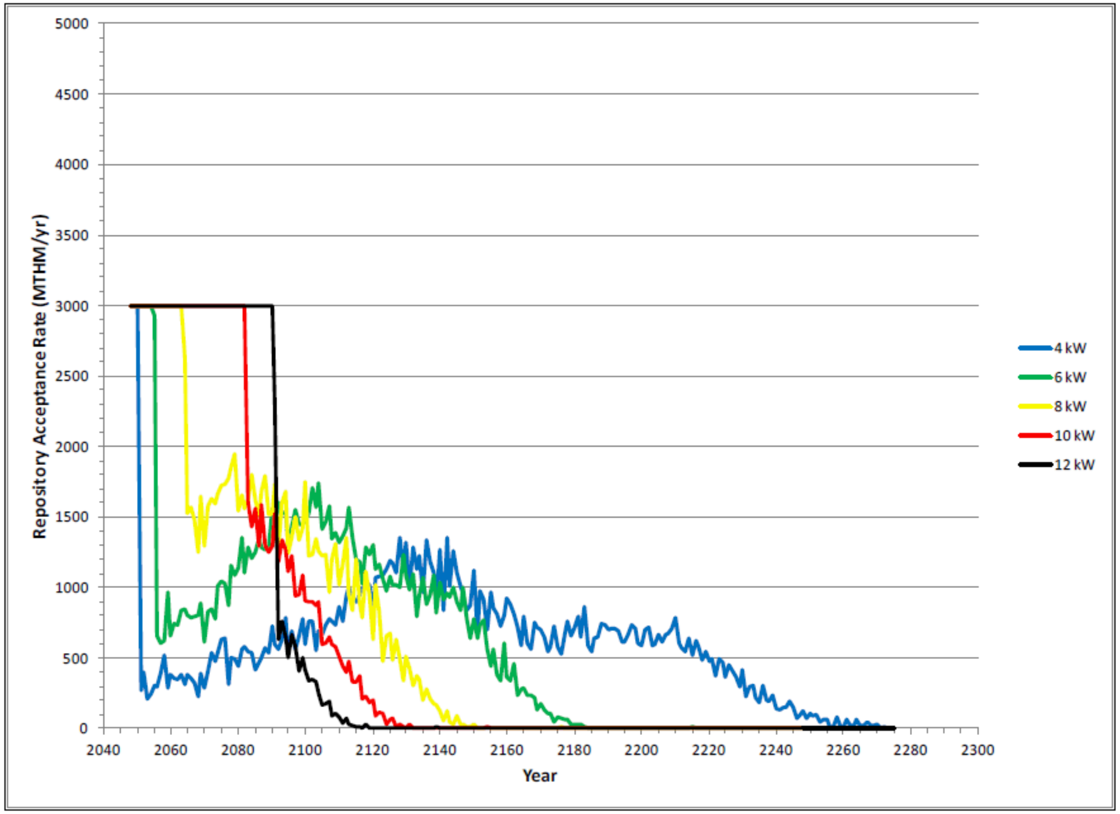


SNF per Year (MTHM) Cooling to 10 kW

Source: Nutt, W.M. 2013. FCRD-UFD-2013-000184.

Repository Acceptance Rates for DPC Direct Disposal Scenarios

- Example: 3,000 MTHM/yr maximum repository throughput, further limited by emplacement power
- Emplacement power limits 4, 6, 8, 10 and 12 kW/package
- Optimal throughput is less than 3,000 MTHM/yr
- Cooling of DPCs much beyond 10 kW could take centuries



Source: Nutt, W.M. 2013. FCRD-UFD-2013-000184.

Thermal Management for Larger/Hotter Packages

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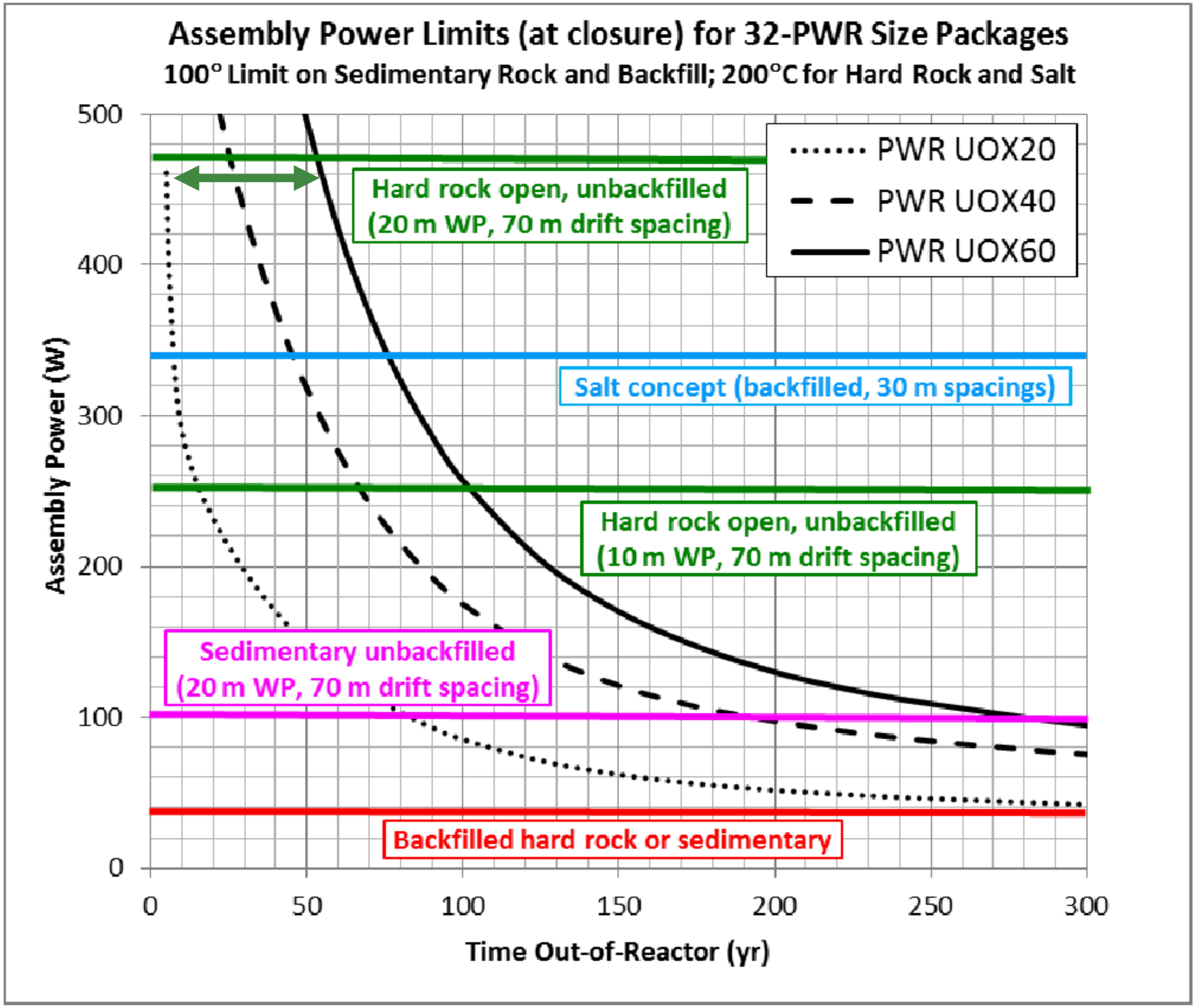
Example Results for 32-PWR Size Packages & Current Temperature Limits

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

Thermal Mgmt. Degrees of Freedom:

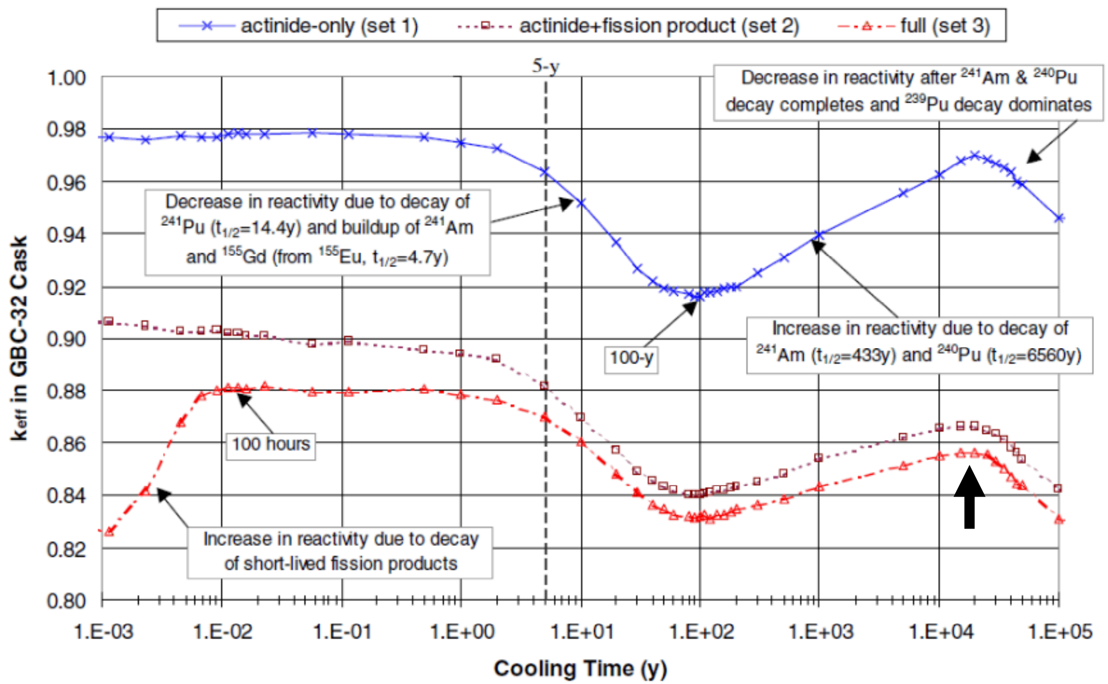
- Package SNF capacity
- Burnup
- Age at emplacement
- Repository ventilation
- Host rock properties
- Spacings
- Use of backfill



 Hardin, E.L., Geologic Disposal Concepts for HLW and Spent Nuclear Fuel

Design Options for Nuclear Reactivity Control

- **Disposal environment**
  - Groundwater availability
  - Salinity
  - Corrosion environment
- **Moderator exclusion**
  - Package integrity
- **Moderator displacement**
  - Fillers (e.g., B4C loaded grout)
- **Reactivity analysis**
  - Burnup credit
  - As-loaded (histories from utilities)
  - Degradation cases



32-PWR Reactivity vs. time

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

DPC Criticality Analysis (Clarity & Scaglione 2013)

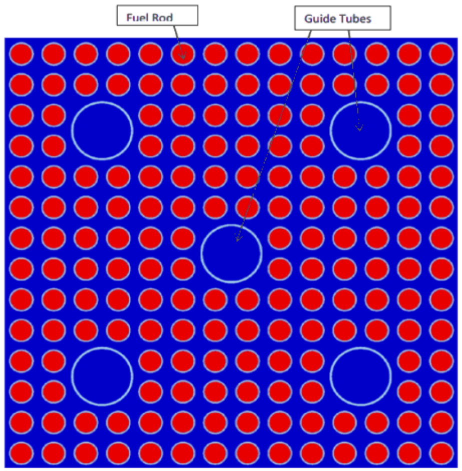
- **DPCs use neutron absorbers that readily corrode in aqueous environments (Boral, Al-B4C metal matrix composites)**
- **Legacy disposal FEP screening approach: YM topical report**
  - **Flooded (precedent in 71.55 analysis)**
  - **Loss of absorber (laboratory corrosion data)**
  - **Basket collapse (general corrosion of stainless steels)**
- **Need reactivity margin to apply against degradation assumptions**
  - **As-loaded configurations**
  - **Burnup credit**
  - **Disposal environment (e.g., brine)**

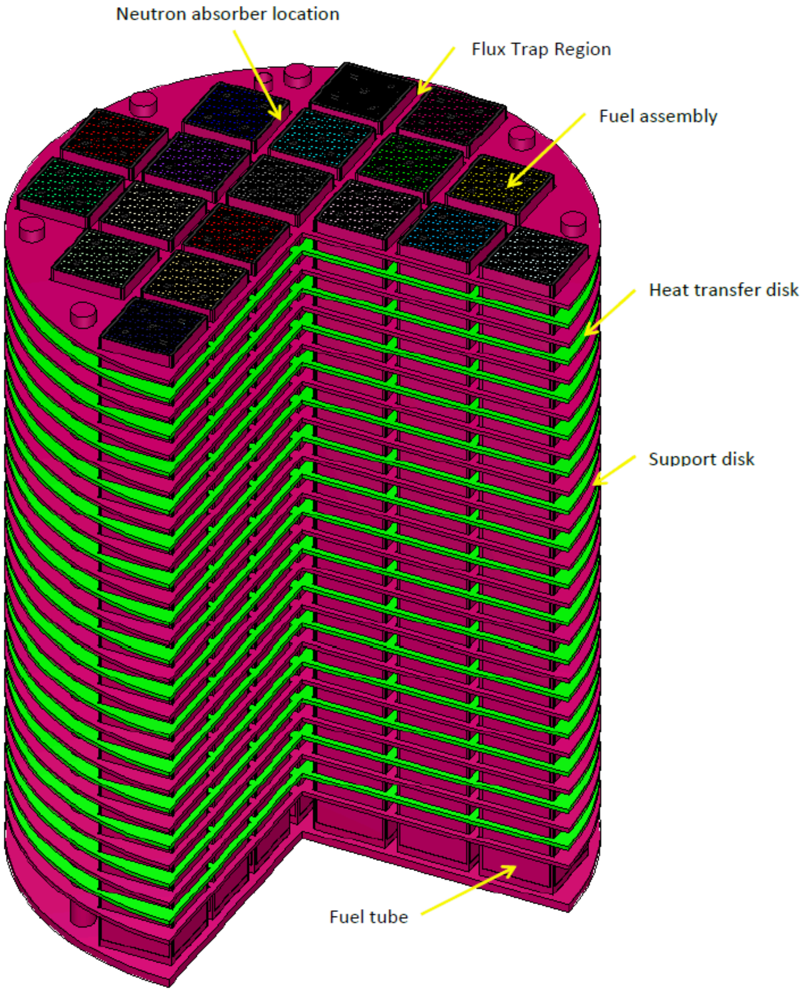
Clarity, J.B. and J.M Scaglione 2013. *Feasibility of Direct Disposal of Dual-Purpose Canisters-Criticality Evaluations*. ORNL/LTR-2013/213.

Actinides					
^{234}U	^{235}U	^{236}U	^{238}U	^{238}Pu	^{239}Pu
^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	^{243}Am	^{237}Np
Fission products					
^{95}Mo	^{99}Tc	^{101}Ru	^{103}Rh	^{109}Ag	^{133}Cs
^{143}Nd	^{145}Nd	^{147}Sm	^{149}Sm	^{150}Sm	^{151}Sm
^{152}Sm	^{151}Eu	^{153}Eu	^{155}Gd		

Reactivity Scoping Analysis, Maine Yankee

Model array representing Westinghouse 17x17 standard assembly in cross-section.

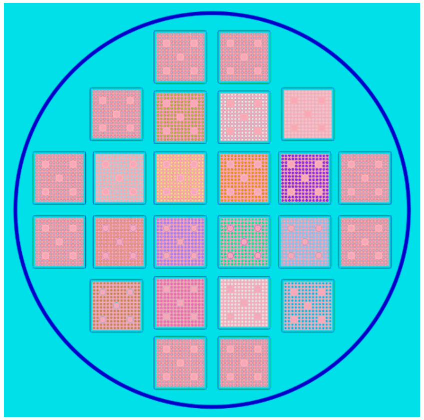




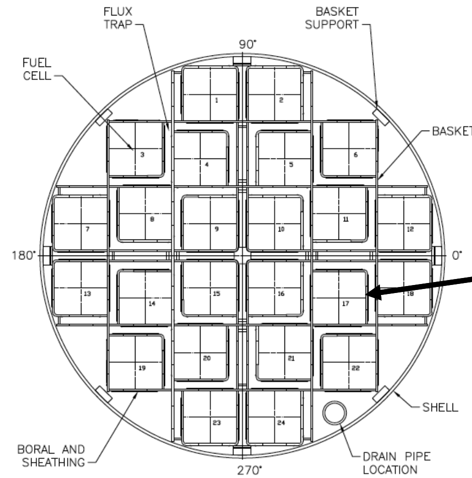
- **Numerical Model of TSC-24 Canisters (31 analyzed)**
- **ORNL Database SNF-ST&DARDS**
- **Software/Data**
  - **SCALE code system (ORNL 2011)**
  - **Details: Clarity and Scaglione (2013)**
- **Also Analyzed: 26 canisters at Sequoyah (Holtec MPC-32 type)**

References:
ORNL (Oak Ridge National Laboratory) 2011. ORNL/TM-2005/39 Version 6.1.
Clarity, J.B. and J.M Scaglione 2013. ORNL/LTR-2013/213.

Basket Configurations for TSC-24 System: Maine Yankee

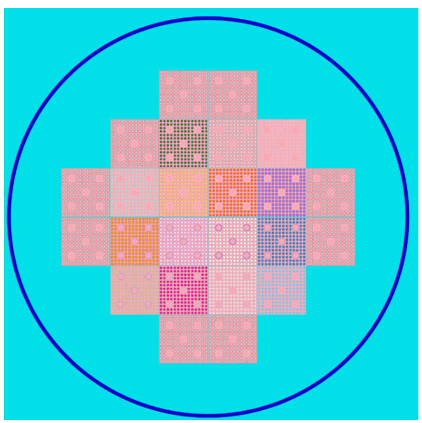


Intact Basket (as considered for preclosure safety analysis)

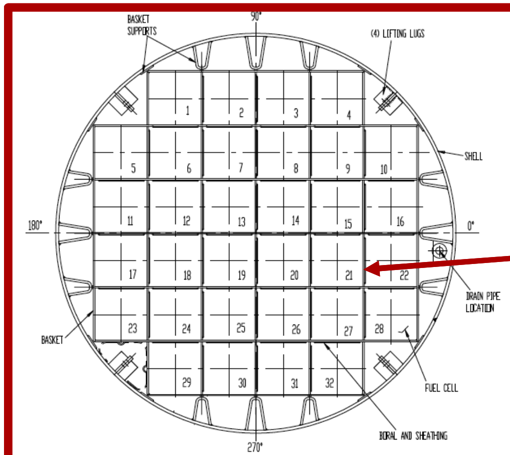


Fuel-tube type basket (e.g., Maine Yankee TSC-24)

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



Collapsed Basket, (with loss of neutron absorbers, in disposal environment)



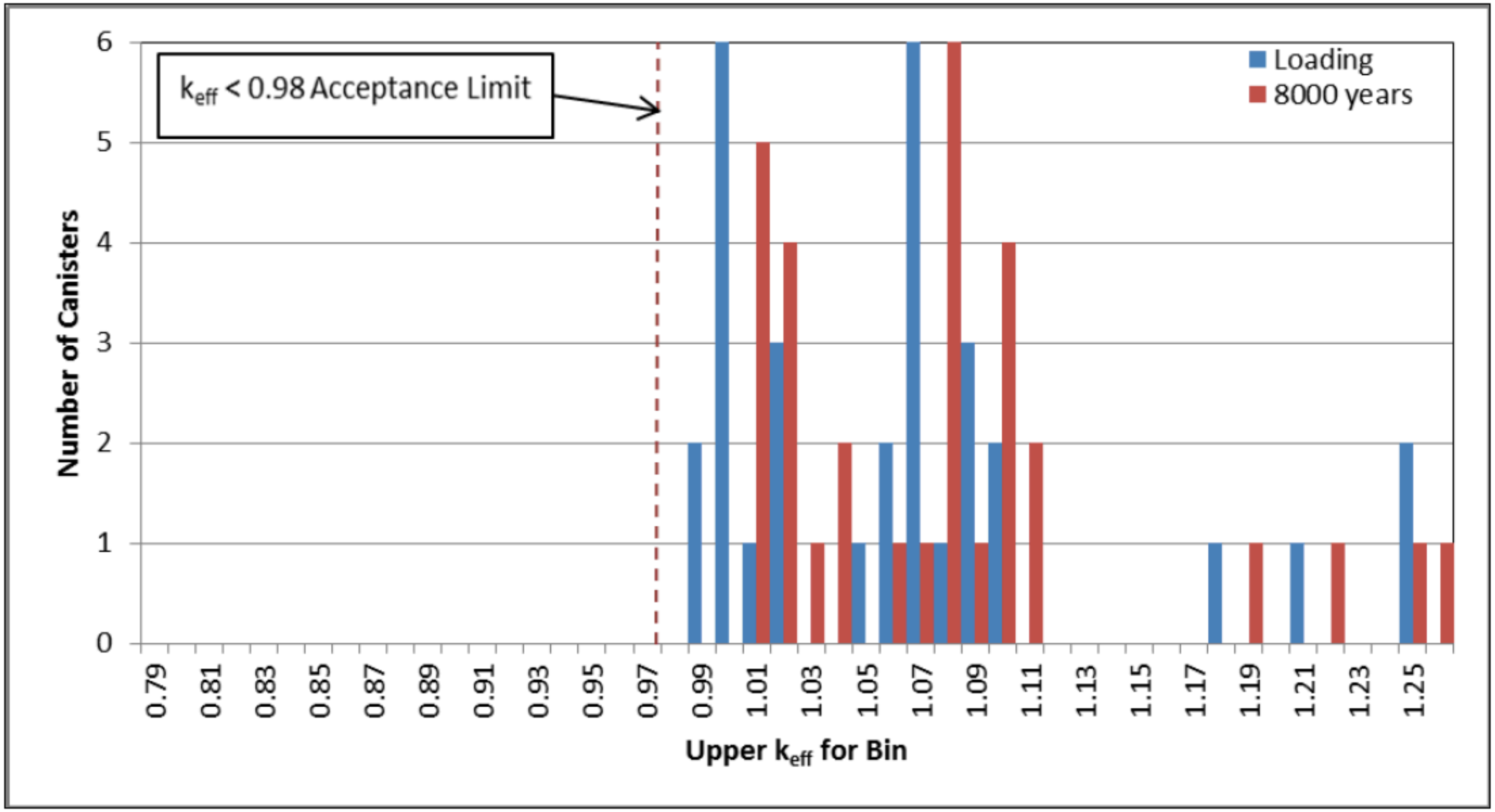
Egg-crate type basket (e.g., Sequoyah MPC-32)

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.

Reactivity Scoping Results, Maine Yankee

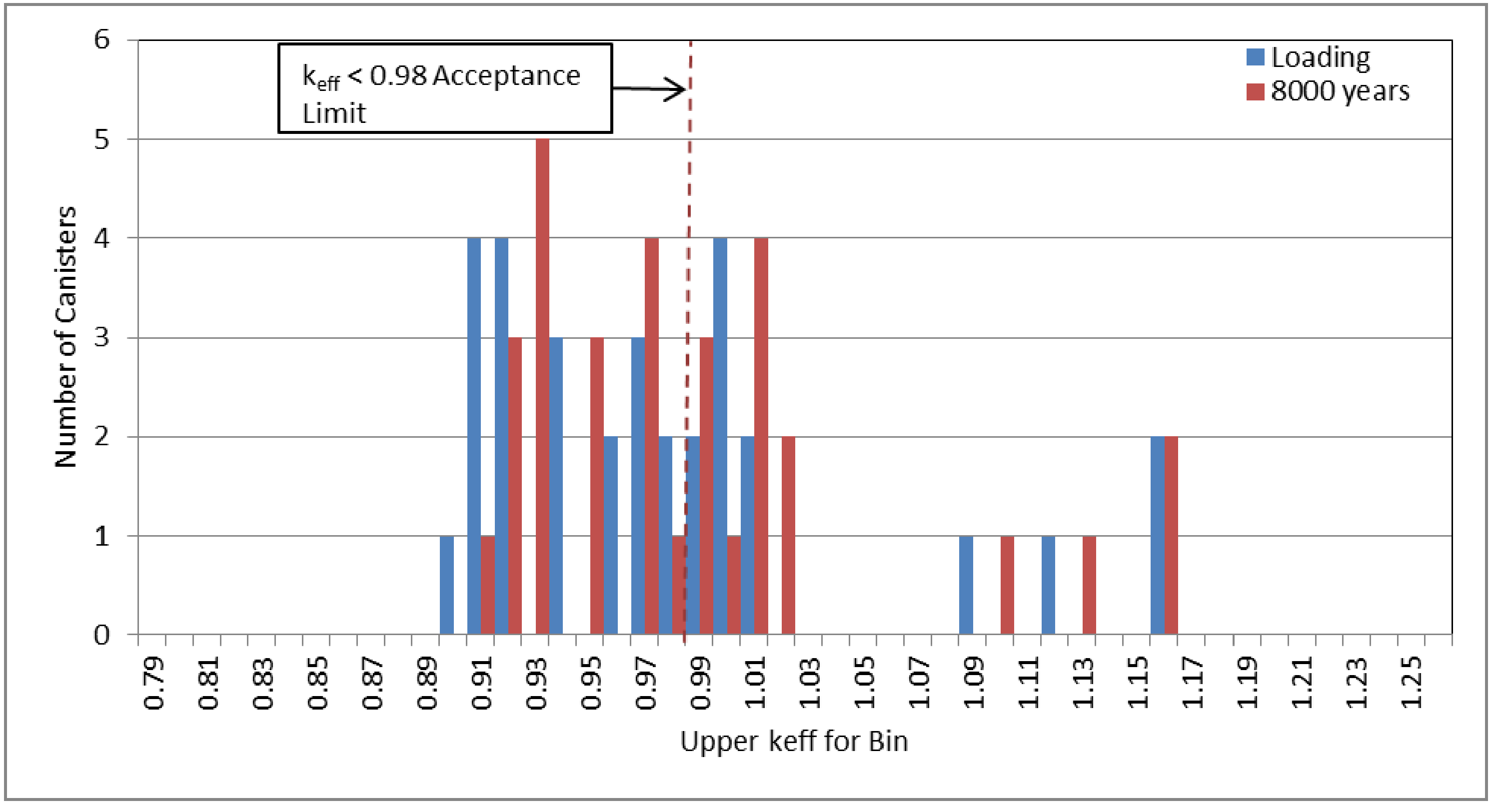
- **Degraded basket case (and loss of absorber), fresh water**
- **Analyzed as-loaded, with burnup credit**



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

Reactivity Scoping Results, Maine Yankee

- **Degraded basket case (and loss of B_4C absorber), <u>flooded with 1 molal NaCl brine</u>**
- **Analyzed as-loaded, with burnup credit**



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

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

DPC Reactivity Scoping Analysis Summary for Maine Yankee and Sequoyah

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Case	Cooling time	Number of DPCs subcritical	Percentage of DPCs subcritical
Maine Yankee (48 no-absorber and 31 degraded-basket canister cases analyzed)			
No absorber	0	48	100%
	8000	48	100%
Degraded basket	0	0	0%
	8000	0	0%
Degraded basket with 1 molal NaCl	0	19	61%
	8000	17	55%
Degraded basket with 2 molal NaCl	0	27	87%
	8000	27	87%
Sequoyah (26 canisters analyzed)			
No absorber	0	4	15%
	8000	9	35%
Degraded basket	0	0	0%
	8000	0	0%
Degraded basket with 1 molal NaCl	0	2	8%
	8000	3	12%
Degraded basket with 2 molal NaCl	0	26	100%
	8000	26	100%

Source: Hardin et al. 2013. *Preliminary Report on Dual-Purpose Canister Disposal Alternatives*. FCRD-UFD-2013-000171 Rev. 0.

Summary (1/2)

- **UFD R&D objectives → *generic disposal concepts cover a wide range of geologic settings***
- **Different waste streams → *repository or panel designs can be different***
- **SNF accumulation projection → *140,000 MTHM, eventually all in dry storage***
- **Enclosed emplacement modes from international experience → *approx. 30,000 to 90,000 small wastes packages for U.S. SNF***
- **WIPP disposal mission**
- **Open emplacement modes → *limit the number of U.S. SNF disposal packages to 10,000 to 15,000***
- **Open-mode disposal of SNF in existing DPCs →**

Summary of Preliminary Evaluation of DPC Direct Disposal Feasibility (2/2)

Sandia National Laboratories

- **Thermal Results**
  - Repository/panel closure <150 yr out-of-reactor (salt and hard rock)
  - Sedimentary media would need: 1) expanded spacings; 2) over-heat of near-field host rock (>100°C); and/or 3) decay storage + ventilation >>150 yr.
  - Backfill temperature >>100°C (if used)
- **Reactivity Scoping Results**
  - Reactivity margin is available with burnup credit analysis and as-loaded information
  - Some, but not all, existing DPCs could be sub-critical for the degradation cases
  - Saline water (^{35}Cl) provides significant neutron absorption
- **Preliminary Thermal/Logistical Result**
  - For a 10 kW power limit, emplacement could be complete at 2130 with average rate of 1,700 MTHM/yr. (In salt, repository panel closure could immediately follow.)

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.

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

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Sandia National Laboratories

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