FCT Quality Assurance Program Document

Appendix E
FCT Document Cover Sheet

Name/Title of Deliverable/Milestone	Assumptions for Evaluating Feasibility of Direct Geologic Disposal of Existing Dual-Purpose Canisters
Work Package Title and Number	Dual Purpose Canisters – SNL (FT-14SN081603)
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Quality Rigor Level for Deliverable/Milestone	☒ QRL-3	☐ QRL-2	☐ QRL-1 ☐ Nuclear Data	☐ N/A*

This deliverable was prepared in accordance with Sandia National Laboratories
(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,
☒ Signature of TR Reviewer(s) below	☐ Signature of PR Reviewer(s) below

Name and Signature of Reviewers

Teklu Hadgu/ Teklu Hadgu

*Note: In some cases there may be a milestone where an item is being fabricated, maintenance is being performed on a facility, or a document is being issued through a formal document control process where it specifically calls out a formal review of the document. In these cases, documentation (e.g., inspection report, maintenance request, work planning package documentation or the documented review of the issued document through the document control process) of the completion of the activity along with the Document Cover Sheet is sufficient to demonstrate achieving the milestone. QRL for such milestones may be also be marked N/A in the work package provided the work package clearly specifies the requirement to use the Document Cover Sheet and provide supporting documentation.

Assumptions for Evaluating Feasibility of Direct Geologi Disposal of Existing Dual-Purpose Canisters

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign

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FCRD-UFD-2012-000352 Rev. 1

CONTEXT FOR THIS STUDY

This is a technical presentation that does not take into account the 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.

Revision History

Revision	Description
FCRD-UFD-2012-000352 Rev. 0	Initial issue. (September 2012)
FCRD-UFD-2012-000352 Rev. 1	Update assumptions to reflect ongoing technical evaluations and to clarify regulatory context. Assigned Sandia control number SAND2013-9780P (November 2013)

Acknowledgement of Previous Authors

The previous version of this report (Rev. 0) included substantial contributions from authors Andy Miller (now at Emporia State University) and Robert Rechard (Sandia National Laboratories).

Sandia National Laboratories

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ACRONYMS

ADAMS	Agency-wide Documents Access and Management System
ANEP	Advanced Nuclear Energy Program
BRC	Blue Ribbon Commission on America’s Nuclear Future
BWR	Boiling Water Reactor
COC	Certificate of Compliance
DOE	U.S. Department of Energy
DPC	Dual-Purpose Canister
DSC	Dry Storage Cask
EBS	Engineered Barrier System
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FEPs	Features, Events, and Processes
FOIA	Freedom of Information Act
FSAR	Final Safety Analysis Report
HLW	High-Level Waste
ISFSI	Independent Spent Fuel Storage Installation
MT	Metric Tons
MTHM	Metric Tons of Heavy Metal
MTU	Metric Tons Uranium
NAS	National Academy of Sciences
NEPA	National Environmental Policy Act
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
OFF	Oldest Fuel First
PWR	Pressurized Water Reactor
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
RMEI	Reasonably Maximally Exposed Individual
SER	Safety Evaluation Report
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratories
TAD	Transportation-Aging-Disposal
TSAR	Topical Safety Analysis Report
TSPA	Total System Performance Assessment

UFD	Used Fuel Disposition
UNF	Used Nuclear Fuel
UNF–ST&DARDS	UNF – Storage, Transportation & Disposal Analysis Resource and Data System
US	United States
YFF	Youngest Fuel First

ASSUMPTIONS FOR EVALUATING FEASIBILITY OF DIRECT DISPOSAL OF EXISTING DUAL-PURPOSE AND STORAGE-ONLY CANISTERS IN VARIOUS MEDIA

1. INTRODUCTION

In the *Nuclear Waste Policy Act of 1982* (NWPA), Congress required the U.S. Department of Energy (DOE) to cooperate with the private sector to conduct demonstrations of alternatives to storage of used nuclear fuel (UNF) in pools (NWPA 1983). The demonstration was to be licensed by the U.S. Nuclear Regulatory Commission (NRC). The cooperative program, which licensed its first demonstration in Virginia in 1986, and various additional studies, provided a foundation for utilities to build dry cask storage to alleviate the limited wet storage available at reactors. A variety of dry fuel storage systems have been developed and deployed since 1986. The total inventory of UNF currently consists of more than 65,000 metric tons of heavy metal (MTHM) discharged from reactors as of 2010, of which more than 25% is stored in approximately 1,700 dry storage canisters. Most of these canisters are, or can be licensed for transportation in addition to storage, and are referred to as dual-purpose canisters (DPCs). A few older systems are single purpose (storage only), and none of the systems are licensed for disposal. The amount of UNF that will be transferred from wet to dry storage is expected to increase at a rate of approximately 100 DPCs/yr. The nuclear power industry is currently using large DPCs, typically containing 32 or more assemblies from pressurized water reactors (PWRs), or boiling water reactor (BWR) equivalent.

1.1 Objective of Evaluation

Direct disposal of the DPCs in a geologic repository is beyond current domestic and international capabilities (Hardin et al. 2012). The large capacities of loaded canisters could require significant duration of surface decay storage, and greater thermal loading may limit the choice of geologic disposal media or may require ventilated, open-drift emplacement. Control of postclosure criticality in the far future after waste packages are degraded by corrosion is another challenge.

This report is part of a multi-year study by the Used Fuel Disposition (UFD) R&D campaign to identify, research, and evaluate technical challenges to DPC direct disposal. The results will provide input to waste management strategy decisions that include the extent to which direct disposal could be deployed in the U.S.

The principal alternative to direct disposal of DPCs is re-packaging of UNF into smaller, purpose-designed canisters for disposal. Re-packaging would increase flexibility in selecting concepts or sites for disposal, potentially decrease surface decay storage duration, and avoid any need to modify DPCs for criticality control. However, re-packaging could incur significant additional costs. As an example, the Virginia Electric Power Company (Dominion) has estimated that the total cost of re-packaging some of their dry storage canisters would be $1.5 million per storage canister: $150K for unloading, $150K for re-loading, $1M for a new canister, and $200K for disposal of the old canister/cask (Rice 2011). In addition, they estimate that re-packaging would increase personnel radiation exposure by an estimated 250 person-mrem per canister.

1.2 Approach

The general approach for this study began in 2012 with an initial Scoping and Assumptions phase, as described in the multi-year plan (Howard et al. 2012, Section 3). This report is the result of that phase. Its purpose is to provide background on the current status of DPCs and single-use canisters (Chapter 2), and define the assumptions that will be used throughout the study to represent technical, regulatory, and administrative constraints (Chapter 3). The original version of this report (FCRD-UFD-2012-000352 Rev. 0) was used during FY13 to identify disposal concepts for evaluation, perform scoping thermal, criticality and logistical analyses, and establish direction for supporting R&D. This update (Rev. 1) changes some of the technical and regulatory assumptions to address lessons learned from technical analysis, and is intended to guide the study through FY14 and beyond.

2. CATALOG OF DRY STORAGE SYSTEMS

Chapter 2 documents principal canister characteristics in order to support future technical analyses related to direct disposal of DPCs, and provide preliminary information for consideration in standardized canister design (Howard et al. 2012, Section 3.1.3). Descriptive information on DPCs was obtained through licensing documents (Tables A-1 and A-2). Data from licensing documents on burnup and enrichment limits, and the age of fuel in dry storage, are compared to projected values from the logistics simulation code CALVIN (BSC 2003b) in Section 2.4. A parallel effort has gathered information on dry storage canisters currently in use at both operating and shutdown reactor sites, and is summarized by a spreadsheet of these characteristics (LeDuc 2012) updated in Table A-3 (filename: *DryCask&WetStagedStorage US_20130205.xls*).

Throughout this discussion the terms canister and cask have specific meanings. A canister is sealed by welding and generally not reusable. Canisters are designed to be used with shielded transfer, storage, and transportation casks that are reusable and have bolted closures. Another type of cask accepts one or more bare fuel assemblies and may be used for storage or transportation, but typically not both.

2.1 Methodology and Resources

2.1.1 Information Presented

The starting point for the data collection effort presented here was a spreadsheet developed under the Transportation/Storage Logistics UFD work package, which listed several characteristics of canisters currently in use. These characteristics include: utility company and site, canister vendor, type of reactor (PWR/BWR), total number of canisters by type and location, and other information related to storage and transportation. This analysis extended the information to include characteristics important to direct disposal of DPCs.

The information presented here for DPCs consists of

- External dimensions (length, diameter)
- Assembly capacity (PWR and BWR)
- Maximum loaded mass
- Maximum thermal output vs. time for both storage and transportation.

In addition the following information was sought for the most commonly used systems:

- Design-basis burnup
- Canister shell material composition
- Canister internal materials and structural design
- Basket materials
- Neutron absorber materials
- Spacers and thermal shunts
- Shield plug (if any)

- Other hardware components (e.g., control rods/burnable poison inserts)
- Actual content of loaded DPCs
- Method relied on for criticality control (e.g., burnup credit, flux traps).

Most of these items were obtained for the more commonly used canister systems. Items that were not obtained include the actual content of loaded DPCs, and thermal histories. These two items are not included among the sources used in this study. Although no information was found on DPC thermal output as a function of time, the maximum initial thermal output (before decay) is a well-documented design specification, and time history can be approximated using initial enrichment, burnup, and fuel age. Limits specified by the license are included both for the canister as a whole and on a per assembly basis. Other information that may be important to future analyses was also included. These items include: internal diameter, canister weight without fuel, min/max loaded weights, and min/max initial uranium enrichment. The spreadsheet also lists originating documents for the listed information. The output from this analysis is both the spreadsheet itself as well as the collected documents. All of this is archived on the Advanced Nuclear Energy Program (ANEP) SharePoint site at Sandia National Laboratories (SNL). The spreadsheet is presented in Tables A-1 and A-2.

An ongoing industry survey, is expected to round out the available information on existing dry storage, and to improve projections. The as-loaded description of existing dry storage systems will be forthcoming from the GC-859 survey of utilities, similar to the RW-859 survey performed in 2002 by the DOE Energy Information Administration. The GC-859 survey is currently underway and the results are expected to be available by 2015. Until then, the available system-wide information on DPCs and fuel inventory for 2002 to the present is limited to that presented in Appendix A to this report, which combines the RW-859 data with current status information from industry trade publications. For 12 currently shutdown sites, additional information on assembly burnup (but not as-loaded information for individual canisters) is provided by Maheras et al. (2013).

Another source of DPC information is the UNF – Storage, Transportation & Disposal Analysis Resource and Data System (UNF–ST&DARDS) database that is managed by Oak Ridge National Laboratory (Peterson et al. 2013), which contains detailed as-loaded information for DPCs at just a few storage sites.

2.1.2 Resources Accessed

The majority of the information gathered here originated from the Agency-wide Documents Access and Management System (ADAMS) on the NRC website. The ADAMS website is divided into two main sections: the Public Library and the Public Legacy Library. The Public Library consists of publicly available documents for which electronic, downloadable copies are available. The Public Legacy Library contains documents that are publicly available but which are not currently available electronically. Obtaining these documents requires a fee to transfer the material from microfiche to electronic versions. A final document type, which is not included in ADAMS, is non-publicly available documents. Although these documents cannot be found through a search on ADAMS, their presence can be detected through other generic search engines (e.g., Google) or from other NRC documentation. Obtaining a non-publicly available document requires making a request under the Freedom of Information Act (FOIA). The documents used here all fall into the first category (ADAMS, Public Library) and were downloaded from the ADAMS website. The other two document types were not pursued, mainly because similar information can be found through other avenues. Also, the few documents that fall into the latter two categories are for canister systems making up only a small fraction of the total number of canisters currently in use.

From the ADAMS website, several main document types could be found relating to the performance characteristics of dry storage canisters. These include (1) the Final Safety Analysis Report (FSAR, also referred to as a Topical Safety Analysis Report, TSAR), (2) a certificate of compliance (COC) for licensed canisters, and (3) a safety evaluation report (SER). The FSAR is the most informative of these documents. It is the culmination of thermal, mechanical, criticality, and operational analyses. The vendor must submit the FSAR to the NRC. The NRC response to the FSAR is the SER and eventually a COC in most cases. Common components of the FSAR include: a general canister description, principal design criteria, structural evaluation, thermal evaluation, shielding evaluation, criticality evaluation, confinement evaluation, operating procedures, canister maintenance, radiation protection and accident analyses. Several of the vendors submitted an “umbrella” FSAR with generic analyses for the canister. Specific consideration of a certain packing condition is then given in an appendix. For example, the Transnuclear NUHOMS series of DPCs uses a single external canister for the majority of their designs but uses different internal components to allow for different fuel arrangements and capacities. The umbrella FSAR addresses the external canister, while the separate appendices give specifics on the internal components and associated analyses for the different fuels and configurations.

A few other documents found through internet searching were also used, including documents from DOE and the Electric Power Research Institute (EPRI). These documents describe testing of the canisters by DOE, or general fuel storage documents from EPRI. For a few of the canisters, an FSAR from an Independent Spent Fuel Storage Installation (ISFSI) was used.

A recently published volume summarizing DPC characteristics and implementation (Greene et al. 2013) includes a wide range of descriptive data for all dry storage systems (canister-based and casks). Because of its coverage and detail, the reader is referred there for additional information. The following sections are provided for background.

2.1.3 Data Limitations

Values tabulated in Tables A-1 and A-2 are generally limits, based on licensing documents as noted. Also, in some cases, optional components or fuel-specific modifications are mentioned with conditions for use. For example, fuel with greater heat output may require thermal shunts. Depending on the geometry of fuel assemblies and the canister, spacers may be required. Licensing documents do not have the as-built information to determine how such components or modifications are used. A similar limitation on data from licensing documents is small uncertainties associated with system specifications such as canister length and diameter, system weight, etc., which can vary according to how such parameters are used in supporting analyses. Licensing documents are inherently limited. While Final Safety Analysis Reports (FSARs) contain much useful information, they are not available for all canister types. As-loaded information is often protected for security reasons.

2.2 Results

More than 1,570 loaded dry storage systems are currently in use at active or decommissioned reactors. Figure 1 shows the proportion of the total made up by each canister type. This same data are re-plotted in Figure 2 with the individual canister types grouped based on design and vendor. Canister systems from a single vendor often share design features such as physical dimensions and material compositions. The top five canisters in use today are the HI-STORM MPC-68 (Holtec), the NAC-UMS UMS-24 (NAC International), the NUHOMS 24P (Transnuclear), the HI-STORM MPC-32 (Holtec), and the NUHOMS 61BT (Transnuclear). When broken down by vendor/design, just three vendors have provided approximately 75% of the total canisters in use. These are, in descending order: NUHOMS (Transnuclear), HI-STORM (Holtec), and NAC-UMS UMS-24 (NAC International).

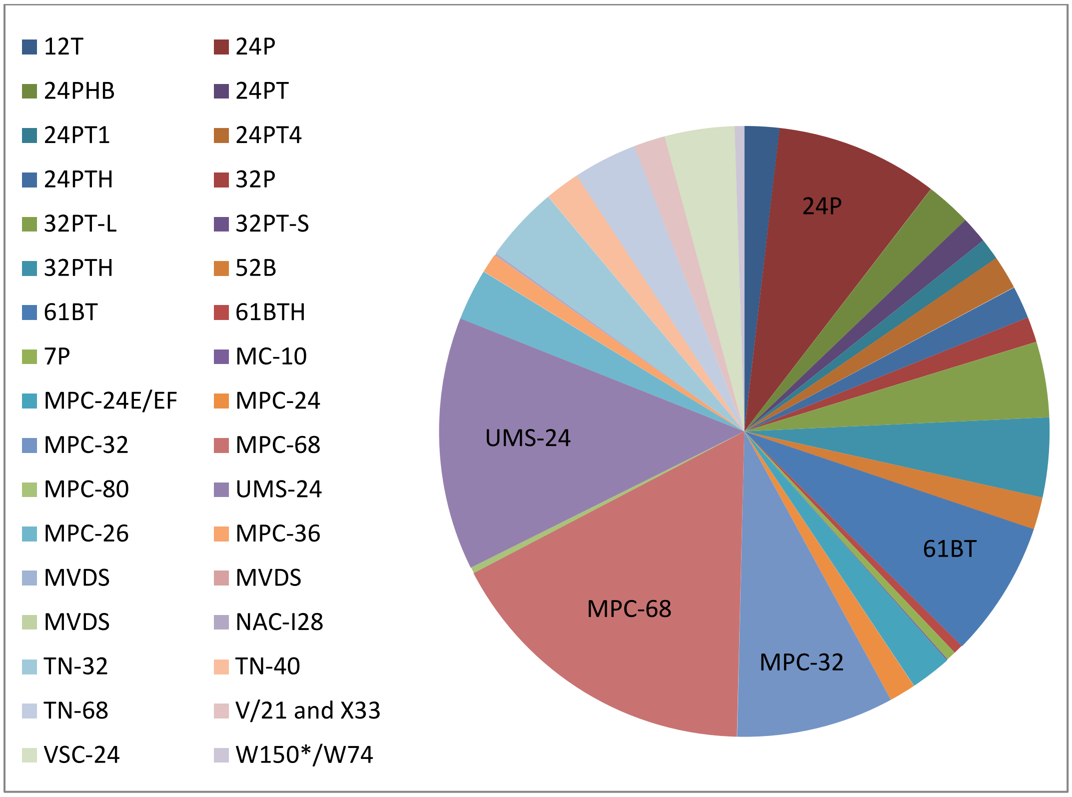


Figure 1. Relative frequency of storage systems in use.

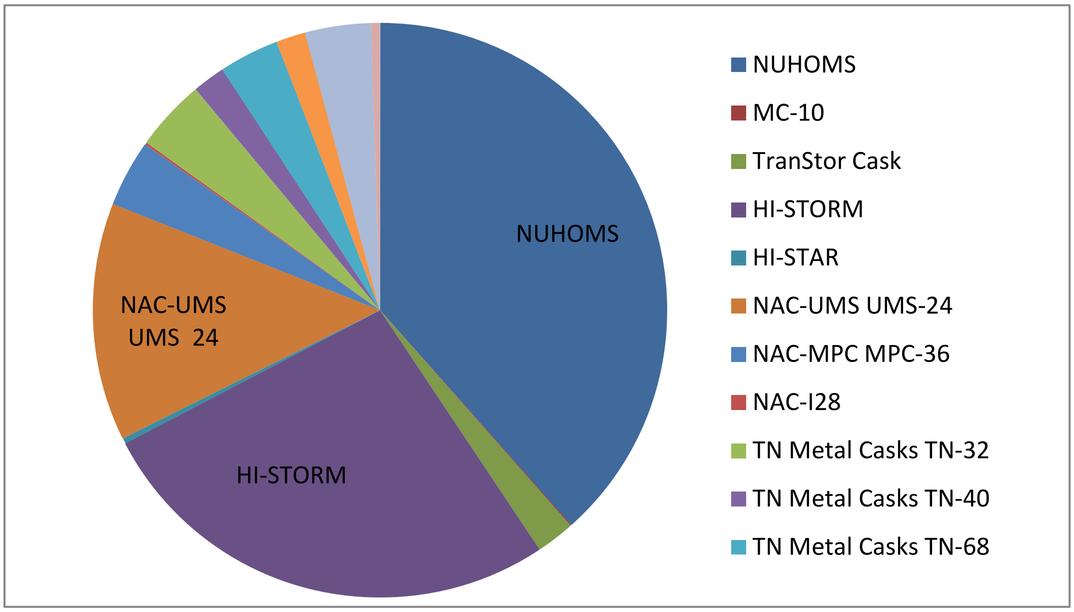


Figure 2. Relative frequency of existing storage systems grouped by design and vendor.

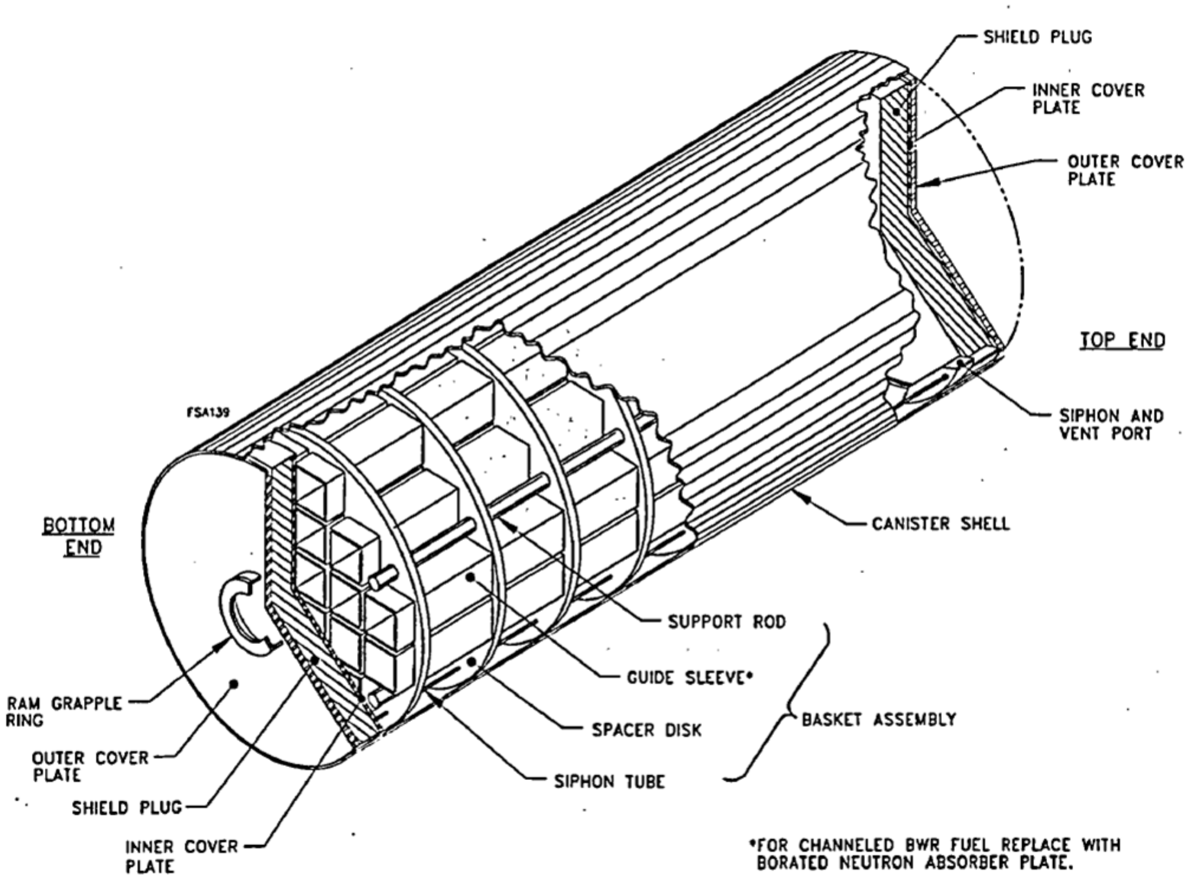
2.3 Comparison of Canister Designs

Designs for the most popular canisters are similar. Basic design features for these systems are likely to remain popular for some time, and are therefore representative. The basic design and components for a majority of existing dry storage canisters are shown in Figure 3. Among the commonly used canisters, nearly all use stainless steel for major components (canister shell, fuel basket, shield plugs, and top and bottom containment and structural lids). Overall dimensions are largely determined by the fuel and are therefore similar. Shell thickness for the most popular canisters is typically 1.5 to 3.7 cm and overall length is just under 5 meters. Canister weights are variable, with empty canisters weighing from ~13 to 56 metric tons (MT). Heavier systems are early, outlier designs and include casks. The most commonly used DPCs weigh from 15 to 25 MT when empty, and from 34 to 46 MT when fully loaded and sealed. Maximum initial thermal limits range from 12.5 to 40.8 kW (including systems for both PWR and BWR fuel). Thermal limits for the more commonly used systems range from approximately 18 to 37 kW.

Internal component designs are also similar among different storage systems, with the greatest differences in materials used, and whether the fuel basket uses a grid of plates (“egg-crate”) or tubes to hold individual assemblies. Baskets are typically made from stainless steel, and typically include the fuel assembly grid or tubes, basket supports (rods and rings), and spacer disks. For criticality control borated aluminum (e.g., Boral®) is typically used, fixed in place by welded covers of stainless steel in thin sheets.

Spacer disks are oriented transversely (Figure 1) and may be made from stainless steel or aluminum. The aluminum disks serve as thermal shunts and are typically alternated with stainless steel ones. Shield plug materials include stainless steel, coated carbon steel, and lead or depleted uranium encased in stainless steel. Coatings are used with reactive materials such as carbon steel to prevent particulate shedding in fuel pools. The major differences in design relate to the numbers of fuel assemblies, and the use of flux traps for criticality control in PWR fuel storage canisters. Figure 3 shows the construction of a typical storage canister of the NUHOMS design containing 24 PWR assemblies.

Among less common systems there is a wider range of designs, such as thick-walled casks with cooling fins. These designs are more difficult to typify. For example, the MC-10 cask design (Efferding 1990) shown in Figure 4 has a wall thickness up to 60 cm for integral shielding. Hydrogenous moderator rods are used for neutron absorption. The exterior fins dissipate heat. In the less common designs there is also wider use of materials other than stainless steel, for example, the CASTOR V/21 system uses a canister shell composed of nodular cast iron with nickel plating (variants of the CASTOR system are common internationally). Various types of steel are used in these designs, including Type 304 and 316 stainless steels in various grades, SA-516 Grade 70, and SA-203 Grade E. Overall, these less common systems comprise a relatively small fraction (<20%) of dry storage systems, and this fraction is likely to decrease as more recent designs proliferate.



Source: TransNuclear (2004, Appendix N)

Figure 3. Representative design of DPC canister. NUHOMS 24PHB shown.

A previous study considering the feasibility of direct disposal of DPCs at an unsaturated, open-mode repository (BSC 2003a) found that the major concerns are: 1) postclosure criticality; 2) physical dimensions; and 3) vertical handling modifications for canisters designed for horizontal storage. Neutron absorbing materials used for criticality controls (e.g., Boral®) can degrade and mobilize in certain disposal environments, separating from the fuel assemblies. Stainless steel supports can also degrade so that the internal fuel structure collapses. These findings were relevant for a specific disposal concept, in an oxidizing environment with groundwater present in amounts sufficient to flood breached waste packages. Suitability of other disposal concepts for DPC disposal will be addressed in the feasibility study. The previous study identified the importance of comprehensive burnup credit in postclosure criticality analyses for DPCs (BSC 2003a).

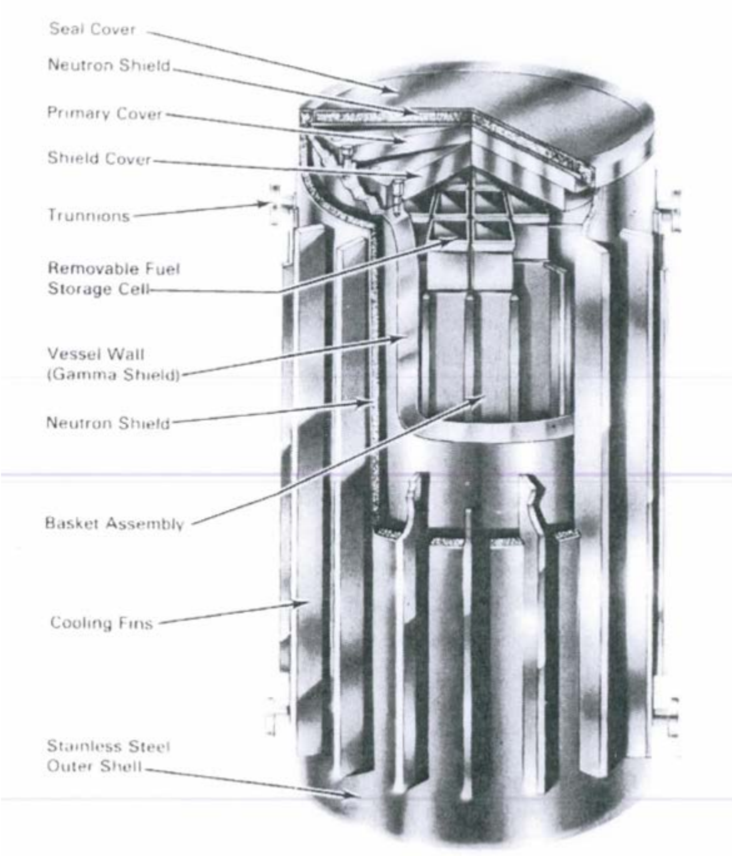


Figure S-1. MC-10 Spent Fuel Storage Cask

Source: Dominion (2004)

Figure 4. Representative uncommon canister design. MC-10 shown.

2.4 Comparison of License Values to Calculated Values

As mentioned previously, the data presented here for burnup and thermal limits on storage systems are defined in licensing documents, and bound the characteristics of UNF actually in storage. For additional perspective, the CALVIN 4.0 (BSC 2003b) database was queried to estimate burnup, enrichment and fuel age for fuel in dry storage. For each of these measures CALVIN reports the average, maximum, and minimum for each site with dry storage. CALVIN 4.0 has limitations, chief among them is that post-2002 data are projections. Also, the data capture most of the sites and most of the systems in use, but are incomplete. Data were tabulated for the more popular canisters located at 53 sites (Table 1), and a few representative values and trends are observed. Figures 5 through 8 show the characteristics for representative storage systems at these sites.

Figures 5 through 8 show the average, minimum, and maximum burnup by site for five commonly used storage systems shown also in Table 1 (HI-STORM MPC-68 and MPC-32, NAC-UMS-24, NUHOMS 24P and 61BT). Of the 37 sites known to be using at least one of these five systems, 27 are represented in the figures. In general, the projected average burnup values are lower than the licensed maximum values. Overall, the average values are distributed through a range of 30 to 90% of the maximum value. The few instances where CALVIN projections are slightly larger than the maximum, can be attributed to limited precision of the estimates.

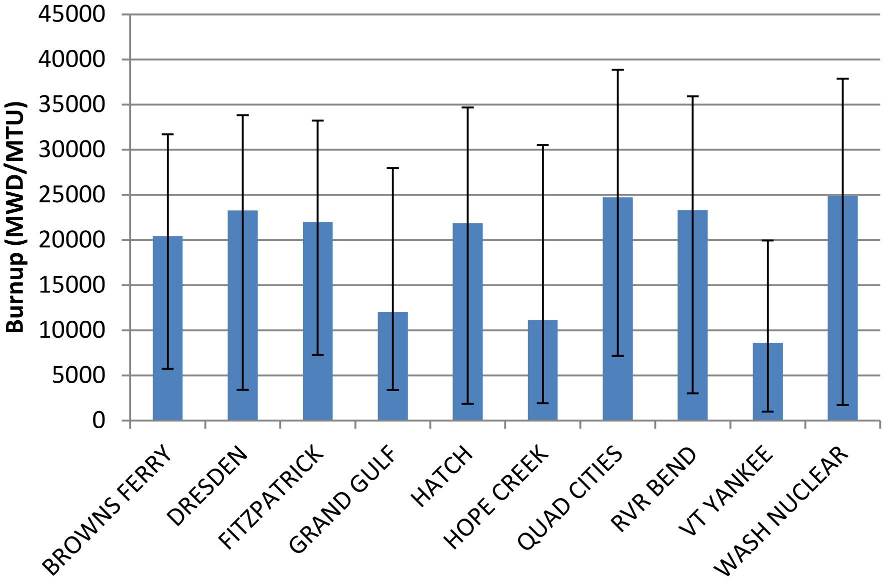
Similarly, the projected enrichment values for UNF in dry storage are mostly lower than the licensed maximum values (Figures 9 and 10). Figure 11 shows that UNF age and burnup have a weak, negative correlation. That trend is expected to continue as facilities continue to increase burnup in reactor operations.

Table 1. Sites and canisters considered at each site (data from CALVIN 4.0, BSC 2003b).

Site	Cask System	Canister Type	Site	Cask System	Canister Type
SURRY	Castor	V/21 and X33	PALO VERDE	NAC-UMS	UMS-24
ARK NUCLEAR	FuelSolutions	VSC-24	HADDAM NECK	Note A	MPC-26
PALISADES	FuelSolutions	VSC-24	BEAVER VALLEY	Note A	Note A
POINT BEACH	FuelSolutions	VSC-24	PERRY	Note A	Note A
BIG ROCK	FuelSolutions	W150	DAVIS-BESSE	NUHOMS	24P
HUMBOLDT BAY	HI-STAR	MPC-80	OCONEE	NUHOMS	24P
BYRON	HI-STORM	MPC-32	RANCHO SECO	NUHOMS	24PT
DIABLO CANYON	HI-STORM	MPC-32	SAN ONOFRE	NUHOMS	24PT1
FARLEY	HI-STORM	MPC-32	CALVERT CLF	NUHOMS	32P
INDIAN PT 1&2	HI-STORM	MPC-32	FORT CALHOUN	NUHOMS	32PT
INDIAN PT 3	HI-STORM	MPC-32	GINNA	NUHOMS	32PT
SALEM	HI-STORM	MPC-32	KEWAUNEE	NUHOMS	32PT
SEQUOYAH	HI-STORM	MPC-32	MILLSTONE	NUHOMS	32PT
BROWNS FERRY	HI-STORM	MPC-68	SEABROOK	NUHOMS	32PTH
DRESDEN	HI-STORM	MPC-68	ST LUCIE	NUHOMS	32PTH
FITZPATRICK	HI-STORM	MPC-68	SUSQUEHANNA	NUHOMS	52B
GRAND GULF	HI-STORM	MPC-68	COOPER STN	NUHOMS	61BT
HATCH	HI-STORM	MPC-68	DUANE ARNOLD	NUHOMS	61BT
HOPE CREEK	HI-STORM	MPC-68	MONTICELLO	NUHOMS	61BT
QUAD CITIES	HI-STORM	MPC-68	OYSTER CRK	NUHOMS	61BT
RVR BEND	HI-STORM	MPC-68	BRUNSWICK	NUHOMS	61BTH
VT YANKEE	HI-STORM	MPC-68	ROBINSON	NUHOMS	7P
WASH NUCLEAR	HI-STORM	MPC-68	TROJAN	Transter Cask	MPC-24E/EF
YANKEE-ROWE	NAC-MPC	MPC-36	NORTH ANNA	TN Metal Casks	TN-32
CATAWBA	NAC-UMS	UMS-24	PRAIRIE ISL	TN Metal Casks	TN-40
MAINE YANKEE	NAC-UMS	UMS-24	PEACHBOTTOM	TN Metal Casks	TN-68
MCGUIRE	NAC-UMS	UMS-24			

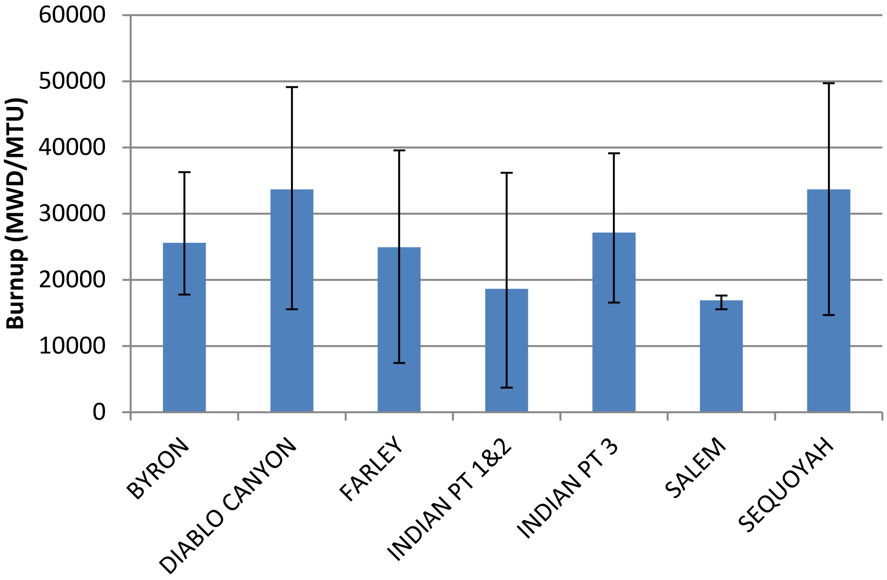
Note A: From CALVIN 4.0 database.

Note: Shaded cells show burnup ranges in Figures 5, 6, 7, and 8.



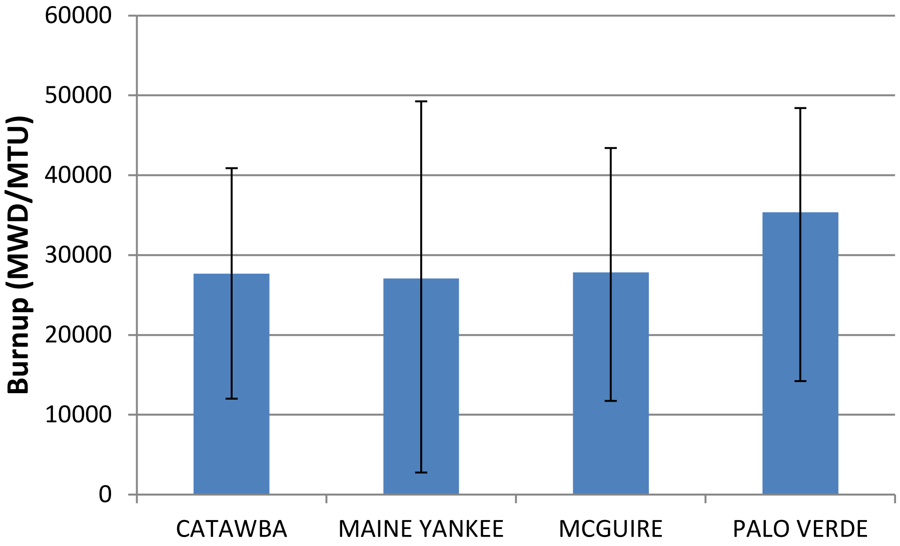
Note: The solid columns represent average burnup, and the bars are maximum and minimum values. The maximum authorized burnup is 68,200 MW-d/MTU.

Figure 5. Burnup for sites using the HI-STORM MPC-68 (BWR) canister.



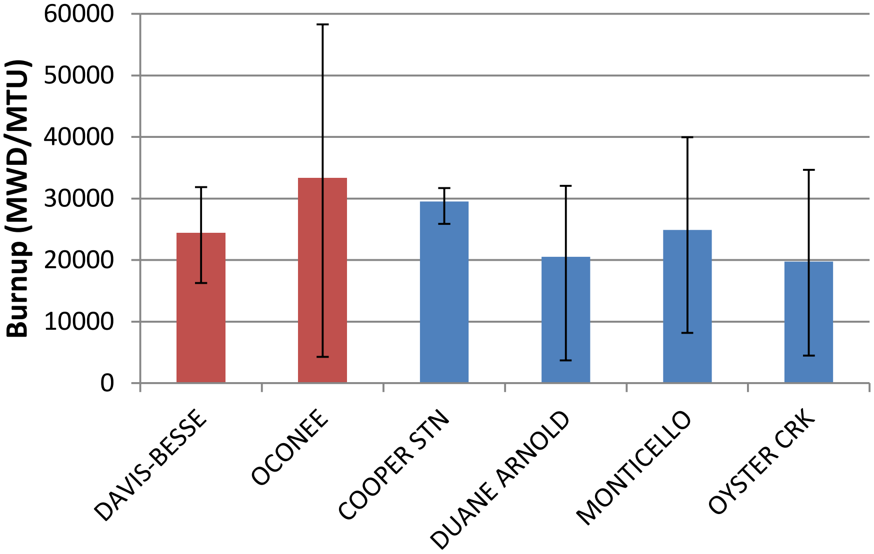
Note: The solid columns represent average burnup, and the bars are maximum and minimum values. The maximum authorized burnup is 68,200 MW-d/MTU.

Figure 6. Burnup for sites using the HI-STORM MPC-32 (PWR) canister.



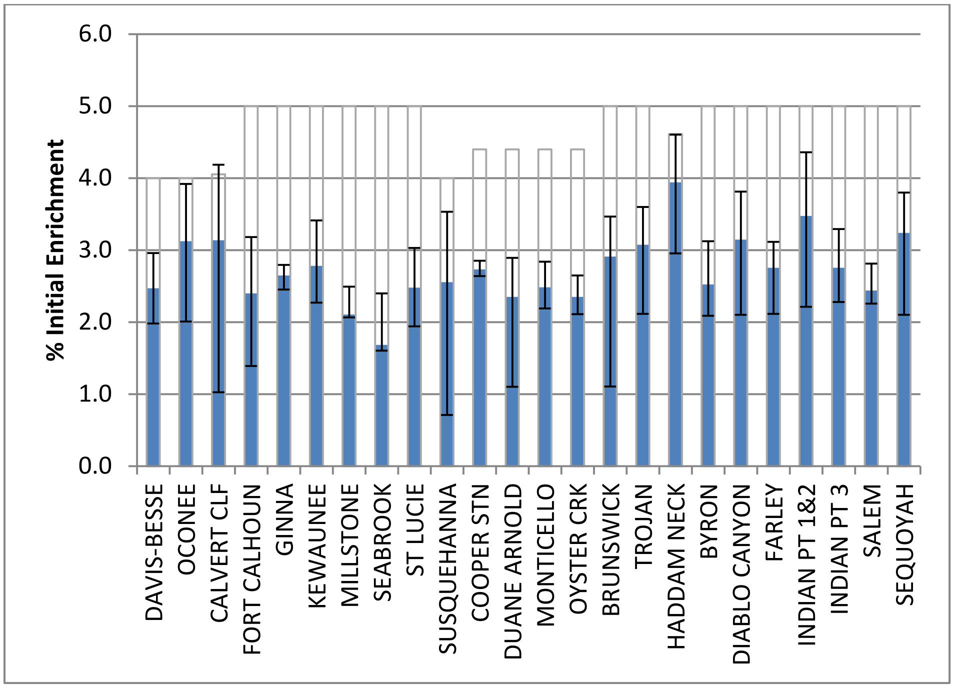
The solid columns represent average burnup, and the bars are maximum and minimum values. The maximum authorized burnup is 45,000 MW-d/MTU.

Figure 7. Burnup for sites using the NAC-UMS 24 (PWR) canister.



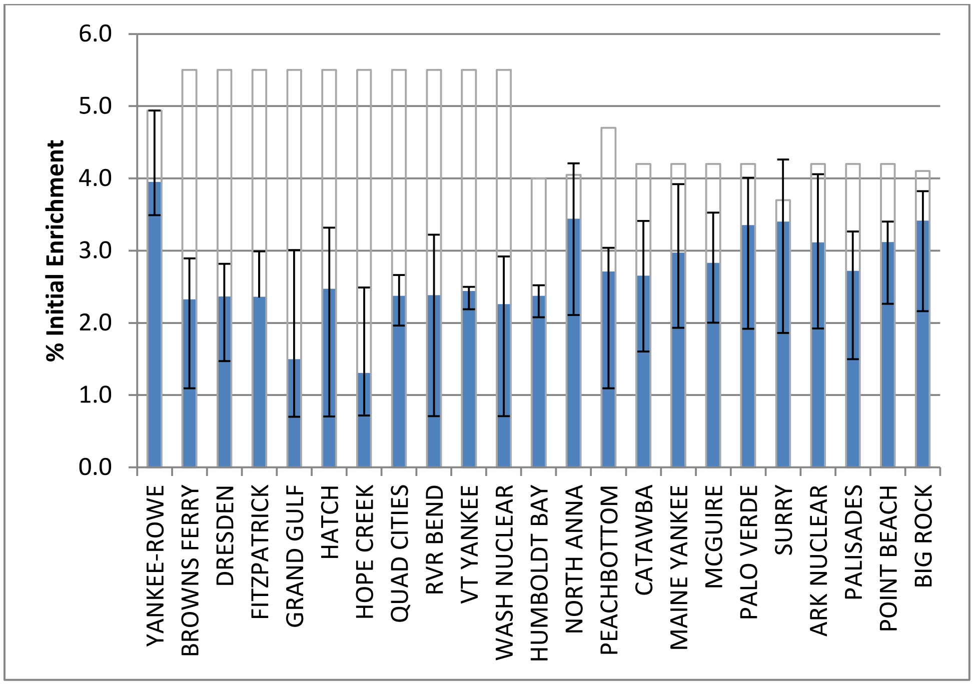
Note: The red columns are type 24P, and the blue columns are 61BT. The columns represent average burnup, and the bars are maximum and minimum values. The maximum authorized burnup is 40,000 MW-d/MTU for both canister types.

Figure 8. Burnup for sites using NUHOMS (PWR and BWR) canisters.



Note: The solid columns are average values, and the bars are maximum and minimum values. The open columns are maximum licensed values.

Figure 9. Percent enrichment by reactor site.



Note: The solid columns are average values, the bars are maximum and minimum values. The open columns are the maximum licensed values.

Figure 10. Percent enrichment by reactor site.

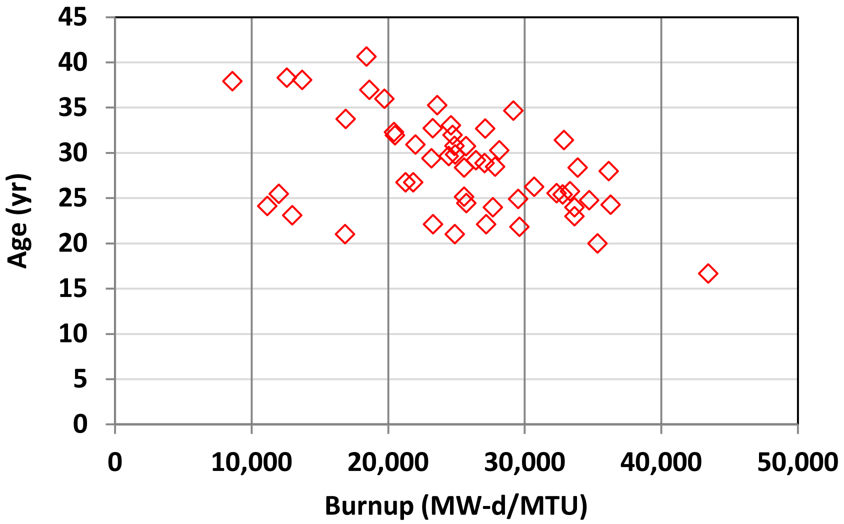


Figure 11. Fuel age as a function of burnup.

It is clear from these figures that using the maximum values from license documents is conservative. A good alternative is to use quantiles of data generated for discrete canisters, to better understand the distributions of important parameters. Generating data for discrete canisters from CALVIN 4.0 is more labor intensive, but for illustrative purposes, projections for individual canisters at the Dresden site were generated. Dresden was chosen as it has a relatively large number of HI-STORM MPC-68 canisters. Dresden has one retired reactor, and the overall fuel age is slightly older than the fleet average. CALVIN estimates the total number of canisters to be 60, while the actual number is 45. Figure 12 shows a cumulative distribution function of burnup for the 60 MPC-68 canisters listed by CALVIN. The distribution (for canister averages reported by CALVIN) is smooth and nearly linear from approximately 7,000 to 32,000 MW-d/MTU.

Further specifics for the Dresden projections are given in Table 2. There are a few small discrepancies between integrating CALVIN data at the site level compared to the canister level. Again, they show that the CALVIN estimates have limited precision, but that using the licensed maximum values for canister characteristics is conservative.

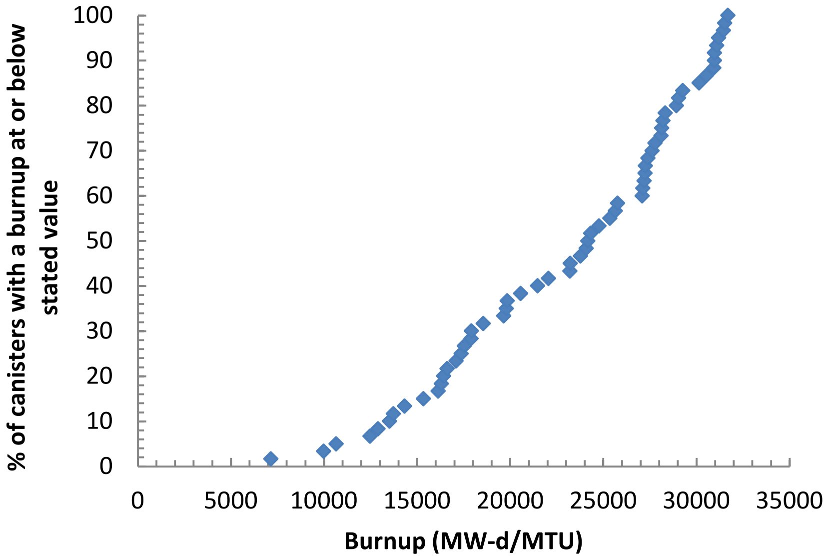


Figure 12. Cumulative distribution of burnup for the 60 total HI-STORM MPC-68 canisters listed in CALVIN for the Dresden site.

Table 1. CALVIN data comparison when integrated by site or by canister.

		CALVIN 4.0 All fuel assemblies at Dresden site	**CALVIN 4.0 Averages for loaded canisters**
Burnup (MW-d/MTU)	Average	23,271	22,988
	Minimum	3,388	7,161
	Maximum	33,835	31,692
Initial Enrichment (%)	Average	2.37	2.34
	Minimum	1.47	1.99
	Maximum	2.82	2.82
Age (yr)	Average	32.69	32.66
	Minimum	24.17	24.17
	Maximum	43.32	42.37

3. ASSUMPTIONS FOR EVALUATING FEASIBILITY OF DIRECT DISPOSAL OF DUAL-PURPOSE CANISTERS

Feasibility evaluation for direct geologic disposal of dual-purpose and storage-only canisters will be evaluated using targeted technical and regulatory analyses. Assumptions are needed because: 1) the analyses are generic (no site specified); 2) there is a recognized need for statutory and regulatory changes or clarifications (BRC 2012); and 3) the timing of disposal is uncertain so that the future state of the overall fuel management system in the U.S. must be assumed. The goal of these assumptions is to provide a common, underlying basis for targeted analyses, and not to specify how the analyses will be conducted. Assumptions are categorized into three areas:

- Engineering and technology assumptions
- Statutory and regulatory framework for disposal
- Logistical, regulatory, and technological assumptions related to storage and transportation that influence disposal feasibility

3.1 Engineering and Technology Assumptions

3.1.1 DPC Characteristics

1. DPCs contain commercial UNF. Average burnup for existing UNF in dry storage is nominally 40 GW-d/MT, with a bounding value of 60 GW-d/MT for future DPCs. These values may be used in generalized analyses to evaluate DPC disposal feasibility (more reactor-site specific or canister-specific bounding values may be available as discussed in Section 2).

   Basis: Analysis and projections in Carter et al. (2012), and an assumption that UNF in DPCs is similar to the overall average of the total inventory. In fact, the enrichment and burnup of UNF in DPCs may be less than the overall averages reported by Carter et al. (2012), as indicated from the data summary (Section 2).

2. The capacity of DPCs is typically 32 PWR assemblies or 68 BWR assemblies. Larger DPCs are now available (Greene et al. 2013) from NAC International (Magnastor 37/87 system, nominally 37-PWR or 87-BWR), Holtec International (MPC-37/88, nominally 37-PWR or 88-BWR), and Transnuclear (NUHOMS 37 series).

   Basis: The 32-PWR size (or BWR equivalent) is typical and addresses a great majority of existing canisters. For limiting analysis the larger size (37-PWR or BWR equivalent) should be used.

3. Storage-only canisters can be included in the evaluations.

   Basis: Storage-only canister based systems include the MSB (24-PWR, Energy Solutions) and the NUHOMS-24PS, -24PL, -24PHBS, -24PHBL, -52B and -07P (Transnuclear). These canisters currently exist at the Idaho National Laboratory, and at the Calvert Cliffs, Surry, Oconee, Arkansas Nuclear One, Palisades, Davis-Besse, Point Beach, Susquehanna, and H.B. Robinson nuclear power plants. These are sealed canisters, not to be confused with non-canistered cask systems (storage-only or storage-transportation) which have bolted closures. An implementing organization could develop approaches to allow transport to a centralized storage facility, and then a repository.

4. DPCs designed for vertical storage can be readily approved, with modifications as appropriate, for horizontal disposal.

   Basis: The NUHOMS canister systems are all designed for horizontal storage and transport, and constitute a large fraction of the existing DPCs. Modifications to canisters designed for vertical storage (and horizontal transport for DPCs) can be readily licensed and implemented to allow horizontal disposal.

5. DPCs designed for horizontal storage can be readily transferred to disposal overpacks in either vertical or horizontal orientation, for disposal.

   NUHOMS canisters do not include features that allow direct lifting of the loaded and sealed canister, for example to remove them from transportation casks in vertical orientation. The NUHOMS system is designed with lifting features on the transfer cask, which may be loaded vertically (e.g., in the fuel pool) or horizontally (e.g., for unloading horizontal storage vaults). To package these canisters for disposal, new fixtures are needed, for example to slide canisters horizontally from either transportation casks or transfer casks, into disposal overpacks. This handling issue was identified by BSC (2003a, Section 3.2).

6. Existing canisters may be analyzed for uniform average enrichment, average burnup, and average age for the assemblies contained.

   Basis: This simplifying assumption avoids the complication of nonuniform loading within canisters, whereby cooler or less reactive assemblies are intentionally placed in certain positions of a DPC basket. The assumption may be used with thermal management analyses, if a suitably conservative maximum canister wall temperature (e.g., 200°C; BSC 2008) is used, to ensure that fuel temperature does not exceed prescribed limits (350°C; CRWMS M&O 2000). Results obtained with uniform loading can be tested later for specific cases of nonuniform loading.

   Investigators may choose not to apply this assumption for some analyses, and to use assembly-specific information instead. For example, analysis of DPC nuclear reactivity (Hardin et al. 2013) may exploit reactivity margin inherent in differences between the as-loaded canister contents, and the fuel content assumptions used to license the canister design.

7. Residual moisture in sealed DPCs can be estimated from the drying procedures required in license documents.

   Basis: Direct measurement of residual water content is not possible for sealed canisters. To the extent that residual moisture content in sealed canisters is important, it can be estimated.

3.1.2 Disposal Concepts

1. Surface decay storage of DPCs and storage-only canisters for up to 100 yr (out-of-reactor) can be assumed in disposal feasibility evaluations.

   Basis: This assumption is equivalent to an assumption that storage licenses can be extended to 100 yr, and that transportation licenses can be extended to fuel with 100-yr age. It is based on reasonable projections of current trends, but has not been substantiated by regulatory findings as to 100-yr extended storage or associated transportation.

This assumption is generally consistent with an "No Action Alternative" considered in an Environmental Impact Statement for a geologic repository. The environmental impact statement (EIS) assumed that storage facilities would be completely replaced in 100 years and possibly every 100 years afterword, including the *existing* DPCs (DOE 2002).

2. Open emplacement modes (Hardin et al. 2012) are limited to 50 yr of operation (e.g., ventilation) after waste emplacement in a disposal panel.

   Basis: The combined durations of surface storage and repository operation will not be evaluated beyond 150 yr out-of-reactor, to limit any additional assumptions about long-term stability of institutions responsible for waste management. Note that spent nuclear fuel (SNF) will be produced in the U.S. for at least 90 years (from circa 1965 to 2055 or beyond), and that emplacement operations could be of similar duration to allow for cooling and other factors. Thus, combined duration in terms of time since reactor discharge is a more representative measure of disposal conditions.

3. Thermal limits will not be assigned to the disposal system *a priori*. Rather, near-field peak temperature targets or other thermal criteria will be used to evaluate thermal loading of the repository and repository performance.

   Basis: Near- and far-field temperature limits have been imposed previously (DOE 2008), but we wish to evaluate whether previous limits can be relaxed and still show adequate performance, provided sufficient scientific understanding of thermal behavior in various media has increased

4. Underground handling and transport of DPCs will be shielded.

   Basis: Shielded transporters and handling equipment substantially decrease the risk of accidental worker exposure, and are the norm in disposal concepts being investigated world-wide.

5. Disposal mode may be shielded (e.g., by borehole emplacement) or unshielded (e.g., in-drift emplacement).

   Basis: Both shielded and unshielded modes continue to be investigated internationally, and have been investigated by previous studies in the U.S.

3.1.3 Criticality Analysis

1. Analysis of postclosure criticality will include burnup credit (i.e., actinides and fission products), and assembly-specific or cask-specific characteristics.

   Basis: Past studies have identified situations where burnup credit and more detailed modeling (principal isotopes, BSC 2003a; more complete isotopics, EPRI 2008) is needed in DPC disposal analysis.

2. Consequence analysis may also be used to include or exclude postclosure criticality.

   Basis: Previous studies (e.g., Rechard et al. 1996) have shown that criticality events may not significantly change postclosure repository performance. Additional analysis may be needed to determine the type of criticality event that could occur, and the impact of heat and pressure on the disposal system.

3. Reactor operating records can be used for selecting more realistic modeling parameters to characterize the discharge isotopic composition and residual reactivity levels associated with UNF

   Basis: Numerous studies (e.g., Wagner and Sanders 2003) have examined the impact of depletion and criticality analysis assumptions which suggest that a considerable amount of uncredited margin is incorporated into most cask loadings. Reducing uncertainty associated with parameter selection and calculating more realistic safety margins will enable a higher percentage of DPCs to satisfy subcriticality requirements.

3.1.4 Surface Facilities

1. Canisters will be sealed at the reactors or at a centralized storage facility and SNF will not be removed at the repository. However, opening and subsequent re-sealing of de-watering ports may be permitted.

   Basis: This study will consider canister remediation options that involve re-opening the canister, such as pumping filler material in through dewatering ports. Canisters would be re-sealed prior to disposal.

2. Surface facility throughput will be sufficient to dispose of all nominally storage-only canisters and DPCs at minimum age/burnup.

   Basis: Surface facilities can be readily designed, constructed and operated to handle and package DPCs for disposal. Such facilities would be similar in scope, with similar throughput, as previously designed facilities to package transportation-aging-disposal (TAD) canisters (DOE 2008). This assumption is needed for logistical studies and costing, where the size of facilities and the duration of operations are estimated.

3. Any necessary DPC inspection can be done remotely in a hot cell, and detected damage can be corrected or mitigated by re-packaging.

   Basis: Inspections may be required to confirm the condition of canisters prior to packaging and emplacement, to protect workers, and to conform to postclosure waste isolation related requirements as applicable. Canisters may accumulate minor damage from corrosion, especially if stored in marine environments.

3.2 Statutory and Regulatory Framework for Disposal

The generic health standard for mined geologic disposal (40 CFR 191) from the U.S. Environmental Protection Agency (EPA) is still in force, and could in principle be applied to future repositories. However, the evolution in the strategy adopted by the EPA and NRC in the site-specific regulations for a repository in tuff, 40 CFR 197 and 10 CFR 63, would likely be adopted for a future repository.

The National Academies/National Research Council (NAS) recommendations for standards specific to a repository in unsaturated tuff developed pursuant to the *Energy Policy Act of 1992*, may be applicable to other repositories for SNF and high-level waste (HLW) even though this act only addresses standards for a repository at Yucca Mountain. If so, then licensing of future repositories will require demonstration of compliance with a peak dose standard, for a period of geologic stability (~10^6 yr was recommended by the NAS).

Any changes to the EPA standards for repositories in media other than at Yucca Mountain would likely change 40 CFR 191, and would be reflected in corresponding changes to NRC regulation 10 CFR 60. The 10 CFR 60 rule is still applicable to any geologic repository other than at Yucca Mountain, and was not revised when fundamental changes were made to performance assessment requirements in the promulgation of 10 CFR Part 63. In particular, NRC has evolved from disposal subsystem requirements (e.g., EBS containment) to rely on mean annual dose computed from total system performance assessment (TSPA). Consequently, NRC stated when promulgating 10 CFR 63 that the “generic Part 60 requirements will need updating” (Rubenstone 2012; NRC 2001). Furthermore, NRC has suggested that regulations for future repositories would likely look similar to 10 CFR 63, in presentations to the Blue Ribbon Commission on America’s Nuclear Future (BRC) and the Nuclear Waste Technical Review Board (McCartin 2010; 2012).

3.2.1 Statutory Framework

1. The *Nuclear Waste Policy Act* (as amended) will be further amended or replaced with legislation that permits developing one or more geologic repositories for U.S. commercial SNF at sites other than Yucca Mountain, and doing so on a schedule consistent with assumptions in Section 3.1.2 above.

   Basis: The scope of this study is to consider DPC disposal alternatives that would not be constrained by current statutory limits, including limits on repository capacity. This assumption does not address the total inventory of U.S. SNF (projected by Carter et al. 2012). The purpose of the study is to determine technical feasibility of DPC direct disposal in repositories of any capacity.

2. Future repositories will be regulated by the NRC, implementing requirements of the National Environmental Policy Act (NEPA), and implementing performance standards promulgated by the EPA.

   Basis: These conditions are required by current legislation in effect.

3.2.2 Regulatory Framework

In general, the regulatory framework controlled and implemented by EPA and NRC will be similar to existing site-specific regulations (§63.113).

1. Expected peak dose to a reasonably maximally exposed individual (RMEI) at the boundary of the accessible environment will be the primary measure of individual dose, for two time periods: a limit of 0.15 mSv/yr before 10^4 yr, and 1 mSv/yr for the mean of simulations beyond 10^4 yr through the period of geologic stability, or approximately 10^6 yr.

2. The accessible environment for performance assessment of DPC disposal will be at least 5 km away from the boundary of the repository (§63.302).

3. The NRC requirement for retrievability will remain similar:

   …the geologic repository operations area must be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the Commission. (§63.111[e])

4. In general, features, events, and processes (FEPs) and scenario classes formed from these FEPs will be retained or omitted based on their influence on performance in the first 10^4 yr (§63.114). The criterion for screening FEPs and scenario classes based on probability will remain at 10^{-8} in any one year. Seismic and climate change effects will be projected beyond 10^4 years (§63.342).
5. Lead, chromium or other materials used in fabrication of DPCs is part of waste packaging that will not be subject to regulation under the *Resource Conservation and Recovery Act* (RCRA).
6. NRC requirements for barriers of the disposal system will remain similar: Licensee must identify components of the disposal system that are important for isolation and demonstrate their performance (§63.115). No subsystem containment requirements will be specified as discussed in Section 3.2 above.
7. Inadvertent human intrusion will not be included in the probabilistic dose calculations. Individual dose to the RMEI will be assessed, conditioned on the intrusion. The dose pathway will be limited to groundwater (or to airborne transport if significant). Dose to the crew responsible for intruding will not be evaluated (§63.321).
8. The human intrusion scenario will be similar to that described in 10CFR63.321, in that a stylized calculation will be specified such that a single well bypasses a portion of the natural barrier system vertically above or below the repository, but the remainder of the natural barrier in the horizontal direction to accessible environment is retained.

3.3 Assumptions for Storage and Transportation

The condition of DPCs or storage-only canisters during storage and transportation establish initial conditions for disposal. Other limits on storage and transportation such as permitted durations or age of UNF, also interface with disposal.

3.3.1 Storage

1. Licensing activities will proceed under 10 CFR Parts 71 and 72 to allow transport of commercial UNF in DPCs (and possibly in existing storage-only canisters) for up to 100 yr from reactor discharge, in accord with Assumption 3.1.2(1).

   Basis: The influence of shorter and long storage durations can be evaluated in sensitivity studies.

3.3.2 Transportation

1. Transportation casks for all existing and future DPCs, and storage-only canisters, will be developed and licensed for use in transporting UNF to a centralized storage facility, and from there to the repository.

   Basis: The availability of licensed infrastructure for transporting DPCs to the repository is beyond the scope of this study.

3.3.3 Movement from Storage

1. The preferred disposition pathway is to transport SNF directly from a centralized storage facility operated conjunctively with the repository.

   Basis: This assumption can be used in logistical simulations, to expedite transfer of responsibility for SNF from the utilities, to an authority responsible for long-term management and disposal.

2. DPCs or storage-only canisters can be selected for transport to the repository using various strategies, including oldest fuel first (OFF) and youngest-fuel-first (YFF), and variations thereof.

   Basis: Once fuel is stored in a centralized facility, selection can be optimized for disposal and other fuel management priorities without directly involving the electric utilities.

3. SNF can be transported from ISFSIs at power plants, directly to the repository, if the fuel is cool enough for disposal and no other fuel suitable for disposal is available at a centralized storage facility.

   Basis: Operation of the disposal system should not be suspended because the only fuel suitable for disposal is at power plant sites.

4. NEXT STEPS

Follow-on work will be performed in accordance with the work plan (Howard et al. 2012). The next phase (Section 3.3 of that plan) will be a multi-year effort that investigates a range of technical issues (Hardin et al. 2013, Section 10). Part of the effort will be performance assessments to compare postclosure safety of DPC direct disposal, with the safety of disposing of the same SNF in the same geologic settings, using re-packaging into new canisters purpose-built for disposal.

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Appendix A: Information on Existing DPCs

Tables A-1 and A-2 present a spreadsheet of information for the individual canisters types, compiled from licensing-related documents available on the NRC ADAMS server. The Excel version of this table has hyperlinks to schematics and drawings for many canister types. The reader is referred to Greene et al. (2013) for more recent data on canister characteristics. Table A-3 is a current (February, 2013) summary of dry storage systems in use at operating and shutdown reactor sites, and wet storage at shutdown sites (LeDuc 2013, personal communication).

Table A-1. DPC types and physical dimensions (from

Cask System	Canister or Cask Type	Type	Vendor	Total # of Canisters of This Type	% of Total Canisters	Summed # of Canisters by Type	Internal Canister Diameter (in.)	Outside Canister Diameter (in.)	Canister Length (in.)	Canister Weight w/o Fuel (lb.)	Gross Weight (lb.)	# Assem-blies	Max Assembly Weight (lb.; PWR)	Max Assembly Weight (lb.; BWR)	Min Assembly Weight (lb.; PWR)	Maximum Decay Heat Load Per Assembly (kW)	Maximum Decay Heat Load (kW; (PWR)	Maximum Decay Heat Load (kW; BWR)	Design-Basis Burnup (MW-d/MTU; PWR)	Design-Basis Burnup (MW-d/ MTU; BWR)
NUHOMS	12T	PWR	TN	29	1.85							12								
NUHOMS	24P	PWR	TN	135	8.60		66.0	67.25	186.0		80,000	24	1,682			1	24		40,000	
NUHOMS	24PHB	PWR	TN	38	2.42		65.9		186.67	37,761 (PHBS)/ 35,426 (PHBL)	78,129 (PHBS)/ 75,794 (PHBL)	24	1,682			1.3	24		55,000	
NUHOMS	24PT	PWR	TN	22	1.40							24								
NUHOMS	24PT1	PWR	TN	18	1.15		65.9	67.19	186.5		82,000	24					14			
NUHOMS	24PT4	PWR	TN	28	1.78		65.9	67.19	196.5			24					24			
NUHOMS	24PTH	PWR	TN	27	1.72		65.9	67.19	186.55 (S), 192.55 (L)	48,600-52,000 (S); 49,700-53,300 (L); 49,100 (S-LC)	89,000 - 92,400 (S); 90,100 - 93,700 (L); 89,500 (S-LC)	24	1682			2.0 (S and L), 1.5 (S-LC)	40.8 (S and L), 24.0 (S-LC)		62,000	
NUHOMS	32P	PWR	TN	21	1.34							32	1533			1.02	32.64		45,000	
NUHOMS	32PT-L	PWR		63	4.01		66.19	67.19	192.2	45,500 (L100)/ 47,600 (L125)	89,200/101,400 (min/max)	32	1365 (L100)/ 1682 (L125)			1.2	24		45,000	
NUHOMS	32PT-S	PWR					66.19	67.19	186.2	44,500 (S100)/ 46,600 (S125)	88,200/100,400 (min/max)	32	1366 (S100)/ 1682 (S125)			1.2	24		45,000	
NUHOMS	32PTH	PWR	TN	66	4,20			69.75	193 (max.)			32	1575		1450	1.5	34.8		60,000	
NUHOMS	52B	BWR	TN	27	1.72		66	67.19	196 (max.)			52		725		0.37		19.24		35,000
NUHOMS	61BT	BWR	TN	113	7.20		66.25	67.25	199.7	45,390	89,390	61		705		0.30	18.3	22.57		40,000
NUHOMS	61BTH	BWR	TN	8	0.51		66.75	67.25	196 (max.)		88,700 Type 1/ 93,120 Type 2	61		705 (w/ channels), 640 (w/o channels)		0.54 (Type 1), 0.70 (Type 2)		22 (Type 1), 31.2 (Type 2)		62,000
NUHOMS	7P	PWR	TN	8	0.51	603						7								
MC-10	MC-10	PWR	W	1	0.06	1	68	88	188			24	1490						35,000	
TranStor Cask	MPC-24E/EF	PWR	Holtec	34	2.17	34	67.375	68.5 (max.)	190.125 (max.)	45,000	90,000	24	1721 (w/o spacers); 1680 (w/ spacers)			1.416 (Zr clad) 0.71 (SS clad)	36.9, 34 (Zr clad)		40,000 (SS clad)	
HI-STORM	MPC-24	PWR	Holtec	22	1.40		67.375	68.5 (max.)	190.125 (max.)	42,000	90,000	24	1720 (w/o spacers) 1680 (w/			1.416 (Zr-clad)	36.9, 34 (Zr clad)		68,200	

Cask System	Canister or Cask Type	Type	Vendor	Total # of Canisters of This Type	% of Total Canisters	Summed # of Canisters by Type	Internal Canister Diameter (in.)	Outside Canister Diameter (in.)	Canister Length (in.)	Canister Weight w/o Fuel (lb.)	Gross Weight (lb.)	# Assemblies	Max Assembly Weight (lb.; PWR)	Max Assembly Weight (lb.; BWR)	Min Assembly Weight (lb.; PWR)	Maximum Decay Heat Load Per Assembly (kW)	Maximum Decay Heat Load (kW; (PWR)	Maximum Decay Heat Load (kW; BWR)	Design-Basis Burnup (MW-d/MTU; PWR)	Design-Basis Burnup (MW-d/ MTU; BWR)
													spacers)							
HI-STORM	MPC-32	PWR	Holtec	131	8.34		67.375	68.5 (max.)	190.125 (max.)	36,000	90,000	32	1722 (w/o spacers); 1680 (w/ spacers)			1.062 (Zr clad), 0.5 (SS clad)	36.9, 34 (Zr clad)		68,200	
HI-STORM	MPC-68	BWR	Holtec	266	16.94	419	67.375	68.5 (max.)	190.3125 (max.)	39,000	90,000	68		730 (w/ channels)		0.5 (Zr clad), 0.095 (SS clad)		36.9, 34 (Zr clad)		68,200
HI-STAR	MPC-80	BWR	Holtec	5	0.32	5	67.375	68.5 (max.)	114	27,000	59,000	80		400 (w/ channels)		0.05		2	23,000	
NAC-UMS	UMS-24	PWR	NAC	210	13.38	210	65.8	67.06	175.1-190.4 (5 classes of canisters)	33,097-35,263 (PWR); 36,383-36,920 (BWR)	70,705-73,902 (PWR); 75,359-75,896 (BWR)	24 (PWR)/56 (BWR)	1,604	696		0.8 (PWR)/ 0.3 (BWR)	20	16	45000 (up to 50,000 at Maine Yankee)	45,000
NAC-MPC	MPC-26	PWR	NAC	43	2.74		69.39	70.64	151.75			26	1,490			0.67	17.5		43,000 (Zircalloy)/ 38,000 (Stainless)	
NAC-MPC	MPC-36	PWR	NAC	16	1.02	59			122.5		54,730	36	850 (actual weights given range: 351-408)			0.347 (Zircalloy)/ 0.264 (stainless)	12.5		43,000 (Zircalloy)/ 38,000 (Stainless)	
Foster Wheeler	MVDS	HTGR-Peach Bottom	DOE		0.00							10 elements					33		900 EFPD	
Foster Wheeler	MVDS	Shipping-port	DOE		0.00							1 reflector module or 127 loose rods					10		30,000 EFPH	
Foster Wheeler	MVDS	TRIGA	DOE		0.00							108 elements					36			
NAC-I28	NAC-I28	PWR	NAC	2	0.13	2	79.3	94.8	181.2			28	1525						22,000	
TN Metal Casks	TN-32	PWR	TN	63	4.01	63	94.75	97.75	201.6	45,500	57,750	32	1533			1.02	32.7		40,000	
TN Metal Casks	TN-40	PWR	TN	29	1.85	29		99.52	175			40					27		45,000	
TN Metal Casks	TN-68	BWR	TN	53	3.38	53	69.5	72.5	189	124,800	172,700	68		705		0.441 (0.312 for 7x7 fuel)		30		60000 (40,000 for 7x7 fuel)
Castor	V/21 and X33	PWR	GNB	26	1.66	26	60.1	94.5 (with fins)	192.4	50,900	58,450	21	1525						40,000	
Fuel Solutions	VSC-24	PWR	BFS/ES	58	3.69	58	59.8 (w/	62.5	164-192.25	28,428-30,544	56,860-68,685	24	1,585		1,110	1	24		45,000	

Cask System	Canister or Cask Type	Type	Vendor	Total # of Canisters of This Type	% of Total Canisters	Summed # of Canisters by Type	Internal Canister Diameter (in.)	Outside Canister Diameter (in.)	Canister Length (in.)	Canister Weight w/o Fuel (lb.)	Gross Weight (lb.)	# Assem-blies	Max Assembly Weight (lb.; PWR)	Max Assembly Weight (lb.; BWR)	Min Assembly Weight (lb.; PWR)	Maximum Decay Heat Load Per Assembly (kW)	Maximum Decay Heat Load (kW; (PWR)	Maximum Decay Heat Load (kW; BWR)	Design-Basis Burnup (MW-d/MTU; PWR)	Design-Basis Burnup (MW-d/ MTU; BWR)
							tolerances)													
Fuel Solutions	W150*/W74	BWR	BFS/ES	8	0.51	8	64.8	66	192.3	44,899 (M)/ 42,735 (T)	77,539 (M)/ 75,375 (T)	64 (Big Rock Point Assemblies)		485 (w/o channels)				24.8		40,000
Legend:	Little information found				<1% of total															
					1-2% of total															
	Public/non-electronic SARs available				2-4% of total															
					4-8% of total															
					>8% of total															

Table A-2. DPC Construction and Criticality Control

Cask System	Canister or Cask Type	Canister Shell composition	Canister Internal Materials	Basket Materials	Neutron Absorber Materials	Spacers and Thermal Shunts	Shield Plug (Y/N, material)	Criticality Control	Max U-235 enrichment (wt. %)	Min U-235 enrichment (wt. %)	NOTES
NUHOMS	12T										
NUHOMS	24P	Type 304 stainless steel (canister), Type F304 SA182 (top and bottom ends)	4 support rods (Stainless steel type XM-19) welded to guide disks	Carbon and Stainless Steel		24 stainless steel guide sleeves, 8 carbon steel spacer discs, 4 Type XM-19 stainless steel	Y, carbon steel or steel-encased lead	Burnup credit, BPRAs, soluble boron	4	1.45	
NUHOMS	24PHB	Stainless steel (ASME SA-240 Type 304)	Support rods same as 24P	Carbon and Stainless Steel		Guide sleeves same as 24P	Y, steel (ASME SA-182 Type 304) encased lead		4.5		Generally identical to the 24P model, additional test port and plug on top cover plate, and integrated cover plate/shield plug
NUHOMS	24PT	Stainless steel		Carbon and Stainless Steel			Y, carbon steel or steel-encased lead				
NUHOMS	24PT1	Stainless steel		Carbon and Stainless Steel			Y, carbon steel or steel-encased lead				
NUHOMS	24PT4	Stainless steel		Carbon and Stainless Steel			Y, carbon steel or steel-encased lead				
NUHOMS	24PTH	Type 304 stainless steel (canister), Type F304 SA182 (top and bottom ends)	Transition rails (4-aluminum type 6061, 4 steel Type 304)	Type 304 Stainless Steel	Poison plates (borated aluminum, MMC, Boral poison plates)	Aluminum plates (Alloy 1100)	Y, A36 carbon steel or Type 304 stainless encased lead (ASTM B29) 6.25 inches thick	Poison plates (borated aluminum, boron carbide aluminum MMC, Boral poison plates)	5		Three different configurations: 24PTH-S, 24PTH-L, and 24PTH-S-LC
NUHOMS	32P	Stainless steel		Carbon and Stainless Steel			Y, carbon steel or steel-encased lead		4.05		
NUHOMS	32PT-L	Stainless steel (SA 240 Type 304), canister outer top and bottom plates	Transition rails (aluminum type 6061)	0.25" thick Stainless Steel (XM-19) welded	Aluminum alloy 1100 plates with basket connected with fasteners	Aluminum alloy 1100 plates with basket connected with fasteners	Y, carbon steel or steel-encased lead, top plug thickness 6.25-7.5 in., bottom plug thickness 4-5.25 in.	Poison plates (borated aluminum, boron carbide aluminum MMC, Boral), geometry, optional poison rod assemblies (304 stainless steel shell filled with boron carbide)	5		
NUHOMS	32PT-S	Stainless steel (SA 240 Type 304), canister outer top and bottom plates	Transition rails (aluminum type 6061)	0.25" thick Stainless Steel (XM-19) welded	Aluminum alloy 1100 plates with basket connected with fasteners	Aluminum alloy 1100 plates with basket connected with fasteners	Y, carbon steel or steel-encased lead, top plug thickness 6.25-7.5 in., bottom plug thickness 4-5.25 in.	Poison plates (borated aluminum, boron carbide aluminum MMC, Boral), geometry, optional poison rod assemblies (304 stainless steel shell filled with boron carbide)	5		
NUHOMS	32PTH	Stainless steel	Stainless steel rails for basket support	Stainless Steel	Poison plates (borated aluminum, MMC, Boral poison plates), Borated polyester resin	Aluminum/borated aluminum disks	Y, steel, 8.75 inches thick (bottom), 12 inches thick (top)	Poison plates (borated aluminum, boron carbide aluminum MMC, Boral), geometry, optional poison rod assemblies	5		
NUHOMS	52B	Stainless steel	6 support rods welded to discs	Carbon and Stainless Steel	BPRAs, Borated Steel	9 spacer disks (top-Grade 2 carbon steel, others-Grade 70 carbon steel), Spacer sleeves (SA-564 Type 630 steel)	Y, carbon steel or steel-encased lead, top plug thickness 8.0 in., bottom plug thickness 5.75 in.	Burnup credit, BPRAs, borated steel (up to 2%)	4		
NUHOMS	61BT	Stainless cteel (SA-240 Type 304); 12 rails same material	6 support rods welded to discs	Stainless Steel SA-240 Type 304 (0.105 in - 0.135 in thick)	Borated plates	Poison plates	Y, A-36 steel, top plug thickness 7.0 in., bottom plug thickness 5.0 in.	Burnup credit, borated aluminum neutron absorber plates for BWR, geometry	3.7, 4.1, 4.4 (Types A,B,C)		
NUHOMS	61BTH	Stainless steel (SA-240 Type 304)	Type 1- Stainless steel transition rails (SA-240, Type 304), Type 2-Stainless/aluminum transition rails (SA-240,	Welded Stainless Steel SA-240 Type 304 (0.105 in - 0.135 in thick)	Borated aluminum, boron carbide/ aluminum MMC, or Boral plates sandwiched between	Poison plates, Type 2-aluminum in transition rails	Y, carbon steel (ASME SA-36) plated with electroless nickel, top 6.25 in. thick	Geometry, borated aluminum, boron varbide/aluminum MMC, or Boral plates	5		Type 1 and 2 are two different fuel compartment assemblies

			Type 304 steel, B209 Type 1100 or 6061 Aluminum, hold down ring		steel rods no welds						
NUHOMS	7P				Borated guide sleeves			Borated guide sleeves			
MC-10	MC-10	Low-alloy steel		Stainless steel	BISCO NS-3 on outer surface of canister		Y, low-alloy steel, 9 in. thick		3.7		Canister design has cooling fins
TranStor Cask	MPC-24E/EF	Alloy X		Multi flange plate weldment (Alloy X)	Boral/Metamic	Optional aluminum (Alloy 1100) heat conduction elements, spacers as necessary (Alloy X)	N, 9.5 in. thick lid and 2.5 in. thick base plate	Geometry, flux traps, Boral, Metamic	5		All MPC components are made of Alloy X (Stainless Steel types 316, 316LN, 304, or 304LN), least favorable thermal and mechanical properties used for modeling
HI-STORM	MPC-24	Alloy X		Multi flange plate weldment (Alloy X)	Boral/Metamic	Optional aluminum (Alloy 1100) heat conduction elements, spacers as necessary (Alloy X)	N, 9.5 in. thick lid and 2.5 in. thick base plate	Geometry, flux traps, Boral, Metamic	5		Further schematics in reference; Conflicting guidance on Max heat and Max burnup, absolute maximum given as 36.9kW and 68,200 MWD/MTU, smaller values for specific fuels
HI-STORM	MPC-32	Alloy X		Multi flange plate weldment (Alloy X)	Boral/Metamic	Optional aluminum (Alloy 1100) heat conduction elements, spacers as necessary (Alloy X)	N, 9.5 in. thick lid and 2.5 in. thick base plate	Geometry, Boral, Metamic	5		
HI-STORM	MPC-68	Alloy X		Multi flange plate weldment (Alloy X)	Boral/Metamic	Optional aluminum (Alloy 1100) heat conduction elements, spacers as necessary (Alloy X)	N, 9.5 in. thick lid and 2.5 in. thick base plate	Geometry, Boral, Metamic	5.5		
HI-STAR	MPC-80	Alloy X		Multi flange plate weldment (Alloy X)	Metamic	Optional aluminum (Alloy 1100) heat conduction elements, spacers as necessary (Alloy X)	N	Geometry, Boral, Metamic, enrichment controls	4	2.09	MPC-80 more commonly referred to as MPC-HB in documentation; Special design for Humboldt Bay; The decay heat listed is that expected from the waste, design parameters are similar to the other HOLTEC MPC systems
NAC-UMS	UMS-24	Stainless steel (Type 304L); 1.75 in. thick bottom plate, 3 in. thick structural lid	Support disks (PWR- 0.5 in. thick, Stainless steel Type 630, 17-4PH {30-34 disks}; BWR- 0.625 in. thick SA533 Carbon steel {40-41 disks});	Type 304 Stainless Steel	Boral plates	Heat transfer disks (Type 6061-T651 aluminum, 29-31 for PWR, 17 for BWR); Disks separated and supported by Type 304 stainless spacers on 1.63 in. diameter rods of the same material	Y, 7in. thick, Type 304 stainless steel	Geometry, Boral	4,2 (PWR)/ 4.0 (BWR)	1.9 (PWR and BWR)	List of assembly weights and dimensions given in reference, Far more component schematics in reference
NAC-MPC	MPC-26	Type 304 stainless shell, Type 304L stainless 3 in. structural lid, Type 304L 1.75in. thick base	Reactor control cluster assembly (Type 304 Stainless assembly with Inconel 625 encapsulating boron carbide), Flow Mixer/Thimble plug assembly	Type 304 Stainless Steel	Boral lined basket	28 Type 17-4 PH stainless support disks, 27 Type 6061-T651 aluminum alloy thermal shunts	Y, 5 in. carbon steel encapsulating 1in. of NS-4-FR neutron shielding	Geometry, Boral	4.61 (Zircalloy)/ 4.03 (Stainless)	2.95 (Zircalloy)/ 3.0 (Stainless)	Specific to Connecticut Yankee, also referred to as CY-MPC. Most reactive fuel used for individual analyses.
NAC-MPC	MPC-36	Type 304 stainless shell, Type 304L stainless 3 in. structural lid, Type 304L 1in. thick base	Reactor control cluster assembly (Type 304 Stainless assembly with Inconel 625 encapsulating boron carbide), Flow Mixer/Thimble plug assembly	Type 304 Stainless Steel	Boral lined basket	22 Type 17-4 PH stainless support disks, 14 Type 6061-T651 aluminum alloy thermal shunts	Y, 5 in. carbon steel encapsulating 1in. of NS-4-FR neutron shielding	Geometry, Boral	4.94	3.5	Specific to Yankee class fuel also referred to as Yankee-MPC. Type A and Type B baskets, Type A has a protruding corner with fuel rods, Type B omits once corner.
Foster Wheeler	MVDS	Stainless steel		Carbon Steel							
Foster Wheeler	MVDS	Stainless steel		Carbon Steel							
Foster	MVDS	Stainless steel		Carbon Steel							

Wheeler											
NAC-I28	NAC-I28	Multi wall structure, outer- 2.63 in. austenitic stainless steel, middle- 3.2 in. lead, inner- 1.5 in. austenitic stainless steel		Aluminum		Aluminum basket			1.9		
TN Metal Casks	TN-32	Carbon steel with sprayed aluminum coating for corrosion resistance				Borated aluminum plates	N	Geometry, neutron absorber plates in basket	4.05		Surry fuel also has BPRAs and TPD's
TN Metal Casks	TN-40										
TN Metal Casks	TN-68	SA-203 Grade E (canister and [bottom closure, 9.75 in. thick]), SA-203 Grade E or SA-350 Grade LF3 (confinement lid, 5 in. thick)	Aluminum 6061-T6 support rails	Stainless steel (SA-240, Type 304)/Aluminum Steel; Fusion welds	Borated aluminum, boron carbide/ aluminum MMC, Boral	Optional fuel spacers; neutron shielding as thermal shunt	Y, 4 in. thick, SA-266 Class 2	Geometry, neutron poisons	3.7-4.7		Safety Analysis Appendix 6a shows measured cask heat loads for Peach Bottom Power Station, measured values 15.7-17.3kW (Table 10.3-3).
Castor	V/21 and X33	Cast Iron in nodular graphite form, Interior coated with galvanic-applied nickel plating		Borate welded stainless steel	Polyethylene rods within the cask perimeter		N	Borated steel fuel basket, Inter-fuel tube spaces acting as flux traps	3.7		
Fuel Solutions	VSC-24	SA-516 Grade 70 steel (1in. Thick wall, 3 in. thick lid, 0.75 in. thick base)		SA-516 Gr. 70 Steel (0.2 in. thick)	RX-877 (lid)	None specified	Y, Steel and RX-277 neutron shielding (9.5 in thick, sandwiched 2.5 in. steel, 2 in. RX-277, 5 in. steel)	Minimum burnup, boron carbide allowed for fuel rod replacement, steel basket shielding	4.2		Also referred to as an MSB (multi-assembly sealed basket)
Fuel Solutions	W150*/W74	Type 316 stainless steel (M-class), Type 304 (T-class) 0.625 in. thickness, same for top and bottom inner and outer closure plates	Basket support tubes and sleeves M-class Type SA-240, XM-19 Steel, T-class SA240 Type 304 Steel; Guide tubes SA-240, Type 316 Steel	Borated stainless steel (from Bohler, specifics given in reference); Upper and lower basket assemblies	Borated steel A887, Type 304 B5, 0.075 in. thick	M-class: top and bottom spacers 2in. thick SA-240 Type XM-19 Steel, 12 other spacers 0.75 in. thick SA-517 or A514 Grade P or F carbon steel; T-class: 13 plates, 0.75in. thick SA-517 or A514 Grade P or F carbon steel	Y, Steel (A36) encased lead (top and bottom)	Borated steel, geometry	4.1		*W150 is a cask, canisters for that cask are W21 and W74, Heat loads up to 26.4 are also possible, M = multi-purpose canister (storage, transport and disposal), T = transport and storage only

Table A-3. Fuel storage data (dry storage and we storage at shutdown reactor sites) updated February, 2013 (LeDuc 2013, personal communication).

U.S. Dry Storage Details (02/05/2013)

Utility	Reactor	Type	License Type	Year of First Load[14]	Vendor	Cask System	Canister or Cask Type	Total Canisters or Casks Loaded	Assemblies Stored	MTiHM (Based on Average Assembly)	Storage Configuration	Primary Canister Transportation Cask (License Num.)	Primary Transport Cask Fabricated?	Alternative Canister Transportation Cask	Alternate Transport Cask Fabricated?	Bare Fuel Cask Transportation License (License Number)	"Storage Only" Canisters or Casks	Minimum Lead Time for Shipment
AEP	D.C.Cook	PWR	GL	2012	Holtec	HI-STORM	MPC-32	12	384	167.2	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
APS	Palo Verde	PWR	GL	2003	NAC	NAC-UMS	UMS-24	98	2352	1,024.3	Canister in Vertical Concrete Overpack	NAC-UMS (71-9270)	No	NAC-MAGNASTOR	No			24 Months[8]
Constellation	Calvert Cliffs	PWR	SS	1992	TN	NUHOMS	24P	48	1152	501.7	Canister in Horizontal Concrete Overpack		No		No		24P	36 Months[10]
Constellation	Calvert Cliffs	PWR	SS	1992	TN	NUHOMS	32P	24	768	334.5	Canister in Horizontal Concrete Overpack		No		No		32P	36 Months[10]
Constellation	Ginna	PWR	GL	2010	TN	NUHOMS	32PT	6	192	83.6	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Constellation	Nine Mile Point	BWR	GL	2012	TN	NUHOMS	61BT	6	366	159.4	Canister in Horizontal Concrete Overpack	MP197 (71-9302)	No	MP197HB(71-9302)	No			24 Months8
Consumers	Big Rock Point[12]	BWR	GL	2002	BFS/ES	FuelSolutions	W150	8	441	78.8	Canister in Vertical Concrete Overpack	TS-125 (71-9276)	No		No			24 Months[8]
Ct.Yankee	Conn Yankee[12]	PWR	GL	2004	NAC	NAC-MPC	MPC-26	43	1019	443.8	Canister in Vertical Concrete Overpack	NAC-STC (71-9235)	No	NAC-MAGNASTOR	No			24 Months[8]
Dairyland Power	Lacrosse	BWR	GL	2012	NAC	NAC	LACBWR	5	333	59.5	Canister in Horizontal Concrete Overpack	NAC-STC (71-9235)	No	NAC-MAGNASTOR	No			24 Months[8]
DOE	INEEL	PWR	SS		TN	NUHOMS	12T	29	177	77.1	Canister in Horizontal Concrete Overpack		No		No		12T	36 Months[10]
Dominion	Kewaunee	PWR	GL	2009	TN	NUHOMS	32PT	8	256	111.5	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Dominion	Millstone	PWR	GL	2005	TN	NUHOMS	32PT	18	576	250.8	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Dominion	North Anna	PWR	SS	1998	TN	TN Metal Casks	TN-32	27	864	376.3	Bare Fuel	-	-		-	No[3]		24 Months[7]
Dominion	North Anna	PWR	GL	2008	TN	NUHOMS	32PTH	13	416	181.2	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Dominion	Surry	PWR	SS	1986	GNB	Castor	V/21 and X33	26	558	243.0	Bare Fuel	-	-		-	No[4]		36 Months[10]
Dominion	Surry	PWR	SS	1986	NAC	NAC-I28	NAC-I28	2	56	24.4	Bare Fuel	-	-		-	No[5]		24 Months[7]
Dominion	Surry	PWR	GL	2007	TN	NUHOMS	32PTH	22	704	306.6	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Dominion	Surry	PWR	SS	1986	TN	TN Metal Casks	TN-32	26	832	362.3	Bare Fuel	-	-		-	No[3]		24 Months[7]
Dominion	Surry	PWR	SS	1986	W	MC-10	MC-10	1	24	10.5	Bare Fuel	-	-		-	No[6]		24 Months[7]
Duke	Catawba	PWR	GL	2007	NAC	NAC-UMS	UMS-24	24	576	250.8	Canister in Vertical Concrete Overpack		No	NAC-MAGNASTOR	No			24 Months[8]
Duke	McGuire	PWR	GL	2001	NAC	NAC-UMS	UMS-24	28	672	292.7	Canister in Vertical Concrete Overpack	NAC-UMS (71-9270)	No	NAC-MAGNASTOR	No			24 Months[8]
Duke	McGuire	PWR	GL	2001	TN	TN Metal Casks	TN-32	10	320	139.4	Bare Fuel	-	-		-	No[3]		24 Months[7]
Duke	Oconee	PWR	GL/SS	1990	TN	NUHOMS	24P	84	2016	878.0	Canister in Horizontal Concrete Overpack		No		No		24P	36 Months[10]
Duke	Oconee	PWR	GL	2000	TN	NUHOMS	24PHB	40	960	418.1	Canister in Horizontal Concrete Overpack		No		No		24PHB	36 Months[10]
Energy Northwest	Columbia	BWR	GL	2002	Holtec	HI-STORM	MPC-68	27	1836	327.9	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Entergy	ANO	PWR	GL	1996	BFS/ES	FuelSolutions	VSC-24	24	576	250.8	Canister in Vertical Concrete Overpack		No		No		VSC-24	36 Months[10]
Entergy	ANO	PWR	GL	1996	Holtec	HI-STORM	MPC-24	22	528	229.9	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Entergy	ANO	PWR	GL	1996	Holtec	HI-STORM	MPC-32	16	512	223.0	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Entergy	Fitzpatrick	BWR	GL	2002	Holtec	HI-STORM	MPC-68	15	1020	182.2	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Entergy	Grand Gulf	BWR	GL	2006	Holtec	HI-STORM	MPC-68	17	1156	206.5	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Entergy	Indian Point 1	PWR	GL	2008	Holtec	HI-STORM	MPC-32	5	160	69.7	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Entergy	Indian Point 2	PWR	GL	2008	Holtec	HI-STORM	MPC-32	17	544	236.9	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Entergy	Palisades	PWR	GL	1993	BFS/ES	FuelSolutions	VSC-24	18	432	188.1	Canister in Vertical Concrete Overpack		No		No		VSC-24	36 Months[10]
Entergy	Palisades	PWR	GL	1993	TN	NUHOMS	24PTH	13	312	135.9	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Entergy	Palisades	PWR	GL	1993	TN	NUHOMS	32PT	11	352	153.3	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Entergy	River Bend	BWR	GL	2005	Holtec	HI-STORM	MPC-68	19	1292	230.8	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Entergy	Vermont Yankee	BWR	GL	2008	Holtec	HI-STORM	MPC-68	14	952	170.0	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Exelon	Waterford	PWR	GL	2011	Holtec	HI-STORM	MPC-32	9	288	125.4	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Exelon	Braidwood	PWR	GL	2011	Holtec	HI-STORM	MPC-32	3	96	41.8	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Exelon	Byron	PWR	GL	2010	Holtec	HI-STORM	MPC-32	14	448	195.1	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Exelon	Dresden	BWR	GL	2000	Holtec	HI-STORM	MPC-68	49	3332	595.1	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Exelon	Dresden	BWR	GL	2000	Holtec	HI-STAR	MPC-68	4	272	48.6	Canister in Metal Cask	HI-STAR100 (71-9261)	Yes[1]		No			12 Months[11]
Exelon	LaSalle	BWR	GL	2010	Holtec	HI-STORM	MPC-68	6	408	72.9	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Exelon	Limerick	BWR	GL	2008	TN	NUHOMS	61BT	19	1159	207.0	Canister in Horizontal Concrete Overpack	MP197 (71-9302)	No	MP197HB (71-9302)	No			24 Months[8]
Exelon	Oyster Creek	BWR	GL	2002	TN	NUHOMS	61BT	23	1403	250.6	Canister in Horizontal Concrete Overpack	MP197 (71-9302)	No	MP197HB (71-9302)	No			24 Months[8]
Exelon	Peach Bottom	BWR	GL	2000	TN	TN Metal Casks	TN-68	59	4012	716.5	Bare Fuel	-	-		-	Yes (71-9293)		12 Months[11]
Exelon	Quad Cities	BWR	GL	2005	Holtec	HI-STORM	MPC-68	35	2380	425.1	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
FirstEnergy	Davis-Besse	PWR	GL	1995	TN	NUHOMS	24P	3	72	31.4	Canister in Horizontal Concrete Overpack		No		No		24P	36 Months[10]
FirstEnergy	Perry	BWR	GL	2012	Holtec	HI-STORM	MPC-68	6	408	72.9	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes					
FPL	Duane Arnold	BWR	GL	2003	TN	NUHOMS	61BT	20	1220	217.9	Canister in Horizontal Concrete Overpack	MP197 (71-9302)	No	MP197HB	No			24 Months[8]
FPL	Point Beach	PWR	GL	1995	BFS/ES	FuelSolutions	VSC-24	16	384	167.2	Canister in Vertical Concrete Overpack		No		No		VSC-24	36 Months[10]
FPL	Point Beach	PWR	GL	1995	TN	NUHOMS	32PT	32	1024	446.0	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
FPL	St.Lucie	PWR	GL	2008	TN	NUHOMS	32PTH	14	448	195.1	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
FPL	Seabrook	PWR	GL	2008	TN	NUHOMS	32PTH	6	192	83.6	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
FPL	Turkey Point	PWR	GL	2011	TN	NUHOMS	32PTH	18	576	250.8	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Luminant	Comanche Peak	PWR	GL	2012	Holtec	HI-STORM	MPC-32	9	288	125.4	Canister in Vertical Concrete Overpack	HISTAR 100 (71-9261)	Yes[1]		No			14 Months[8]
Maine Yankee	Maine Yankee[12]	PWR	GL	2002	NAC	NAC-UMS	UMS-24	64	1434	624.5	Canister in Vertical Concrete Overpack	NAC-UMS (71-9270)	No	NAC-MAGNASTOR	No			24 Months[8]

U.S. Dry Storage Details (02/05/2013), continued

Utility	Reactor	Type	License Type	Year of First Load[14]	Vendor	Cask System	Canister or Cask Type	Total Canisters or Casks Loaded	Assemblies Stored	MTiHM (Based on Average Assembly)	Storage Configuration	Primary Canister Transportation Cask (License Num.)	Primary Transport Cask Fabricated?	Alternative Canister Transportation Cask	Alternate Transport Cask Fabricated?	Bare Fuel Cask Transportation License (License Number)	"Storage Only" Canisters or Casks	Minimum Lead Time for Shipment
NPPD	Cooper	BWR	GL	2010	TN	NUHOMS	61BT	8	488	87.2	Canister in Horizontal Concrete Overpack	MP197 (71-9302)	No	MP197HB (71-9302)	No			24 Months[8]
OPPD	Fort Calhoun	PWR	GL	2006	TN	NUHOMS	32PT	10	320	139.4	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
Portland	GE Trojan	PWR	GL	2002	Holtec	TranStor Cask	MPC-24E/EF	34	780	339.7	Canister in Vertical Concrete Overpack	HISTAR 100 (71-9261)	Yes[1]		No			14 Months[8]
PPL	Susquehanna	BWR	GL	1999	TN	NUHOMS	52B	27	1404	250.8	Canister in Horizontal Concrete Overpack		No		No		52B	36 Months[10]
PPL	Susquehanna	BWR	GL	1999	TN	NUHOMS	61BT	44	2684	479.4	Canister in Horizontal Concrete Overpack	MP197 (71-9302)	No	MP197HB(71-9302)	No			24 Months[8]
Progress	Brunswick	BWR		2010	TN	NUHOMS	61BTH	8	488	87.2	Canister in Horizontal Concrete Overpack	MP197HB (71-9302)	No	MP197HB(71-9302)	No			24 Months[8]
Progress	Robinson	PWR	SS	1989	TN	NUHOMS	7P	8	56	24.4	Canister in Horizontal Concrete Overpack		No		No		7P	36 Months[10]
Progress	Robinson	PWR	GL	2007	TN	NUHOMS	24PTH	14	336	146.3	Canister in Horizontal Concrete Overpack		No	MP197HB	No			24 Months[8]
PS Colorado	Ft. St. Vrain[15]	HTGR	SS	1991	DOE	Foster Wheeler	MVDS		1464	1,023.3	Canister in Vault	TN-FSV (71-9253)	Yes[2]		No			12 Months[2]
PSE&G	Hope Creek	BWR	GL	2006	Holtec	HI-STORM	MPC-68	16	1088	194.3	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
PSE&G	Salem	PWR	GL	2010	Holtec	HI-STORM	MPC-32	16	512	223.0	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
PG&E	Diablo Canyon	PWR	SS	2009	Holtec	HI-STORM	MPC-32	23	736	320.5	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
PG&E	Humboldt Bay[12]	BWR	SS	2008	Holtec	HI-STAR	MPC-80	5	390	69.7	Canister in Metal Cask	HI-STAR100 (71-9261)	Yes[1]		No			12 Months[11]
SMUD	Rancho Seco[12]	PWR	SS	2001	TN	NUHOMS	24PT	22	493	214.7	Canister in Horizontal Concrete Overpack	MP187 (71-9255)	Yes[2]	MP197HB	No			12 Months[2]
Southern Cal Edison	SONGS 1[12,13]	PWR	GL	2003	TN	NUHOMS	24PT1	18	395	172.0	Canister in Horizontal Concrete Overpack	MP187 (71-9255)	Yes	MP197HB	No			24 Months[8]
Southern Cal Edison	SONGS 2	PWR	GL	2003	TN	NUHOMS	24PT4	33	792	344.9	Canister in Horizontal Concrete Overpack		No	MP197HB (71-9302)	No			24 Months[8]
Southern Nuclear	Farley	PWR	GL	2005	Holtec	HI-STORM	MPC-32	21	672	292.7	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			24 Months[8]
Southern Nuclear	Hatch	BWR	GL	2000	Holtec	HI-STORM	MPC-68	48	3264	583.0	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			24 Months[8]
Southern Nuclear	Hatch	BWR	GL	2000	Holtec	HI-STAR	MPC-68	3	204	36.4	Canister in Metal Cask	HI-STAR100 (71-9261)	Yes[1]		No			12 Months[11]
TVA	Browns Ferry	BWR	GL	2005	Holtec	HI-STORM	MPC-68	40	2720	485.8	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
TVA	Sequoyah	PWR	GL	2004	Holtec	HI-STORM	MPC-32	32	1024	446.0	Canister in Vertical Concrete Overpack	HI-STAR100 (71-9261)	Yes[1]		No			14 Months[8]
Xcel Energy	Prairie Island	PWR	SS	1993	TN	TN Metal Casks	TN-40	29	1160	505.2	Bare Fuel	-	-		-	Yes (71-9313)		12 Months[9]
Xcel Energy	Monticello	BWR	GL	2008	TN	NUHOMS	61BT	10	610	108.9	Canister in Horizontal Concrete Overpack	MP197 (MP197HB)	No		No			24 Months[8]
YAEC	Yankee Rowe[13]	PWR	GL	2002	NAC	NAC-MPC	MPC-36	16	533	232.1	Canister in Vertical Concrete Overpack	NAC-STC (71-9235)	No					24 Months[8]
							Totals:	**485**	**22613**	**6,806.7**								

U.S.Wet Storage at Shutdown Reactor Sites

Utility	Reactor / Storage Facility	Reactor Type	ISFSI License Type	Planned Load Date	Vendor	Cask System	Canister or Cask Type	Estimated Canisters or Casks to be Loaded	Assemblies in Wet Storage	Future Dry Storage Configuration	Primary Canister Transportation Cask	Primary Transport Cask Fabricated?	Alternative Canister Transportation Cask	Alternate Transport Cask Fabricated?
Progress/Duke	Crystal River	PWR	GL	2013	TN	NUHOMS	32PT	39	1217	Canister in Horizontal Concrete Overpack		No	MP197HB	No
Zion Solutions	Zion	PWR	SS	2013	NAC	MAGNASTOR	TSC-37	61	2,226	Canister in Vertical Concrete Overpack	NAC-MAGNATRAN	No	-	-
General Electric	GE Morris	NA	SS	NA	NA	NA	NA		3,217	Storage Sytem not Selected	NA	NA	NA	NA
							Totals:	**100**	**6660**					

Storage Summary

	Number of Casks	Number of Assemblies	% of Dry Stored Assemblies	
Bare Fuel Casks	29	1160	5.1	%
Canisters in Concrete Overpacks	448	19395	85.8	%
Canisters in Transport Casks	8	594.0	2.6	%
Vault Storage	NA	1464	6.5	%
			100.0	%

□	Red Border indicates "ISFSI Only Site"
□	Orange Border indicates a Site with a Shutdown Reactor but One or More Operating Reactors Remaining
🟩	Green shading indicates shortest lead time of 12 months -- fuel is already in casks licensed (Impact Limiter Fabrication Required) for transportation.
🟥	Red shading indicates indefinite lead time to first shipment -- canisters are "storage only" and casks are not licensed, or fuel is in cast iron bare-fuel casks that are not licensable.
	Unshaded indicates intermediate lead time -- cask is licensed but not fabricated (or available), or cask license is in progress but not fabricated, or fuel is in (bare-fuel) cask but cask not licensed.

NOTES:

[1] 12 units actively storing fuel are the only HISTAR 100 Casks available in U.S. 7 of these can accommodate standard size MPCs

[2] One MP187 staged empty at Rancho Seco Site; one TN-FSV staged empty at INL.(Only one canister per shipment possible)

[3] No TN-32 Transporation License under review

[4] Castor Casks not licensed for shipment in the U.S.

[5] No NAC-I28 Transportation License under review

[6] No MC-10 Transporation License under review

[7] Lead time mostly cask license application and review

[8] Lead time due to primary cask not yet fabricated

[9] TN-40 Certificate issued June 2011, TN-40HT Submittal which includes High Burnup Fuel as Content to follow in 2011

[10] Lead time addressess "Storage Only" canister issue, and cast iron bare-fuel casks. Repackaging might be required.

[11] Designates Shortest Lead Time for Shipment of Fuel in Dry Storage. Fuel is Already in Cask Licensed for Transportation. 6 Months Includes Cask Preparation Time, Leak Tests, Impact Limiter Mounting, etc.

[12] includes GTCC waste

[13] All the spent fuel from the shuttered Unit 1

[14] For multiple cask ISFSI sites the earlies load date applies to all casks

[15] Ft St Vrain Initial Heavy Metal does not include Thorium