A Review of Multipurpose Canister Concepts for Standardization in the Waste Management System[a]– 15563

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ABSTRACT

Since the early 1980s, the federal government and individual utilities have put forth considerable effort to develop a canister for spent nuclear fuel (SNF) that could be used as part of a dry storage system, transportation system, and disposal system without having to be reopened. While the terminology for this type of canister has changed over the years, the underlying concept and purpose have not. These efforts and ongoing activities in this area are highlighted, expanding upon several previous works [1, 2, 3].

During development of dry storage systems in the 1980s, there was growing interest in triple-purpose (storage, transportation, and disposal) canister concepts, and preliminary studies were conducted [4, 5]. That interest evolved into a project to develop a multipurpose canister (MPC) in the 1990s [6, 7, 8]. After the defunding of that project, the concept lived on in a canister system for US DOE–owned fuel from the mid 1990s to the early 2000s. The commercial spent fuel version of the concept resurfaced in the mid-2000s as the transportation aging and disposal (TAD) canister [2, 9, 10]. After the halting of the Yucca Mountain project, the specific implementation of triple-purpose canisters was reevaluated. This re-evaluation resulted in the standardized transportation aging and disposal (STAD) canister conceptual design and evaluation effort [11]. Each of these efforts is reviewed and summarized.

INTRODUCTION

Canister system[b] design is influenced by many factors, some of which have changed with time. Canister systems must maintain containment, provide subcriticality, reject the heat produced by the SNF, and provide neutron and gamma shielding. At the reactor, the canister must be compatible with the spent fuel pool and, for use in an on-site dry storage system, must meet the applicable requirements of Title 10 of the Code of Federal Regulations Part 72 (10CFR72). During transportation, the canister and transportation overpack must maintain their integrity during design basis accidents and be licensable under 10 CFR Part 71. For disposal, the canister and disposal overpack must be compatible with the repository concept and licensable under applicable repository regulations. In addition to all of these requirements, the system should also be as economical as possible.

At present, commercial SNF management practice does not integrate storage, transportation and disposal

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[b] Note that a canister-based system consists of a thin-walled canister that is placed into a different type of overpack for each function (storage, transportation, disposal). An overpack is simply a container that encases the canister. A cask system is a single-unit (a cask) with integrated shielding that can serve multiple functions but must be designed to meet the most limiting requirements of each function.

capability into a single system. Rather, the commercial waste management system reflects the full variety of dry storage canister designs, ranging from the bolted canisters of the 1980s, to the 24 PWR assembly welded canisters of the 1990s, to the much larger 37 PWR assembly canisters of today. This presents numerous challenges for disposition and for interim storage and transportation activities. For waste disposition, larger canisters present numerous challenges due to thermal and operational considerations. Additionally, emplacing large canisters into a repository is beyond the current experience base domestically and internationally.

An alternative to this ad-hoc approach is to standardize a SNF canister for use in storage, transportation and disposal. SNF containers[c] have evolved over the years, going through several iterations that result in the designs of today. The idea to use the same containers for storage, transportation, and disposal without the need to open and repackage emerged in the 1980s and remained a recurring objective in the various canister designs that followed. Another recurring objective—canister standardization—was also considered around that time. Canister standardization refers to creating more uniform design requirements to improve compatibility across the system. This paper focuses on conceptual designs of triple-purpose[d] canisters for commercial SNF. Overviews of dual-purpose and single-purpose canisters and casks are available elsewhere [12, 13].

In the early 1980s, the Tennessee Valley Authority (TVA) developed integrated cask storage designs described in *Integrated Cask Storage Systems for Storage, Transportation, and Disposal* [4]. Canisters were not receiving widespread attention at that point, so most concepts involved casks. This was followed by a Westinghouse cask system in 1985 [14]. A report was then commissioned by the Office of Civilian Radioactive Waste Management (OCRWM), which detailed truck- and rail-compatible universal canister concepts [5]. For economic reasons, canister-based systems were replacing cask systems by the early 1990s, when Virginia Power proposed a triple-purpose, *universal container system* [15, 16]. The Electric Power Research Institute (EPRI) explored the feasibility of this concept in detail in 1993 [17]. During this timeframe, US DOE worked closely with the nuclear utilities [1, 6, 18], and these efforts culminated in the *multi-purpose canister* (MPC) [6]. US DOE issued a single award to Westinghouse to design the MPC, and phase 1 of the project was completed in 1996 [19]. By 1997, the MPC work ended, but the concept came back into prominence in the mid-2000s when the *transportation, aging, and disposal* (TAD) canister was incorporated into the Civilian Radioactive Waste Management System as the container for most commercial SNF [9, 10]. The Blue Ribbon Commission for America's Nuclear Future [20] suggested reevaluation of the standardized (multi-purpose) canister/cask concept in early 2012. Later in 2012, US DOE awarded contracts to AREVA and EnergySolutions to develop multiple design concepts for a standardized transportation, aging, and disposal (STAD) canister system [11]. By the end of 2013, US DOE initiated a standardization assessment to quantify the impacts of using a standardized canister system to help integrate the waste management system. To support collecting data for that assessment, US DOE recently awarded contracts to more fully develop a 4 PWR standardized canister system and to define and identify ways to mitigate the operational effects of loading smaller canisters at reactors. This is summarized in Fig. 1.

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[c] "Containers" is used as generic term that includes both casks and canisters.
[d] Triple-purpose refers to storage, transportation, and disposal.

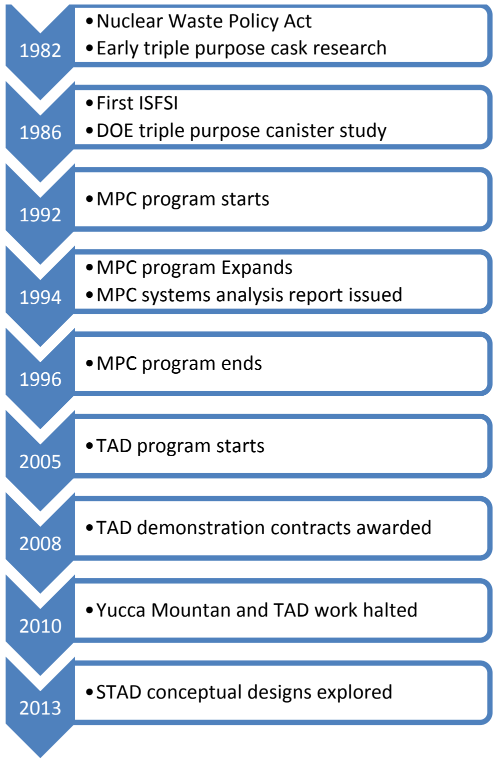

Fig. 1. Timeline representing standardized multipurpose canister development.

DISCUSSION

In the early 1980s, the nuclear community was experiencing the aftermath of the Three Mile Island reactor accident. The termination of the Lyons Kansas repository project a decade earlier was also an issue, along with the realization that reprocessing would not likely occur due to political and economic factors. It became clear SNF would remain at reactor sites for an extended period of time, so spent fuel storage pools were re-racked with high density racks to increase capacity [21]. Prior to 1982, some research on dry storage and other technologies was being performed by utilities and US DOE [4]. The Nuclear Waste Policy Act of 1982 further supported that work by directing US DOE to collaborate with industry to demonstrate at-reactor dry storage technology [22]. Some systems being developed at the time included but weren't limited to the NUHOMS™ canister system, CASTOR™ casks made of ductile cast iron, and the MC-10™ [4, 12]. Many of those storage systems were also appropriate for transportation use. Rod consolidation was being examined at the time, so a rod consolidation option was often included in canister and cask designs of the era. The idea of using the same container for at-reactor storage through final disposition was beginning to be explored by TVA and others [4].

1985 Universal Waste Package Concepts

DOE, TVA and Florida Power and Light commissioned a systems analysis report which was published by Westinghouse in 1985. It examined a number of concepts including a *universal self-shielded waste package* (USSWP), the *universal waste package plus system* (UWP-Plus), and the *thin-walled universal waste package* (TWUWP). All systems included smaller versions of containers for truck shipments. Rod consolidation was considered economical and important in the study, so it was included in most of the scenarios. In many scenarios, consolidation was performed at some intermediate point, so the container would need to be re-opened. Therefore, all the designs under consideration employed bolted closure lids [14].

The USSWP system was a triple-purpose cask, requiring no overpacks for storage, transportation or disposal. The concept accommodated 9 intact PWR assemblies or 25 intact BWR assemblies [14]. (Using an abbreviated notation, it was a 9P/25B design. Also, unless otherwise stated, capacities are given for intact fuel assemblies.)

The UWP-Plus system consisted of a thick walled canister that could be fitted with a transportation overpack or a storage/disposal overpack. The cylindrical canister was made of ductile cast iron or gray cast iron with a wall thickness of 28 cm and a diameter of 1.42 m. When loaded with intact fuel, the canister had a mass of 47,000 kg. It had a 5P/12B capacity for intact fuel. The storage/disposal overpack consisted of graphite sandwiched between outer layers of steel. The wall thickness was 24 cm. The stainless steel shipping overpack was assumed to weigh 91,000 kg when loaded [14].

The TWUWP concept was distinct from the previous universal concepts because it was designed not to be reopened after loading at the reactor. In this scenario, rod consolidation could only be performed at the reactor. Overpacks provided protection during transportation and disposal. The TWUWP came in two varieties made from carbon steel. One was a container for a tuff repository, and one was for a salt repository. The tuff repository container had a wall thickness of 5.7 cm, a loaded mass of 10,000 kg, and a capacity of 6P/14B for consolidated fuel. The salt repository container had a wall thickness of 11.4 cm, a loaded mass of 18,000 kg, and an 8P/24B capacity for consolidated fuel. The containers were designed to be loaded with consolidated fuel and not re-opened. Before final disposal, the canister lid could be sealed by welding and the TWUWP placed in a stainless steel disposal overpack [14].

1986 Canister Concept

In 1986, Surry Nuclear Power Plant obtained the first license to operate a dry storage installation. In the same year, a report commissioned by US DOE was published evaluating the feasibility of utilizing the same container from the reactor all the way to the repository. In that study, a canister-based design was considered with appropriate overpacks for storage, transportation, and disposal. The canister design was justified by the expectation that the various overpacks would provide some protection and containment capability, especially in the cases of transportation and disposal. The systems were designed to transport 7-year-old SNF burned to 40 GWd/MTU [5].

In that report, two canister designs were considered: a small canister for truck and rail shipments, and a larger canister for rail-only shipments. The small canister was a unique noncircular 3P/6B design. Six of these small canisters could be loaded into a rail transport overpack (Fig. 2). The closure lid was attached using cam locks and was to be welded shut prior to permanent disposal. Additionally, a second welded lid could be installed on top of the first lid prior to disposal. This second lid would cover the penetrations in the first lid such as the cam locks and vent port. Presumably, the first lid would also be welded onto the canister during the installation of the second lid. Lids of canisters are welded to help meet regulatory requirements.

A heavier circular 19P/44B design was also considered for rail-only transport. Because overpacks were to satisfy requirements such as physical protection and containment, canisters were envisioned to be constructed of 4.8 mm thick stainless steel or coated carbon steel with extra material on the ends. This canister design is unique in that it has a very thin wall thickness. Aluminum-clad boron carbide was used for criticality control inside both canisters [5].

The truck overpack was designed to have a mass of 32,000 kg when loaded with intact assemblies. The overpack’s structural material was 12.7 cm thick. A rail transportation overpack was designed to have a loaded mass of about 90,000 kg for routing flexibility. As part of the concept, if the assemblies were consolidated, the loaded rail transport overpack would fall under 136,000 kg and could be shipped on a rail line to a repository. The rail overpack wall had a 12.7 cm layer of structural material, with extra material on the ends [5].

Both transportation overpacks were bolted shut with double O-ring seals. The O-rings were protected from fire by a thermal shield installed between the closure lid and the impact limiter used in transport. There was also an internal impact limiter to prevent damage to the canister in the event of sudden deceleration. Both overpacks had gamma shields made from a combination of depleted uranium and steel with equivalent steel thicknesses of 28.2 cm for the rail-only canister and 27.2 cm for the truck canister. Neutron shielding was comprised of borosilicone for both overpacks with a thickness of approximately 15 cm. The rail-only overpack had slightly more neutron shielding [5].

The storage overpack consisted of a thick-walled cast-iron design with tubes of borated water as the neutron shield. Air-filled hoses provided surge volume for the water in the event of temperature changes. Like the rail transport overpack, the storage overpack was designed to accommodate six truck canisters or one rail canister. It also had an epoxy coating to ease decontamination and could be placed in the reactor pool for loading. When being loaded into the reactor pool, a skirt was to be attached to the overpack to reduce contamination, and an inflatable seal would prevent ingress of pool water into the volume between the canister and storage overpack [5].

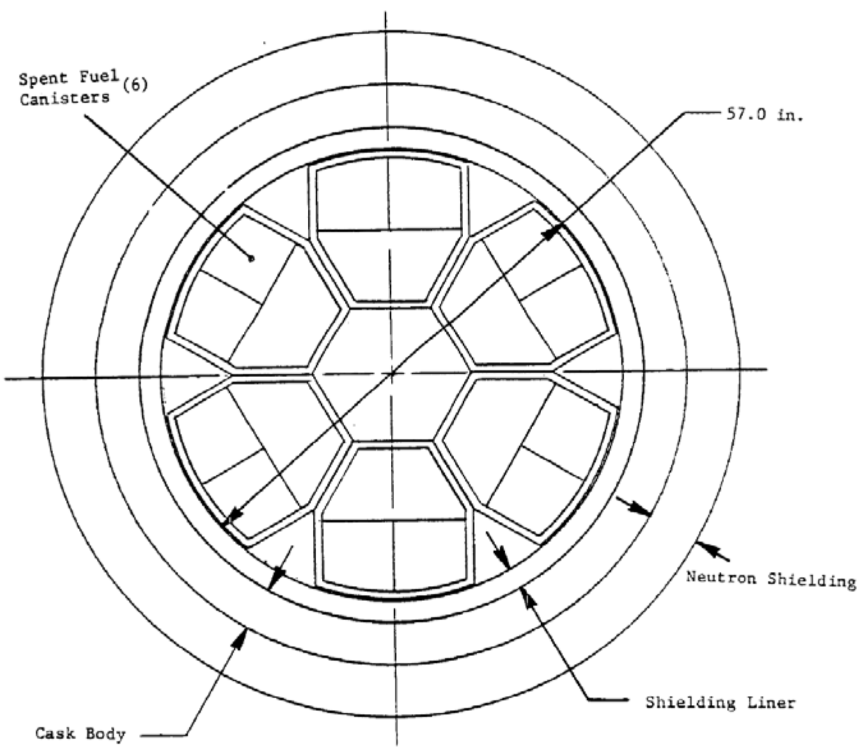

Fig. 2. Six truck-sized canisters placed in a rail shipping overpack [5].

In 1992, representatives from DOE and Virginia Power presented the triple-purpose canister concept to the Nuclear Waste Technical Review Board [15, 23]. In October of that year, OCRWM initiated the MPC program, beginning with a feasibility study [18]. The next year, EPRI issued a report exploring designs of triple-purpose casks and triple-purpose canisters [17, 24].

1993 Canister Concepts

The EPRI study included ductile iron triple-purpose casks, as well as triple-purpose canisters. Terminology then was not as specific as it is today, so in the report, triple-purpose casks were called “multipurpose casks,” and the triple-purpose canister was referred to as a multi-element sealed canister (MESC). The triple-purpose canister had four variants, including cross-combinations of two diameter options and two length options. Most of the work was focused on economic analysis, so the system was largely based on existing technology. Short canisters were designed for PWR fuel only, and long canisters were intended for both PWR and BWR fuels. The heavy long option held 24P/52B, and the shorter option held 24 PWR assemblies. The 24 PWR design had a mass of 36,000 kg when loaded and was based on the NUHOMS 24P™ canisters used at the Oconee Nuclear Station dry storage installation [12, 17]. When fully loaded inside a transport overpack, the large triple-purpose canister had a mass of around 113,000 kg. The smaller triple-purpose canisters were available in a 15P/37B long design and a 15P short design [17].

In the EPRI triple-purpose canister concept, horizontal storage modules were used, and cost estimates were based on a simplified model of a shipping overpack developed by the designers of the NUHOMS system; details were not explicitly specified [17, 25]. The disposal overpack was made from cast iron to provide a good basis for comparison to the cast iron triple-purpose cask [17].

1993 Multipurpose Canister Concepts

A DOE systems analysis of the *multi-purpose canister* (MPC) system was issued in September of 1994. The systems report analyzed a conceptual design of the MPC against a storage and transportation cask concept, as well as a triple-purpose cask concept. It found the MPC concept to be the most suitable [6]. The DOE MPC program expanded around that time, becoming focused on design and procurement of a supply of MPCs. The program was to be conducted in three phases, beginning with design and drafting of a safety analysis report (SAR). The second phase would be development and testing of the models while the SAR was being evaluated by the NRC. Finally, steps would be taken to procure a two year supply of canisters [26].

The MPC was intended to be a universal design. Along with compatible variants, the MPC could accommodate 90% of commercial fuel [1], and modifications were considered so that the MPC could accept the diverse, DOE-owned fuel, along with other fuel types [27, 28]. The system would have included two sizes of: canisters, transfer casks (really overpacks), rail transportation overpacks, vertical storage overpacks, and eventually, disposal overpacks. The later conceptual designs included two canister sizes. The large canister was a 113,000 kg 21P/44B design. It had a 1.68 m diameter and a wall thickness of 19mm. Aluminum heat removal plates were to be used for thermal management. The small canister was a 68,000 kg design that could hold 12 PWR assemblies or 24 BWR assemblies. It had a 1.4 m diameter and a 16mm thickness. The canisters were made of stainless steel. They had inner and outer closure lids, with the inner lid containing an inlet and drain port. Beneath the lids, which were welded to the canister, was a shield plug to reduce any worker dose encountered during lid welding. The shield plug was to be made of depleted uranium or carbon steel coated in stainless steel [29]. In some designs, boron-aluminum alloys were used for in-basket criticality control, but due to the corrosion characteristics of aluminum subjected to radiation, it was later recommended that other materials should be examined for repository compatibility [30]. The other candidates were boron dispersed in stainless steel and zirconium hafnium alloys [8, 30]. The baseline for burnup compatibility was 40GWD/MTU fuel enriched to 3.75wt%, but the large canisters were designed to handle 4wt% enriched fuel [7, 8, 29].

The MPC transportation overpacks were to be made of stainless steel. In the MPC design concept, the gamma shielding consisted of depleted uranium [29], but some lead may have been used in thermally stable areas [28]. The neutron shielding was to be made of borated concrete (NS-3), and the impact limiters were composed of stainless steel–lined polyurethane foam. They were to travel on six axle 176,000 kg gross mass rail cars, pending design approval by the Association of American Railroads (AAR). The overpack lid was bolted on [29].

A transfer cask (really an overpack) was to be loaded in the spent fuel pool. It had a liquid neutron shield and a lead gamma shield, as well as a supplementary shield that could be bolted on for additional radiation protection. The upper closure lid was a two-piece design, while the lower closure lid was one piece. The upper lid had a donut-shaped section comprising most of the lid area. The hole in the middle was covered with the second piece of the upper lid. The hole allowed a ram to push the MPC out of the transfer cask during transfer operations. The transfer operation took place in a horizontal configuration, using a storage overpack upender and a hydraulic piston. The storage overpack consisted of reinforced concrete with air vents [19, 29].

The MPC program abruptly ended in 1996, near the end of the first phase [27]. At that point, DOE explored other standardized triple-purpose canister concepts for DOE-owned fuel. That generation of canister designs was smaller than the MPC, having two sizes with diameters of 46 and 61 cm, with lengths between 3 and 4.6 m. Some of these studies involved scale model drop testing [31–35].

2005 Transportation Aging and Disposal Canisters

The standardized canister concept reemerged in 2005 as the transportation, aging, and disposal (TAD) canister. Initially, four vendors were contracted to provide proof of concept [2, 36]. AREVA TN and NAC were selected to design, license, and demonstrate the TAD system. It was similar in size to the large MPC and had the same capacity. Criticality management was expected to be achieved through stainless steel–based neutron absorbers such as borated stainless steel or through inclusion of old PWR fuel control rod assemblies. Structural baskets were to be made from type 300 stainless steel. The canister material was unspecified but was to be compatible with various operating environments encountered during storage, transportation and disposal. The weight of the entire system was intended to be under 162,000 kg for transport on a rail car. Similar design envelopes were defined for the various overpacks [2].

The TAD design produced by NAC was known as the UNITAD™ system and used a stainless steel canister based on NAC's existing UMS 24-PWR™ canister system. The canister lid was a single lid design to reduce operator dose from welding and checking two lids. The canister was 1.69 m in diameter and 1.3 cm thick. The basket used radially oriented aluminum disks and stainless steel disks to hold neutron absorbers and fuel tubes in place. The aluminum disks were likely included to improve heat transfer. The fuel tubes included borated stainless steel to provide criticality control. The transportation overpack design was based on the NAC-STC™ with impact limiters consisting of stainless steel shells filled with balsa and redwood [37].

The AREVA TN design was based on the NUHOMS™ system. Aluminum plates parallel to the canister axis were used to transfer heat away from the fuel assemblies, and stainless steel was used for the remainder of the structure. The transportation overpack was based on a modified NUHOM MP197™ overpack. The transportation overpack conducted heat away from the fuel using aluminum boxes surrounding the borated polyester neutron shielding placed on the outside of the steel shell. Lead provided gamma shielding. The impact limiters were also made from stainless steel shells filled with wood. The storage overpack was a vertical concrete cylinder with openings for natural convection [38, 39].

Following the halting of the Yucca Mountain work, the Blue Ribbon Commission for America's Nuclear

Future recommended considering a standardized canister system [20]. After that recommendation, DOE contracted AREVA and EnergySolutions to develop conceptual designs for STAD canister systems. Both studies recommended developing large, medium and small designs so that once a repository design was developed, a canister design would be ready to implement [11]. At the end of 2013, a standardization assessment was initiated to quantify the impacts of using a standardized canister system. As part of that assessment, DOE issued a contract to perform studies to more fully understand the complete 4 PWR STAD canister system and operations, including loading, storage, transfer, etc. DOE also issued a contract to perform a study of the impacts of STAD implementation at reactors and identify innovative approaches to minimize those impacts.

CONCLUSION

Various standardized canister concepts have been developed over the past 30 years. Numerous triple-purpose canister and cask design concepts were created in the 1980s. Those early designs employed a wider variety of concepts than the more refined systems to follow. In the mid-1990s, the triple-purpose canister concept was embodied in the MPC concept. The MPC was the first concept that received enough support to begin planning for implementation. In the 2000s, the TAD canister was being developed in concert with a repository in volcanic tuff. Like the MPC, the TAD program proceeded towards implementation. However, it too ended abruptly with the halting of the repository project. Most recently, different STAD concepts have emerged and are currently being explored, and the potential benefits and issues are being assessed.

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