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Dual-Purpose Canister Direct Disposal Technical Feasibility Evaluation: Introduction and Summary

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Unclassified, Internal Use Only
UFD Annual Working Group Meeting – UNLV
June 11, 2015

DPC Direct Disposal Technical Feasibility

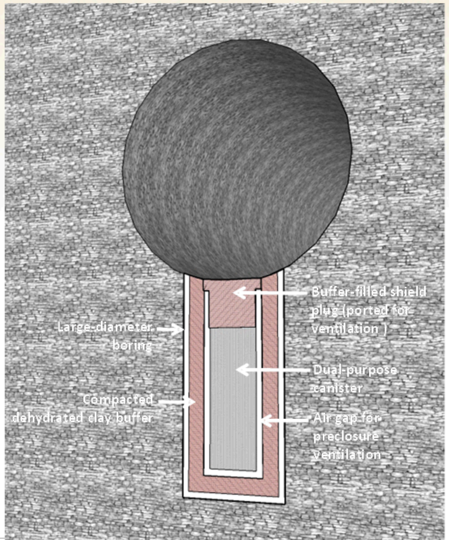
Multi-year Budget by Lab and Topic (FY12-15)

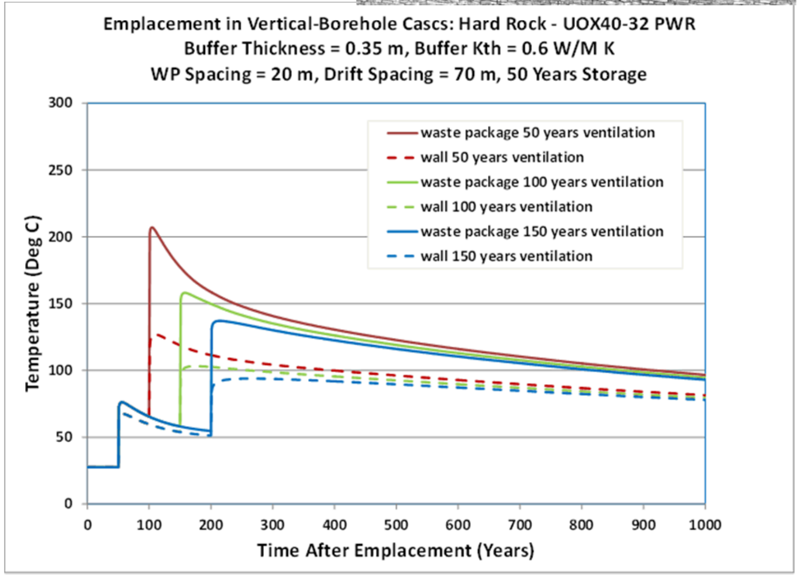
		Planning, assumptions, regulatory, reporting, peer review	Nuclear criticality	Concepts, available tech.	FEPs, safety strategy	Logistics	Thermal mgmt.	DPC matl. perf., over-pack matl. selection, environments	Ground-water salinity	Fillers	Argilla-ceous THM	Overpack reliability	Costing
FY12	SNL	165											
	ORNL	45	45										
	ANL	20		80									
	LLNL	51		34									
Total	440												
FY13	SNL	175			75								
	ORNL	65	165	75	20								
	ANL	48		30		40							
	LLNL	45					120						
	SRNL	30		70									
Total	958												
FY14	SNL	212	28			181		89					
	ORNL	121	267					35					
	INL		25										
	LBNL										100		
	SRNL	30		30						60			
	LANL								100				
Total	1,456												
FY15	SNL	145		50			35					150	35
	ORNL	33	197										
	SRNL	21											127
Total	793												
By Topic	3,647	1,206	727	369	95	221	155	124	100	60	100	150	162

DPC Direct Disposal Technical Feasibility Evaluation

FY15 Accomplishments

- Vault concept and thermal calculations
- 37-PWR thermal analysis
- Criticality validation study
- Add DPCs to UNF-ST&DARDS
- Overpack reliability (early failure) study
- Multi-year summary report
- Conference presentations





DPC Direct Disposal Technical Feasibility Evaluation
Papers and Publications

- **Waste Management: 2014 and 2015 (multiple papers)**
- **NEI Used Fuel Management: 2013, 2014 and 2015 (multiple papers)**
- **ANS IHLRWMC 2015 Topical: Session on DPC direct disposal**
- **INMM 2014 Annual Meeting**
- **ICNC 2015 Annual Meeting**
- **ORACS Albuquerque Workshop (2015)**
- **RadWaste Solutions cover article, Spring 2014 issue**
- **ACS 247th National Meeting (2014)**
- **NWTRB November, 2013 workshop**
- **Summary paper FY15??**

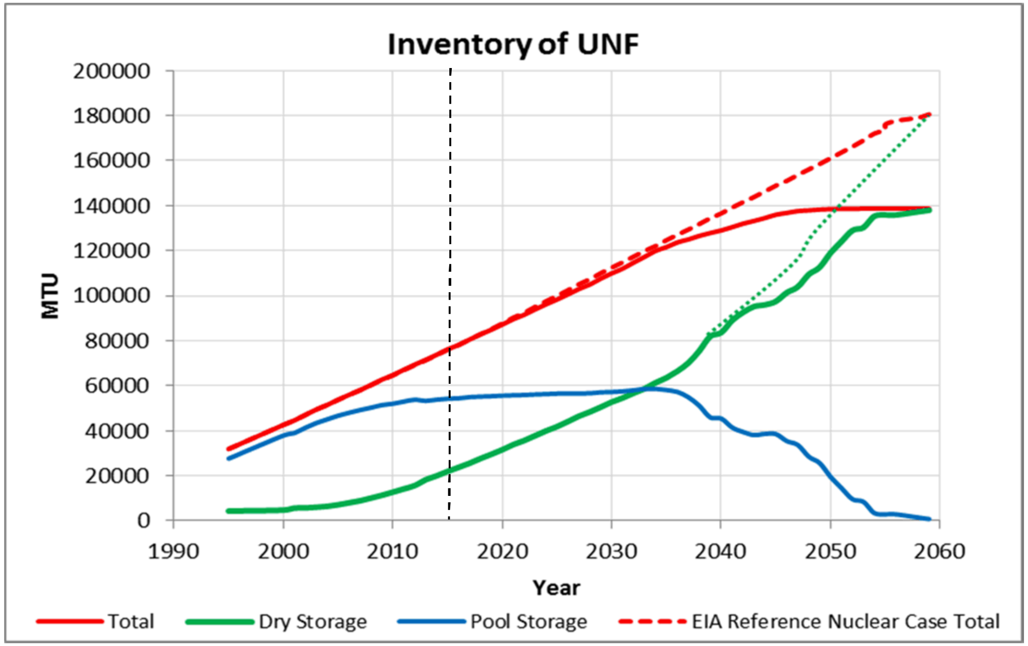
DPC Cost Perspective (ROM)

• **Sunk cost to procure/load/store DPCs**	**~$100,000 /MTU**
Cost to continue through >2055:	**~$10B**
• **Future costs for all fuel, current fleet:**	
Unload	**>$10,000 /MTU**
Transport and dispose of hull	**>$150,000 each**
Re-canister for disposal	**~$100,000 /MTU**
Total for 140,000 MTU	**>$36B***

** Substantial cost savings could be achieved by:*

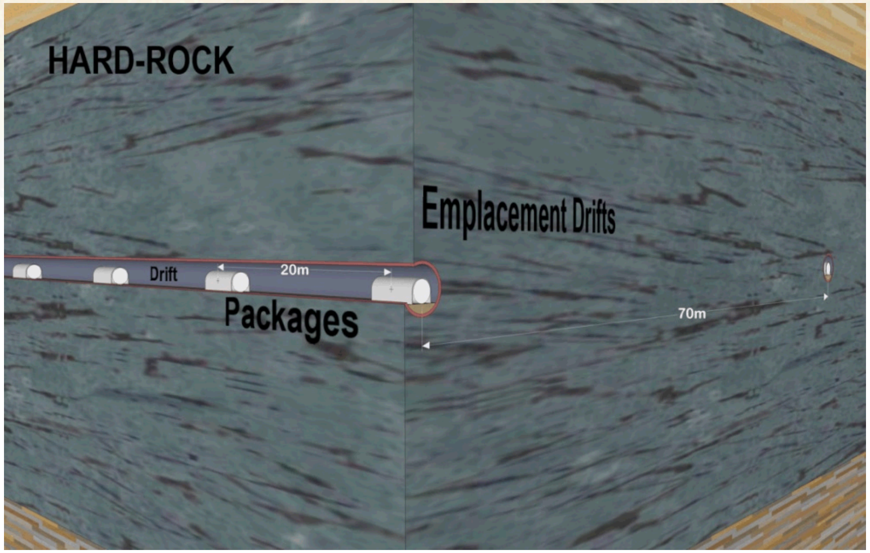
1) Direct disposal of all DPCs; or

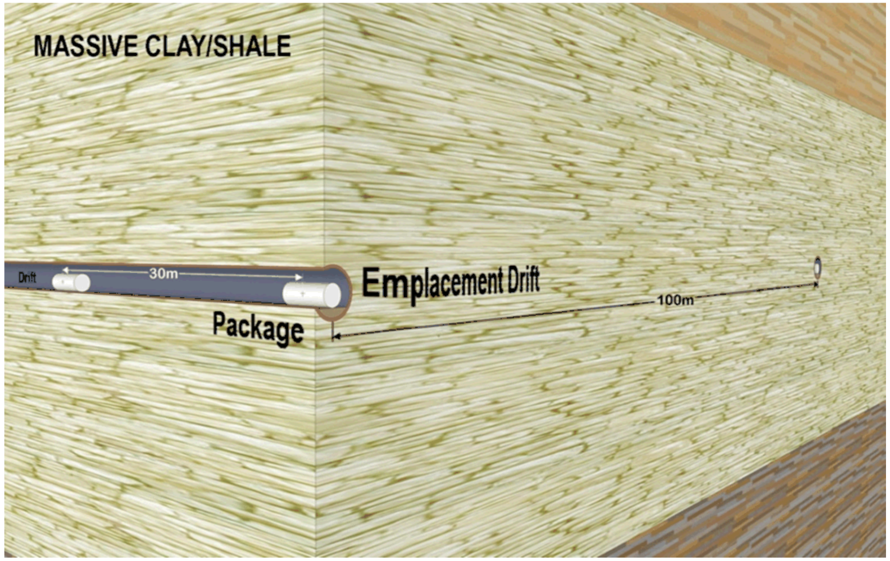
2) Direct disposal of existing DPCs, and transition to purpose-built and licensed multi-purpose canisters (storage-transport-disposal).

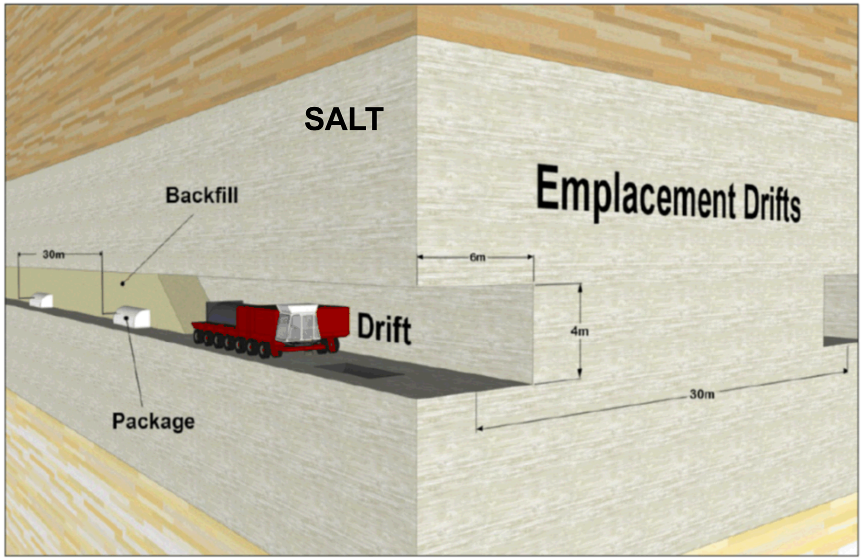


DPC Direct Disposal Concepts

- Engineering challenges are technically feasible
- Shaft or ramp transport
- In-drift emplacement
- Repository ventilation (except salt)
- Backfill at emplacement or prior to closure (except unsaturated)

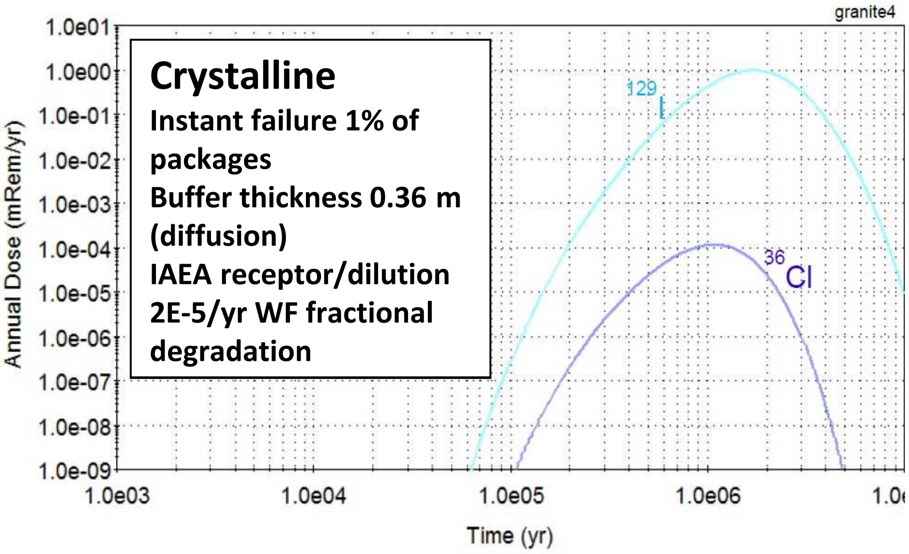






(Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 1)

Generic Performance Assessment



Crystalline

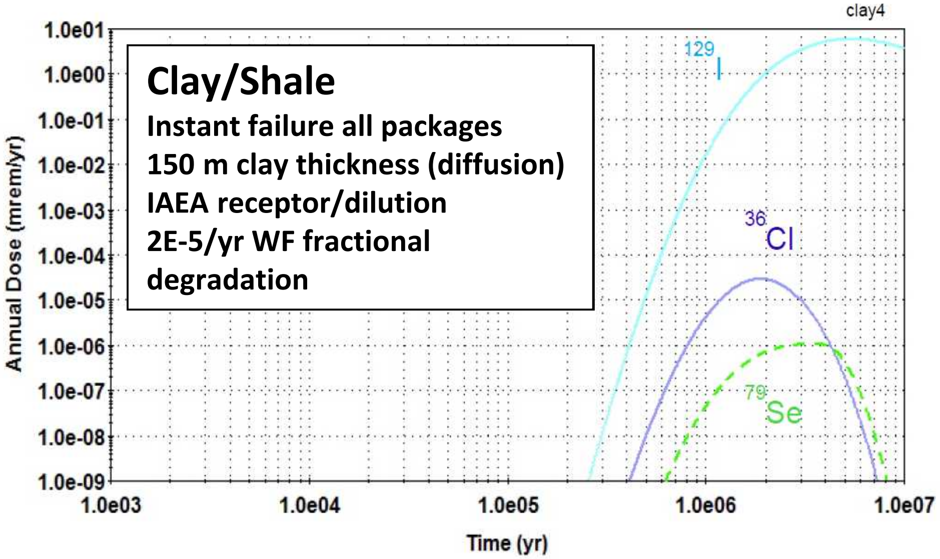
Instant failure 1% of packages

Buffer thickness 0.36 m (diffusion)

IAEA receptor/dilution

2E-5/yr WF fractional degradation

- Nominal performance, 1-D transport
- Diffusion-dominated barrier (natural and/or engineered)
- Response proportional to inventory (package size → granularity)
- DPC effects (nominal scenario) limited to thermal



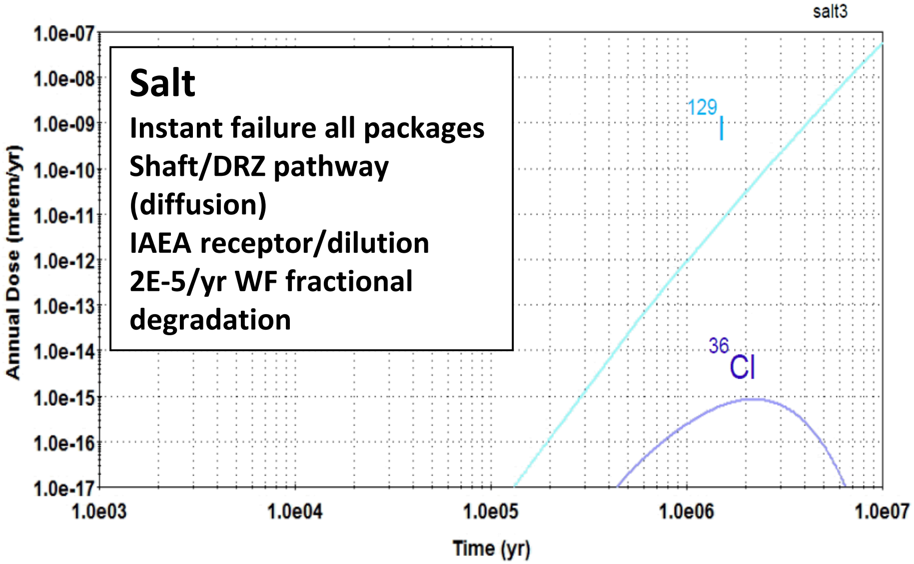
Clay/Shale

Instant failure all packages

150 m clay thickness (diffusion)

IAEA receptor/dilution

2E-5/yr WF fractional degradation



Salt

Instant failure all packages

Shaft/DRZ pathway (diffusion)

IAEA receptor/dilution

2E-5/yr WF fractional degradation

(Freeze et al. 2012, FCRD-UFD-2012-000146 Rev. 1)

Safety of Workers and the Public – Summary

Preclosure operational safety:

- Handling/packaging of large DPCs is within the state of practice
- Operations would be similar for any DPC direct disposal concept

→***No significant technical questions concerning operational safety until the waste is transported underground***

Postclosure waste isolation:

- Containment would be assigned to the disposal overpack
- As for any geologic repository, waste isolation is enhanced with *diffusion-dominated transport*, and properties that are insensitive to the expected temperature history

→***No significant generic technical concerns for waste isolation with multiple engineered and natural barriers***

"Hallway" Engineering Rumors

- **"DPCs are much heavier than YM TADs."**

  Loaded Magnastor (47 MT) vs. loaded TAD (< 49.3 MT)

- **"DPCs are much larger than YM TADs."**

  Magnastor canister (1.80 m D x 4.87 m L → 12.4 m^3) vs. TAD dimensional envelope (1.69 m D x 5.39 m L → 12.1 m^3)

- **"DPC-based waste packages would be too heavy to lower down a shaft."**

  Not necessarily, e.g., DPC package (70 MT) with shield (80 MT) + carriage < 175 MT (DBE TEC DIREGT conceptual hoist design)

- **"DPC-based packages would be too big/hot/heavy for a salt repository."**

  Package bearing stress is small (< 50 kPa) and even creep models calibrated to recent low-stress data produce < 0.5 m of sinking in 10^4 years, without interbeds. Heating/cooling displaces packages up/down due to expansion.

Sources:

1. Greene et al. 2013. Storage and Transport Cask Data for Used Commercial Nuclear Fuel – 2013 U.S. Edition. ATI-TR-13047.
2. BSC 2008. *Basis of Design for the TAD Canister-Based Repository Design Concept*. 2008000-3DR-MGRO-00300-000-003.
3. Hardin & Kalinina 2015. *Cost Estimation Inputs for Spent Nuclear Fuel Geologic Disposal*. SAND2015-0687.

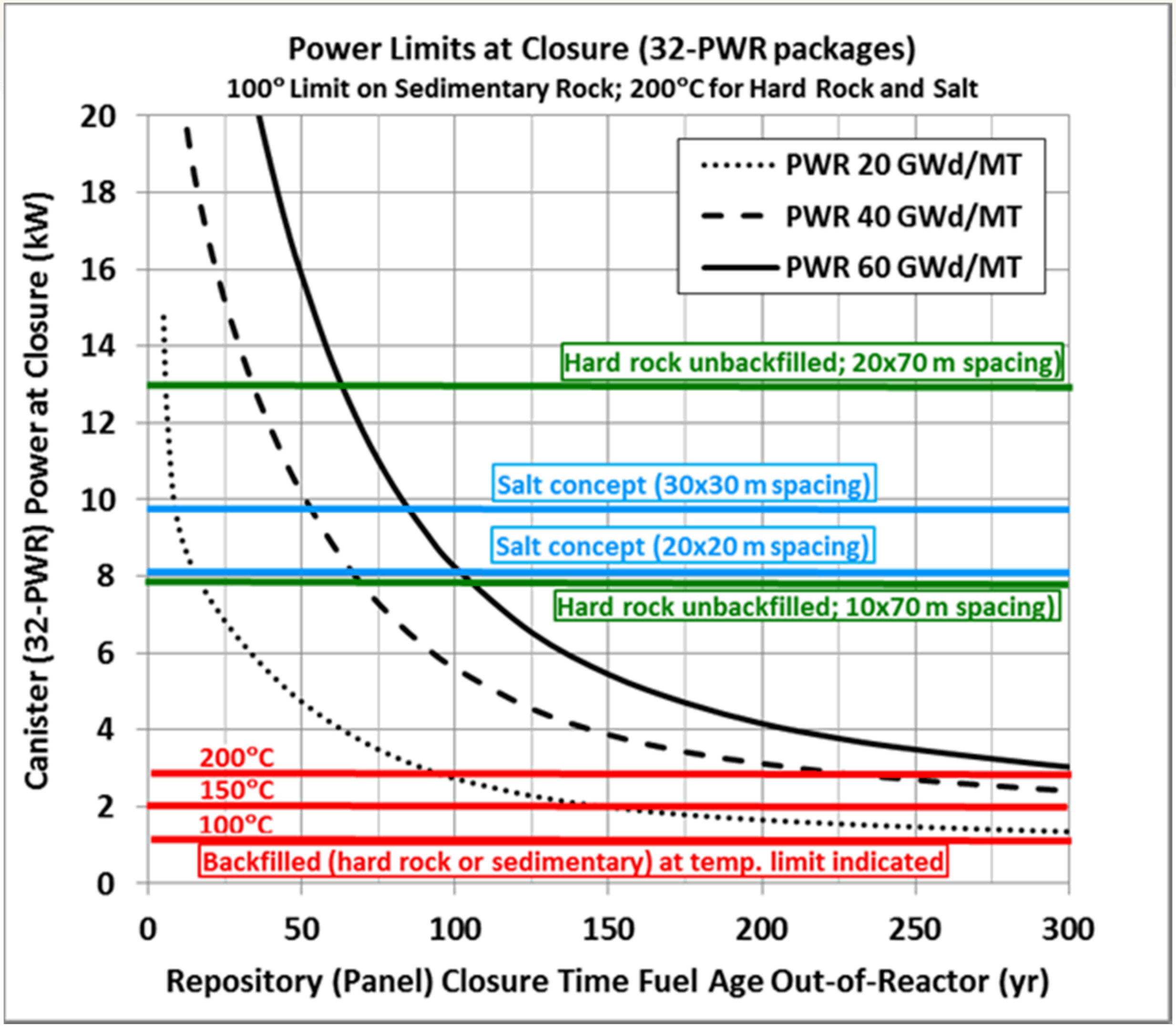
Engineering Feasibility – Summary

Engineering feasibility position:

- Solutions are available for transporting and emplacing DPC-packages underground, although some could be largest of kind
- Repository construction costs would be manageable
- Openings could be stable for >50 years in many rock types
- Improved overpack containment reliability is possible

→ ***No significant technical concept questions concerning engineering feasibility of DPC direct disposal***

Fuel Burnup-Aging Thermal Requirements for Disposal Concepts

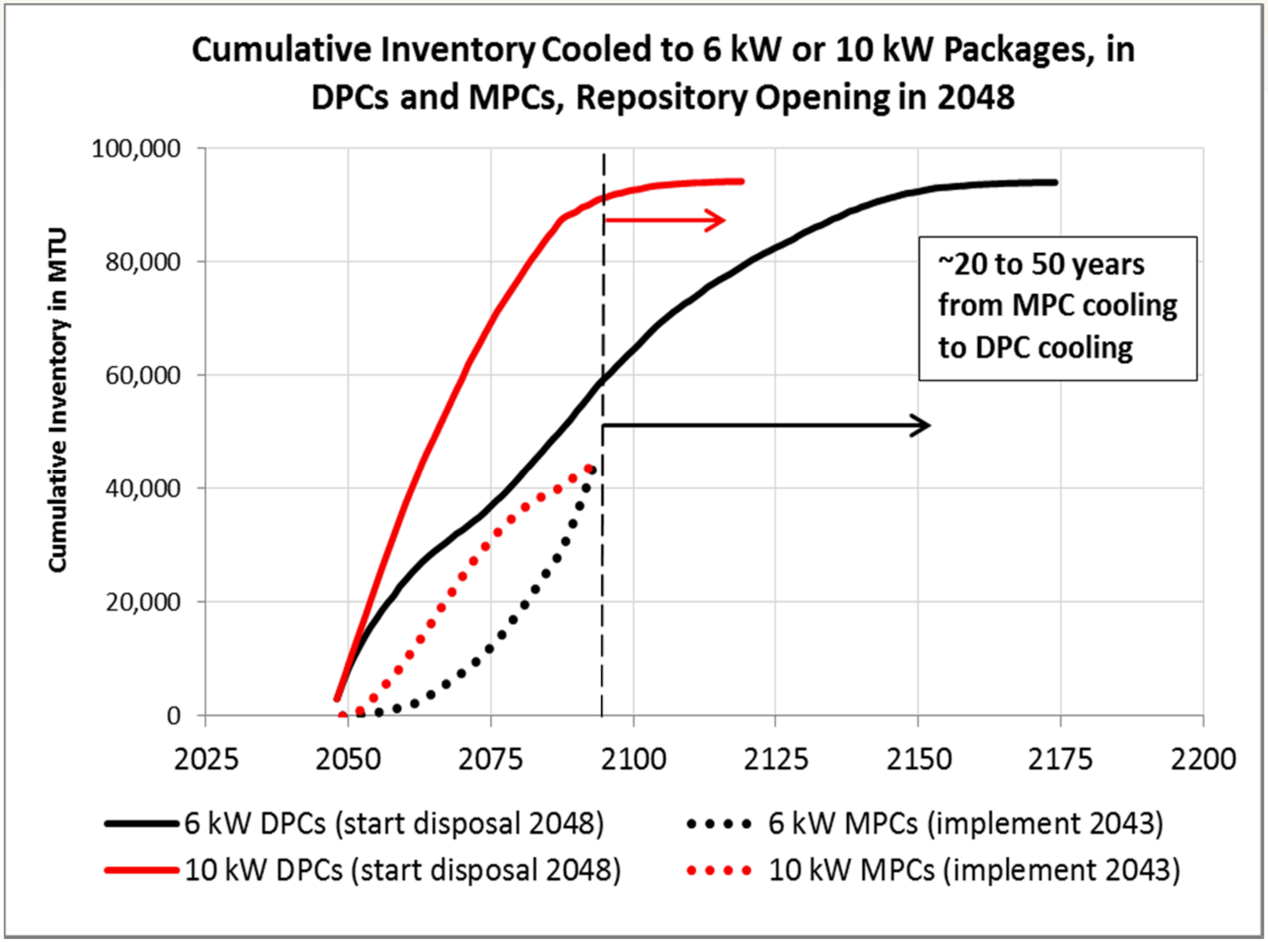


- For SNF burnup (black curves) crossing points give minimum aging time to meet peak temperature targets, for 32-PWR size packages
- Heat dissipation is best for salt and unsaturated/ unbackfilled disposal concepts
- Where backfill is used, backfill constraints dominate

(Based on Hardin et al. 2013, FCRD-UFD-2013-000170 Rev. 0)

Cooling Time With Transition from DPCs to Small MPCs (Storage-Transport-Disposal)

- **Repository start in 2048**
- **4-PWR size MPCs implemented 5 yrs prior**
- **MPCs meet cooling targets 20 to 50 yrs before DPCs (with higher burnup fuel)**
- **Other start dates (2036 and 2060):**
  - Change ratio of MPCs vs. DPCs
  - Earlier start (2036) → Cooling to 6 kW < 2100
  - Later start (2060) → Cooling to 6 kW > 2150



TSL-CALVIN simulation of existing reactor fleet with 20-yr life extensions and gradual burnup increase.

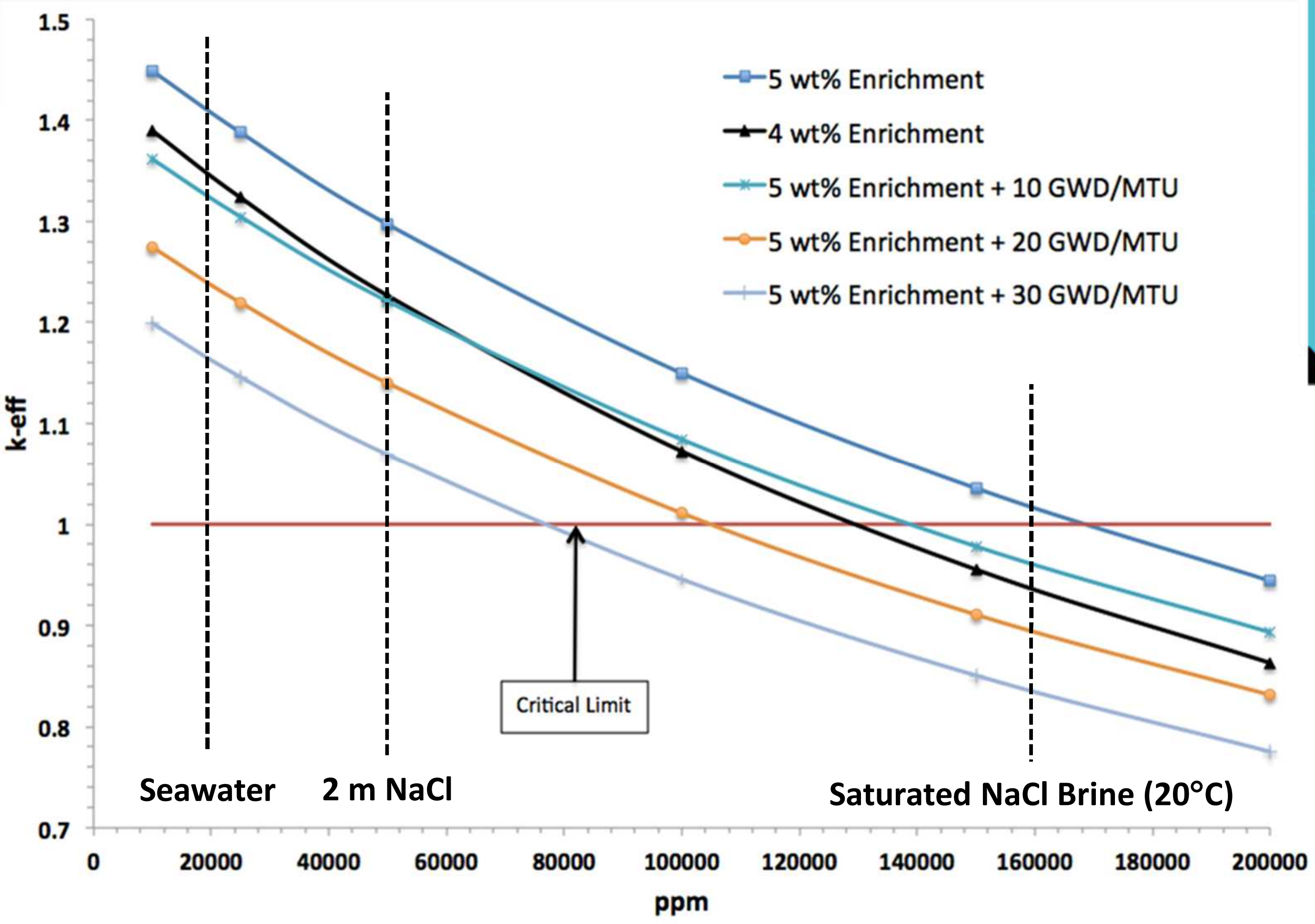
Thermal Management – Summary

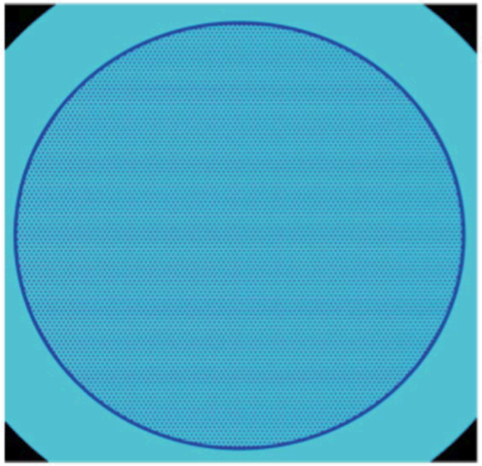
Thermal management position:

- Repository host media exist (salt, unsaturated hard rock) with high conductivity and high temperature tolerance (200°C)
- Concepts that call for clay-based backfill could require much longer decay storage/aging time and larger repository layouts

→ ***Thermal management is not a generic technical concern, at least for salt and unsaturated hard rock.***

Criticality Analysis for High-Reactivity Stylized Case



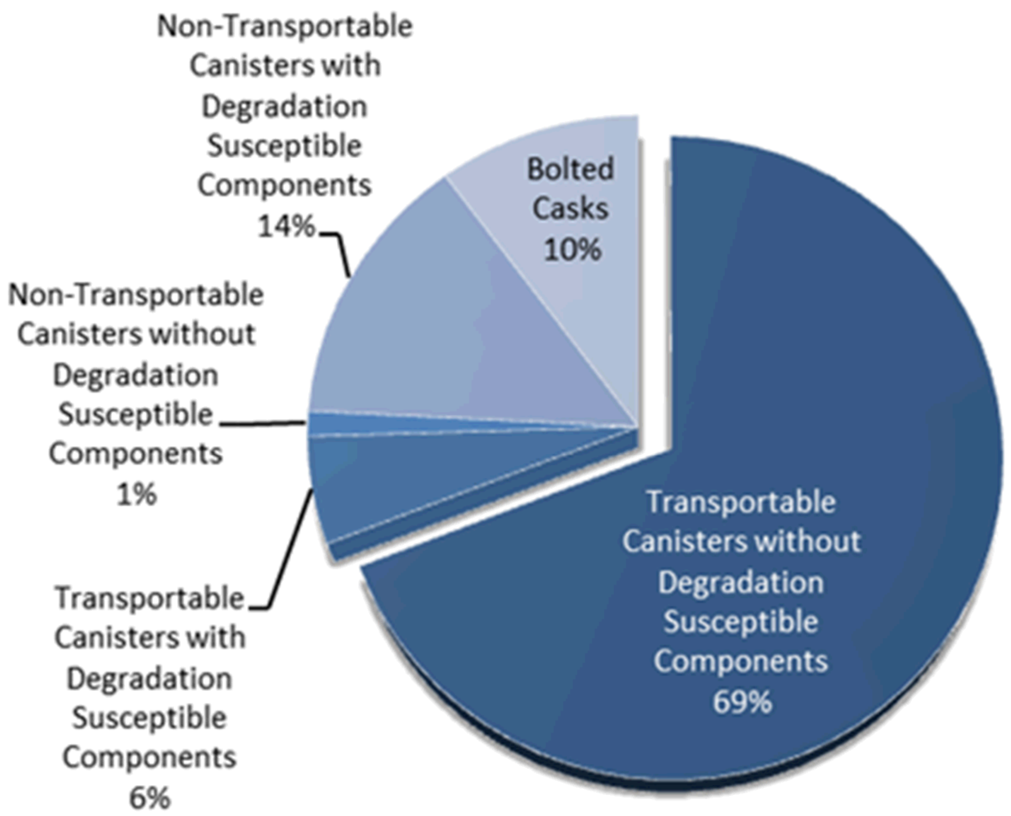


High-reactivity case:

- Hexagonal array of 8617 PWR fuel rods (W17x17WL)
- Rods from slightly more than 32 assemblies, in a 32-PWR DPC

(Banerjee et al. 2014. Dual Purpose Canister Reactivity and Groundwater Absorption AnalysesFCRD-UFD-2014-000520)

DPC Construction Affects Potential for Postclosure Criticality and Thus, Disposability



- Fresh-water disposal environment, flooding possible
- Reliance on uncredited margin (as-loaded, full burnup credit)
- After package breach, degradation of neutron absorbers
- Basket structural integrity maintains assembly fuel rod pitch
- Stainless steel has the longest corrosion lifetime

Postclosure Criticality – Summary

Postclosure criticality position:

- **Without flooding criticality potential is negligible**
- **Once flooded, Al-based neutron absorber materials will degrade**
- **Reactivity increase can be offset by:**
  - High-reliability overpacks (limit manufacturing defects)
  - Minimal impact of disruptive events on overpack containment
  - Available uncredited margin (for analyzed configurations)
  - Natural chloride in ground water (e.g., salt repository)
  - Fillers implemented after closure

→***Postclosure criticality is not a generic technical concern, at least for salt and unsaturated hard rock media***

Technical Feasibility Study Summary

- **Technical feasibility evaluation results for:**
    - Safety of workers and the public
    - Engineering feasibility
    - Thermal management
    - Postclosure criticality control

No generic or conceptual concerns

- **Most favorable disposal concepts: salt and hard rock unsaturated/unbackfilled**
- **Transition to MPCs facilitates repository loading/closure**
    - Begin disposal with MPCs; DPCs cool 20 to 50 years later
- **Other considerations important for DPC disposability:**
    - Basket structural longevity
    - Disposal overpack reliability (better than 4.5×10^{-5} /each)
    - UNF-ST&DARDS unified database (ORNL) capabilities

Path Forward – Stakeholder Actions

Suggested collaborative stakeholder actions (utilities, vendors, government):

- **Develop a generic disposability standard and licensing basis for DPCs and MPCs (storage-transport-disposal)**
  - Mainly for postclosure criticality
  - Generic disposability case will be similar for DPCs and MPCs
- **Perform as-loaded, burnup credit analysis (e.g., loss of absorber) when DPCs are loaded**
- **Ensure DPC lifetime in storage to allow sufficient cooling for direct disposal (e.g., up to 150 yr)**
- **Collect data and analyze existing DPCs (e.g., GC-859)**

UFD Annual Meeting June 9-11, 2015
DPC Direct Disposal Technical Feasibility Evaluation
Session Agenda

- Introduction (E. Hardin)
- **Disposal Concepts for Costing Study (E. Hardin)**
- **Costing (T. Severynse/J. Carter)**
- **Criticality (K. Banerjee/J. Scaglione)**
- **Logistical Simulations (E. Kalinina)**
- **Summary and Recommendations (L. Price)**

Disposal Concepts for Repository Costing, Including DPC Direct Disposal

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UFD Annual Meeting – UNLV
June 11, 2015

☑Cost estimated previously		4-PWR/9- or 12-BWR	12-PWR/ 24-BWR[1]	21-PWR/ 44-BWR	DPC Direct
"Enclosed"					
Crystalline	Based on KBS-3V (SKB 2011)	🟩 ✓ 1	(Note 2)	(Note 3)	(Note 3)
Argillaceous	Based on ANDRA (2005) (for SNF in horiz. boreholes)	🟩 ✓ 2	(Note 2)	(Note 3)	(Note 3)
	Based on NAGRA (2002, 2003) (for in-drift, self-shielded pkgs, with immediate backfilling)	(Note 4)	3	(Note 5)	(Note 5)
Salt	U.S. reference (in-drift)	4	🟩 ✓ 5	6	7
"Open"					
Hard Rock (e.g., Crystalline)	Unsaturated, unbackfilled, open (YM concept, DOE 2008a)	(Note 6)	8	🟨 ✓ 9	10
	Saturated, backfilled, open	(Note 6)	11	12	13
Argillaceous	Backfilled, open	(Note 6)	14	🟩 ✓ 15	16

Notes:

1. The BWR equivalent to 12-PWR assemblies could be 32, and because thermal limits in this report are based on instantaneous package power, the only impact of such a change would be on Appendix A which calculates decay storage time and repository throughput.
2. T_{peak}> 100°C; canister handling problematic for borehole emplacement.
3. T_{peak}>> 100°C; canister handling problematic.
4. Can assume cost would not be significantly different from the concept based on ANDRA (2005).
5. T_{peak}>> 100°C.
6. Open-mode ventilation not needed to meet thermal goals (use enclosed concepts above).

🟩 Cost estimated previously for a similar arrangement (Hardin et al. 2012).
🟨 Cost estimated previously for YM TSLCC analysis (DOE 2008b)

Disposal Concept Description (1/5)

Waste Package Capacity, Count and Overpack Material

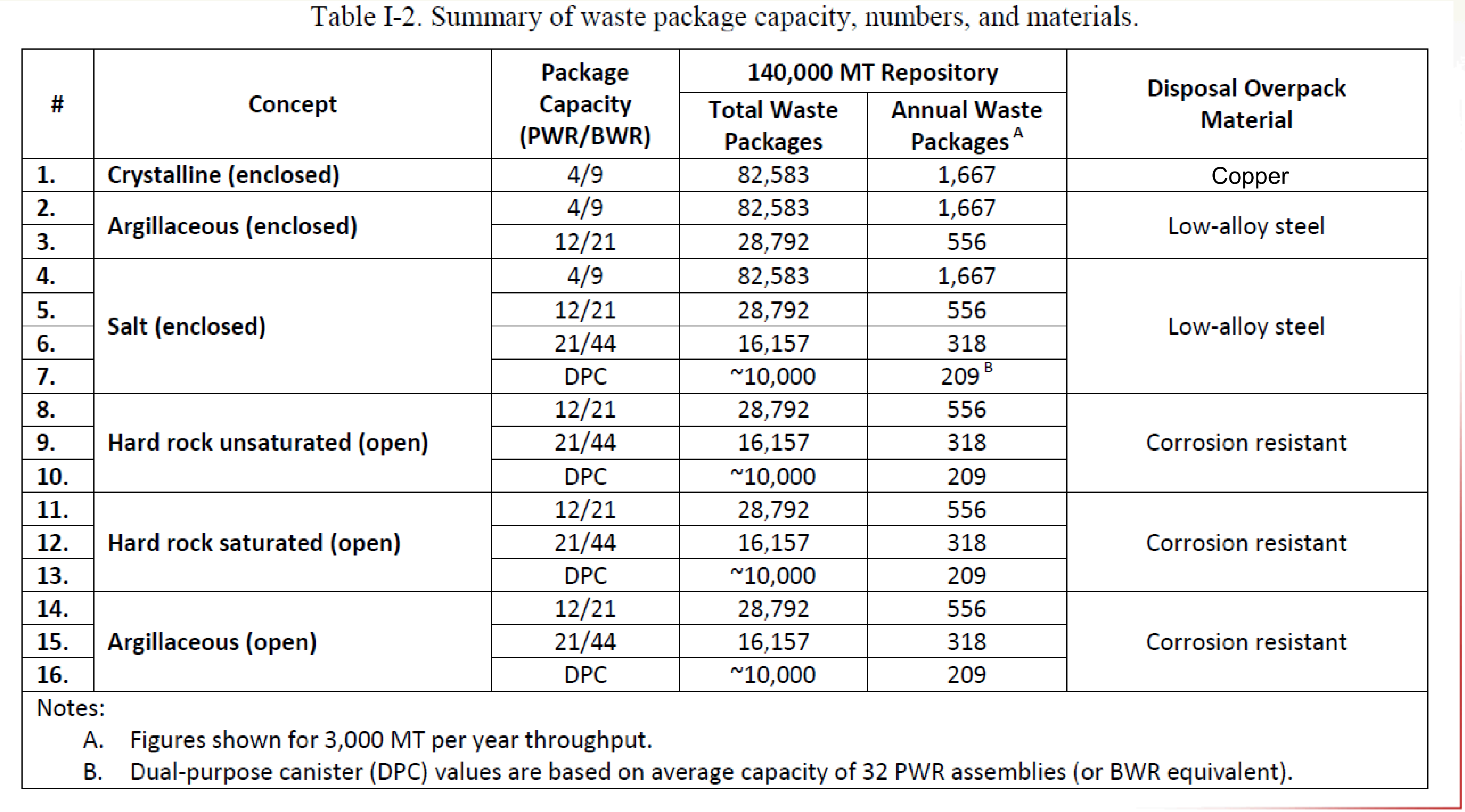


Table I-2. Summary of waste package capacity, numbers, and materials.

#	Concept	Package Capacity (PWR/BWR)	140,000 MT Repository		Disposal Overpack Material
			Total Waste Packages	Annual Waste Packages [A]	
1.	Crystalline (enclosed)	4/9	82,583	1,667	Copper
2.	Argillaceous (enclosed)	4/9	82,583	1,667	Low-alloy steel
3.		12/21	28,792	556	
4.	Salt (enclosed)	4/9	82,583	1,667	Low-alloy steel
5.		12/21	28,792	556	
6.		21/44	16,157	318	
7.		DPC	~10,000	209 [B]	
8.	Hard rock unsaturated (open)	12/21	28,792	556	Corrosion resistant
9.		21/44	16,157	318	
10.		DPC	~10,000	209	
11.	Hard rock saturated (open)	12/21	28,792	556	Corrosion resistant
12.		21/44	16,157	318	
13.		DPC	~10,000	209	
14.	Argillaceous (open)	12/21	28,792	556	Corrosion resistant
15.		21/44	16,157	318	
16.		DPC	~10,000	209	

Notes:

A. Figures shown for 3,000 MT per year throughput.

B. Dual-purpose canister (DPC) values are based on average capacity of 32 PWR assemblies (or BWR equivalent).

Disposal Concept Description (2/5)

Drift Diameter

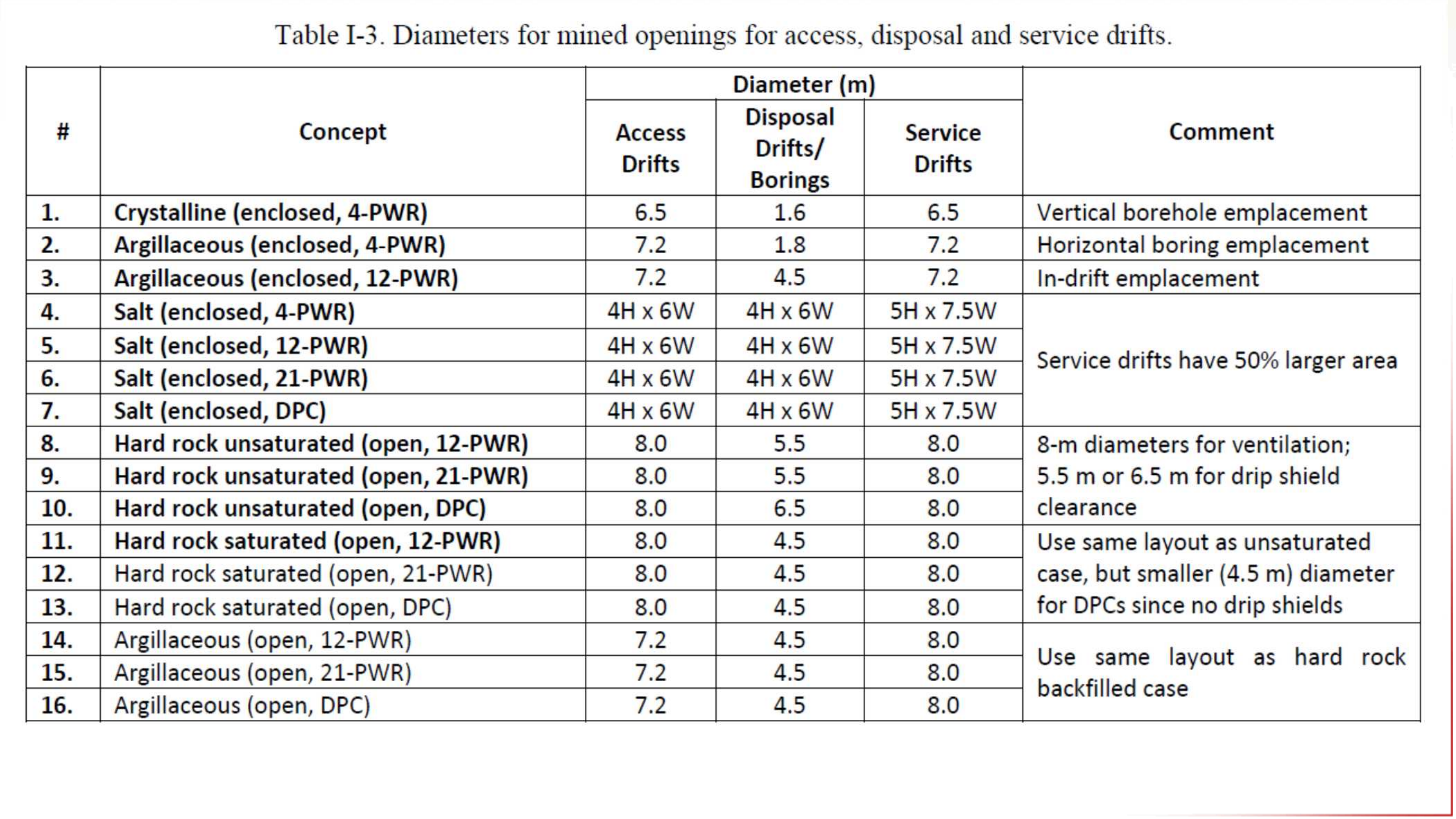


Table I-3. Diameters for mined openings for access, disposal and service drifts.

#	Concept	Diameter (m)			Comment
		Access Drifts	Disposal Drifts/ Borings	Service Drifts	
1.	**Crystalline (enclosed, 4-PWR)**	6.5	1.6	6.5	Vertical borehole emplacement
2.	**Argillaceous (enclosed, 4-PWR)**	7.2	1.8	7.2	Horizontal boring emplacement
3.	**Argillaceous (enclosed, 12-PWR)**	7.2	4.5	7.2	In-drift emplacement
4.	**Salt (enclosed, 4-PWR)**	4H x 6W	4H x 6W	5H x 7.5W	Service drifts have 50% larger area
5.	**Salt (enclosed, 12-PWR)**	4H x 6W	4H x 6W	5H x 7.5W	
6.	**Salt (enclosed, 21-PWR)**	4H x 6W	4H x 6W	5H x 7.5W	
7.	**Salt (enclosed, DPC)**	4H x 6W	4H x 6W	5H x 7.5W	
8.	**Hard rock unsaturated (open, 12-PWR)**	8.0	5.5	8.0	8-m diameters for ventilation; 5.5 m or 6.5 m for drip shield clearance
9.	**Hard rock unsaturated (open, 21-PWR)**	8.0	5.5	8.0	
10.	**Hard rock unsaturated (open, DPC)**	8.0	6.5	8.0	
11.	**Hard rock saturated (open, 12-PWR)**	8.0	4.5	8.0	Use same layout as unsaturated case, but smaller (4.5 m) diameter for DPCs since no drip shields
12.	Hard rock saturated (open, 21-PWR)	8.0	4.5	8.0	
13.	Hard rock saturated (open, DPC)	8.0	4.5	8.0	
14.	Argillaceous (open, 12-PWR)	7.2	4.5	8.0	Use same layout as hard rock backfilled case
15.	Argillaceous (open, 21-PWR)	7.2	4.5	8.0	
16.	Argillaceous (open, DPC)	7.2	4.5	8.0	

Disposal Concept Description (3/5)

Waste Package and Drift Spacings

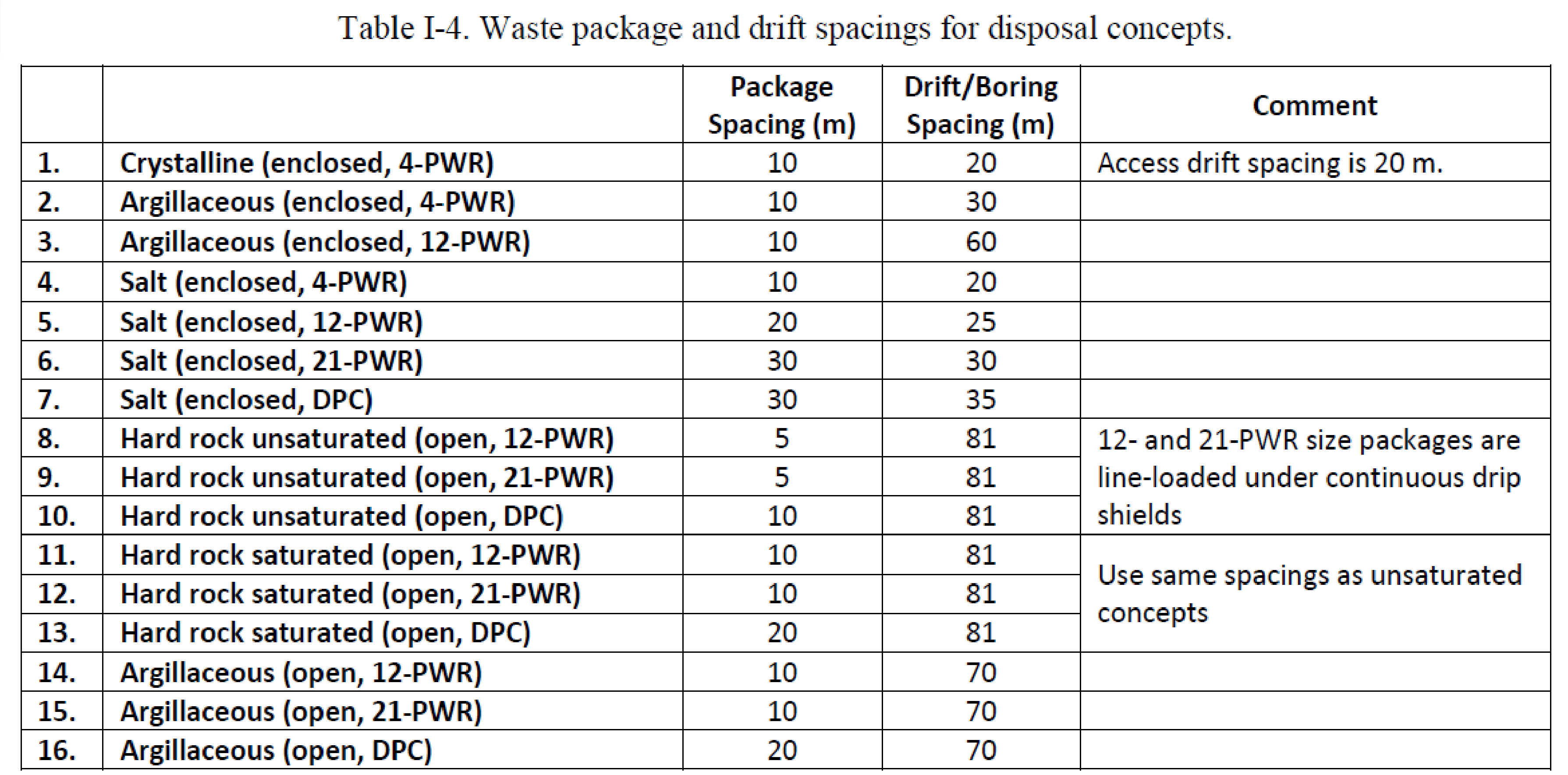


Table I-4. Waste package and drift spacings for disposal concepts.

		Package Spacing (m)	Drift/Boring Spacing (m)	Comment
1.	Crystalline (enclosed, 4-PWR)	10	20	Access drift spacing is 20 m.
2.	Argillaceous (enclosed, 4-PWR)	10	30	
3.	Argillaceous (enclosed, 12-PWR)	10	60	
4.	Salt (enclosed, 4-PWR)	10	20	
5.	Salt (enclosed, 12-PWR)	20	25	
6.	Salt (enclosed, 21-PWR)	30	30	
7.	Salt (enclosed, DPC)	30	35	
8.	Hard rock unsaturated (open, 12-PWR)	5	81	12- and 21-PWR size packages are line-loaded under continuous drip shields
9.	Hard rock unsaturated (open, 21-PWR)	5	81	
10.	Hard rock unsaturated (open, DPC)	10	81	
11.	Hard rock saturated (open, 12-PWR)	10	81	Use same spacings as unsaturated concepts
12.	Hard rock saturated (open, 21-PWR)	10	81	
13.	Hard rock saturated (open, DPC)	20	81	
14.	Argillaceous (open, 12-PWR)	10	70	
15.	Argillaceous (open, 21-PWR)	10	70	
16.	Argillaceous (open, DPC)	20	70	

Disposal Concept Description (4/5)

Drift Length and Excavated Volume

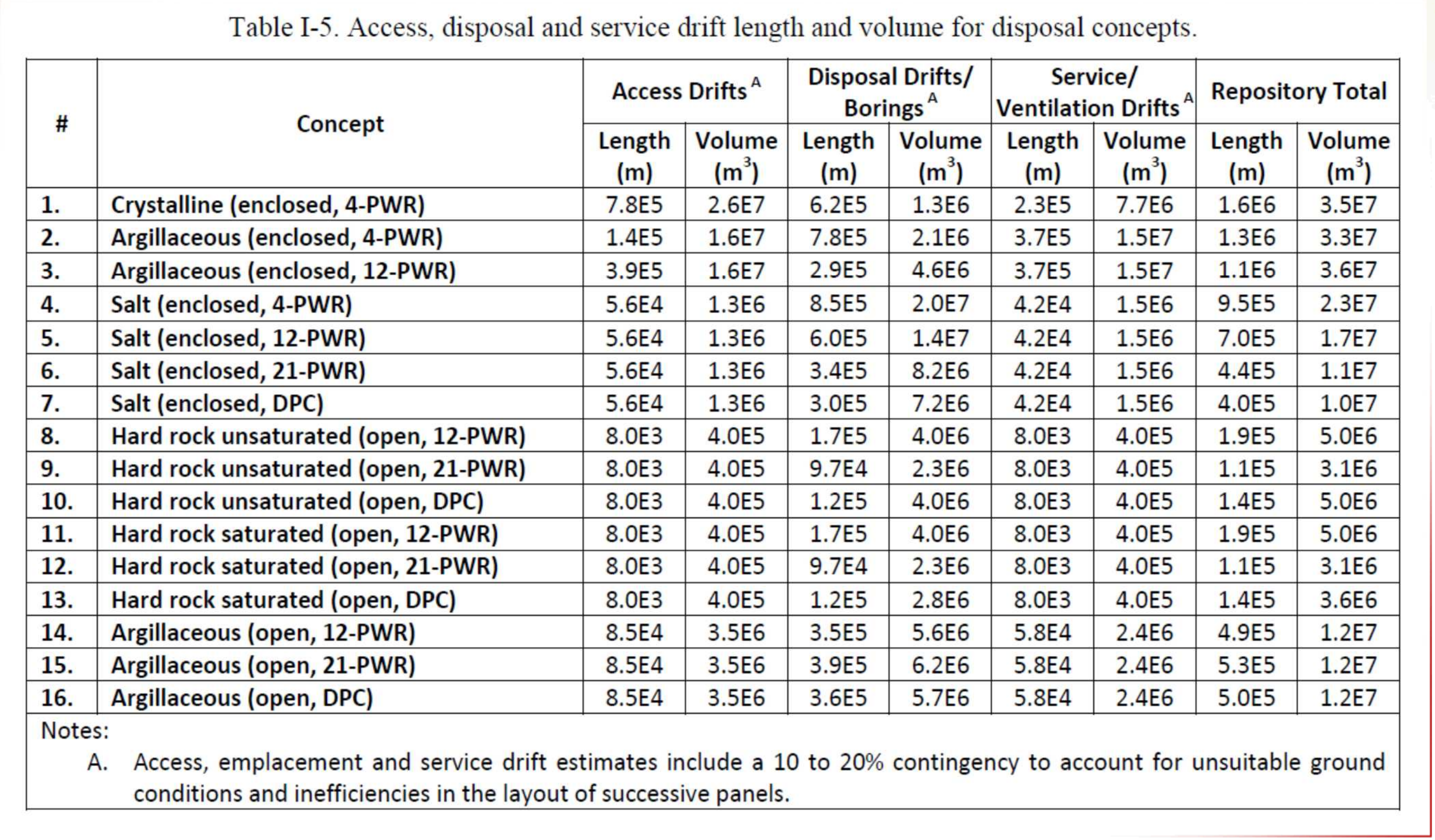


Table I-5. Access, disposal and service drift length and volume for disposal concepts.

#	Concept	Access Drifts[A]		Disposal Drifts/ Borings[A]		Service/ Ventilation Drifts[A]		Repository Total	
		Length (m)	Volume (m^3)	Length (m)	Volume (m^3)	Length (m)	Volume (m^3)	Length (m)	Volume (m^3)
1.	Crystalline (enclosed, 4-PWR)	7.8E5	2.6E7	6.2E5	1.3E6	2.3E5	7.7E6	1.6E6	3.5E7
2.	Argillaceous (enclosed, 4-PWR)	1.4E5	1.6E7	7.8E5	2.1E6	3.7E5	1.5E7	1.3E6	3.3E7
3.	Argillaceous (enclosed, 12-PWR)	3.9E5	1.6E7	2.9E5	4.6E6	3.7E5	1.5E7	1.1E6	3.6E7
4.	Salt (enclosed, 4-PWR)	5.6E4	1.3E6	8.5E5	2.0E7	4.2E4	1.5E6	9.5E5	2.3E7
5.	Salt (enclosed, 12-PWR)	5.6E4	1.3E6	6.0E5	1.4E7	4.2E4	1.5E6	7.0E5	1.7E7
6.	Salt (enclosed, 21-PWR)	5.6E4	1.3E6	3.4E5	8.2E6	4.2E4	1.5E6	4.4E5	1.1E7
7.	Salt (enclosed, DPC)	5.6E4	1.3E6	3.0E5	7.2E6	4.2E4	1.5E6	4.0E5	1.0E7
8.	Hard rock unsaturated (open, 12-PWR)	8.0E3	4.0E5	1.7E5	4.0E6	8.0E3	4.0E5	1.9E5	5.0E6
9.	Hard rock unsaturated (open, 21-PWR)	8.0E3	4.0E5	9.7E4	2.3E6	8.0E3	4.0E5	1.1E5	3.1E6
10.	Hard rock unsaturated (open, DPC)	8.0E3	4.0E5	1.2E5	4.0E6	8.0E3	4.0E5	1.4E5	5.0E6
11.	Hard rock saturated (open, 12-PWR)	8.0E3	4.0E5	1.7E5	4.0E6	8.0E3	4.0E5	1.9E5	5.0E6
12.	Hard rock saturated (open, 21-PWR)	8.0E3	4.0E5	9.7E4	2.3E6	8.0E3	4.0E5	1.1E5	3.1E6
13.	Hard rock saturated (open, DPC)	8.0E3	4.0E5	1.2E5	2.8E6	8.0E3	4.0E5	1.4E5	3.6E6
14.	Argillaceous (open, 12-PWR)	8.5E4	3.5E6	3.5E5	5.6E6	5.8E4	2.4E6	4.9E5	1.2E7
15.	Argillaceous (open, 21-PWR)	8.5E4	3.5E6	3.9E5	6.2E6	5.8E4	2.4E6	5.3E5	1.2E7
16.	Argillaceous (open, DPC)	8.5E4	3.5E6	3.6E5	5.7E6	5.8E4	2.4E6	5.0E5	1.2E7

Notes:

A. Access, emplacement and service drift estimates include a 10 to 20% contingency to account for unsuitable ground conditions and inefficiencies in the layout of successive panels.

Disposal Concept Description (5/5)

Numbers of Ramps and/or Shafts for 140,000 MTU Repository

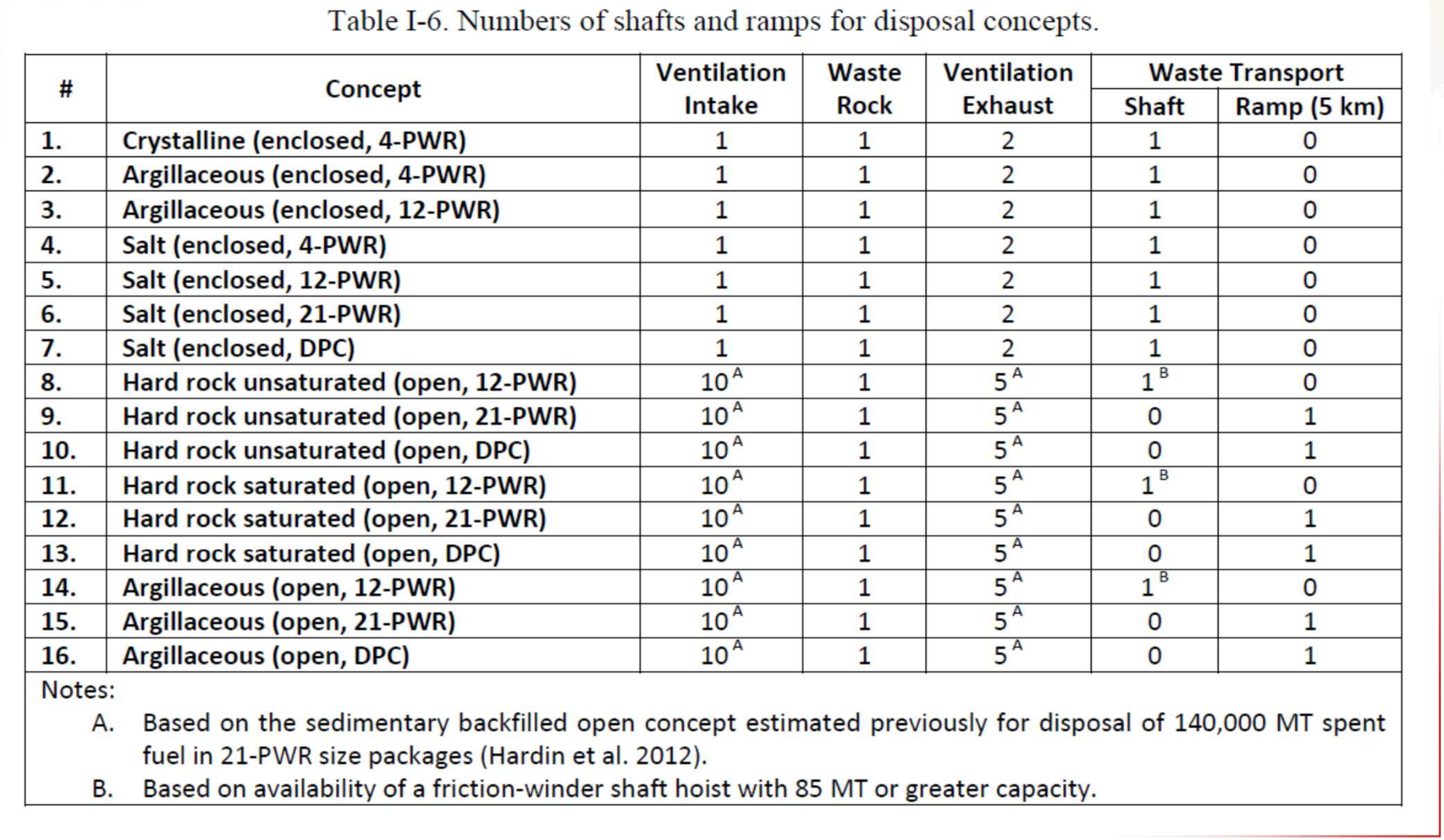


Table I-6. Numbers of shafts and ramps for disposal concepts.

#	Concept	Ventilation Intake	Waste Rock	Ventilation Exhaust	Waste Transport	
					Shaft	Ramp (5 km)
1.	Crystalline (enclosed, 4-PWR)	1	1	2	1	0
2.	Argillaceous (enclosed, 4-PWR)	1	1	2	1	0
3.	Argillaceous (enclosed, 12-PWR)	1	1	2	1	0
4.	Salt (enclosed, 4-PWR)	1	1	2	1	0
5.	Salt (enclosed, 12-PWR)	1	1	2	1	0
6.	Salt (enclosed, 21-PWR)	1	1	2	1	0
7.	Salt (enclosed, DPC)	1	1	2	1	0
8.	Hard rock unsaturated (open, 12-PWR)	10[A]	1	5[A]	1[B]	0
9.	Hard rock unsaturated (open, 21-PWR)	10[A]	1	5[A]	0	1
10.	Hard rock unsaturated (open, DPC)	10[A]	1	5[A]	0	1
11.	Hard rock saturated (open, 12-PWR)	10[A]	1	5[A]	1[B]	0
12.	Hard rock saturated (open, 21-PWR)	10[A]	1	5[A]	0	1
13.	Hard rock saturated (open, DPC)	10[A]	1	5[A]	0	1
14.	Argillaceous (open, 12-PWR)	10[A]	1	5[A]	1[B]	0
15.	Argillaceous (open, 21-PWR)	10[A]	1	5[A]	0	1
16.	Argillaceous (open, DPC)	10[A]	1	5[A]	0	1

Notes:

A. Based on the sedimentary backfilled open concept estimated previously for disposal of 140,000 MT spent fuel in 21-PWR size packages (Hardin et al. 2012).

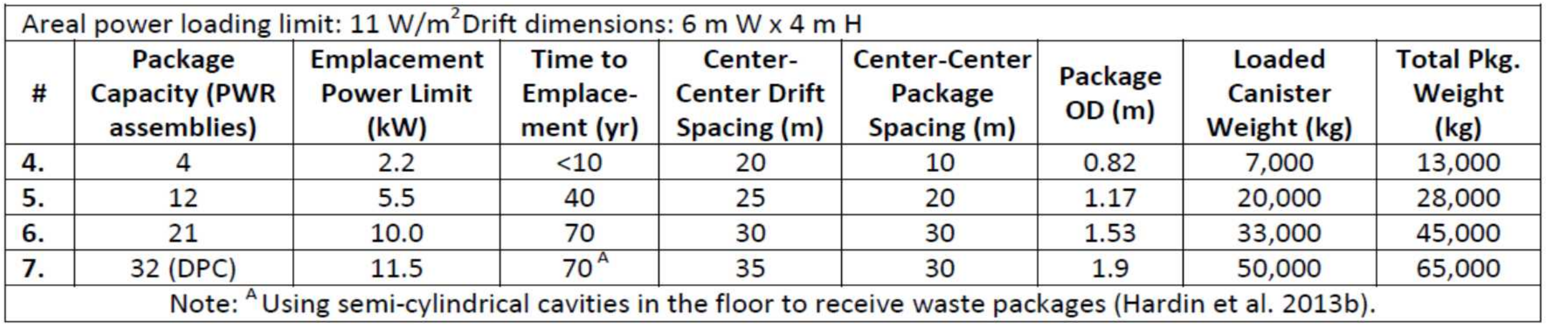
B. Based on availability of a friction-winder shaft hoist with 85 MT or greater capacity.

Disposal Concept Details (1/2)

Emplacement power and timing, package dimensions

- **Salt Repository Concepts**

Table 4-1. SNF package size, emplacement power limits, and repository spacings for salt repositories



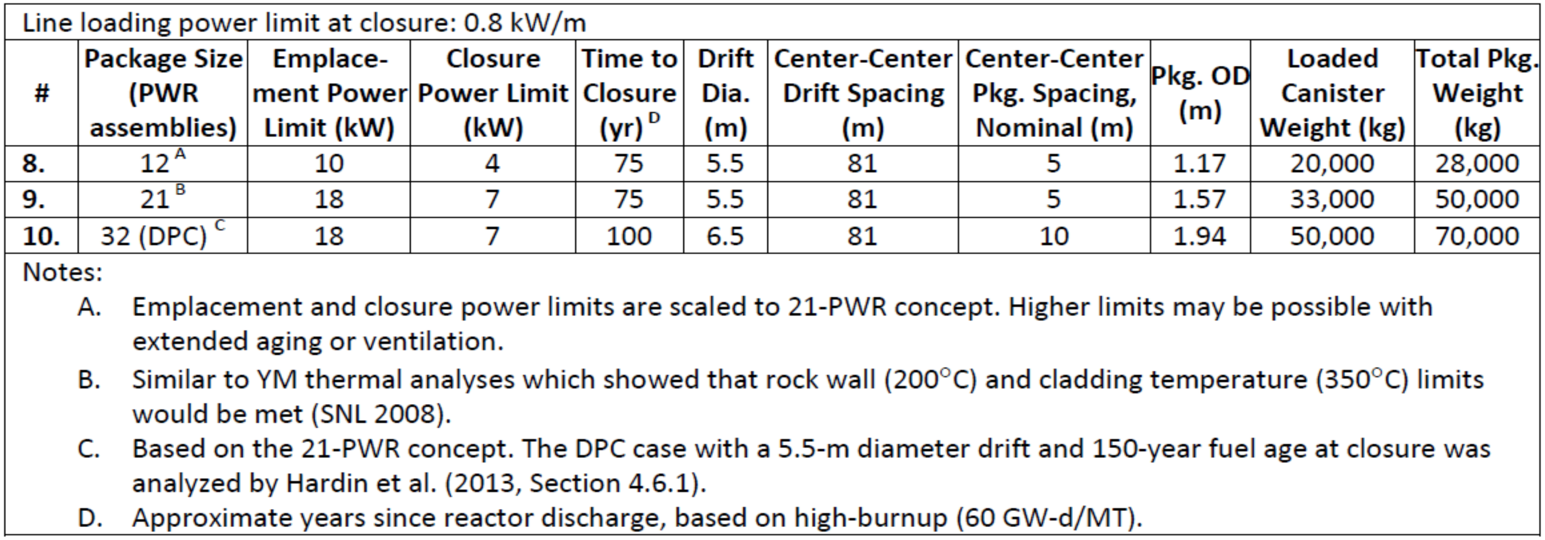
Areal power loading limit: 11 W/m^2 Drift dimensions: 6 m W x 4 m H

#	Package Capacity (PWR assemblies)	Emplacement Power Limit (kW)	Time to Emplace-ment (yr)	Center-Center Drift Spacing (m)	Center-Center Package Spacing (m)	Package OD (m)	Loaded Canister Weight (kg)	Total Pkg. Weight (kg)
4.	4	2.2	<10	20	10	0.82	7,000	13,000
5.	12	5.5	40	25	20	1.17	20,000	28,000
6.	21	10.0	70	30	30	1.53	33,000	45,000
7.	32 (DPC)	11.5	70 [A]	35	30	1.9	50,000	65,000

Note: [A] Using semi-cylindrical cavities in the floor to receive waste packages (Hardin et al. 2013b).

- **Hard-Rock Unsaturated, Unbackfilled Concepts**

Table 8-2. Repository emplacement drift and waste package package dimensions and emplacement power limits for hard-rock unsaturated, unbackfilled (open-mode) repositories.



Line loading power limit at closure: 0.8 kW/m

#	Package Size (PWR assemblies)	Emplace-ment Power Limit (kW)	Closure Power Limit (kW)	Time to Closure (yr) [D]	Drift Dia. (m)	Center-Center Drift Spacing (m)	Center-Center Pkg. Spacing, Nominal (m)	Pkg. OD (m)	Loaded Canister Weight (kg)	Total Pkg. Weight (kg)
8.	12 [A]	10	4	75	5.5	81	5	1.17	20,000	28,000
9.	21 [B]	18	7	75	5.5	81	5	1.57	33,000	50,000
10.	32 (DPC) [C]	18	7	100	6.5	81	10	1.94	50,000	70,000

Notes:

A. Emplacement and closure power limits are scaled to 21-PWR concept. Higher limits may be possible with extended aging or ventilation.

B. Similar to YM thermal analyses which showed that rock wall (200°C) and cladding temperature (350°C) limits would be met (SNL 2008).

C. Based on the 21-PWR concept. The DPC case with a 5.5-m diameter drift and 150-year fuel age at closure was analyzed by Hardin et al. (2013, Section 4.6.1).

D. Approximate years since reactor discharge, based on high-burnup (60 GW-d/MT).

Disposal Concept Details (2/2)

Emplacement power and timing, package dimensions

- **Hard-Rock Backfilled Concepts**

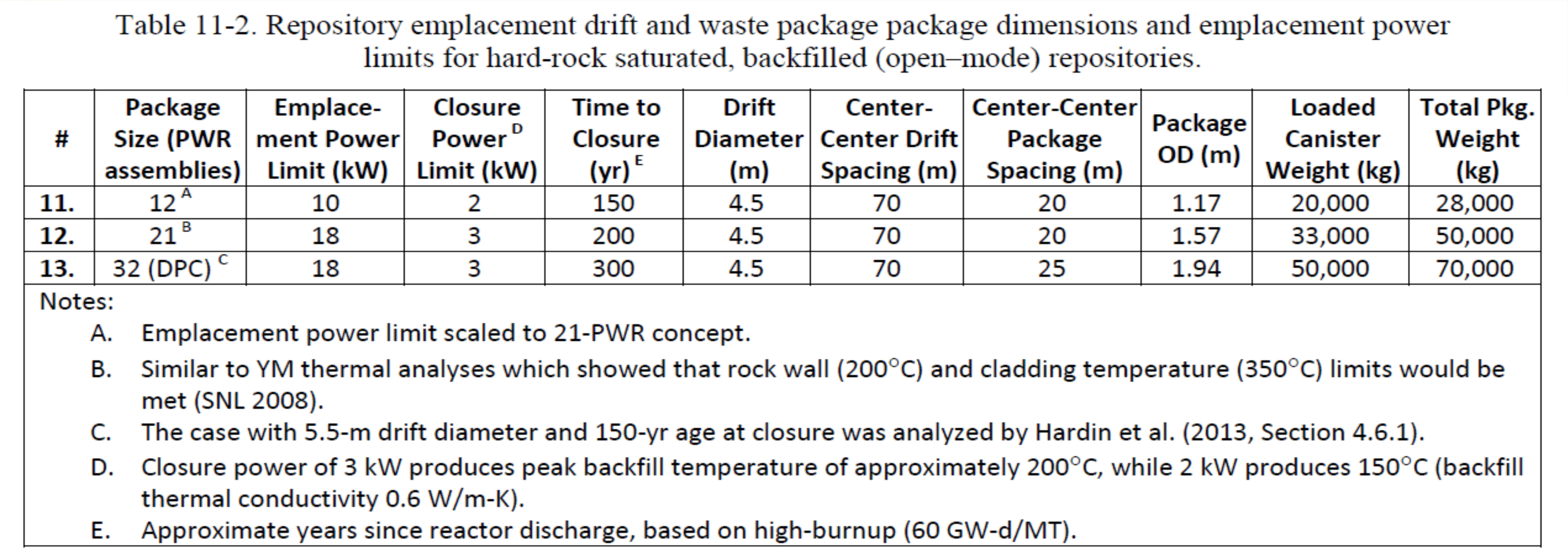


Table 11-2. Repository emplacement drift and waste package package dimensions and emplacement power limits for hard-rock saturated, backfilled (open–mode) repositories.

#	Package Size (PWR assemblies)	Emplace-ment Power Limit (kW)	Closure Power[D] Limit (kW)	Time to Closure (yr)[E]	Drift Diameter (m)	Center-Center Drift Spacing (m)	Center-Center Package Spacing (m)	Package OD (m)	Loaded Canister Weight (kg)	Total Pkg. Weight (kg)
11.	12[A]	10	2	150	4.5	70	20	1.17	20,000	28,000
12.	21[B]	18	3	200	4.5	70	20	1.57	33,000	50,000
13.	32 (DPC)[C]	18	3	300	4.5	70	25	1.94	50,000	70,000

Notes:

A. Emplacement power limit scaled to 21-PWR concept.

B. Similar to YM thermal analyses which showed that rock wall (200°C) and cladding temperature (350°C) limits would be met (SNL 2008).

C. The case with 5.5-m drift diameter and 150-yr age at closure was analyzed by Hardin et al. (2013, Section 4.6.1).

D. Closure power of 3 kW produces peak backfill temperature of approximately 200°C, while 2 kW produces 150°C (backfill thermal conductivity 0.6 W/m-K).

E. Approximate years since reactor discharge, based on high-burnup (60 GW-d/MT).

- **Argillaceous Backfilled Concepts**

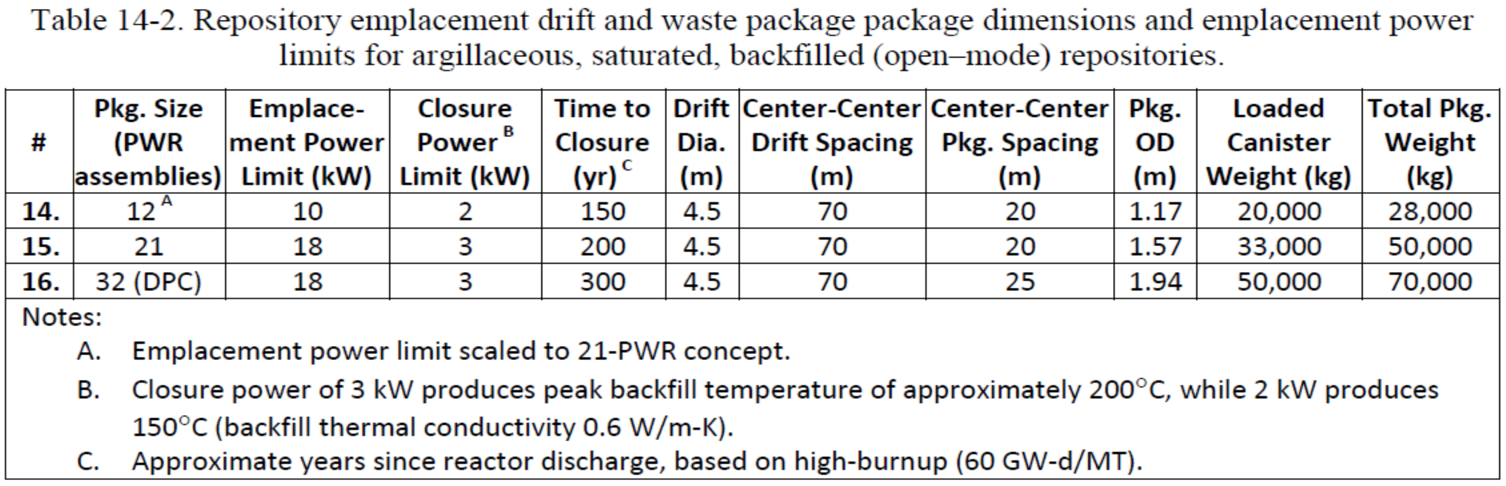


Table 14-2. Repository emplacement drift and waste package package dimensions and emplacement power limits for argillaceous, saturated, backfilled (open–mode) repositories.

#	Pkg. Size (PWR assemblies)	Emplace-ment Power Limit (kW)	Closure Power[B] Limit (kW)	Time to Closure (yr)[C]	Drift Dia. (m)	Center-Center Drift Spacing (m)	Center-Center Pkg. Spacing (m)	Pkg. OD (m)	Loaded Canister Weight (kg)	Total Pkg. Weight (kg)
14.	12[A]	10	2	150	4.5	70	20	1.17	20,000	28,000
15.	21	18	3	200	4.5	70	20	1.57	33,000	50,000
16.	32 (DPC)	18	3	300	4.5	70	25	1.94	50,000	70,000

Notes:

A. Emplacement power limit scaled to 21-PWR concept.

B. Closure power of 3 kW produces peak backfill temperature of approximately 200°C, while 2 kW produces 150°C (backfill thermal conductivity 0.6 W/m-K).

C. Approximate years since reactor discharge, based on high-burnup (60 GW-d/MT).