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SAND2013-9712C

Results of the Waste Form / Disposal Options Evaluation

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U.S. Nuclear Waste Technical Review Board Winter Meeting
Washington, D.C., November 20, 2013

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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)

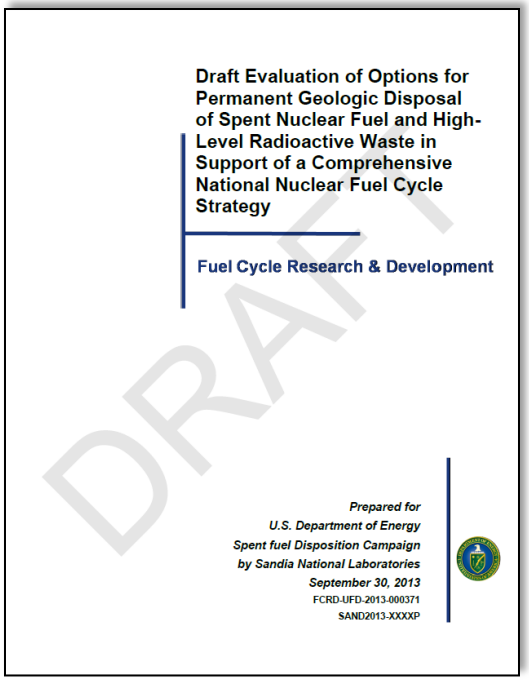
Group wastes into categories based on similar disposal characteristics

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: 44 individuals, 14 organizations

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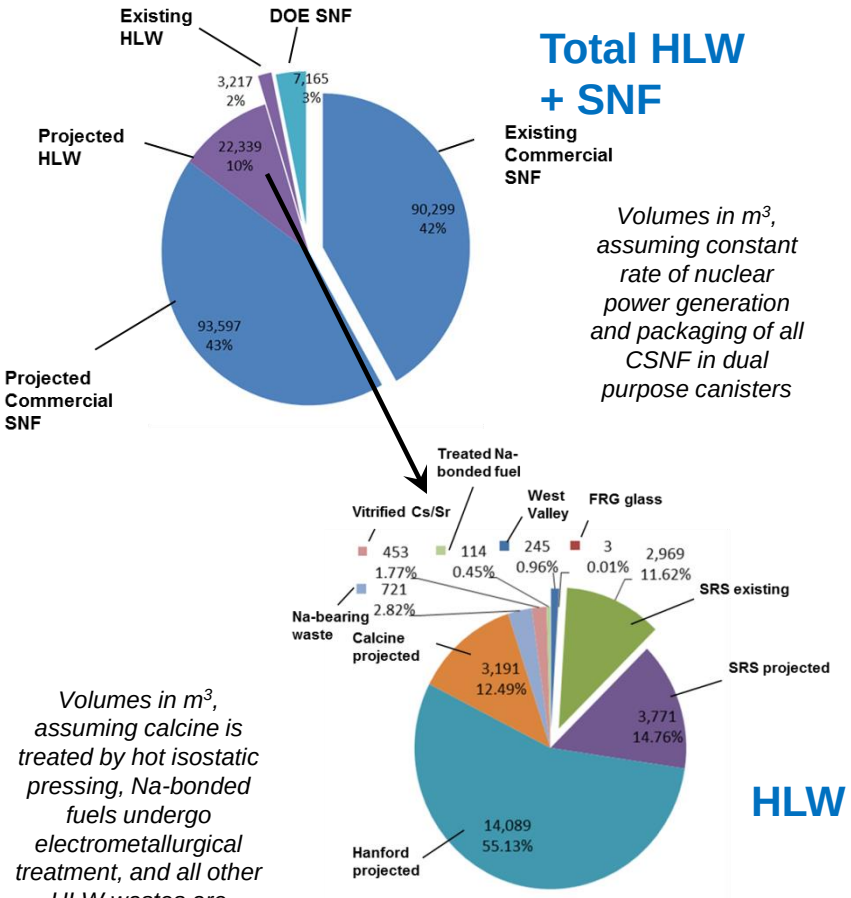
Observations about the SNF and HLW Inventory

- **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 disposal 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



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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**
  - Includes salt wastes from electrorefining of Na-bonded fuel, untreated calcine, untreated Cs-Sr capsules
- **WG9: Coated-particle fuel**
  - E.g., Fort St. Vrain, Peach Bottom
- **WG10: Naval fuel**

- **All of the 43 "Waste Types" 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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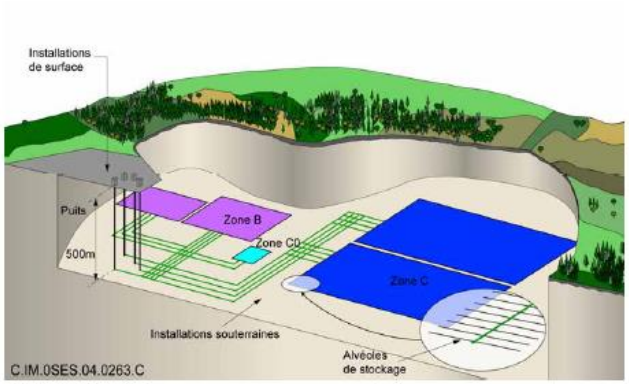
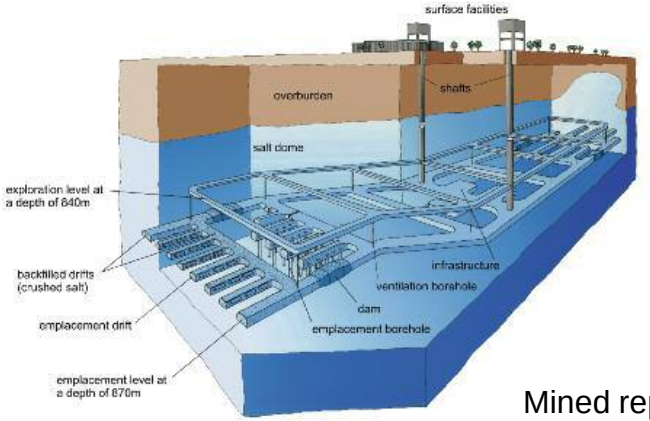
Disposal Concepts Evaluated in the Study

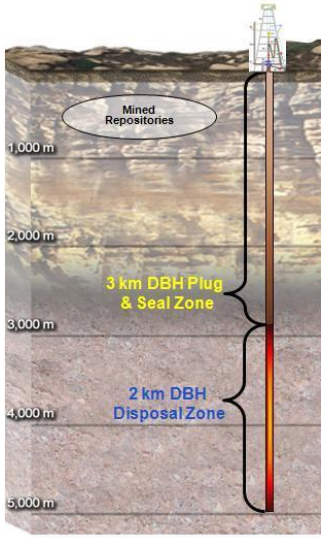


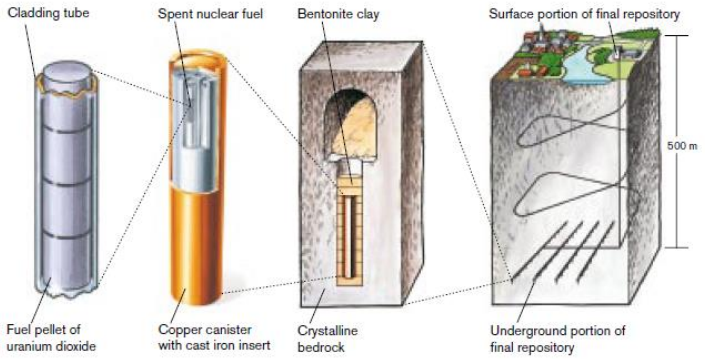
Mined repositories in clay/shale



Mined repositories in salt

Deep boreholes in crystalline rock





Mined repositories in crystalline rock

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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

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

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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)

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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

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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						
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 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)

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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						
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 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)

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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

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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						
Crystalline						
Clay/Shale						
Deep Borehole						

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						
Crystalline						
Clay/Shale						
Deep Borehole						

Legend	Strong	Moderate	Weak/Uncertain	Not Feasible

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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						
Crystalline						
Clay/Shale						
Deep Borehole						

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						
Crystalline						
Clay/Shale						
Deep Borehole						

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

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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: Strong | Moderate | Weak/Uncertain | Not Feasible

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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						
Crystalline						
Clay/Shale						
Deep Borehole						

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						
Crystalline						
Clay/Shale						
Deep Borehole						

Legend	Strong	Moderate	Weak/Uncertain	Not Feasible

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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						
Crystalline						
Clay/Shale						
Deep Borehole						

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						
Crystalline						
Clay/Shale						
Deep Borehole						

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