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Nuclear Fuels Storage & Transportation Planning Project
Office of Fuel Cycle Technologies
Nuclear Energy

Containers for Commercial Spent Nuclear Fuel

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Nuclear Waste Technical Review Board
August 24, 2016
Washington DC

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Disclaimer

- This is a technical presentation that does not take into account contractual limitations under the Standard Contract. Under the provisions of the Standard Contract, DOE does not consider spent fuel in canisters to be an acceptable waste form, absent a mutually agreed to contract modification.

- This presentation reflects research and development efforts to explore technical concepts which could support future decision making by DOE. No inferences should be drawn from this presentation regarding future actions by DOE.

NWTRB Questions

From the Agenda

i. The commercial nuclear power industry uses more than 25 types of dry-storage casks and canisters for commercial SNF, and the number is growing. In addition, DOE is evaluating several options for "standardized" containers that may be used for storing, transporting, or disposing of commercial SNF. The standardized containers include small, medium, and large Standardized Transportation, Aging, and Disposal (STAD) canisters. Reusable, bolted-lid transportation-only cask concepts were also recently developed (designs by AREVA and EnergySolutions). Briefly describe the in-use containers and recently examined container concepts. Discuss the integration issues known or anticipated—in particular, focus on:

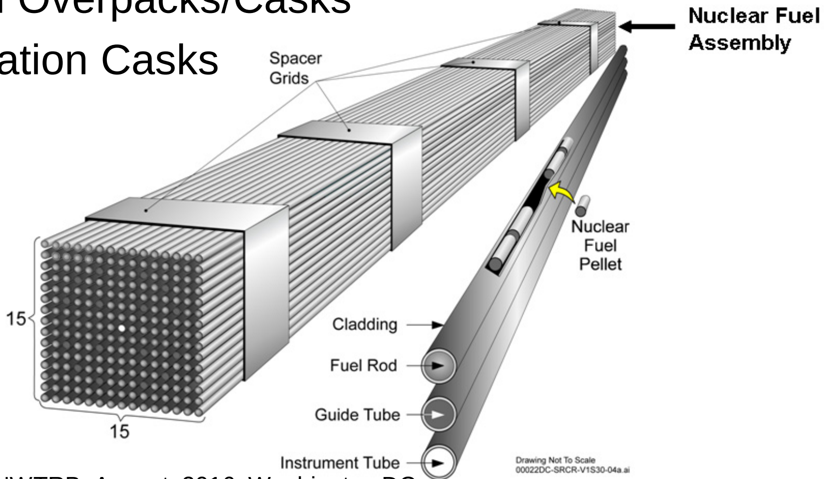
a. Challenges presented by the physical dimensions and capacity of the containers.
b. The scope of commercial SNF types that can be loaded.
c. The ability to accommodate damaged SNF (in "damaged fuel cans").
d. Challenges for licensing for storage and transportation.
e. Limitations for the transportation casks and trailers/railcars to be used (if applicable) and the status of design and procurement of the transportation casks.

ii. Explain whether any of the SNF containers may exceed storage or transportation limits for temperature, criticality safety, radiation dose, or weight. If the limits are challenged or exceeded, how will containers be managed and what is being done to mitigate the problems in the future?

Overview

- **Background**
- **Dry Storage Container Inventory**
  - Non-Canistered SNF ("Bare Fuel") Storage Casks
  - SNF Canisters
  - Vendor Canistered SNF Storage Systems
- **SNF Canister Physical Attributes**
- **Storage Overpack/Cask Physical Attributes**
- **Transportation Container Physical Attributes**
  - Canistered SNF Transportation Overpacks/Casks
  - Non-canistered SNF Transportation Casks
- **Potential "New" Containers**
  - Standardized Canisters
  - Additional Non-canistered SNF Transportation Cask Concepts
- **Data Tables**


MP-187 Transportation Cask



Background

Primary Sources of Information

- "Commercial Spent Nuclear Fuel and High-Level Radioactive Waste Inventory Report"; Vinson, Carter, Wilson; FCRD-NFST-2013-000263 updated preliminary data for Rev 4
  - Historical inventory as reported by the utilities on GC-859 thru June 2013
  - Forecast discharges, individual reactor basis thru December 2016
  - Forecast discharges thru 2065
  - Dry storage status thru May 5, 2016
- "Dry Storage Cask Inventory Assessment"; Jones; FCRD-NFST-2014-000602, August 31, 2015 updated preliminary data for Rev 2
  - Dry storage status from FCRD-NFST-2013-000263 Rev 4 data update
  - Canister and cask attributes from "Storage and Transport Cask Data for Used Commercial Nuclear Fuel U.S. Edition" ATI-TR-13047, August 9, 2013, including error correction and verification (where possible)
  - Updated annually with publically available SAR and CoC from NRC ADAMS database
- Both the Fuel Forecast Database and Cask Assessment Database are uploaded to the "Unified Database" annually
  - Other program elements utilize the Unified Database for use of consistent data

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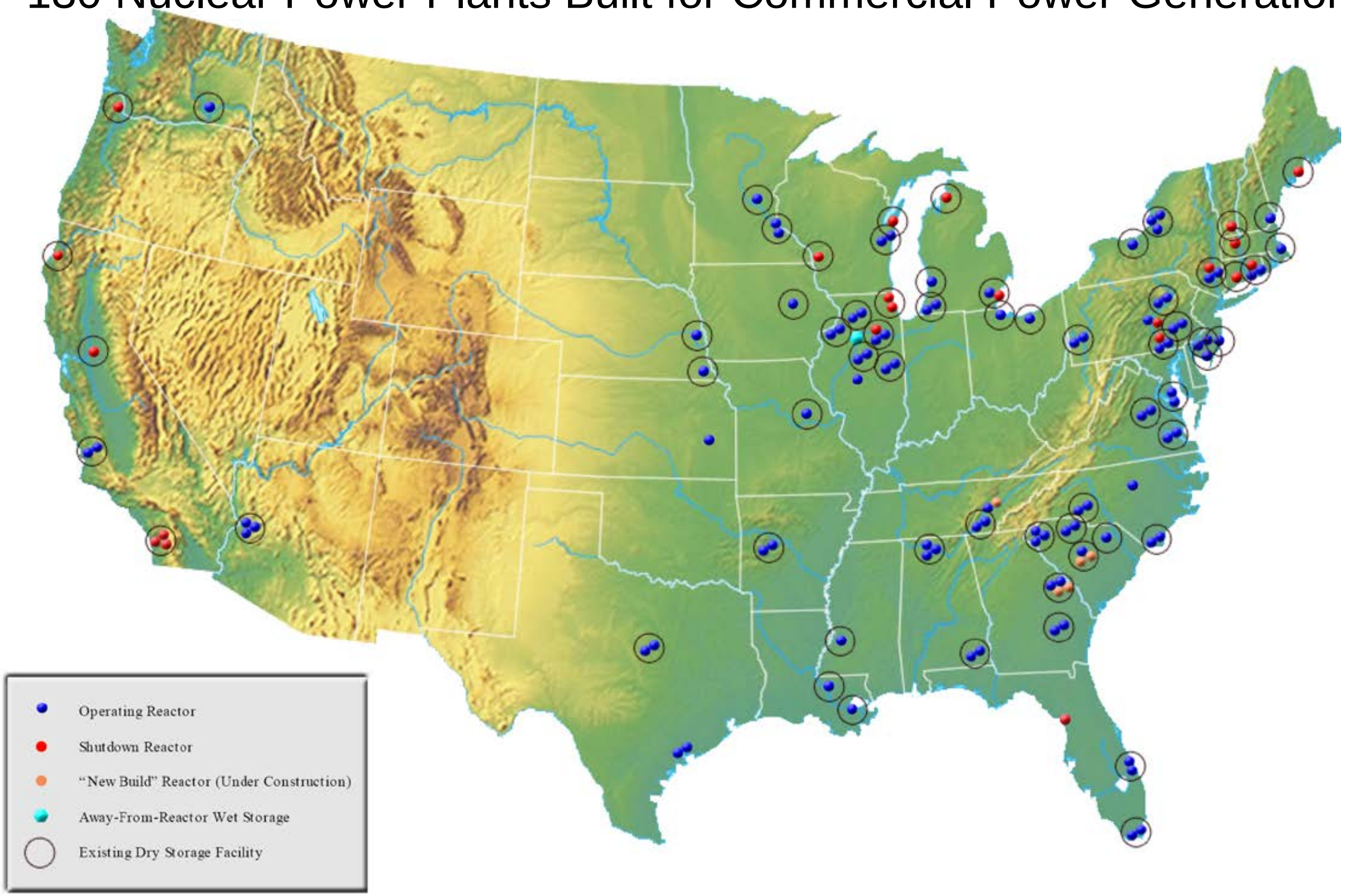
US History of Commercial Power Reactors

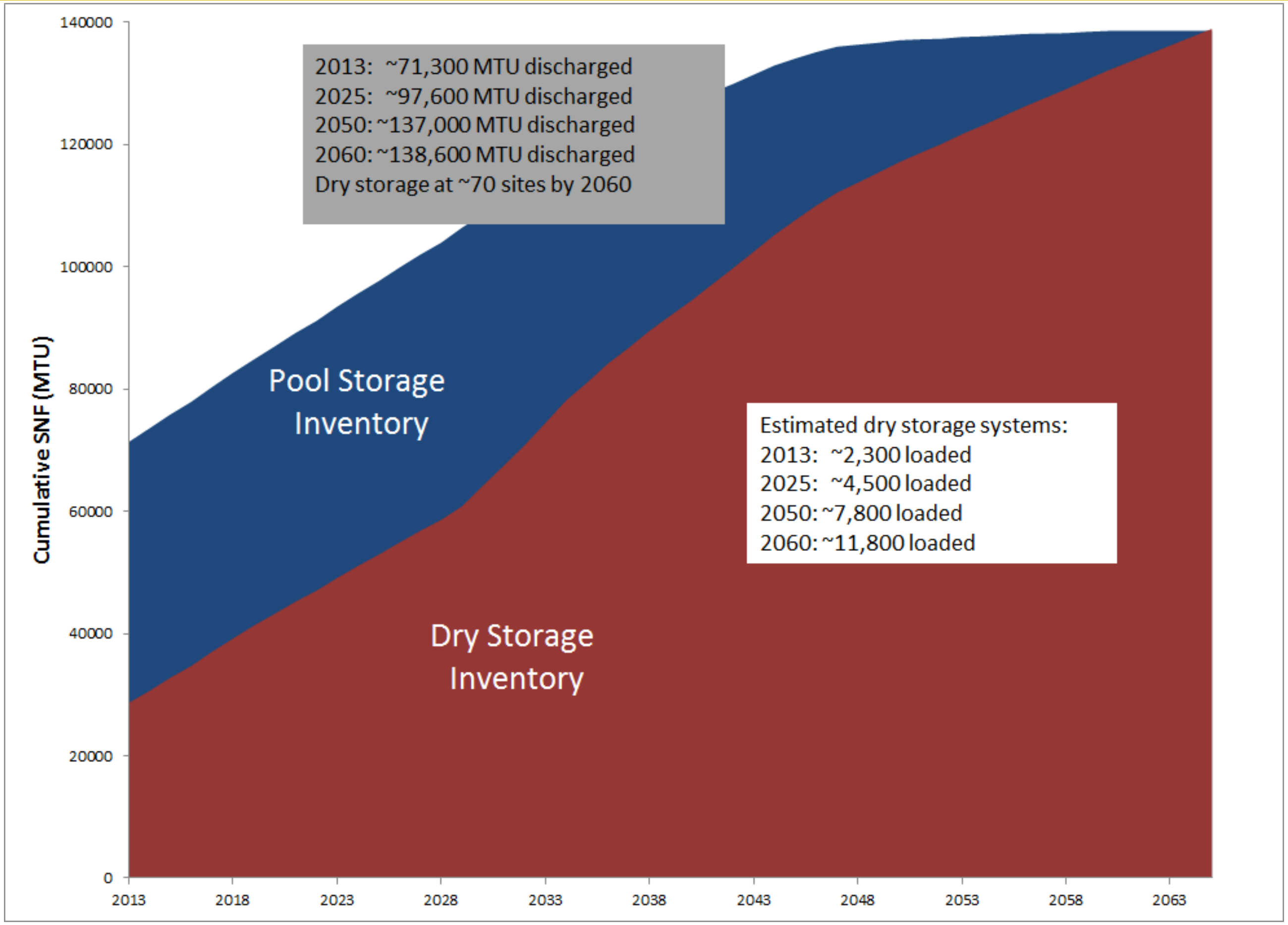
130 Nuclear Power Plants Built for Commercial Power Generation



- **9 Early Prototypes**
  - No fuel on site
- **1 Never Operated**
- **1 Disabled**
  - Fuel managed by DOE
- **1 High Temperature Gas Reactor**
  - Fuel managed by DOE
- **19 Ceased Operations**
  - Fuel on site
  - 3 reactors on sites with on going nuclear operations
  - 16 reactors on 13 sites with no other nuclear operations
- **99 Operating Reactors**
  - 9 w/ Announced Shutdown dates
- **5 New Units Under Active Construction**

Source: Preliminary data for "Commercial Spent Nuclear Fuel and High-Level Radioactive Waste Inventory Report", FCRD-NFST-2013-263, Rev. 4

Commercial SNF in Storage Continues to Increase by ~2,000 MTHM Annually; 150 – 200 Dry Storage Canisters are Loaded Annually



Current Reactors Operate 60 Years Unless Announced Shutdown Date, 5 New Builds Operate 40 Years, Current ISFSI Practices

Source: Derived from preliminary data for "Commercial Spent Nuclear Fuel and High-Level Radioactive Waste Inventory Report", FCRD-NFST-2013-263, Rev. 4

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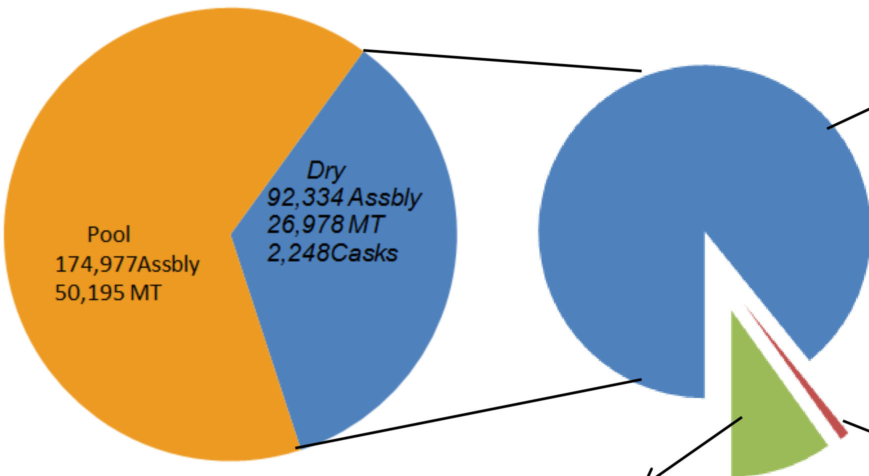
Commercial Dry Storage System Inventory is Diverse and Growing

Projected Reactor Discharges at Dec 2016, Dry Inventory as of May, 2016



2,032 Welded Metal Canisters In Vented Concrete Casks/ Overpacks
82,318 Assemblies, 89.2% of Dry

Transnuclear (35.2%)
Holtec (49.7%)
NAC (12.9%)

204 Non-canistered SNF Storage Casks
9,150 Assemblies, 9.9% of Dry

12 Welded Metal Canisters in Storage/Transport Casks
866 Assemblies, 0.9% 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

Source: Derived from preliminary data for “Commercial Spent Nuclear Fuel and High-Level Radioactive Waste Inventory Report”, FCRD-NFST-2013-263, Rev. 4, and for “Dry Storage Cask Inventory Assessment”, FCRD-NFST-2014-000602, Rev 2.

Non-canistered SNF ("Bare Fuel") Cask Systems in Use

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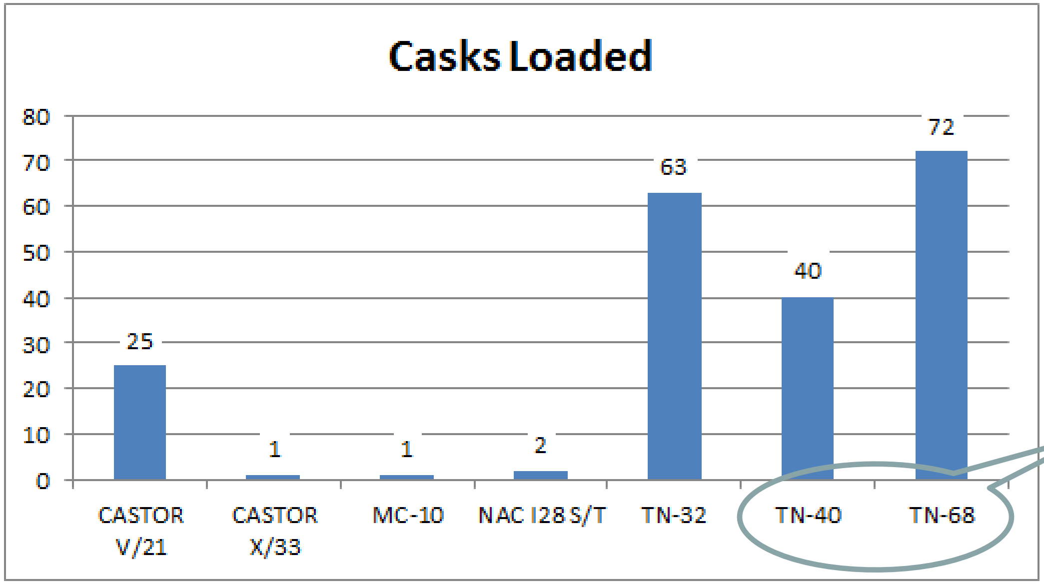
- Four Utilities Use Non-canistered SNF Storage Systems At 5 Reactor Sites
- Seven Unique Non-canistered SNF Storage Systems Are Used To Store 9,150 SNF Assemblies In 204 Total Casks
- Two (TN-40 and TN-68) are Currently Licensed for Transport



Non-canistered SNF Casks Continue to be Loaded

Source: Preliminary data for "Dry Storage Cask Inventory Assessment", FCRD-NFST-2014-000602, Rev 2.

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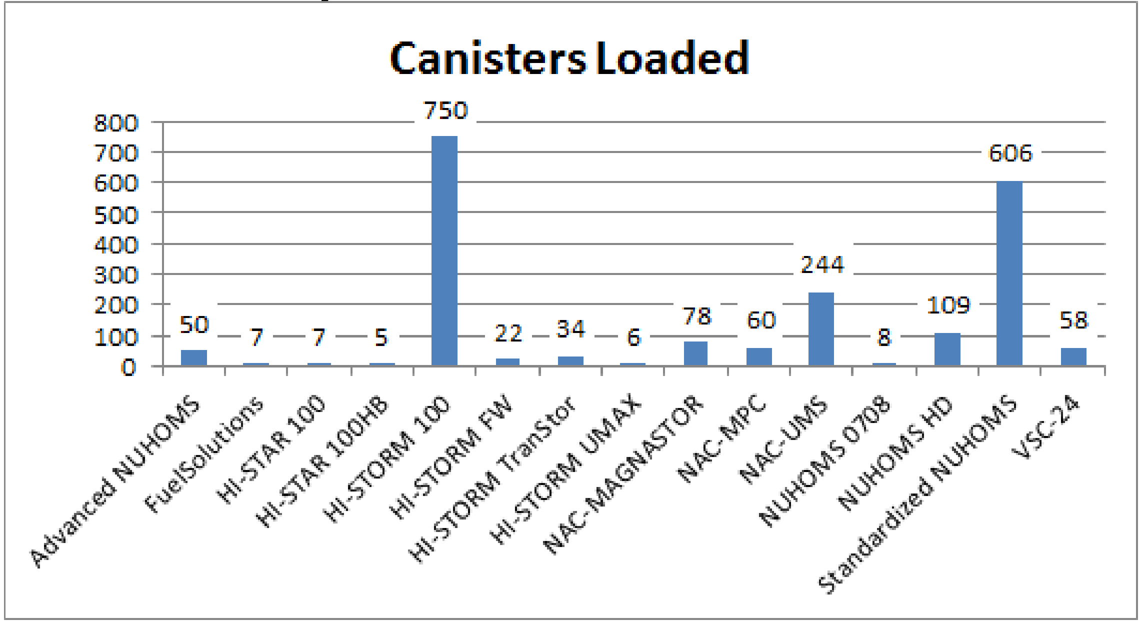
Canistered SNF Storage Systems at Reactor Sites

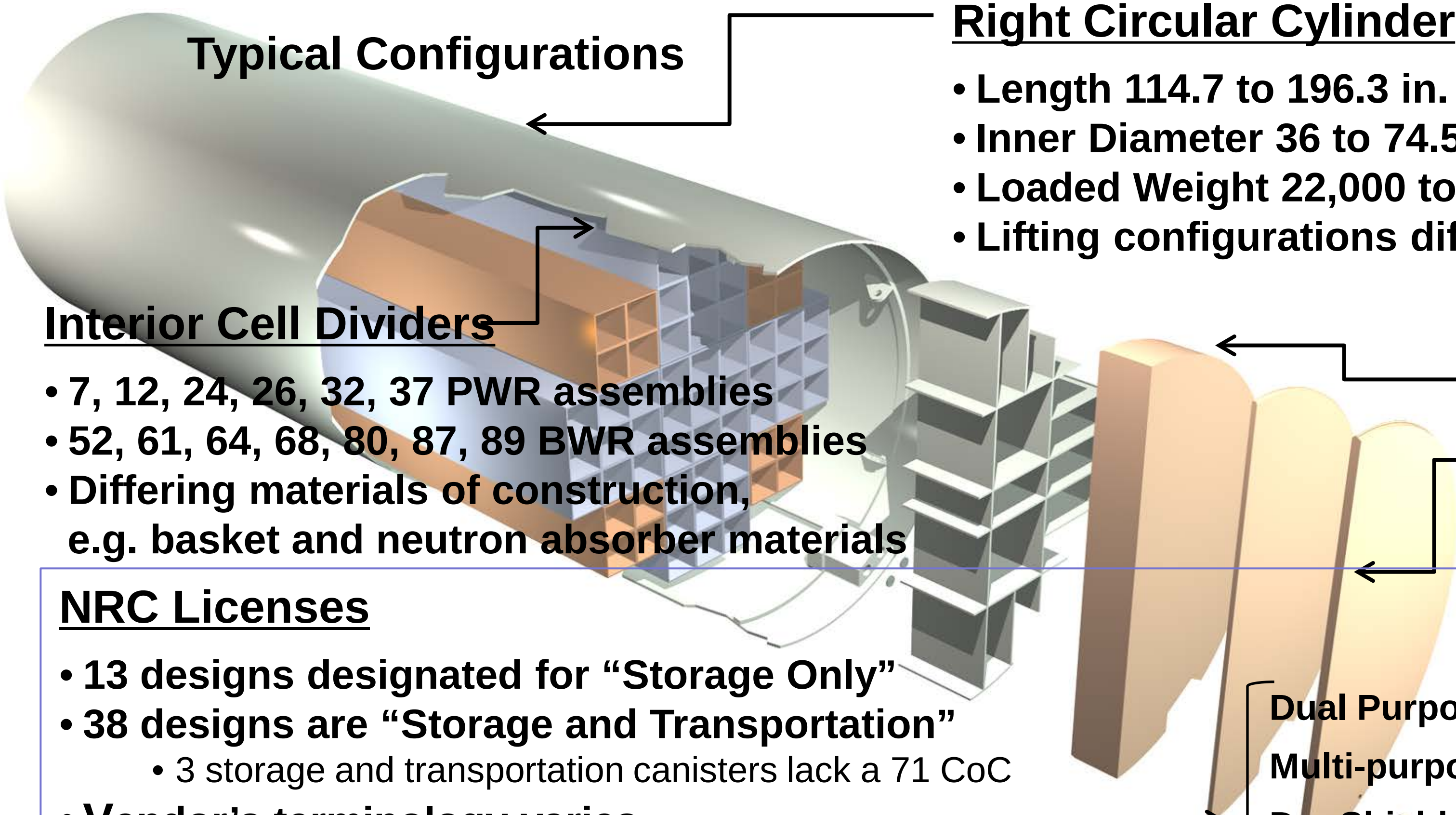
- 30 Utilities Use Canistered SNF Storage Systems At 69 Reactor Sites
- 16 Unique Canistered SNF Storage Systems Are Used To Store 83,184 SNF Assemblies In 2,044 Total Canisters
- Up To 51 Unique Canisters Could Be In Current Use (Insufficient Data To Be Certain)



- 43 General Licenses
- 8 Site Specific Licenses

Source: Preliminary data for "Dry Storage Cask Inventory Assessment", FCRD-NFST-2014-000602, Rev 2

More Than 50 Different Welded Metal Canister Designs Have Been Licensed



Typical Configurations

Right Circular Cylinder

- Length 114.7 to 196.3 in.
- Inner Diameter 36 to 74.5 in.
- Loaded Weight 22,000 to 116,400 lbs.
- Lifting configurations differ

Interior Cell Dividers

- 7, 12, 24, 26, 32, 37 PWR assemblies
- 52, 61, 64, 68, 80, 87, 89 BWR assemblies
- Differing materials of construction, e.g. basket and neutron absorber materials

Shield Plug

Welded Lid

NRC Licenses

- 13 designs designated for "Storage Only"
- 38 designs are "Storage and Transportation"
  - 3 storage and transportation canisters lack a 71 CoC
- Vendor's terminology varies
- None are licensed for disposal
- Allowable enrichment, decay heat, cooling time and fuel burnup varies by design
- Allowable damaged fuel cans varies by design

Dual Purpose Canister (DPC)
Multi-purpose Canister (MPC)
Dry Shielded Canister (DSC)
Transportable Storage Canister (TSC)

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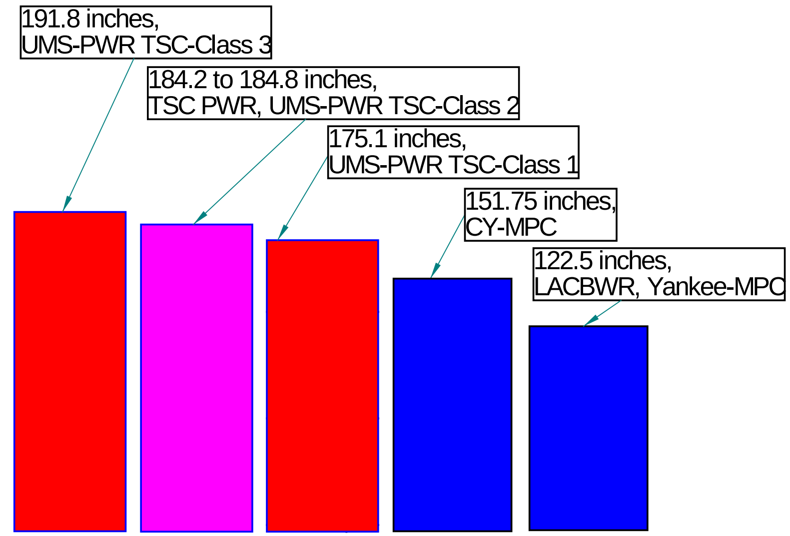
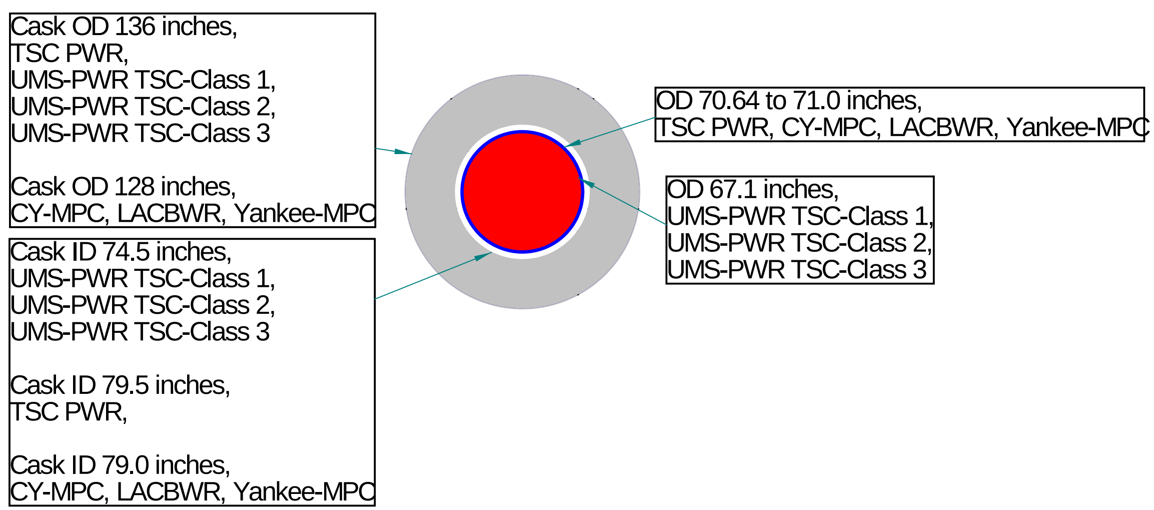
NAC Canistered SNF Storage Systems: Diameters and Lengths Illustrated

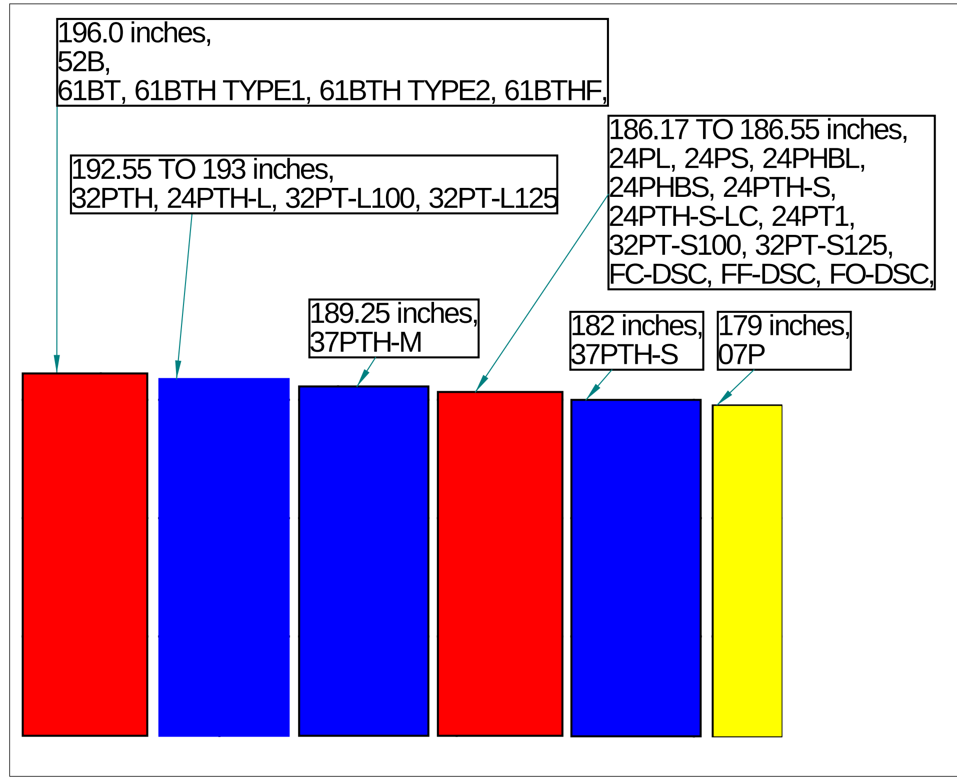
NAC UMS System at Maine Yankee

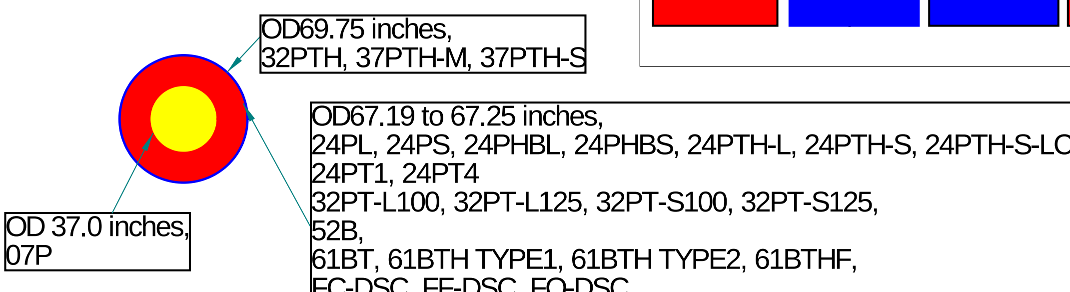




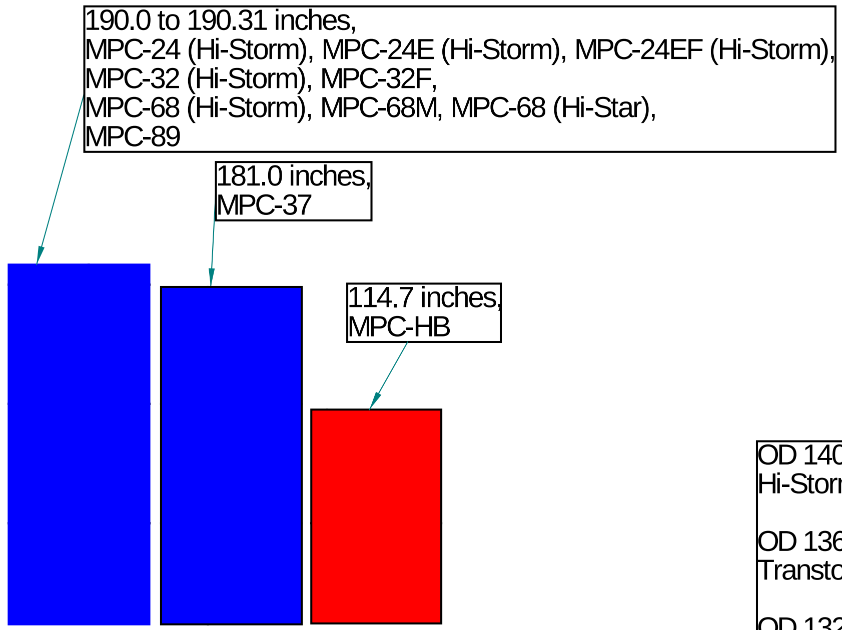
AREVA-TN Canistered SNF Storage Systems: Diameters and Lengths Illustrated

AREVA- TN System

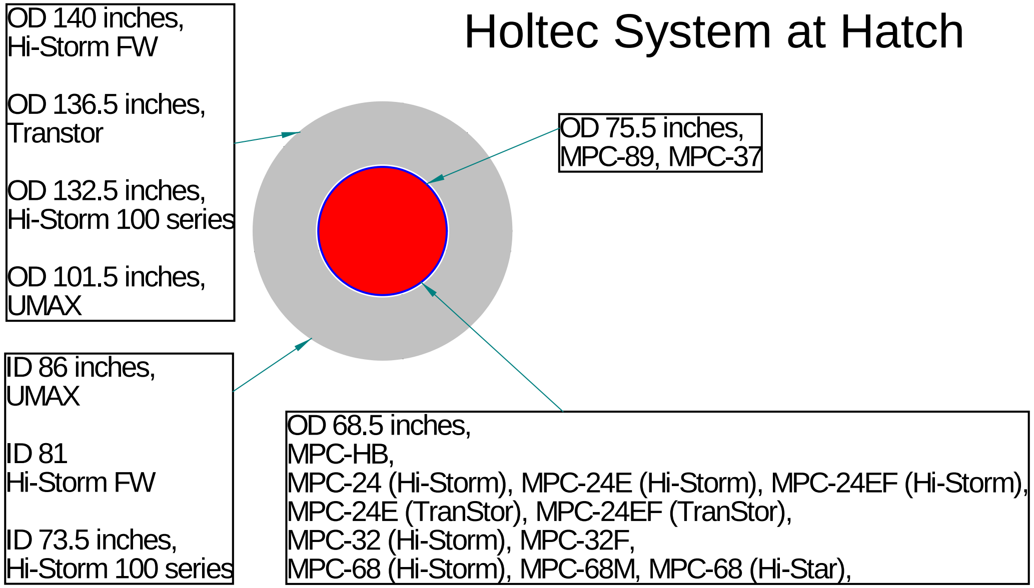




Holtec Canistered SNF Storage Systems: Diameters and Lengths Illustrated

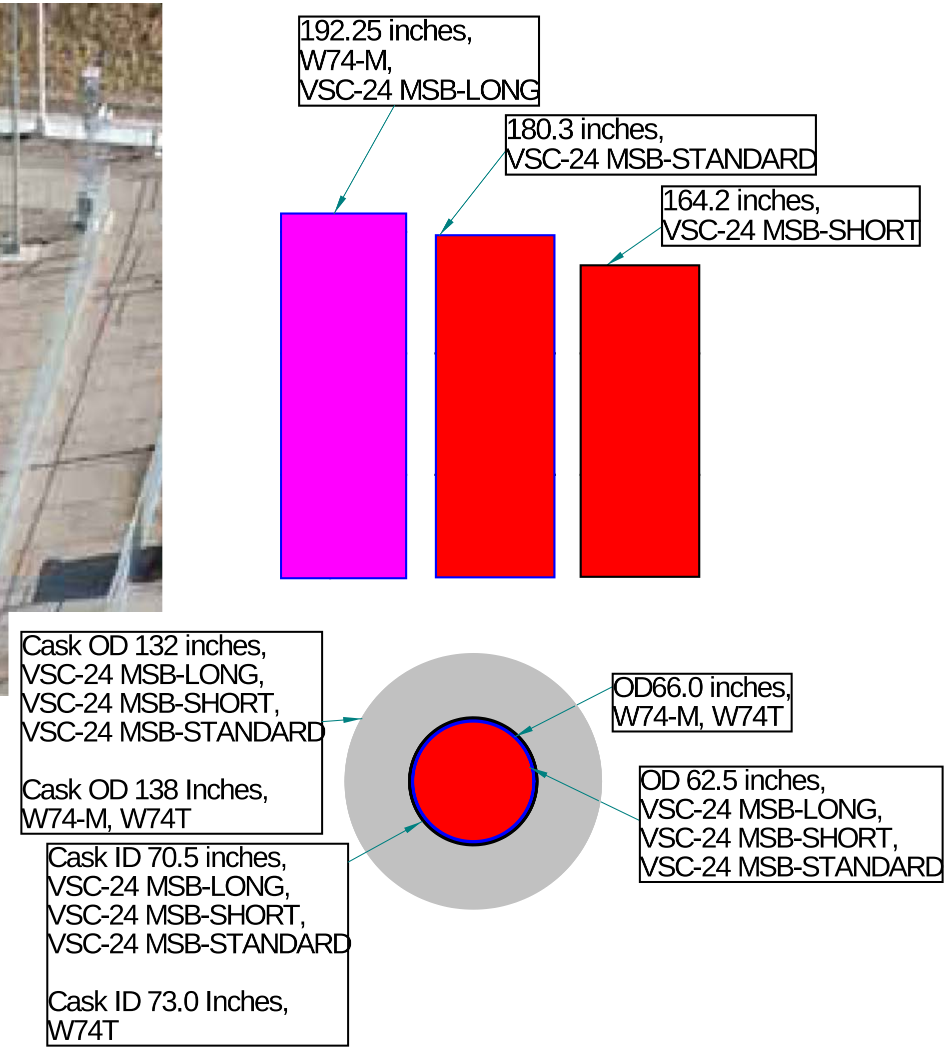


Holtec System at Hatch



Fuel Solutions Canistered SNF Storage Systems: Diameters and Lengths Illustrated

Fuel Solutions System at
Big Rock Point



Detailed Data Tables

Canister Attributes – Data Table

- 51 canisters included
- Part 72 and Part 71 (if applicable) CoC number
- Maximum decay heat for storage and transportation (if applicable), these are often different limits – must remain in storage service until transport limit is reached
- Maximum burn-up for storage and transportation (if applicable), these are often different limits – requires transport license modification
- Number of damaged/failed fuel or fuel debris cans requires particular attention to the CoC for applicability

Canistered SNF Storage Overpack Attributes – Data Tables

- 35 storage overpacks included
- Specific licensed canister payloads provided

Non-canistered SNF Storage/Transport Cask Attributes – Data Table

- 11 casks included
  - Currently 2 have transport licenses (TN-40, TN-68)

Storage Only Canister Summary

- **No Storage Only Canisters are Located at Shutdown Reactor Sites**
- **Qualitative Assessment of the Transportability of the “Storage Only” Canisters:**
  - Structural Design of Many of these Canisters is Not Sufficiently Robust to Allow for Certification for Transportation
  - “Specific Exemption” Provision in 10 CFR71.12 May Be Explored in the Future
  - If Certification or an Exemption Cannot be Obtained, Re-Packaging will be Required

Source: “Assessment of the Transportability of Storage Only Used Nuclear Fuel Canister”, FCRD-UFD-2014-000511, September 24, 2014.

Transportation Containers and S-2043 “Atlas” Railcar

- **Transportation Container Attributes – Data Table**
  - 17 Transportation Containers Included
    - 11 canistered fuel transportation overpacks
    - 6 non-canistered fuel transportation casks
      - 4 Storage and Transport (only 2 have transport licenses)
      - 2 Transport only (HI-STAR 60 and HI-STAR 180)
    - Fabrication status is provided
    - Design upgrade status is provided
- **Contract Awarded for the Design and Prototype Fabrication of an Association of American Railroads (AAR) Standard S-2043 Compliant Cask Car (a.k.a. Atlas Cask Car) and Buffer Cars**
  - A recent design change to the Atlas cask car could allow it to accommodate all of the above transportation casks including the HI-STAR 190 SL and XL

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Transportation Cask Readiness Summary

- **No Certification Issues Identified that Require SNF Re-Packaging**
- **Various actions are necessary to support transportation readiness:**
  - 2 Transport Casks (MP-187 & TS-125) Require an Update from 1985 to 1996 IAEA requirements
  - No Impact Limiters have been Fabricated for Any Cask
  - Very Few Casks have been Fabricated
  - Validation of As Fabricated and As Loaded SNF Contents Meet the CoC at the Time of Shipment
  - 6 damaged Fuel Assemblies at Rancho Seco are Not in Damaged Fuel Cans
  - Mismatches between Transport CoC and Storage CoC Parameters such as Min/Max Burn-up, Drying Methods, Min./Max Enrichment, etc.

Storage-Transport-Storage (72-71-72) Operational Sequence

- **DOE is Supporting Resolution of Potential Issues Associated with a Storage–Transport–Storage Operational Sequence**
  - ASME Code Case requested by the NRC to define canister inspection criteria, frequencies, methods, etc.
  - EPRI Extended Storage Collaboration Program,
    - Reactor ISFSI canister inspections
    - *In-Situ* canister inspection method development
  - Design Report and Topical Safety Analysis Report for the Pilot ISF

Potential New Container Concepts: Standardized Transportation, Aging and Disposal (STAD) Canisters

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- **STAD Canister Concepts were Developed for Assessment of STAD Integration (when/where/what) into a Waste Management System**
  - Feasibility Studies in Task Order 12
    - Sizes proposed were Small (4 PWR/9 BWR), Medium (12 PWR/32 BWR), and Large (21 PWR/44 BWR by AREVA and 24 PWR/68 BWR by Energy*Solutions*)
  - STAD specifications and rationale documents developed by ORNL
    - The specified sizes were Small (4 PWR/9 BWR), Medium (12 PWR/32 BWR), and Large (21 PWR/44 BWR)
    - Key specifications included a canister lifetime (for storage and transportation) of 150 years and the use of corrosion resistant neutron absorbers (powder metallurgy borated stainless steel)
  - Evaluated Interim Storage Facility receipt and storage methods in Task Order 16
  - Developed a generic design for a small STAD canister system in Task Order 18
    - Four-canister carrier to facilitate loading, storage and transportation
  - Evaluated operational impacts for loading various STAD sizes in Task Order 21
    - Proposed approach to optimize operations and minimize impacts

Sources:

"Task Order 12 – Standardized Transportation, Aging and Disposal Canister Feasibility Study", AREVA, RPT-3008097-000, Rev. 1., June 21, 2013
"Task Order 12 – Standardized Transportation, Aging and Disposal Canister Feasibility Study", Energy*Solutions* Team, June 2013
"Task Order 16 Generic Design Alternatives of Dry Storage of SNF", CB&I May 15, 2015
"Task Order 18: Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems", Energy*Solutions* Team, Updated Final Report, May 14, 2015
"Task Order 21: Operational Requirements for Standardized Dry Fuel Canister Systems", Energy*Solutions* Team, Updated Final Report, June 19, 2015
"Performance Specification for Standardized Transportation, Aging and Disposal Canister Systems", FCRD-NFST-2014-000579 Rev. 2, July 20, 2015
"Rationale for the Performance Specification for STAD Systems", FCRD-NFST-2015-000106 Rev. 1, July 20, 2015

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Example STAD Canister Attributes from Recent Study Tasks with Industry

Parameter	Canister variant		
Capacity (Assemblies)	4 PWR/9 BWR[1]	12 PWR/32 BWR[2]	21 PWR/44 BWR[3]
Thermal Capacity (kW)	8 (storage) or 6 (transport)[a]	TBD	TBD
External Length (in.)	196[b]	194[c]	198[c]
External Diameter (in.)	29	52	66.25
Cavity Length (in.)	180	183	181.5[d]
Cavity Diameter (in.)	28.5	51	64.75
Weight Loaded (pounds)	13,280 (4 PWR) 13,804 (9 BWR)	46,500 (12 PWR) 50,000 (32 BWR)	TBD
Weight Empty (pounds)	6,380 (4 PWR) 7,450 (9 BWR)	26,100 (12 PWR) 27,500 (32 BWR)	TBD

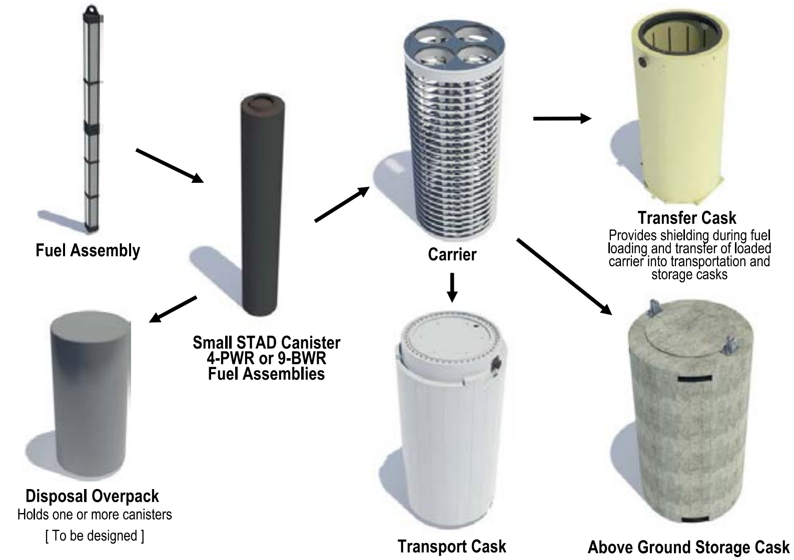
[a] For a single canister based on loading four small STAD canisters in an overpack.
[b] Includes integral lifting ring
[c] Does not include lifting ring
[d] "Cell Length" based on Task Order 12 report from AREVA
TBD = To be determined. Based on current licensed designs, thermal capacities up to 32 kW for storage and 24 kW for transportation are licensable for higher capacity systems.

Sources:
[1]Task Order 18 – Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems, Energy*Solutions* Team, Updated Final Report, May 14, 2015Task
[2]Task Order 12 – Standardized Transportation, Aging and Disposal Canister Feasibility Study, Energy*Solutions* Team, June 2013
[3]Task Order 12 – Standardized Transportation, Aging and Disposal Canister Feasibility Study, AREVA, RPT-3008097-000, Rev. 1., June 21, 2013

Small STAD Canister System Concept Characteristics

Parameter	Canister	Transport Cask	Storage Cask
Capacity (Assemblies)	4 PWR/9 BWR	16 PWR/36 BWR	16 PWR/36 BWR
Thermal Capacity (kW)	8	24	32
External Length (in.)	196	219	222
External Diameter (in.)	29	106	144
Cavity Length (in.)	180	201	200
Cavity Diameter (in.)	28.5	78	85
Weight Loaded (lbs)	13,280 (4 PWR) 13,804 (9 BWR)	294,686 (4 PWR) 296,782 (9 BWR)	343,920 (4 PWR) 346,016 (9 BWR)
Weight Empty (lbs)	6,380 (4 PWR) 7,450 (9 BWR)	212,266	267,000

AN INTEGRATED SYSTEM FOR TRANSFER, STORAGE, TRANSPORTATION AND DISPOSAL



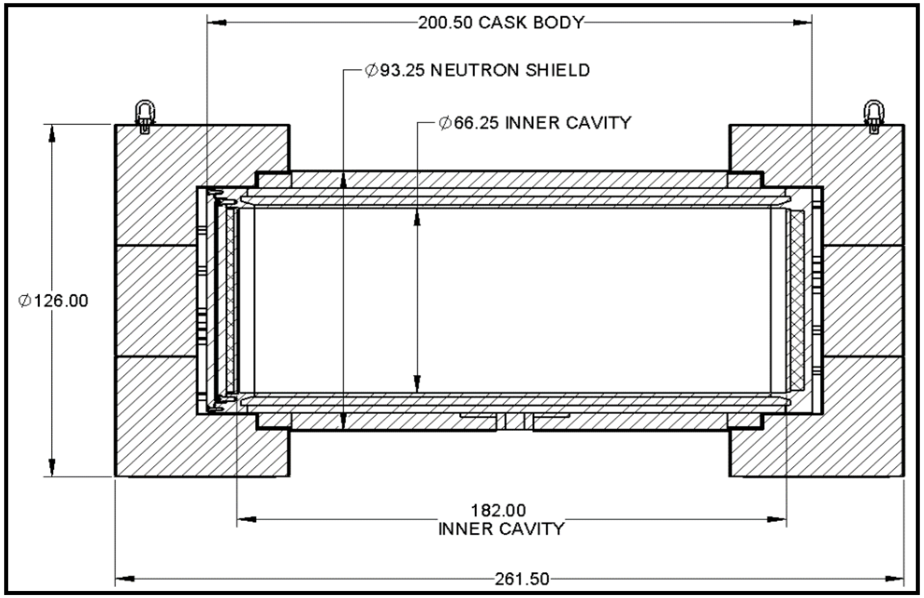
Source: “Task Order 18: Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems”, Energy*Solutions* Team, Updated Final Report, May 14, 2015

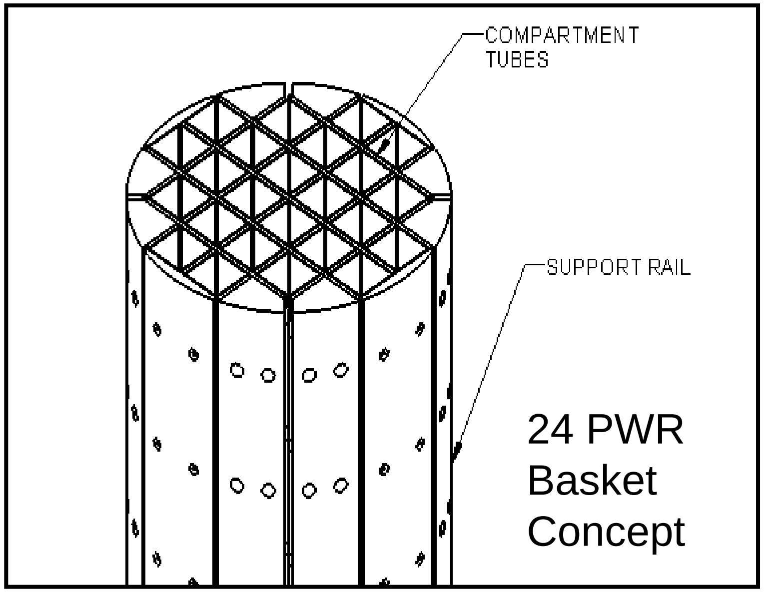
Potential New Container Concepts:
Reusable Rail Transportation Casks for Shipment of High-Burnup Short-Cooled Bare SNF

- **The key parameters/objectives for the cask concepts are**
  - Maximum width (including impact limiters) of 128 inch
  - Shipment of HBU SNF with a target average assembly burnup up to 62.5 GWd/MTU with up to 5.0 wt.% enrichment and out-of-reactor cooling time of 5 years
  - Concepts for two PWR and two BWR baskets
    - A basket with all SNF assemblies bare in the basket cells
    - A basket with all SNF assemblies in damaged fuel cans (DFCs)
    - A third basket variant that could accommodate bare SNF assemblies as well as DFCs in a few basket locations could be considered
  - Reasonable assurance that the design concepts can accommodate essentially the entire SNF inventory
    - Potential limitations due to fuel assembly length are acceptable
    - Crane capability considerations (target under-hook weight of 125 tons)
- **Concepts by AREVA and Energy*Solutions* Teams**
  - These Casks are NOT Sufficiently Defined to Begin Licensing

Reusable Transport Cask Concepts for Bare (Non-Canistered) SNF - AREVA

- Under-hook weight <125 tons
  - Requires draining as cask is lifted from pool
- Diameter (with impact limiters) = 126 inches
- Overall heat load = 30.4 kW
  - Four basket thermal zones based on kW/assembly (burnup and cooling time)
- Capacity of 24 PWR or 61 BWR assemblies
  - Accommodates bare fuel or DFCs in all positions
- Accommodates entire SNF inventory except STP and CE 16x16 with nonfuel hardware (NFH)
- Burnup credit for PWR SNF as-loaded configuration
- Dual-lid design to facilitate moderator exclusion licensing under HAC (ISG-19)





Source: "Task Order 17- Cask Design Study Report", AREVA,RPT-3011681-000, March 25, 2015

Reusable Transport Cask Concepts for Bare (Non-Canistered) SNF – Energy*Solutions*

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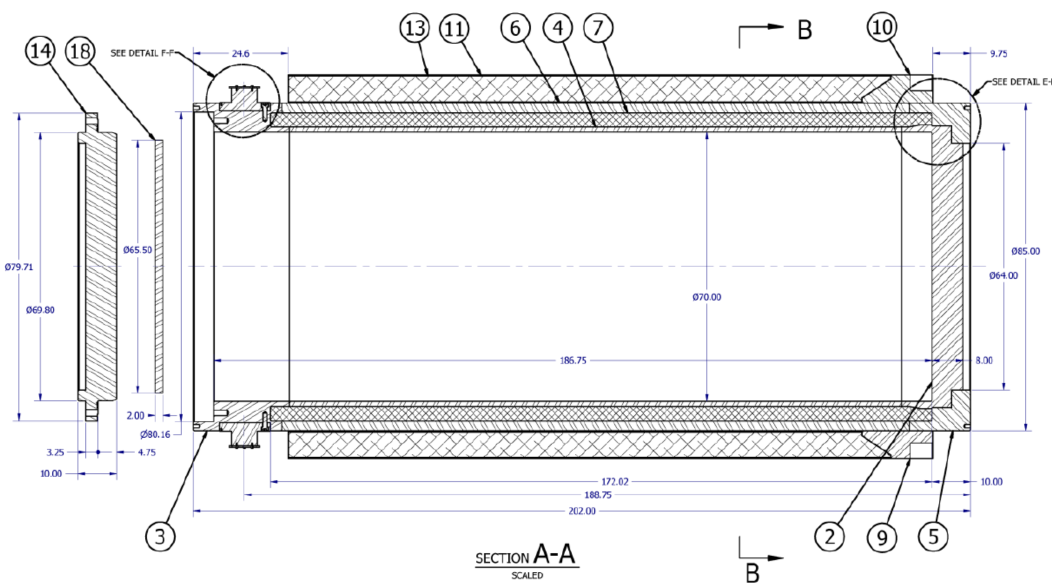
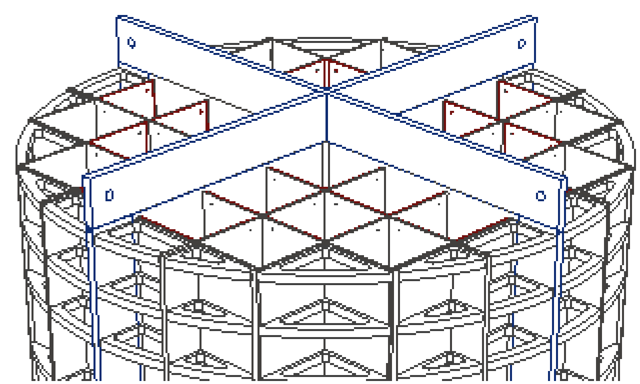
- Under-hook weight <125 tons
  - Requires draining as cask is lifted from pool
- Diameter (with impact limiters) = 128 inches
- Overall heat load = 24 kW (no zone restrictions)
- Two basket variants
  - Capacity of 32 PWR or 68 BWR bare assemblies
    - Accommodates 8 DFCs in corner positions
  - Capacity of 28 PWR or 61 BWR DFCs
- Accommodates entire SNF inventory except STP and CE 16x16 with NFH
  - Average weight limit <1,500 lbs
  - Proposed a short cask variant to accommodate heavier assemblies
- Burnup credit for PWR SNF as-loaded configuration and HAC
- Single-lid design





32 PWR Basket Concept

Source: "DOE Advisory and Assistance Services Contract Task Order 17: Spent Nuclear Fuel Transportation Cask Design Study" Energy*Solutions*, Updated Final Report, April 22, 2015

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Conclusions

- **Data Tables Provided for:**
  - 51 Welded-lid canisters
  - 35 Canistered SNF storage overpacks/casks
  - 11 Non-canistered SNF storage casks (currently 2 also licensed for transport)
  - 17 Transportation containers
    - 11 Canistered SNF transportation overpacks
    - 4 Non-canistered SNF storage/transport casks (only 2 have transportation licenses)
    - 2 Non-canistered SNF transport-only casks
- **Preliminary Information Provided for:**
  - 3 STAD canisters concepts (small, medium, large) each for PWR and BWR
  - 2 Reusable non-canistered SNF (bare fuel) rail transportation cask concepts

Questions?