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Sandia National Laboratories

Integrating Management of Spent Nuclear Fuel from Generation to Disposal in the United States

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NNSA National Nuclear Security Administration

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Talk discusses interface between societal preferences and noted advantages of consolidated interim storage facility

- Current state of waste management due to interaction between societal preferences and technical challenges
- Consolidated interim storage is path to integrating US waste management system
  - Theme previously acknowledged
- Analysis underway to understand implications of delayed repository and implementing consolidated interim storage facility by Nuclear Fuel Storage and Transportation (NFST) Planning Project
  - Logistical analysis and planning (Joseph et al. and Nutt et al.)
  - Standardization (Jarrell et al. yesterday)
  - Societal perceptions

Road block to disposal in volcanic tuff, revealed lack of integration and flexibility in current US waste management system

- Because of safe at-reactor storage, no urgency but lack of integration and flexibility continues to grown as an issue
- Storage in many varieties of large dual-purpose canisters poses challenges
  - Can be coupled to disposal in unsaturated zone in tuff, in salt, or with other saturated media with extensive ventilation but have long stranded storage for high burnup fuel
  - Other geologic media for repository* without extensive ventilation require long stranded storage or repackaging

**1st repository (or 2nd repository, if can earn consent for Yucca Mountain but may require working on a 2nd repository)*

Advantages of consolidated interim storage facility have been acknowledged

- 1987 DOE Monitored Retrievable Storage (MRS) proposal to Congress
  - an MRS "designed to be an integral component of the waste management system would significantly improve the performance of the system."
- 1987 Nuclear Waste Policy Amendments Act
- 1989 MRS Review Commission
- 2012 Blue Ribbon Commission (BRC) on America's Nuclear Future emphasized interim storage to integrate waste management

1987 NWPAA noted potentially increased reliability and flexibility of waste system

...the Secretary shall consider the extent to which siting a monitored retrievable storage facility at each site surveyed would—

1. **enhance the reliability and flexibility of the system for the disposal of spent nuclear fuel and high-level radioactive waste established under this Act...**

1989 MRS Review Commission noted several advantages of consolidated storage facility

- Provide storage for emergencies at reactors
- Provide more efficient storage and safety compared to at-reactor storage
- Provide storage of stranded CSNF
- Lower costs if repository delayed much beyond 2013
- Provide greater redundancy in the waste management system
- Offer buffer capacity for the repository
- Provide flexibility in the system
- Assist in standardization
- Fulfill federal responsibility for taking possession of CNSF
- Provide experience in siting and licensing

BRC emphasized interim storage as part of an integrated waste management system

- Consolidated Storage would…
  - Allow for the removal of stranded spent fuel from shutdown reactor sites
  - Enable the federal government to begin meeting waste acceptance obligations
  - Provide flexibility to respond to lessons learned from Fukushima and other events
  - Support the repository program
  - Provide options for increased flexibility and efficiency in storage and future waste handling functions

Interim Storage Facility couples disparate at-reactor storage with future repository

- Flexibly adapts to operating schedules and numbers of reactors and construction schedules and numbers of repositories (MRS, BRC)
- Provides buffer in system for emergencies at reactors (MRS)
- Support of repository program (BRC)
  - Allows time for large DPCs to cool without stranding SNF at former reactor sites
  - Eases preparation of CSNF for disposal (survey)
- Reduces complications from extreme events such as flooding and terrorists (BRC) (survey)
- Eases aging management requirements (e.g., inspections)
- Eases repackaging CSNF if problems occur (survey)

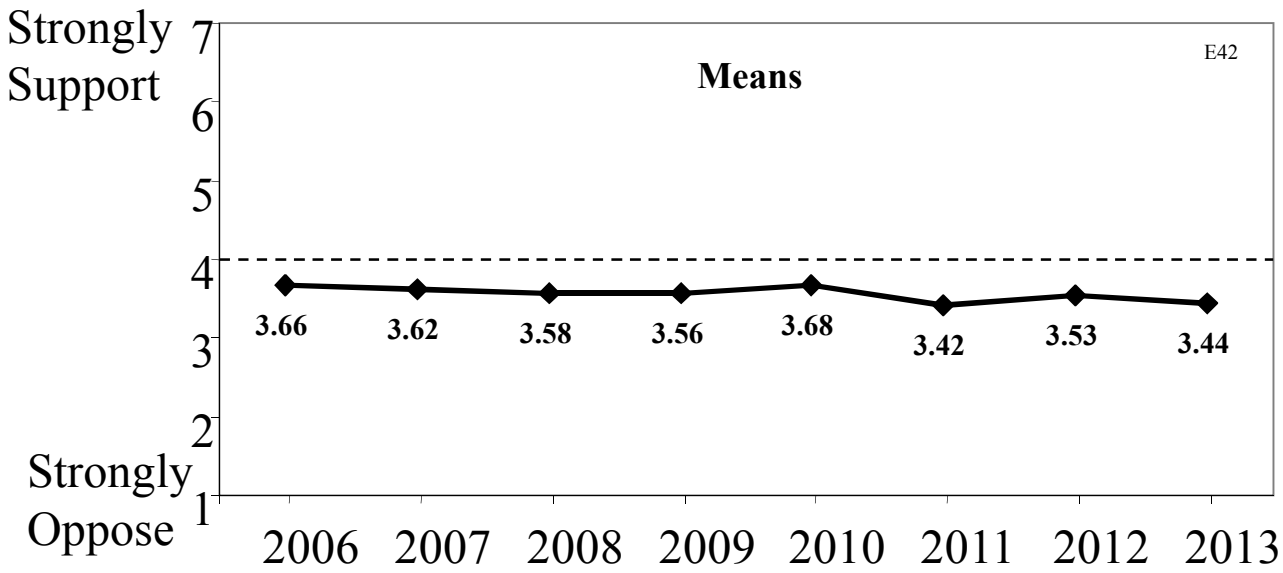
Addition benefits if consolidated storage constructed separate from and sooner than repository

- Early federal ownership of CSNF (MRS, BRC)
- Removes stranded CSNF (MRS, BRC) (survey)
- Learn from early implementation of consent-based siting (MRS, BRC)
- Early learning from licensing and facilitation of uniform licensing approaches to storage and disposal (MRS)
- Reduce long-term costs of storage (MRS, BRC) (survey)
- Facilitate integration of storage and disposal costs (return to “polluter pay” approach)
- Early initiation of transportation planning and indirect benefits of interactions with stakeholders
- Early preparation of CSNF for disposal
- Early release of reactor property to other uses (survey)

Although sound arguments, interim storage facility has not been implemented in US

- Governor of Wyoming not convinced Congress was committed to implementing consolidated storage under Waste Negotiator process for volunteer siting
- Can always point to "politics" as simplistic reason but what are the root causes for this impression?
  - Cannot continue to label "politics" as something that is a black box when it continues to cause system failure
- What are the public impressions of consolidated storage and the reasons for implementing it?

When informed of situation in survey, public uncomfortable with at-reactor storage



2006–2013

Support: –6.0 %

- **Mean support consistently below mid-scale**
- **Unease across social and ideological groups**
- **US public open to longer-term solutions**

2012 national survey examined efficacy of 4 general arguments for siting a consolidated storage facility

Only reducing the costs of storing stranded CSNF made a statistical difference in the level of support

	Response				
Rationale (4 groups)	Oppose (1-3)	Unsure (4)	Support (5-7)	Mean	%Δ
Base case ISF	22	29	49	4.45	—
+Release land, or	20	28	52	4.45	0.0
+Repack CSNF, or	21	33	46	4.48	+0.6
+Reduce costs	19	24	57	4.68	+5.2

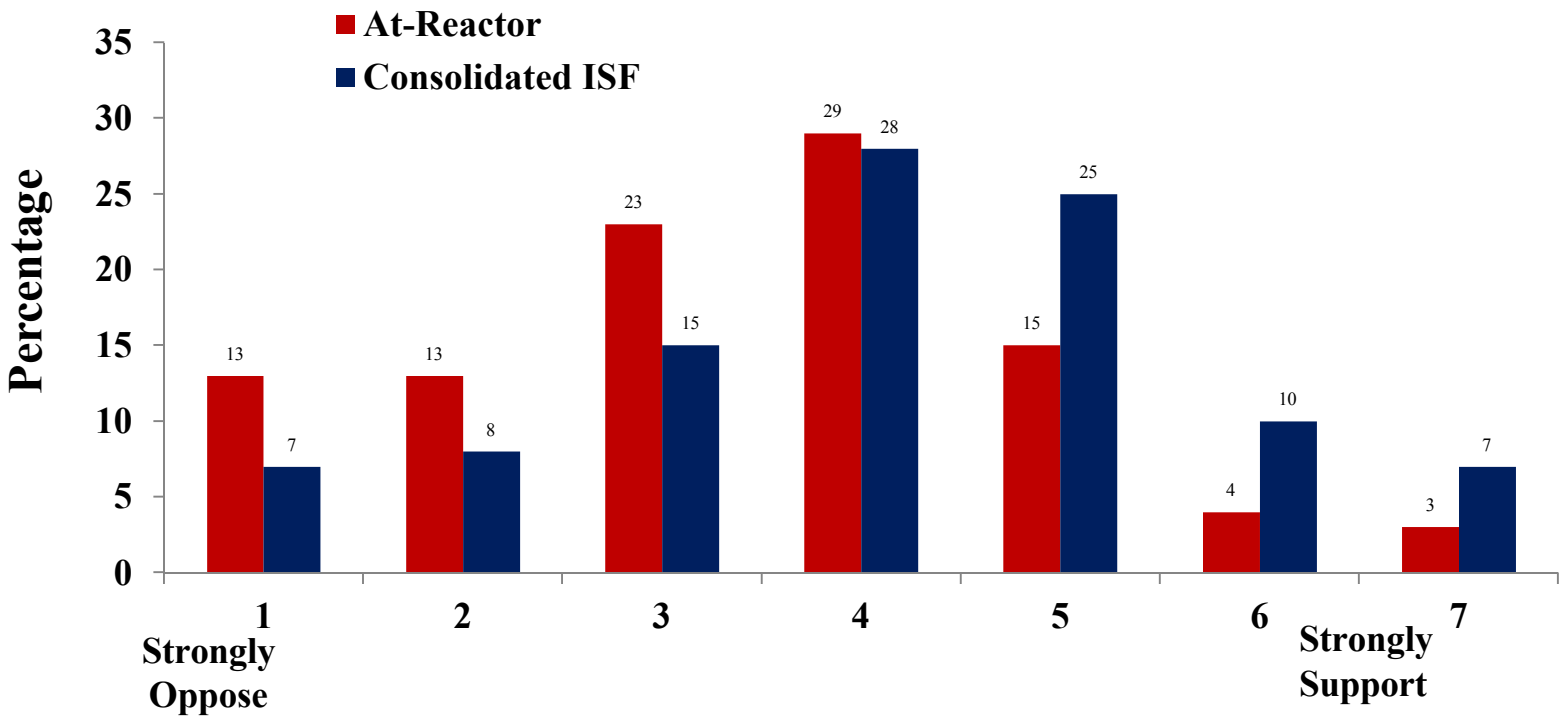
Uneasiness with at-reactor storage and modest support for consolidated storage in 2013 survey

AGAINST

- Postpones long-term solution
- Adds transportation risks
- More costly in short term
- No-harm from current practices

FOR

- Available much sooner
- Consolidates security
- Reduces on-site inventories
- Removes "stranded" fuel



2013 survey presented public competing arguments for and against implementing consolidated storage

Arguments FOR consolidated storage

- ISF can be constructed sooner (within 10-15 yr) to store SNF for up to 100 yr and allow more time to develop repositories.
- ISF consolidates SNF while providing better protection from terrorists and allows CSNF to cool and be packaged for repository.
- ISF reduces SNF stored at reactors, many of which are near large population centers, rivers, and oceans where flooding is possible.
- ISF removes stranded SNF from 10 sites and eventually others where security measures must continue to protect SNF. The savings could partially pay for constructing ISF.

2013 survey presented public competing arguments for and against implementing consolidated storage

Arguments AGAINST consolidated storage

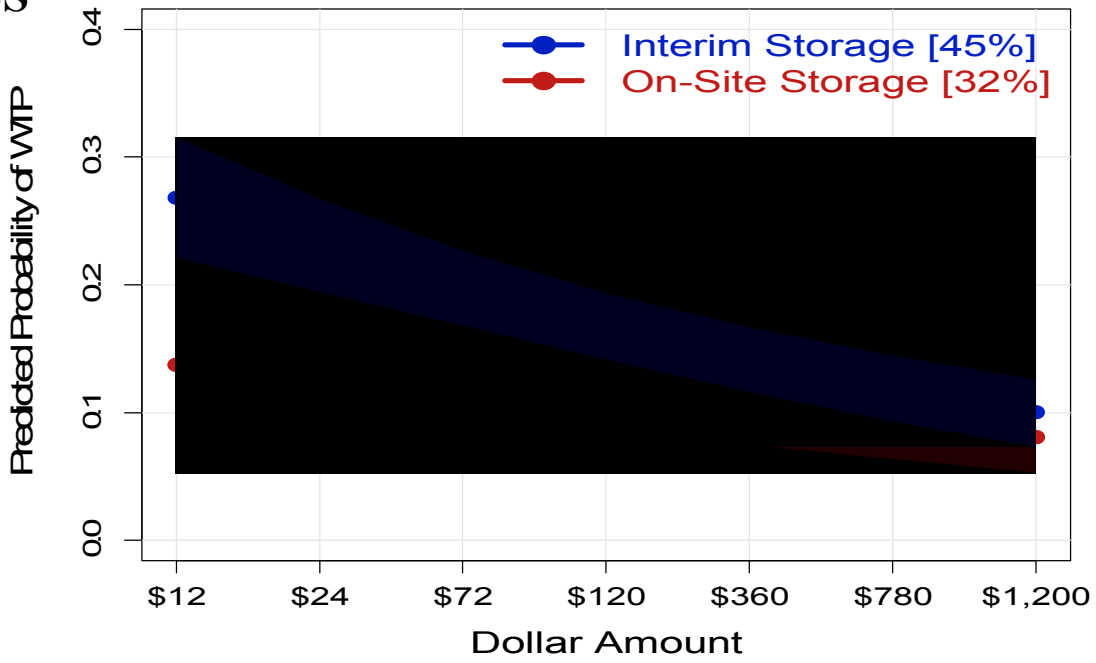
- ISF might delay the more politically difficult construction of repositories, which may take 30 or 40 yr.
- Transporting SNF by barge, train, or truck to ISF is more risky than continuing at-reactor storage.
- Expanding at-reactor storage near *existing* operating plants is cheaper and politically more acceptable than building ISF.
- Public has not been harmed by at-reactor storage; and through many sites are near large population centers, improvements can reduce the risk of terrorist attacks and flooding.

When asked in 2014, public more willing to pay for consolidated interim storage

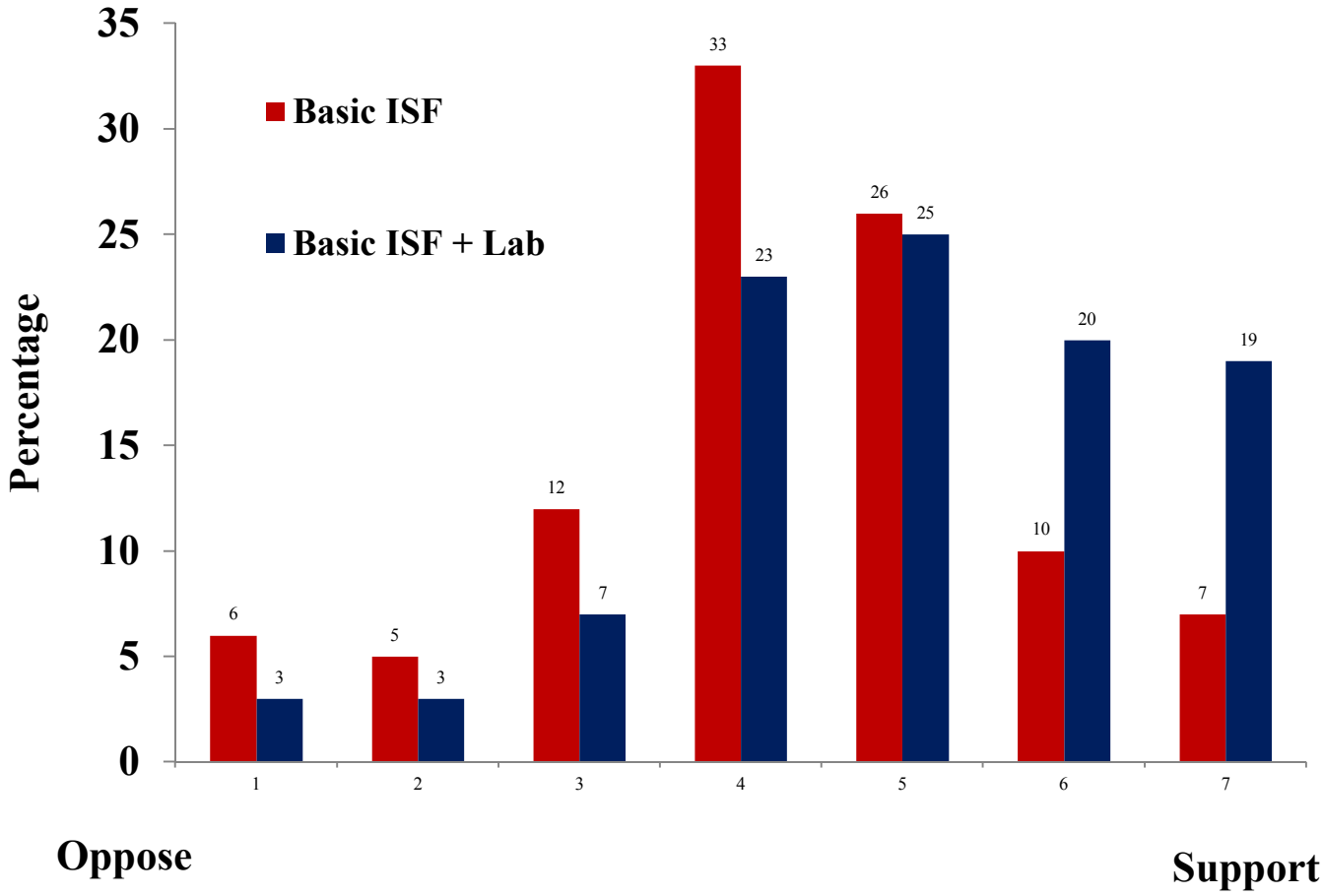
Public first asked to vote for preferred option; for ISF, reminded

- **More expensive in the near term than at-reactor storage**
- **Less expensive in long term than at reactor storage**
- **Less vulnerable to extreme risks such as flooding and terrorist attacks.**
- **More vulnerable risks associated with transporting SNF**

Public then asked their willingness to pay a tax (randomly assigned between $12 and $1200) for their preferred option on scale of 1~definitely NO to 5~definitely YES



Support for siting an ISF increases significantly when a research function for ISF was added



Concern for transportation route as great as concern for siting a consolidated storage facility

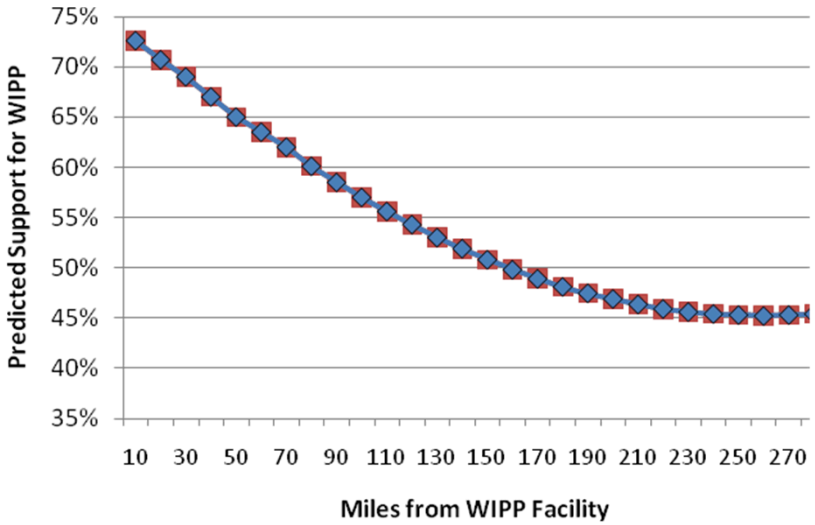
If storage / transportation route for SNF was proposed within 50 miles of your residence, how likely is it that you would …

Likelihood of Activities (1 = Not At All Likely—7 = Extremely Likely)	Interim Storage Means	Transportation Route
Attend informational meetings held by authorities (E75/T)	4.37	4.22
Write or phone your elected representatives (E78S/T)	4.20	4.24
Express your opinion using social media (E77S/T)	3.96	4.02
Serve on a citizens' advisory committee (E81S/T)	3.92	3.91
Help organize public ***support*** (E80S/T)	3.07	3.09
Help organize public ***opposition*** (E79S/T)	3.05	3.10
Speak at a public hearing in your area (E76S/T)	2.97	3.08

Acceptability of transportation influenced by acceptability of consolidated storage

WIPP transportation planning and emergency preparedness key to expanding support

- Expanded support beyond local community
- WIPP implemented training of emergency personnel along truck route
  - Full scale exercises
  - Training accompanied with public announcement and opportunity for press to observe, interview officials, and interview emergency responders



WIPP transportation planning and emergency preparedness key to expanding support

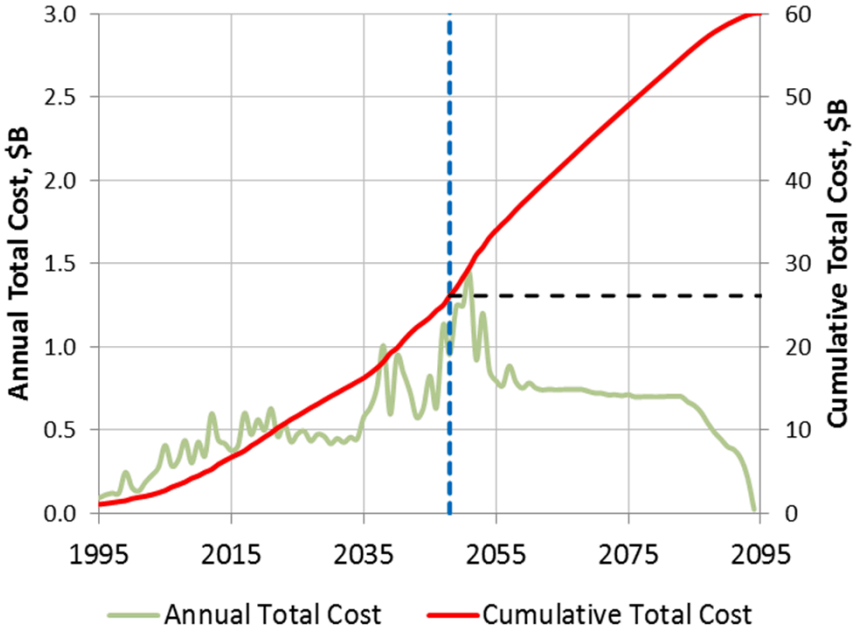
- WIPP used several State groups already in existence
  - Western Governors Association (WGA) to
    - Report on transportation issues
    - Plan safety program
  - National Vehicle Safety Alliance to develop truck inspection program
- Several working groups started, for example
  - Technical Evaluation Committee to develop emergency training materials

20

Stranded SNF storage at shutdown reactors motivation for consolidated storage

- Long term costs of storing SNF at a shutdown reactor are large and provide impetuous for consolidated interim storage facility (or repository if implemented early)
- Prior to 2000, focus of cost comparisons were between
  - at-reactor storage (at operating reactor) then repository disposal and
  - consolidated interim storage then repository disposal
- By 2013, at-reactor storage had been implemented but a repository was far in the future
- By 2013, focus of cost comparisons are between
  - at-reactor storage *followed by stranded storage* then repository disposal and
  - at-reactor storage followed by storage at consolidated interim facility then repository disposal

Cost of storage at reactor followed by stranded storage until alternative available in 2048 is ~$60 in 2095



- Annual cost for storage is 10 times greater at shut down site versus operating site (i.e., ~$1 million/y versus ~$10 million/y)
- Costs increase around 2035 when many reactors shut down
- Transportation costs not included but only 15% of costs of storage

Take away points

- Public uneasy with current at-reactor storage
- Consolidated storage provides integrating function (universal coupler) for current system
  - But using "flexibility" as the primary argument for consolidated storage will be challenging
- Including attributes of research and repackaging to address storage issues increases support
- Transportation presents opportunity to discuss the ISF
- Public understands value of reducing long-term costs but
  - Congress focuses on annual costs (consolidated storage more expensive to implement on short-term)
  - Technically hard to define when transition to long-term cost reduction occurs

Consolidated interim storage is path to integrating US waste management system

Consolidated interim storage facility way for the US waste system to be more flexible to changing situations

- Different repository media, emergency closure of reactor, and temporary closure for repository for upgrades

Advantages of consolidated interim storage facility

- Flexible siting criteria by implementing schemes to lower thermal output
  - Buffer storage for hot canisters, or
  - Mixing SNF fuel in disposal canister
  - Re-packaging of DPCs
- Ease burden of aging inspections at shutdown sites and operating sites
- Accommodate shipment of bare fuel currently in wet storage
- Same organization responsible for storage and disposal
  - Current scheme uses utilities for storage and federal government for disposal

Licensing of storage is deterministic and rule-based in US

- Wet storage licensed as part of reactor operations
  - Reactor license for up to 60 y, with 20 y renewal
  - 10 CFR 50
- Dry storage licensed separately
  - 69 Independent Spent Fuel Storage Installations (ISFSI) in 2013
  - Licensed up to 40 y with up to 40 y extensions
  - 10 CFR 72
- 2 types of ISFSI licenses
  - 54 General licenses
    - Co-located with operating reactor
    - 3.5 y to complete application
  - 15 Site-specific licenses
    - Separate from reactor or reactor is shut down
    - 6 y to complete application

Several types of ISFSI designs in US

- Vertical below ground
- Horizontal bunker
- Vertical (most common)
- 1 Vault: DOE site in Colorado for Fort St. Vrain SNF (high temperature gas cooled reactor)

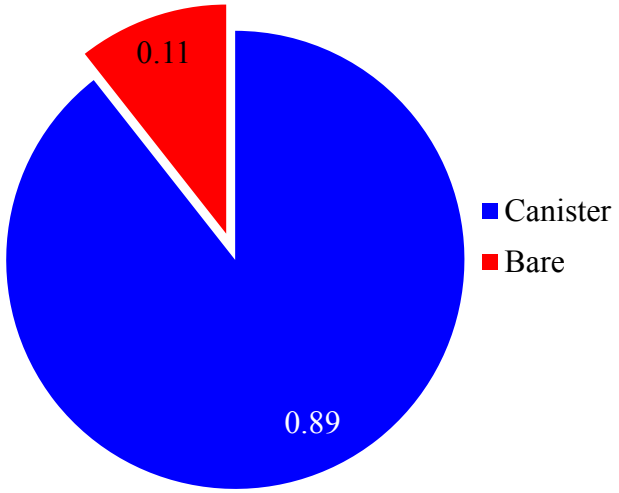
Humboldt Bay
Holtec below grade

Rancho Seco
TN horizontal

Maine Yankee
NAC vertical

Two categories of casks for dry storage

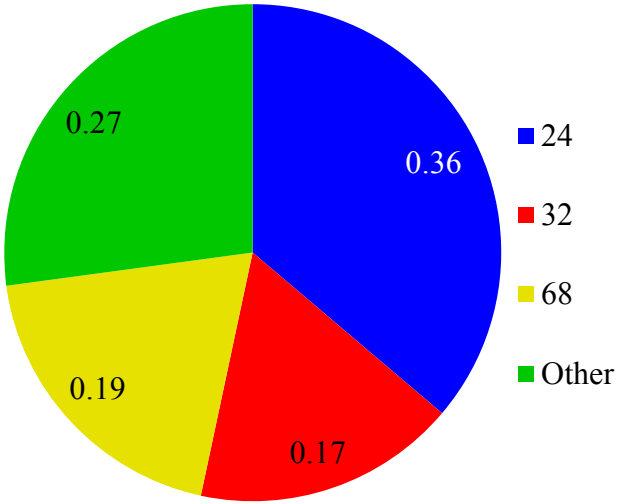
- Bare fuel (also called direct load)
  - 11% in 2012
  - All metal containers
  - Bolted closed
- Canister, thin-walled inner stainless steel
  - 89% in 2012
  - Overpack of concrete (or sometimes metal)
  - Welded closed



- Licensed for up to 20 yr with 20 yr renewal increments
- 10 CFR 71
- Current assumption in environmental impact statement (EIS) is that casks will be reloaded after 100 y

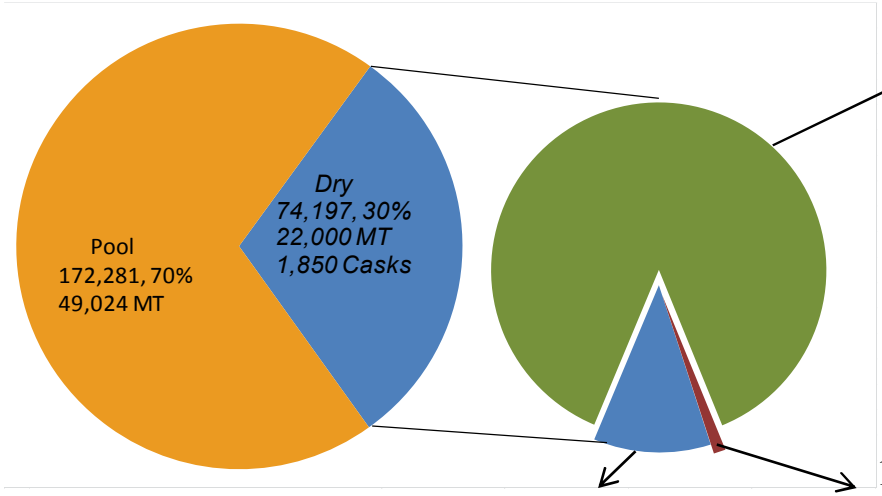
Large sizes and number of casks show US waste management system not integrated

- NRC has approved 34 designs, which include
  - 5 storage only designs (316 casks)
  - 29 dual-purpose designs (licensed for storage and transportation which started in late 1980s)
  - Many more versions because of license revisions and amendments
- Trend is for larger casks
  - 37 PWR fuel assemblies
  - 87 BWR fuel assemblies
- Cask certification mostly based on modeling



canister capacities in the current fleet

Dry Storage Inventory



1,655 Welded Metal Canisters In Vented Concrete Overpacks
65,102 Assemblies,
87.5% of Dry

Transnuclear (34%)
Holtec (41%)
NAC (10%)

12 Welded Metal Canisters in Transport Overpacks
866 Assemblies, 1.2% of Dry

183 Bare Fuel Casks
8,406 Assemblies, 11.3% of Dry

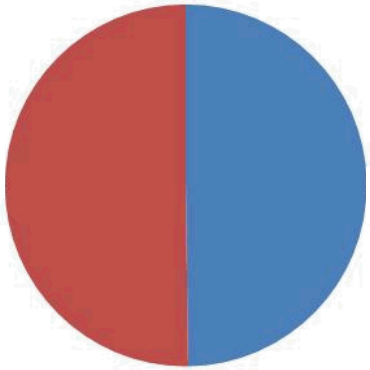
- *Majority is in Large Welded Canisters*
- *Current dry storage inventory is diverse*
- *Trend toward higher capacities*

Transnuclear TN-32

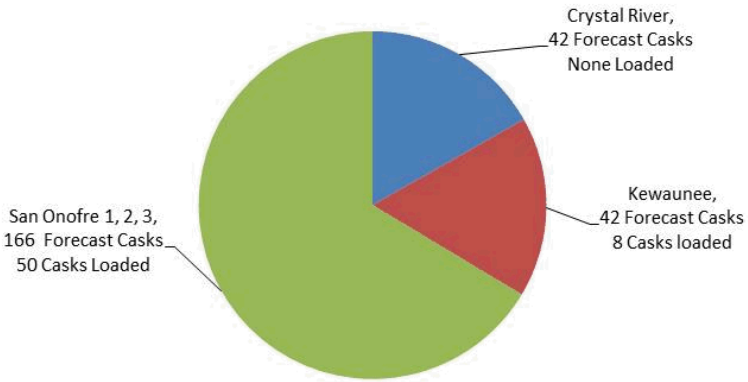
Holtec Hi-Star 100

Shutdown Reactor Sites Use Several Different Storage Designs

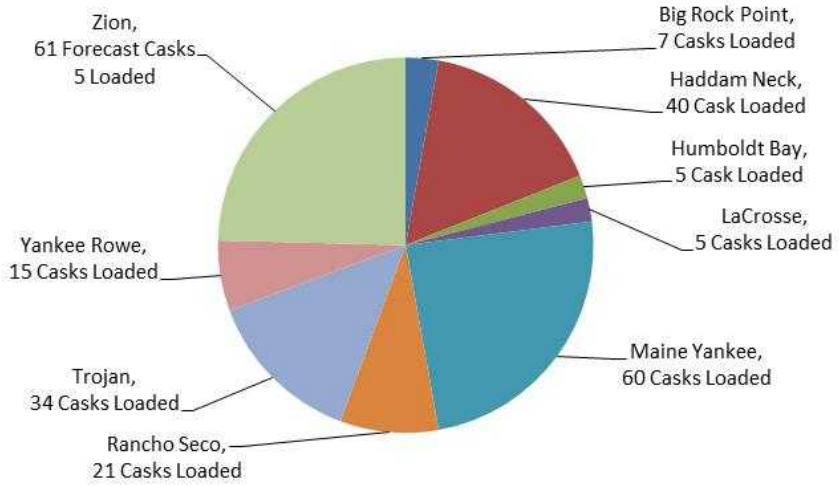
498 Fuel Casks, ~25 GTCC Casks
5,561 MT, 14,266 Assemblies



Early Shutdown Reactor Fuel Cask
250 Fuel Casks, ~10 GTCC Casks,
2,747MT, 6,617 Assemblies

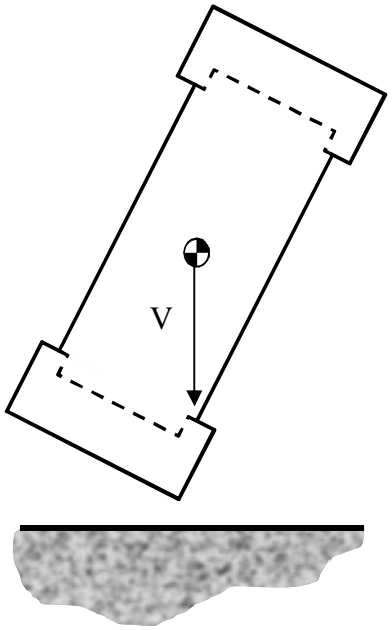


Stranded Reactor Fuel Casks
248 Fuel Cask, 15 GTCC Casks,
2,813MT, 7,649 Assemblies



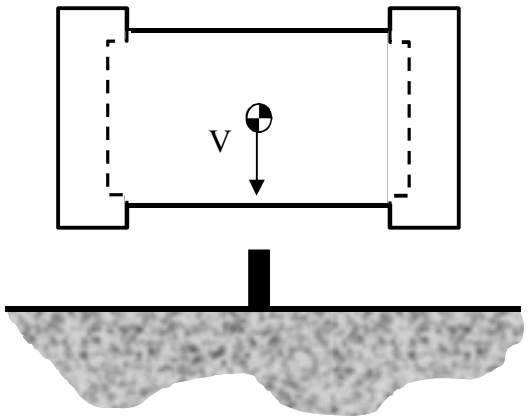
NRC certifies compliance of transportation casks through 3 tests

Impact



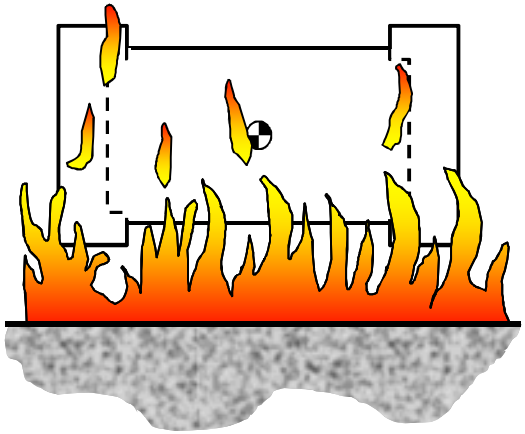
9 m drop onto unyielding surface

Puncture



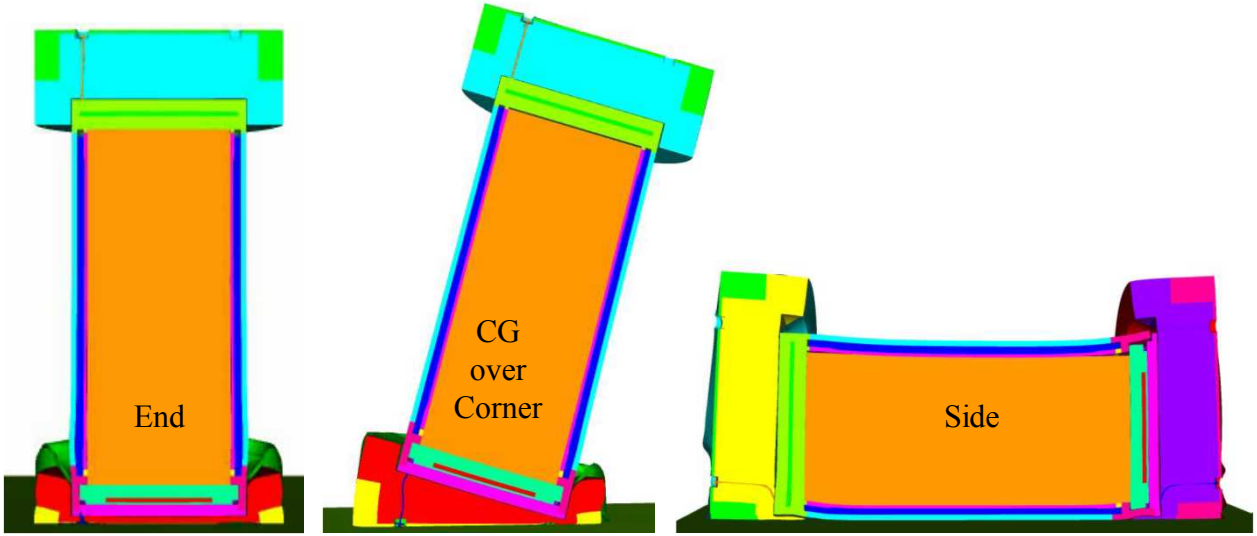
1 m drop onto 15 cm steel bar

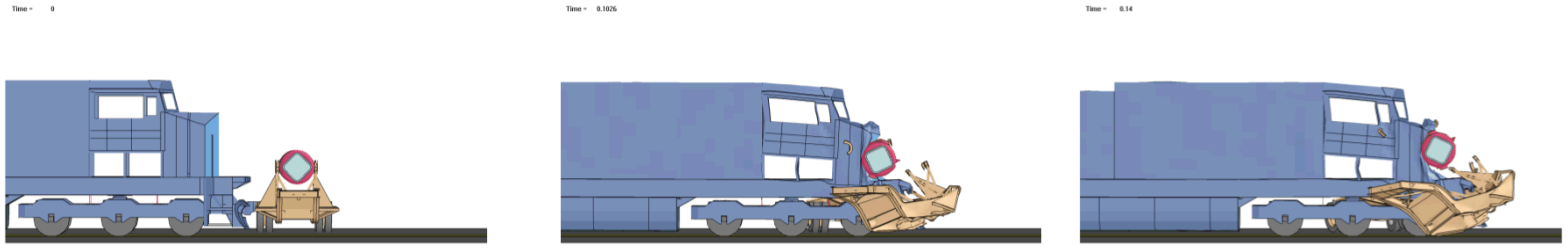
Fire



800 °C fully engulfing fire for 30 minutes

Numerical simulations often sole basis of certification





New railcars necessary for transporting massive casks

- Without new railcars, US has no capability to move massive dual-purpose casks
- Association of American Railroads sets the standard for the specialized railcars
- Developing new compliant railcars is long and detailed process of analysis and testing
- DOE currently developing a request for proposals (RFP) to design, test, and certify new railcars
- Would start small by only moving SNF from stranded sites

Dedicated train for rail transportation

Locomotive

- Two 4000 HP
- Electronically controlled pneumatic brakes

Cask Car

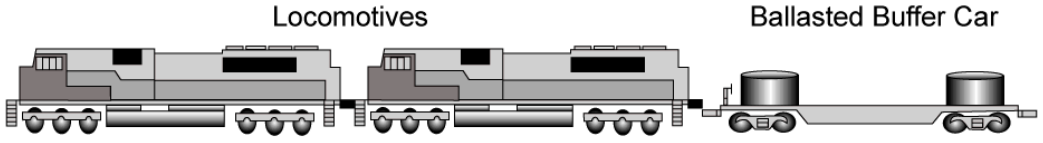
- Carry casks and cradle from 25 to 160 ton
- 17 ft long, 12 ft wide, <15 ft tall

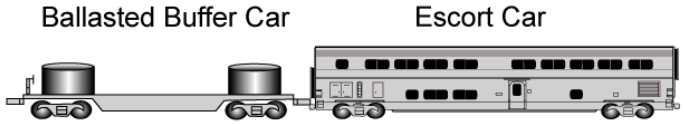
Buffer Cars

- Spread axle loads for bridges
- Provide distance to protect locomotive and escort car
- Carry spare parts

Escort Car

- Carry security and technical personnel
- Provide location monitoring, and security/emergency communications



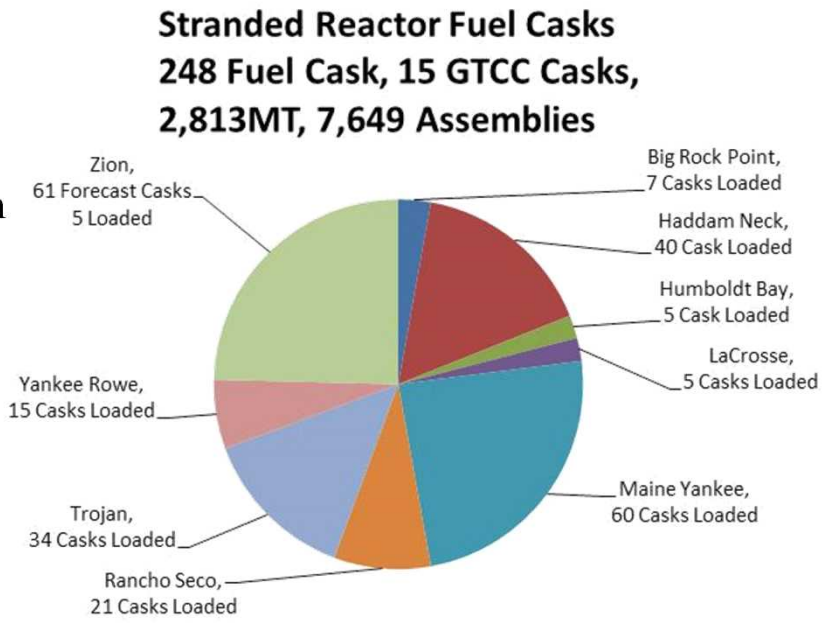


Estimated Weight and Length of Rolling Stock

Unit	Weight	No. in Consist	Length
4000 HP Locomotive	136 tons	2 per consist	61 ft. length
Cask Car	72 tons	3-5 per consist	80 - 90 ft. length
Cask & Cradle	150 tons	3-5 per consist	25 ft. length
Buffer Car	32 tons	2 per consist	60 ft. length
Escort Car	80 tons	1 per consist	85 ft. length

Pilot storage facility to start in 2021

- **5,000 to 10,000 tonne capacity with a receipt rate of 1,500 tonne/y**
  - Accept dry storage containers from stranded sites
  - Transport fuel dual purpose canisters (DPC) in approved transportation overpack casks
  - Transfer the DPC to a new storage overpack cask approved for each DPC
  - 9 stranded sites use 13 canister designs, 8 storage, and 7 transport overpack designs
    - Transition from short-term storage to transportation to long-term storage
    - Aging Management Plans expected
- **Facilities will include:**
  - Rail yard and associated maintenance equipment
  - Cask-handling building for transfer of the DPC from transportation to storage overpacks
  - Storage pads with multiple vertical and horizontal storage overpack designs
  - Security facilities
  - Infrastructure and balance of plant facilities



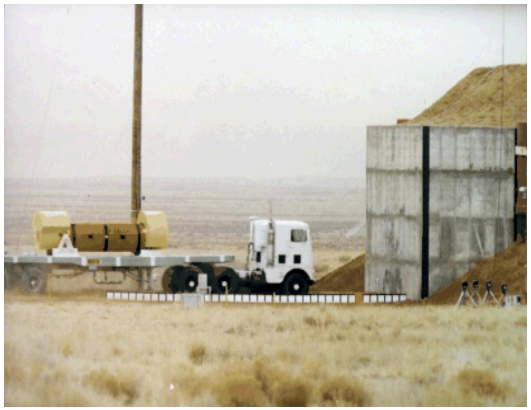
More facilities included for full ISF design

- **Larger ISF starts operations in 2025**
  - 20,000 tonne or greater
  - 3000 tonne/y to be greater than US discharge rate (~2000 tonne/y)
  - Modular approach for flexibility
- **Assumed ISF capacity is about 70,000 tonnes**
  - Based on 3,000 tonnes/y receipt rate and repository starts in 2048
- **Continued DPC storage using the storage method selected for the Pilot**
- **Bare fuel receipt and storage capability for efficient acceptance from reactors**
  - Pools –
    - Technically mature, but expensive
    - Choice for Central Interim Storage in Sweden (CLAB)
  - Vaults
    - Approach used in Spain
- **Potential packaging facility to support disposal**
  - DPC would become LLW if re-packaging required
- **Pilot and ISF licensed as ISFSI (10 CFR 72)**

36

Public comments on SNF National Transportation Plan ask for full-scale testing to address risk concerns

Sandia truck cask test at 130 km/h in 1978



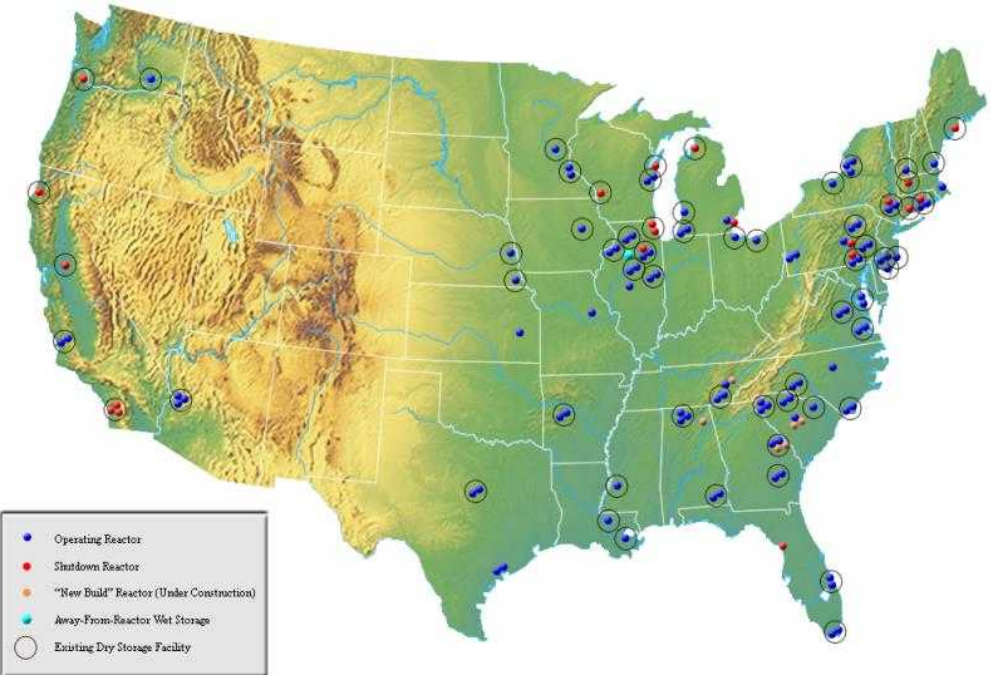
BAM CASTOR side impact test (BAM public website)

Possible full-scale testing in a Package Performance Study (PPS)

- NRC recommendations
  - Impact test of a rail cask into an unyielding target at 96 to 144 km/h (60 to 90 mph)
  - "Back breaker" test of a cask onto a rigid semi-cylinder where impact limiters are by-passed
  - Engulfing fire tests for a duration beyond the 30 minute limit specified in 10 CFR 71.73
- National Academy of Science recommendations
  - Long duration fire test with instrumented package to provide validation data
  - Regulatory and credible, extra-regulatory impact testing to support analytical, simulation, and scaled testing efforts

19 Reactors shutdown with fuel on 16 sites

130 Commercial Nuclear Power Plants Built



- **100 Operating Reactors**
- **9 Early Prototypes**
  - **No fuel on site**
- **1 Never Operated**
- **1 Disabled (Three Mile Island)**
  - **Fuel moved to DOE Idaho ISFSI**
- **1 Demonstration High Temperature Gas Reactor (Fort St. Vrain in vault ISFSI in Colorado)**
- **18 Reactors Ceased Operations**
  - **Fuel on site**
  - **3 reactors on sites with other active reactors**
  - **15 reactors on 12 sites with no other nuclear operations**
    - **12 stranded reactors (9 sites)**
    - **3 early shutdown reactors (3 sites)**

Current waste management system uses at-reactor storage

- 100 operating reactor at 62 sites in 2014
  - 65 pressurized water reactors (PWR)
  - 35 boiling water reactors (BWR)
- 71,000 tonnes heavy metal radioactive waste in 2013
  - 49,000 tonnes in wet storage
  - 22,000 tonnes in dry storage

General recommendations of Blue Ribbon Panel

- A new, consent-based approach to siting future waste management facilities
- A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed
- Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management
- Prompt efforts to develop one or more consolidated storage facilities (NFST Planning Project within NE-DOE)
- Prompt efforts to develop one or more geologic disposal facilities (UFD Program within NE-DOE)
- Prompt efforts to prepare for the eventual large-scale transport of SNF and HLW to consolidated storage and disposal facilities when such facilities become available (NFST)
- Support for continued US innovation in nuclear energy technology and for workforce development
- Active US leadership in international efforts to address safety, waste management, non-proliferation, and security concerns

Application of Social Science Research to Consent-Based Siting

- Survey research starting point on consent-based siting
- How can we use this research to have a continuous conversation with communities?
- Matt Nowlin (College of Charleston): Set stage of public learning--discuss example of directed choice, Yucca Mountain
- Kuhika Gupta (University of Oklahoma): Research on multiple streams of data for researching public perceptions
- Joe Ripberger (University of Oklahoma): Research on real-time monitoring of what public learns
- Judith Holms (North Wind): Application of interacting with public that resulting in substantial public learning