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Generic Disposal Concepts and Thermal Load Management for Larger Waste Packages

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Outline

- Disposal concepts ("enclosed"): crystalline, clay/shale, salt, deep borehole (Re: January, 2012 briefing)
- Thermal analysis for mined, "enclosed" concepts
- Finite element analysis for generic salt repository (waste package size up to 32-PWR)
- "Open" disposal concept development: shale unbackfilled, sedimentary backfilled, and hard-rock unsaturated (waste package sizes up to 32-PWR)
- Thermal analysis for mined, "open" concepts
- Summary and conclusions

Disposal Concept Definition, and Settings Evaluated

1. **Waste inventory**
   – Commercial SNF, 40 and 60 GW-d/MT burnup (existing inventory and bounding SNF case; Carter et al. 2012a)
   – Representative MOX and HLW types (summary: Hardin et al. 2012)
2. **Geologic settings**
   – Crystalline, clay/shale, bedded salt, crystalline basement, massive shale, sedimentary (e.g., alluvium), "hard rock"
3. **Engineering concepts of operation**
   – Crystalline (enclosed)*
   – Clay/shale (enclosed)*
   – Generic salt repository (enclosed)*
   – Deep borehole*
   – Hard-rock unsaturated (open)
   – Shale unbackfilled (open)
   – Sedimentary backfilled (open)

* January, 2012 briefing

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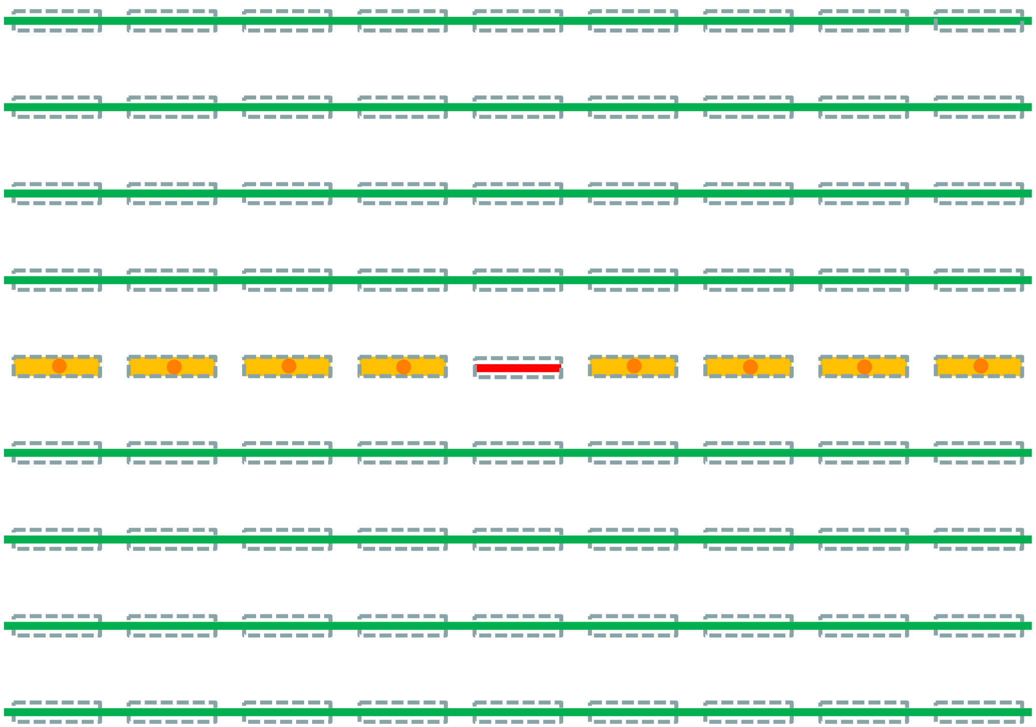
Transient Superposition Solution for Multiple Packages & Drifts

- **A central waste package is modeled as a finite line source**
- **Adjacent waste packages are point sources**
- **Adjacent drifts (or emplacement boreholes) are infinite line sources**
- **Homogeneous host medium**



Back-calculate approximate temperatures for radial layers representing the engineered barrier system.

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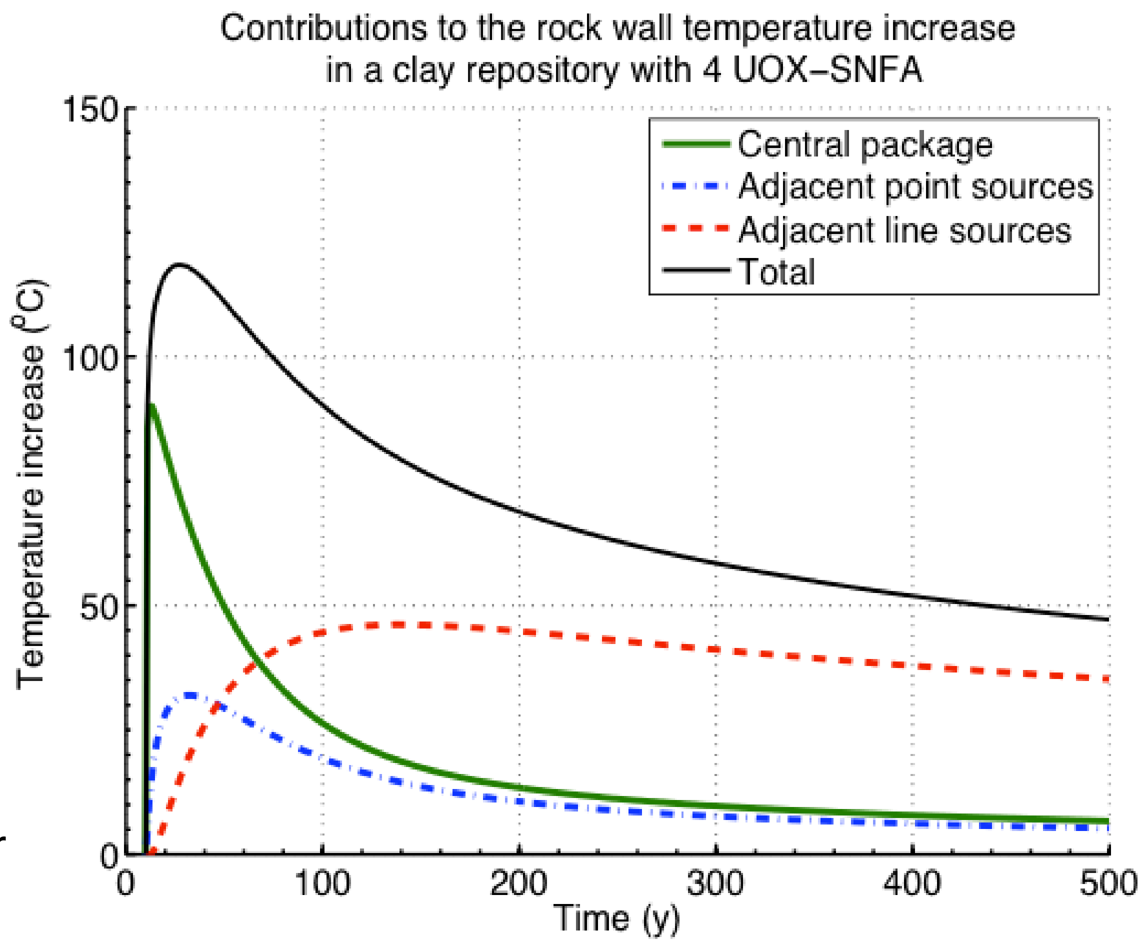
Relative Contributions to Transient Temperature Histories

- **Example: Relative contributions to calculated host rock temperature (at EBS boundary)**
  - LWR UOX spent fuel (60 GW-d/tHM; bounding)
  - 10-yr age out-of-reactor
  - 4-PWR package
  - Clay/shale reference (enclosed) concept, similar to Andra (2005) concept for SNF



Source: Greenberg et al. 2012a.

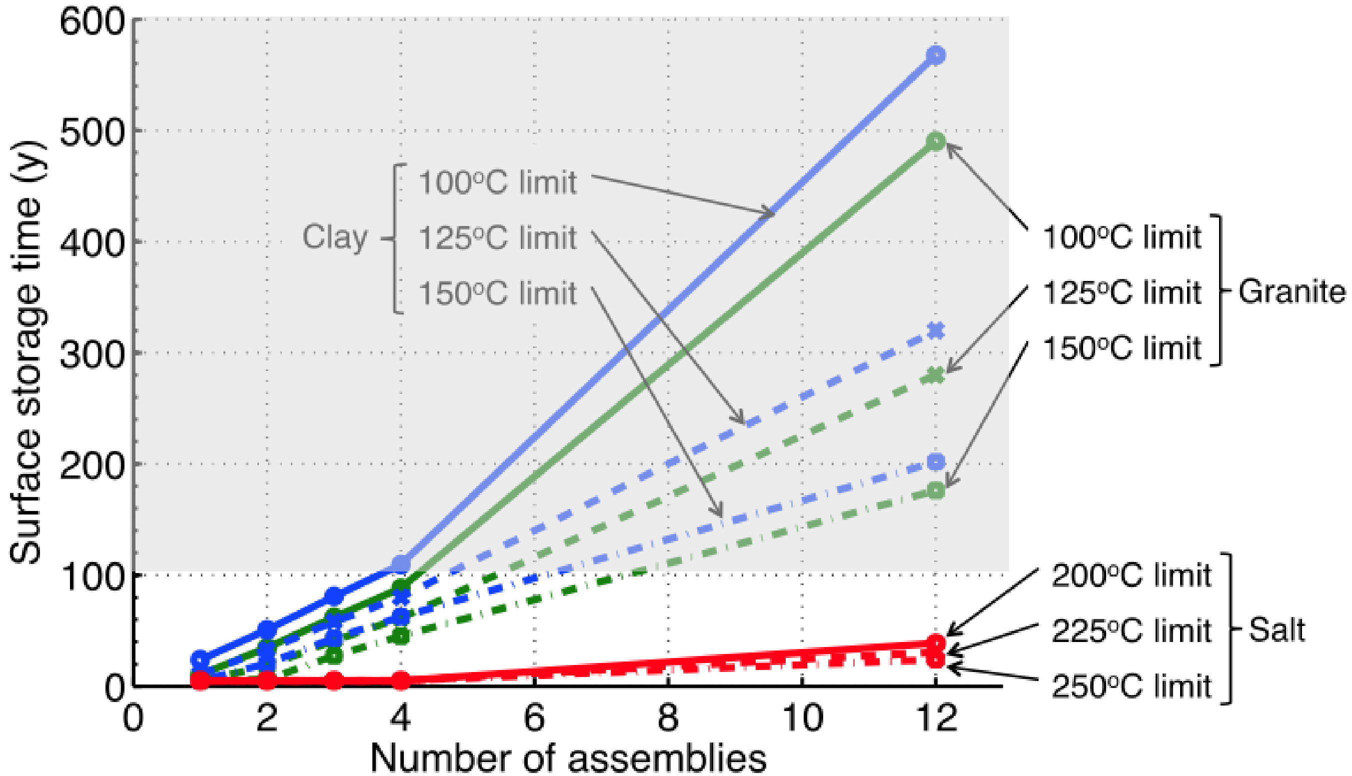
Thermal Analysis Results
Effect of Varying 100°C or 200°C Limits

Decay Storage Needed to Meet WP Surface Temperature Limits vs. WP Size or 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 2006)**
- **200°C for salt (e.g., Salt Repository Project, Fluor 1986)**

Final temperature constraints will be site- and design-specific

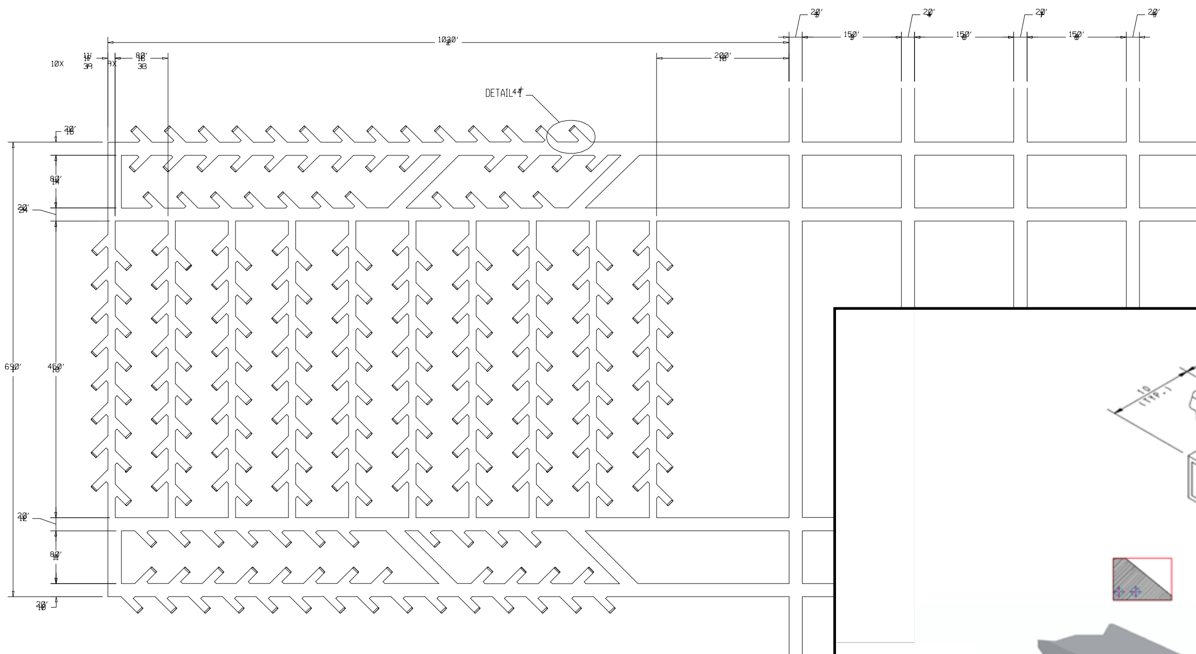


Thermal conductivity for all media selected at 100°C.

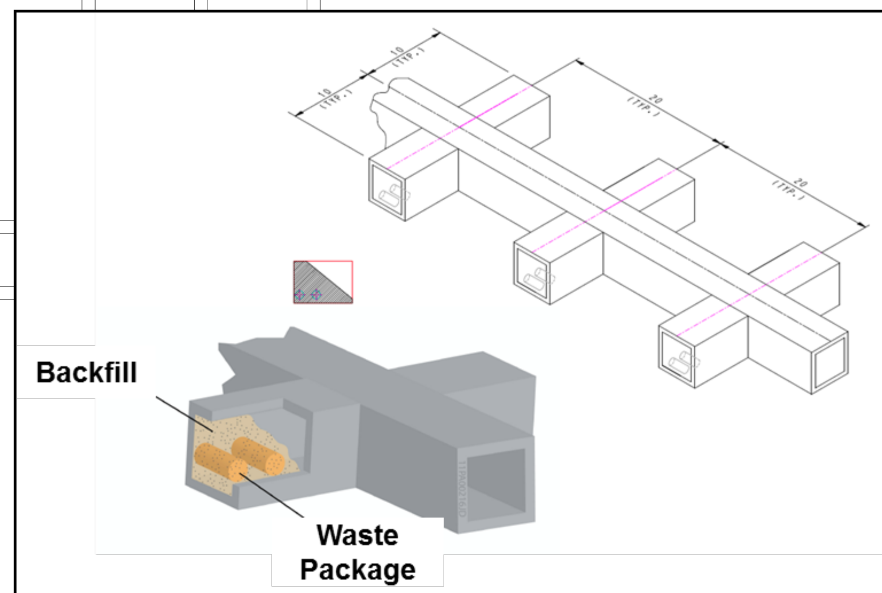
Source: Greenberg et al. 2012a.

Disposal of Large Waste Packages in Salt
Generic Salt Repository

- Generic salt repository layout (Carter et al. 2011)



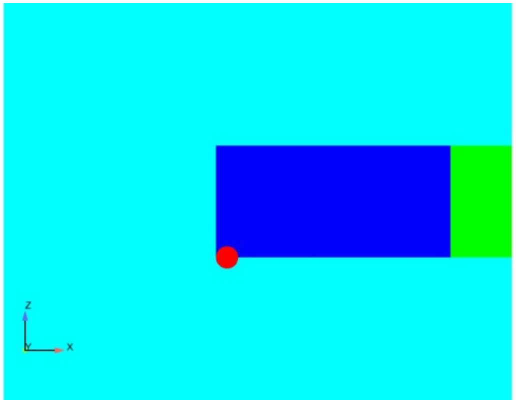
- Abstracted to right-angle geometry (Hardin et al. 2012)

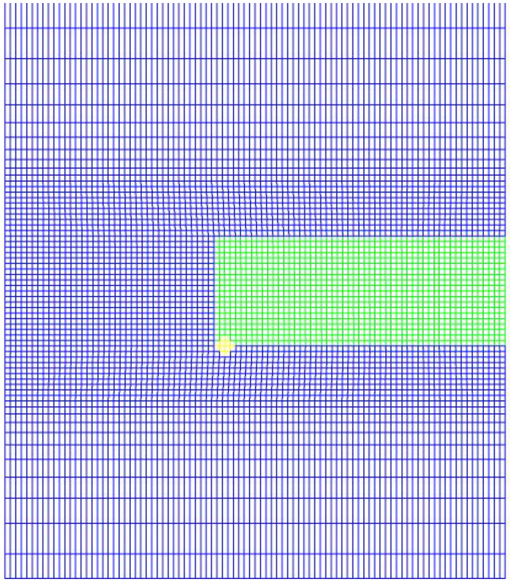


Generic Salt Repository
T-M and T-only Simulation Approach

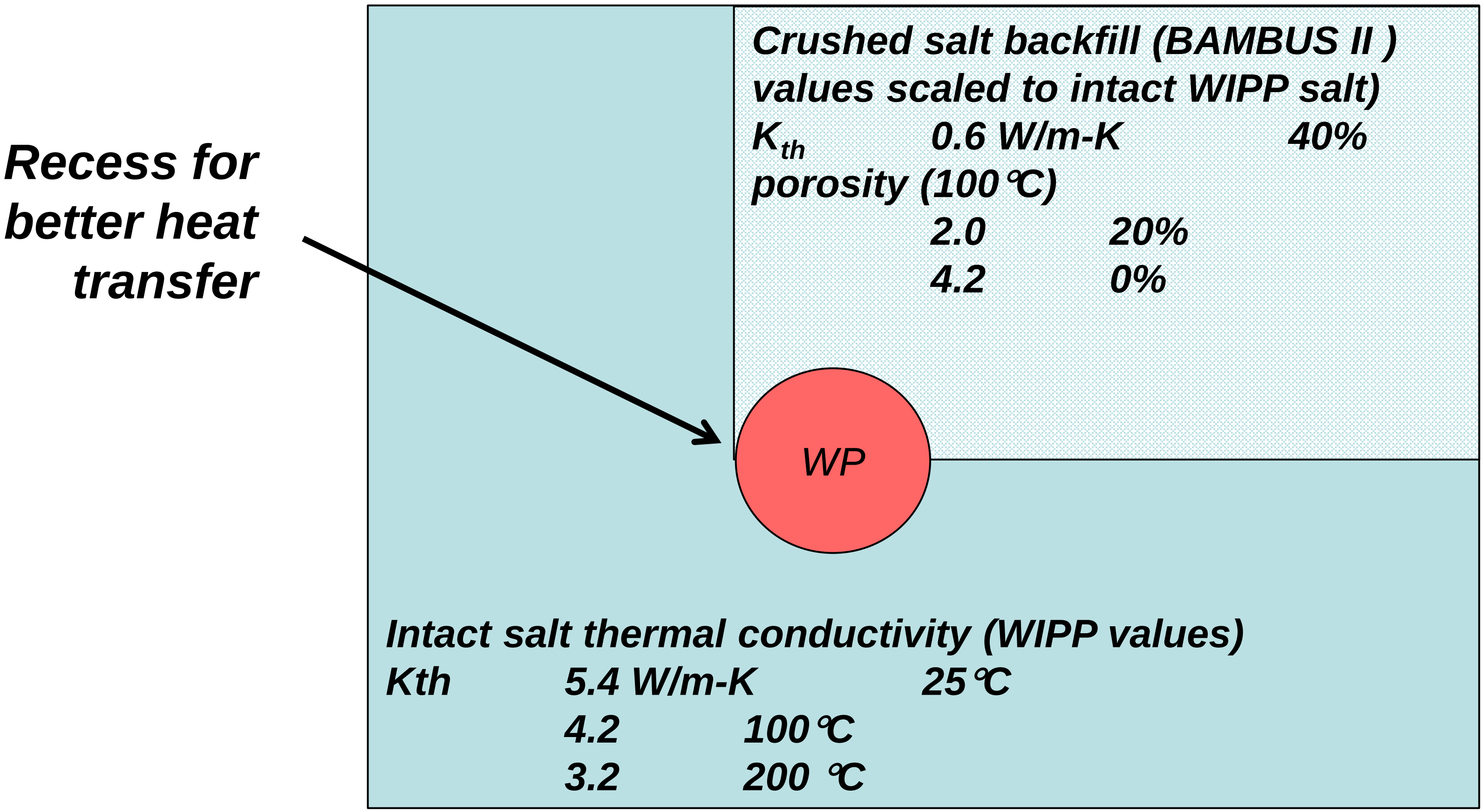
- **Coupled thermal-mechanical model (Clayton et al. 2012)**
- **Sierra codes (Sandia)**
- **Salt properties and constitutive models**
  - Multi-mechanism creep model (Munson et al. 1989)
  - Crushed salt creep (Callahan 1999)
  - Thermal conductivity (Bechthold et al. 2004)
- **Approach:**
  - Test T-M dependence for initial problem
  - Use T-only model for sensitivity analyses

Waste Package Size	Diameter (m)	Length (m)
4 PWR assemblies	0.82	5.00
12 PWR assemblies	1.29	5.13
21 PWR assemblies	1.60	5.13
32 PWR assemblies	2.0	5.13





Schematic of Waste Package Emplacement in Salt



Disposal of Large Waste Packages in Salt

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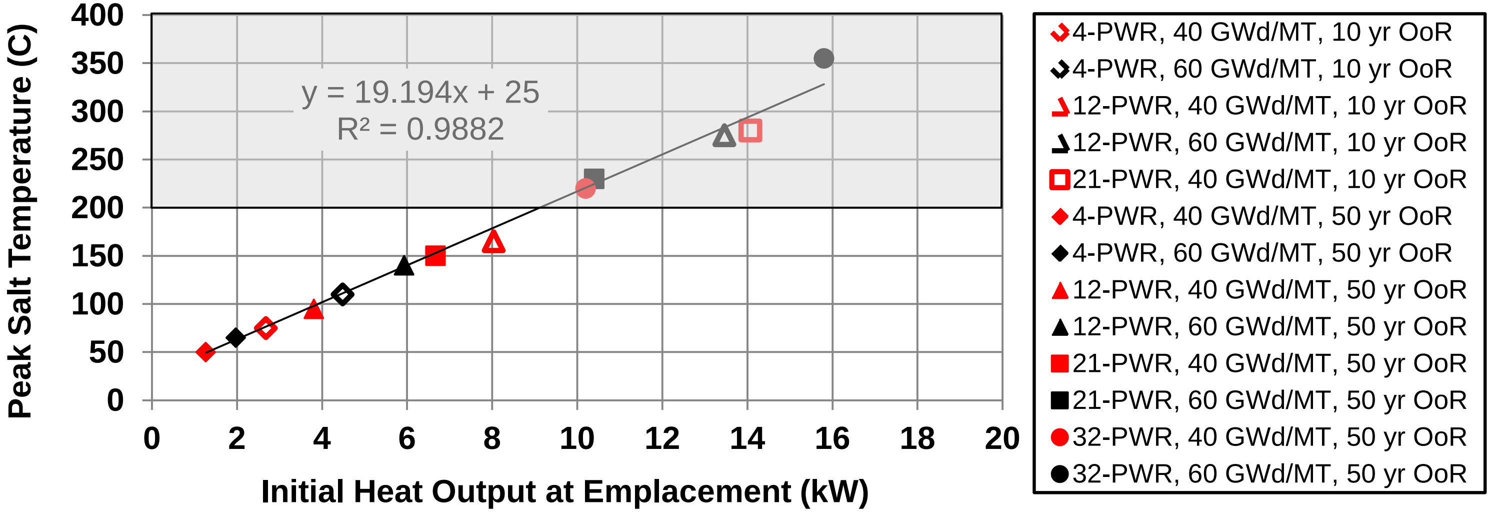
- Peak salt temperature vs. initial package thermal power correlation (>200°C limit shown shaded)
- Burnup, age, and package dimensions are 2nd order



- Also true for other geologic media and disposal concepts
- Use waste package surface temperature to control interface with in-package analyses

Source: Hardin et al. (2012).

Reference Mined Disposal Concepts: Open vs. Enclosed Emplacement Modes

- **Open: excavated emplacement openings persist**
  - Heat spread by thermal radiation → lower temperature at the waste package
  - Pre-closure ventilation possible while drifts remain open for decades
- **Enclosed: emplacement openings close (salt, clay/shale) and/or clay buffer surrounds the waste package (crystalline rock)**
  - More thermal resistance than radiation across a gap→ higher peak temperature in the EBS (e.g., KBS-3, Andra 2005, others)

Reference Mined Disposal Concepts: Open vs. Enclosed Emplacement Modes

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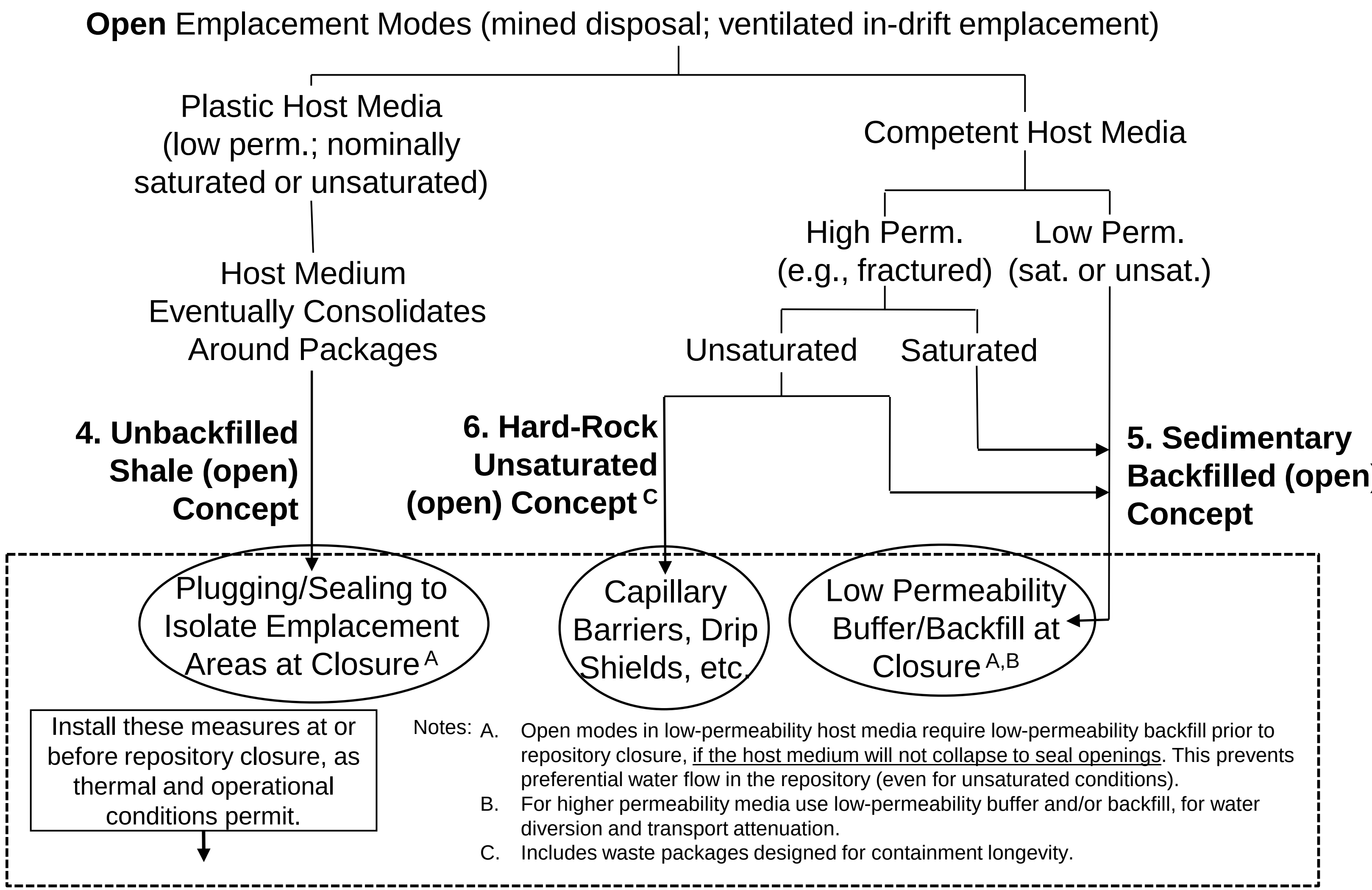
- **Problem Statement (discussed in January, 2012 briefing):**

  For reference portfolio: Develop (open mode) disposal concepts that allow: 1) earlier emplacement, and 2) larger waste packages. Focus on commercial SNF, using a range of geologic settings and concepts of operation.

- **Potential benefits:**
  - Improved cost/schedule efficiency
  - Flexibility not to transport SNF with age > 50 yr
  - Limit packaging and re-packaging (especially if existing storage canisters can be disposed directly)
  - Fewer package-specific operations of all types

Open Disposal Concept “Taxonomy”



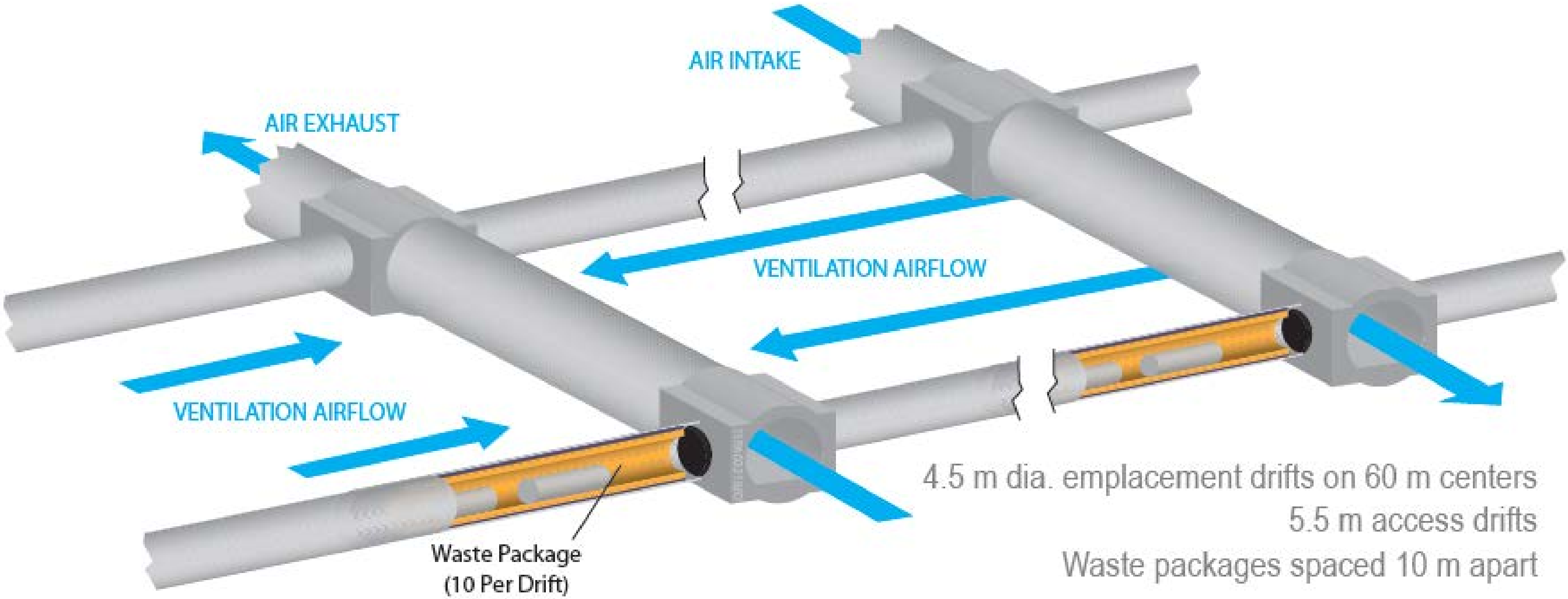
Source: Hardin et al. (2012)

Reference Disposal Concepts

1. KBS-3 (vertical) disposal (enclosed)
2. Generic salt repository (enclosed)
3. Clay/shale repository (enclosed)
4. **Shale unbackfilled open mode**
5. **Sedimentary backfilled open mode**
6. **Hard-rock unsaturated open mode**
7. Deep borehole concept

Source: Hardin et al. (2012).

4. Shale Unbackfilled Open Mode Concept
(low-permeability, nominally sat. or unsat.)



Drift segments containing small numbers of waste packages are isolated by plugging/sealing (backfill is retained as an option at repository closure).

Not to Scale

Source: Hardin et al. (2012).

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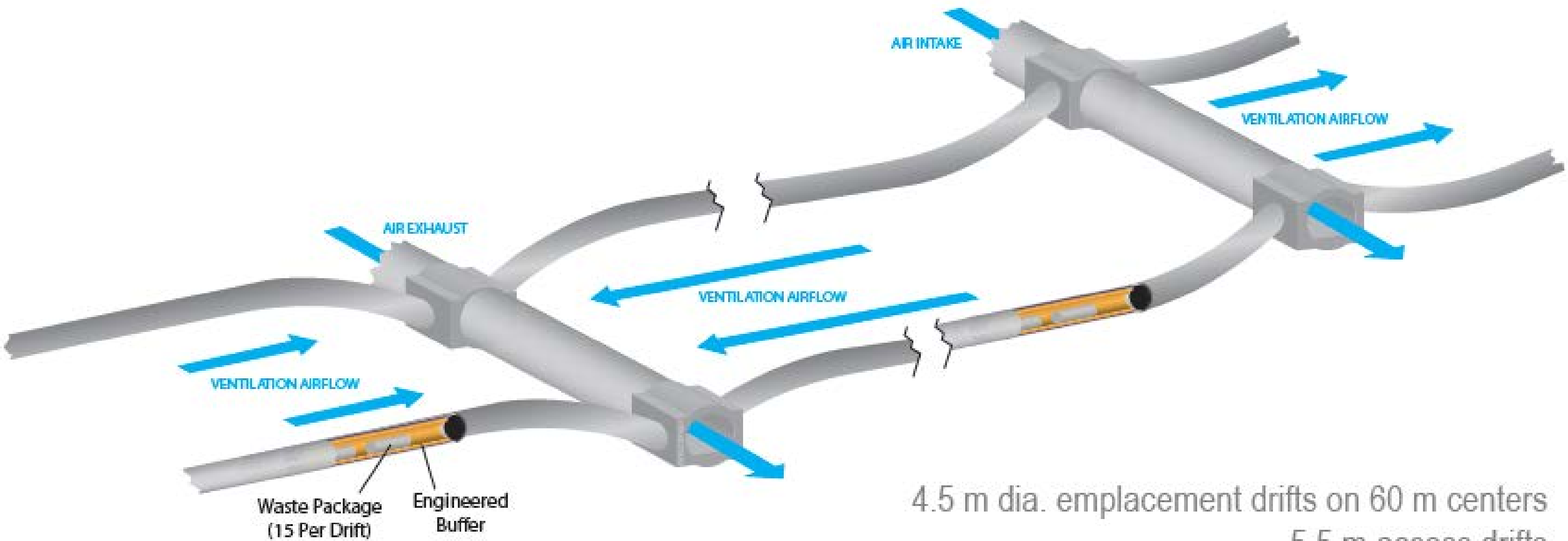
5. Sedimentary Backfilled Open Mode (high- or low-permeability; saturated or unsaturated setting)



4.5 m dia. emplacement drifts on 60 m centers
5.5 m access drifts
Waste packages spaced 10 m apart

Drift segments containing small numbers of waste packages are <u>backfilled with low permeability (e.g., clay-rich) material at closure</u>

Not to Scale

Source: Hardin et al. (2012).

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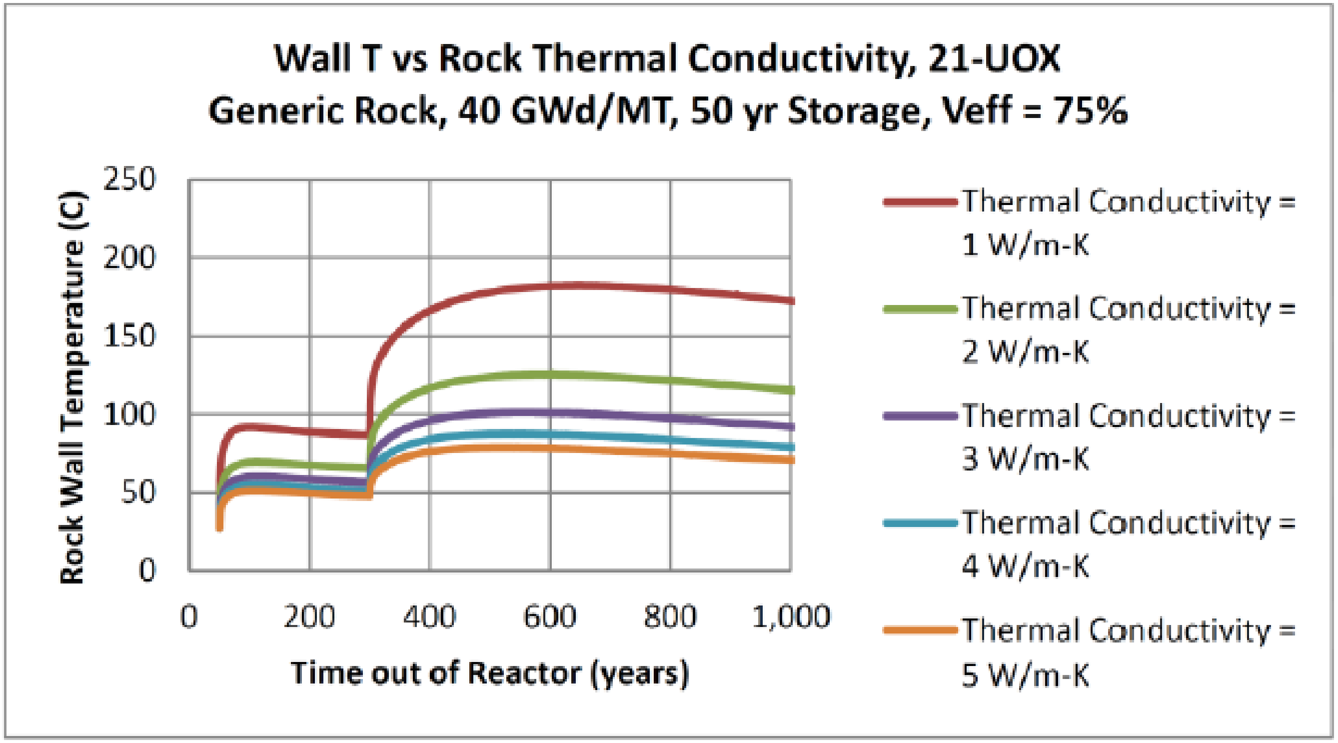
6. Hard Rock, Unsaturated Concept

- Comprehensive design selection study (CRWMS M&O 1999)
- Pre-closure ventilation for at least 50 years (all design alternatives considered in the study included this feature)
- Long-term surface decay storage is not needed
- Ventilation >> 50 years provides an option for a cooler repository
- Free drainage → No need for complete backfilling at closure
- Unsaturated → Shallow depth, facilitating ramp access

Key point: A similar open concept for saturated fractured rock would require complete backfilling at closure (remote operation) to limit groundwater movement through the repository.

Open Mode Thermal Analysis Results for Shale Unbackfilled Open Concept: Host Rock Thermal Conductivity

- Repository closure at 300 yr SNF age; surface storage 50 yr
- Burnup 40 GW-d/MT; V_{eff} = 75%; Package size 21-PWR
- "High" host rock K_{th} for thermal analyses is ~3 W/m-K



Source: Greenberg et al. (2012b).

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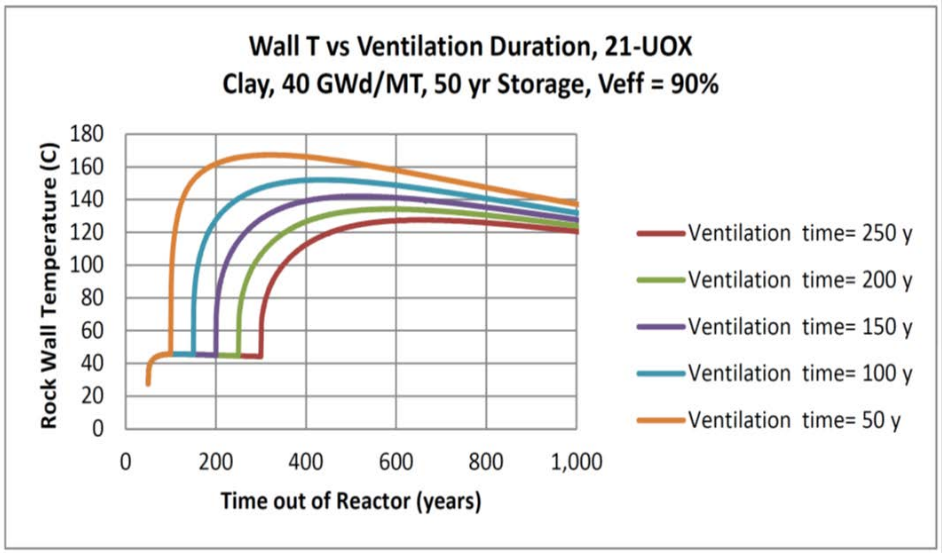
Open Mode Thermal Analysis Results for Shale Unbackfilled Open Concept: Ventilation Duration and Drift Spacing

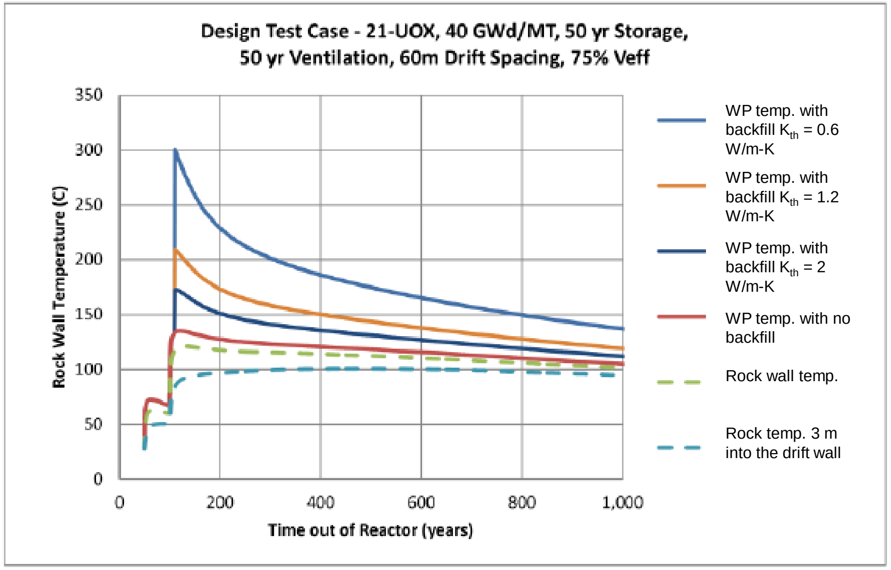
- Surface storage 50 yr (vary SNF age at closure from 100 to 300 yr)
- Burnup 40 GW-d/MT; V_{eff} = 90%; Package size 21-PWR
- Diminishing effect from ventilation duration > 200 yr
- Effect from ~2X drift spacing is greater than ~3X SNF age at closure



Ventilation Period (yr)	Drift Spacing (m)	Peak Rock Temp. (°C)	Peak Time (yr)
250	30	127.6	659
200	30	134.3	602
150	30	142.0	518
100	30	152.0	424
50	30	167.4	322
50	40	141.3	349
50	50	124.2	322

Open Mode Thermal Analysis Results for Shale Unbackfilled Open Concept: "Design Test Case"

- Surface decay storage 50 yr; repository closure at 100 to 150 yr SNF age
- Burnup 40 GW-d/MT; V_{eff} = 75%; 21-PWR; 4.5 m drift diameter
- Strategy: Heat a zone of host shale to > 100°C (3 meters into the drift wall)
- Compare no-backfill with backfill options (varying backfill K_{th})



Host Medium	Description	SNF Age at Closure (yr)	Peak Rock Temp. (°C)	Peak Time (yr)
Shale	Drift wall	100	121.3	129
	r_{DW} = 5.25 m [A]	100	100.9	470
	Drift wall	150	107.3	384
	r_{DW} = 5.25 m [A]	150	95.1	562
[A] Location 3 m into the drift wall				

Sources: Greenberg et al. (2012b); Hardin et al. (2012).

Summary and Conclusions (1/4)
Disposal Concepts

- **Identified 3 Generalized "Open" Disposal Concepts:**
  - **Shale Unbackfilled Open Concept**
    - Low permeability, massive shale, limited water inflow
    - Compartmentalize emplacement areas at closure (e.g., seal crossing drifts)
  - **Sedimentary Backfilled Open Concept**
    - Wide variety of potentially suitable host media (e.g., alluvium, tuff)
    - Backfill at closure (low permeability, e.g., crushed rock, swelling clay)
  - **Hard Rock Unsaturated Concept**
    - Long-term opening stability; temperature resistant host rock
    - No backfilling, plugging, or sealing required in emplacement areas
- **Thermal Analysis**
  - Larger Packages Meet Temperature Limits (200°C) in Salt and Hard Rock Unsaturated concepts (<100 yr aging, ≥ 21-PWR size packages)

Summary and Conclusions (2/4)
Thermal Analysis Summary

Reference Enclosed Emplacement Modes (SNF)

	High K_{th}	Tolerance (EBS up to 200°C?)	WP (PWR assy.'s)	Min. UOX Fuel Age at Emplacement (yr) [B]	Constraint
1. Crystalline	Note A		4	100	Clay-based buffer (100°C)
2. Generic Salt					
Reference	√	√	12	<50	Peak salt temp. (200°C)
21-PWR, 40 GWd/MT			21	50	
32-PWR, 40 GWd/MT or 21-PWR, 60 GWd/MT			21 or 32	<100	
3. Clay/Shale (enclosed)			4	100	Clay-based buffer (100°C)
7. Deep Borehole		√	1	10	None

[A] Host rock thermal conductivity >3 W/m-K; possible for some rock types.

[B] All age values are approximate to ±20%.

Summary and Conclusions (3/4)
Thermal Analysis

Reference Open Emplacement Modes (SNF)

	High K_{th}	Tolerance (EBS up to 200°C?)	WP (PWR assy.'s)	Min. UOX Fuel Age at Closure (yr) [B]	Constraint
4. Shale Unbackfilled			< 21	300 (for 12-PWR WP)	Host rock (100°C)
"Design Test Case"			21	<150	Host rock (100°C at 3 m into drift wall)
5. Sedimentary Backfilled			< 21	300 (for 12-PWR WP)	Clay-based buffer (100°C)
6. Hard Rock Unsat.	Note A	√	≥ 21	>50	Host rock (200°C)

[A] Host rock thermal conductivity >3 W/m-K; possible for some rock types.

[B] All age values are approximate to ±20%.

Summary and Conclusions (4/4)
Continuing Work

- **Direct Disposal of Large Canisters including Dual-Purpose Canisters (DPCs)**
  - Regulatory framework for disposal concepts
  - Key features, events and processes affected (e.g., postclosure criticality)
  - Generic performance assessments
  - Thermal and logistical analyses
  - Cost comparison with concepts using smaller packages
- **Disposal R&D**
  - Temperature limits greater than 100°C (clay buffer) and 200°C (salt)
  - Heating of host media (e.g., heating shale above 100°C in the near field)
  - Engineered materials and admixtures that improve heat transfer or thermal stability

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