Used Fuel Disposition Campaign

DOE-Managed SNF and HLW Research:
Preliminary Design Concepts
-Work Package Overview
-Waste Package Considerations
-DREP Salt Design Concept

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UFD Working Group

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Outline

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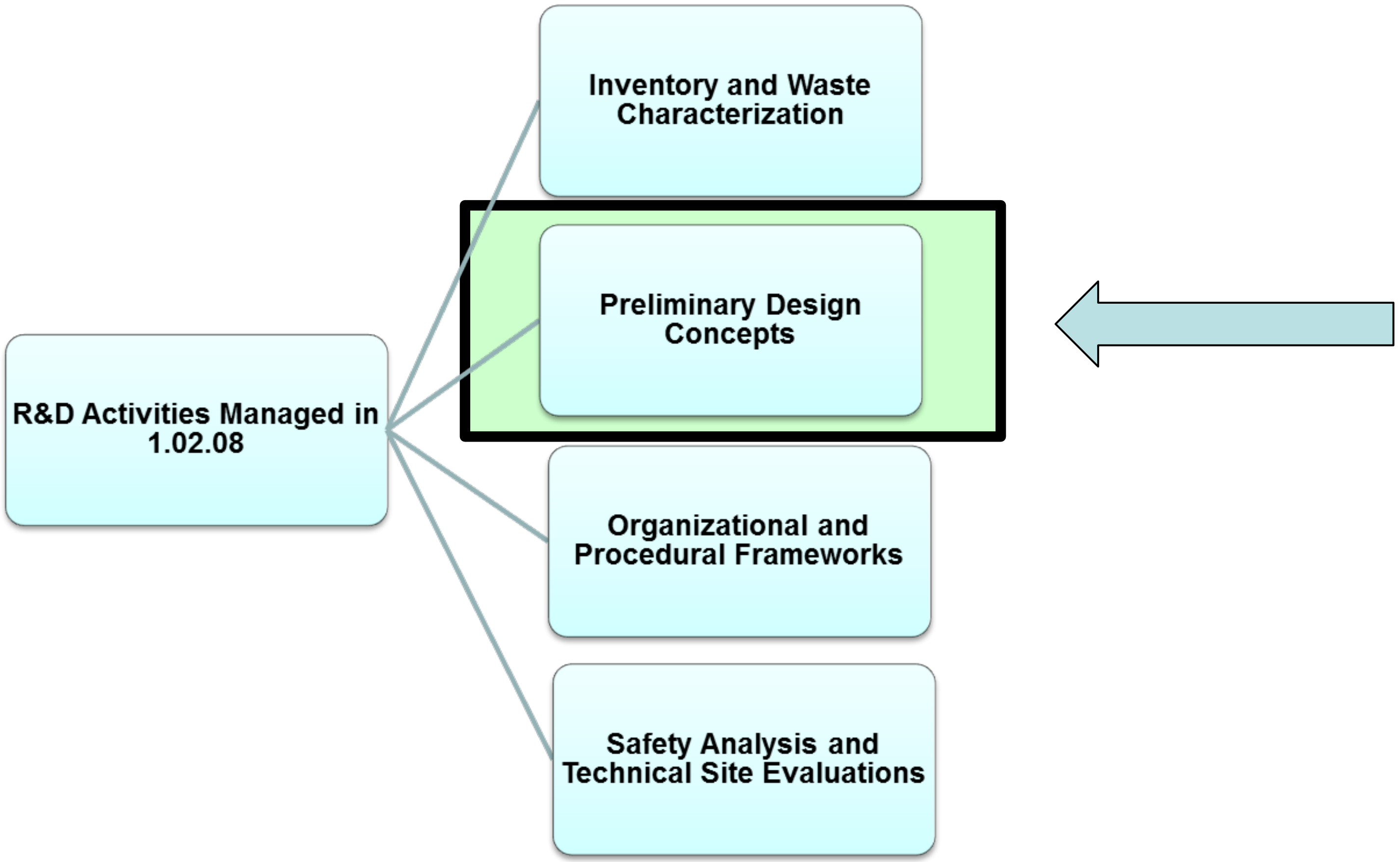
- **Part 1 -- Overview of *Preliminary Design Concepts* Work scope**
  - Inventory
  - Host Media and Design Considerations
- **Part 2 -- Waste Packaging Considerations**
- **Part 3 -- DREP Design Concept for Salt**

Structure of Technical Work Areas



DOE Managed HLW and SNF Research: *Preliminary Design Concepts for Selected Media*

OBJECTIVES:

Evaluate the preliminary design concepts for the inventory within select media.

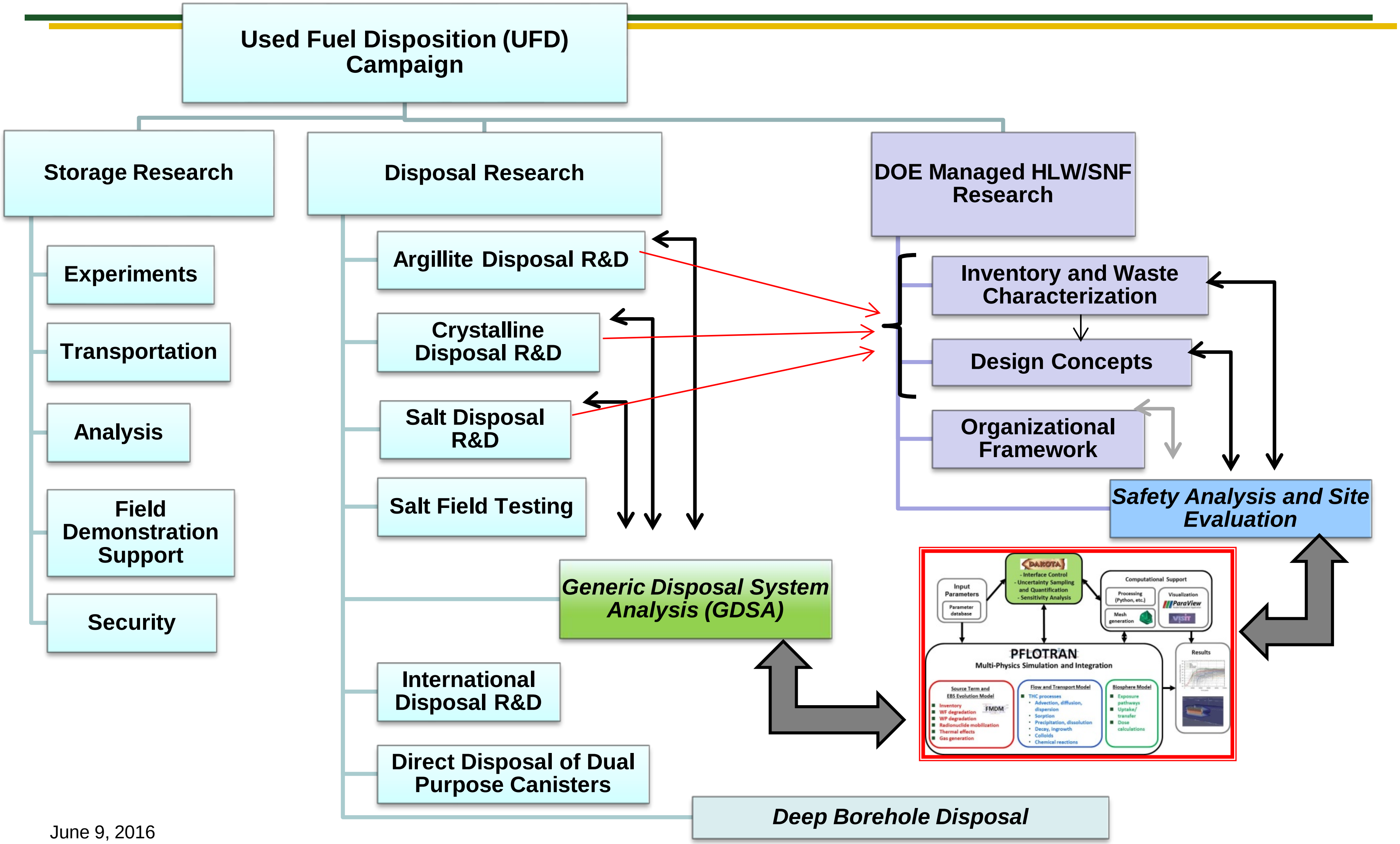
Specific geologic media under consideration are those currently investigated within the Used Fuel Disposition Campaign (argillite, **crystalline**, deep borehole, and **salt**).

SCOPE:

- Assess feasibility and applicability of Engineered Barrier Systems (EBS) concepts in select geologic media for the technical challenges specific to the inventory.
- A particular emphasis will be placed on analyzing thermal conditions and their effect on the inventory's compatibility with EBS concepts/disposal media. (WP1)
- Investigate and evaluate options for both disposal overpack and waste package design. (WP2)
- Layout and emplacement. (WP3)

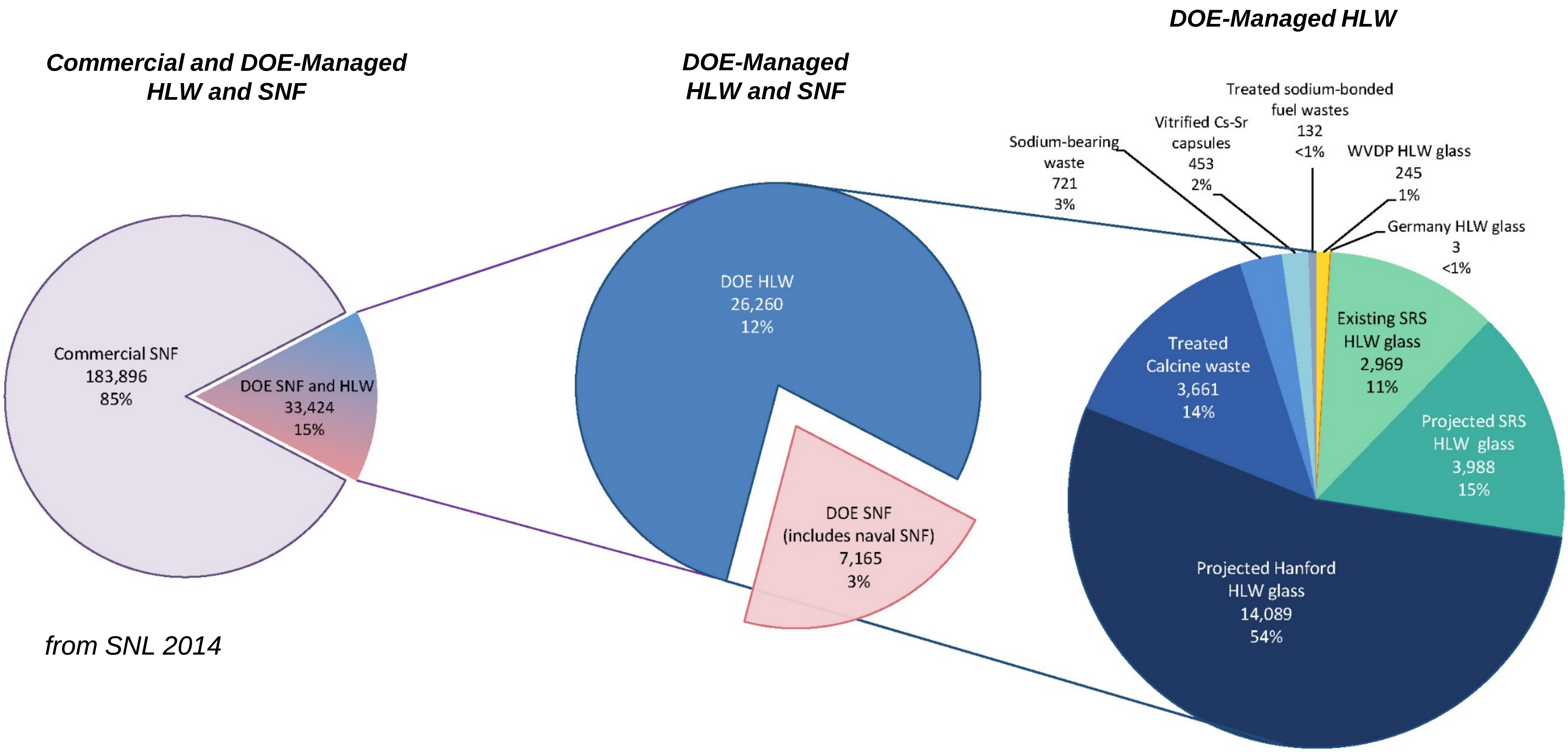
Used
Fuel
Disposition

Integration Linkages



80% of DOE-Managed HLW volume is glass

Projected volumes in m^3



from SNL 2014

Used Fuel Disposition

Table 3. Waste groups and pertinent characteristics for SNF in the US nuclear waste inventory (source: SNL 2014)

Waste Group	Description	Waste Form	Waste Package Dimensions	[b] Number of Waste Packages	[b] Avg. thermal output per waste package
[a] WG1	CSNF in PBC	[d] Purpose-built canister (PBC) Borehole Small Medium Large	 10.6" dia by 181.1" 32.3" dia by 196.9" 50.8" dia by 202.0" 63.0" dia by 202.0"	 470,063 89,364 31,163 16,924	<25 kW[c]
[a] WG2	CSNF in DPC	Dual-purpose canister (DPC)	98" dia. by 197" to 225"	11,413	<25 kW[c]
WG5 – Metallic Spent Fuels WG6 – Sodium bonded fuels WG7 – DOE oxide fuels WG9 – coated particle spent fuels	Heterogeneous mix of DSNF	Multi-canister Overpack (MCO) 18x10 18x15 24x10 24x15	24" dia by 166.4" 18" dia by 10' 18" dia by 15' 24" dia by 10' 24" dia by 15'	413 1,506 1,474 133 27	500W or less
WG10 – Naval fuel	Naval SNF	Naval SNF canister	66" dia by 187" 66" dia by 201.5"	90 310	11.8 kW limit 4.25 kW avg.

[a] WG1 and WG2 are not under current consideration as DOE-Managed HLW and SNF. These WG's are included merely for the purpose of comparison between CSNF and DOE-Managed SNF.
[b] Year 2048, if projected. Thermal output data correspond to thermal output per waste package in the year 2048.
[c] Stipulated by regulation to be <25kW
[d] Assumes only one size PBC is used for all the CSNF waste, such that the number of waste packages (solely for CSNF in PBC's) corresponds to the number of PBC's, all of a particular size, that would be needed for all CSNF. For example, if all CSNF were to be disposed of in borehole-sized PBC's, 470,063 of these canisters would be needed to contain all of the CSNF waste.

Used Fuel Disposition

SRS Glass

39 % of canisters	< 50 W
6.1%	50–100W
51.4%	100–220W
3.5%	220–300W

Hanford Glass

83.9% of canisters	< 50 W
11.1%	50–100W
4.7%	100–220W
0.3 %	220–300W

All glass

72.2% of canisters	< 50 W
7.4%	50–100W
19.1%	100–220W
0.2%	220–300W
1.1%	300-500W

Data from Carter et al. 2013

Waste Group	Description	Waste Form	Waste Package Dimensions	[a] Number of Waste Packages	[a] Avg. thermal output per waste package
WG3 – HLW Glass	Existing SRS HLW Glass	SRS canister	24" dia by 118"	3,339	30 W
	Existing West Valley HLW Glass	WVDP canister	24" dia by 118"	275	238W
	FRG HLW Glass	FRG canister	11.8" dia by 47.2"	34	[b] 950W
	Projected Hanford HLW Glass	Hanford canister	24" dia by 177"	10,586	29W
	Projected SRS HLW Glass	SRS canister	24" dia by 118"	4,485	30W
	Calcine Waste (vitrified)	Vitrified Calcine Waste Canister	24" dia by 118"	11,400	1.2-15.4 W
	Cs/Sr capsules at Hanford (vitrified)	Vitrified Cs/Sr waste in Hanford HLW Glass canister	24" dia by 177"	340	905W
WG4 – other Engineered waste forms	[c] *Metallic sodium bonded*	Glass-bonded sodalite from EMT	24"dia by 118"	64	2,240W
		INL Metal waste from EMT	24"dia by 118"	64	neglible
	[d] *Calcine waste Hot Isostatic Pressing (HIP – A)*	HIP canister (encloses 10 HIP cans)	66" dia by 204"	3,200	40-540W
	Calcine waste (HIP – B)	HIP canister (encloses 10 HIP cans)	66" dia by 204"	1,600	80-1080W
WG8 –salt, granular solids, powders	*Metallic sodium bonded*	Salt waste from EMT direct disposal canister	24"dia by 118"	64	2,240 W
	Calcine Waste (Direct Disposal)	Direct disposal canister	26" dia by 121"	4,900	2.4-36W
	Sodium bearing waste (SBW) at INL	SBW canister	26" dia by 120"	688	2.5W
	Cs/Sr Capsules (Direct Disposal)	Untreated in overpack/canister	24" dia by 120" (6 capsules per canister)	Cs- 267 Sr - 121	800W 1,170W

[a] Year 2048, if projected. Thermal output data correspond to thermal output per waste package in the year 2048.
[b] Final configuration not selected. The canisters listed in Table 4 could be disposed of individually or stacked 2 or 3 per container.
[c] Metallic sodium bonded fuels can be processed by electro-metallurgical treatment (EMT) to produce either 1) metal waste and glass-bonded [illegible]
[d] An alternative to HIP-B, HIP-A includes calcine waste plus Si, Ti, and $CaSO_4$ to produce RCRA-compliant glass ceramic waste form.

Creating a Design Concept

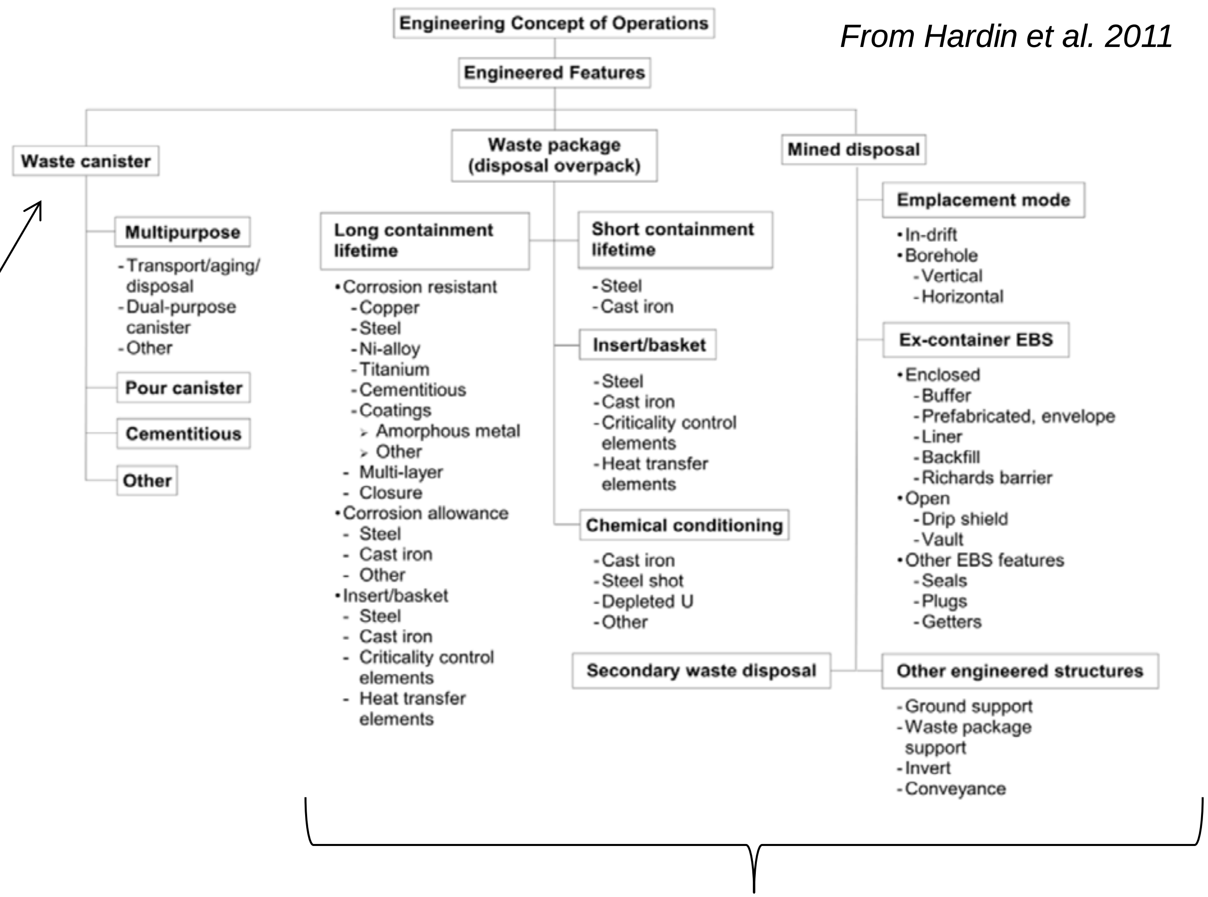
Inventory

- *Dimensions*
- *Quantity*
- *Thermal output*

Design Concepts

- *Packing spacing*

From Hardin et al. 2011



Disposal Media

Geologic Setting Classification (Baldwin *et al.*, 2008)

No	General Description	Host rock	Overlying rocks
G1	Stronger rocks with very low flow of likely saline waters	Crystalline rock	Low permeability sedimentary rock formations
			High permeability sedimentary rock formations
G2	Stronger rocks with higher water flow; probably relatively fresh water	Crystalline rock	Low permeability sedimentary rock formations
			High permeability sedimentary rock formations
			Crystalline rock to surface
		Carbonate	Sedimentary rock formations (permeability unspecified)
G3	Weaker rocks with no effective flow and relatively saline waters in pores (transport is dominated by diffusion with no advective flow)	Indurated low permeability sedimentary rock formation	Low permeability sedimentary rock formations
			High permeability sedimentary rock formations
		Plastic low permeability sedimentary rock formation	Sedimentary rock formations (permeability unspecified)
G4	Weaker rocks with very low water flow and relatively saline waters in pores (there is some advective flow)	Indurated low permeability sedimentary rock formation	Low permeability sedimentary rock formations
			High permeability sedimentary rock formations
G5	Evaporite formations: plastic, with no water flow and little accessible water (brine) content	Evaporites - salt dome & bedded salt	Sedimentary rock formations (permeability unspecified)

Geologic Setting Characteristics in Baldwin's Schema

		G1	G2	G3	G4	G5
Geological Environments in Baldwin *et al.* (2008)	**General rock properties**	Stronger rocks	Stronger rocks, greater water flow	Weaker rocks	Weaker rocks	Evaporite formations, plastic, little accessible water
	Probable porewater salinity	Saline	Relatively fresh	Relatively saline	Relatively saline	Brine
	Water flow characteristics	Very little flow	Greater flow	No effective flow	Very little flow	No effective flow
	Main transport mechanisms	Some advection	Advection	Diffusion, no advection	Some advection	Diffusion, no advection
	Host rock	Crystalline rock	Crystalline rock or Carbonate	Indurated low permeability or Plastic low permeability sedimentary	Indurated low permeability sedimentary	Evaporites - salt dome and bedded

Disposal Concepts in Baldwin's Schema

Key feature	Variants	Concept No.
In-tunnel (borehole)	Vertical borehole	1
	Horizontal borehole	2
In-tunnel (axial)	Short-lived canister and buffer	3
	Long-lived canister and buffer	4
In-tunnel (axial) with supercontainer	Small working annulus	5
	Small annulus + concrete buffer	6
	Large working annulus	7
Caverns with cooling, delayed backfilling	Steel multi-purpose transport/storage/disposal containers (MPC) + bentonite backfill	8
	Steel or concrete/DUCRETE container + cement backfill	9
Mined deep borehole matrix		10
Hydraulic cage	Around a cavern repository	11
Very deep boreholes		12

Potential Design Considerations related to specific disposal concepts

Operational impact:

- Lateral (horizontal) extent of host rock formation and/or easement/withdrawal area
- Stability of excavations in the stress field
- Ensure quality buffer construction
- Shielding throughout emplacement operation

Safety Impact:

- Minimize EDZ
- Waste emplacement in relatively undisturbed zone (beyond access tunnel EDZ)
- Cementitious passivation of metal components
- Ensure compact repository footprint
- Minimize excavation volume
- Thermal Management – open vs. closed mode

Pt. 2, Waste Packaging Considerations

Used
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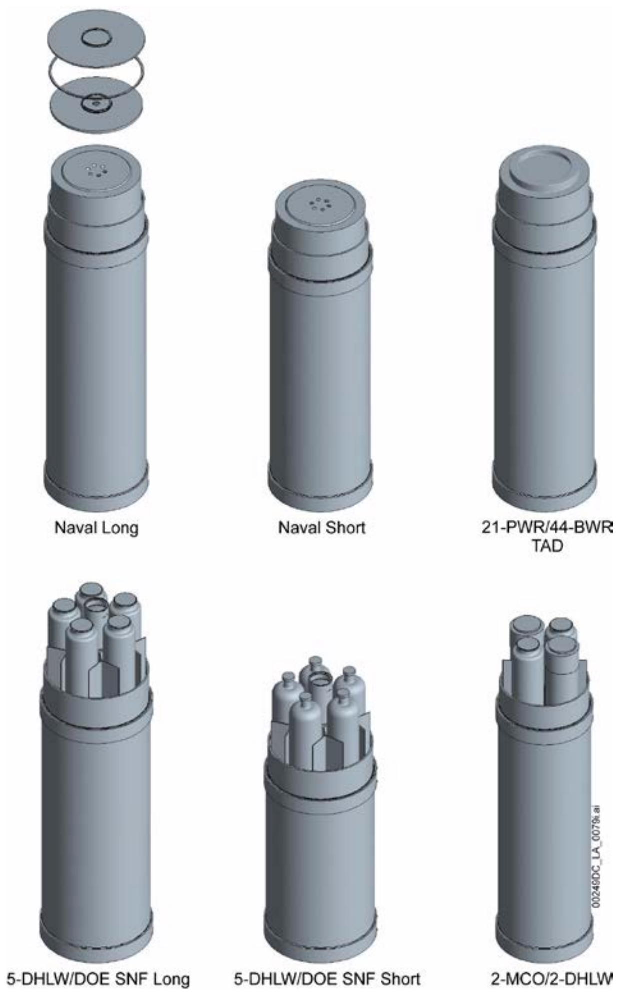
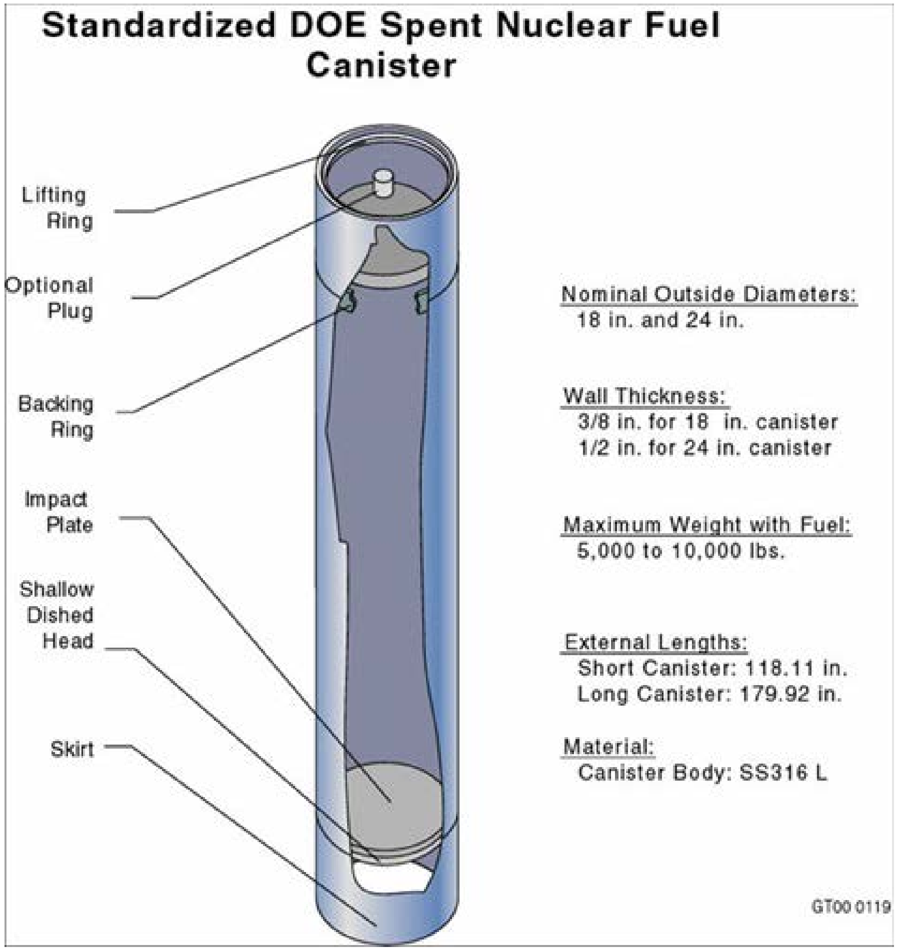
Crystalline Waste Packages





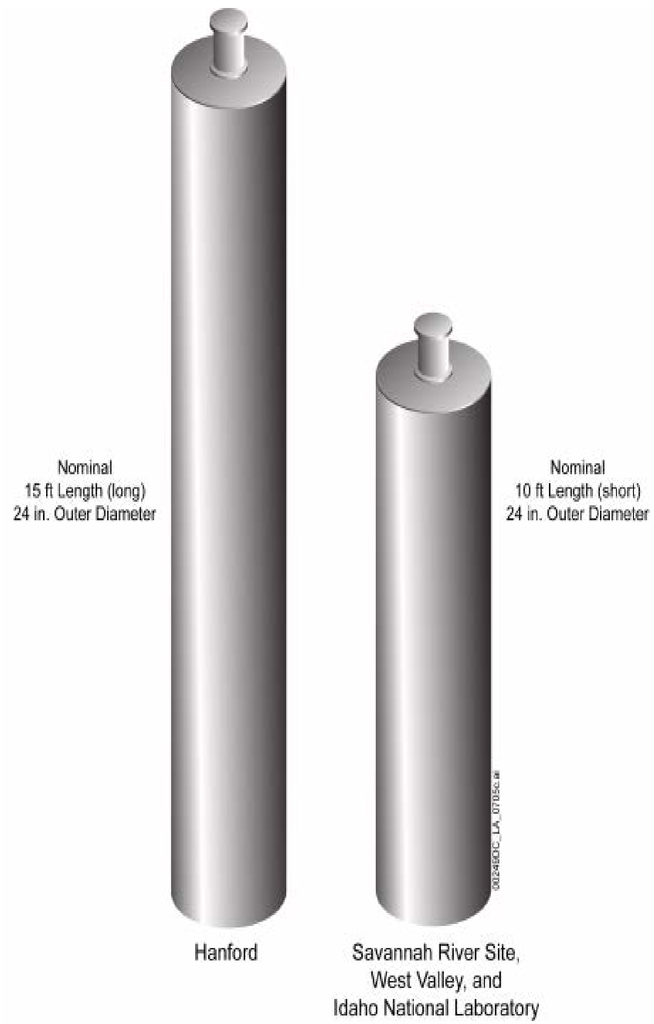
Crystalline Waste Packaging Options, 1/2

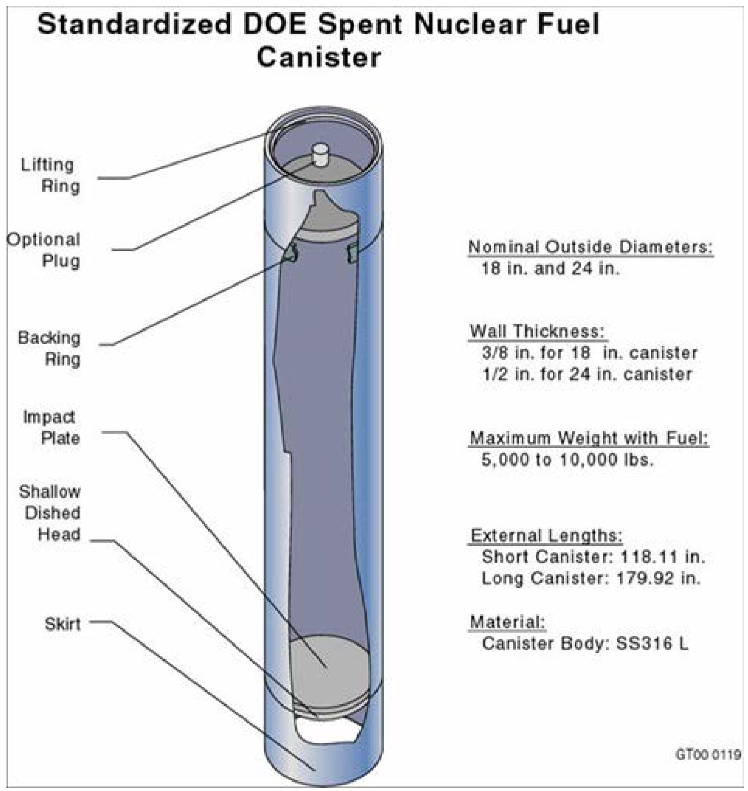
Waste Group	Description	Waste Form	Waste Package Dimensions	[b] Number of Waste Packages	Average Thermal output per package (W)	Granite Disposal Package Type	Number of Disposal Packages	Granite Emplacement Mode
WG3 – HLW Glass	Existing SRS HLW Glass	SRS canister	24" dia by 118"	3,339	30	Co-disposal Package (short)	668	Horizontal Borehole
	Projected Hanford HLW Glass	Hanford canister	24" dia by 177"	10,586	29	Co-disposal Package (long)	2,118	Horizontal Borehole
	Projected SRS HLW Glass	SRS canister	24" dia by 118"	4,485	30	Co-disposal Package (short)	897	Horizontal Borehole
	Calcine Waste (vitrified)	Vitrified Calcine Waste Canister	24" dia by 118"	11,400	1.2-15.4	Co-disposal Package (short)	2,280	Horizontal Borehole
	Cs/Sr capsules at Hanford (vitrified)	Vitrified Cs/Sr waste in Hanford HLW Glass canister	24" dia by 177"	340	905	Individual disposal overpack	340	Vertical Borehole
WG4 – other Engineered HLW forms	[c] *Metallic sodium bonded*	Glass-bonded sodalite from EMT Metal waste from EMT	Copackaged in 24" dia by 118" canister	148 total combined	2,240	Individual disposal overpack	148	Vertical Borehole
	[d] *Calcine waste Hot Isostatic Pressing (HIP – A)*	HIP canister (encloses 10 HIP cans)	66" dia by 204"	3,200	40-540	Individual disposal overpack	3,200	Horizontal Borehole
	Calcine waste (HIP – B)	HIP canister (encloses 10 HIP cans)	66" dia by 204"	1,600	80-1080	Individual disposal overpack	1,600	Horizontal Borehole

Crystalline Waste Packaging Options, 2/2

Waste Group	Description	Waste Form	Waste Package Dimensions	[b] Number of Waste Packages	Average Thermal output per package (W)	Disposal Package Type (Granite)	Number of Disposal Packages	Granite Emplacement Mode
WG5 – Metallic Spent Fuels	Heterogeneous mix of DSNF	Multi-canister Overpack (MCO)	24" dia by 166.4"	413	500 or less			
WG6 – Sodium bonded fuels (Na removed)						Individual disposal overpack	413	Vertical Borehole
WG7 – DOE oxide fuels		18x10 18x15 24x10 24x15	18" dia by 10' 18" dia by 15' 24" dia by 10' 24" dia by 15'	1,506 1,474 133 27				
WG9 – coated particle spent fuels						Individual disposal overpack	1,506 1,474 133 27	Vertical Borehole
WG8 –salt, granular solids, powders	*Metallic sodium bonded*	Salt waste from EMT direct disposal canister	24"dia by 118"	25	2,240	Individual disposal overpack	25	Vertical Borehole
	Calcine Waste (Direct Disposal)	Direct disposal canister	RH-72B 26" dia by 121"	4,900	2.4-36	Co-disposal Package	1,225	Horizontal Borehole
	Sodium bearing waste (SBW) at INL	SBW canister	26" dia by 120"	688	2.5W	Co-disposal Package	172	Horizontal Borehole
	Cs/Sr Capsules (Direct Disposal)	Untreated in overpack/canister	24" dia by 120" (6 capsules per canister)	Cs- 267 Sr - 121	800-1170	Individual disposal overpack	Cs- 267 Sr – 121	Vertical Borehole
WG10 – Naval fuel	Naval SNF <1000W	Naval SNF canister	66" dia by 187" 66" dia by 201.5"	11	<1,000	Naval SNF canister	11	Horizontal Borehole

Salt Waste Packages





Salt Waste Packaging Options, 1/2

Waste Group	Description	Waste Form	Waste Package Dimensions	[b] Number of Waste Packages	Average Thermal output per package (W)	Salt Disposal Package Type	Number of Disposal Packages	Salt Emplacement Mode
WG3 – HLW Glass	Existing SRS HLW Glass	SRS canister	24" dia by 118"	3,339	30	As Packaged	3,339	Horizontal
	Projected Hanford HLW Glass	Hanford canister	24" dia by 177"	10,586	29	As Packaged	10,586	Horizontal
	Projected SRS HLW Glass	SRS canister	24" dia by 118"	4,485	30	As Packaged	4,485	Horizontal
	Calcine Waste (vitrified)	Vitrified Calcine Waste Canister	24" dia by 118"	11,400	1.2-15.4	As Packaged	11,400	Horizontal
	Cs/Sr capsules at Hanford (vitrified)	Vitrified Cs/Sr waste in Hanford HLW Glass canister	24" dia by 177"	340	905	As Packaged	340	Horizontal
WG4 – other Engineered HLW forms	[c] *Metallic sodium bonded*	Glass-bonded sodalite from EMT	24"dia by 118"	148 total combined		As Packaged		Horizontal
		Metal waste from EMT	24"dia by 118"		negligible	As Packaged		Horizontal
	[d] *Calcine waste Hot Isostatic Pressing (HIP – A)*	HIP canister (encloses 10 HIP cans)	66" dia by 204"	3,200	40-540	As Packaged	3,200	Horizontal
	Calcine waste (HIP – B)	HIP canister (encloses 10 HIP cans)	66" dia by 204"	1,600	80-1080	As Packaged	1,600	Horizontal

Used Fuel Disposition

Salt Waste Packaging Options, 2/2

Waste Group	Description	Waste Form	Waste Package Dimensions	[b] Number of Waste Packages	Average Thermal output per package (W)	Disposal Package Type (Salt)	Number of Disposal Packages	Salt Emplacement Mode
WG5 – Metallic Spent Fuels	Heterogeneous mix of DSNF				500 or less			
WG6 – Sodium bonded fuels (Na removed)		Multi-canister Overpack (MCO)	24" dia by 166.4"	413		As Packaged	413	Horizontal
WG7 – DOE oxide fuels								
WG9 – coated particle spent fuels		18x10 18x15 24x10 24x15	18" dia by 10' 18" dia by 15' 24" dia by 10' 24" dia by 15'	1,506 1,474 133 27		As Packaged	1,506 1,474 133 27	Horizontal
WG8 –salt, granular solids, powders	*Metallic sodium bonded*	Salt waste from EMT direct disposal canister	24"dia by 118"	64	2,240	As Packaged	64	Horizontal
	Calcine Waste (Direct Disposal)	Direct disposal canister	RH-72B 26" dia by 121"	4,900	2.4-36	As Packaged	4,900	Horizontal
	Sodium bearing waste (SBW) at INL	SBW canister	26" dia by 120"	688	2.5W	As Packaged	688	Horizontal
	Cs/Sr Capsules (Direct Disposal)	Untreated in overpack/canister	24" dia by 120" (6 capsules per canister)	Cs- 267 Sr - 121	800-1170	As Packaged	Cs- 267 Sr – 121	Horizontal
WG10 – Naval fuel	Naval SNF <1000W	Naval SNF canister	66" dia by 187" 66" dia by 201.5"	11	<1,000	As Packaged	11	Horizontal

Pt. 3 – Salt Disposal Concept

Disposal Concepts for a DRep in Salt:
Identify Candidate Concepts for Evaluation

- **Objectives for Review: <u>safety</u>, cost, portability**
- **Disposal Concept ≡ WF + geologic setting + concept of ops.**
  - **Waste form:**
    - Mostly HLW glass, low heat output, SS pour canisters
    - DSNF of various types, pre-canistered
  - **Geologic setting:**
  - **Concept of operations?**

Disposal Concepts for a D-rep:
Defense Waste Characteristics

- **Low-thermal (up to 1 kW per 3- or 5-m canister)**
- **Long-lived radionuclides (~10^6-year assessment)**
- **Large numbers of canisters (data from Carter et al. 2012)**
  - 3,542 DSNF (99.4% < 1 kW in 2030)
  - 23,032 HLW (SRS, Hanford & Idaho; all < 1 kW)
- **Small canisters (mostly 18- and 24-inch diameters)**
  - Neglecting Naval SNF which is most similar to CSNF
  - (Assume Idaho calcine is package in standardized canisters.)
- **Relatively lightweight (canister + contents; no overpack)**
  - DSNF 5,000 to 10,000 lb
  - HLW 5,512 yto 9,260 lb
- **Material: stainless steel (welded, no heat treat, sensitized)**
- **All require some shielding (±)**

Disposal Concepts for a DRep in Evaporite (Salt): Salt Geologic Settings

- **Plastic formation**
  - Creep behavior impacts concept of operations
    - *Excavations will close due to creep*
    - ***Just-in time drift construction***
    - ***Self-healing***
- **Brine pore water**
- **Virtually impermeable media (diffusion dominated)**
- **Ramp Access only in domal salt**
  - For bedded salt, shaft access only

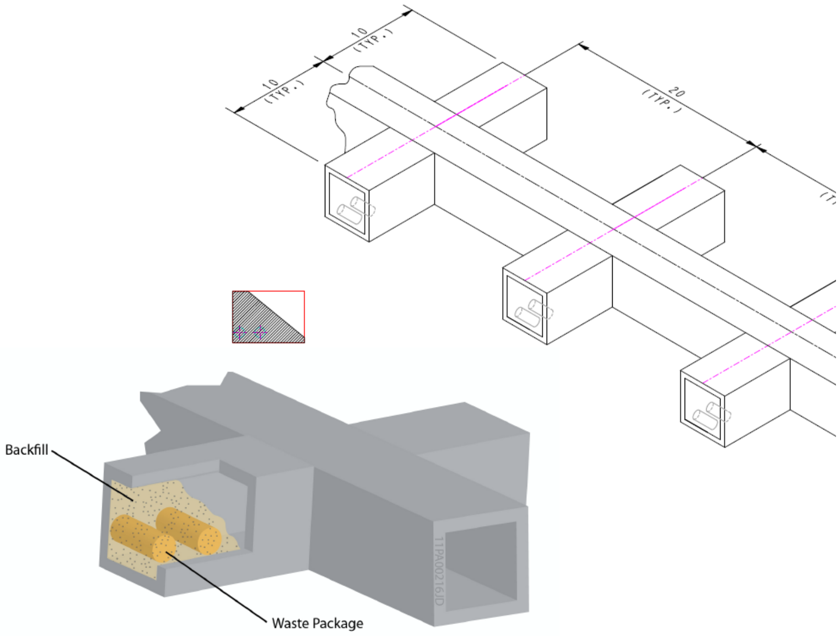
Salt D-Rep Design Considerations

- Bedded or Domal Salt Constructability
  - Opening stability
  - Salt backfill
- Superior Heat Dissipation
- Nominal and Disturbed Performance
  - Releases dominated by human intrusion
- Natural Barrier
  - Insignificant groundwater abundance and mobility (nominal)
  - Brine saturation (esp. human intrusion)
- Engineered Barriers
  - Backfill and seals
  - Robust containment during operations
  - Emplacement borehole behavior (e.g., heavy liners)

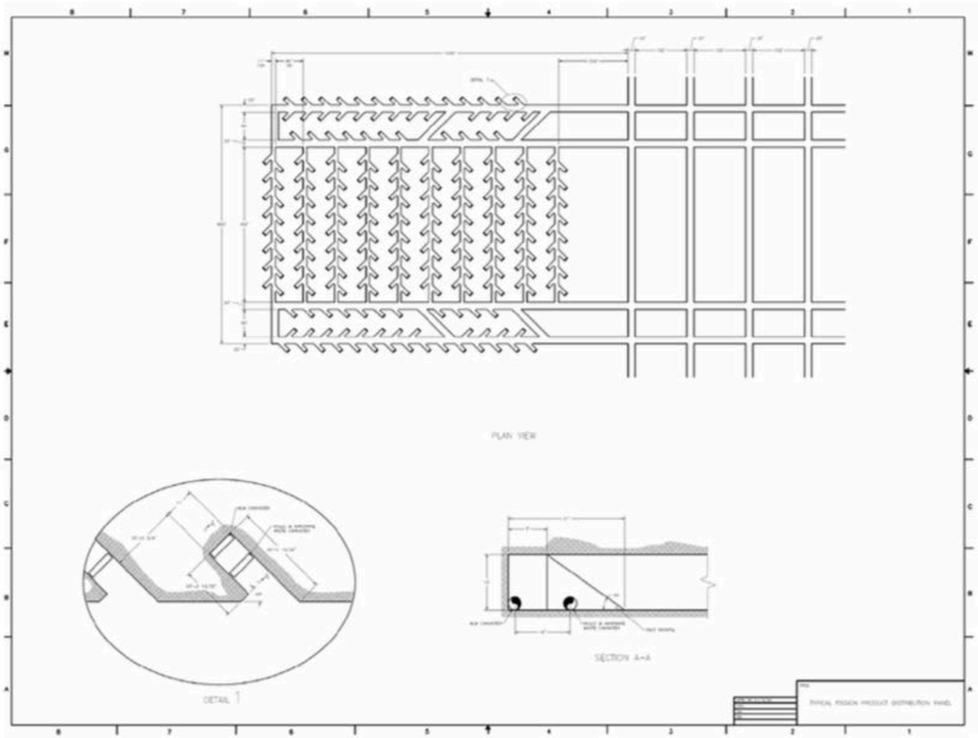
Salt D-Rep Disposal Concept

- Direct Disposal of Pour Canisters
  - HLW glass stability in operational environment
- Robust Overpacking of Other Waste Forms
  - Carbon steel overpack (e.g., DSNF)
- Just-in-Time Drift Construction
  - Minimize handling of crushed salt
- In-Drift Emplacement (axial or transverse)
  - Relatively small, lightweight canisters (e.g., 6 MT HLW)
  - Immediate backfilling with crushed salt
- Constructability Challenges
  - Remote operation in unshielded environments

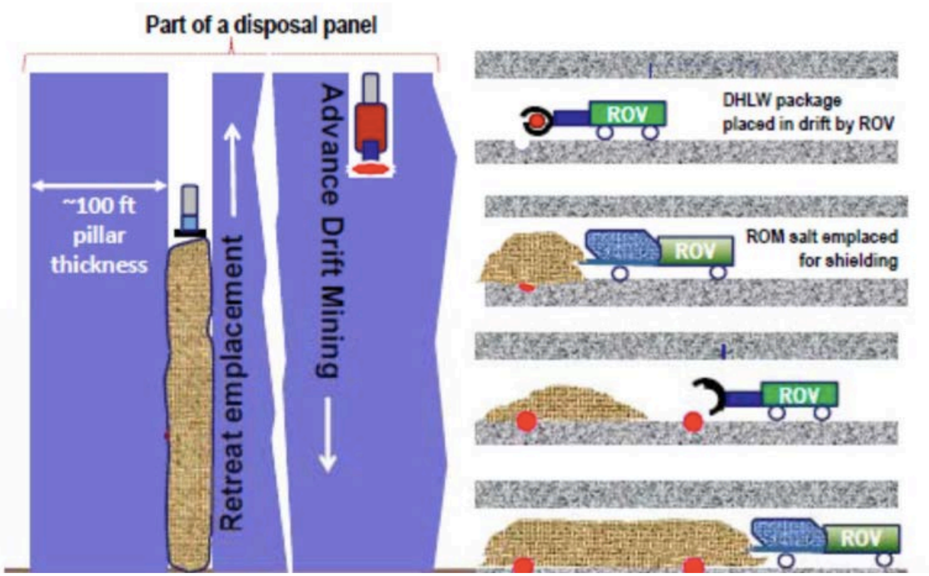
Salt Concept Illustrated

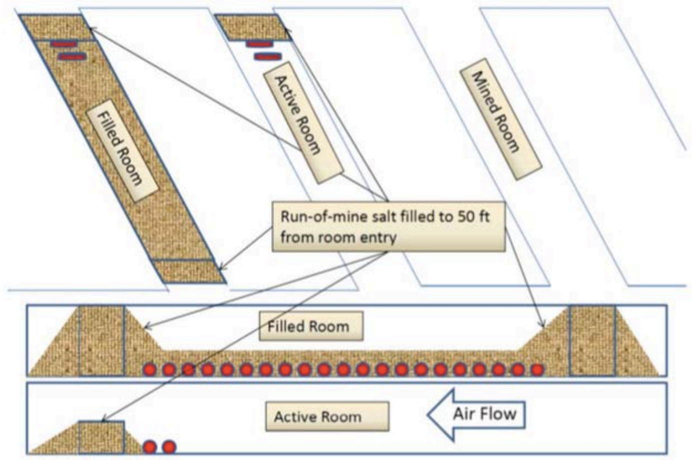


GENERIC SALT REPOSITORY LAYOUT
(ALL DIMENSIONS ARE IN METERS)



Salt Concept Illustrated (cont.)





Conclusions

- ***Preliminary Design Concepts*** **WP is focused on disposal concepts for salt and crystalline host media**
  - *Characteristics of DOE-Managed Waste*
    - *Thermal, volume, waste groups*
  - *Design considerations specific to host media*
- ***Waste packaging options specific to crystalline and salt concepts***
- ***Preliminary Salt concept***
  - *Bedded salt formations*
  - *Shaft access*
  - *Axial or transverse emplacement with crushed salt backfill*

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