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

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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.

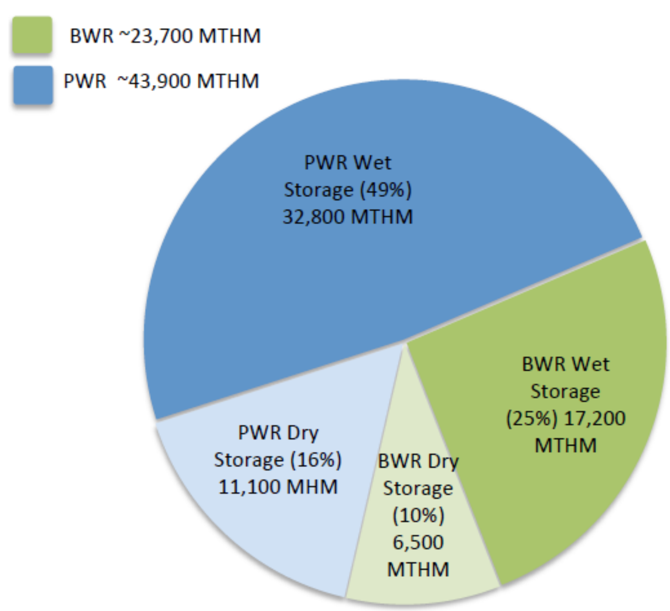
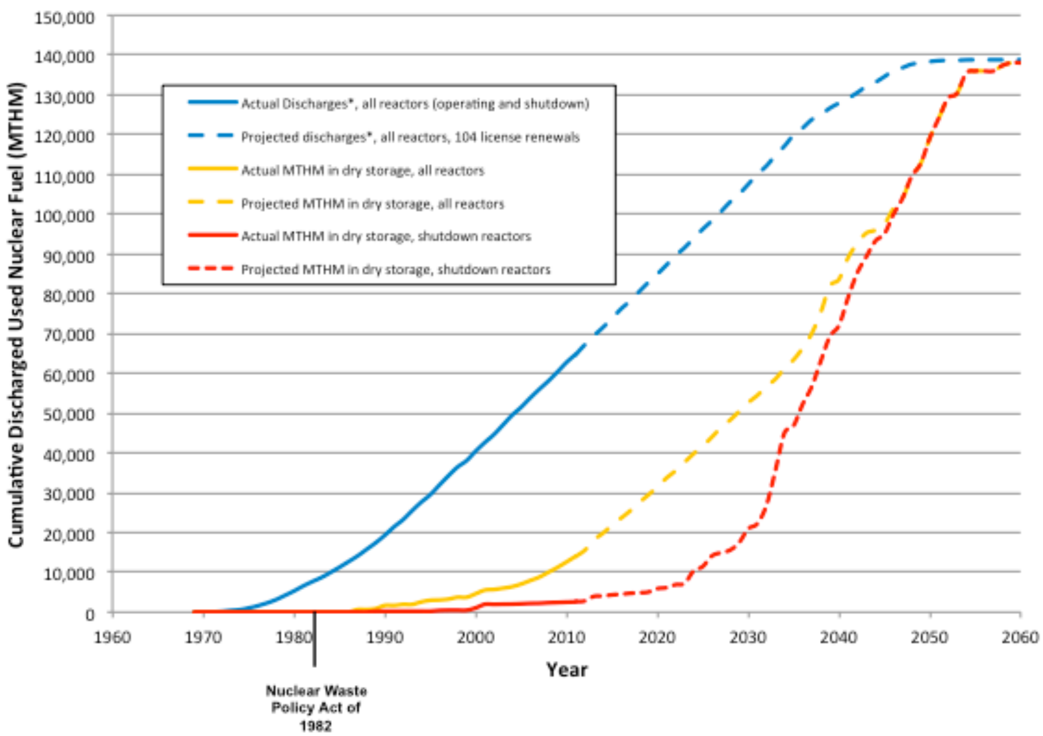


Figure 1. Distribution of 2011 commercial UNF inventory from PWRs and BWRs in wet and dry storage (Wagner et al., 2013).



Source: *Based on actual discharge data as reported on RW-859s through 12/31/02, and projected discharges, in this case for 104 license renewals

Figure 2. Historical and projected UNF discharges and transfer to dry storage.

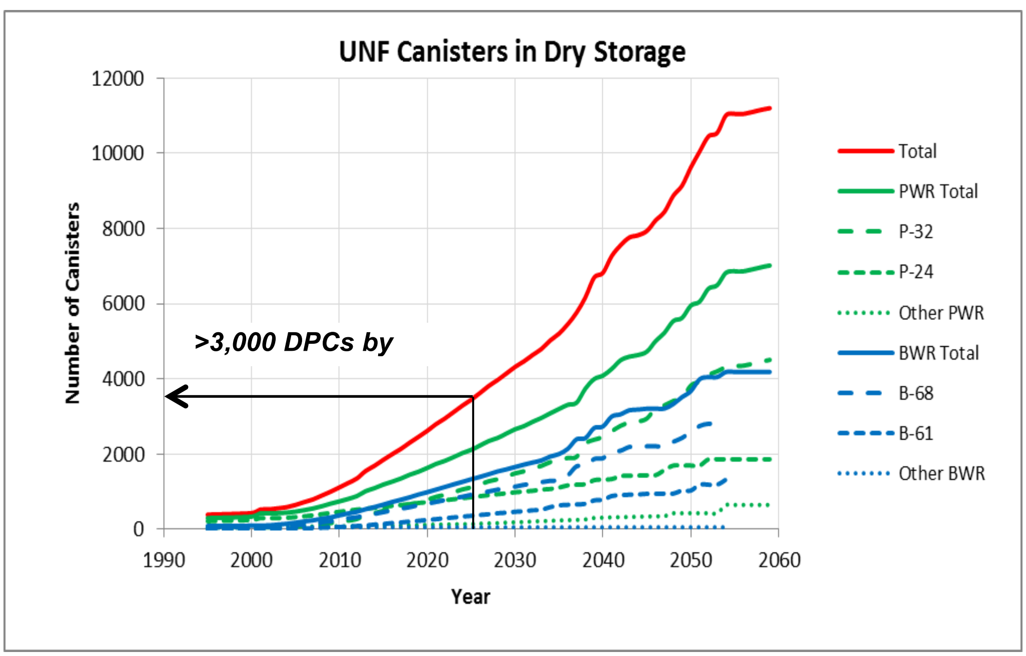


Figure 3. Dry storage canister projection for the United States, using the TSL-CALVIN simulator and assuming existing power reactors are operated with life-extension licenses (Hardin et al., 2014).

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.

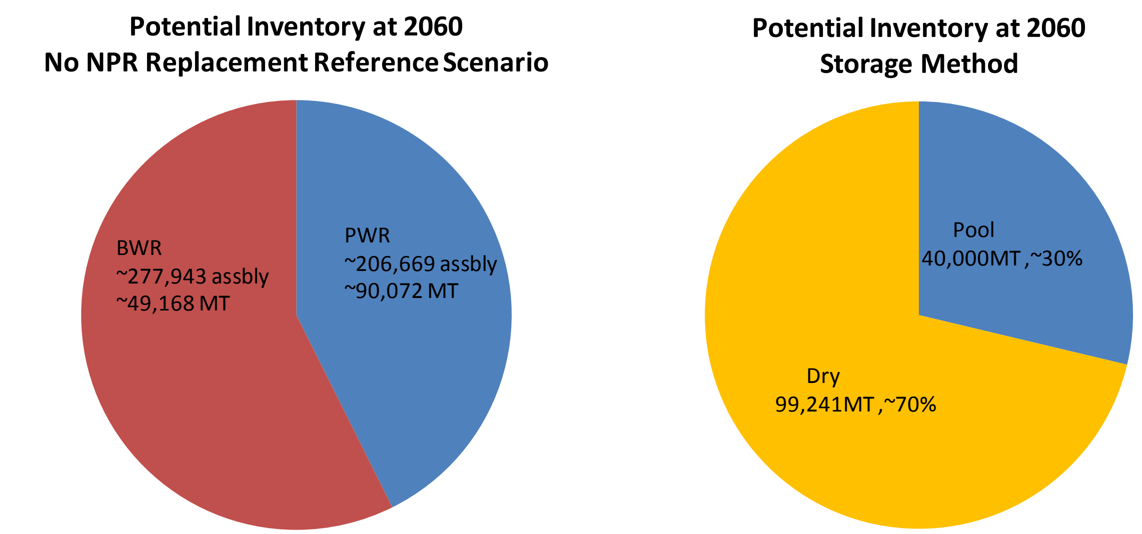


Figure 4. Potential commercial spent fuel inventory in the United States by 2060 assuming no replacements for the existing fleet of nuclear power plants.

Variety of the Dry Canister/Cask Systems That Must Be Dispositioned

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.

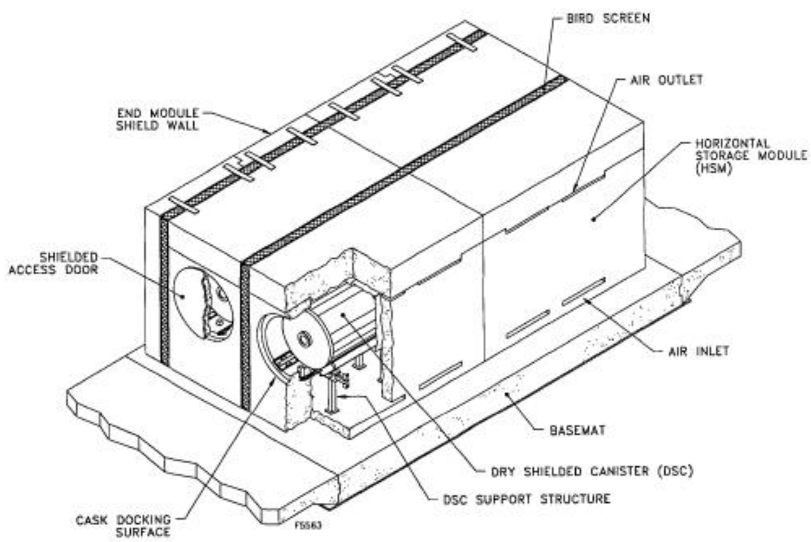


Figure 5. Example of ventilated above-grade storage module (Transnuclear Horizontal Storage Module).

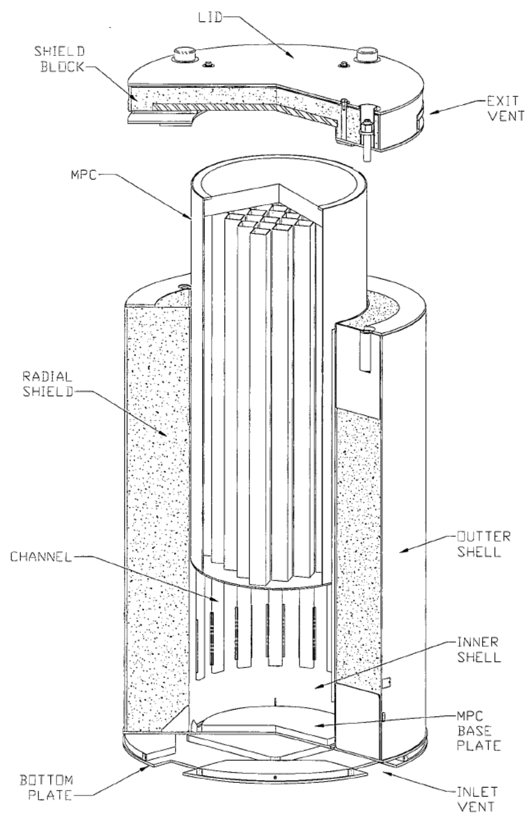


Figure 6. Above-grade storage module (Holtec High-Storm System).

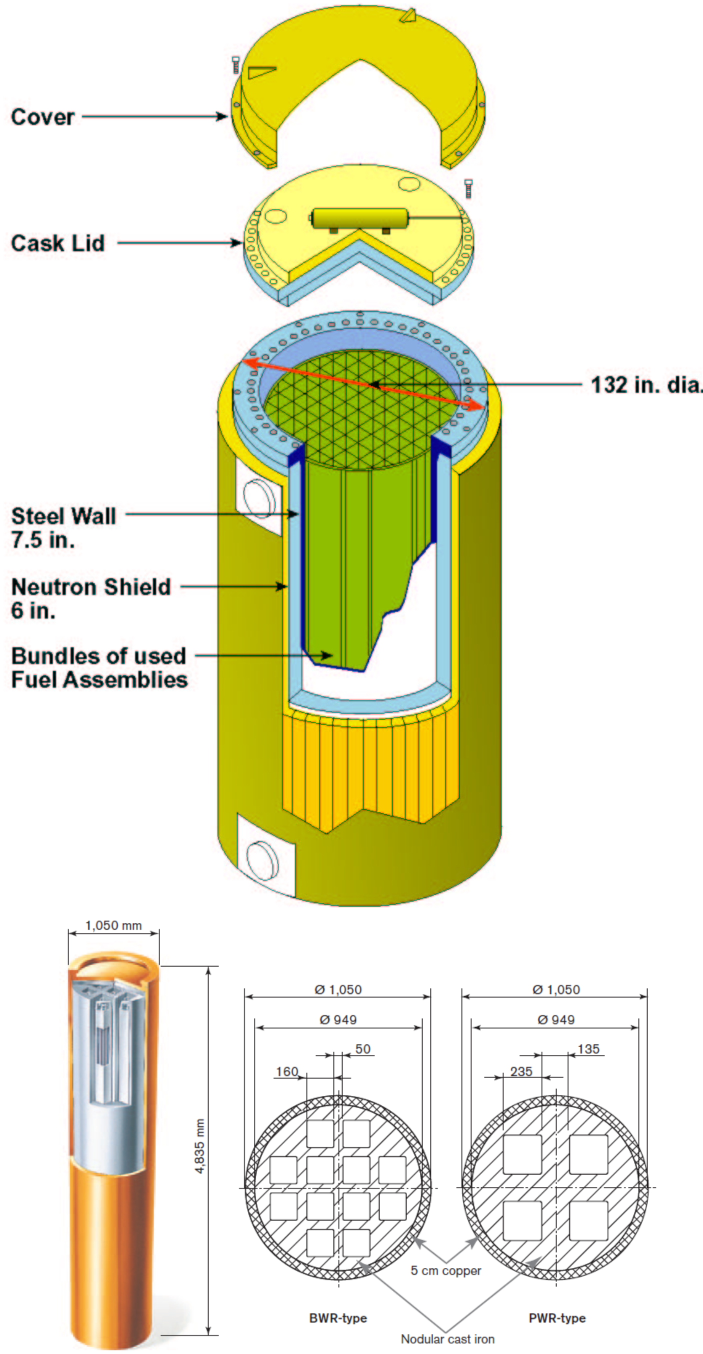


Figure 7. Examples of TN-68 configuration (above) and KBS-3 4 PWR/12 BWR configuration (below).

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 CO_2 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 m^3 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/ft^3 up to \$1000/ft^3 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.

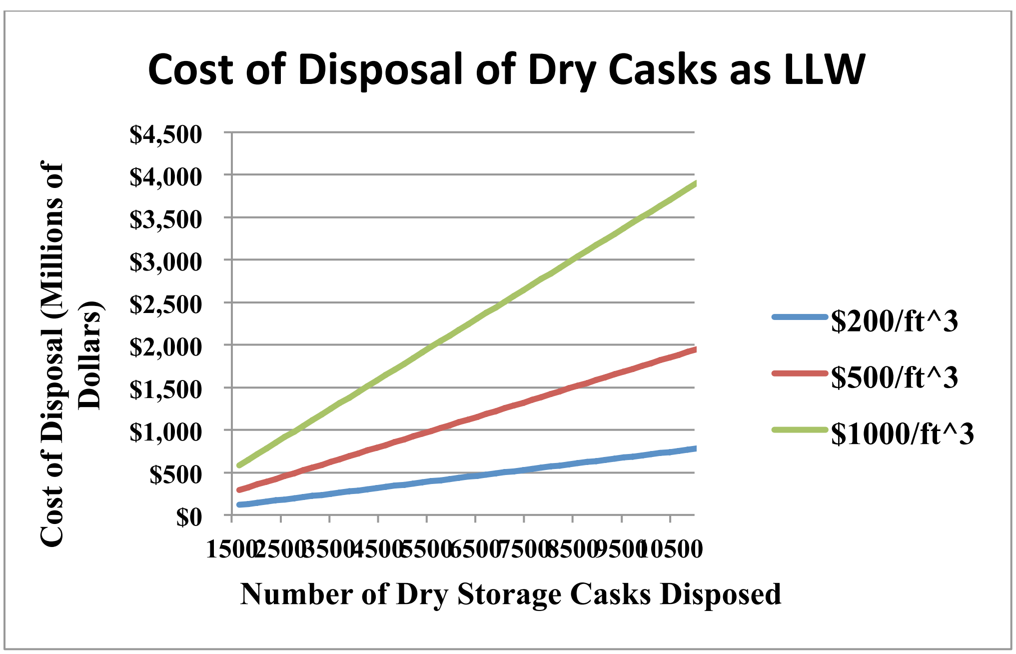


Figure 8. Cost estimates for the disposal of dry storage casks as LLW.

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.

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