Appendix E
FCT Document Cover Sheet

Name/Title of Deliverable/Milestone	Assessment of the Transportability of Storage-Only Used Nuclear Fuel Canisters
Work Package Title and Number	Transportation FT-14OR081302
Work Package WBS Number	1.02.08.13
Responsible Work Package Manager	John M. Scaglione (Name/Signature) John M. Scaglione

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Date: 2014.09.24 16:04:18 -04'00'

Date Submitted 9/24/2014

Quality Rigor Level for Deliverable/Milestone	☐ QRL-3	☐ QRL-2	☐ QRL-1 ☐ Nuclear Data	☒ N/A*

This deliverable was prepared in accordance with ORNL
(Participant/National Laboratory Name)

QA program which meets the requirements of
☒ DOE Order 414.1 ☒ NQA-1-2000

This Deliverable was subjected to:

☒ Technical Review	☐ Peer Review
Technical Review (TR)	**Peer Review (PR)**
Review Documentation Provided	**Review Documentation Provided**
☐ Signed TR Report or,	☐ Signed PR Report or,
☒ Signed TR Concurrence Sheet or,	☐ Signed PR Concurrence Sheet or,
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Publication Tracking System ▸ PTS

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Pub ID	51495
Title	Assessment of the Transportability of Storage-Only Used Nuclear Fuel Canisters
Status	Submitted for review
Communication Type	Letter report
ORNL Review?	Scientific communication that requires ORNL review
Information Category	Internal Use Only
ORNL Report Classification	Topical
Contact Person	Bowen, Douglas G
Responsible Organization	Reactor & Nuclear Systems Division (50159781)
Prepared at	This scientific communication is being prepared by someone at ORNL.
Internal Access	Available to this document's authors and reviewers / approvers and line management.
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Acknowledgements	

Workflow

08/27/2014 17:04:35	Draft	Scaglione, John M by Ragle, Katherine L	
08/27/2014 17:06:21	Author Certification	Bowen, Douglas G	
08/27/2014 17:06:21	Submitted for review	Bowen, Douglas G	
08/27/2014 17:20:34	Supervisor	Wagner, John C by Ragle, Katherine L	Approved
09/04/2014 07:19:49	Technical Reviewer	Feldman, Matthew R	Recommended
09/16/2014 17:58:52	Technical Reviewer	Howard, Rob L	Recommended
09/23/2014 16:18:15	Technical Editor	Raney, Rose B	Recommended
09/23/2014 16:27:54	Administrative Check	Ragle, Katherine L	Recommended
09/24/2014 14:44:31	Supervisor	Wagner, John C by Poarch, Sandra J	Approved
09/24/2014 15:47:43	Program Manager	Scaglione, John M	Approved
	Waiting on the following review(s)		
	Division Approver	Wagner, John C	
	Distributed	Bowen, Douglas G	

View Comments from Reviewers

Requested Approval Date	September 02, 2014
Document	FCRD_UFD Report_Transportability_Assessment_Final_09-23-2014_v2_clean.docx
Abstract	
Report Number	ORNL/LTR-2014/383
Secondary ID Number	FCRD-UFD-2014-000511
Additional Information	
User Facility	Not applicable
Account Number(s)	35304984
B&R Codes	AF5865010
IANs	
FWPs	NEAF346
Overhead Categories	
Proposal Numbers	
Keywords	

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Assessment of the Transportability of Storage-Only Used Nuclear Fuel Canisters

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Office of Used Nuclear Fuel Disposition

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September 24, 2014
FCRD-UFD-2014-000511

SUMMARY

This report documents work performed supporting the U.S. Department of Energy Office of Nuclear Energy Fuel Cycle Technologies Used Fuel Disposition Campaign under work breakdown structure element 1.02.08.13, "ST Transportation." In particular, this report fulfills the M4 milestone M4FT-14OR0813021, "Initial assessment and recommendations for transportation of storage only canisters," documenting an overview of storage-only used nuclear fuel (UNF) canisters/casks and assessing their transportability options. The following UNF canisters/casks were considered: VSC-24, CASTOR V/21 & X33, NAC I-28, Westinghouse MC-10, and five NUHOMS® canisters (24P, 32P, 12T, 52B, and 07P). The primary issue with these storage-only containers involves shipping them and their contents, without repackaging, to a consolidated storage location or geologic repository. Approving a storage-only canister or cask for transportation requires a Nuclear Regulatory Commission license in accordance with the regulations in 10 Code of Federal Regulations (CFR) Part 71. These regulations ensure the package can be transported safely for all normal conditions of transport and hypothetical accident conditions. This work has concluded that obtaining a transportation license may be challenging for many of these containers because the structural design is not sufficiently robust to survive the rigorous testing required for the hypothetical accident conditions (10 CFR §71.73). Several options exist for the transportation of these storage-only containers, including the "Specific Exemption" provision in 10 CFR §71.12 and the "Special Package Authorization" in 10 CFR §71.41(d) that could also be considered for the one-time transport of these UNF storage-only canisters/casks. Based on this study, it appears the exemption criteria in 10 CFR §71.12 would be the most successful if repackaging operations cannot be performed.

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ACRONYMS

BWR	boiling water reactor
CFR	Code of Federal regulations
DOE	U.S. Department of Energy
DSC	dry shielded canister
HAC	hypothetical accident conditions
INL	Idaho National Laboratory
ISFSI	independent spent fuel storage installation
MSB	multiassembly sealed basket
NCT	normal conditions of transport
NRC	Nuclear Regulatory Commission
PWR	pressurized water reactor
SARP	safety analysis report for packaging
UNF	used nuclear fuel

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USED NUCLEAR FUEL DISPOSITION ASSESSMENT OF THE TRANSPORTABILITY OF STORAGE-ONLY USED NUCLEAR FUEL CANISTERS

1. INTRODUCTION

This report provides an overview of the types of storage-only canisters licensed in the US for used nuclear fuel (UNF), and it explores potential options to enable these canisters to be transportable. A review of applicable regulations for UNF canisters for the purposes of storage and transportation was performed. Various transportation methods were explored for the transportation of the storage-only canisters and any constraints that can adversely affect the transportation options (e.g., speed restrictions).

2. STORAGE ONLY CANISTERS EVALUATED

This section provides background information regarding the canisters used for the storage of UNF. The locations of storage-only canisters are provided, along with an overview of design information and canister licenses. A discussion of applicable standards for cask storage and transportation activities is also provided. The focus of this report is on those canisters licensed for storage only activities.

Table 1 provides details about the seven canisters used for UNF storage that are licensed only for storage purposes at various sites. Figure 1 illustrates the distribution of storage-only canisters used in the US based on a summary of the data in Table 1. About 67% of the storage-only canister designs being used are the NUHOMS® 24P (50.1%) and the NUHOMS® 32P (16.8%) stored in a horizontal concrete overpack configuration. About 22.0% of the NUHOMS® 24P canisters used for storage-only operations are the NUHOMS® 24PHB canister type.

Table 1. Storage-only UNF canisters in the US

Utility	Reactor	Type	License type	Vendor	Cask system	Canister or cask type	Total canisters or casks loaded	Assemblies stored	Storage configuration
Constellation	Calvert Cliffs	PWR[a]	SS[b]	TN[c]	NUHOMS®	24P	48	1152	Canister in horizontal concrete overpack
Constellation	Calvert Cliffs	PWR	SS	TN	NUHOMS®	32P	21	672	Canister in horizontal concrete overpack
DOE	INL		SS	TN	NUHOMS®	12T	29[1]	177	Canister in horizontal concrete overpack
Dominion	Surry	PWR	SS	GNS	Castor	V/21 and X33	26	558	Bare fuel
Dominion	Surry	PWR	SS	NAC	NAC-I28	NAC-I28	2	56	Bare fuel
Dominion	Surry	PWR	SS	W	MC-10	MC-10	1	24	Bare fuel
Duke	Oconee	PWR	GL/SS	TN	NUHOMS®	24P	84	2016	Canister in horizontal concrete overpack
Duke	Oconee	PWR	GL	TN	NUHOMS®	24PHB	38	912	Canister in horizontal concrete overpack
Entergy	ANO	PWR	GL	BFS/ES	FuelSolutions	VSC-24	24	576	Canister in concrete overpack
Entergy	Palisades	PWR	GL	BFS/ES	FuelSolutions	VSC-24	18	432	Canister in vertical concrete overpack
FirstEnergy	Davis-Besse	PWR	GL	TN	NUHOMS®	24P	3	72	Canister in horizontal concrete overpack
FPL	Point Beach	PWR	GL	BFS/ES	FuelSolutions	VSC-24	16	384	Canister in vertical concrete overpack
PPL	Susquehanna	BWR	GL	TN	NUHOMS®	52B	27	1404	Canister in horizontal concrete overpack
Progress	Robinson	PWR	SS	TN	NUHOMS®	7P	8	56	Canister in horizontal concrete overpack

[a] PWR = pressurized water reactor
[b] SS = Site specific license
[c] TN = Transnuclear, Inc.
[d] GNS = General Nuclear Services
[e] NAC = NAC International
[f] W = Westinghouse
[g] GL = General license
[h] ANO = Arkansas Nuclear One
[i] BFS/ES = BNFL Fuel Solutions/EnergySolutions
[j] FPL = Florida Power and Light
[k] PPL = Pennsylvania Power and Light (formerly)
[l] BWR = boiling water reactor

[1] The NUHOMS® 12T canisters in the inventory are DOE owned.

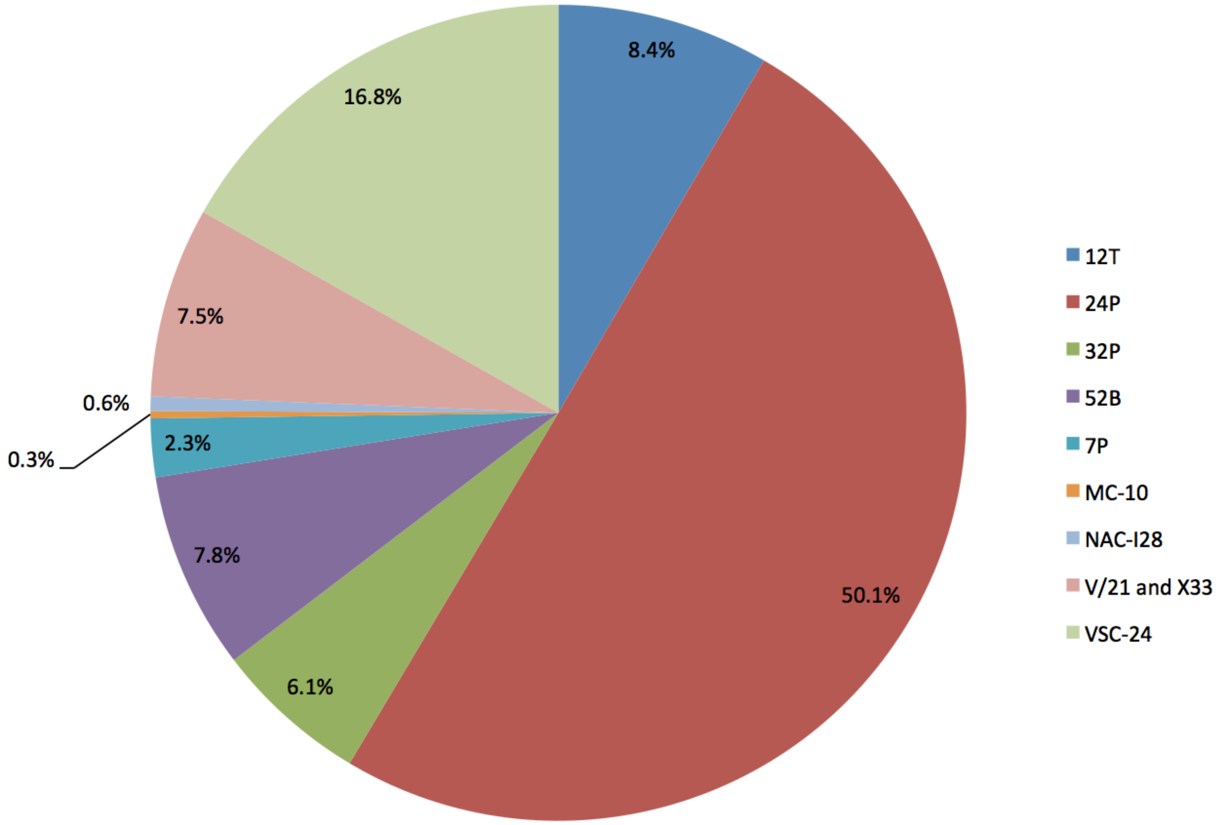


Figure 1. Illustration of the total canisters loaded as a function of canister type.

2.1 Overview of Canister Design

There are currently ten types of UNF canisters approved only for storage activities. The design specifications and illustrations for these UNF canisters are included to provide understanding regarding their original intention (for storage only or for storage and transportation) and their licenses. The NAC-I28, MC-10, NUHOMS® 7P, 12T, 24P, 24PHB, 32P, and 52B canisters and the Fuel Solutions VSC-24 use horizontal storage modules. The VSC-24 canisters are typically stored vertically in a concrete overpack in an independent spent fuel storage installation (ISFSI).

2.1.1 NUHOMS® 24P

The NUHOMS® 24P is a dry shielded canister (DSC) that consists of a stainless steel cylindrical shell with welded end plates to form a containment vessel (Ref. 1). The specifications for variations of the 24P DSC are provided in Table 2. The steel basket within the canister is used to control thermal loads, to ensure subcriticality, and to provide structural support. This DSC has a 24 pressurized water reactor (PWR) fuel assembly capacity. There are four types of 24P canisters, two for high burnups (24PHB) and two for lower burnups (24P). The high burnup version has a cavity length about 6 in. longer than the low burnup version. These DSCs are licensed specifically for storage activities in horizontal concrete casks. The canisters are not licensed for transportation activities. Figure 2 provides an illustration of the NUHOMS® 24P canister. As summarized in Table 1, two versions of the 24P canister are being used at Calvert Cliffs (48 canisters), Oconee (84 24P canisters and 38 24PHB canisters), and Davis-Besse (3 canisters).

Table 2. NUHOMS® 24P/PHB specifications (Ref. 1)

Attribute	Types of dry shielded canisters			
	NUHOMS® 24PS	**NUHOMS® 24PL**	**NUHOMS® 24PHBS**	**NUHOMS® 24PHBL**
Capacity (intact assemblies)	24 PWR	24 PWR	24 PWR	24 PWR
Weight (lb.)				
Empty	37,761	35,426	37,761	35,426
Loaded	78,128	75,794	78,128	75,794
Thermal				
Design heat rejection (kW)	24	24	24	24
Maximum per assy heat load (kW)	1.0	1.0	1.3	1.3
Maximum burnup (GWd/MTU)	45	45	55	55
Shape	Cylindrical	Cylindrical	Cylindrical	Cylindrical
Dimensions (in.)				
Overall length	186.29	186.29	186.17	186.17
Cross section	67.19	67.19	67.19	67.19
Cavity length	167	173	167	173
Wall thickness	0.625	0.625	0.625	0.625
Materials of construction				
Canister body	SS	SS	SS	SS
Basket	Steel	Steel	Steel	Steel
Shield plugs	CS	SS/Pb	CS	SS/Pb
Cavity atmosphere	He	He	He	He
Maximum Leak Rate (atm-cm^3/sec)	1×10^{-4}	1×10^{-4}	1×10^{-7}	1×10^{-7}
Canister type	Storage only	Storage only	Storage only	Storage only
Transfer cask	Standard/ OS197/OS197H	Standard/ OS197/OS197H	Standard/ OS197/OS197H	Standard/ OS197/OS197H
Storage overpacks	HSM model 80 or 102	HSM model 80 or 102	HSM model 102	HSM model 102
Transport cask	N/A – not licensed for transport	N/A – not licensed for transport	N/A – not licensed for transport	N/A – not licensed for transport

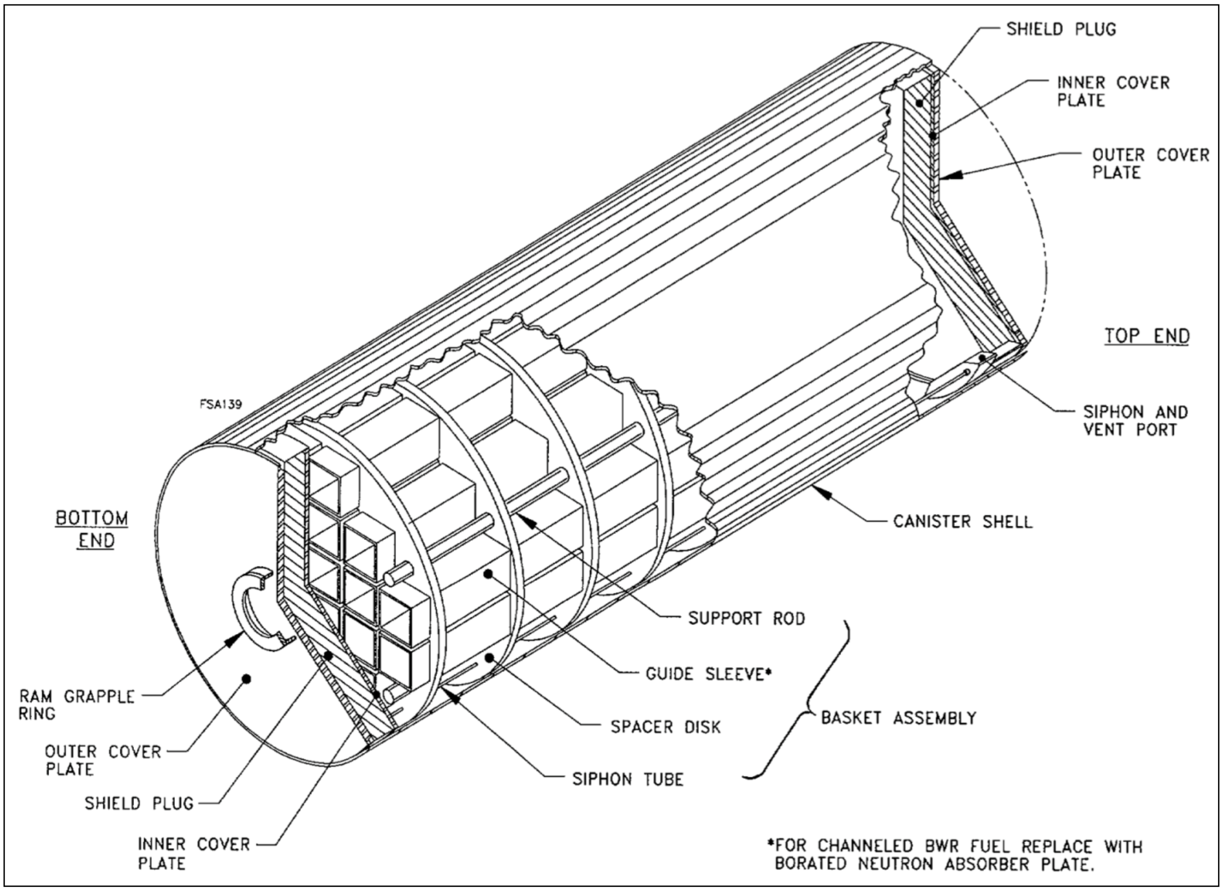


Figure 2. NUHOMS® 24P – DSC.

2.1.2 NUHOMS® 32P

The NUHOMS® 32P DSC is used to store UNF at the Calvert Cliffs Nuclear Power Plant ISFSI. There are a total of 21 canisters each with up to 32 PWR fuel assemblies present (Table 1). The primary difference between the 32P DSC design and other 32P designs (e.g., the 32PHB) is that the steel and aluminum frame basket rails have been replaced with solid aluminum rails (Ref. 2). These canisters were upgraded and licensed for the use of high burnup UNF (> 45 GWd/MTU). Ref. 3 states that the Calvert Cliffs site-specific canister design contains neutron poisons for criticality safety control for normal, off-normal, and credible accident conditions during storage activities. Figure 3 illustrates the 32PHB canister, which is similar to the 32P DSC.

Table 3. NUHOMS®-32P Specifications (Ref. 3)

Attribute	Types of dry shielded canister
	NUHOMS® 32
Capacity (intact assemblies)	32 PWR
Weight (lb.)	
Empty	48,402
Loaded	92,402
Thermal	
Maximum burnup (GWd/MTU)	52
Shape	Cylindrical
Dimensions (in.)	
Overall length	176.5
Cross section	67.25
Wall thickness	0.625
Materials of construction	
Canister body	SS
Basket	Steel
Shield plugs	CS
Cavity atmosphere	He
Canister type	Storage only
Transfer cask	Standard/ OS197/OS197H (Same as NUHOMS® 24P DSC transfer cask)
Transport cask	N/A – Not licensed for transport

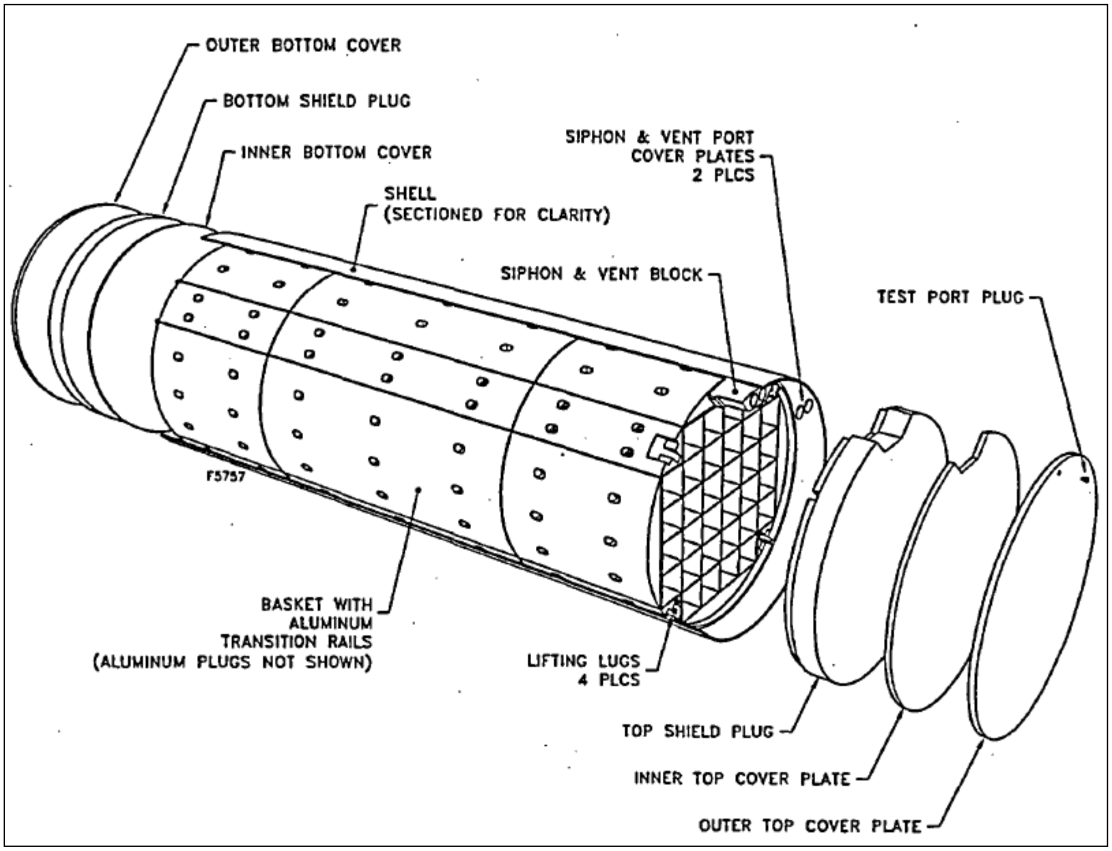


Figure 3. NUHOMS® 32PHB – DSC.

2.1.3 NUHOMS® 12T

The transportation of TMI-2 core debris from the TMI-2 site to Idaho National Laboratory (INL) was accomplished using the Nuclear Packaging, Inc., NUPAC-125B rail cask. This rail cask was designed specifically to contain the plutonium-bearing materials from TMI-2. This transportation cask was designed and licensed over about an 18 month period specifically for the TMI debris canisters. The casks were unloaded at INL, and the debris canisters were placed in a wet storage configuration for over 10 years. The debris canisters were then loaded into the NUHOMS® 12T dry shielded canisters and placed into dry storage. This DSC consists of a steel cylindrical shell with welded end plates to form a containment vessel (Ref. 1). Specifications for variations of the 12T DSC are provided in Table 4. This DSC has the capacity of 12 TMI-2 fuel debris canisters in a steel basket.

These DSCs are licensed specifically for storage activities in horizontal concrete casks. The canisters are not licensed for transportation activities. Figure 3 provides an illustration of the NUHOMS® 12T canister. Table 1 specifies that 29 canisters (177 total assemblies) of TMI-2 debris are stored at INL for the U.S. Department of Energy (DOE).

Table 4. NUHOMS®-12T Specifications (Ref. 1)

Attribute	NUHOMS® 12T
Capacity (intact assemblies)	12 TMI-2 fuel debris canisters
Weight (lb.)	
Empty	N/A
Loaded	<70,000
Thermal	
Design heat rejection (kW)	0.86
Maximum fuel clad temp. (^oF)	N/A
Maximum burnup (GWd/MTU)	3.2
Shape	Cylindrical
Dimensions (in.)	
Overall length	163.5
Cross section	67.2
Cavity length	151.0
Wall thickness	0.625
Materials of construction	
Canister body	CS
Basket	CS
Shield plugs	CS
Cavity atmosphere	Air
Maximum leak rate (atm-cm^3/sec)	N/A
Canister type	N/A
Transfer cask	N/A
Storage overpacks	N/A
Transport cask	N/A – not licensed for transport.

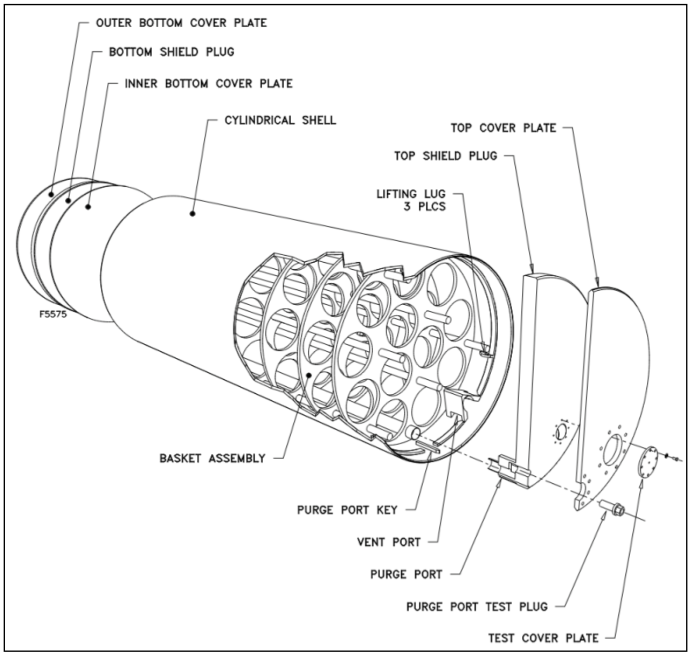


Figure 4. NUHOMS®12T DSC.

2.1.4 NUHOMS® 52B

The NUHOMS® 52B is a DSC that consists of a steel cylindrical shell with welded end plates to form a containment vessel (Ref. 1). The specifications for variations of the 52B DSC are provided in Table 5. This DSC has the capacity of 52 boiling water reactor (BWR) assemblies in a steel basket. These DSCs are licensed specifically for storage activities in horizontal concrete casks. The canisters are not licensed for transportation activities. Figure 4 provides an illustration of the NUHOMS® 52B canister. Table 1 specifies that there are 27 canisters of BWR fuel at Susquehanna.

Table 5. NUHOMS® 52B Specifications (Ref. 1)

Attribute	NUHOMS® 52B
Capacity (intact assemblies)	52 BWR
Weight (lb.)	
Empty	37,225
Loaded	74,925
Thermal	
Design heat rejection (kW)	19.24
Maximum per assy heat load (kW)	0.37
Maximum burnup (GWd/MTU)	35.0
Shape	Cylindrical
Dimensions (in.)	
Overall length	196.0
Cross section	67.19
Cavity length	177.5
Wall thickness	0.625
Materials of construction	
Canister body	SS
Basket	CS/B-SS
Shield plugs	CS
Cavity atmosphere	He
Maximum leak rate (atm-cm^3/sec)	1×10^{-4}
Canister type	N/A
Transfer cask	N/A
Storage overpacks	N/A
Transport cask	Not licensed for transport

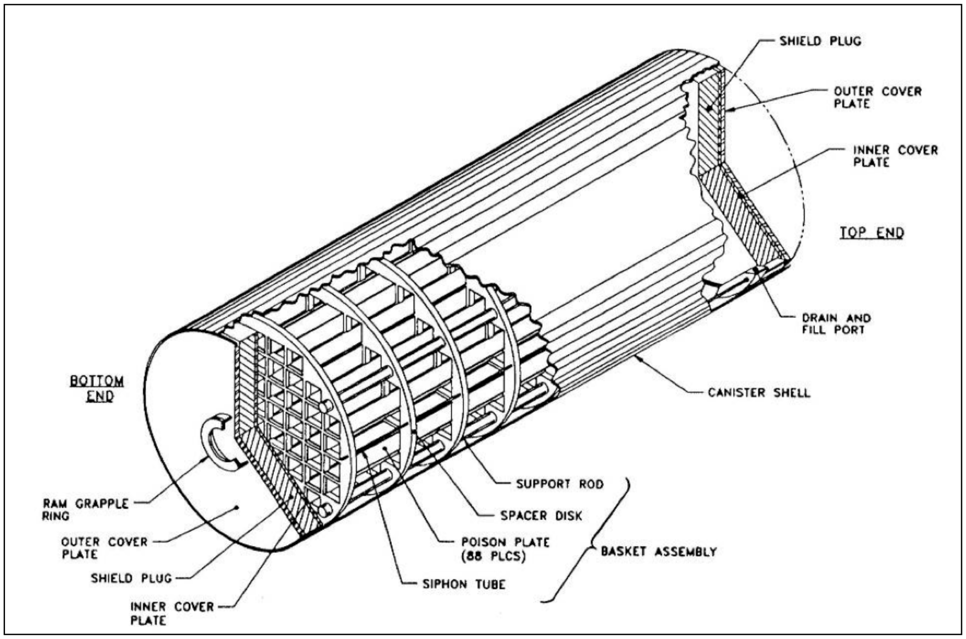


Figure 5. NUHOMS® 52B – dry shielded canister.

2.1.5 NUHOMS® 07P

The NUHOMS® 07P is a DSC that consists of a steel cylindrical shell with welded end plates to form a containment vessel (Ref. 1). The specifications for variations of the 07P DSC are provided in Table 1 shows 8 canisters (56 total assemblies) being stored at the Robinson nuclear power plant.

This DSC has the capacity of 7 PWR assemblies in a steel and aluminum basket. These DSCs are licensed specifically for storage activities in horizontal concrete casks. The canisters are not licensed for transportation activities. Figure 6 provides an illustration of the NUHOMS® 07P canister.

Table 6. NUHOMS® 07P specifications (Ref. 1)

Attribute	NUHOMS® 07P
Capacity (intact assemblies)	7 PWR
Weight (lb.)	
Empty	N/A
Loaded	22,000
Thermal	
Design heat rejection (kW)	7.0
Maximum fuel clad temp. (^{o}F)	<716
Maximum burnup (GWd/MTU)	N/A
Shape	Cylindrical
Dimensions (in.)	
Overall length	179.0
Cross section	37.0
Cavity length	163.5
Wall thickness	0.50
Materials of construction	
Canister body	SS
Basket	SS/Al-B
Shield plugs	Pb
Cavity atmosphere	He
Maximum leak rate (atm-cm^3/sec)	1×10^{-4}
Canister type	N/A
Transfer cask	N/A
Storage overpacks	N/A
Transport cask	N/A – not licensed for transport

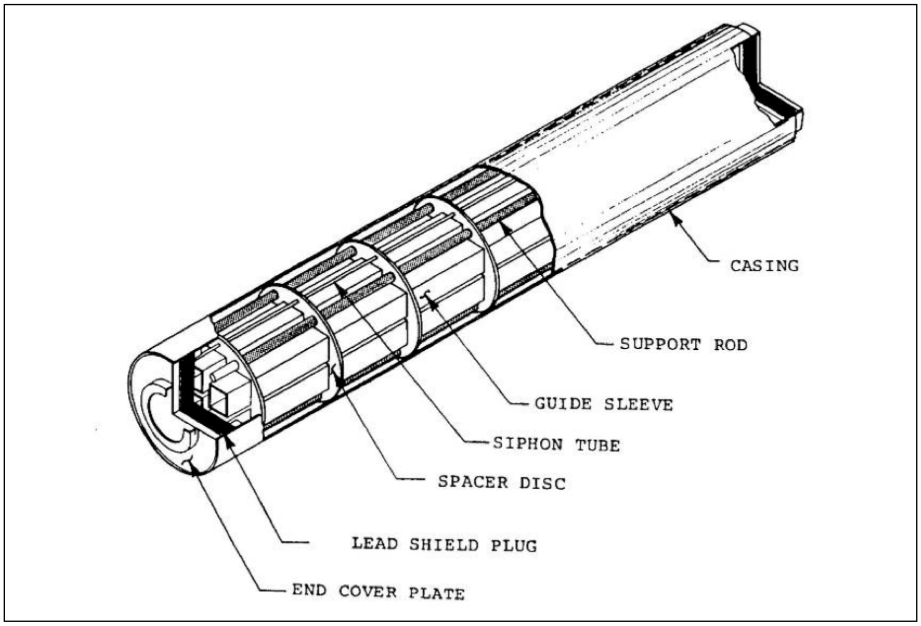


Figure 6. NUHOMS® 07P – DSC.

2.1.6 VSC-24 Multi-Assembly Sealed Basket

The VSC-24 multiassembly sealed basket (MSB) canister is designed as a steel cylindrical shell that is sealed at the bottom with a welded steel plate and at the top with welded steel shielding and structural support lids (Ref. 1).

Table 7 lists the specifications for the VSC-24 MSB, and summarizes the specifications for the VSC-24 ventilated concrete cask. The MSB provides spent fuel containment, ensures subcriticality, and provides structural support during storage, loading, and transfer operations. Figure 7 illustrates the VSC-24 MSB configuration. An MSB is loaded into a VSC-24 ventilated concrete task and staged vertically. Figure 8 illustrates the vertically oriented ventilated concrete cask.

Table 7. VSC-24 MSB specifications (Ref. 1)

Attribute	MSB
Capacity (intact assemblies)	24 PWR
Maximum weight (lb.)	
Empty without lids	21,686
Loaded	68,685
Thermal	
Design heat rejection (kW)	24
Maximum per assy heat load (kW)	1.0
Maximum Burnup (GWd/MTU)	45.0
Shape	Cylindrical
Dimensions (in.)	
Overall length	164.2-192.25
Basket length	147.5-163.6
Cross section	62.5
Wall thickness	1.00
Lid assembly thickness	12.5
Bottom plate thickness	0.75
Materials of construction	
Canister body	CS
Canister internals	CS
Shield plugs	CS, RX-277
Cavity atmosphere	He
Maximum leak rate (atm-cm^3/sec, air)	1×10^{-4}

Table 8. VSC-24 ventilated concrete cask specifications (Ref. 1)

Attribute	Ventilated Concrete Cask
Capacity (MSB)	1
Maximum loaded weight	287,920
Shape	Cylindrical
Dimensions (in.)	
Overall length	196.7 – 225.1
Overall cross section	132.0
Cavity length	174.7 – 203.1
Cavity cross section	70.5
Concrete thickness	29.0
Steel inner shell thickness	1.75
Lid thickness	0.75
Bottom thickness	24.0
Materials of construction	
Cask body	Concrete (reinforced)/steel
Outside surface dose (mrem/hr)	<100 (Side)/<200 (Top)

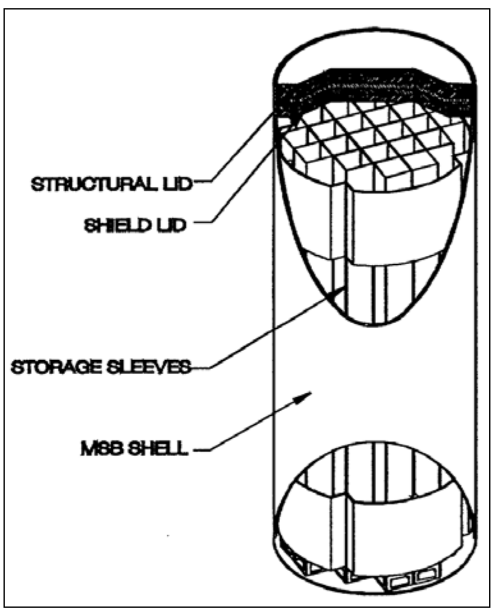


Figure 7. VSC-24 MSB (Ref. 1)

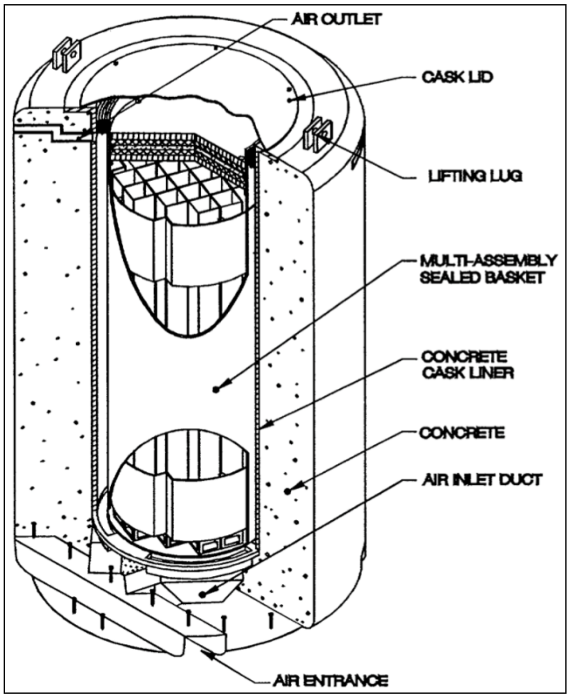


Figure 8. VSC-24 ventilated concrete cask.

2.1.7 CASTOR V/21, CASTOR X33, NAC I-28, and Westinghouse MC-10

The CASTOR V/21 and X33 are UNF dry storage casks for the dry storage of PWR fuel. The V21 and V33 casks store 21 and 33 Westinghouse PWR UNF assemblies from Dominion's Surry power station in a vertical orientation, respectively. These casks were used as part of a spent fuel research and development project to demonstrate the capability of the cask for UNF storage and transportation activities for the US DOE Office of Civilian Radioactive Waste Management (Ref. 5). These casks were licensed by the Nuclear Regulatory Commission (NRC) for the transportation of UNF from the Surry Power Station to the Nevada Test Site and ultimately to INL. The CASTOR V/21 casks were examined and tested by INL to characterize the effects of long-term storage of UNF.4 The Westinghouse MC-10 was built for a similar purpose as the CASTOR V/21 but could accept three more fuel assemblies than the CASTOR V/21 (Ref. 4). The NAC I-28 is designed to vertically store 28 intact PWR fuel assemblies. Figure 9–11 illustrate the CASTOR V/21, the CASTOR X33, the Westinghouse MC-10 cask, and the NAC I-28 cask configurations, respectively. Table 9 provides some of the CASTOR V/21 and Westinghouse MC-10 casks design specifications. These casks are currently licensed by the NRC for use at Dominion's Surry ISFSI.

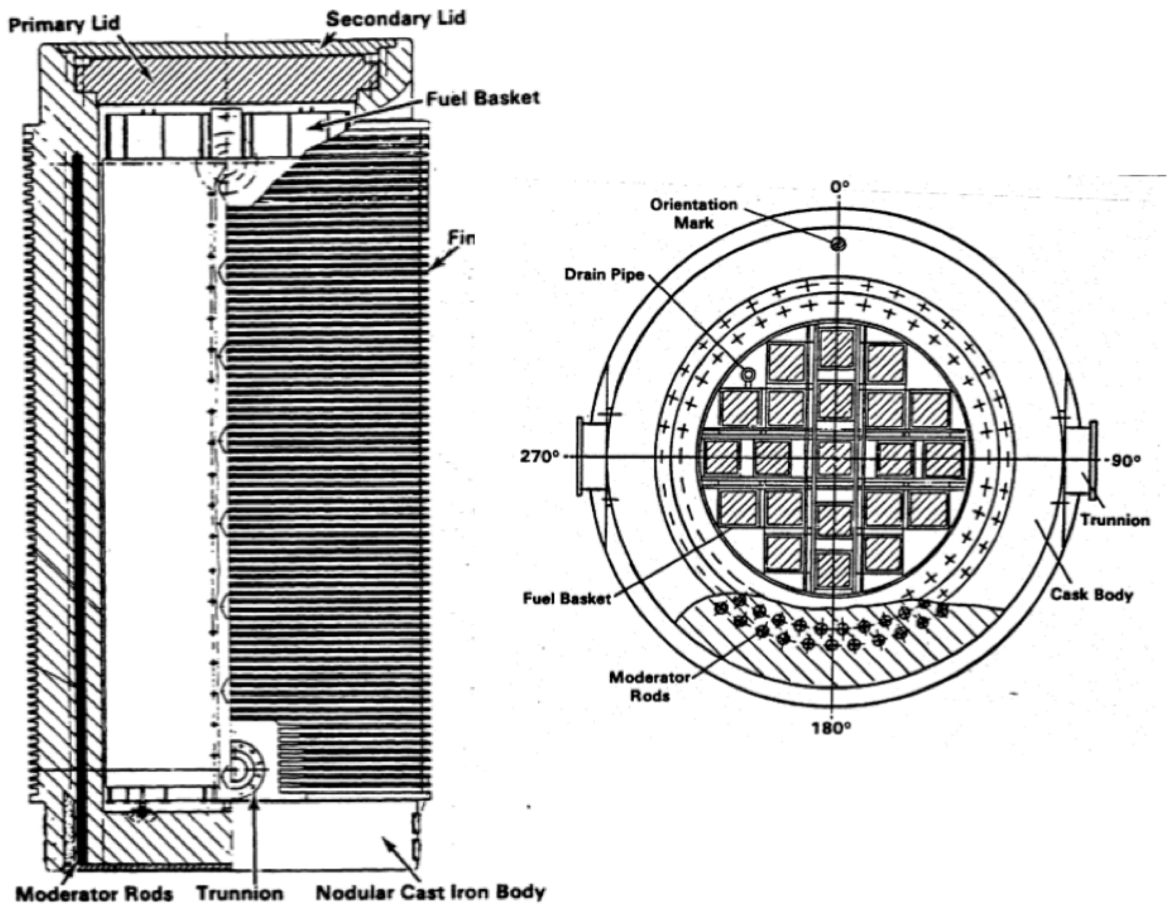


Figure 9. CASTOR V/21 ventilated concrete cask.

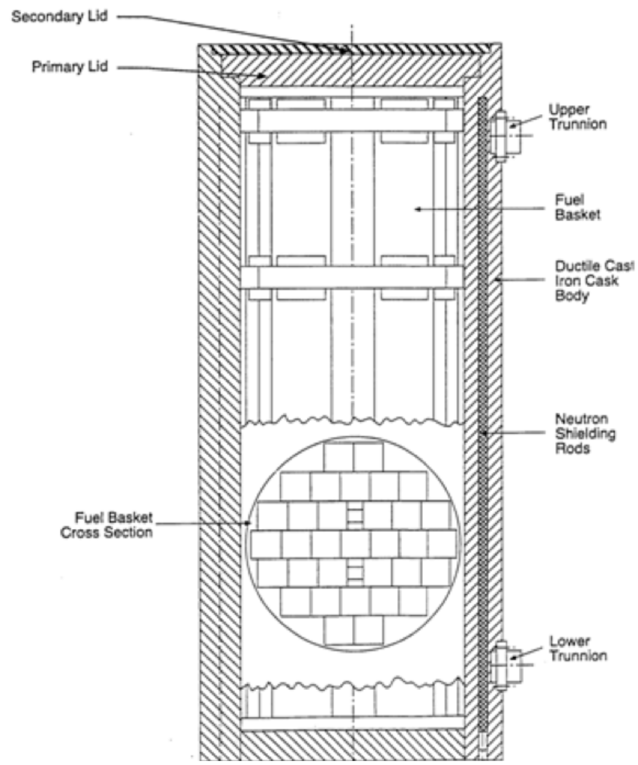


Figure 10. CASTOR X33 metal storage cask (Ref. 5)

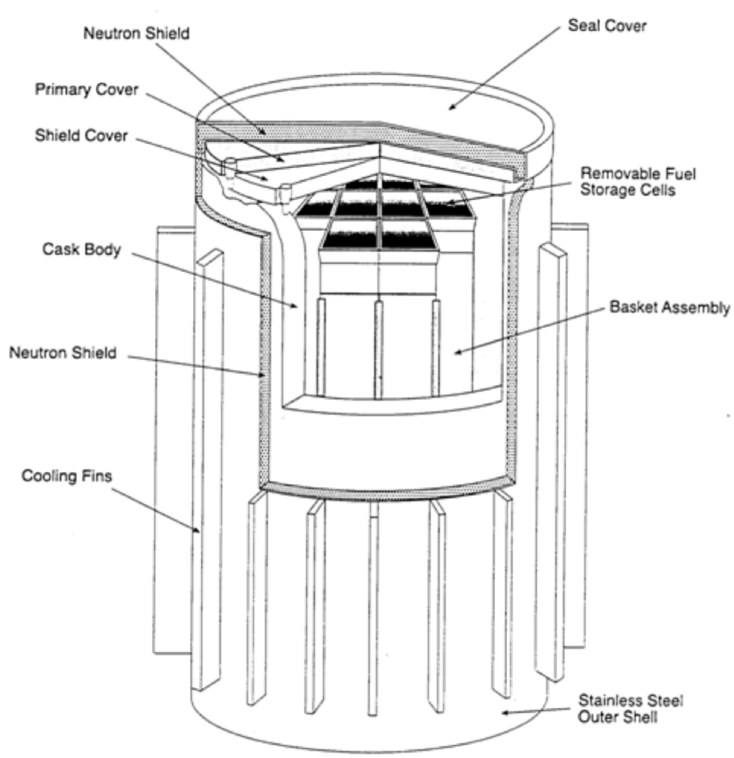


Figure 11. Westinghouse MC-10 metal storage cask (Ref. 5)

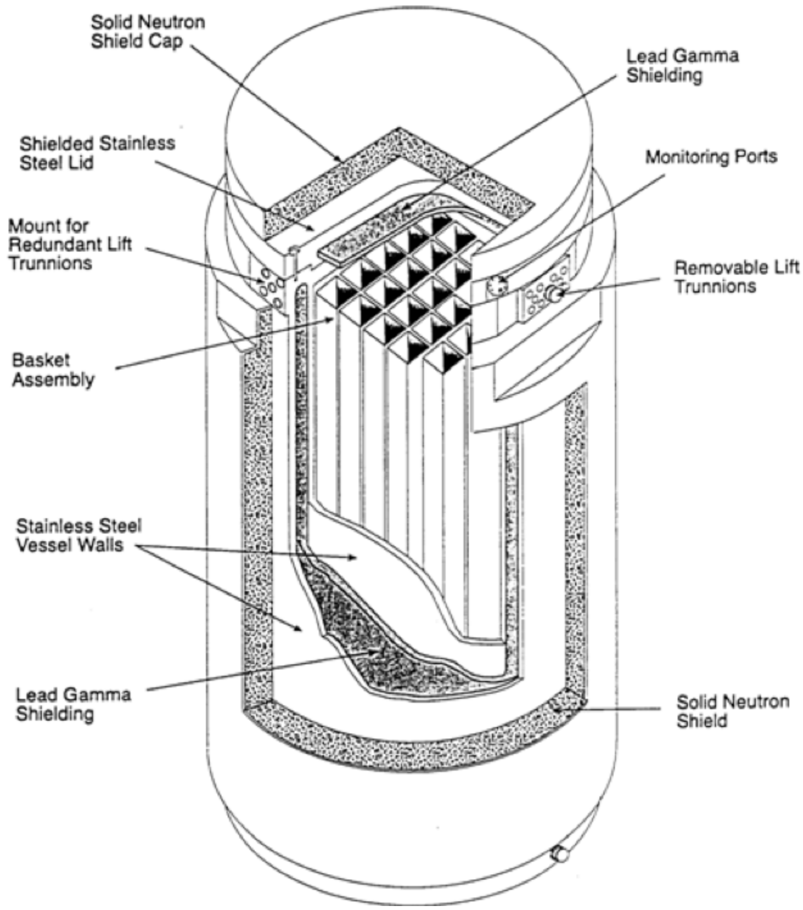


Figure 12. NAC I-28 Metal Storage Cask (Ref. 5)

Table 9. CASTOR V/21, X33, & MC-10 specifications (Refs. 4, 5, and 6)

Attribute	CASTOR V/21	CASTOR X33	Westinghouse MC-10	NAC I-28
Capacity (intact assemblies)	21 (PWR)	33 (PWR)	24 (PWR)	28 (PWR)
Weight (lb.)				
Empty	-	-	-	-
Loaded	234,000 (cask)	214,000 (cask)	90,718 kg (cask)	-
Thermal				
Design heat rejection (kW)	21.0	-	24.0	-
Dimensions (in.)				
Overall length	16.0	15.8	15.7	15.1
Cross section	8.0	7.8	8.9	7.9
Cavity length	163.0	N/A	N/A	N/A
Wall thickness	N/A	12.0 in. (cast iron cask)	N/A	N/A
Materials of construction				
Canister body	Nodular cast iron	Ductile cast iron	Low alloy steel with forged steel walls	Stainless steel
Basket	Welded stainless steel plate and borated stainless steel plate (1% boron content)	Welded stainless steel and borated stainless steel plates	N/A	Aluminum and stainless steel spacers and tie bars with borated neutron poison material in the basket assembly

2.2 Applicable Regulations

2.2.1 10 Code of Federal Regulations (CFR) Part 71 – Packaging and Transportation of Radioactive Material

The storage of wet and dry UNF in an ISFSI is licensed under the regulations in 10 CFR Part 72.7 The license application for the long-term storage of spent fuel considers hazard scenarios specific to the storage activities and can include concerns such as assembly corrosion issues, seismic events, weather events, etc. For offsite transportation activities, the hazards analyzed for these activities differ significantly from the hazards associated with onsite transportation activities. Offsite transportation activities require a robust cask to contain UNF canisters that can withstand the normal conditions of transport (NCT) and hypothetical accident conditions (HAC) required by the provisions in 10 CFR Part

71. To obtain a transportation certificate for a particular UNF package, a safety analysis report for packaging (SARP) must be developed and approved by the NRC. A SARP contains the following interrelated chapters:

1. General Information,
2. Structural Analysis,
3. Thermal Analysis,
4. Containment Analysis,
5. Shielding Analysis,
6. Criticality Analysis,
7. Package Operations,
8. Acceptance Tests and Maintenance, and
9. Quality Assurance.

The packaging and transportation of radioactive material, including UNF, is governed under 10 CFR Part 71 (Ref. 8), and the provisions contained within 10 CFR Part 71 are used to develop a SARP to ensure worker and public protection with fissionable material in a single package and in arrays of similar packages. Ultimately, a criticality safety index is derived based on the characteristics of the package and its contents subject to the provisions of 10 CFR Part 71. With respect to transporting a storage-only cask or canister containing UNF, there are several key issues to certify a UNF package for general transportation activities. 10 CFR §71.43 is applicable to the general specifications for packages. These regulations are applicable for ensuring the proper package dimensions, containment features, and chemical/radiological resistance. The regulations in 10 CFR §71.71 are designed to ensure that a package is properly designed to withstand NCT such as heat, cold, reduced external pressure, increased external pressure, vibration, water spray, free drop, corner drop, compression, and penetration. The regulations in 10 CFR §71.73 are designed to ensure that the package is designed to withstand HAC during transport. The tests from 10 CFR §71.73 designed to ensure that the package can survive the HACs are briefly discussed below.

- The package must survive a 30 ft free drop of the package onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected. This simulates a package being struck by a train or other vehicle, falling from a 30 ft bridge onto solid rock, etc.
- The package must survive a dynamic crush test in which it is positioned on a flat, essentially unyielding horizontal surface as to suffer maximum damage by the drop of a 1100 lb (500 kg) mass from 30 ft on to the package. This test considers accidents in which the vehicle or other heavy object falls onto the package or the package is crushed by vehicle impact.
- The package must survive a puncture test that involves the package falling a distance of one meter in a position for which maximum damage is expected onto the upper end of a solid, vertical (long axis), cylindrical, mild steel bar (15 cm diameter) mounted on an essentially unyielding horizontal surface. This test considers damage resulting from a 10 mile per hour impact, simulating being speared by the frame rail from a truck or being impacted by a railroad track.
- The package must then survive a thermal test in which it is fully engulfed in a hydrocarbon fuel/air fire with an average flame temperature of at least 800ºC for a period of 30 minutes (or equivalent test). This test considers whether or not the package can survive the consequences of being engulfed in a gasoline or diesel fire during the accident scenario. Specifically, it considers damage to a package when it is in an accident with a gas tanker truck or with 5000 gallons of fuel where it is fully engulfed in flames with no protection.
- The package must also be subjected to full immersion in water to address the following:

- A package containing fissile material must be immersed at least 0.9 m (3 ft) if the criticality analysis for the package did not consider water inleakage to the containment vessel containing the fissile material. This ensures that neutron reflection concerns have been adequately addressed in the criticality safety analysis for scenarios involving firefighting or subsequent handing from shallow ponds, etc., where personnel could be present.
- All packages must be immersed under a head pressure of at least 15 m (50 ft.) to simulate the package being submerged at sea or in a river.
- 10 CFR §71.61 requires the immersion of packages for transporting spent fuel containing more than about 37 petabecquerels of activity to an external water pressure of two megapascals (water depth of about 200 meters or 290 psi) for one hour without collapse, buckling, or inleakage of water.

NRC guidance has been developed to assist licensees in preparing SARP applications for UNF transportation packages (Refs. 9 and 10). The regulations include provisions to eliminate the need to comply with the applicable requirements of 10 CFR Part 71 for preparing an application for a UNF transportation package. A specific exemption (10 CFR §71.12) from portions of Part 71 regulations may be granted by the NRC under circumstances that will not endanger life or property nor the common defense and security. Another provision relevant to licensing packages when it would be impractical to meet the regulations in 10 CFR Part 71 is addressed in the special package authorization regulations in 10 CFR §71.41(d), which state:

> *(d) Packages for which compliance with the other provisions of these regulations is impracticable shall not be transported except under special package authorization. Provided the applicant demonstrates that compliance with the other provisions of the regulations is impracticable and that the requisite standards of safety established by these regulations have been demonstrated through means alternative to the other provisions, a special package authorization may be approved for one-time shipments. The applicant shall demonstrate that the overall level of safety in transport for these shipments is at least equivalent to that which would be provided if all the applicable requirements had been met.*

3. ANALYSES

This section identifies the actions required to transport storage-only canisters from their existing sites without repackaging the UNF within the canisters. Casks licensed only for UNF dry storage are not permitted to be transported offsite; therefore, unless some specific actions are taken, the UNF will require repackaging into a licensed transportation cask prior to being transported. If the capability exists at a site, a storage-only cask is moved into a UNF pool, and the fuel assemblies in the canister are transferred into a canister that is licensed and approved for offsite transportation. The only option for sites that cannot transfer storage-only canisters into canisters licensed for transportation would be an exemption from the transportation regulations in 10 CFR Part 71 or a special package authorization. Both options require approval from the NRC.

3.1 Transportability of Storage-Only Containers

3.1.1 Characteristics of Storage-Only Containers

There are physical differences between canisters designed for dry storage operations only and those designed for both dry storage and transportation operations. Canisters and casks used for the dry storage of UNF are designed per 10 CFR Part 72 to withstand the normal and credible abnormal conditions experienced in the course of operating a dry storage facility. Credible abnormal conditions during dry storage operations include natural phenomena (e.g., tornados, hurricanes, and earthquakes, fires, power failures). Applicable regulations also require that criticality events are precluded and that the worker and public are protected adequately from radiation exposure. For static operations, this process is somewhat straightforward and requires much less structural design than for transportation operations. Credible abnormal scenarios related to UNF transportation are much more significant and dynamic than those considered for storage operations (e.g., fire, flooding, impact, penetration). The transportation regulations are provided in 10 CFR Part 71 and require that transportation packages for radioactive materials be designed to withstand both NCT and HAC. The regulations also require the licensee to have an NRC-approved quality assurance program and that the license application for the UNF package include operational guidance (e.g., maintenance requirements, operating procedures, and the conditions for operational use). Due to the lack of integration between 10 CFR Parts 71 and 72, designing canisters to withstand both sets of regulations is costly. This expense is one factor in the decision process for the designing and licensing of canisters and casks for storage-only purposes. For the long term, however, it may be more economical to design and license dual-use canisters and casks that can be used for both storage and transportation operations because all sites will eventually be required to transport UNF offsite to a consolidated dry storage facility or a geologic repository.

3.1.2 Transportation Requirements

The storage-only containers listed in Table 1 were compared against the provisions in 10 CFR Part 71 for packaging and transportation operations to determine the specific requirements that would need to be enhanced or exempted to enable the cask or canister to be transported. This qualitative comparison of the 10 CFR Part 71 requirements to the storage-only containers listed in Table 1 is provided in Table 11. Specific information regarding transportation issues for canister and cask designs in Table 10 are difficult to find in the literature, and technical judgment has been applied based on the canister/cask design and rigor of the 10 CFR Part 71 requirements. For example, in most cases, the lack of robust structural design for storage-only upset conditions is the primary concern if a storage-only canister or cask were to be used directly for transportation operations. Figure 13 shows the significant differences between 24PT2 and 24P/24PHB canister structural designs for storage vs transportation. A more robust structure is required for the package to survive the intensive HAC testing required to obtain a 10 CFR Part 71 license. The figure clearly shows the transportation canister has more spacer disks and support rods to ensure that the package meets 10 CFR Part 71 regulations. With the exception of the CASTOR V/21, X33, and NAC I28, the other storage-only canisters require repackaging into a canister licensed for transportation purposes. The other approach would involve an NRC-approved exemption from 10 CFR Part 71 requirements. A special package authorization (see Section 3.1.4) may also apply; however, this provision in 10 CFR Part 71 has only been applied to items such as reactor vessels or other large items where the development of a transportation package is not practical.

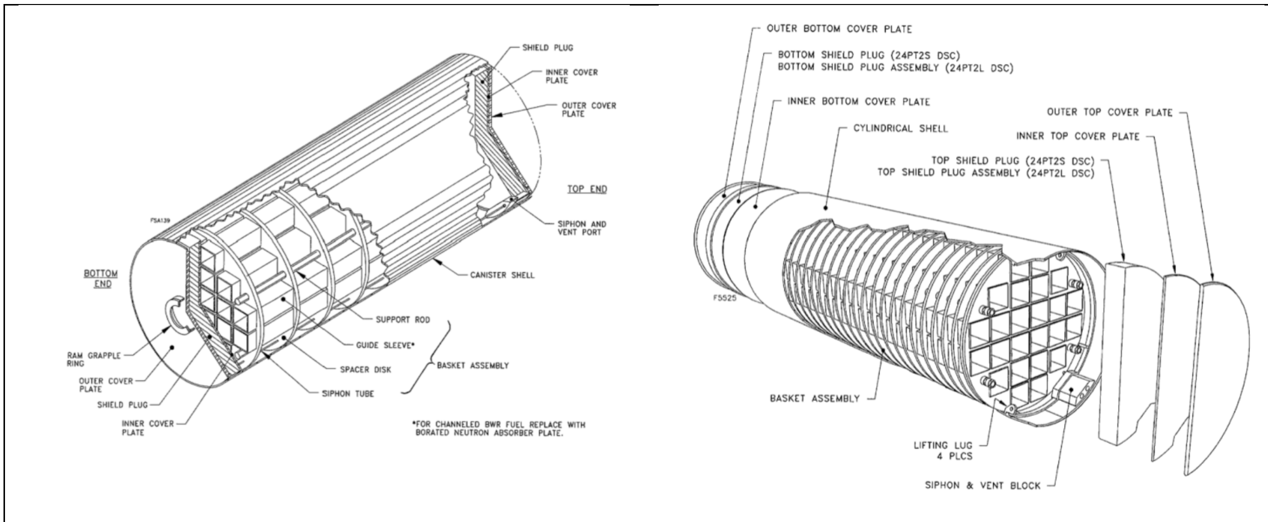
Table 10. Qualitative assessment of 10 CFR 71 to storage-only containers

Type	12T	24P	32P	52B	7P	MC-10	NAC I-28	V/21 and X33	VSC-24
NCT [a]	Tests similar to storage-only scenarios. Exemption may not be necessary.								
HAC [b]	Exemption may be needed. Current structural design based on storage accident scenarios (e.g., wind, lightning, earthquake).	24P & 24PH (storage only) not designed for transportation. 24PT2 designed to provide significantly more structural integrity in the basket region (see Figure 13) to support fuel assemblies during accident scenarios.	Exemption required due to current structural design based on storage accident scenarios (e.g., wind, lightning, earthquake) not the 10 CFR Part 71 HAC scenarios. HAC testing requires very rigorous design to survive transportation scenarios compared to storage-only scenarios.						
Thermal	• ISG-7 (Ref. 11) requirements should be examined for HAC to ensure that overpressurization is not possible during a fire. • ISG-19 (Ref. 12) recommends consideration of reconfigured fuel to locations near temperature-sensitive components as elastomeric seals								
Containment	Containment of fissile material and fission products within the package depends on structural integrity of the canister and transportation cask. If an exemption is required for structural issues for HAC, an exemption for containment purposes may also be needed.								
Shielding	• ISG-19 (Ref. 12) recommends that the shielding analyses consider reconfigured fuel inside the canister that could drive up worker and public dose rates near the package. Realistically, distance and time restrictions during package movement can be used to control exposures in the event of an accident. • 52B has BISCO NS-3 between the cask wall and outer protective skin for use as a neutron shield. • NAC-I28 cask has neutron shielding in the cask body and three in cap at the top of the cask.								
Criticality	No neutron poisons present. A moderator exclusion approval may be required.	No neutron poisons present except in 24PTH. 24P uses borated aluminum, metal matrix composite (Boral). Current loading approvals may require moderator exclusion exemption to meet criticality safety criteria	Neutron poisons present in 32PT and 32PTH1 in the form of borated aluminum or metal matrix composite.	Layer of BISCO NS-3 for neutron shielding can be credited for absorbing neutrons as necessary.	Stainless steel/aluminum with boron present in the basket and canister for neutron shielding & criticality safety control.	Layer of BISCO NS-3 for neutron shielding can be credited for absorbing neutrons as necessary.	Basket contains Boral plates for criticality safety control.	Welded stainless steel basket contains borated stainless steel plates for criticality control.	No neutron poisons present. A moderator exclusion approval may be required.
Current use and classification	Used only for storage of TMI-2 debris at INL. Inadequate structural design for HAC precludes use for transport. (Ref 14).	Recently licensed storage-only canisters	Recently licensed storage-only canisters			Borated neutron poisons present in basket assembly for criticality safety purposes.	Two NAC I-238s are used to store PWR fuel assemblies at Surry (only NRC-licensed ISFSI location using this cask design. A single NAC I-28 cask	NRC license for storage-only at Surry. Cannot be transported due to design for storage-only accident scenarios. Early fracture toughness concerns prevented licensing for transport of monolithic nodular cast iron casks like the CASTOR design in the US.	FuelSolutions VSC-24 canisters classified by vendor as storage-only.

Table 11. Qualitative assessment of 10 CFR 71 to storage-only containers (continued)

Type	12T	24P	32P	52B	7P	MC-10	NAC I-28	V/21 and X33	VSC-24
Repackaging/ exemption options	Per Ref. 1, could be transported in MP-187 cask (not listed in CoC).	NUHOMS ®MP197 cask could be used to transport. 24P & 24PH would need an exemption from 10 CFR Part 71 drop testing requirements.	NUHOMS®MP197 transportation cask (Ref. 13) could be used to transport 32PT, 32PTH, and 32PTH1.	Canister transfer to transfer cask. Must be exempted from 10 CFR Part 71 requirements or repackaged for transport.	Must be exempted from 10 CFR Part 71 requirements or repackaged for transport.	Must be exempted from 10 CFR Part 71 requirements or repackaged for transport.	Must be exempted from 10 CFR Part 71 requirements or repackaged for transport.	Fuel transfer to transport cask. Exemption required for transportation.	Canister transfer to transfer cask. Must be exempted from 10 CFR Part 71 requirements or repackaged for transport.
Notes		If water can flood the container when fissile material is present, criticality safety concerns may exist. Neutron poisons can help preclude criticality safety issues in flooding scenarios but should be verified based on actual configuration.	32PHB designs contain more robust structure (solid aluminum rails instead of steel and aluminum frame basket rails).					International Atomic Energy Agency (IAEA) acceptance of similar designs may influence future NRC licensing.	

[a] = NCT (normal conditions of transport) include heat, cold, pressure, vibration, water spray, drop test, corner drop, compression, penetration
[b] = HAC (hypothetical accident conditions) include free drop, crush, puncture, thermal, immersion



24P and 24PHB (Storage Only) **24PT2 (Storage and Transportation)**

Figure 13. Difference in structural design between storage-only and transportation canisters.

3.1.3 Transportation Approval Via Exemption from 10 CFR Part 71 Requirements Per 10 CFR §71.12

The exemption process in 10 CFR §71.12, "Specific Exemptions," can be used to exempt the storage-only canisters and casks from some of the regulations in 10 CFR Part 71. For example, a canister licensed for storage-only operations of UNF at an ISFSI can be exempted from the drop testing requirements in 10 CFR §71.73 (c)(1)-(3) to satisfy the tests for HAC if it is known in advance that the container may not survive the 30 ft. drop test but could survive a 10 ft. drop. If compensating measures can be conceived to ensure the safety margin is approximately intact, the NRC may approve a one-time exemption for the transportation of a storage-only canister. Other exemptions exist in 10 CFR Part 71, such as §71.13, "Exemption of physicians," §71.14, "Exemption for low-level materials," and §71.15, "Exemption from classification as fissile material." However, these are not applicable for UNF transportation operations. The exemption process is intended to exempt portions of the regulations with a supporting technical basis for NRC review. The process is not intended to exempt a package from all transportation requirements in 10 CFR Part 71 regulations.

This process may be implemented for the storage-only containers discussed in Section 2 for one-time shipment from an ISFSI to another site. Table 10 provides a qualitative view of the cask and canister characteristics that need to be enhanced or exempted based on technical judgment. Specifically, the requirements relevant to the transportation of radioactive material in the particular canister or cask were reviewed against the 10 CFR Part 71 regulations to determine which requirements cannot be met or are impractical to meet (e.g., entirely new package design is required, canister/cask will not survive the 30-ft. HAC drop tests) based on the current canister/cask design and configuration. Particularly relevant regulations are 10 CFR §71.43, "General Standards for All Packages," 10 CFR §71.71, "Normal Conditions of Transport," and 10 CFR §71.73, "Hypothetical Accident Conditions." The NRC will expect a robust technical basis to support the exemption request, which should include sufficient justification for the NRC to conclude the proposed operations related to the exemption will not "…endanger life property nor the common defense and security."

3.1.4 Transportation Approval Via Special Package Authorization from 10 CFR Part 71 Requirements Per 10 CFR Part 71.41(d)

The special package authorization process is applicable for the transportation of large pieces of equipment items and nonstandard items that cannot be shipped inside a certified package or for which designing a packaging that meets the requirements in 10 CFR Part 71 would be impracticable (Ref. 14). For example, Duratek, Inc. submitted an application for a special package authorization to ship the La Crosse reactor pressure vessel transportation package (Ref. 15). The special package authorization process in 10 CFR §71.41(d) was used for a one-time, exclusive-use shipment of the pressure vessel in a specific configuration. The NRC has also denied special package authorization requests that are not one-time only shipments of large components that cannot be shipped inside a certified package. For example, a requested shipment of an S5W Power Unit Shipping Container with an expired certificate of compliance for the US DOE Division of Naval Reactors was denied because it did not meet the intent of the regulations (Ref. 16). Based on the review of NRC responses for special package authorization requests from the industry, it can be concluded that the NRC may not approve special package authorizations for the one-time shipment of the storage-only containers discussed in Section 2 because these canisters and casks are considered "non-standard" items or "large pieces of equipment items" that are infrequently shipped. The storage-only canisters and casks listed in Table 1 would likely not be considered "non-standard" items or "large pieces of equipment items" (e.g., steam generator or reactor vessel) due to the fact the canisters and their UNF contents could be repackaged into a transportation cask designed per 10 CFR Part 71 requirements. It should be noted that a transportation package may not yet exist for some of these canister types; however, one could be designed and developed via the provisions in 10 CFR Part 71.

3.2 Transportation Methods

Various options exist for shipping the storage-only containers from their storage sites to a consolidated UNF storage facility or geologic repository. Storage-only containers with an exemption from 10 CFR Part 71 HAC requirements or a special package authorization will likely require more time prior to the shipment to obtain permissions from state and local officials to ship the package because of a perceived reduction in public and worker safety margin. Further, it is likely that local emergency response personnel in various locations along the transportation route will require training to handle the foreseen hazards shipping these packages. However, in general, the transportation methods are the same as those for UNF shipments performed in a certified transportation cask. It is likely each site can utilize local roads to access either state and interstate highways or railroads. Local authorities would issue permits for overweight and/or oversize vehicles to travel on nonstate, nonfederal local roads (Ref. 17). Heavy-haul shipments on local roads to a nearby railroad or siding could take a great deal of time because travel speeds are typically limited to about 5 mph, so more than 8 hours may be required to travel distances of 10 miles or less. Because heavy-haul vehicles can block roads during use, shipment of the UNF packages may require that time-of-day restrictions be imposed, and alternate route(s) may need to be designated. For interstate highway shipments, states can issue permits for vehicles that exceed weight and size restrictions. These permits consider the route to be used, normal traffic patterns, time of day, duration of use, total vehicle weight, etc. These permits provide restrictions necessary based on the roadway characteristics in the various locations (e.g., speed restrictions, escort requirements). The standards for state roadways are typically less restrictive, but lanes are generally more narrow, and the roadways have steeper grades and sharper curves than federal interstate highways. State roads also have narrow shoulders and less overhead clearances than interstate highways. These features should be considered accordingly when planning for a shipment on local, state and interstate highways. Off-site railroads, either Class I (mainline railroads), Class II (typically regional railroads), or III (typically shortline railroads), might be used to transport casks at sites that have either direct rail access or near-site rail access with an acceptable branch line or rail siding where casks would be transferred to railcars from heavy haul trucks or barges (Ref. 14). Unique restrictions (weight restrictions, overhead clearance, track curves, etc.) also apply to rail shipments of UNF. An advantage of rail shipment is the reduced reliance on busy local, state, and interstate highways, which could reduce the time required for the shipment. Navigable waterways can also be used to transport UNF casks (rail/intermodal casks) via barge as necessary. The US Army Corps of Engineers, port authorities, and other federal authorities (e.g., Tennessee Valley Authority) maintain inter-coastal waterways used by commercial maritime traffic. Resources necessary to load and unload the transportation casks from barges must meet certain requirements as discussed in Ref. 14.

4. CONCLUSIONS AND FUTURE WORK

An overview of storage-only UNF canisters/casks has been provided in this report for the sake of assessing their transportability. The following UNF canisters/casks were considered: VSC-24, CASTOR V/21 & X33, NAC I-28, Westinghouse MC-10, and various NUHOMS® canisters (24P, 32P, 12T, 52B, and 07P). The primary issue with these storage-only containers involves whether they can be shipped without repackaging to a consolidated storage location or geologic repository. Approving a storage-only canister or cask for transportation requires an NRC license in accordance with the regulations in 10 CFR Part 71. These regulations ensure the package can be transported safely for all NCT and HAC. This work has concluded that obtaining a transportation license would not be possible for many of these containers because its structural design is not sufficiently robust to survive the rigorous testing required for HAC (10 CFR §71.73). Other options exist for the transportation of these storage-only containers. The first and most likely to succeed is the "Specific Exemption" provision in 10 CFR §71.12. This would allow a site to generate a technical basis in a license application to request an exemption from some of the testing regulations in 10 CFR Part 71 that currently limit their use for transportation operations. This exemption has been used successfully by some licensees for one-time shipments of radioactive material. The "Special Package Authorization" in 10 CFR §71.41(d) could also be considered for the one-time transport of these UNF storage-only canisters/casks. Based on a review of the intent of this provision of 10 CFR Part 71, it is not likely that a request for transporting these canisters would be approved by the NRC. This is because the intent of this provision is to cover gaps in the regulations for the transportation of large pieces of equipment items and nonstandard items that cannot be shipped inside a certified package or for which designing a package that meets the requirements of 10 CFR Part 71 would be impracticable. The NRC has denied the use of 10 CFR §71.41(d) for transportation packages because they are not "nonstandard" and not "large pieces of equipment items." These packages currently have options under the 10 CFR Part 71 regulations to obtain a license for transportation purposes. Based on this study, it appears the exemption criteria in 10 CFR §71.12 would be the most successful if repackaging operations cannot be performed.

Future studies are needed to initiate the 10 CFR §71.12 exemptions from relevant 10 CFR Part 71 provisions for the casks and canisters listed in Table 1. Specifically, this work involves the review of the relevant 10 CFR Part 71 information required to develop a SARP compared to the actual design and physical characteristics of the each of the casks and canisters listed in Table 1. In particular, the following sections of 10 CFR 71 are relevant to approve a cask/canister for transportation:

- 10 CFR §71.55(b), (c), (d), and (e) – General Requirements for Fissile Material Packages,
- 10 CFR §71.59(a), (b), and (c) – Standards for Arrays of Fissile Material Packages,
- 10 CFR §71.71(a)(1) – Normal Conditions of Transport, and
- 10 CFR §71.73(a)(2) – Hypothetical Accident Conditions.

Those provisions that cannot be satisfied by the design of the canister or cask will require an exemption request in writing along with a technical justification of the requested exemption. The technical basis of the justification should include the reasons for the exemption request in addition to a discussion regarding the potential implications of risk to the life, property, or the common defense/security. For example, if a UNF canister is breached and water can enter the package if the package is immersed in water, the justification could include the resulting criticality safety consequences (e.g., the effective multiplication factor increases as a result of water ingress near fissile material, but the resulting configuration will remain subcritical). The results for the HAC analysis for water ingress indicate that the overall risk increase is negligible because a criticality accident would not result. The exemption requests for these containers will be atypical from the standpoint that most exemption requests consider only a single 10 CFR Part 71 requirement, whereas the requests for the storage-only canisters and casks would involve potential exemptions from multiple requirements. However, this study will provide the scope necessary to request exemptions for each of the storage-only canisters/casks from 10 CFR Part 71 requirements to allow for one-time transportation activities. This study should also consider if special package authorizations per 10 CFR §71.41(d) would be applicable for transporting the storage-only canisters/casks. Currently, it appears that the special package authorization provision does not apply to these storage-only casks/canisters.

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