Development of a Universal Canister for Disposal of High-Level Waste in Deep Boreholes - 16482

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ABSTRACT

The mission of the United States Department of Energy's (DOE's) Office of Environmental Management is to complete the safe cleanup of the environmental legacy brought about from five decades of nuclear weapons development and government-sponsored nuclear energy research. Some of the wastes that must be managed have been identified as good candidates for disposal in a deep borehole in crystalline rock. In particular, wastes that can be disposed of in a small package are good candidates for this disposal concept. A canister-based system that can be used for handling these wastes during the disposition process (i.e., storage, transfer, transportation, and disposal) could facilitate the eventual disposal of these wastes. Development of specifications for the universal canister system will consider the regulatory requirements that apply to storage, transportation, and disposal of the capsules, as well as operational requirements and limits that could affect the design of the canister (e.g., deep borehole diameter). In addition, there are risks and technical challenges that need to be recognized and addressed as Universal Canister system specifications are developed. This paper provides an approach to developing specifications for such a canister system that is integrated with the overall efforts of the DOE's Used Fuel Disposition Campaign's Deep Borehole Field Test and compatible with planned storage of potential borehole-candidate wastes.

INTRODUCTION

Some of the wastes that must be managed by the United States Department of Energy's (DOE's) Office of Environmental Management (EM) have been identified as good candidates for disposal in a deep borehole in crystalline rock [1]. In particular, wastes that can be disposed of in small packages are good candidates for this disposal concept. A canister that could be used to store, transport, and dispose of the waste without having to be re-opened would have to meet regulatory and operational requirements for these waste management functions, as well as operational limits and restrictions. The purpose of this paper is to demonstrate the initial approach to developing the specifications for a universal canister system for disposal of high-level waste (HLW) using cesium (Cs) and strontium (Sr) capsules as an example waste type.

DISCUSSION

The essential elements of specifying a universal canister system are the waste type, how that waste might be stored and transported, and how that waste might be disposed, as well as the requirements and limitations applicable to each element. These are discussed below.

Waste Type

Several different waste types were identified as good candidates for disposal in a deep borehole in crystalline rock [1]. Among these were 1,936 Cs and Sr capsules currently stored in pools at the Waste Encapsulation and Storage Facility (WESF) at the Hanford Site in Washington. These capsules contain Cs chloride (CsCl) (1,335 capsules) and Sr fluoride (SrF_2) (601 capsules). The waste inside the capsules is doubly encapsulated (i.e., a capsule within a capsule). In the case of the Cs capsules, both the inner capsule and the outer capsule are made of 316L stainless steel with welded outer caps. In the case of the Sr capsules, the inner capsule is made of Hastelloy C-276 and, for most capsules, the outer capsule is made of 316L stainless steel. Some of the initial Sr outer capsules were made of Hastelloy C-276, rather than 316L stainless steel [2]. In addition, 23 of the 1,335 Cs capsules were overpacked in Type W capsules. The outer diameter of the capsules ranges between 5.72 cm (2.25 in.) and 8.26 cm (3.25 in.), while the length of the capsules ranges between 48.39 cm (19.05 in.) and 55.44 cm (21.83 in.).

The Cs capsules were limited to 8.00×10^4 Ci of Cs-137 upon loading, which is equivalent to a heat generation rate of about 380 W [3]. The SrF_2 capsules were limited to 1.70×10^5 Ci of Sr-90 at the time of loading, which is equivalent to a heat generation rate of about 1,020 W [3]. The radioactivity of each capsule varied; statistics for the radioactivity, the heat generation, and the unshielded dose rate of the capsules as of January 1, 2016 are shown in Table I. The capsules contain 4.90×10^7 Ci of Cs and Sr, and another 4.70×10^7 Ci of their respective daughter products, mBa-137 and Y-90 (as of January 1, 2016).

Cs has several radioactive isotopes, but only Cs-135 and Cs-137 are of concern for storage, transfers, transportation, and disposal because the other isotopes have such short half-lives (on the order of days, or at most 2 years) that they have already decayed into stable isotopes. The half-life of Cs-135 is 2,300,000 years, making it of concern primarily for long-term performance of the disposal system. The half-life of Cs-137 is 30.17 years, making it of concern for storage, transfers, transportation, and the preclosure and handling phases of disposal. Cs-135 decays via beta emission to Ba-135, which is stable. About 95% of the Cs-137 decays via beta emission to mBa-137, which has a half-life of 2.5 minutes and decays to stable Ba-137 via isomeric transition, thereby emitting a gamma ray. The remaining 5% of the Cs-137 decays directly to stable Ba-137.

Sr also has several radioactive isotopes, but only Sr-90 is of concern for storage, transfers, transportation, and the preclosure and handling phases of disposal of radioactive waste because the other isotopes have half-lives on the order of hours or days and have already decayed into stable isotopes of other elements. Sr-90 has a half-life of 29.1 years and beta decays to Y-90, which has a half-life of 64 hours and beta decays to stable Zr-90.

TABLE I. Radioactivity, Heat Generation, and Dose Rate Characteristics of Cs and Sr Capsules as of January 1, 2016 [9]

Capsule Type	**Number of Capsules**	**Statistical Parameter**	**Power (W)**	**Cs or Sr Activity (Ci)**	Surface **Dose Rate[b] (rem/h)**	**Dose Rate at 3 ft from Capsule[b] (rem/h)**
CsCl	1335	Average	118.6	2.51×10^4	6.34×10^5	4.81×10^3
		Standard Deviation	11.6	2.5×10^3	6.31×10^4	4.79×10^2
		Minimum	13	2.8×10^3	7.07×10^4	5.37×10^2
		Maximum	161	3.42×10^4	8.63×10^5	6.56×10^3
SrF_2	600[a]	Average	157.1	2.35×10^4	2.92×10^4	6.50×10^2
		Standard Deviation	82.4	12.3×10^3	1.53×10^4	3.40×10^2
		Minimum	18	2.7×10^3	3.36×10^3	7.46×10^1
		Maximum	411	6.14×10^4	7.64×10^4	1.70×10^3

[a] Does not include one SrF_2 capsule that is a tracer and contains no radioactive Sr and, thus, emits no heat.

[b] Dose rate estimations performed at ORNL.

The material placed into the capsules contained other chemical constituents in addition to the CsCl and SrF2. Because of the presence of these other constituents, some of which are considered hazardous, all the capsules are considered to be mixed waste by the State of Washington [4].

Storage and Transfer

The 1,936 Cs and Sr capsules are currently being stored under water at the WESF in pool cells that were constructed specifically for storage of the capsules, as shown in Figure 1. This facility has been granted a permit by the State of Washington [4]. There are 12 concrete pool cells, each of which is lined with stainless steel and equipped with a monitoring system to detect leakage from the capsules. The water in the pools is approximately 4 m (13 ft) deep and provides cooling and shielding for the capsules [5]. However, the WESF is 11 years past its design life and is the greatest risk of any facility at Hanford to the threat represented by a natural event occurring that is beyond its designed capacity to sustain [6]. Hanford is currently seeking to move the capsules into dry storage and has stated that the mission to store the capsules in a dry storage facility will incorporate options for disposing of the Cs and Sr capsules in a deep borehole [7].

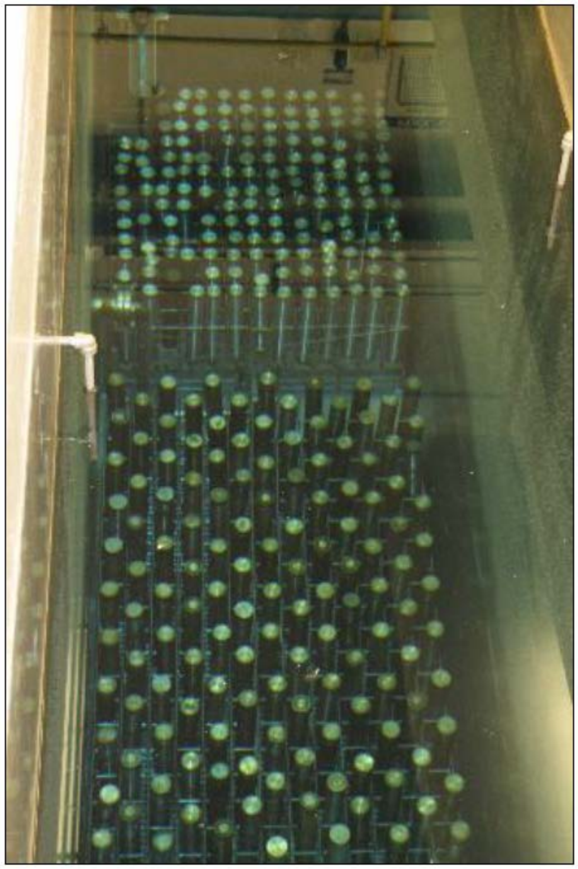

Fig. 1. WESF Pool Cell Containing Capsules [7]

The capsules were filled with CsCl and SrF_2 in hot cells that are adjacent to the WESF pool, welded shut, and then transferred to the pool through an underwater transfer drawer. This transfer drawer is located in hot cell G, the hot cell closest to the pool, as shown in Figure 2. The other six hot cells are no longer functioning. One of the ways that the capsules could be removed from the pool is through the transfer drawer from the pool into hot cell G, which is 2.4 m (8 ft) wide × 4.9 m (16 ft) long × 3.7 m (12 ft) high. More features of the WESF and hot cell G are given in Table II.

There is also a cask pit at the end of pool cell #12, the pool cell used to transfer capsules to and from hot cell G. The cask pit is 1.3 m (4 ft 5 in.) wide × 2.3 m (7 ft 5 in.) long × 5.5 m (18 ft) deep. The overhead canyon crane can access the cask pit, hot cell G, and the truck port [8]. The cask pit has never been used.

It appears that removing the capsules from the pool will require using either the transfer drawer in hot cell G or the cask pit in pool cell #12. The capsules could be placed in universal canisters in either hot cell G or in universal canisters that have been preloaded into a cask that is subsequently placed in the cask pit. The physical dimensions, limits, and capacities of the WESF limit how large any single universal canister can be, as well as how large any transfer cask can be. In addition, the options for welding the universal canister lid shut are limited by the current infrastructure of the WESF. One of the first tasks for moving forward with the universal canister system design is to ascertain which of the welding options are feasible given the current WESF equipment and conditions, or what equipment could be added.

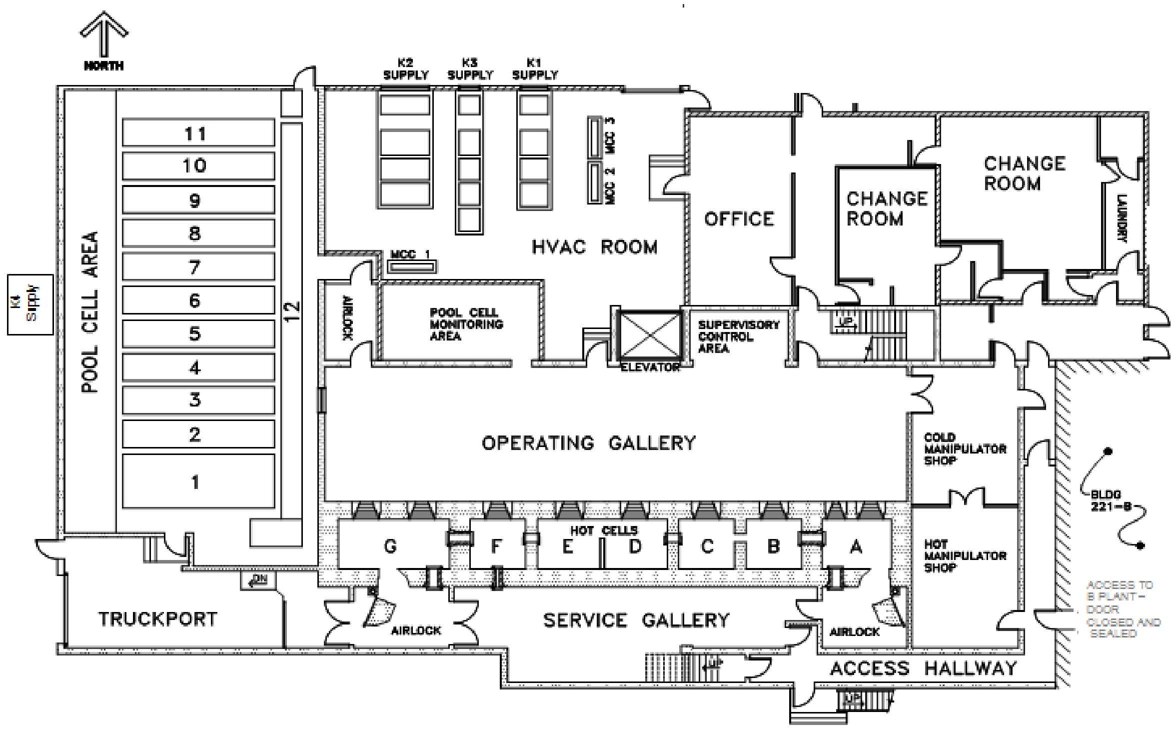

Fig. 2. First Floor of the WESF [8]

TABLE II. Features of the Current Capsule Transfer System and the WESF [8]

Component	Limit, Dimension, or Capacity
Truck Port Door (usable opening)	3.0 m (10 ft) wide × 3.7 m (12 ft) high
Truck Port Cover Block	3.7 m (12 ft) × 2.1 m (7 ft)
Hot Cell G Cover Block	2.4 m (8 ft) × 4.9 m (16 ft)
Overhead Canyon Crane (access to hot cell G, the truck port, and the underwater cask loading area)	13,600 kg (15 tons)
Hot Cell G Hoist	1,800 kg (2 tons), 3.0 m (10 ft)
Hot Cell G Door	0.76 m (2.5 ft) wide × 1.9 m (6.5 ft) high
Hot Cell G Floor	10,400 kg (23,000 lb)[a]
Hot Cell G Manipulators	45.4 kg (100 lb) vertical capacity 22.7 kg (50 lb) horizontal capacity

[a] The floor has been analyzed to support this weight. It may have a higher capability, beyond the previous analysis.

Once the capsules have been removed from the pool, dried, and placed in universal canisters, the capsule-filled universal canisters could be stored in certified storage containers at a storage site at Hanford. These containers must provide confinement of the waste, provide shielding to keep doses within regulatory limits, manage temperatures within acceptable limits, and be amenable to transfer of the waste from the WESF. Ideally, the storage containers would be dual-purpose, i.e., certified for both storage and transportation (see next section).

Transportation

In the past, the capsules were transported via the Beneficial Uses Shipping System (BUSS) cask, shown in Figure 3, which has four different basket configurations for different capsule loadings: 4, 6, 12, or 16 capsules. This cask was also used to transfer capsules into hot cell G. However, the BUSS cask is no longer certified, although it is in the process of being re-certified as a storage-only packaging.

Fig. 3. BUSS Cask with Impact Limiters Attached (left); BUSS Cask Basket Configured with 16 Holes (right)

Many other currently certified transportation packagings exist that, with some adaptation and subsequent certification, would be suitable for transporting the Cs and Sr capsules. In particular, truck and rail casks intended for the transport of used nuclear reactor fuel are attractive for this use as they are designed for the high heat loads associated with the capsules and can provide the necessary shielding for the highly radioactive capsules. Some of these are also dual-purpose and could thus be used for both storage and transportation of the waste-filled universal canisters, thereby avoiding having to transfer the canisters from a storage container to a transportation packaging.

Transportation packagings intended for the transport of used nuclear reactor fuel are on the order of 4 to 5 m long and 0.5 to 1.8 m in diameter (inner), with the rail casks tending to be larger than the truck casks [9]. The universal canister for Cs and Sr capsules is likely to be relatively small, given the capsule size and the current infrastructure at the WESF, so these casks would be able to transport multiple capsule-filled universal canisters, on the order of dozens to a few hundred, most likely limited by the heat generation limit associated with the packaging. Also, with respect to transport, the cost/capacity tradeoff is generally favorable for largest possible cask, so placing many capsule-filled universal canisters in a single transportation package is reasonable from this perspective.

Disposal

At its most basic, the deep borehole disposal concept consists of drilling a large diameter borehole to a depth of 5,000 m in crystalline basement rock, emplacing waste packages in the lower 2,000 m of the borehole, and then sealing the upper 3,000 m of the borehole with a combination of bentonite, cement plugs, and cement/crushed rock backfill. As shown in Figure 4, the deep borehole disposal system is intended to be several times deeper than typical mined repositories. For reference, the dashed blue line shows the typical maximum depth of fresh groundwater resources.

Waste packages disposed of in a deep borehole would have to withstand an extreme environment. The temperature at a depth of 5,000 m may be as high as 170°C (340°F) [10] without heat-generating waste. The hydrostatic pressure at a depth of 5,000 m would probably be between 50 MPa (490 atm) and 65 MPa (640 atm). The fluids at a depth of 5,000 m are expected to consist of high ionic strength chloride brines, and reducing conditions are also expected to prevail [11]. Waste packages must also be designed to accommodate the emplacement method used to lower the packages into the borehole.

Waste packages disposed of in a deep borehole must also be small enough to fit in the borehole. Borehole total depth and diameter are related in that the deeper the borehole, the smaller the associated diameter. For a 5,000 m borehole, several different diameter boreholes have been suggested, ranging from 22 cm (8.5 in.) to 56 cm (22 in.). After accounting for the casing that would be installed in the disposal zone of the borehole, boreholes of this diameter would accommodate a waste package with an outer diameter ranging from 11 cm (4.5 in.) to 36 cm (14.2 in.) [9]. If the smallest diameter borehole is used to dispose of the Cs and Sr capsules, then the universal canister could contain only one capsule per layer. If a larger borehole is used to dispose of the Cs and Sr capsules, then the waste package (or the universal canister) could contain more capsules per layer, up to 14 for the largest diameter borehole [9].

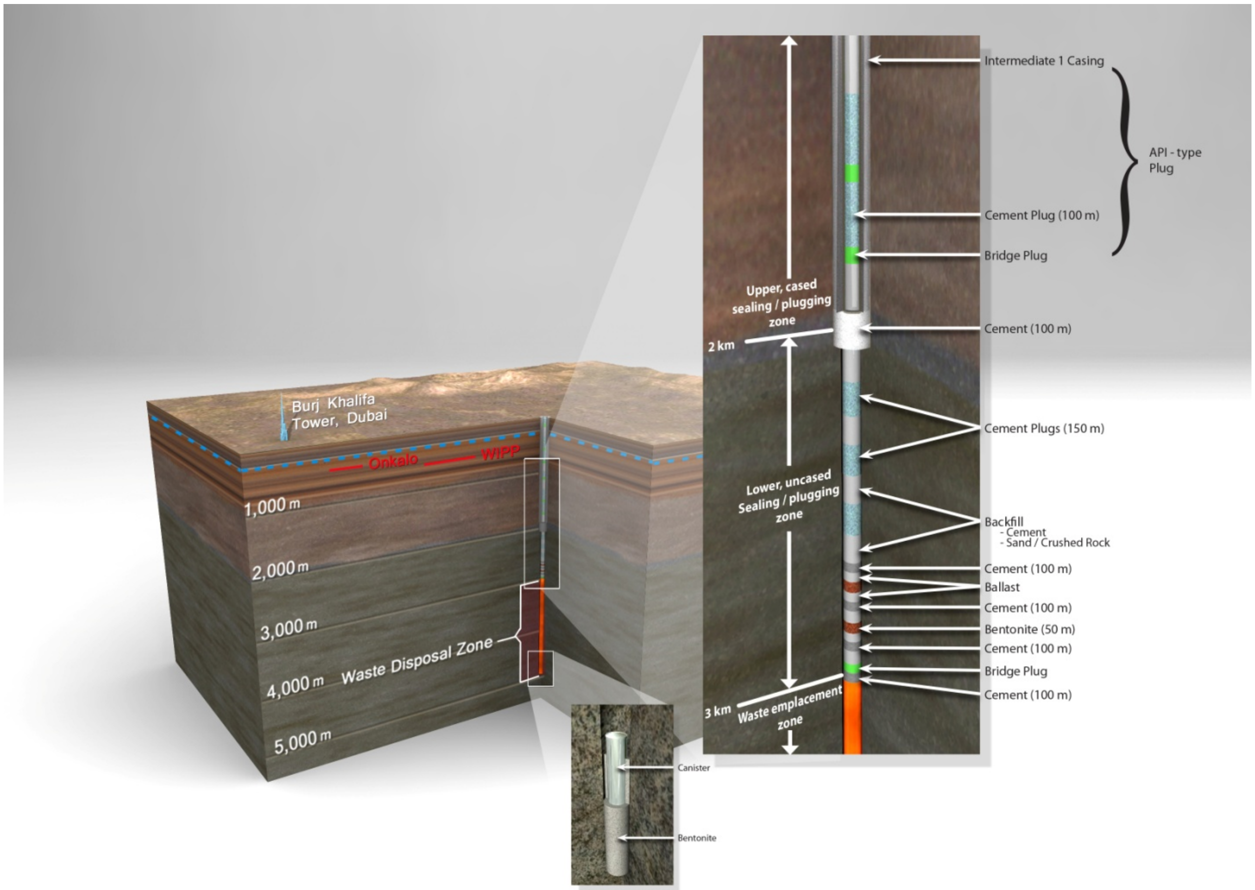

Fig. 4. Generalized Schematic of the Deep Borehole Concept [9]

The DOE is currently engaged in a Deep Borehole Field Test (DBFT) designed to develop the logistics and advance the technical basis for the siting and implementation of a deep borehole disposal facility [12]. The DBFT will be used to validate proof-of-concept, but will not involve the disposal of actual waste. Two boreholes will be drilled as a part of the DBFT: a characterization borehole intended to facilitate downhole scientific testing, and a field test borehole intended to facilitate proof-of-concept for the disposal system using surrogate test packages. The current schedule calls for the characterization borehole to be completed in February 2017, the field test borehole to be completed in January 2018, and emplacement demonstration to be completed in January 2019.

Requirements

The universal canister system would have to be designed to meet multiple requirements, some of which are not yet specified. Requirements would include the type of waste it would have to hold (Cs and Sr capsules in the example case here), canister diameter, canister service lifetime, orientation during storage and transport, lifting requirements, structural requirements, thermal requirements, containment requirements, materials requirements, security requirements, and operational requirements associated with the existing infrastructure at the WESF. For example, hot cell G has a heat load limit of 1,800 W and a capsule inventory limit of 1.50×10^5 Ci of Sr-90 and 1.5×10^5 Ci of Cs-137. A more complete discussion of these requirements is available in [9].

In addition, the universal canister system would have to be designed to meet multiple regulatory requirements and DOE Orders. For storage and transfers, the universal canister system will need to meet the requirements of DOE Order 435.1, which in turn requires the universal canister system to meet the requirements of several additional DOE Orders and other requirements. In addition, assuming the waste is stored in the State of Washington, a permit would have to be obtained for such storage from the Washington Department of Ecology, which has the authority to implement Resource Conservation and Recovery Act requirements in the State of Washington. A fuller description of the requirements related to storage is available in [9].

Transportation of the waste in a universal canister falls under the authority of the Department of Transportation, which has promulgated its regulations in Title 49 of the Code of Federal Regulations (CFR). As required by the Department of Transportation, the package used to transport the waste must be certified by the Nuclear Regulatory Commission (NRC) or the DOE under standards specified in 10 CFR Part 71. These standards require the package to pass tests for normal conditions of transport as well as tests for hypothetical accident conditions. As mentioned above, multiple rail and truck packagings that are currently certified to these standards could, with some modification and subsequent certification, be used to transport the waste in the universal canister. A fuller description of the requirements related to transportation is available in [9].

Disposal of the Cs and Sr capsules in a deep borehole would be subject to the Environmental Protection Agency’s 40 CFR Part 191, as well as whatever regulatory requirements are deemed to be applicable by the NRC. It is not clear if any of the disposal requirements currently promulgated by the NRC in Title 10 of the CFR would be applicable to disposal of radioactive waste in a deep borehole. It is likely that the NRC will need to develop a framework for such disposal. This rulemaking effort would likely consider certain preclosure and operational issues such as handling of waste on site (e.g., transfers), filling and sealing of waste package, lowering of waste packages, and backfilling and sealing boreholes. One of the more significant questions is whether the NRC would require the waste to be retrievable from a deep borehole after closure. Whether the waste must be retrievable and the period of time over which it must be retrievable have a significant effect on waste package and borehole design, as well as selection of emplacement techniques. Disposal of the Cs and Sr capsules would also be subject to relevant Resource Conservation and Recovery Act requirements.

CONCLUSIONS

While multiple factors must be considered in designing a universal canister system for disposal of Cs and Sr capsules in deep boreholes, a few of these factors limit the flexibility of possible design choices. First, the currently available infrastructure at the WESF (e.g., the size of hot cell G, thermal limits in hot cell G, radioactivity limits in hot cell G, crane capacities, lack of underwater welding capabilities) that can be used to remove the Cs and Sr capsules from the pool, place them into universal canisters, and weld the canisters shut limits possible design choices to relatively small universal canisters. The cost/capacity trade-off for transportation usually favors using the largest possible cask and transporting as many waste-containing universal canisters as possible in a single load, leading to transportation packages that would likely contain many (dozens to a few hundred) waste-filled universal canisters. If dual purpose packaging is used for transportation, the storage cask would also be large and would contain many waste-filled universal canisters. The storage cask must also be amenable to receiving universal canisters transferred from the WESF, most likely in multiple transfers, a few at a time. A small universal canister is consistent with the deep borehole disposal concept, which is feasible only for small waste packages. While the universal canister can be designed to also be a waste package, if it is not, each universal canister (or multiple universal canisters) will have to be placed in a waste package prior to disposal.

While possible design options are currently being developed, one option would be to put each capsule into its own universal canister, thereby maintaining the greatest degree of flexibility for downstream storage, transfer, transportation, and disposal. Another option would be to put multiple (e.g., three) capsules in a single universal canister. For either option, the universal canisters could be stacked in a “sleeve” that was sized to fit the storage container and, possibly, the waste package. Having a sleeve would reduce the number of handling operations and could also provide a confinement barrier or a secondary containment barrier if the sleeve were closed and sealed appropriately.

Another factor that limits the flexibility of design options is the timing of events that affect the universal canister system. On the one hand, Hanford is interested in moving the Cs and Sr capsules into dry storage, preferably in universal canisters, within a few years. On the other hand, the DBFT will not have finished its emplacement demonstration until January 2019, and the NRC does not currently have requirements for licensing deep borehole disposal, making it problematic to specify requirements for a waste package. It follows that it is also problematic to design a universal canister that can also serve as a waste package. Therefore, the universal canister system will most likely be designed such that the universal canister needs to be inserted into a waste package prior to disposal, rather than being a waste package in itself.

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