SAND2016-2248C

Used Fuel Disposition R&D Campaign

DOE-Managed Spent Nuclear Fuel and High Level Waste Research

Ed Matteo

Sandia National Laboratories

Used Fuel Disposition R&D Campaign

BGR

Hanover, Germany

March 2016

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Acknowledgements

Peter Swift, SNL, National Technical Director, UFD

Kevin McMahon and Bob MacKinnon, Control Account Managers

SNL Technical Leads:
Gordon Appel, Dave Sassani, and Dave Sevougian

SNL Work Package Leads:
Ernie Hardin, Joe Carter, Emily Stein, Mark Rigali, Rob Rechard, and Teklu Hadgu

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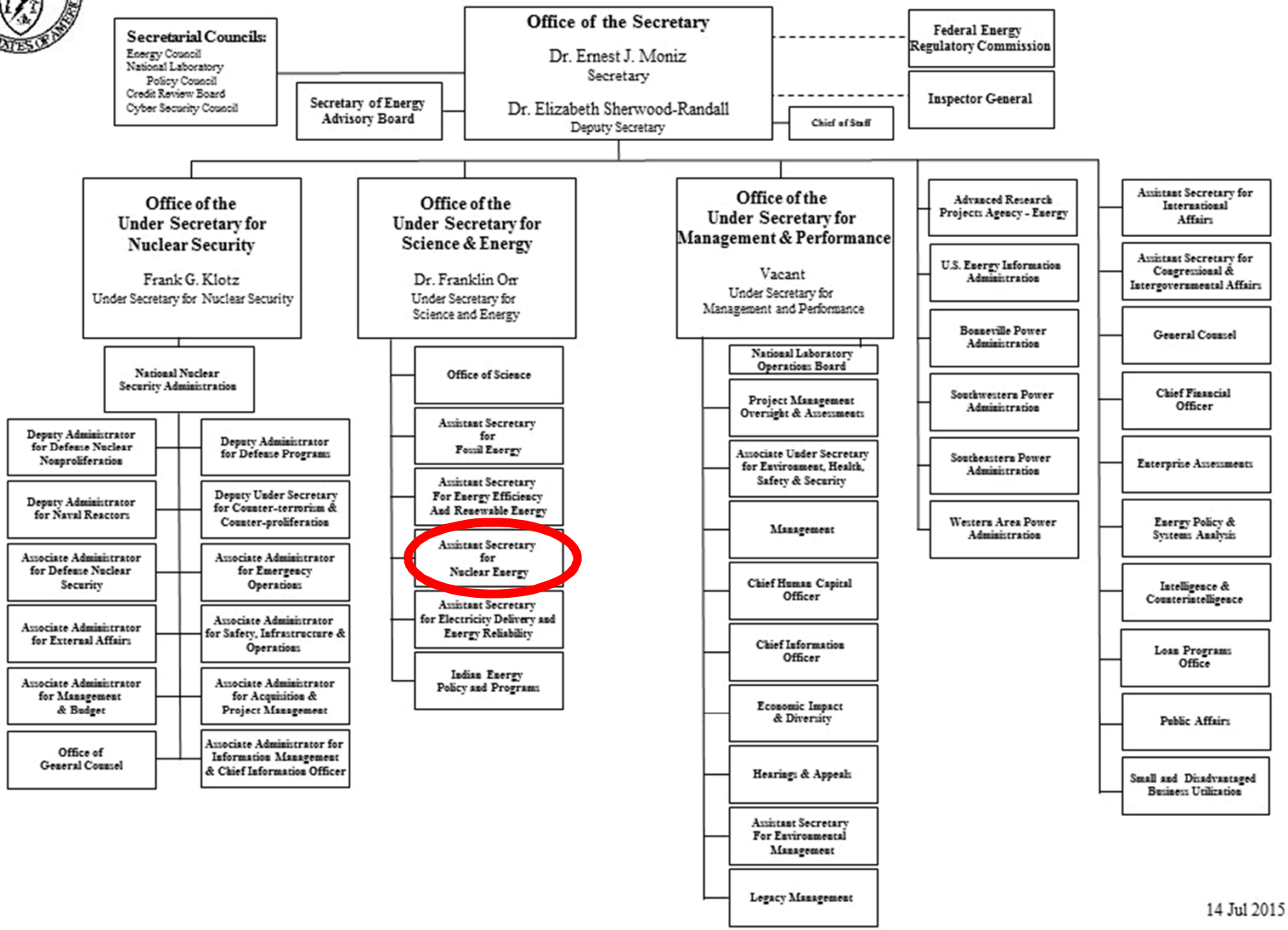
Outline for this presentation

I. Overview and Background
- *A. Background on USDOE-UFD Structure*
- *B. What is DOE-Managed Nuclear Waste? Separate Repository?*
- *C. DOE-Managed Nuclear Waste and its Characteristics*

II. Structure of the DOE-Managed SNH/HLW Research Program
- *A. Overview of each technical area*
  1. *Inventory*
  2. *Design Concepts*
  3. *Organizational and Procedural Frameworks*
  4. *Safety Analysis*
- *B. Integration of technical areas*

III. Conclusions

DEPARTMENT OF ENERGY



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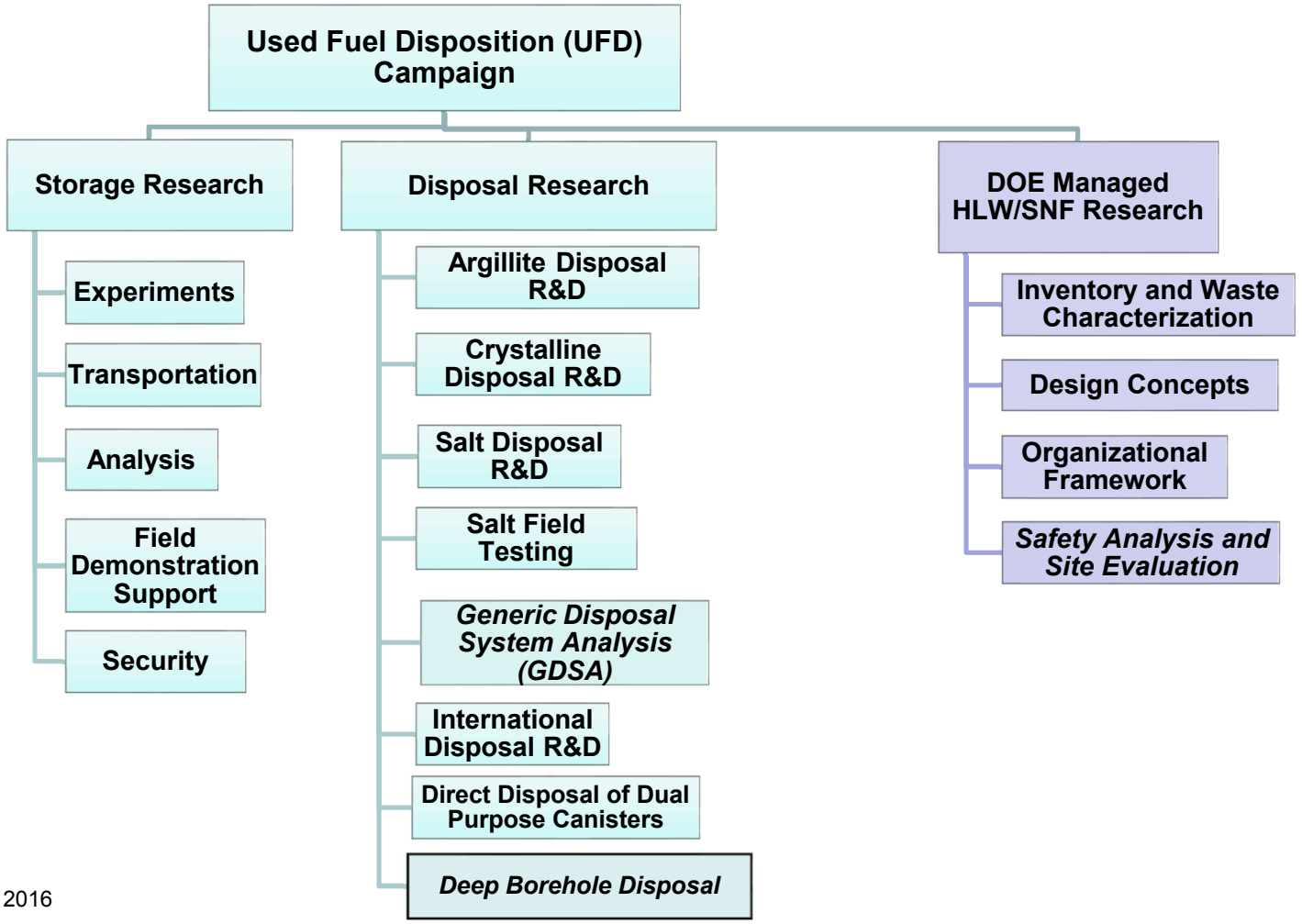
Integration Linkages



The March 24, 2015 Decision

The White House

Office of the Press Secretary

For Immediate Release March 24, 2015

Presidential Memorandum -- Disposal of Defense High-Level Radioactive Waste in a Separate Repository

MEMORANDUM FOR THE SECRETARY OF ENERGY

SUBJECT: Disposal of Defense High-Level Radioactive Waste in a Separate Repository

Your memorandum and accompanying report of January 9, 2015, analyze the factors enumerated in section 8 of the Nuclear Waste Policy Act of 1982 (the "Act") concerning disposal of high-level radioactive waste resulting from atomic energy defense activities, conclude that a strong basis exists to find a separate repository is required pursuant to section 8 of the Act, and recommend that I make this finding.

In accordance with the Act, I find the development of a repository for the disposal of high-level radioactive waste resulting from atomic energy defense activities only is required.

BARACK OBAMA

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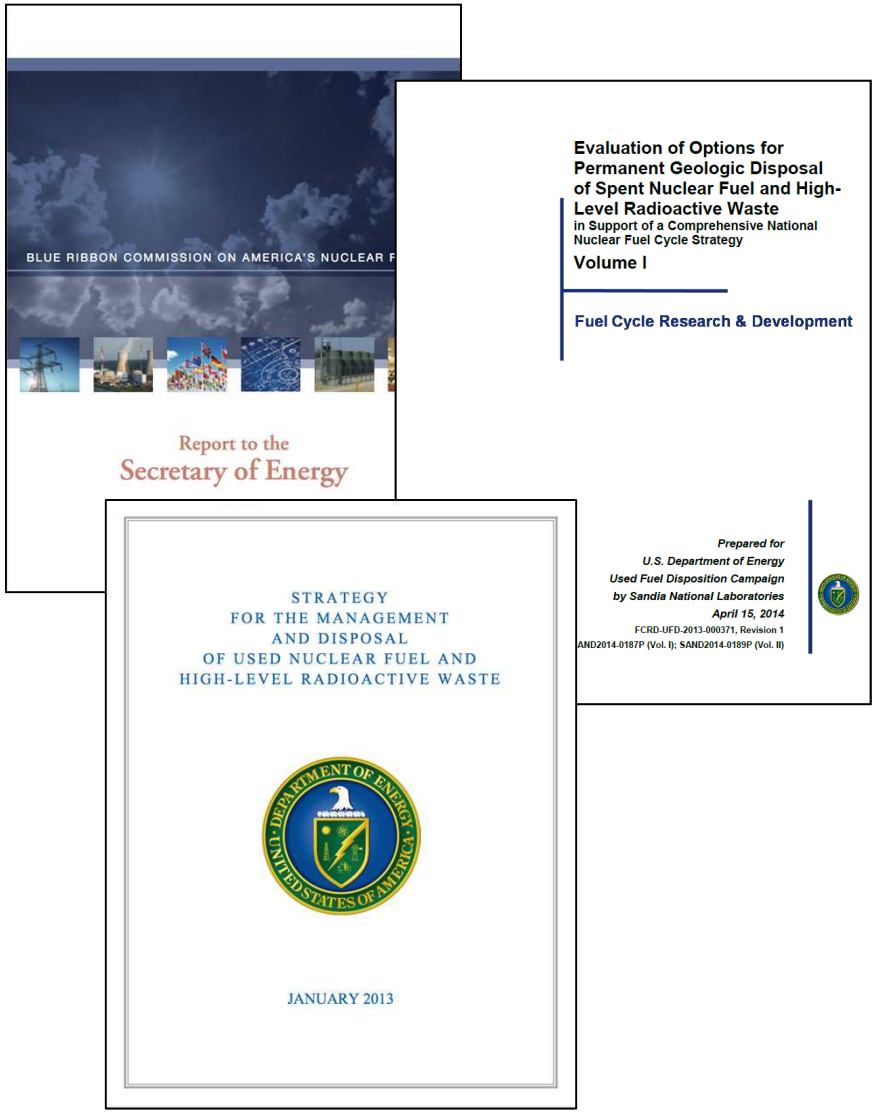
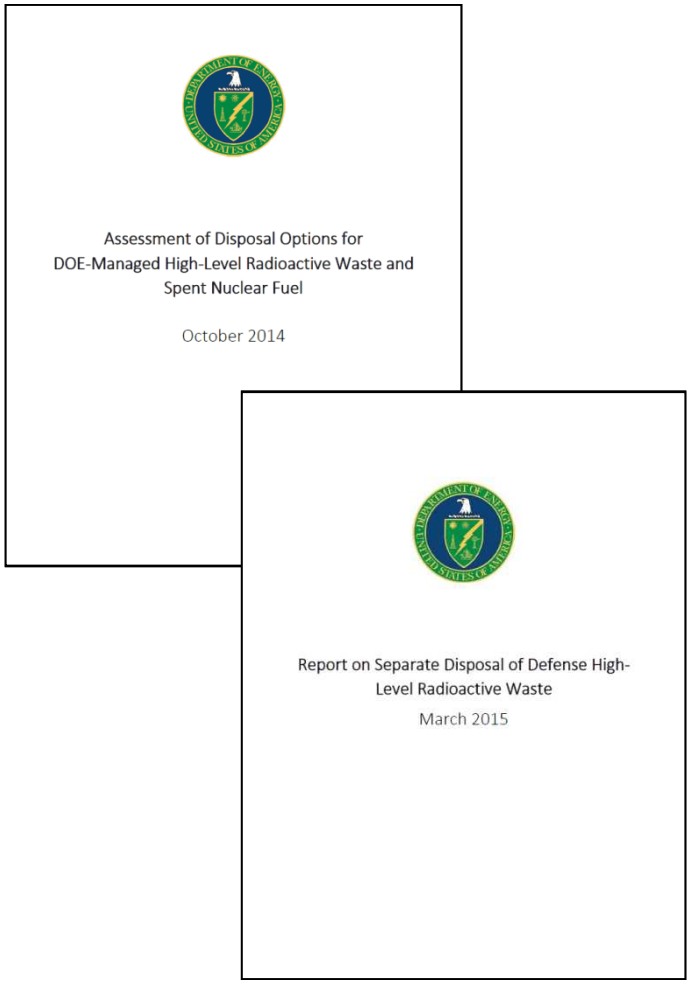
Underlying Documents

- **January 2012 Blue Ribbon Commission (BRC) on America's Nuclear Future report to the Secretary of Energy**
  - *Recommends review of "single repository" policy, whereby defense-related and commercial wastes are co-mingled*
- **2013 Administration releases "Strategy for the Management and Disposal of Used Nuclear and High-Level Radioactive Waste"**
  - *Follows the BRC Report's recommendation to review repository policy*
- **April 2014 UFD report "Evaluation of Options for Disposal…"**
  - *Concludes that both commingled and separate repositories are technically feasible*



Underlying Documents

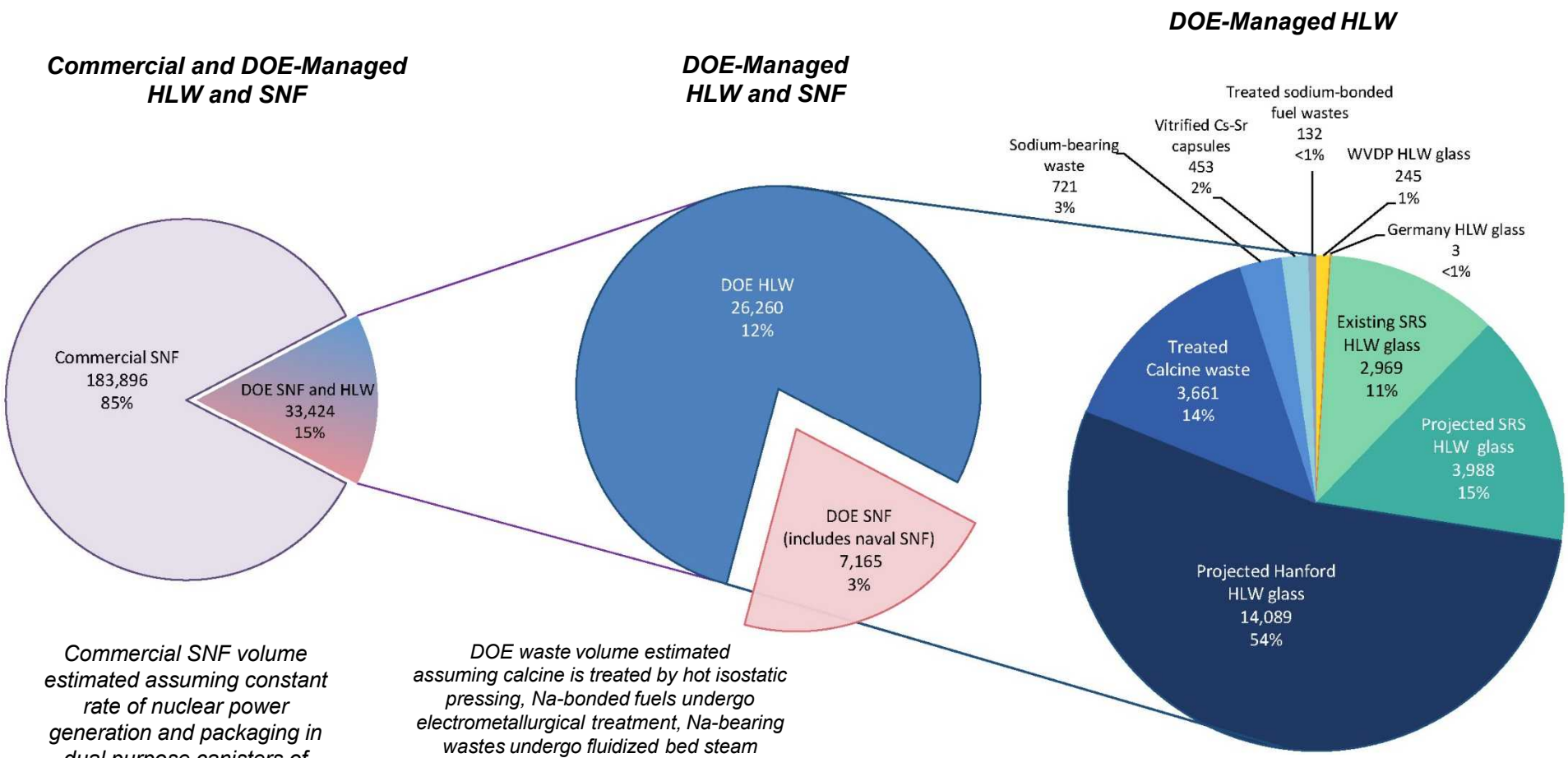
- **October 2014 DOE report "Assessment of Disposal Options…"**
  - Recommends that the DOE begin implementation of a phased, adaptive, and consent-based strategy with development of a separate repository for some DOE-managed HLW and SNF
  - Also recommends the DOE retain flexibility to consider deep borehole disposal of some smaller DOE-managed waste forms
- **March 2015 DOE report "…Separate Disposal of Defense High-Level Radioactive Waste"**
  - Presents the basis for a decision in the context of the Nuclear Waste Policy Act



Used Fuel Disposition

Projected Volumes of HLW and SNF in 2048

Projected volumes in m^3

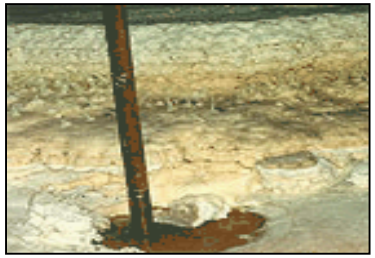


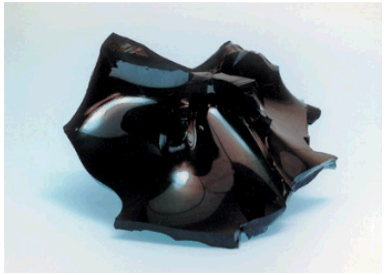
Commercial SNF volume estimated assuming constant rate of nuclear power generation and packaging in dual purpose canisters of existing design

DOE waste volume estimated assuming calcine is treated by hot isostatic pressing, Na-bonded fuels undergo electrometallurgical treatment, Na-bearing wastes undergo fluidized bed steam reforming, and all other HLW wastes are vitrified. Naval SNF estimated as of 2035

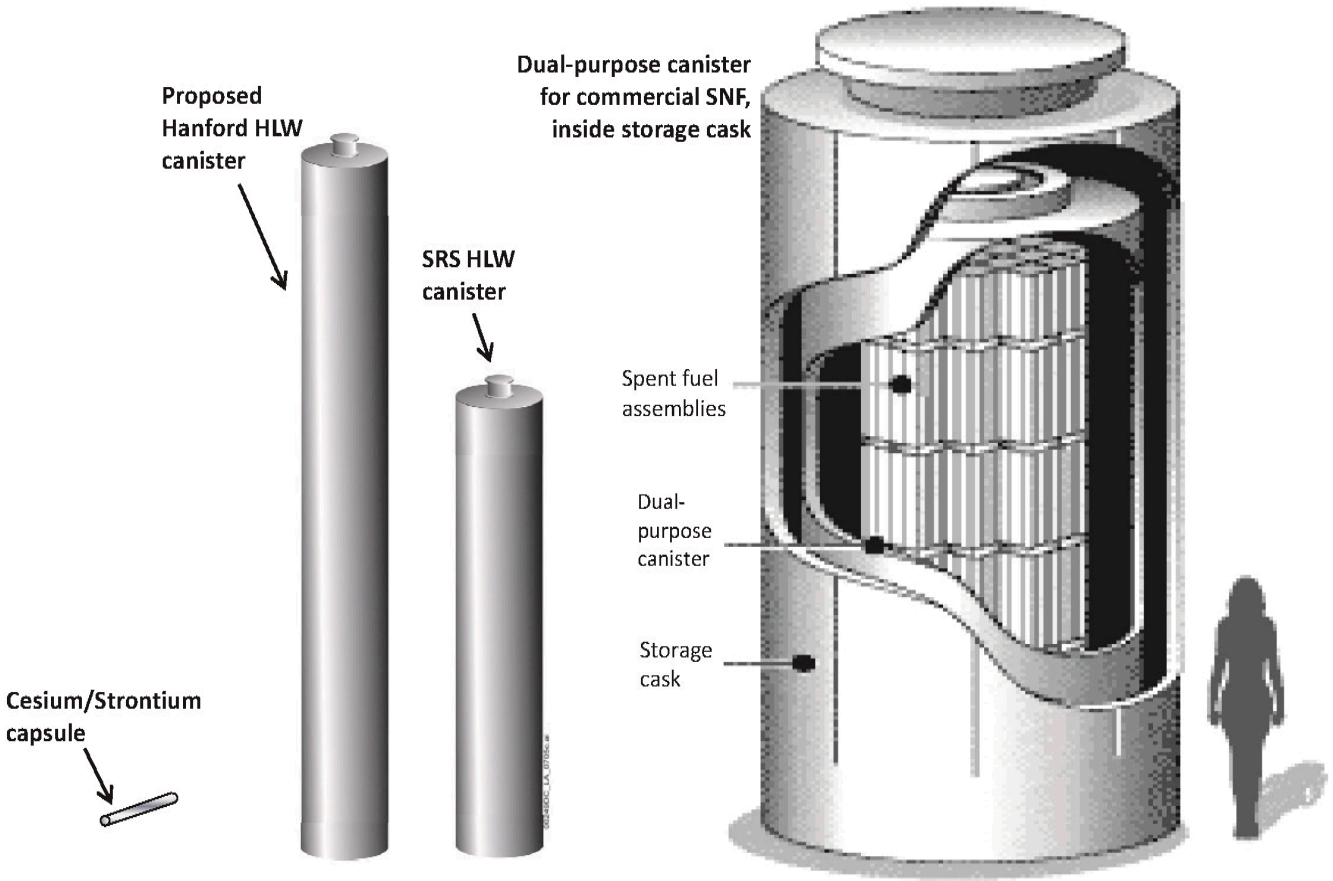
Physical Characteristics of Waste Can be a Factor When Considering Disposal Options

- **Commercial SNF**
  - Essentially all U0x fuel of various types
  - Presently being loaded in large dual-purpose dry storage canisters; *significant thermal management issues*
  - Most repository concepts call for repackaging
- **DOE-managed HLW**
  - Vitrified wastes at Savannah River Site, projected at Hanford and Idaho sites
  - Projected other engineered forms
    - *e.g., electrometallurgical treatment wastes, solids created by hot isostatic pressing of granular calcine at Idaho site*
  - Salts, granular solids, and powders
- **DOE-managed SNF**
  - Metallic and non-oxide SNF
  - Sodium-bonded SNF
  - U and Pu oxide SNF
  - Coated particle SNF
  - Naval SNF





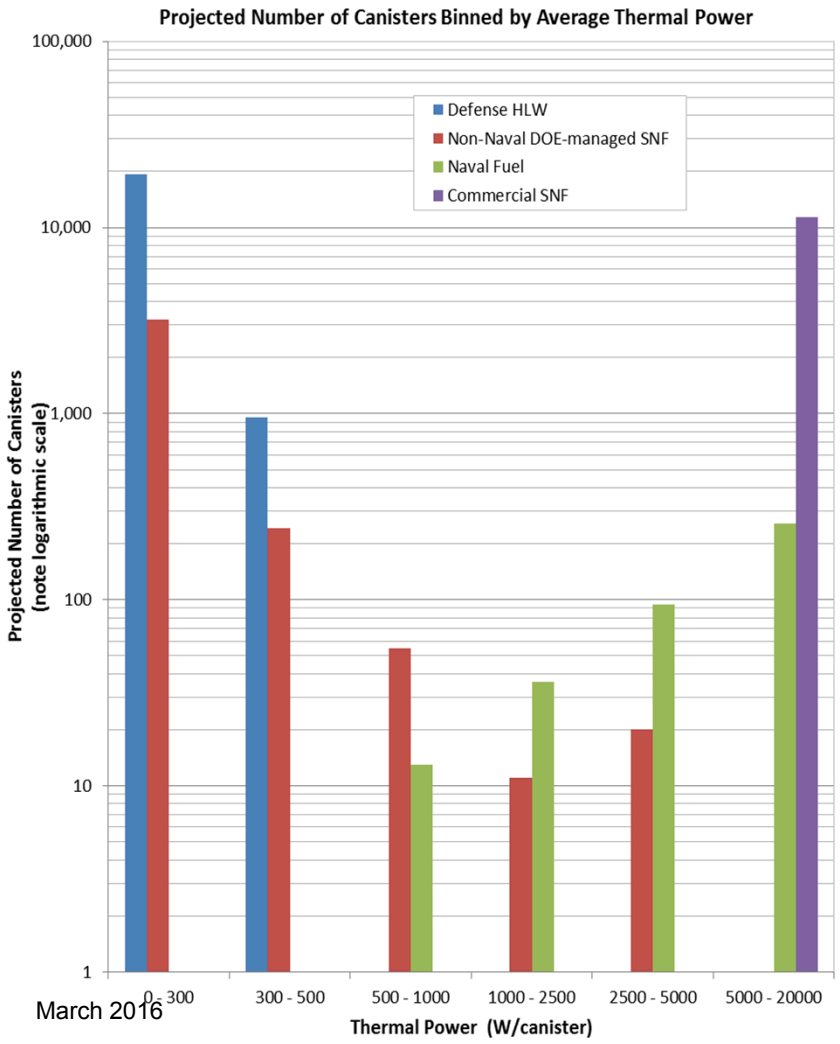
Relative Size of Waste Packaging May Have an Impact on Disposal Options



Approximate Scale

The smallest forms of HLW and SNF that can fit into small diameter canisters could be candidates for deep borehole disposal

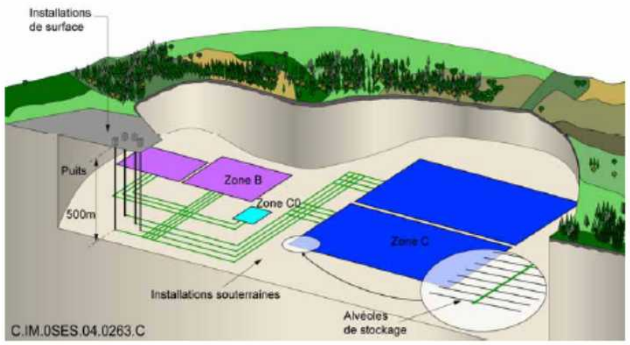
Thermal Characteristics of HLW and SNF Affect Disposal Strategies



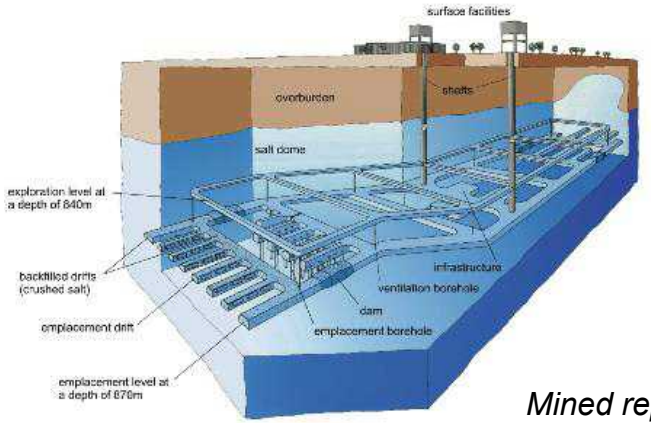
- All defense HLW is relatively cold: less than 500 W per canister
- Most DOE-managed SNF is relatively cold: less than 1000 W per canister
- All commercial SNF has comparatively high thermal output
- Some naval SNF is comparable in thermal power to commercial SNF
- Repository designs and operational concepts can be engineered to address waste form thermal characteristics

Used Fuel Disposition

Disposal Concepts

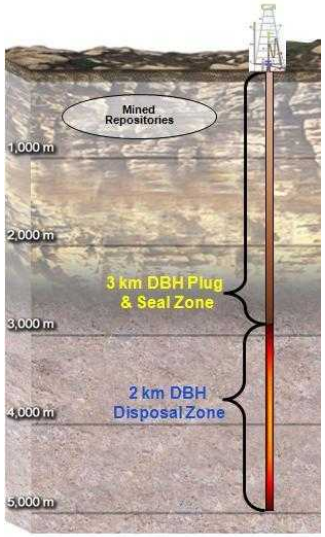


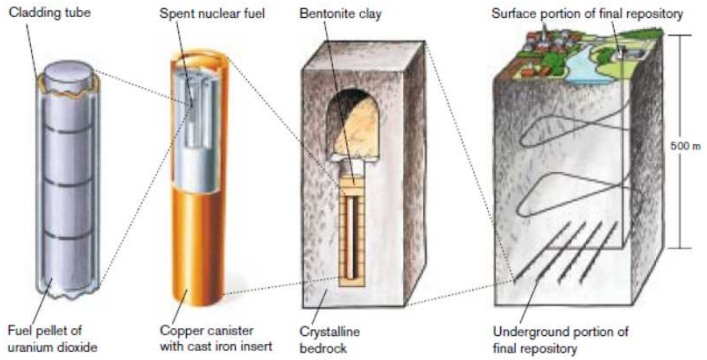
Mined repositories in clay/shale



Mined repositories in salt

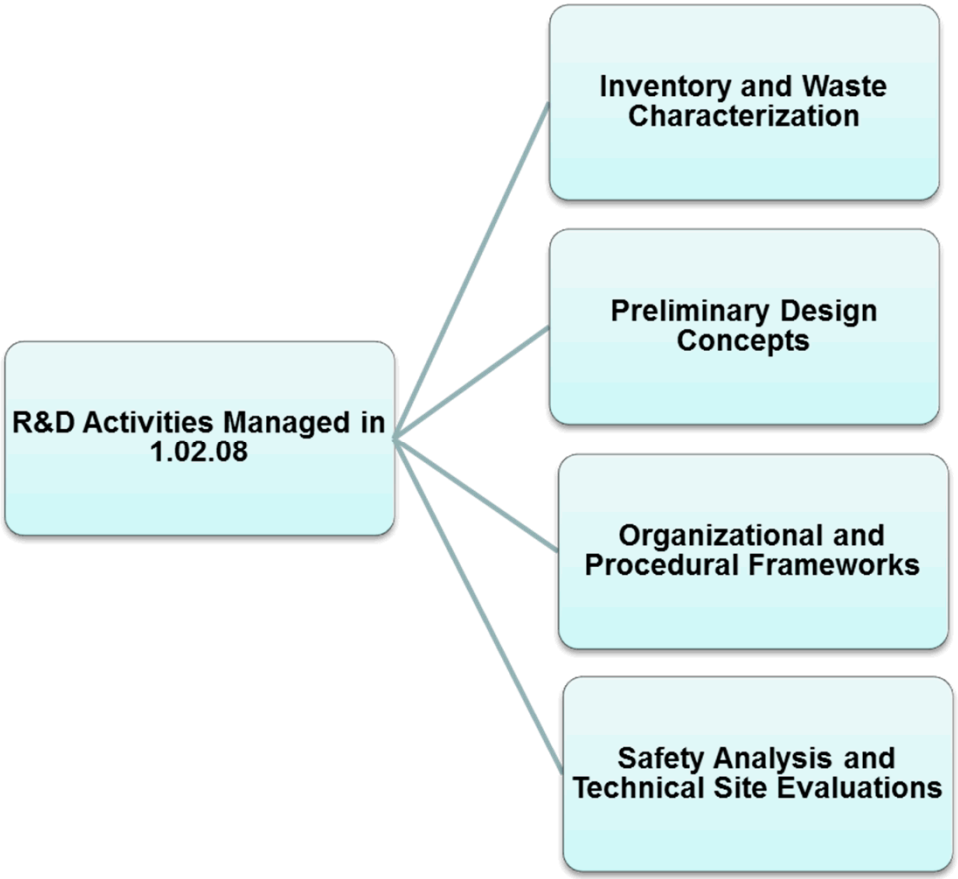
Deep boreholes in crystalline rock



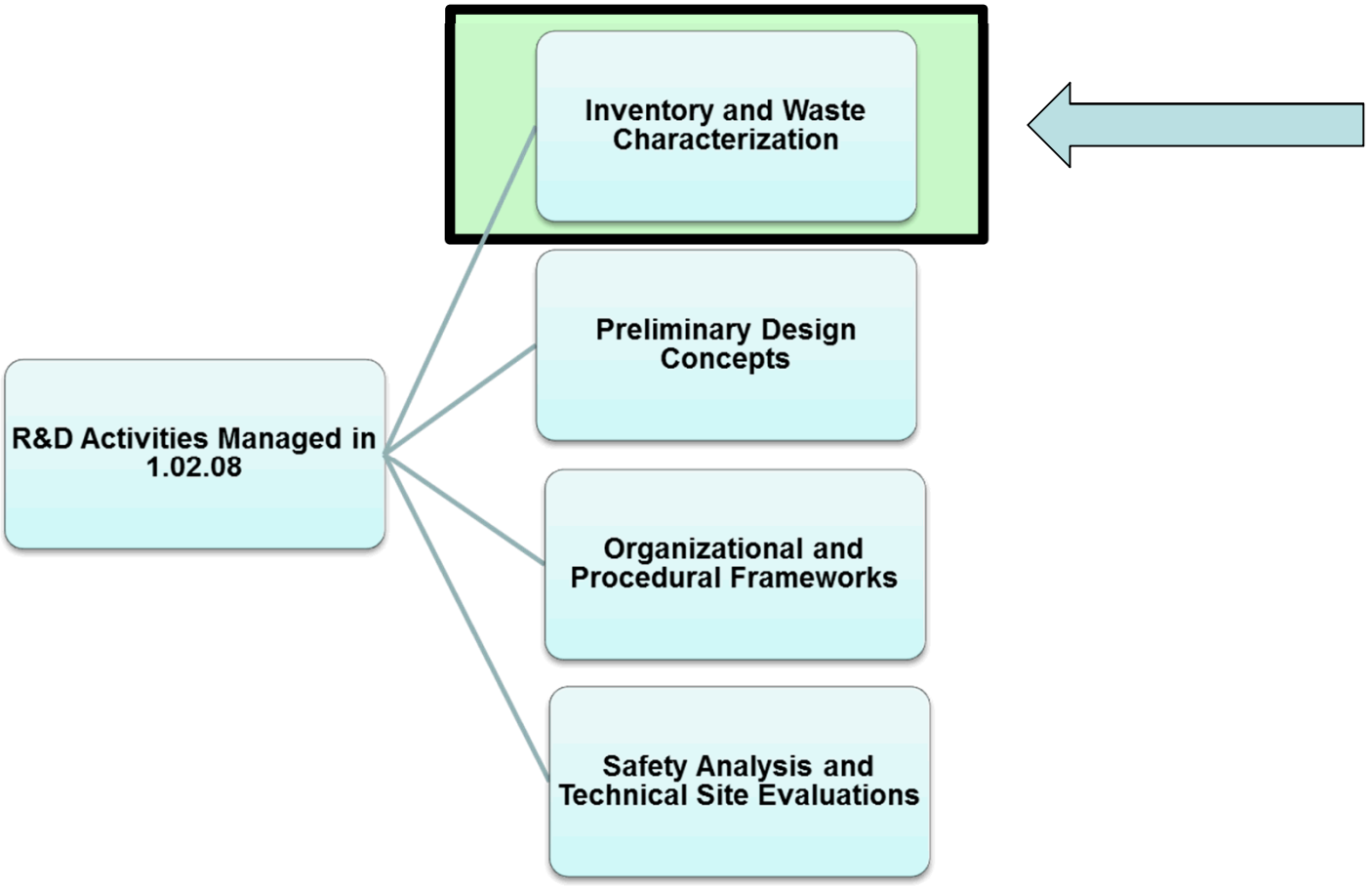


Mined repositories in crystalline rock

Structure of Technical Work Areas



Structure of Technical Work Areas



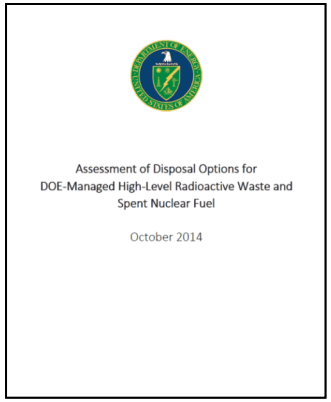
DOE Managed HLW and SNF Research: *Inventory and Waste Characterization*

OBJECTIVE:

Delineate the inventories of waste forms for disposal and their expected behavior in various disposal concepts.

SCOPE:

- **Organize and coordinate information on both waste forms** to be disposed and repository concepts for disposal to inform safety assessments (WP1)
- **Develop a listing and inventory of DOE-managed HLW and SNF radioactive wastes** which were assessed in the disposal options evaluation work and identify any additional waste forms to be added (WP2)
- **The on-line waste library (OWL) will be constructed for information on DOE-managed HLW, SNF, and other wastes** that are potential candidates for deep geologic disposal, with links to supporting documents (WP3)
- **Characterize long-term performance of alternative waste forms** (WP4)



Used Fuel Disposition

Inventory and Waste Characterization: Organize Repository Design Assessment Information

SCOPE:

- *Assessing a waste repository for DOE managed high level waste (HLW) and spent nuclear fuel (SNF) (D-wastes) entails information regarding both the waste forms to be disposed therein and the repository concept in which disposal would be implemented. Both of these aspects will be organized and coordinated in this planning package.*

OBJECTIVES:

Update the cross-walk of information needs for D-wastes and potential repository concepts (and design aspects) so that safety assessments of such a disposal option would consider a comprehensive set of possible combinations.

Identify the information/features of various repository concepts which may be different for a D-waste repository vs the same concept that would include CSNF as well.

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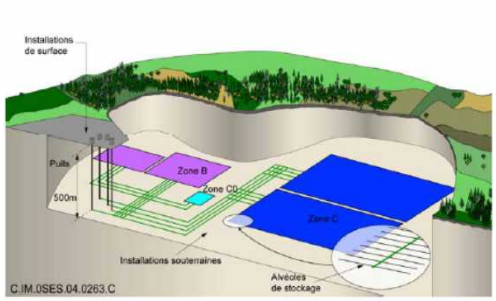
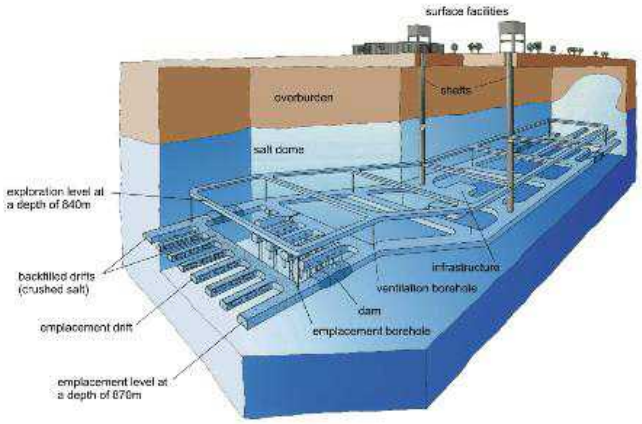
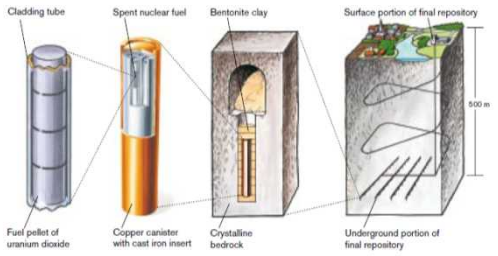


Mined repositories in clay/shale

(from SNL 2014)



Mined repositories in salt



Mined repositories in crystalline rock

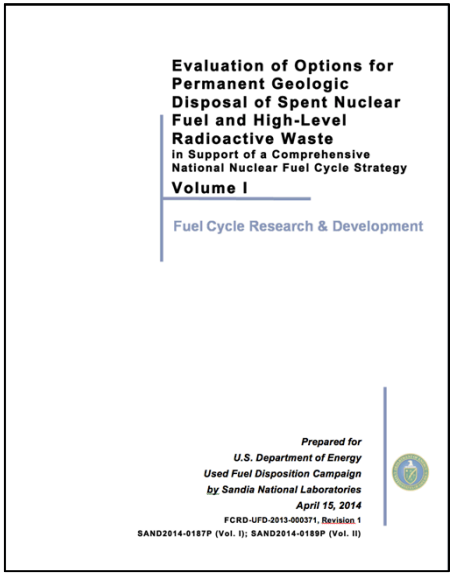
Used Fuel Disposition

Inventory and Waste Characterization: Update inventories for DOE-Managed HLW and SNF

SCOPE:

Identifying, listing, and developing inventories for DOE managed high level waste (HLW) and spent nuclear fuel (SNF) (D-wastes) which were assessed in the disposal options evaluation work (SNL 2014), as well as for any additional D-wastes identified since that previous study.

- *Note that the data in Appendix C, Table C-1 of SNL (2104) represent about 90-95% of the waste types expected to be included (in exclusion of the commercial SNF in that table).*
- *Waste types that do not exist and are not within the identified accepted disposition pathway will not be included in the disposal inventory, however alternate waste forms for waste types that exist, or are defined to exist, would be included.*



OBJECTIVE:

<u>Delineate the full set of D-wastes to be considered for a DOE-managed radioactive waste repository</u>

Identify those with inventory data included in the disposal options evaluation (SNL 2014) and those for which inventory data must be collected and compiled.

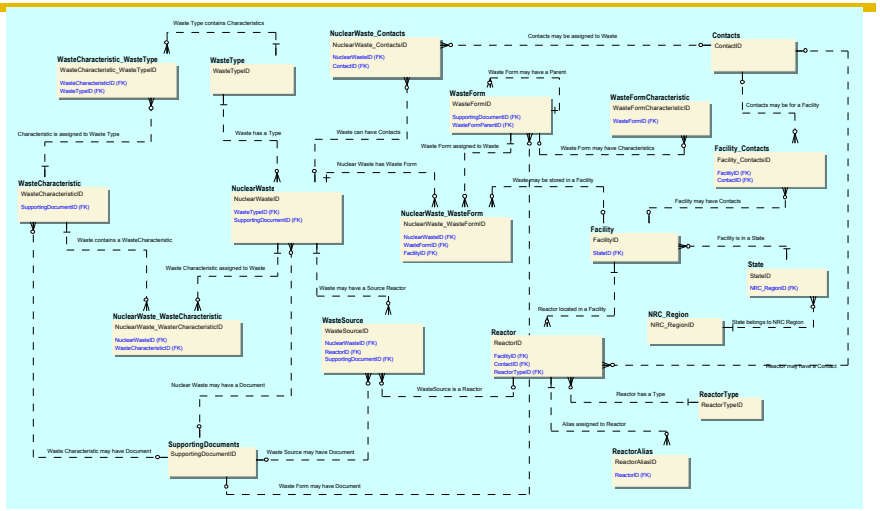
Continue compiling the inventory data for those D-wastes that are beyond the information in the disposal options evaluation.

Used Fuel Disposition

Inventory and Waste Characterization: Complete & Populate Online Waste Library (OWL)

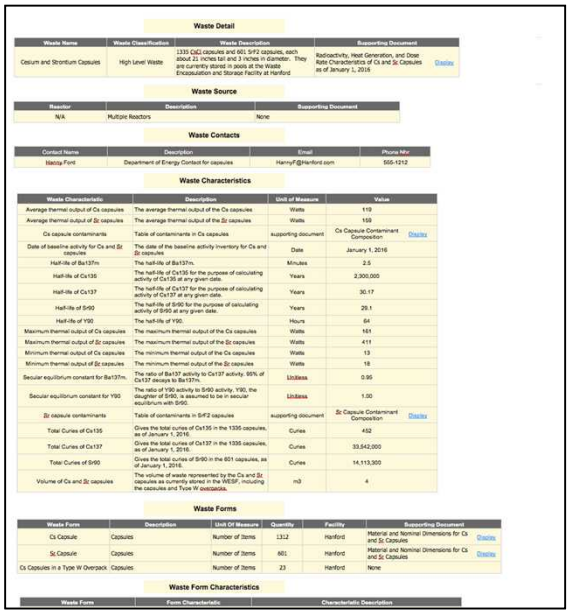
SCOPE:

*The on-line waste library (OWL) will be implemented to contain detailed **cross-linked information**, both **technical** and **organizational**, regarding DOE-managed high-level waste (HLW) and spent nuclear fuel (SNF) (D-wastes), and other DOE-managed radioactive wastes that are likely candidates for deep geologic disposal, with **links to the current supporting documents** for the data (where possible).*



OBJECTIVES:

- *Finalize the initial design of the information system that implements the database*
- *Implement the database onto a platform with account access available to a prototype group (i.e., DOE and National Laboratory participants)*
- *Populate the database with at least a portion of the primary technical data for the waste types/forms.*



Inventory and Waste Characterization: Characterize Alternative Waste Forms Long-term Performance

SCOPE:

Characterization of the long-term performance of alternative waste forms (WF)
that are likely candidates for deep geologic disposal in a repository for DOE-managed high-level waste (HLW) and spent nuclear fuel (SNF) (D-Wastes).

Such information on expected WF degradation rates would be used to constrain in part the source-term of the various waste forms in safety assessments of a D-repository.

OBJECTIVES:

Develop a set of constraints (and/or a list of existing gaps in the constraints) for expected degradation behavior for the suite of waste forms identified for deep geologic disposal in a repository for D-wastes.

This work would include:

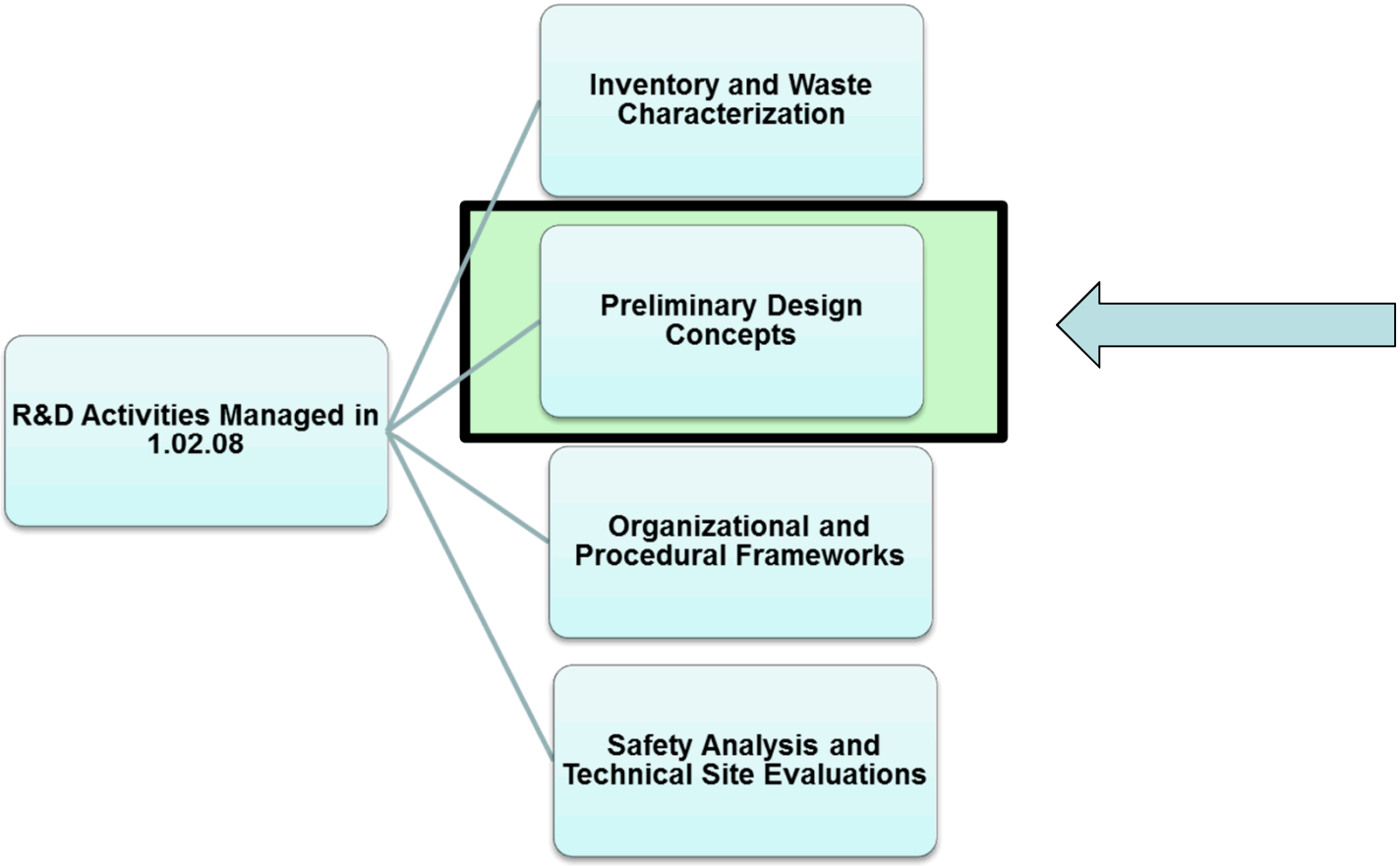
1) *a literature survey, including the Yucca Mountain Safety Analysis Report, to identify existing data/models to define these constraints, including rationale for bounding degradation rate behavior.*
2) *Identification of gaps in the constraints will be used to elucidate a further approach to collect missing data.*

Inventory and Waste Characterization: Waste Form Groups

Waste group	Description
WG1	All commercial SNF packaged in purpose-built disposal containers
WG2	All commercial SNF packaged in dual-purpose canisters of existing design
WG3	**All vitrified HLW (all types of HLW glass, existing and projected, canistered)**
WG4	**Other engineered waste forms**
WG5	**Metallic and non-oxide DOE spent fuels**
WG6	**Sodium-bonded fuels (driver and blanket), direct disposed[1]**
WG7	**DOE oxide fuels**
WG8	**Salt, granular solids, and powders**
WG9	**Coated-particle spent fuel**
WG10	**Naval fuel**

Table ES-2. Waste group descriptions
Note: it was concluded that insufficient data exist to evaluate direct disposal of sodium-bonded fuels.
[from SNL, 2014]

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**).

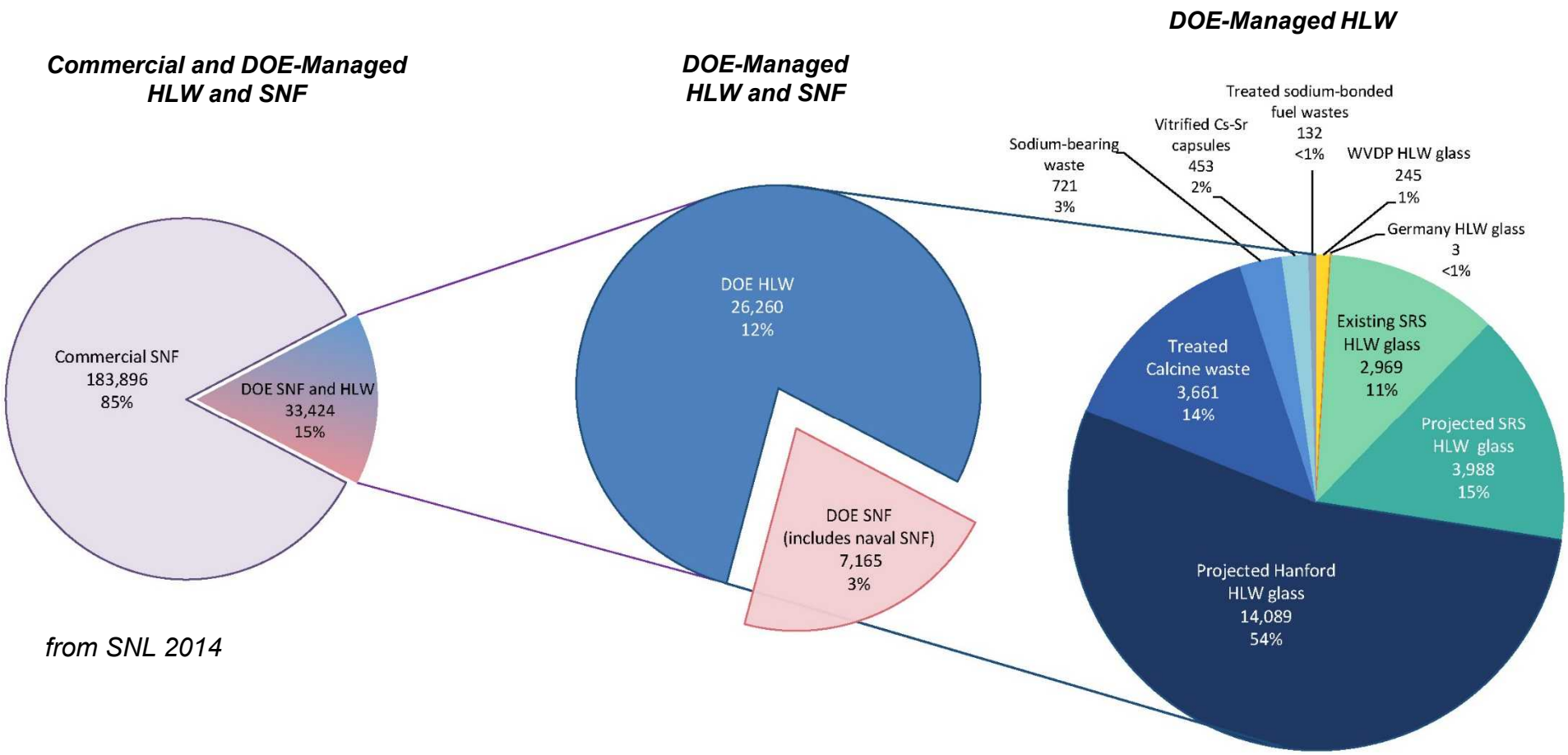
SCOPE:

- 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

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

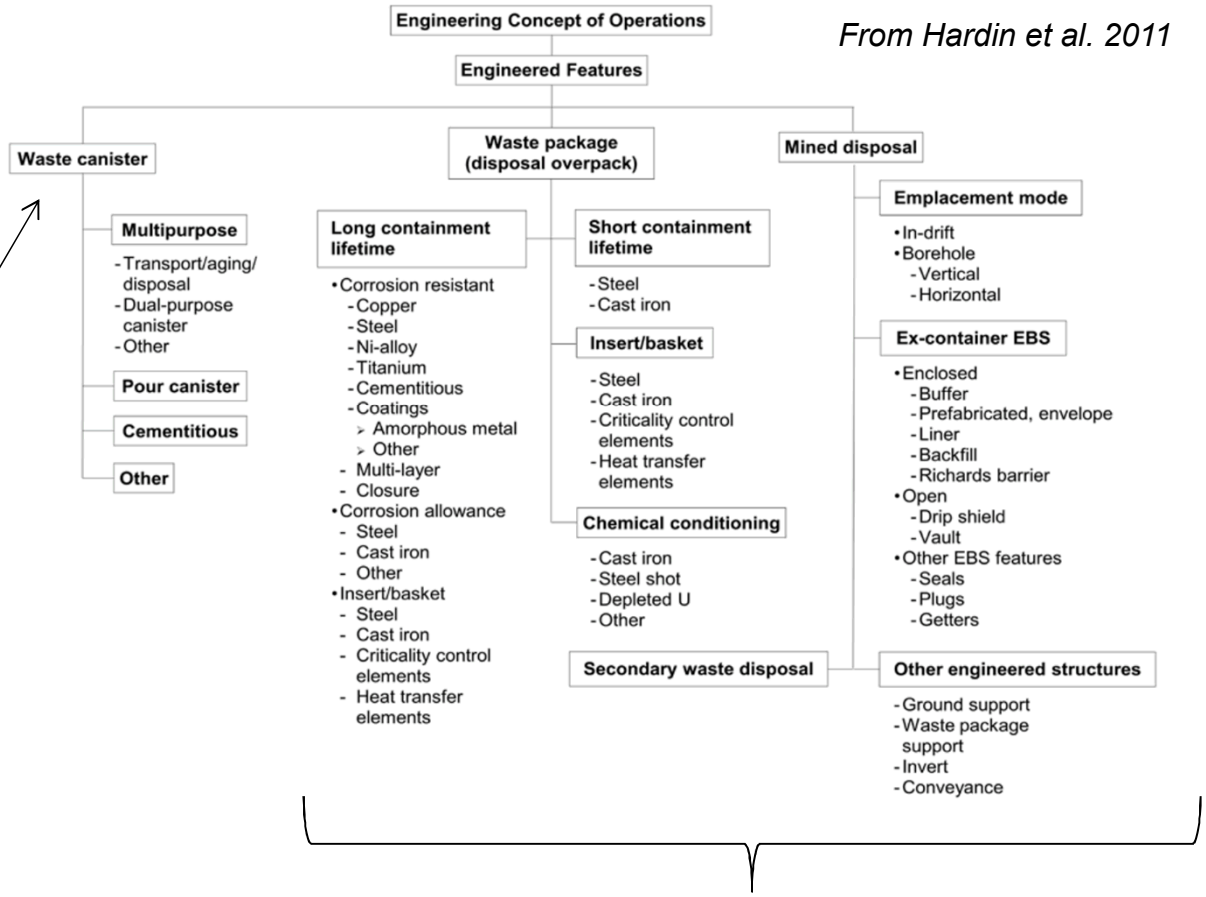
[a] Year 2048, if projected. Thermal output data correspond to thermal output per waste package in the year 2048.
[b] Final configuration not selected. The canisters listed in Table 4 could be disposed of individually or stacked 2 or 3 per container.
[c] Metallic sodium bonded fuels can be processed by electro-metallurgical treatment (EMT) to produce either 1) metal waste and glass-bonded sodalite or 2) metal waste and salt waste.
[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

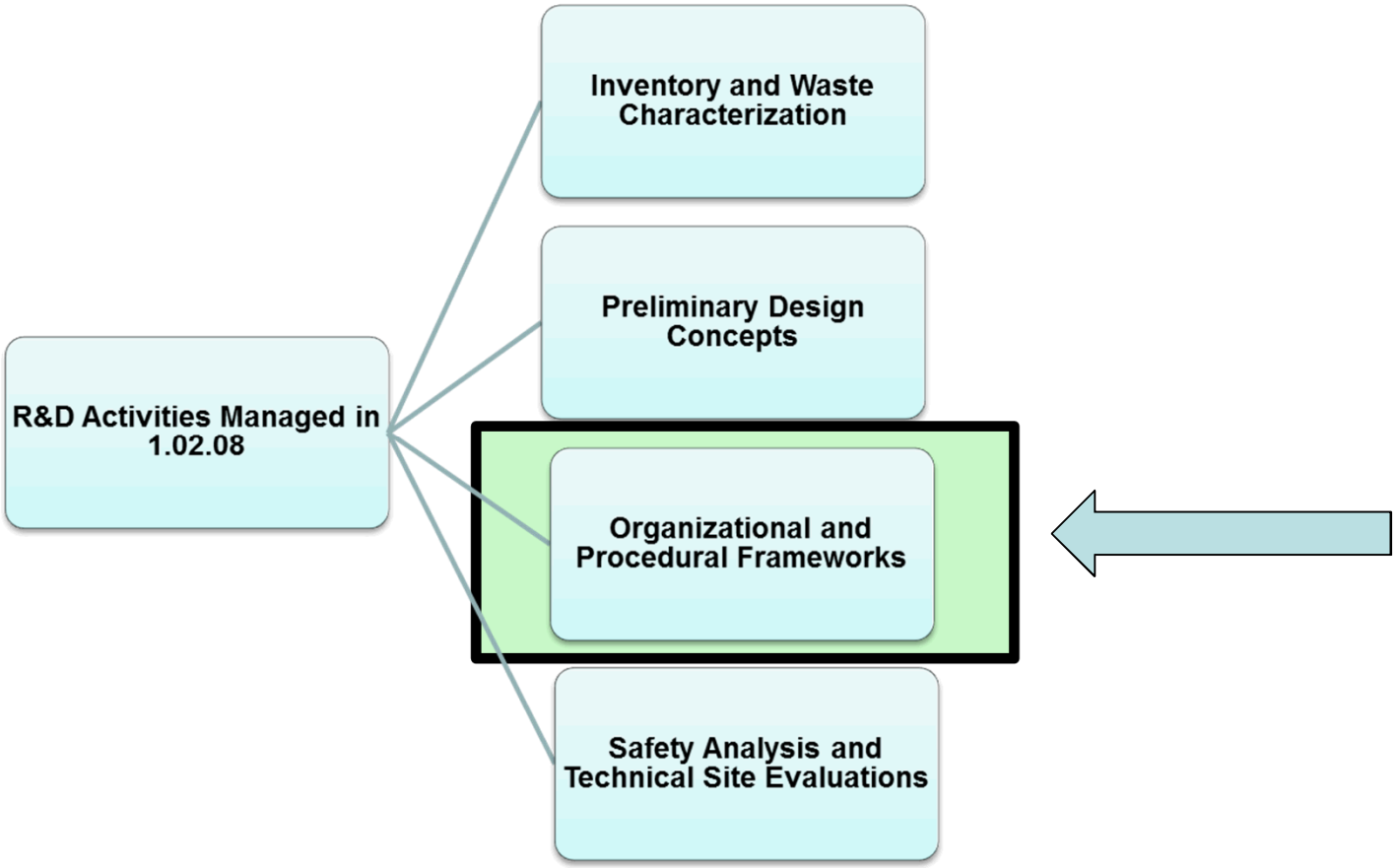
Inventory
- *Dimensions*
- *Quantity*
- *Thermal output*

Design Concepts
- *Packing spacing*

From Hardin et al. 2011



Structure of Technical Work Areas



DOE Managed HLW and SNF Research: *Organizational and Procedural Frameworks*

OBJECTIVES:

Develop generic organizational and procedural frameworks aligned with DOE Managed HLW and SNF licensing efforts.

SCOPE:

- **Identify the principal elements of a generic repository licensing organization infrastructure**

- Identify the principal **operating procedures for a generic repository licensing organization**:
  such as:
  - information management
  - organizational assurance
  - quality assurance

- Identify and initiate regulatory interactions related to **organizational and procedural frameworks**

DOE Managed HLW and SNF Research: *Program Planning*

The Functional Organization

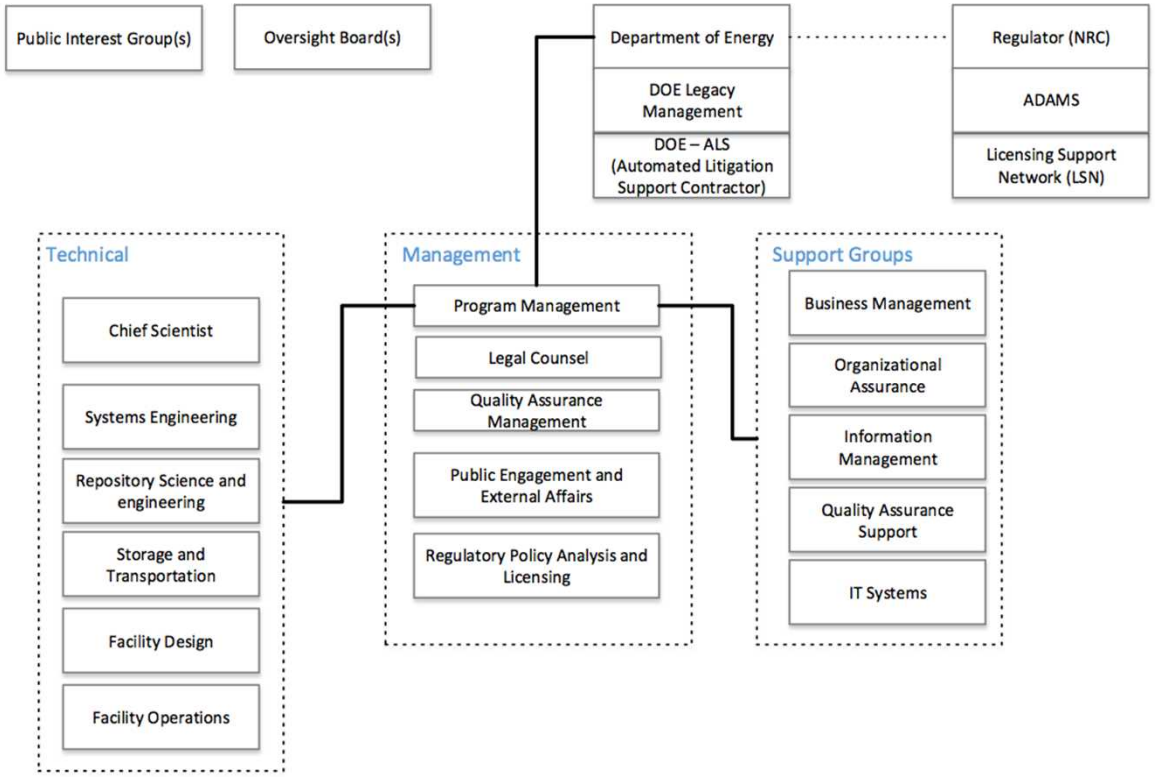
OBJECTIVES:

Develop a Draft Generic Program Plan identifying and summarizing the principle elements necessary for a generic repository program for disposal of DOE managed HLW and Spent Fuel.

SCOPE:

Identify and elaborate on the principle elements of a generic program plan for the disposal, including:

- *system integration*
- *siting*
- *and licensing*



Used Fuel Disposition

DOE Managed HLW and SNF Research: *Establish organizational framework to meet regulator expectations*

OBJECTIVES:

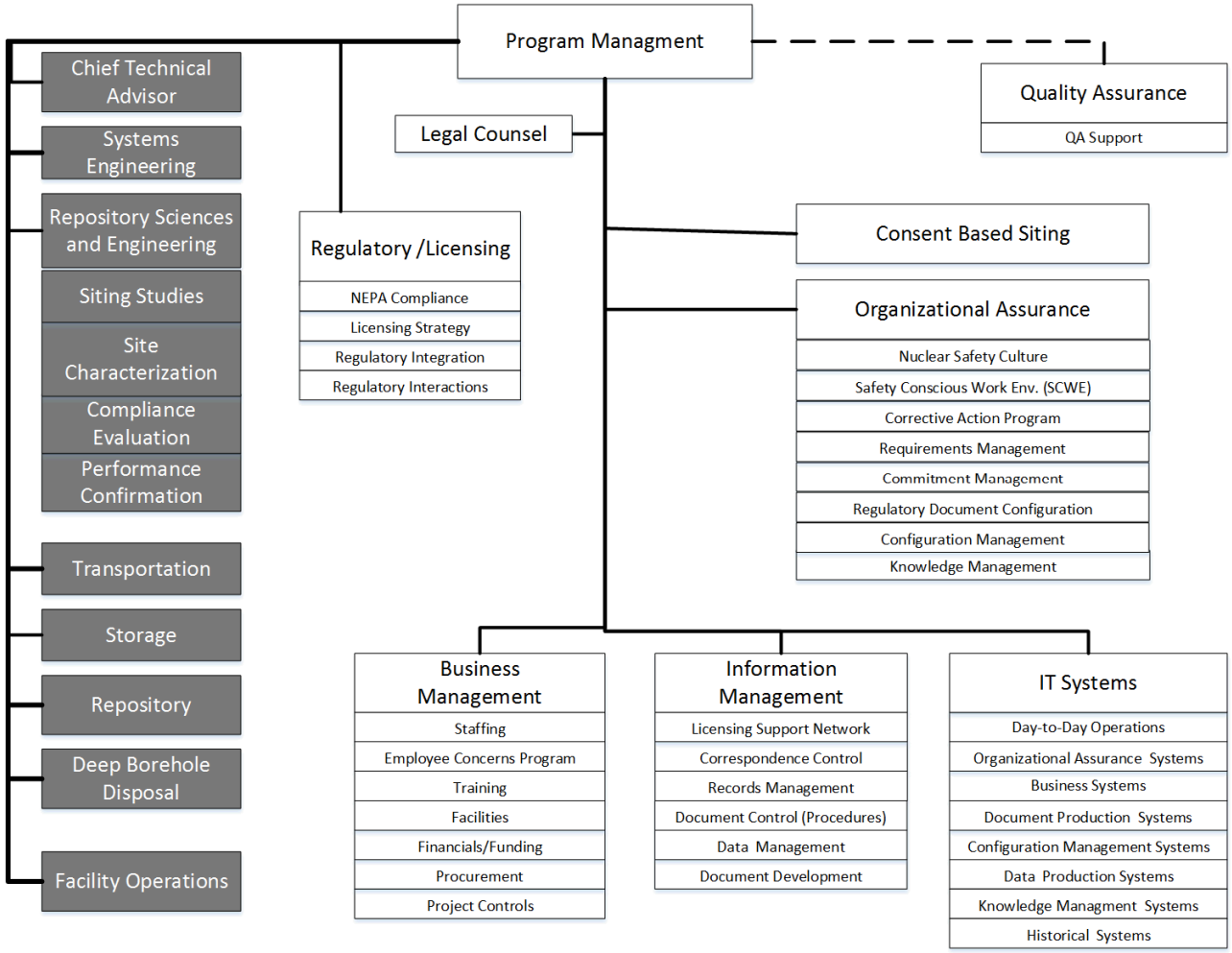
Develop a draft document identifying and summarizing the principle elements of a generic repository licensing infrastructure and organizational framework.

SCOPE:

Identify the principle elements of a generic repository licensing infrastructure such as:

- *information management;*
- *quality assurance;*
- *systems engineering*
- *a supporting IT infrastructure*

Because the task scope is generic, it will not include the specific scientific or engineering elements needed for repository licensing.



DOE Managed HLW and SNF Research:
Develop operating procedures

OBJECTIVES:

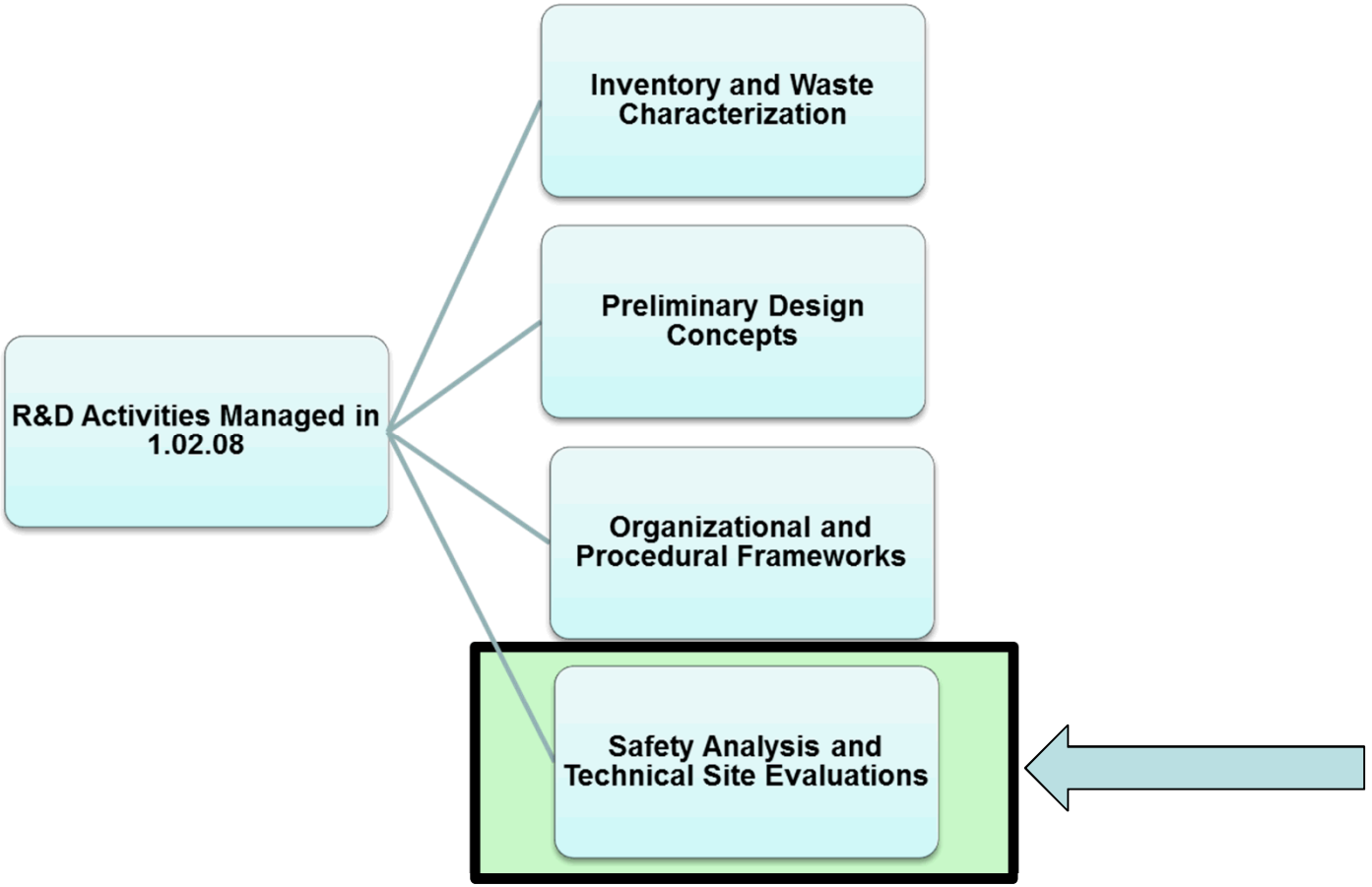
Develop a draft document identifying and summarizing the principle operating procedures for a generic repository licensing organization

SCOPE:

Identify the principle operating procedures for a generic repository licensing organization, such as:

- *information management*
- *organizational assurance*
- *quality assurance*

Structure of Technical Work Areas



DOE Managed HLW and SNF Research: *Safety Analysis and Technical Site Evaluations*

OBJECTIVES:

Establish the safety case associated with select repository sites.

SCOPE:

- Complete reference cases for selected geologic media currently under investigation within the Used Fuel Disposition Campaign (argillite, crystalline, deep borehole and salt). (WP1)
- Perform Features, Events and Processes (FEPS) analyses for the selected geologic media. (WP2)
- Create definitions for generic safety performance objectives. (WP3)
- Evaluate alternative Engineered Barrier Systems (EBS) concepts and provide testing to support the evaluations. (WP4)
- Develop a total systems performance assessment (TSPA) for repositories in selected media. (WP5)
- Develop a technical site evaluation plan. (WP6)
- Perform regional geologic evaluations for technical site selection options. (WP7)

Safety Analysis and Technical Site Evaluations

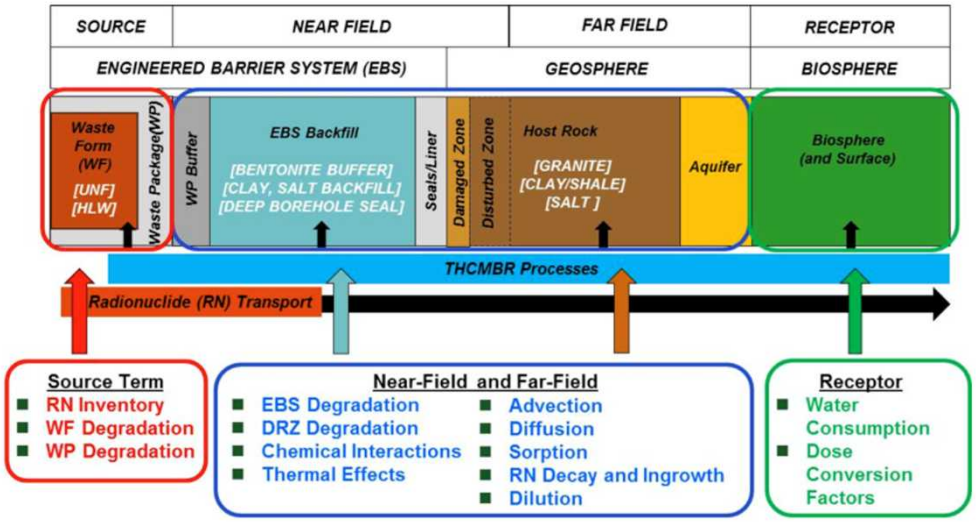
OBJECTIVE:

Establish a safety case and conduct performance assessment.

Work Packages:

WP1: **Perform post-closure Performance Assessment (PA).** Augment reference cases being developed under the GDSA work package for selected geologic media currently under investigation in the Used Fuel Disposition Campaign (salt, argillite, crystalline, and deep borehole).

WP2: **Perform Features, Events and Processes (FEPs) analyses for selected geologic media**, including FEPs related to the EBS design concepts and the waste inventory. Evaluate FEPs that are relevant to safety assessment analyses related to site selection and evaluation for a repository for DOE-managed high level wastes.



Source: Freeze and Vaughn (2012, Figure 2-4)

Safety Analysis and Technical Site Evaluations

WP4: **Define generic post-closure safety performance objectives and metrics**, tailored toward the site-selection and site-evaluation phases of a repository development program.

WP5: **Evaluate alternative Engineered Barrier Systems (EBS) concepts** for selected geologic media, particularly as related to a repository for DOE-managed high level wastes

WP6: **Augment the GDSA performance assessment (PA) model and analyses** developed under as needed, to analyze a repository for DOE-managed waste. As appropriate, perform preliminary deterministic and probabilistic analyses of system performance. Conduct initial sensitivity analyses with the PA model to examine FEPs and input parameters that have an important impact on performance metrics. These FEPs, either natural system or engineered system FEPs, will be candidates for further uncertainty reduction through continued R&D.

WP7: **Develop a technical site-evaluation plan**, which describes the suite of activities necessary to gather the information required for a post-closure safety assessment and to support the safety case. This evaluation plan will specify activities required for sites with little previous geologic information as well as those that may already be well characterized. It will include a review of the existing environmental and regulatory framework that is applicable to siting a repository for the permanent disposal of high-level radioactive waste and spent nuclear fuel from defense and DOE research and development activities.

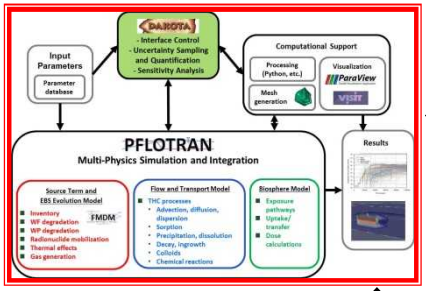
Integration Linkages

Used Fuel Disposition (UFD) Campaign

Storage Research
- Experiments
- Transportation
- Analysis
- Field Demonstration Support
- Security

Disposal Research
- Argillite Disposal R&D
- Crystalline Disposal R&D
- Salt Disposal R&D
- Salt Field Testing
- *Generic Disposal System Analysis (GDSA)*
- International Disposal R&D
- Direct Disposal of Dual Purpose Canisters
- *Deep Borehole Disposal*

DOE Managed HLW/SNF Research
- Inventory and Waste Characterization
- Design Concepts
- Organizational Framework
- *Safety Analysis and Site Evaluation*



Annual Progress for Each Area Summarized in Report Summaries ("Milestones")

- **Inventory and Waste Characterization**
  - The On-line Waste Library (OWL): Usage and Status Report
- **Preliminary Design Concepts for the Inventory in Select Media**
  - Status of Progress Made Toward Preliminary Design Concepts for the Inventory in Select Media for DOE Managed HLW/SNF
- **Organizational and Procedural Frameworks**
  - Draft Program Plan for the Permanent Disposal of High-Level Radioactive Waste and Spent Nuclear Fuel from Defense and Department of Energy Research and Development Activities
  - Generic Organizational and Procedural Framework for DOE Managed HLW and SNF Licensing
- **Safety Analysis and Technical Site Evaluations**
  - Status of Progress Made Toward Safety Analysis and Technical Site Evaluations for DOE Managed HLW and SNF

Conclusions

- **The US is studying the feasibility of a separate nuclear waste repository for DOE-Managed SNF and HLW.**
  - The waste has several distinguishing characteristics:
    - *Comprises ~15% (by volume) of total projected US waste to 2048*
    - *The majority is much thermally cooler than CSNF*
    - *a variety of sources and forms*
  - Generic repository design phase, select media under consideration
    - *(argillite, crystalline, salt, DBH)*
    - *FY16 focus on crystalline and salt*
  - Work commenced FY15 and has continued into FY16
- **The research program includes 4 technical areas:**
  - Inventory and Waste Characterization
  - Design Concepts
  - Program Planning (Organizational and Procedural Frameworks)
  - Safety Analysis
- **Integration between the above technical area and other DOE-UFD programs**

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