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

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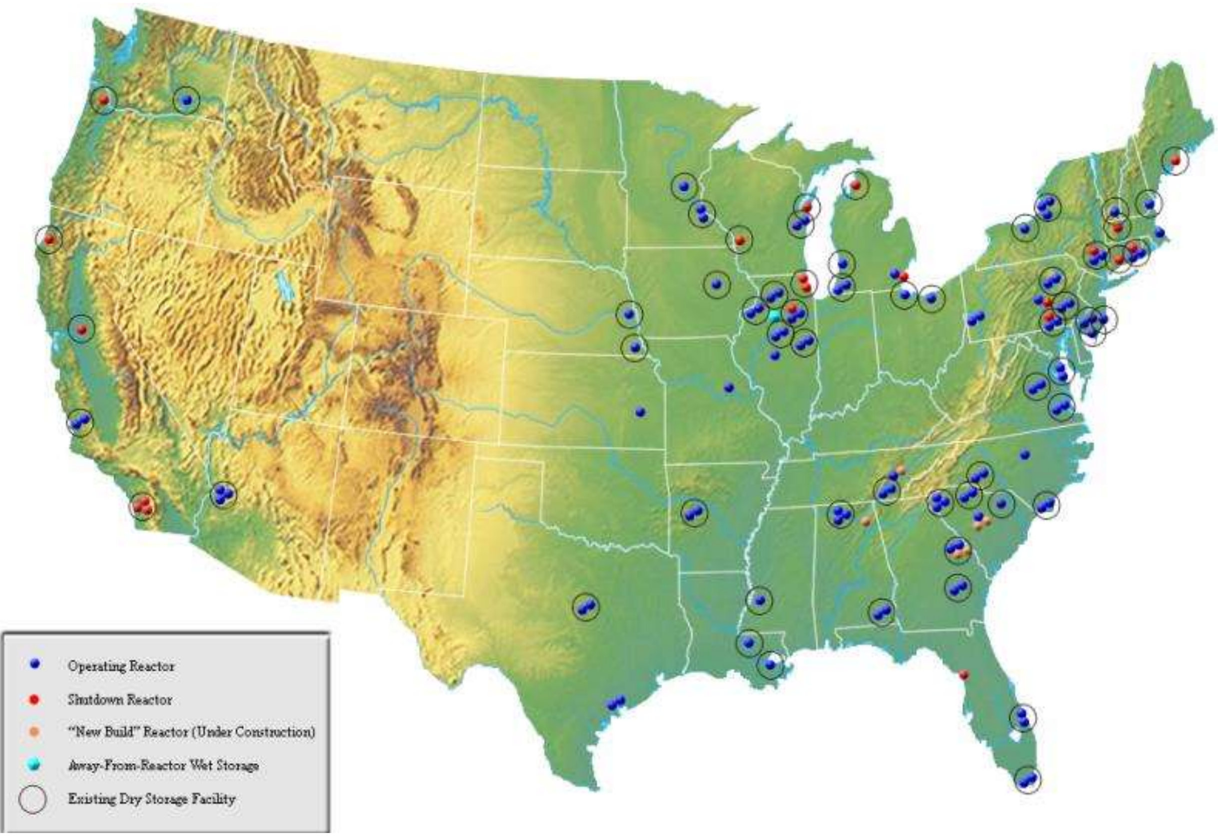
US History of Commercial Power Reactors

130 Commercial Nuclear Power Plants Built



- **9 Early Prototypes**
  - **No fuel on site**
- **1 Never Operated**
- **1 Disabled (Three Mile Island)**
  - **Fuel moved to DOE**
- **1 Demonstration High Temperature Gas Reactor (Fort St. Vrain in Colorado)**
- **18 Ceased Operations**
  - **Fuel on site**
  - **3 reactors on sites with on going nuclear operations**
  - **15 reactors on 12 sites with no other nuclear operations**
- **100 Operating Reactors**
- **6 New Reactors at Existing Sites Under Construction**

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

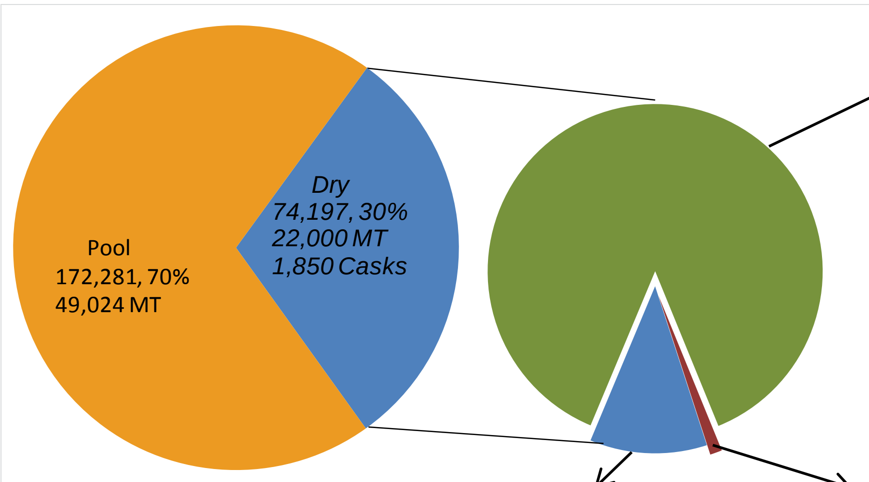
Licensing of storage is deterministic and rule-based in US

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

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%)

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

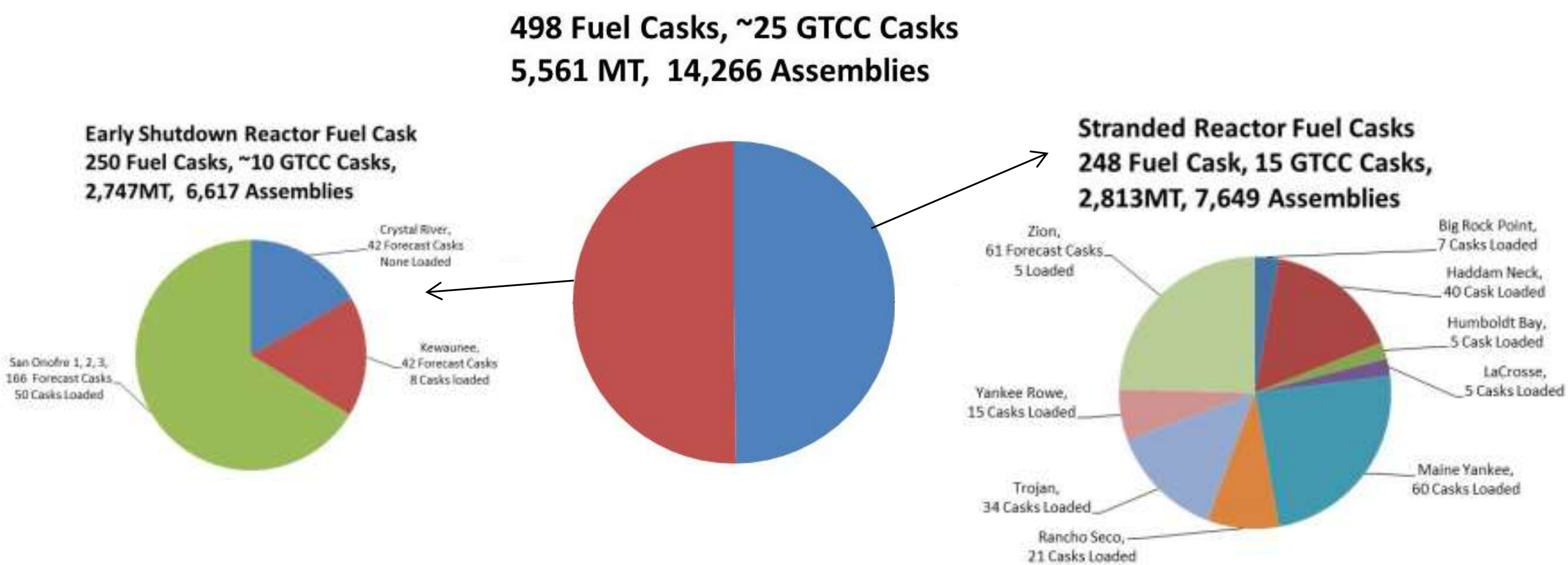
12 Welded Metal Canisters in Transport Overpacks
866 Assemblies, 1.2% of Dry

- *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



Humboldt Bay, Holtec below grade

Rancho Seco, TN horizontal

Maine Yankee, NAC vertical

Two categories of casks for dry storage

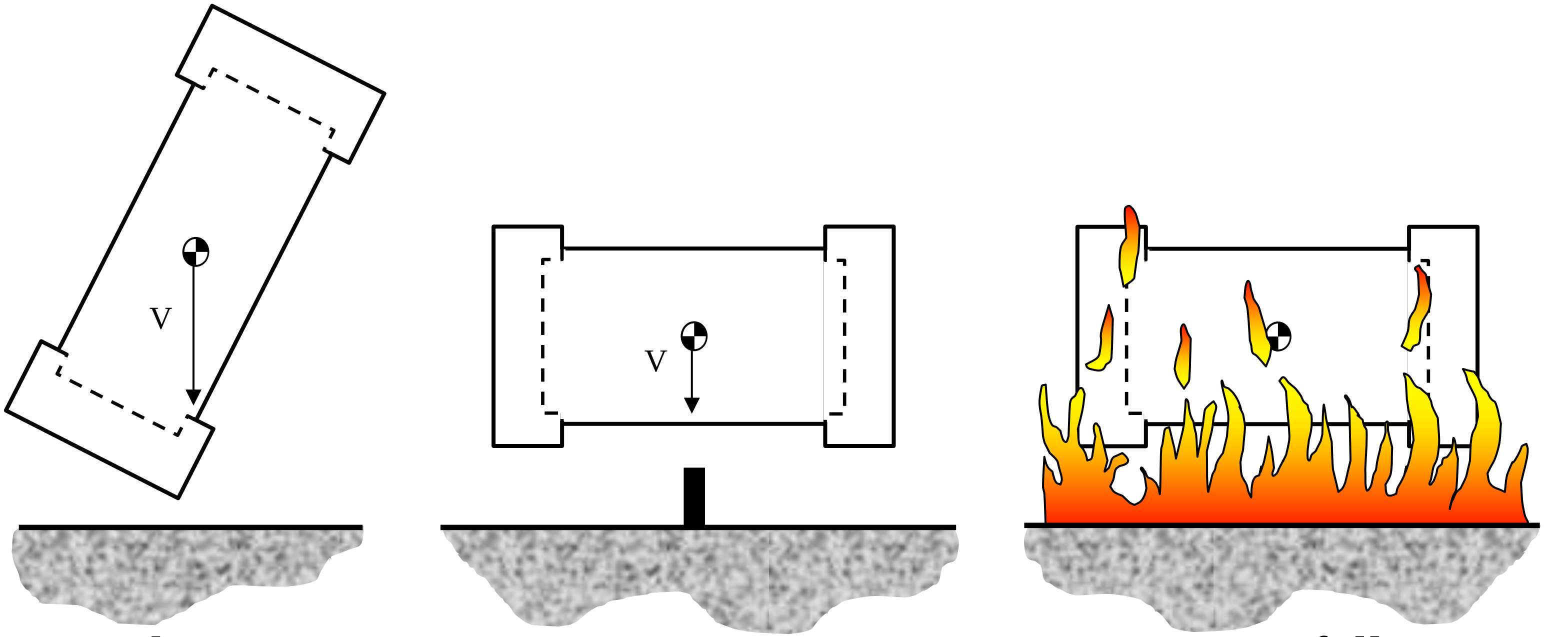
- Bare fuel (also called direct load)
  - 11% in 2012
  - All metal containers
  - Bolted closed
- Canister, thin-walled inner stainless steel container
  - 89% in 2012
  - Overpack of concrete (or sometimes metal)
  - Welded closed
- Licensed for up to 20 yr with 20 yr renewal increments
- 10 CFR 71
- Current assumption in environmental impact statement (EIS) is that casks will be reloaded after 100 y

NRC has approved 34 designs

- Many more versions because of license revisions and amendments
  - 5 storage only designs (316 total casks)
  - 29 dual-purpose designs (licensed for storage and transportation which started in late 1980s)
- Cask certification mostly based on modeling
- QA program adequate for certification supplemented by observation from an approved aging management program

NRC certifies compliance of transportation casks through 3 tests

Impact | Puncture | Fire

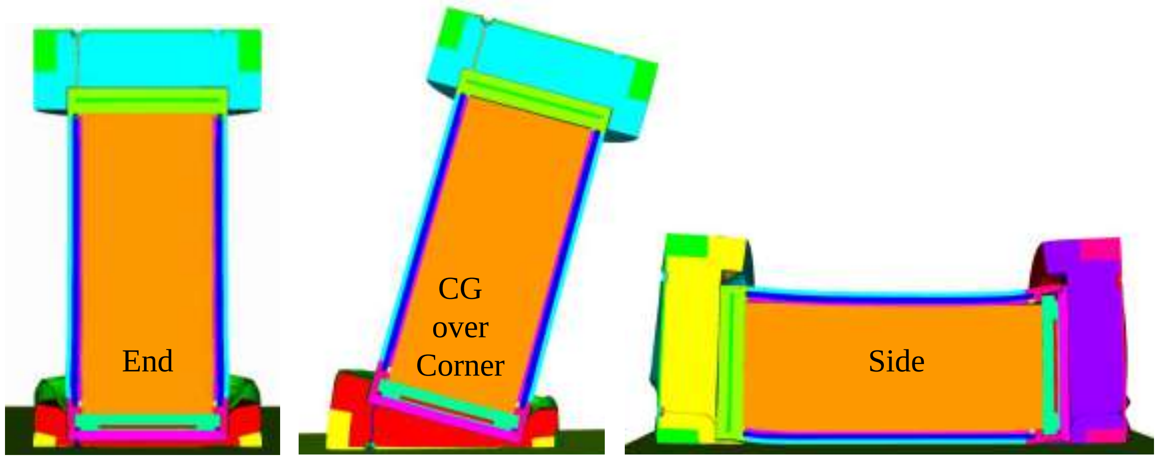


9 m drop onto unyielding surface

1 m drop onto 15 cm steel bar

800 °C fully engulfing fire for 30 minutes

Modeling has progressed such that numerical simulations usually sole basis of certification



New railcars necessary for transporting massive casks on large scale basis

- 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

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 Car

- 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

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 …

Means

Likelihood of Activities (1 = Not At All Likely—7 = Extremely Likely)	**Interim Storage**	**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

Public comments on National Transportation Plan for SNF 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)

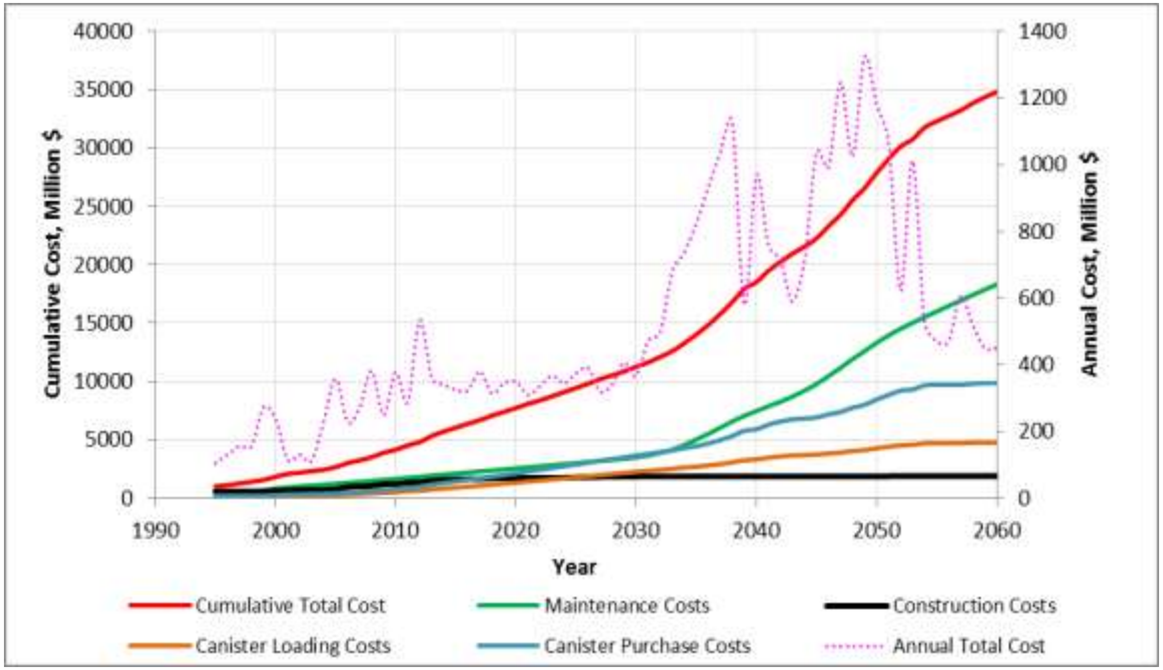
Possible full-scale testing

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

Stranded SNF storage at shutdown nuclear reactors big issue

- Costs of storing SNF at a shutdown reactor are large and provide large impetuous for consolidated interim storage facility
- Prior to 2000, focus of cost comparisons were between
  - (a) at-reactor storage (at operating reactor) then repository disposal and
  - (b) 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 were between
  - (a) at-reactor storage *followed by stranded storage* then repository disposal and
  - (b) at-reactor storage followed by storage at consolidated interim storage then repository disposal

Combined cost of storage at reactor followed by stranded storage was ~$35 billion in 2012



- **Annual cost for storage is 10 greater at shut down site versus operating site (i.e., ~$6 million/y versus ~$0.6 million/y)**
- **Costs increase around 2035 when many reactors shut down**
- **Cost has increased to ~$50 billion based on higher costs for preparing fuel for storage and annual costs for storage at shutdown reactors**

Consolidated interim storage is path to integrating US waste management system

Consolidated interim storage facility could

- Facilitate more flexible siting criteria by implementing schemes to lower thermal output by
  - Buffer storage of hot canisters, or
  - mixing SNF fuel in disposal canister
- Ease burden of aging inspections at shutdown sites and operating sites
- Accommodate shipment of bare fuel in wet storage
- Make same national organization responsible for long-term storage and disposal (versus current scheme of private utilities for storage and federal government for disposal)

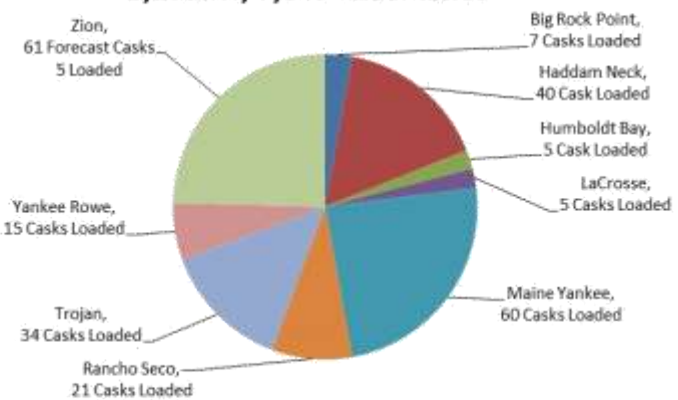
Consolidated interim storage facility way for the US waste management system to be more flexible to changing situations (e.g., different repository media, emergency closure of reactor, and temporary closure of repository for upgrades)

Blue Ribbon Commission on America's Nuclear Future Reviewed the Back End of the Cycle

- **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
- **The Administration agrees that interim storage should be included as a critical element in the waste management system**
- **The Administration supports a pilot interim storage facility initially focused on serving shut-down reactor sites.**

Pilot Storage Facility Concept

- **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



Pilot Alternative Design
(Flexible, Adaptable, and Expandable)

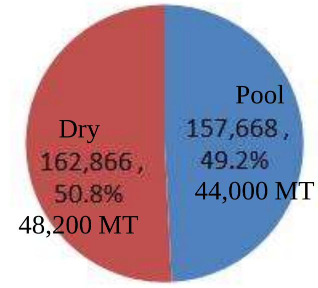
- **Dry Storage Alternatives**
  - Vented concrete at grade in horizontal and vertical vendor specific systems currently in use
  - Vaults for dry canisters
  - Universal storage overpacks
  - Universal underground systems

Humboldt Bay Underground Storage

- **Required Support Systems/Facilities**
  - Cask-handling facility
    - large shielded cell vs. transfer cask may offer time in motion and ALARA advantages
  - Storage overpack fabrication
  - Rail and cask maintenance
  - Security systems, infrastructure, and balance of plant
- **Potential Co-located Systems**
  - Laboratory for supporting long-term storage and developing repackaging techniques
  - Fuel remediation capability for damaged or failed fuel
  - Related manufacturing facilities

Larger ISF Concept

- **DOE Strategy document provides guidance**
  - ISF starts operations in 2025
  - 20,000 tonne or greater
  - Receipt rate is greater than the U.S. discharge rate (~2000 tonne/y), working basis is 3,000 tonne/y
  - Repository starts operation in 2048
  - Modular approach for functional capability and capacity increases and provide flexibility

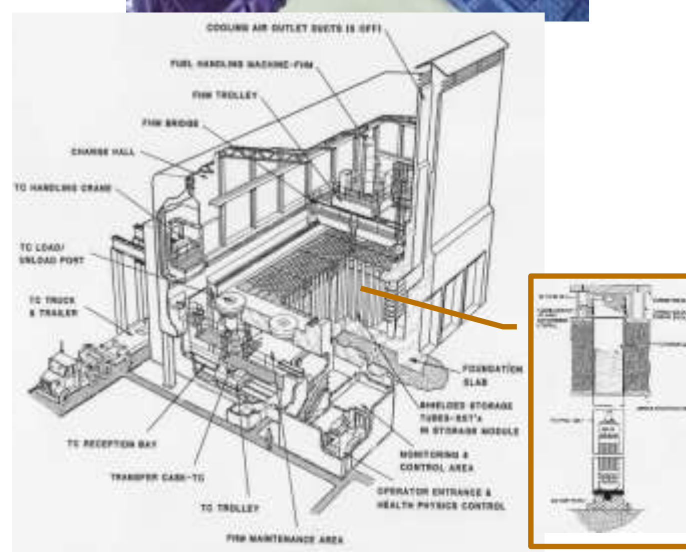


2024 Projected Inventory

- **Assummed ISF capacity is about 70,000 tonnes**
  - Based on 3,000 tonnes/y receipt rate and schedule in DOE Strategy (2048 repository)
- **Continued DPC storage using the storage method selected for the Pilot**
- **Significant bare fuel receipt and storage capability may be needed for efficient acceptance from reactors**
- **Pilot and ISF licensed as ISFSI (10 CFR 72)**

For Full ISF Design Bare Fuel Storage May be Included

- **Bare fuel receipt and storage systems**
  - Pools – technically mature, but expensive
    - Choice for Central Interim Storage in Sweden (CLAB)
  - Continue to load dry canisters
    - decay heat per package may limit transportation and disposal
    - DPC may become LLW if repackaging for disposal is required
  - Vaults
    - approach used in Spain
- **Dry storage continues using technologies selected for the Pilot**
- **Support facility capacity increases**
  - Examine a range of receipt rates
- **Potential packaging facility to disposal if required**



Why has Germany abandoned Consolidated Interim Storage?

- **Transportation risks have been cited, but how extensive was the public discussion?**
- **Will the prospect of 80 y long term storage cause Germany to re-examine decision?**