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Spent Nuclear Fuel and High Level Radioactive Waste Inventories for the Waste Form / Disposal Options Evaluation

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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)

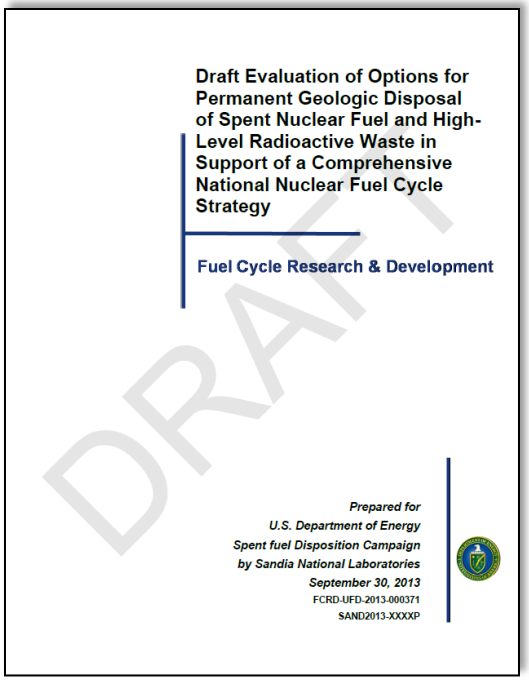
Group wastes into categories based on similar disposal characteristics

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



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Contributors to *Waste Form Disposal Options Evaluation*

Contributors: 44 individuals, 14 organizations

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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**

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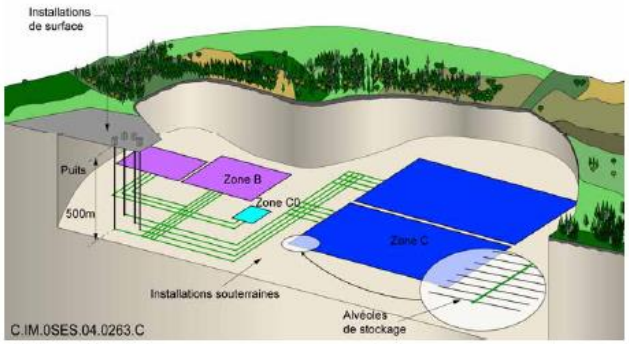
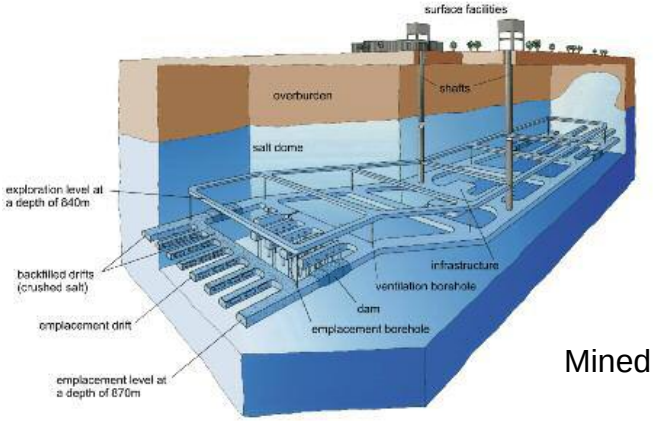
Disposal Concepts Evaluated in the Study

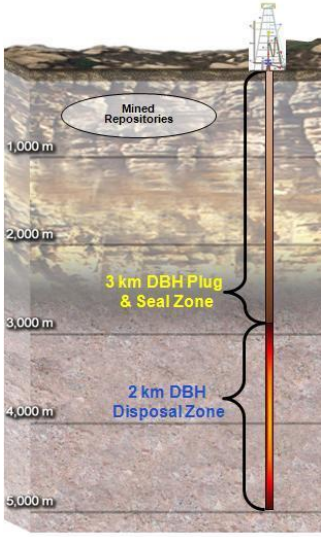


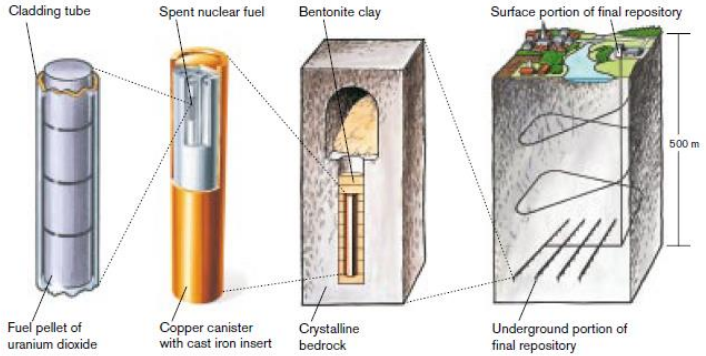
Mined repositories in clay/shale



Mined repositories in salt

Deep boreholes in crystalline rock





Mined repositories in crystalline rock

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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

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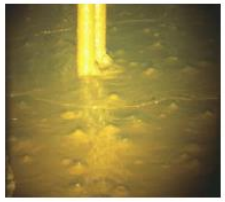
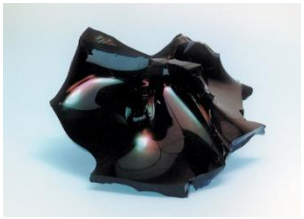
Waste Types, Waste Forms, and Waste Groups: A Note on Terminology

Example Using High-Level Waste Glass

Waste Type is what exists today



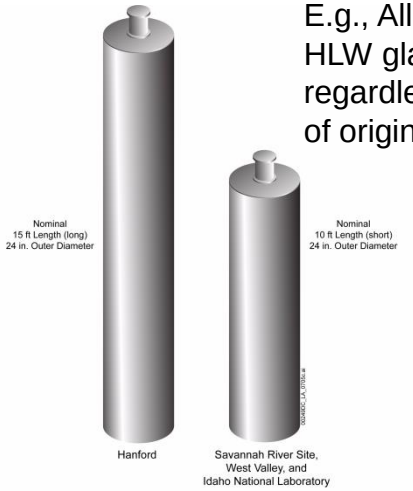


E.g., existing tank waste, existing HLW glass

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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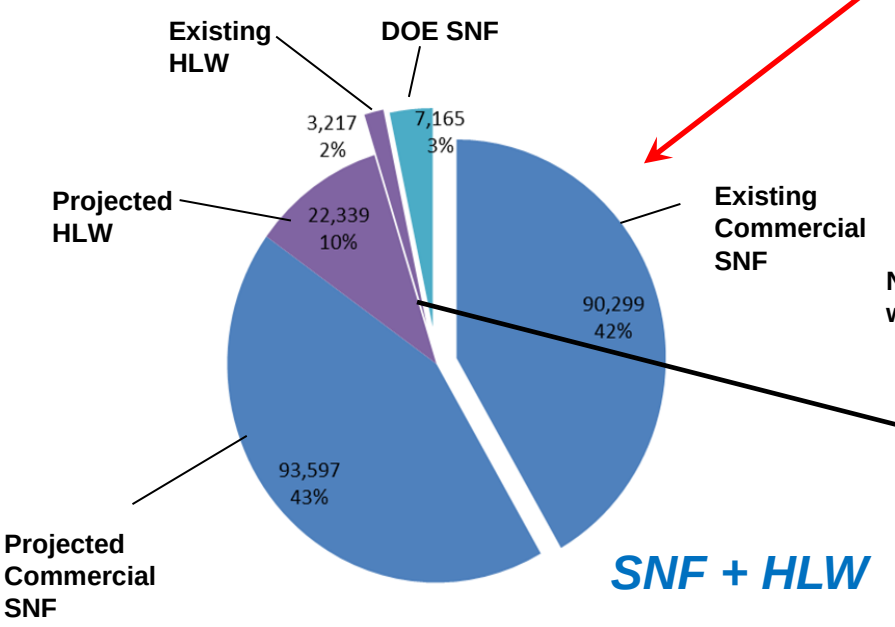
Volumes of the Main Waste Forms Existing and Projected to 2048

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

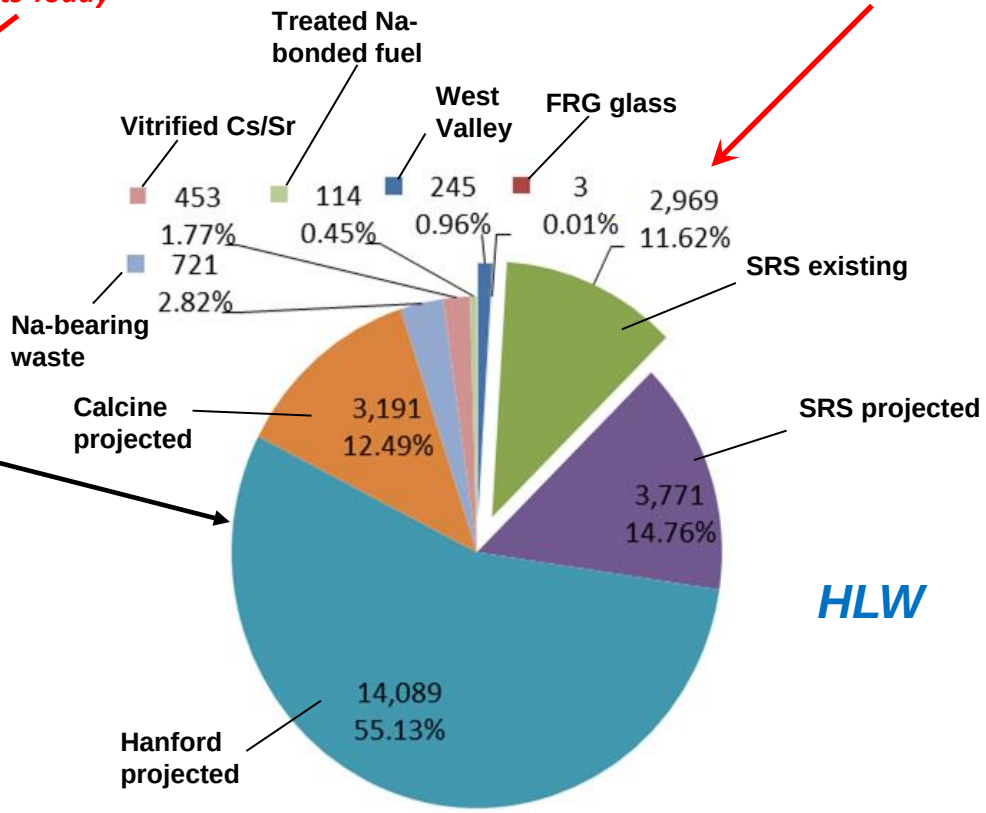
~97,500 m³ (~74,000 MTHM) SNF (DOE and Commercial) Exists Today



SNF + HLW

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

~ 3200 m³ HLW Glass Exists Today



HLW

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

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

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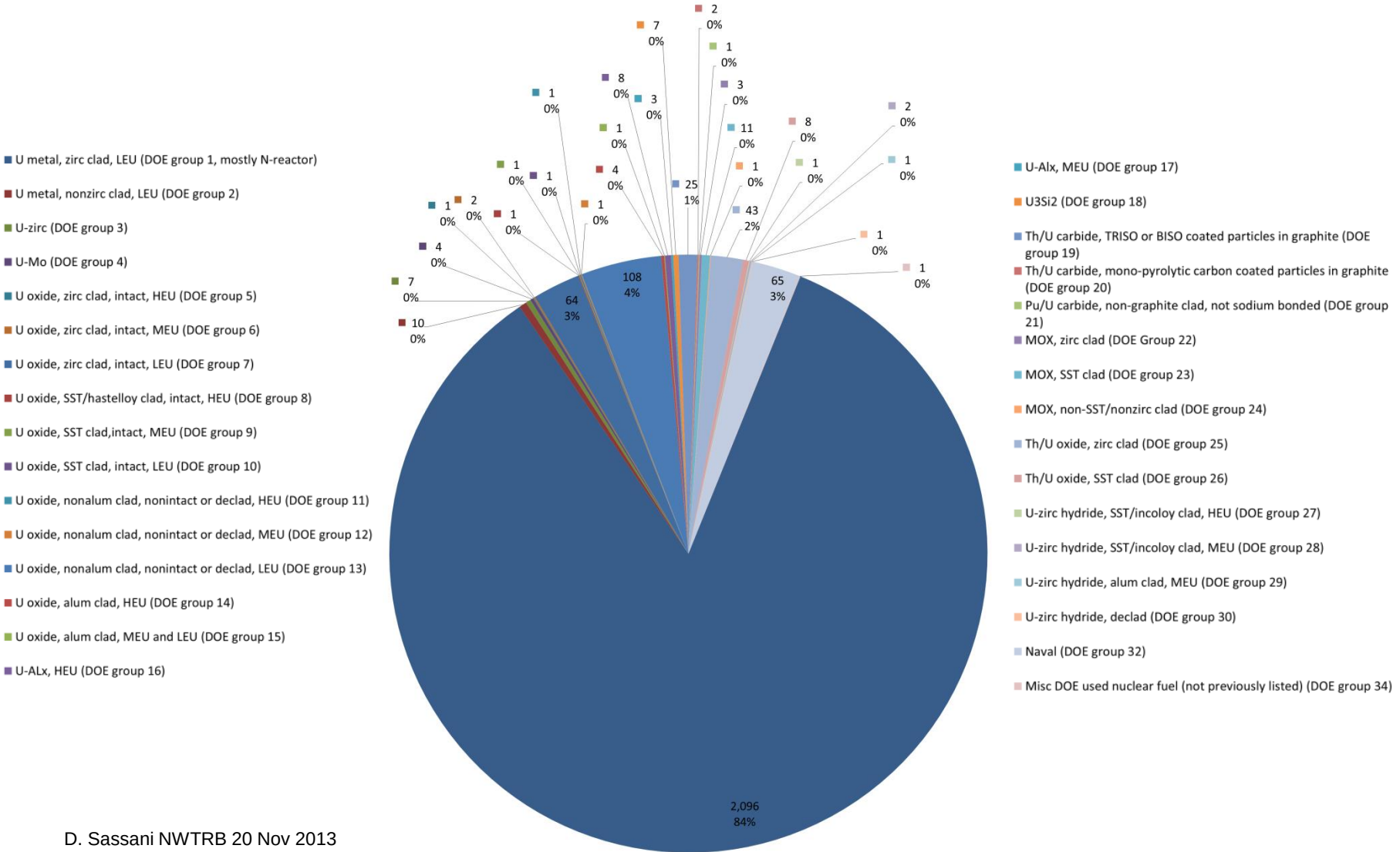
Relative Quantities (by mass) of DOE-Managed Spent Nuclear Fuel



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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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Evaluation SubGroup

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- ANL – Jim Jerdin, Mark Nutt
- CSG – Tom Cotton
- LANL – Mike Miller, Bruce Robinson
- MIT – Charles Forsberg
- ORNL – Rob Howard, John Wagner
- PNNL – John Vienna
- SRNL – Jim Marra

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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**

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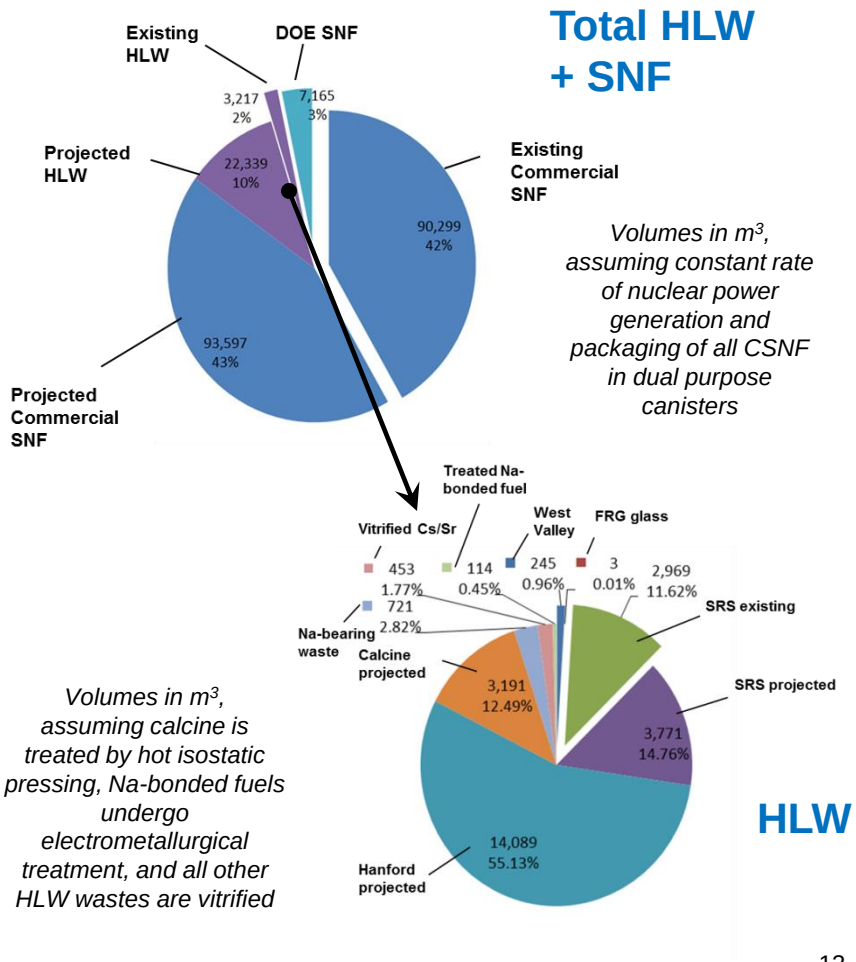
Observations about the SNF and HLW Inventory

- **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



BACKUP MATERIALS

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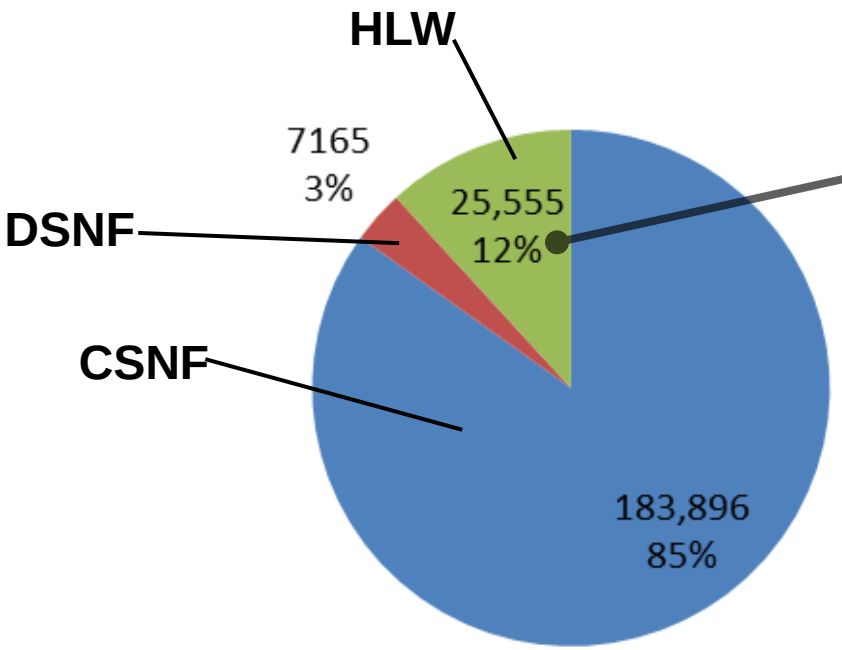
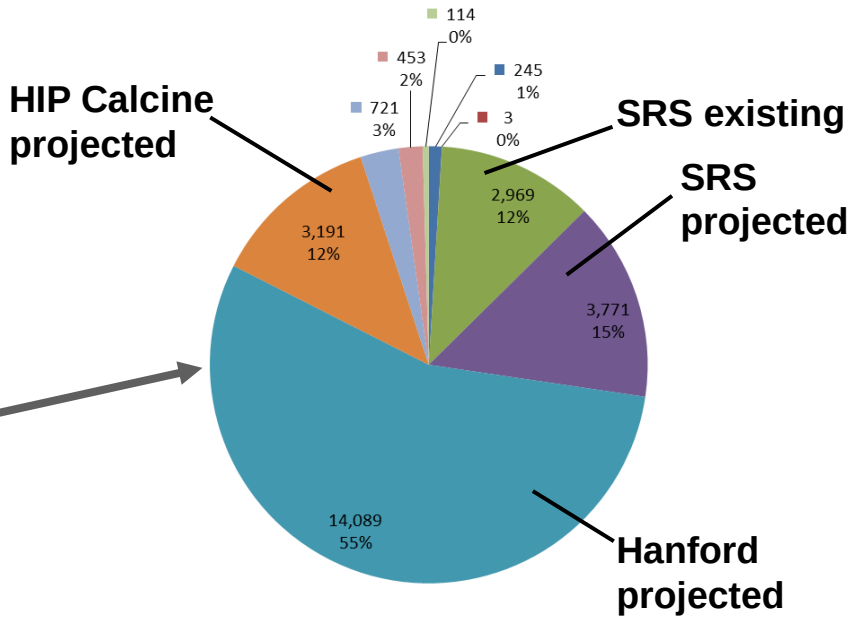
Relative Amounts of Projected HLW and SNF in 2048

88% (by volume, m³) of the HLW and SNF in 2048 will be SNF (plot assumes current rate of nuclear power generation, packaging of all CSNF in DPCs)



Total HLW + SNF (m³)



HLW (m³)

55% (by volume, m3) of the HLW in 2048 will be Hanford HLW

(plot assumes all indicated waste types are vitrified except for calcine, which is assumed to be hot isostatic press treated)

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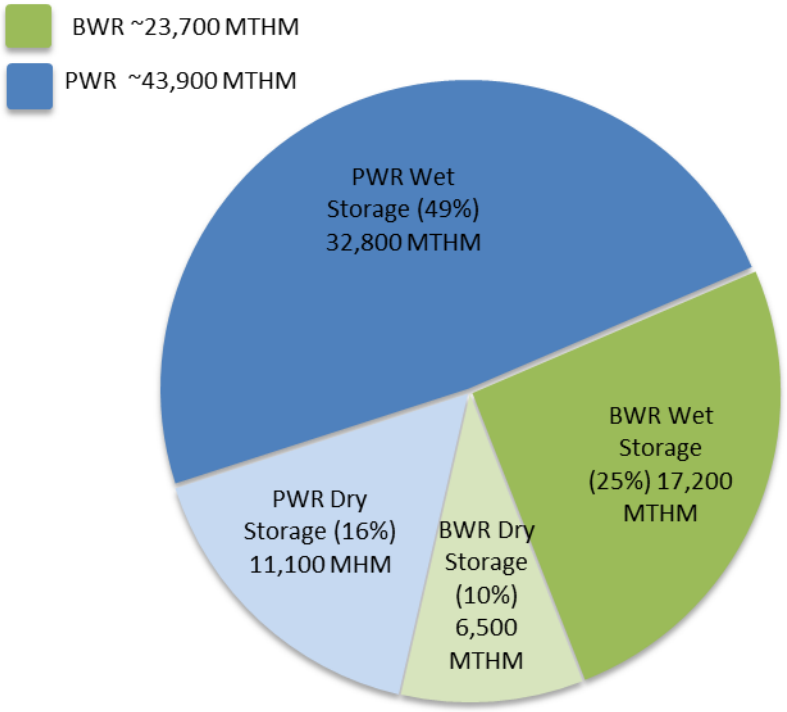
Current Commercial SNF Storage



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

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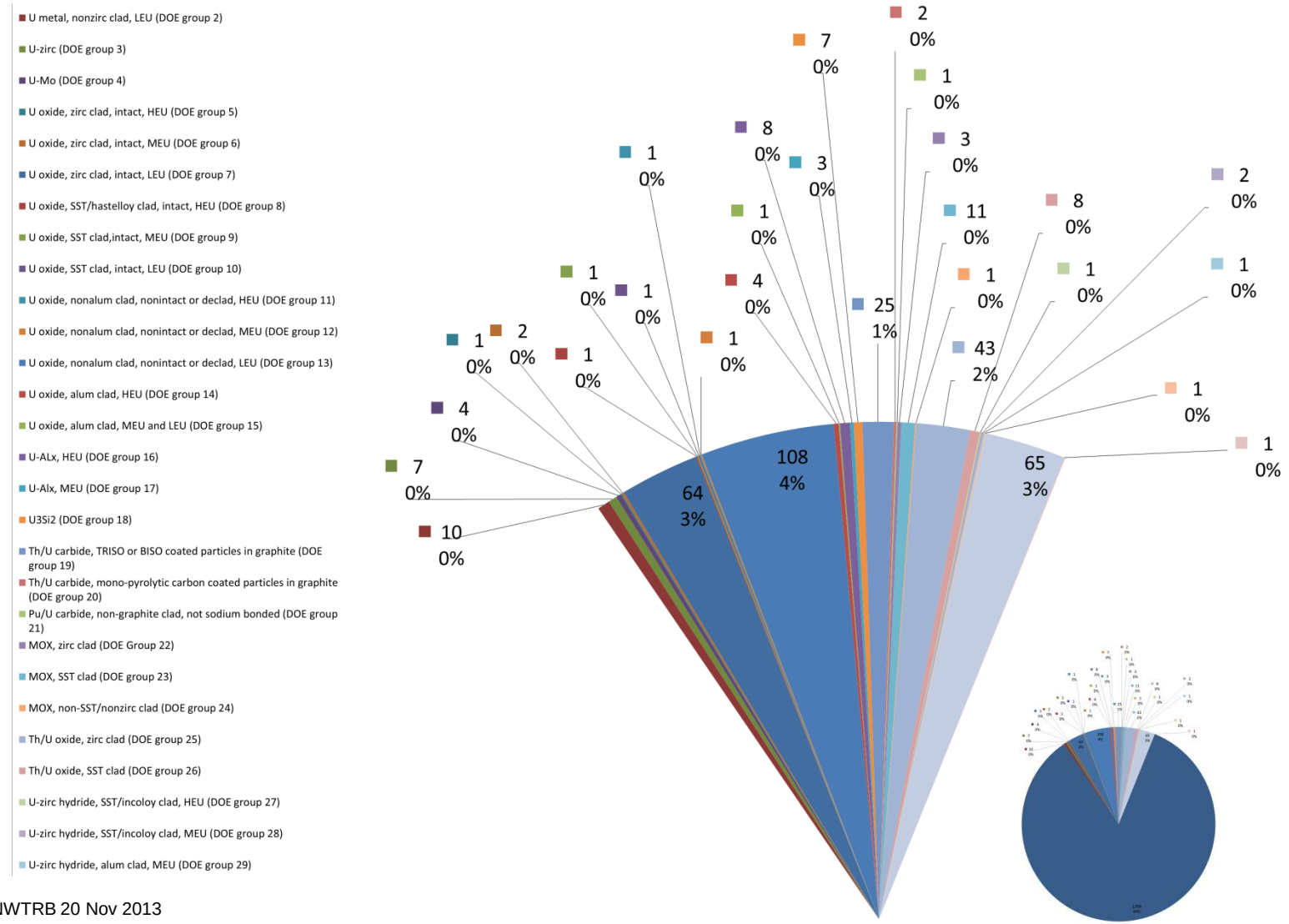
Relative Quantities (by mass) of DOE-Managed Spent Nuclear Fuel



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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

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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

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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 Details (p. 4 of 4)

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