Abstract- Considerations for Disposition of Dry Cask Storage System Materials at End of Storage System Life

Rob Howard, Oak Ridge National Laboratory

Dry cask storage systems are deployed at nuclear power plants for used nuclear fuel (UNF) storage when spent fuel pools reach their storage capacity and/or the plants are decommissioned. An important waste and materials disposition consideration arising from the increasing use of these systems is the management of the dry cask storage systems’ materials after the UNF proceeds to disposition. Thermal analyses of repository design concepts currently under consideration internationally indicate that waste package sizes for the geologic media under consideration may be significantly smaller than the canisters being used for on-site dry storage by the nuclear utilities. Therefore, at some point along the UNF disposition pathway, there could be a need to repackage fuel assemblies already loaded into the dry storage canisters currently in use.

In the United States, there are already over 1650 of these dry storage canisters deployed and approximately 200 canisters per year are being loaded at the current fleet of commercial nuclear power plants. There is about 10 cubic meters of material from each dry storage canister system that will need to be dispositioned. The concrete horizontal storage modules or vertical storage overpacks will need to be reused, repurposed, recycled, or disposed of in some manner. The empty metal storage canister/cask would also have to be cleaned, and decontaminated for possible reuse or recycling or disposed of, likely as low-level radioactive waste. These material disposition options can have impacts of the overall used fuel management system costs. This paper will identify and explore some of the technical and interface considerations associated with managing the dry cask storage system materials.
Considerations for Disposition of Dry Cask Storage System Materials at End of Storage System Life

Robert Howard and Bret van den Akker
Oak Ridge National Laboratory

Abstract
Dry cask storage systems are deployed at nuclear power plants for used nuclear fuel (UNF) storage when spent fuel pools reach their storage capacity and/or the plants are decommissioned. An important consideration arising from the increasing use of these systems is management of the dry cask storage systems’ materials after the UNF proceeds to disposition. Thermal analyses of repository design concepts currently under consideration indicate that waste packages for certain geologic media may be significantly smaller in size than the canisters being used for on-site dry storage by the nuclear utilities. Therefore, at some point along the UNF disposition pathway, there could be a need to repackage fuel assemblies already loaded into the dry storage canisters currently in use.

In the United States, there are already over 1850 of these dry storage canisters deployed and approximately 200 canisters per year are being loaded at the current fleet of commercial nuclear power plants. About 10 cubic meters of material from each dry storage canister system is not UNF. The concrete horizontal storage modules or vertical storage overpacks will need to be reused, repurposed, recycled, or disposed of in some manner. The empty metal storage canister/cask will also have to be decontaminated for possible reuse or recycling or disposed of as low-level radioactive waste. These material disposition options can have an impact on the cost of the overall used fuel management system. This paper explores some of the considerations associated with managing the dry cask storage system materials.

Introduction
Used/spent fuel storage practices have evolved in response to changes made by the nuclear power industry. The fuel cycle originally envisioned in which low-burnup fuel is reprocessed quickly to provide fresh fuel is now a once-through fuel cycle in which the fuel is burned to reasonably high values, with the ultimate fuel disposal not yet reached. Delays (since 1998) in establishing a permanent repository have also forced evolution of the used/spent fuel storage concept. What was once envisioned as short-term wet (pool) storage has been augmented by expanded pool storage (re-racking) and the addition of dry fuel storage. A variety of dry fuel storage systems have been and continue to be developed and deployed. For economic reasons, the nuclear industry is currently using large dry storage systems with canister capacities up to 37 pressurized water reactor (PWR) and 89 boiling water reactor (BWR) fuel assemblies. These systems are either single purpose (storage only) or dual purpose (storage and transportation), but none of them were designed or are currently licensed for disposal. In addition, emplacement of such large-capacity canisters in a geologic repository may not be possible because of either physical constraints or the need for long periods of extended storage to allow the thermal output of the fuel to decay so that repository thermal limits are met (Hardin et al., 2012). While efforts are under way to evaluate the feasibility of directly disposing large-capacity canisters loaded with spent fuel (Hardin et al., 2014), repackaging of the fuel assemblies from these large canisters may be necessary (Howard et al., 2013). The empty metal canisters and associated
storage system overpacks will also have to be dispositioned at the end of life, and the number of empty canisters that will have to be dispositioned is substantial.

**Extent of the Issue**

Of the approximately 72,000 MTU of UNF estimated to have been generated in the United States, approximately 31% is stored in over 1,850 dry storage casks, as shown in Figure 1 (Wagner et al., 2013; Leduc, 2012). The amount of fuel that will be transferred from wet to dry storage is expected to increase steadily, at least until some off-site option is available. Total UNF discharges will increase to approximately 88,000 MTU by 2020 (Carter et al., 2012). Roughly 35,000 MTHM of that is expected to be in dry storage by that time, with the remaining 53,000 MTHM in the reactor pools. The fuel in dry storage by the time waste acceptance starts (assuming movement to an interim storage facility or repository) represents a legacy that must be dealt with regardless of what approach is taken to managing newly discharged fuel going forward. By 2060, when all currently licensed reactors will have reached the end of their operational lives, assuming a 60-year maximum, there will be approximately 140,000 MTU of UNF discharged from the reactor fleet (Carter et al., 2012), as shown in Figure 2. Furthermore, Figure 3 (Hardin et al., 2013) shows the anticipated growth in UNF canisters in dry storage resulting from the accumulation of the above SNF. SNF canisters in dry storage will roughly double in the next 10 years and will exceed 10,000 canisters by the year 2050. These figures are considered to be a reasonable lower bound as they do not take into account any further expansion of the current nuclear fleet of reactors.

---

**Figure 1.** Distribution of 2011 commercial UNF inventory from PWRs and BWRs in wet and dry storage (Wagner et al., 2013).
Figure 2. Historical and projected UNF discharges and transfer to dry storage.

Figure 3. Dry storage canister projection for the United States, using the TSL-CALVIN simulator and assuming existing power reactors are operated with life-extension licenses (Hardin et al., 2014).
As shown in Figure 4 (left side), approximately 205,000 PWR UNF assemblies and approximately 275,000 BWR assemblies have to be packaged into waste-package-compatible canisters. If all UNF is transferred into very large canisters prior to shipment from the reactors, approximately 11,200 canisters may have to be opened and the contents repackaged into smaller waste package containers suitable for the repository host geology and design concept (Nutt, 2012). (See Figure 7 for a comparison of canister size.) The empty canisters would then have to be dispositioned. However, as inferred in Figure 4 (right side), if a repository can be sited, designed, and licensed before the mid-century consistent with the *Strategy for the Management and Disposal of UNF and High Level Radioactive Waste* report (DOE, 2013) and spent fuel can be moved directly from reactor pools to appropriately sized waste package canisters, then the number of large dry storage canisters that have to be dispositioned could be smaller.

Variety of the Dry Canister/Cask Systems That Must BeDispositioned

There are four basic categories of dry cask storage systems:

1. metal canisters in vertical concrete overpacks or horizontal concrete modules,
2. metal canisters in metal overpack/storage/shipping casks,
3. metal canisters in concrete vaults, and
4. bare fuel casks that provide both primary containment and shielding for storage and transportation.

Most assemblies in dry storage in the United States are in welded metal canisters inside vented concrete vertical overpacks or horizontal storage modules (Figure 5 and Figure 6). For this configuration, the canister with its internal basket, fuel, and fuel component contents is the only portion of the storage cask system that is transported. These systems all require a separate transportation cask with a Type B containment vessel to overpack the fuel canister. The transfer usually requires the use of a transfer cask except for the NUHOMS transportation casks, which can interface directly with the horizontal storage module.
Figure 5. Example of ventilated above-grade storage module (Transnuclear Horizontal Storage Module).

Figure 6. Above-grade storage module (Holtec High-Storm System).
End-of-Life Options for Dry Cask Storage Systems

Because dry cask storage systems are not currently licensed for use as disposal containers for a high-level waste (HLW) repository, four basic options exist for their treatment after the repackaging of the SNF: i) reuse, ii) repurposing, iii) recycling, and iv) direct disposal in a low-level waste (LLW) facility. However, before options i, ii, or iii can be considered, the casks and
overpacks will need to be decontaminated (CB&I Federal Services LLC, 2013). Additionally, if
direct disposal is to be considered, the casks should be decontaminated sufficiently to meet the
criteria for LLW disposal. The dry cask overpack consists of steel and/or concrete and is
expected to have no interior or exterior radioactive surface contamination. Any neutron
activation of the steel and concrete is expected to be extremely small, and the assembly should
qualify as Class A LLW (Holtec, 2012).

Assuming a dry storage cask needs to be opened and separated from the SNF before
emplacement in a HLW repository, its interior metal surfaces will need to be decontaminated
using existing mechanical or chemical methods. The fuel basket and the smooth metal surfaces
of the interior structure, which are designed to minimize crud traps, will facilitate this process.
However, even given this design, it is recognized that the largest source of contamination will be
the basket and internals of the dry storage cask that came into direct contact with the SNF or pool
water.

The egg crate design of the baskets means that the interiors of the dry storage casks have a large
surface area that will pick up small amounts of crud that have flaked off the surface of the SNF.
Additional sources of contamination could come from volatile fission products exiting fuel pins
via hairline fractures that developed during their lifetime. The primary radiological source in
surface crud is Co-60 (with approximately a 5 year half-life), so that by the time the SNF
transfers occur, much of the Co-60 will have decayed away. The quantity of radioisotopes from
leaking SNF will likely be small, as few pins have actually been found to leak during operation
in the reactor (AREVA Federal Services LLC, 2013).

Though the amount of radiological contaminants will be small, the cleanliness of the used dry
storage casks must be ensured before release. Reliable technologies exist for cleaning of metal
surfaces that are lightly contaminated. This could be accomplished by chemical cleaning with a cleaning
compound such as oxalic acid, or by CO₂ ice blasting and/or sandblasting. After the surface contamination
is removed, the amount of radioactivity on the dry storage cask will be reduced significantly,
allowing disposal at a LLW facility, potential secondary applications at the licensee's facility, or
the option to recycle or dispose of the cask (AREVA Federal Services LLC, 2013; CB&I Federal
Services LLC, 2013).

Options to reuse or repurpose dry storage casks or overpacks are rather limited. There is no
agreement among vendors regarding the reuse dry storage casks once they have been reopened,
although one vendor did suggest that if the welds were carefully removed, the casks could
potentially be reused. However, the issue of reuse adds further technical challenges and would
require protocols for ensuring the integrity of the reused package. There is a possibility that the
storage overpacks can be reused. If additional storage of SNF is required until it can be shipped
off site, these overpacks can be reused for such storage. If storage of other wastes is required
onsite, the metal and vertical concrete overpacks could be utilized for this purpose. This activity
would be particularly suitable for contaminated overpacks and would not have to be
decontaminated. However, subsequent to this reuse, the overpack would likely be destined for
final disposition and/or recycling and would eventually require decontamination if sufficiently
contaminated.
In order to recycle the dry storage casks and overpacks, they would have to be decontaminated, chopped up, and melted down. However, prior to sending them away for recycling, free release criteria would need to be established along with protocols to ensure that the free release criteria were being met. This could include extensive monitoring and screening to ensure that radioactive materials are not inappropriately released, in addition to further cleaning or decontamination of materials that do not meet the free release criteria. An alternative to releasing the materials to the public or metals industry would be to construct special recycling facilities to accept and process the dry storage casks. If such a facility were located near the HLW repository, it is possible that transportation fees associated with moving the containers could be minimized. Such a facility would require a sizable workforce of skilled laborers and could be a boon to a local community. However, the economics of building or converting and operating such a facility are beyond the scope of this paper.

If the dry casks or some portions of the dry casks and overpacks cannot be sufficiently decontaminated to reuse, recycle, or repurpose, or if the economics of such a use prove prohibitive, the direct disposal of the containers and the overpacks will be necessary. Following the decontamination protocols discussed above, it is likely that the materials will be classified as Class A LLW and suitable for shallow burial (Holtec, 2012). Figure 8 shows costs estimates for the disposal of the current and future fleet of dry storage casks assuming 10 m³ LLW is generated per cask over the range of 1600 to 11,000 casks which are assumed to be generated by the current fleet of reactors (assuming a 60 year operational lifetime). Estimates for the cost of LLW disposal vary over wide ranges from about $200/ft³ up to $1000/ft³ (Shropshire et.al 2009). Depending on the availability of disposal facilities, the growth of the dry cask container inventories, and the costs associated with the disposal of LLW, this economic burden of disposal could be as high as $3.8 Billion by the year 2050.

![Cost of Disposal of Dry Casks as LLW](image)

*Figure 8. Cost estimates for the disposal of dry storage casks as LLW.*
Discussion
Substantial challenges exist in managing the fleet of dry storage casks deployed currently and in the future. The potential for a tenfold growth of the dry cask inventory over the lifetime of the current fleet of reactors (assuming no further development of nuclear power) necessitates consideration of the economics and practicalities of decommissioning, recycling, or repurposing these casks. Limited options are available for the reuse or repurposing of the dry casks and their overpacks. Furthermore, such reuse and repurposing is only a temporary solution for the management of these material as they will eventually need to be either recycled or disposed of. The recycling of the dry casks and their overpack represents substantial challenges as the infrastructure necessary to process these materials is not yet in place. Additionally, the economics of such an endeavor have not been addressed. Nevertheless, should the economics of recycling these materials prove favorable, especially in light of the costs of disposal, this is an option that should be considered in further detail. The direct disposal of the dry casks and their overpack remains the most straightforward option of managing these materials. The majority of the dry cask inventory is likely to be classified as LLW and suitable for shallow burial disposal. The cost of such disposal varies widely depending on the both the size of the inventory and the disposal costs. The cost of the disposal of the current inventory of approximately 1850 dry storage casks varies between $130M and $653M, depending on the assumed disposal cost. The ultimate disposal of the approximately 11,000 dry casks estimated to be produced by the current fleet of nuclear reactors varies between $780M and $3.9B.

References:


Considerations for Disposition of Dry Cask Storage System Materials at End of Storage System Life

Rob Howard and Bret van den Akker
DOE-NE Nuclear Fuels Storage and Transportation Planning Project (NFST)
Oak Ridge National Laboratory
howardrl1@ornl.gov

Symposium on Recycling of Metals arising from Operation and Decommissioning of Nuclear Facilities
Nykopiong Sweden
April 8-10, 2014
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.
End of life dry cask/canister storage system disposition: Why, Where, When, and How all Matter

Canister repackaging could be required for several reasons (why):
- Some storage systems in use are not certified for transportation (see Williams’ presentation)
- Repository constraints (e.g., thermal, criticality)

Repackaging is complicated (how):
- Increases total fuel-handling operations
- Complicates pool operations and increases worker doses if performed at reactor sites
- Requires development and deployment of on-site repackaging systems if performed at shut-down reactor sites
- Will generate additional low-level waste including discarded dry storage canisters
- Repackaging facility as part of an integrated waste management system may be appropriate

Repackaging could be reduced or eliminated provided (when, where):
- Direct disposal of existing dry storage canisters is proven acceptable
- Standard storage, transportation and disposal canisters are developed and deployed
Canisters Considered in International Disposal Programs are Considerably Smaller than US Dual-Purpose Canisters

KBS-3 (Sweden) waste package
12 BWR / 4 PWR

Empty 64 BWR Dual Purpose Canisters

Swiss disposal concept (Nagra) mockup at the Mont Terri URL 4 PWR

Volcanic Tuff TAD
21 PWR / 44 BWR
1. 10 NPR on 9 sites shutdown prior to 2000 with only fuel management activities on site and some decommissioning activities ongoing.
2. 1 NPR disabled and UNF owned by DOE (Three Mile Island unit 2).
3. 3 NPR permanently shutdown on sites with continued nuclear operations.
4. 4 NPR on 3 sites ceased operations or restart activities in 2013.
   - 5 NPR total are shutdown on these sites.
5. 120 Nuclear Power Reactors (NPR) Built and Operated (incl. Shoreham).
6. 100 in Operation as of November, 2013.
   - 2 Operating NPR have announced “Early Shutdown” dates of 2014 and 2019.
7. 2 NPR Nearing Completion.
8. 4 New Build NPR.
The current inventory of dry storage systems in the United States is large.

- **Pool**: 172,281, 70% 49,024 MT 1,862 Casks
- **Dry**: 74,197, 30% 22,000 MT

1,687 Welded Metal Canisters In Vented Concrete Overpacks
65,102 Assbly, 87.5% of Dry

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

191 Bare Fuel Cask
8,406 Assbly, 11.3% of Dry

13 Welded Metal Canisters in Transport Overpacks
866 Assbly, 1.2% of Dry

Transnuclear TN-32
Holtec HiStar 100
Potential Inventory Estimated at 2060, Reference Scenario, No NPR Replacement

- Current pool storage is ~50,000MT
- Early reactor shutdowns assumed to reduce the combined pool capacity to ~40,000MT
- Balance of fuel moved to dry storage
  - Assumes no incentive to reduce the pool Inventory

- Reference Scenario No Replacement NPR – Potential Inventory Includes:
  - Shutdown reactor UNF
  - Announced “early shutdown” reactor UNF for NPR not planning to operate 60 years
  - Remaining NPR assumed to get a single license extension and operate for 60 years
  - New builds are not included
The number of canisters that have to be dispositioned depends on UNF management strategy and facility availability.

- Potentially package or re-package ~206,000 BWR and ~277,000 PWR fuel assemblies.

- Earlier facility availability (when) and higher acceptance rates and use of bare fuel transporation systems will mitigate the issue.

---

### Acceptance Rate (MT/yr)

<table>
<thead>
<tr>
<th>Acceptance Rate (MT/yr)</th>
<th>Acceptance Start</th>
<th>PWR Canisters</th>
<th>BWR Canisters</th>
<th>Total Canisters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>2020</td>
<td>6998</td>
<td>4210</td>
<td>11208</td>
</tr>
<tr>
<td>3000</td>
<td>2020</td>
<td>6974</td>
<td>4190</td>
<td>11164</td>
</tr>
<tr>
<td>6000</td>
<td>2020</td>
<td>6964</td>
<td>4183</td>
<td>11147</td>
</tr>
<tr>
<td>1500</td>
<td>2035</td>
<td>7017</td>
<td>4223</td>
<td>11240</td>
</tr>
<tr>
<td>3000</td>
<td>2035</td>
<td>7001</td>
<td>4216</td>
<td>11217</td>
</tr>
<tr>
<td>6000</td>
<td>2035</td>
<td>7000</td>
<td>4208</td>
<td>11198</td>
</tr>
</tbody>
</table>

### Need to open, empty, and disposition these canisters to re-package fuel into these disposable canisters.

---

### Repository constraints and timing drive size:

- PWR Waste Packages: 52,250 / 17,417 / 9,952
- BWR Waste Packages: 30,333 / 11,375 / 6,205
- Total Waste Packages: 82,583 / 28,792 / 16,157
The canister configurations and materials that must be dispositioned is diverse

**Typical Configurations**
- Right Circular Cylinder
  - Length 122.5 to 196 in.
  - Inner Diameter 60.5 to 68.75 in.
  - Weight 55,000 to 105,000 lbs.
  - Lifting configurations differ

**Interior Cell Dividers**
- 7, 12, 24, 32, 37 PWR assemblies
- 52, 61, 68, 80, 87, 89 BWR assemblies
- Differing materials of construction, especially neutron absorber materials

**NRC Licenses**
- 26 different welded metal canister designs have been licensed
- 5 designs (308 canisters) designated for “Storage Only”
- 21 designs are “Storage and Transportation”
- None are licensed for disposal
- Allowable failed fuel canisters varies by design from 4 upwards
Above grade vented storage overpacks and modules are most widely deployed

Typical vertical cask at grade Holtec and NAC

Holtec HI-STORM

Transnuclear
Horizontal Storage Module

Loaded vertical storage systems at Trojan ISFSI
Bare fuel in bolted casks represent a smaller portion of the existing inventory in the United States.

- **4 Vendors have provided bare fuel casks**
  - Westinghouse MC-10
  - GNB Castor V21/V33 (cast iron body)
  - NAC I-128
  - Transnuclear TN-32, TN-40, TN-40HT and TN-68

- **Physical configuration varies**
  - Length from 175 to 215 inches
  - OD from 94.8 to 110.25 inches
  - Weight from 230,000 to 250,000 lbs

**Transportation of Legacy Casks is Challenging**
Empty DSC, Storage Overpack, & Repackaging Process Waste and Materials Must Be Managed

**DSC-Related Materials**

- Typical Wastes:
  - DPC itself
  - DPC basket and other internals
  - DPC shield plug and lids
- Characteristics:
  - Low specific activity waste
  - Surface contaminated objects
  - Dependent on fuel characteristics and loading/unloading activities

**Storage Overpack could be:**

- Free released for recycling (no contamination expected)
- Reused for at-reactor UNF storage (in DSC)

**Process Wastes depend on repackaging method and equipment**
DSC Reuse, Repurpose, Recycle

- **Reuse for packaging of Used Nuclear Fuel, HLW, or Greater than Class C (GTCC) Wastes**
  - Cutting activity must be on lid and not shell
  - DSCs that are certified for transportation (DPCs) can be used again to ship UNF from reactor sites to ISF/repository
  - Requires some decontamination of interior surfaces
  - Requires re-certification after cutting (new or reconditioned lids)

- **Repurpose for disposal of Low Level Waste (LLW)**
  - Cutting activity must allow for DSC to be resealed (e.g., no jagged or diagonal cuts)
  - Likely need to remove DSC basket and reduce for disposal
  - No decontamination would be necessary

- **Recycle for scrap metal or production of STAD**
  - Chemical cleaning (e.g., with oxalic acid)
    - Removes surface contamination
    - Produces cleaning agent waste, which itself can be treated and result in resins
  - Free release criteria needed for recycle to scrap metal
  - Extensive scanning needed to ensure release criteria are satisfied
  - Size reduction necessary and should be performed after decontamination
Empty Canisters: Systems will be needed for Material Management

- Heavy load-handling capability
- Radiation dose surveying
- Cutting and removal of canister baskets
- Decontamination of internal canister surfaces (e.g., CO$_2$ ice blasting)
- Size reduction (wire cutting)
- Processing throughput
- Transportation interface
- Consider remelt and reuse in the fabrication of disposal canister (off site DD)

Source: CBI
Direct Disposal may be necessary

- Reuse: little demand to reuse a non-disposable canister
- Repurpose: must meet free release criteria NRC IE Information Notice 85-95
- Recycle: consider melting down and reusing in the fabrication of disposable canisters

Low Level Waste

- Approximately 350 cubic feet of LLW/DSC
- Disposal cost range $200-$1000 per cubic foot (Class A LLW)