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High Level Waste and Spent Fuel Inventory and Disposal Options Evaluation

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Nuclear Energy Advisory Committee
Fuel Cycle Sub-Committee
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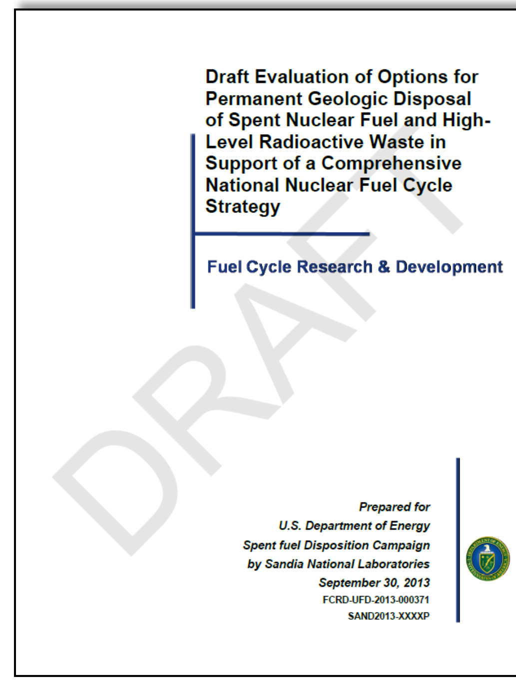
Goals of the *Waste Form Disposal Options Evaluation*

- **Catalog the inventory of US spent nuclear fuel (SNF) and high-level radioactive waste (HLW)**
- **Group wastes into categories based on similar disposal characteristics**
- **Identify potential disposal options for each of the waste forms**
- **Provide answers to questions such as:**
  - Is a "one-size-fits-all" repository a good strategic option?
  - Do different waste forms perform differently enough in different disposal environments to warrant different approaches?
  - Do some disposal concepts perform better with or without specific waste forms?
- **Draft report delivered September 30, 2013**


Draft Evaluation of Options for Permanent Geologic Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste in Support of a Comprehensive National Nuclear Fuel Cycle Strategy

Fuel Cycle Research & Development

DRAFT

Prepared for
U.S. Department of Energy
Spent fuel Disposition Campaign
by Sandia National Laboratories
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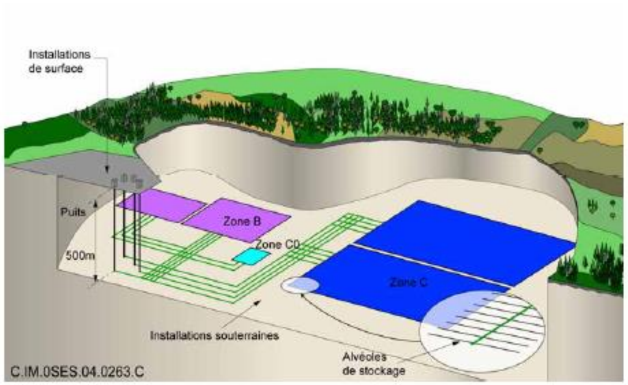
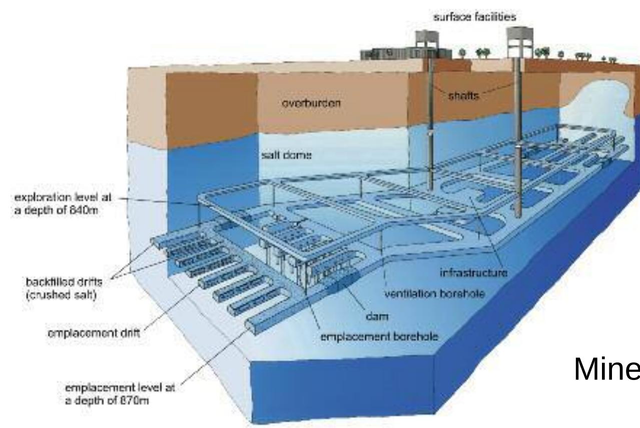
Evaluation Assumptions

- **HLW and SNF considered in the evaluation are restricted to existing materials and those reasonably expected to be generated by existing/currently planned processes**
  - The inventory of HLW and SNF in the U.S. requiring deep geologic isolation; based on the best available information
- **Technologies under consideration, including both for waste treatments and disposal concepts, are limited to those that can be deployed in the near future**
- **Programmatic constraints (e.g., legal, regulatory, and contractual) are acknowledged where applicable, but are not used as bases**
- **Evaluations are primarily qualitative**
  - Based in large part on insights from past experience in waste management and disposal programs in both the U.S. and other nations
- **Disposal concepts identified by DOE's Used Fuel Disposition Campaign are adopted as useful and representative, rather than comprehensive**

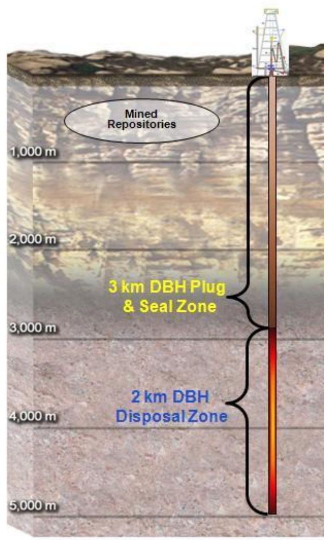
Disposal Concepts Evaluated in the Study



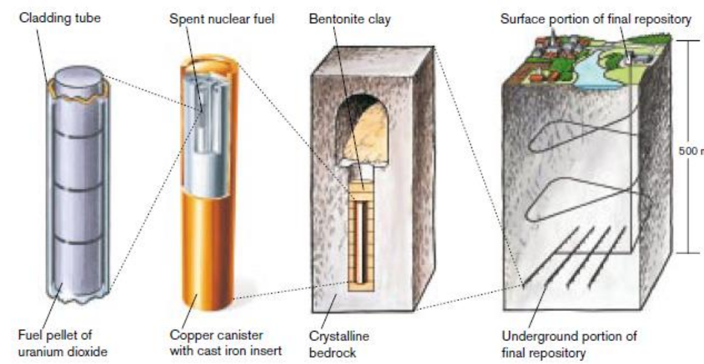
Mined repositories in clay/shale



Mined repositories in salt



Deep boreholes in crystalline rock



Mined repositories in crystalline rock

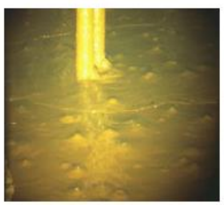
Evaluation Scope – Waste Types

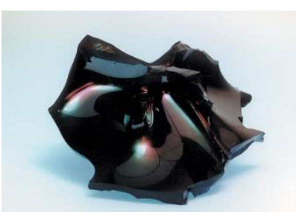
- **SNF: Existing and reasonably foreseeable (as of 2048) SNF from existing commercial, defense, and research reactors (Wagner et al., 2012)**
- **HLW: Existing and projected (as of 2048) HLW from SRS, West Valley, Hanford and INL**
- **Waste types not presently planned for direct disposal without further treatment (e.g., calcine waste at INL; Cs/Sr capsules)**
  - Some wastes have multiple treatment options, including direct disposal, resulting in multiple possible waste forms for some waste types
- **Report identifies 43 waste types and 50 possible waste forms**
  - Waste forms consolidated into 10 "Waste Groups" for analysis, based on similar properties
  - Full listings included in appendices

Waste Types, Waste Forms, and Waste Groups: A Note on Terminology

Example Using High-Level Waste Glass

Waste Type is what exists today





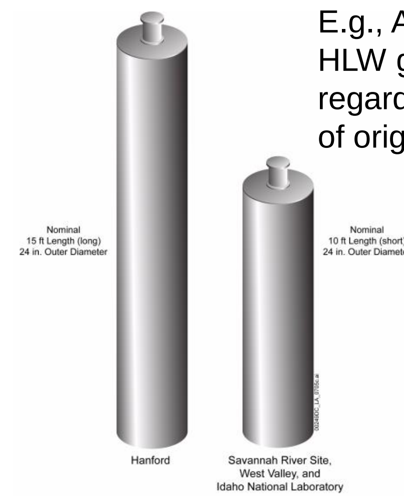
E.g., existing tank waste, existing HLW glass

Waste Form is what could go underground

E.g., Canisters of HLW glass from multiple sites and sources

Waste Group is an aggregation of Waste Forms with similar characteristics

E.g., All HLW glass regardless of origin



Across the full inventory, this study identified 43 waste types, 50 waste forms, and 10 waste groups

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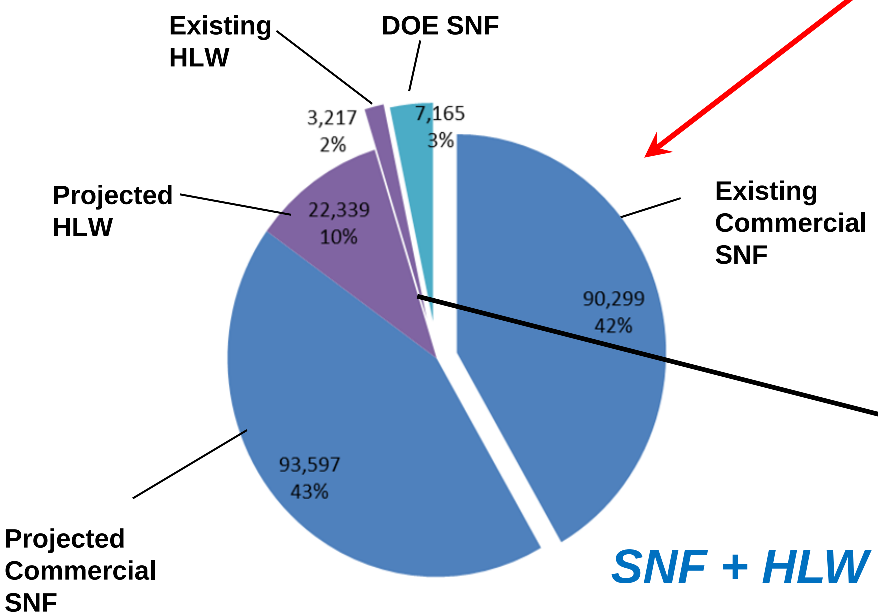
Volumes of the Main Waste Forms Existing and Projected to 2048

Projected (2048) Commercial and DOE-Managed SNF and HLW ~ 217,000 m³ [Note: ~47% (by volume) exists today]

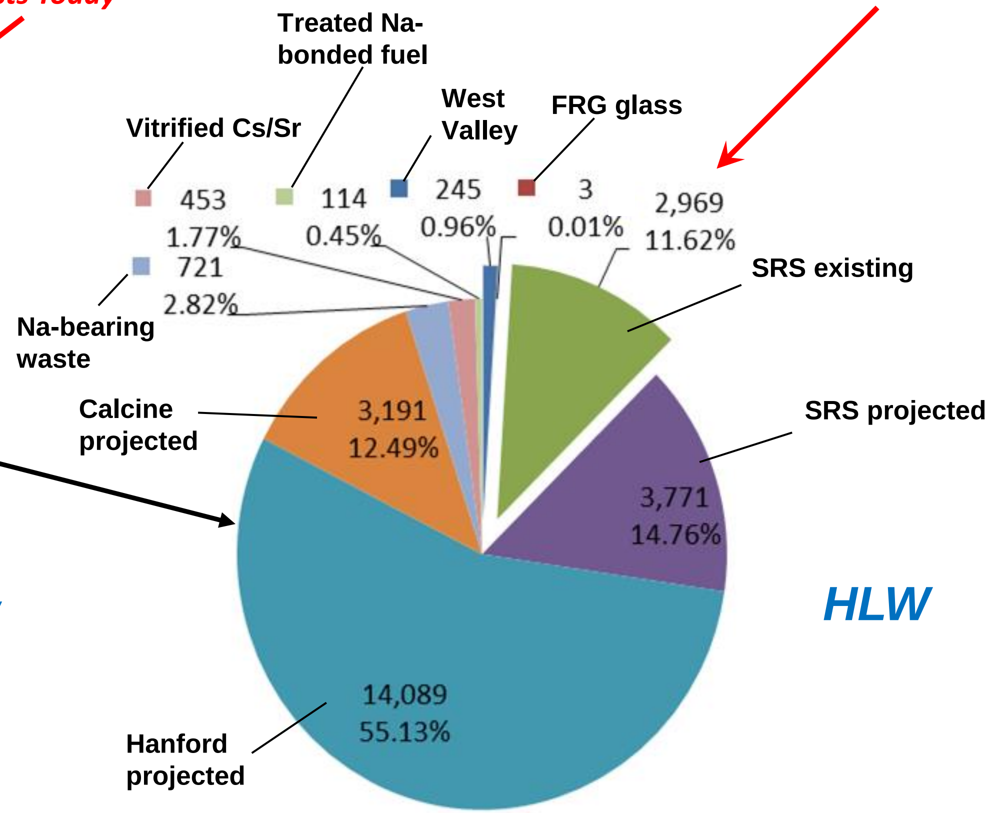
~97,500 m³ (~74,000 MTHM) SNF (DOE and Commercial) Exists Today



Volumes in m³, assuming constant rate of nuclear power generation and packaging of all CSNF in dual purpose canisters. For simplicity, all DOE SNF is shown as "existing"; approx. 3500 m³ of Naval SNF remains to be generated

Projected (2048) DOE-Managed HLW ~ 25,500 m³ [Note: less than 15% exists today]

~ 3200 m³ HLW Glass Exists Today



Volumes in m³, assuming calcine is treated by Hot Isostatic Press, Na-bonded fuels undergo electrometallurgical treatment, and all other HLW wastes are vitrified

Characteristics Considered and Process for Delineating Waste Groups

- **Characteristics Considered for Grouping Waste Forms**
  - Radionuclide Inventory
  - Thermal
  - Chemical
  - Physical
  - Packaging
  - Safeguards and Security
- **Evaluation SubGroup Defined Waste Groups**
  - Discussion of above characteristics using common set of information
- **Some Waste Groups Rely on One or More Distinct Aspects**
  - E.g., direct disposal of Metallic Na-bonded Fuels
- **Alternate Waste Forms Fall into Different Groups**
  - E.g., Vitrified/ceramic HIP calcine vs. untreated calcine

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Waste Groups

- **WG1: All Commercial SNF packaged in purpose-built disposal containers**
- **WG2: All Commercial SNF disposed of in dual-purpose containers of existing design**
- **WG3: All HLW glass (all types, existing and projected)**
- **WG4: Other engineered waste forms, including**
  - Glass-bonded sodalite from salt waste stream of treated Na-bonded fuels
  - Metal ingots from metallic waste stream of treated Na-bonded fuels
  - Glass/ceramic calcine treated by hot isostatic pressing (HIP) (with, and without, additives)
- **WG5: Metallic and non-oxide spent fuels**
  - E.g., N-reactor, various research reactors
- **WG6: Na-bonded fuel**
  - E.g., Fermi-1
- **WG7: DOE oxide fuels**
  - Includes some HEU (e.g., Shippingport)
- **WG8: Salt, granular solids, powders**
  - E,g., salt waste stream from treated Na-bonded fuels, untreated calcine, Cs/Sr capsules
- **WG9: Coated-particle fuel**
  - E.g., Fort St. Vrain, Peach Bottom
- **WG10: Naval fuel**

- **All of the 43 “Waste Types” (50 Waste Forms) map to these 10 Waste Groups**
- **Some Waste Types map to more than one Waste Group, based on treatment options (e.g., Na-bonded fuels)**
- **For this study, we chose to map the 34 DOE fuel groups to 5 Waste Groups based on disposal characteristics**

Assumptions and Approach for the Evaluation of Disposal Options

- **Evaluations are qualitative informed judgment, based on full range of available information**
  - Results are color coded

Strong	Moderate	Weak/Uncertain	Not Feasible

- **Evaluation of options based on technical considerations**
  - Impacts of current laws and regulations are noted, but are not treated as prescriptive
  - Estimated costs are discussed qualitatively but not used as a metric
- **Criteria and metrics include**
  - Disposal option performance (could it comply with standards)
  - Confidence in expected performance bases (based on present knowledge)
  - Operational feasibility (worker health and safety, physical considerations)
  - Secondary waste generated during future treatment of existing waste
  - Technical readiness (technology status for waste form, transportation, disposal)
  - Safeguards and security (special nuclear material, radiological dispersion)

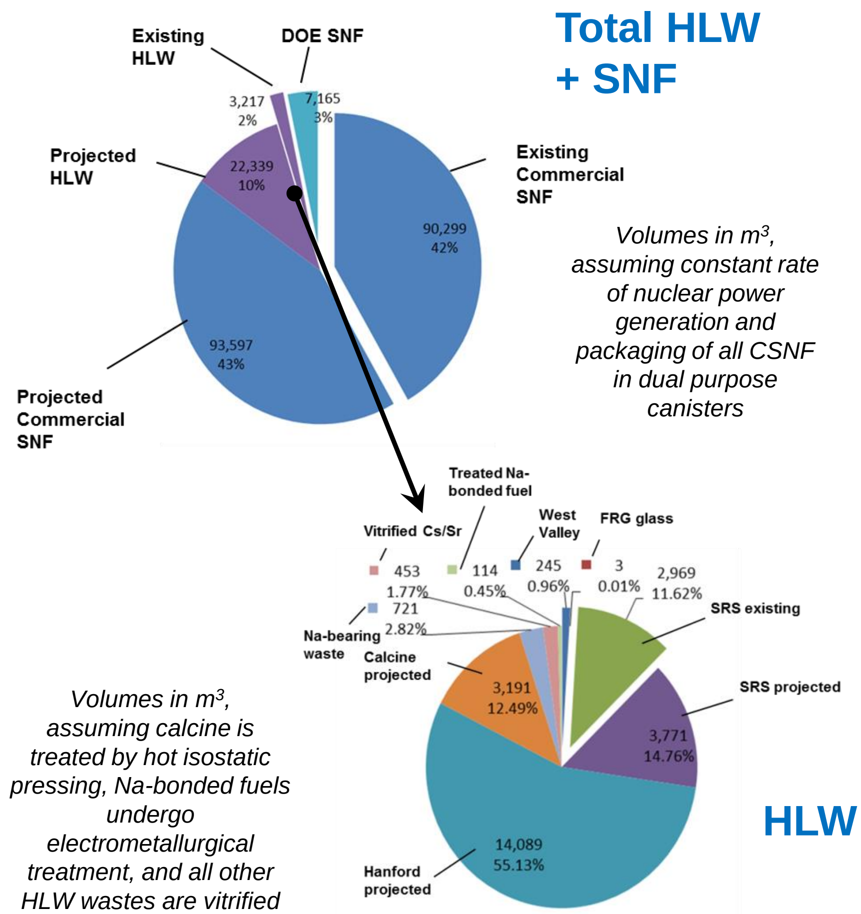
Disposal Options are defined to be pairings of Disposal Concepts and Waste Groups

PRELIMINARY RESULTS

Observations about the SNF and HLW Inventory

- **Commercial SNF is the largest volume of waste (85% projected in 2048)**
- **HLW will be the second largest volume**
- **Other DOE-managed wastes have a variety of characteristics**
  - Most DOE waste types exist in relatively small volumes
- **Some waste types could have multiple treatment options, and some wastes could perhaps be disposed of without planned treatments**
- **No wastes pose unusual safeguards and security concerns except granular and powdered waste forms and small capsules**

Waste Volumes projected in 2048



Preliminary Results: Question 1

Is a "one-size-fits-all" repository a good strategic option? (Assume "one-size-fits-all" means a single repository at a single location)

- Technically it can be done
- Has potential cost savings
- Would have to be a mined repository
- May be advantageous to segregate some waste forms from others in some disposal concepts
  - Specifically, halide-bearing wastes have the potential to corrode waste packages, and if they are disposed of without treatment they should be isolated from other wastes in concepts that rely on long-lived packages

Multiple repository options are also technically viable, and strategic decisions are outside the scope of this analysis

Preliminary Results: Question 2

Do different waste forms perform differently enough in different disposal environments to warrant different approaches?

- We did not identify any waste forms that require a specific disposal option
- We did not have enough information to evaluate disposal of untreated Na–bonded fuels; they may require treatment for any disposal concept
- Halide-bearing wastes (e.g., the Cs/Sr capsules) are potentially corrosive, and if they are disposed of without treatment they should be isolated from other wastes in concepts that rely on long-lived waste packages
- Small waste forms are candidates for deep borehole disposal
  - Salt (electrochemical refining waste), granular solids (calcine), and Cs/Sr capsules (WF8)
  - Some DOE-managed SNF (WF5, WF7, WF9) that has not yet been packaged
  - HLW and Engineered Waste Forms (WF3 and WF4) that have not yet been made could be redesigned and packaged for deep borehole disposal
- Salt allows for more flexibility in managing high-heat waste
- We did not identify technical issues with disposing of mixed waste (i.e., waste containing both radioactive and RCRA constituents)
- Direct disposal of Dual Purpose Canisters is a challenge

Preliminary Results: Question 3

Do some disposal concepts perform better with or without specific waste forms?

- No. But…
- For certain waste forms and disposal concepts, confidence in technical basis for demonstration of performance is lower (see yellows and purples)

Criteria and Metrics

Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Likely to comply with long-term standards? (Yes/No)	Additional EBS components needed above baseline for each design concept Robustness of information bases; simplicity vs. complexity; knowledge gaps	Ease in ensuring worker health and safety at all stages Special physical considerations at any stages based on physical characteristics	Amount of low-level waste generated during handling and treatment Amount of mixed waste generated	Status of waste form technologies Status of transportation and handling systems Status of disposal technologies	National security implementation difficulty Radiological dispersion device prevention implementation difficulty

Strong	Moderate	Weak/Uncertain	Not Feasible

Preliminary Results: Mined Repository in Salt

Mined Repository in Salt

Waste Group	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
WG1 - CSNF Purpose-built containers	Strong	Strong	Moderate	Weak/Uncertain	Strong	Strong
WG2 – CSNF DPCs	Strong	Moderate	Weak/Uncertain	Strong	Moderate	Strong
WG3 – HLW glass	Strong	Strong	Strong	Strong	Moderate	Strong
WG4 - Other engineered waste forms	Strong	Strong	Strong	Moderate	Moderate	Strong
WG5 – Metallic and non-oxide fuels	Strong	Strong	Moderate	Strong	Moderate	Strong
WG6 – Na-bonded fuel	Unknown					Strong
WG7 – DOE oxide fuels	Strong	Strong	Strong	Strong	Strong	Strong
WG8 - Salt, granular solids, powders	Strong	Strong	Moderate	Strong	Strong	Moderate
WG9 – Coated-particle spent fuel	Strong	Strong	Strong	Strong	Strong	Strong
WG10 – Naval Fuel	Strong	Moderate	Weak/Uncertain	Strong	Moderate	Strong

Legend: Strong | Moderate | Weak/Uncertain | Not Feasible

- Overall strong performance in most metrics
- High confidence from very low reliance on engineered materials, past operational experience
- Thermal properties contribute to high confidence for all but very large high-heat packages
- Operational challenges for very large packages (Dual Purpose Canisters and Naval fuel)

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Preliminary Results: Mined Repository in Crystalline Rock

Mined Repository in Crystalline Rock

Waste Group	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
WG1 - CSNF Purpose-built containers						
WG2 – CSNF DPCs						
WG3 – HLW glass						
WG4 - Other engineered waste forms						
WG5 – Metallic and non-oxide fuels						
WG6 – Na-bonded fuel	Unknown					
WG7 – DOE oxide fuels						
WG8 - Salt, granular solids, powders						
WG9 – Coated-particle spent fuel						
WG10 – Naval Fuel						

Legend	Strong	Moderate	Weak/Uncertain	Not Feasible

- Overall good performance in most metrics
- Reliance on long-lived engineered materials and relative lack of operational experience in US leads to lower confidence
- Thermal constraints of engineered backfill reduce confidence for large and high-heat packages
- Stable rock properties enhance operational feasibility for very large packages (Dual Purpose Canisters and Naval fuel)

Preliminary Results: Mined Repository in Clay/Shale

Mined Repository in Clay/Shale

Waste Group	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
WG1 - CSNF Purpose-built containers	Strong	Strong	Moderate	Weak/Uncertain	Strong	Strong
WG2 – CSNF DPCs	Strong	Moderate	Weak/Uncertain	Strong	Moderate	Strong
WG3 – HLW glass	Strong	Strong	Strong	Strong	Moderate	Strong
WG4 - Other engineered waste forms	Strong	Strong	Strong	Moderate	Moderate	Strong
WG5 – Metallic and non-oxide fuels	Strong	Strong	Moderate	Strong	Moderate	Strong
WG6 – Na-bonded fuel	Unknown					Strong
WG7 – DOE oxide fuels	Strong	Strong	Strong	Strong	Strong	Strong
WG8 - Salt, granular solids, powders	Strong	Strong	Moderate	Strong	Strong	Moderate
WG9 – Coated-particle spent fuel	Strong	Strong	Strong	Strong	Strong	Strong
WG10 – Naval Fuel	Strong	Moderate	Weak/Uncertain	Strong	Moderate	Strong

Legend: Strong | Moderate | Weak/Uncertain | Not Feasible

- Overall strong performance in most metrics, summary-level scores for clay/shale repositories are identical to salt
- High confidence from low-permeability host rock allows for intermediate reliance on engineered materials, provides some flexibility in thermal management
- Operational challenges for very large packages (Dual Purpose Canisters and Naval fuel)

Preliminary Results: Deep Borehole Disposal

Deep Borehole Disposal in Crystalline Rock

Waste Group	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
WG1 - CSNF Purpose-built containers	Strong	Moderate	Weak/Uncertain	Weak/Uncertain	Moderate	Moderate
WG2 – CSNF DPCs			Not Feasible			
WG3 – HLW glass	Strong / –	Moderate / –	Moderate / Not Feasible	Strong / –	Moderate / –	Strong / –
WG4 - Other engineered waste forms	Strong	Moderate	Strong	Moderate	Moderate	Strong
WG5 – Metallic and non-oxide fuels	Strong / –	Moderate / –	Strong / Not Feasible	Strong / –	Moderate / –	Strong / –
WG6 – Na-bonded fuel	Unknown					Strong
WG7 – DOE oxide fuels	Strong / –	Moderate / –	Weak/Uncertain / Not Feasible	Moderate / –	Moderate / –	Moderate / –
WG8 - Salt, granular solids, powders	Strong	Moderate	Moderate	Strong	Moderate	Moderate
WG9 – Coated-particle spent fuel	Strong / –	Moderate / –	Moderate / Not Feasible	Strong / –	Moderate / –	Strong / –
WG10 – Naval Fuel			Not Feasible			

Legend: Strong | Moderate | Weak/Uncertain | Not Feasible

Split scores indicate that size constraints preclude borehole disposal for some, but not all, wastes in a group

- Size is the key constraint, deep borehole disposal is simply not possible for large waste forms
- Some small waste forms in many waste groups are good candidates
- Salts, granular solids, powders, Cs/Sr capsules, some unpackaged DOE fuels
- Robust isolation allows the possibility of disposal of some wastes without treatment
- Borehole disposal of large quantities of SNF or HLW would require extensive redesign of packaging (e.g., rod consolidation, smaller glass canisters)

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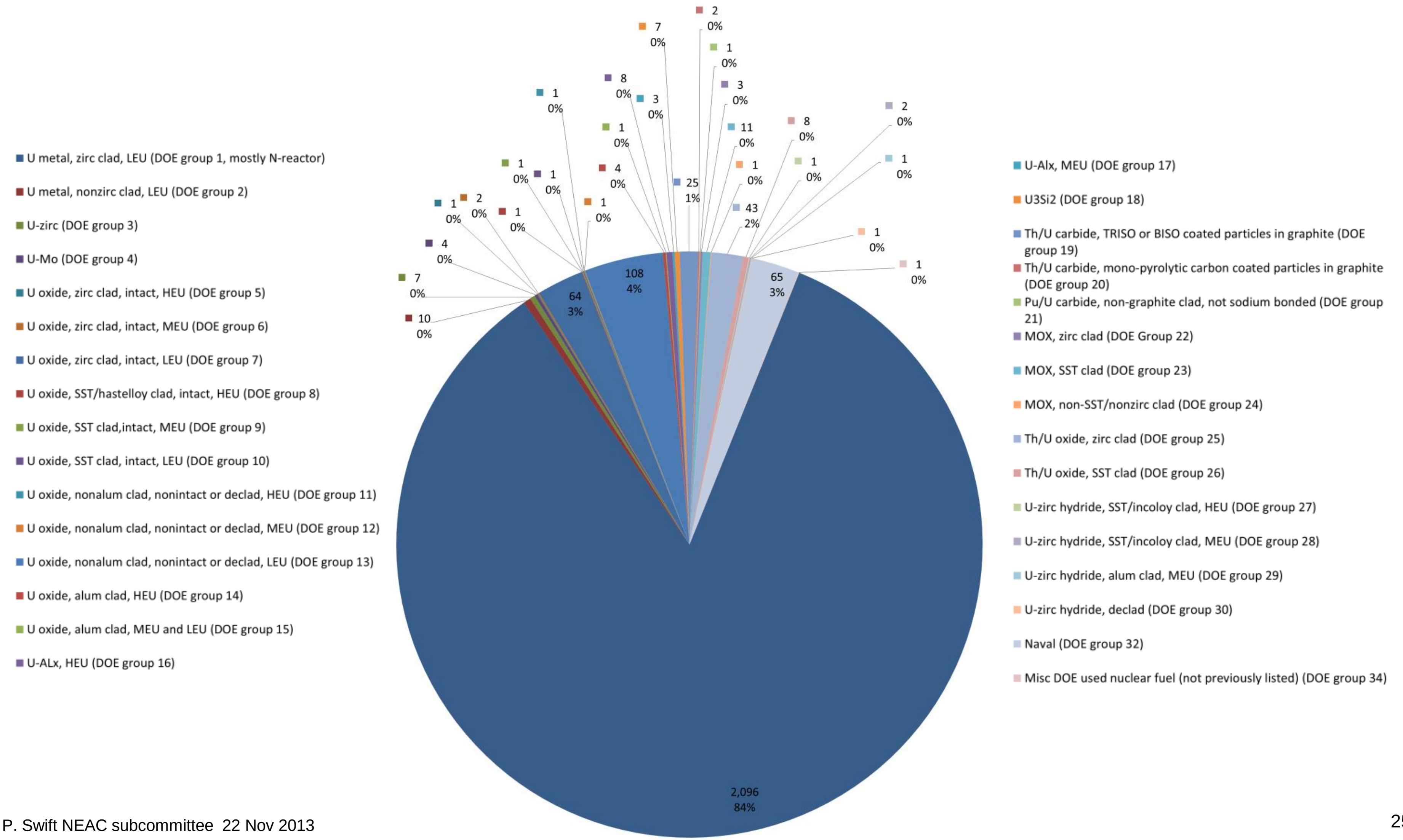
Preliminary Conclusions from the *Waste Form Disposal Options Report*

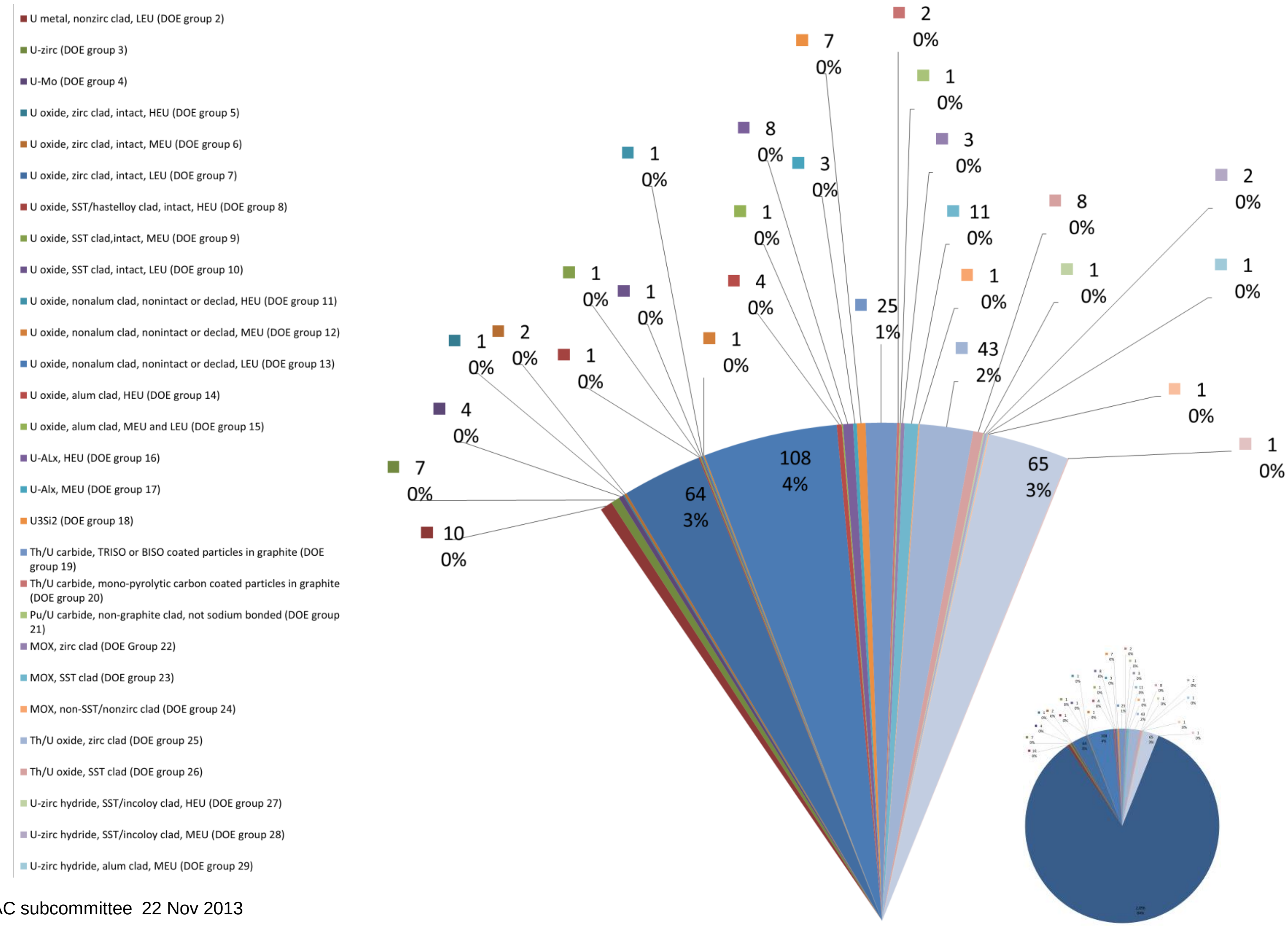
- **All wastes could go to one mined repository**
- **No wastes require a specific disposal concept**
  - Information is incomplete for sodium-bonded fuels, which may require treatment before disposal
- **The evaluation did not provide a compelling basis for choosing one medium over others: All media considered in the study are viable for all wastes**
  - Salt and clay/shale scored comparably
  - Evaluation for mined crystalline repositories suggests greater R&D needs
- **Deep borehole disposal scores well for some small and low-volume waste types**
  - Placing large volumes of waste in deep boreholes would likely require significant modifications to waste forms, e.g., rod consolidation for pressurized water reactor fuel, redesign of canister sizes for HLW

BACKUP MATERIALS

Relative Quantities (by Mass) of DOE-Managed Spent Nuclear Fuel



Relative Quantities (by Mass) of DOE-Managed Spent Nuclear Fuel



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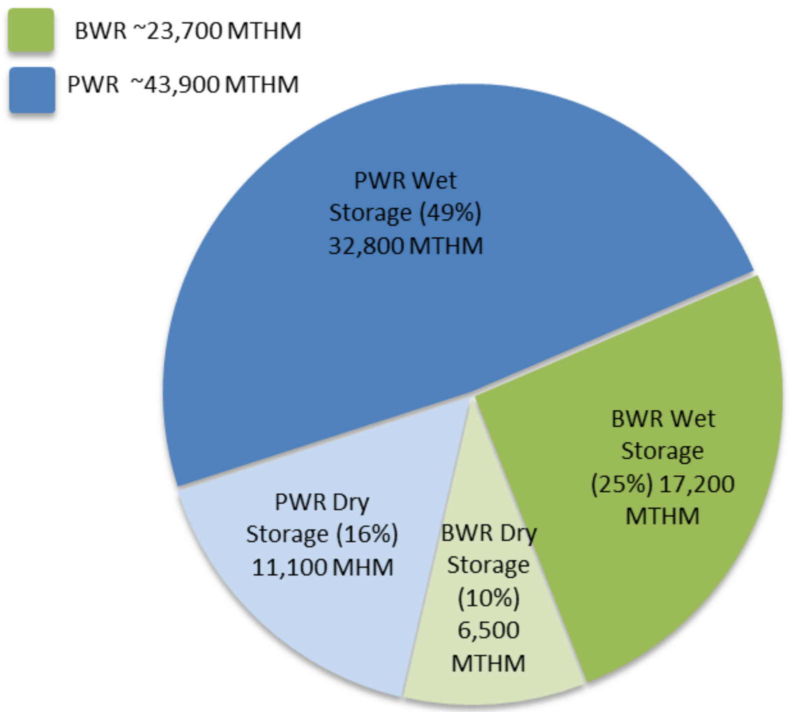
Current Commercial SNF Storage



Distribution of current (2011) commercial SNF inventory in wet and dry storage

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Waste Group Details (p. 1 of 4)

Table 3-1. Waste groups

Waste Group Identifier	Waste Form Identifier	Overlaps With	Waste Type (projected as of 2048)	Quantity of Waste Type	Waste Form
WG1—CSNF purpose-built containers	1A	1B	Commercial SNF, currently existing and projected through 2048	142,000 MTHM	Purpose-built disposal canister
WG2—CSNF in DPCs	1B	1A	Commercial SNF, currently existing and projected through 2048	142,000 MTHM	Dual purpose canisters (DPCs)
WG3—HLW glass	36		Savannah River HLW tank waste	4,000,000 gallons of reprocessing waste in tanks	Existing Savannah River HLW Glass
	37		West Valley HLW tank waste	600,000 gallons of reprocessing waste in tanks	Existing West Valley HLW Glass
	38		Federal Republic of Germany glass at Hanford	34 canisters	Glass logs containing Sr and Cs
	39		Hanford tank waste	53 million gallons of reprocessing waste in tanks	Projected glass waste from Hanford
	40		Savannah River tank waste	28,000,000 gallons of reprocessing HLW in tanks	Projected glass waste from Savannah River
	41C	41A, 41B, 41D	Calcine waste	4400 m^3	Calcine waste that has been vitrified
	43B	43A	Cs-Sr capsules at Hanford	1335 Cs capsules, 601 Sr capsules	Vitrified Cs and Sr from capsules
WG4—Other engineered waste forms	32		Metallic sodium bonded (EBR-II, INTEC, and FFTF) (group 31)	26 MTHM	Glass-bonded Sodalite Waste form from EMT
					INL Metal Waste Form resulting from EMT
	33B	33A, 33C	Metallic sodium bonded (Fermi-1) (group 31)	34 MTHM	Glass-bonded Sodalite Waste form from EMT
		33A, 33C			INL Metal Waste Form resulting from EMT
	41A	41B, 41C, 41D	Calcine waste	4400 m^3	Calcine waste treated by hot isostatic pressing, including silica, titanium and calcium sulfate

Waste Group Details (p. 2 of 4)

Waste Group Identifier	Waste Form Identifier	Overlaps With	Waste Type (projected as of 2048)	Quantity of Waste Type	Waste Form
	41B	41A, 41C, 41D	Calcine waste	4400 m^3	Calcine waste treated by hot isostatic pressing without silica, titanium and calcium sulfate
WG5—Metallic spent fuels	2		U metal, zirc clad, LEU (group 1, mostly N-reactor)	2,096 MTHM	Multicanister overpack (MCO) 18x15 canister
	3		U metal, nonzirc clad, LEU (group 2)	10 MTHM	MCO 18x10 canister
	4		U-zirc (group 3)	7 MTHM	18x10 canister 18x15 canister
	5		U-Mo (group 4)	4 MTHM	18x10 canister
	17		U-ALx, HEU (group 16)	8 MTHM	18x10 canister 18x15 canister
	18		U-Alx, MEU (group 17)	3 MTHM	18x10 canister
	19		U3Si2 (group 18)	7 MTHM	18x10 canister 18x15 canister
	22		Pu/U carbide, non-graphite clad, not sodium bonded (group 21)	<1 MTHM	18x10 canister 18x15 canister
	28		U-zirc hydride, SST/incoloy clad, HEU (group 27)	<1 MTHM	18x10 canister
	29		U-zirc hydride, SST/incoloy clad, MEU (group 28)	2 MTHM	18x10 canister
	30		U-zirc hydride, alum clad, MEU (group 29)	<1 MTHM	18x10 canister
	31		U-zirc hydride, declad (group 30)	<1 MTHM	18x10 canister
	35		Misc DOE spent nuclear fuel (not previously listed) (group 34)	<1 MTHM	18x10 canister 18x15 canister
WG6—Na-bonded fuels	33A	33B, 33C	Metallic sodium bonded (Fermi-1) (group 31)	34 MTHM	Metallic sodium bonded (Fermi-1)
WG7—DOE oxide fuels	6		U oxide, zirc clad, intact, HEU (group 5)	<1 MTHM	18x10 canister 18x15 canister
	7		U oxide, zirc clad, intact, MEU (group 6)	2 MTHM	18x10 canister

Waste Group Details (p. 3 of 4)

Waste Group Identifier	Waste Form Identifier	Overlaps With	Waste Type (projected as of 2048)	Quantity of Waste Type	Waste Form
	8		U oxide, zirc clad, intact, LEU (group 7)	64 MTHM	18x10 canister 18x15 canister MCO
	9		U oxide, stainless steel/hastelloy clad, intact, HEU (group 8)	<1 MTHM	18x10 canister
	10		U oxide, stainless steel clad,intact, MEU (group 9)	<1 MTHM	18x10 canister 18x15 canister
	11		U oxide, stainless steel clad, intact, LEU (group 10)	<1 MTHM	18x10 canister 18x15 canister
	12		U oxide, nonalum clad, nonintact or declad, HEU (group 11)	<1 MTHM	18x10 canister 18x15 canister
	13		U oxide, nonalum clad, nonintact or declad, MEU (group 12)	<1 MTHM	18x10 canister 18x15 canister
	14		U oxide, nonalum clad, nonintact or declad, LEU (group 13)	108 MTHM	18x10 canister 18x15 canister
	15		U oxide, alum clad, HEU (group 14)	4 MTHM	18x10 canister 24x10 canister
	16		U oxide, alum clad, MEU and LEU (group 15)	<1 MTHM	18x10 canister
	23		MOX, zirc clad (Group 22)	3MTHM	18x10 canister
	24		MOX, stainless steel clad (group 23)	11 MTHM	18x10 canister 18x15 canister
	25		MOX, non-stainless steel/nonzirc clad (group 24)	<1 MTHM	18x10 canister 18x15 canister
	26		Th/U oxide, zirc clad (group 25)	43 MTHM	18x10 canister 18x15 canister 24x15 canister
	27		Th/U oxide, stainless steel clad (group 26)	8 MTHM	18x10 canister 18x15 canister
WG8—salt, granular solids, powder	33C	33A, 33B	Metallic sodium bonded (Fermi-1) (group 31)	34 MTHM	Salt waste from EMT

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Waste Group Identifier	Waste Form Identifier	Overlaps With	Waste Type (projected as of 2048)	Quantity of Waste Type	Waste Form
	41D	41A, 41B, 41C	Calcined waste	4400 m^3	Calcined waste that is disposed of without further treatment
	42		Sodium-bearing waste at INL	810,000 gallons	Sodium-bearing waste treated by fluidized bed steam reforming (FBSR)
	43A	43B	Cs-Sr capsules at Hanford	1335 Cs capsules, 601 Sr capsules	Overpacked Cs-Sr capsules from Hanford
WG9—coated particle spent fuels	20		Th/U carbide, TRISO or BISO coated particles in graphite (group 19)	25 MTHM	18x10 canister 18x15 canister
	21		Th/U carbide, mono-pyrolytic carbon coated particles in graphite (group 20)	2 MTHM	18x15 canister
WG10 –Naval Fuel	34		Naval (group 32)	65 MTHM	Naval fuel in Naval canister

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Preliminary Results Organized by Waste Form Group

WG1 - CSNF Purpose-built containers

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Strong	Strong	Moderate	Weak/Uncertain	Strong	Strong
Crystalline	Strong	Strong	Moderate	Weak/Uncertain	Strong	Strong
Clay/Shale	Strong	Strong	Moderate	Weak/Uncertain	Strong	Strong
Deep Borehole	Strong	Moderate	Weak/Uncertain	Weak/Uncertain	Moderate	Moderate

WG2 – CSNF disposed of in dual-purpose canisters

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Strong	Moderate	Weak/Uncertain	Strong	Moderate	Strong
Crystalline	Strong	Weak/Uncertain	Moderate	Strong	Moderate	Strong
Clay/Shale	Strong	Moderate	Weak/Uncertain	Strong	Moderate	Strong
Deep Borehole			Not Feasible			

Legend				
Legend	Strong	Moderate	Weak/Uncertain	Not Feasible

Preliminary Results Organized by Waste Form Group (cont.)

WG3 – HLW Glass

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Strong	Strong	Strong	Strong	Moderate	Strong
Crystalline	Strong	Strong	Strong	Strong	Moderate	Strong
Clay/Shale	Strong	Strong	Strong	Strong	Moderate	Strong
Deep Borehole	Strong / blank	Moderate / blank	Moderate / Not Feasible	Strong / blank	Weak/Uncertain / blank	Strong / blank

Note: split scores indicate that size constraints preclude borehole disposal for some, but not all, wastes in a group

WG4 - Other engineered waste forms (treated Na-bonded sodalite waste, treated Na-bonded metal waste, HIPd calcine with additives, HIPd calcine without additives)

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Strong	Strong	Strong	Moderate	Moderate	Strong
Crystalline	Strong	Moderate	Strong	Moderate	Moderate	Strong
Clay/Shale	Strong	Strong	Strong	Moderate	Moderate	Strong
Deep Borehole	Strong	Moderate	Strong	Moderate	Moderate	Strong

Legend			
Strong	Moderate	Weak/Uncertain	Not Feasible

Preliminary Results Organized by Waste Form Group (cont.)

WG5 – Metallic and non-oxide spent fuels

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt						
Crystalline						
Clay/Shale						
Deep Borehole						

Note: split scores indicate that size constraints preclude borehole disposal for some, but not all, wastes in a group

WG6 – Na-bonded fuels

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Unknown					
Crystalline	Unknown					
Clay/Shale	Unknown					
Deep Borehole	Unknown					

Legend				
Legend	Strong	Moderate	Weak/Uncertain	Not Feasible

Preliminary Results Organized by Waste Form Group (cont.)

WG7 – DOE oxide fuels

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Strong	Strong	Strong	Strong	Strong	Strong
Crystalline	Strong	Strong	Strong	Strong	Strong	Strong
Clay/Shale	Strong	Strong	Strong	Strong	Strong	Strong
Deep Borehole	Strong / [blank]	Moderate / [blank]	Weak/Uncertain / Not Feasible	Moderate / [blank]	Moderate / [blank]	Moderate / [blank]

Note: split scores indicate that size constraints preclude borehole disposal for some, but not all, wastes in a group

WG8 – Salt, granular solids, powder

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Strong	Strong	Moderate	Strong	Strong	Moderate
Crystalline	Strong	Moderate	Moderate	Strong	Strong	Moderate
Clay/Shale	Strong	Strong	Moderate	Strong	Strong	Moderate
Deep Borehole	Strong	Moderate	Moderate	Strong	Moderate	Moderate

Legend: Strong | Moderate | Weak/Uncertain | Not Feasible

Preliminary Results Organized by Waste Form Group (cont.)

WG9 – Coated particle spent fuel

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Strong	Strong	Strong	Strong	Strong	Strong
Crystalline	Strong	Strong	Strong	Strong	Strong	Strong
Clay/Shale	Strong	Strong	Strong	Strong	Strong	Strong
Deep Borehole	Strong / (blank)	Moderate / (blank)	Moderate / Not Feasible	Strong / (blank)	Moderate / (blank)	Strong / (blank)

Note: split scores indicate that size constraints preclude borehole disposal for some, but not all, wastes in a group

WG10 – Naval Fuel

Disposal Concept	Disposal Option Performance	Confidence in Expected Performance Bases	Operational Feasibility	Secondary Waste Generation	Technical Readiness	Safeguards and Security
Salt	Strong	Moderate	Weak/Uncertain	Strong	Moderate	Strong
Crystalline	Strong	Weak/Uncertain	Moderate	Strong	Moderate	Strong
Clay/Shale	Strong	Moderate	Weak/Uncertain	Strong	Moderate	Strong
Deep Borehole			Not Feasible			

Legend				
Legend	Strong	Moderate	Weak/Uncertain	Not Feasible