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RECENT PROGRESS ON THE STANDARDIZED DOE SPENT NUCLEAR FUEL CANISTER[1]

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ABSTRACT

The Department of Energy (DOE) has developed a set of containers for the handling, interim storage, transportation, and disposal in the national repository of DOE spent nuclear fuel (SNF). This container design, referred to as the standardized DOE SNF canister or standardized canister, was developed by the Department's National Spent Nuclear Fuel Program (NSNFP) working in conjunction with the Office of Civilian Radioactive Waste Management (OCRWM) and the DOE spent fuel sites. This canister had to have a standardized design yet be capable of accepting virtually all of the DOE SNF, be placed in a variety of storage and transportation systems, and still be acceptable to the repository.

Since specific design details regarding the storage, transportation, and repository disposal of DOE SNF were not finalized, the NSNFP recognized the necessity to specify a complete DOE SNF canister design. This allowed other evaluations of canister performance and design to proceed as well as providing standardized canister users adequate information to proceed with their work.

This paper is an update of a paper [1] presented to the 1999 American Society of Mechanical Engineers (ASME) Pressure Vessels and Piping (PVP) Conference. It discusses recent progress achieved in various areas to enhance acceptance of this canister not only by the DOE complex but also fabricators and regulatory agencies.

INTRODUCTION

The standardized canister is a container in which DOE SNF is to be placed. The goal of the standardized canister design is to simplify the handling of DOE SNF and meet applicable regulatory criteria. This canister must be capable of being integrated into:

- a storage facility or storage cask
- a transportation cask, and
- a repository waste package.

However, by itself, the DOE SNF canister is not a storage cask or storage facility per 10 CFR Part 72 [2], not a transportation cask per 10 CFR Part 71 [3], nor a repository waste package per 10 CFR Part 63 [4]. The intent of the design was to have the standardized canister be incorporated into interim storage facilities (acting as one of the confinement barriers if necessary), be placed into an approved transportation cask during transportation (acting as an inner containment if necessary), and being placed into a repository waste package for final disposal (acting as a confinement barrier during canister handling at the surface facility). The most stringent requirements from either of these three uses had to be imposed on the canister since there was to be only one standardized canister design.

It should be kept in mind that DOE SNF is unlike commercial fuel. DOE SNF is typically highly enriched fuel, having a variety of shapes and sizes, and a significant portion is damaged (as defined in NUREG-1617 [5]). Therefore, the precise requirements deemed necessary by a regulatory agency may be more rigorous than those currently in place for commercial SNF.

BACKGROUND

The design for the standardized canister had to consider a number of issues. To maintain simplicity, efficiency, and to keep costs low, the intent was to have these canisters envelope the SNF but not provide numerous safety features, such as shielding. Other components (including the interim storage facilities, transportation casks, and the repository waste packages) could be relied upon to provide these other safety functions. Simple fabrication, without expensive machining, was the objective of the canister design.

Although the goal was to shift various safety functions onto other facilities or components, the potential still existed that when these canisters are being handled by themselves, they could be accidentally dropped. This means that the standardized canister has to be sufficiently robust to withstand anticipated operational loads and at least confine the DOE SNF after an accidental drop event. Therefore, providing some means of protecting these canisters during potential drop events was a significant design consideration. However, the lack

[1]Work supported by the U. S. Department of Energy, Idaho Field Office, under DOE Contract No. DE-AC07-99ID13727.

of shielding meant that workers could not be relied upon to easily attach and remove external impact limiters. In addition, the physical presence of external impact limiters could potentially impose unnecessary handling restrictions and excessive usage of limited space. Therefore, the use of removable external impact limiters was deemed undesirable. However, this increased concern over the ability of the standardized canisters to satisfy desired performance objectives during potential accidental drop events.

Since most of the DOE spent fuel sites did not have finalized plans in place regarding interim storage, transportation cask details were not finalized, and the repository design was not finalized, progress toward designing a standardized canister was difficult. However, DOE spent fuel sites and repository personnel wanted detailed standardized canister information for their own planning purposes.

Therefore, the NSNFP decided to write a preliminary design specification [6] that would identify specific canister geometry with a robust design as well as include a number of significant repository requirements (though not yet finalized). This would allow the NSNFP to proceed with certain aspects of gaining repository acceptance of the standardized canister design. It would also permit initial contracts to be awarded to begin the process of placing DOE SNF into dry storage.

With a clear focus on future use, the preliminary design specification required the standardized canister to be N-stamped per the criteria of the ASME Boiler and Pressure Vessel (B&PV) Code, Section III, Division 3 [7]. The basis for this requirement is that the standardized DOE SNF canister can then function (as necessary) as the inner containment system for transporting damaged SNF with more than 20 Curies (0.74 terabecquerels) of plutonium, based on the guidance provided in Section 4.5.1.3 of NUREG-1617. Because the current decision is to allow the various DOE sites to procure the standardized canisters on an as-needed basis over the next several decades, imposing ASME Section III, Division 3 criteria results in appropriate quality assurance controls for the construction of these canisters. The preliminary specification acknowledged that modifications to Division 3 rules were necessary before actual Code construction and stamping could be accomplished. At first, a Code Case was envisioned but after discussions with ASME Code personnel, permanent Code changes were considered more appropriate.

To address the increased concerns over the drop response of the standardized canister with no external impact limiter, the canister design incorporated an integral energy-absorbing skirt (Figures 1 and 2) that deforms on impact during an accidental drop event, providing significant protection to the containment system of the canister. The skirt helps to protect the canister containment system in virtually all accidental drop events by absorbing impact energy. Only when the canister impacts in a horizontal (flat) orientation does the skirt not absorb significant energy. However, in horizontal orientations, the entire length of the canister is then able to absorb the drop energy. A deformed skirt can be removed if necessary without disrupting the canister containment system, enhancing the canister's ability to still fit into other containers.

The standardized DOE SNF canister design has two nominal diameters [18 inches (457 mm) and 24 inches (610 mm)] and two nominal lengths [10 feet (3.00 m) and 15 feet (4.57 m)], and is made of 316L stainless steel. The nominal wall thickness is 0.375 inches (9.53 mm) for the 18-inch (457-mm) diameter canister, and 0.500 inches (12.7 mm) for the 24-inch (610-mm) diameter canister. Although a 50 psig (344.8 kPa) internal pressure was established for design conditions [22 psig (151.7 kPa) operational], the standardized DOE SNF canister actually has the capability of withstanding a much higher pressure limit [working pressure of about 350 psig (2.41 MPa)]. This is just one example of the robust design of the standardized DOE SNF canister.

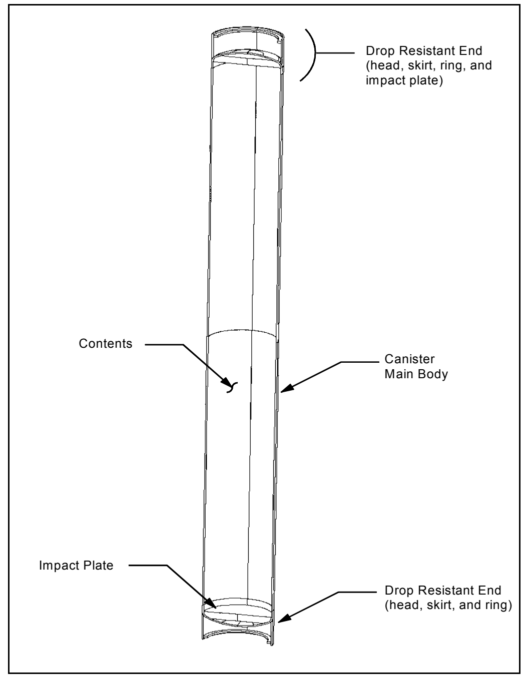

Figure 1. Canister Overall Design (Section View)

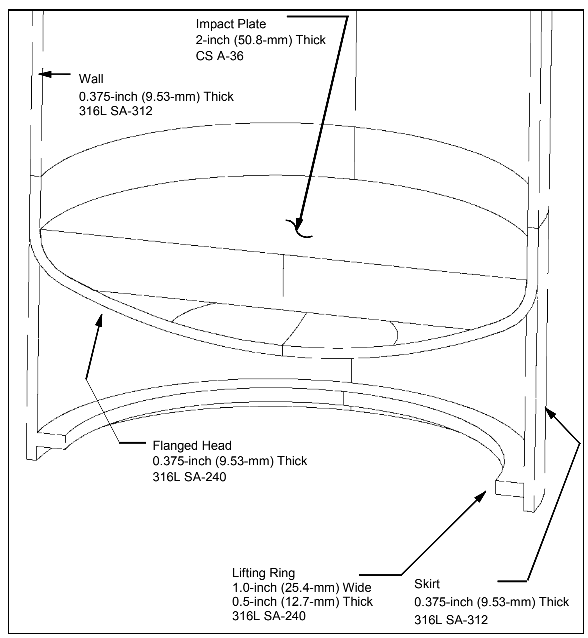

Figure 2. Smaller Canister Lower End Cross Section

RECENT PROGRESS

In 1998, the standardized canister design was established in the preliminary design specification. Since then, multiple developments have occurred which have demonstrated its robust performance and enhance the acceptability of the standardized canister.

1999 Drop Testing

Even though the standardized canister design has skirts that absorb significant amounts of impact energy, the skirts are made from stainless steel pipe and do not cushion the standardized canister enough, when subjected to a 30-foot (9-m) accidental drop of the canister by itself, to permit compliance with the stress limits for a hypothetical accident condition established by the ASME B&PV Code, Section III, Division 3 or the stress limits for a Level D Service Condition established by Section III, Division 1 [8]. Therefore, whenever the standardized canister was to be handled by itself, the design intent was to let the facility provide any required confinement function in the event of an accidental drop. However, the NSNFP still believed it was necessary to demonstrate the actual response of the standardized canister to a 30-foot (9-m) drop event. If full functionality could be demonstrated, the robust design of the standardized canister would be established.

During 1999, the NSNFP funded the fabrication of nine full–sized, 18-inch (457-mm) diameter test canisters. The goal was to drop these test canisters to assess their structural performance, to demonstrate the resulting integrity of the pressure boundary and leak tightness of the containment after the drop tests, and to see how accurately computer predictions could be made of the resulting plastic deformations. The results of this effort were presented to the 2000 ASME PVP Conference [9]. Summarizing, the resulting deformations were within acceptable limits, the test canisters were all proven to be able to maintain the structural integrity of the pressure boundary, the four worst-damaged test canisters were helium leak tested and were found to be leaktight [10] with helium leak rates less that 10^{-7} std cc/sec, and the computer predictions accurately matched the resulting deformations, many times within 5% or less variance. The ability of the standardized canister to maintain a leaktight containment after a 30-foot drop event enhances its acceptability. These results may also be useful to facilities that do not provide the full confinement function necessary to satisfy regulatory criteria.

Friction Parameter Determination

Although this specific effort is still under evaluation, preliminary results from a scientific investigation in 2001 have indicated that the value of friction (between the dropped component and the impact surface) used in accidental drop analyses can have a significant affect on the predicted structural results. The scientific investigation dropped identical test specimens at different angles of impact from a consistent 40-foot (12.2-m) drop height. Computer predictions were made to determine which appropriate friction factors best matched the actual resulting deformations from each drop test.

Surprisingly, the analysis determined friction values shifted from 0.025 to nearly 1.0 as the impact angle increased from nearly vertical (14 degrees) to approaching horizontal (62 degrees). These preliminary results were surprising since the analytically determined friction values were much different than those typically published in engineering handbooks for steel on steel (typically 0.45 to 0.60). The preliminary results of this scientific investigation were presented to the 2001 ASME PVP Conference [11]. Additional drop tests using different test specimen geometries have been completed but funding limitations have delayed the full evaluation of these other drop tests.

The significance of these preliminary results is that many safety evaluations for accidental drop events are based on computer analysis predictions. However, the analysis methodology used may yield non-conservative results. The analyst must be aware of the significance of the friction values used in such analyses. The ultimate goal of this scientific investigation is to establish the appropriate friction values for the standardized canister so that all associated drop analyses performed yield the correct results.

ASME B&PV Code, Section III, Division 3 Revisions

As identified in the preliminary design specification, certain revisions to the ASME B&PV Code, Section III, Division 3, Subsections WA and WB were necessary before the standardized canister could be fabricated to Code criteria and N-stamped. All of the revisions were necessary due to the fact that the containment would not be completed until after the SNF or other radioactive material has been loaded into the canister and the final closure weld completed. The Code revisions identified as necessary to permit canister construction were:

1. Allowing an alternative procedure that permitted applying the N-stamp prior to final completion of the containment due to personnel exposure concerns once SNF or other radioactive materials have been loaded into the canister,
2. Allowing field operations in order to complete the final closure weld at a location other than the Code shop,
3. Allowing ultrasonic testing to be an acceptable method for volumetric examination of the Category B final closure weld, and
4. Once loaded with SNF, substituting a helium leak test for the mandatory pressure test due to safety concerns.

Note that these changes are applicable to storage containments as well as inner containments for transportation.

Most of these Code changes have already been achieved. Currently, in the 2001 Edition, WA-8311 specifies alternative stamping requirements, WA-8151 permits field operations, and WB-5279 allows the use of ultrasonic examination plus liquid penetrant or magnetic particle examination when environmental conditions (e.g., background radiation from the loaded SNF or other radioactive materials) do not permit radiographic examination to be performed. Discussions are currently being held in the Subgroup NUPACK (responsible for Section III, Division 3 rules) to revise WB-6000, allowing the substitution of helium leak testing for pressure testing under certain conditions.

In addition to the Division 3 changes discussed above, Subgroup NUPACK is also currently writing rules for storage containments. The goal is to issue these new rules for storage containments and eliminate Nuclear Code Case N-595 [12], the Division 1 Code Case that currently allows storage containments to be built under Division 1, Subsection NB rules as modified by the Code Case. Tentatively identified as a new Subsection WC for Division 3, these new storage containment rules are expected to be similar to the Subsection WB rules for transportation containments. Since the standardized canister is to be an N-stamped, Division 3 inner containment for transportation, using the standardized canister as a Division 3 storage containment is expected to be a viable option.

Repository Acceptance

The repository, being designed under the direction of OCRWM, has been designated to receive both civilian and federal government (DOE) radioactive spent nuclear fuels. Addressing just the DOE aspects of the repository design, the concept of co-disposal is being pursued. Under co-disposal, five 24-inch (610-mm) vitrified high level waste containers will be placed into the repository's waste package. A center hole will result when the five vitrified canisters are placed in a circular pattern. This center hole is where the canistered DOE SNF is to be placed. Hence, the term co-disposal, meaning both DOE high level waste and DOE SNF are to be placed into the same waste package.

In late 1998, the standardized canister design was accepted for use at the repository, assuming the final waste acceptance criteria will be satisfied at the time of DOE SNF transport to the repository. The preliminary design specification included specific repository acceptance criteria [13] known at that time, including (1) a maximum internal canister pressure of 22 psig (151.7 kPa), (2) canister materials to be low-carbon austenitic stainless steel or stabilized stainless steel, (3) sealed canisters backfilled with inert gas, (4) unique alphanumeric identifier on each canister, (5) the capability of a canister to stand upright on a flat surface without support, (6) damaged or deformed canisters still maintaining a seal, still capable of being lifted and moved, and still meeting the dimensional envelope required for loading into a waste package, and (7) a canister able to be vertically lifted with remote lifting fixtures.

The standardized canister was incorporated into the repository's Interface Control Document [14], a document meant to provide envelope measurements of all significant components in order to assure proper interfaces and fits. Later, the repository also completed a study (referred to as the performance allocation study) to evaluate the performance of a number of canisters expected to be received at the repository. Based on the results of the 1999 drop testing effort, the standardized canister's drop performance was superior to less robust canisters that drove the surface facility design and the expected handling and operating procedures for DOE SNF.

The most recent repository waste acceptance criteria [15] appears to be less prescriptive. Rather than many specific limitations, the current criteria reflects a philosophy that if the DOE SNF can be transported to the repository in a sealed canister and that canister can adequately perform its required safety functions (e,g, contains or adequately confines the SNF after an accidental drop event) prior to being loaded into a waste package, the repository will accept that DOE SNF. The NSNFP firmly believes that the standardized canister fulfills these criteria.

ASME Division 3 Nuclear Code Case

In order to timely support an existing DOE SNF storage contract that was identified to use the standardized canister, an ASME Nuclear Code Case was generated. This Division 3 Nuclear Code Case, tentatively identified as N-656, is similar to the Division 1 Nuclear Code Case N-595, written for storage canisters. However, it was specially written to apply to only an inner containment for transportation, as identified in NUREG-1617. Formal issuance of this Division 3 Nuclear Code Case is expected by the end of 2002.

Code Case N-656 includes ten items and requires (1) the final closure weld to be a full penetration weld, (2) final closure welds be exempted from pressure tests provided a helium leak test is performed with an acceptable leakage rate no greater than 10^{-4} std cc/sec, (3) buckling and instability evaluations follow Division 1, NB-3133 requirements, (4) inelastic analyses for Level D operating conditions, including those associated with accidental drops, follow the rules in Appendix F, (5) the dimensions of standard items comply with Division 1, Table NB-3132-1, (6) Section III, Division 3, 2001 Edition or later shall be used, (7) the requirements of WA-8152 are applicable to the inner transportation containment final closure weld, (8) definitions in terminology provided in Subsection WA take precedence over Subsection WB, (9) the stress limits shall be in accordance with WB-3000 except that primary stresses for Level B operating limits may be in accordance with NB-3223(a) and primary stresses for Level C operating limits may be in accordance with Figure NB-3224 –1, and (10) the Code Case number shall be indicated on the Code Data Report.

Many of the Division 3 Code Case items may appear confusing by referring to Division 1 or specifying that rules or definitions in Subsection WA have precedence over Subsection WB. The reason for these clarifications is that the 2001 Edition of Subsection WB still needs to be modified to match the recently revised Subsection WA and to clarify the use of rules that currently exist in Division 1 that are expected to be incorporated into Division 3, Subsection WB rules sometime in the near future. Item (7) of the Division 3 Code Case is necessary to take advantage of a recent change in Subsection WA that was inadvertently restricted to storage containments.

10 CFR 71.63 Changes

The United States Nuclear Regulatory Commission (NRC) undertook efforts to revise the double containment ruling as specified in 10 CFR 71.63(b) in order to establish compatibility with International Atomic Energy Agency (IAEA) standards. The basis for the separate inner containment (i.e., the "double containment") rule dates back to 1974 when the Atomic Energy Commission believed that safety would be significantly enhanced if plutonium in excess of 20 Curies (0.74 terabecquerels) were being shipped. The proposed rule change, identified as Issue 17, was established in a Federal Register notice [16]. The NRC staff later documented their position in SECY-01-0035 [17]. Summarizing, the NRC believed that a single Type B containment barrier is adequate for all transportation packages. This rule making process is still in progress. It should be noted that the NRC did not change the requirement to ship plutonium (in excess of 20 Curies) as a solid, per 10 CFR 71.63(a).

Although the design basis of the standardized canister was to perform this inner containment function during transportation of damaged SNF with plutonium in excess of 20 Curies (0.74 terabecquerels), the possible elimination of the double containment rule does not eliminate the need to have nuclear quality construction for the standardized canister. Having a certified, N-stamped transportation inner containment still means that (1) incorporating the standardized canister into a 10 CFR 72 approved storage facility is easier, especially if damaged DOE SNF is to be stored, (2) transporting either intact or damaged DOE SNF or other radioactive materials is still more easily achieved with additional qualified barriers in place, and (3) the repository still expects to receive DOE SNF in sealed canisters of sufficient quality and structural integrity as to be able to withstand a repository defined potential accidental drop event and still contain or adequately confine the material. Regardless of this regulation change, the NSNFP will stay with its original design approach for the standardized canister since the result is an additional barrier, increased safety, and the prevention of major programmatic perturbations if a double containment requirement is ultimately imposed for DOE SNF.

Flaw Evaluation Work

The 1999 drop testing effort confirmed the ability of an 18-inch (457-mm) diameter standardized canister (in an essentially flaw-free condition) to maintain a leaktight containment after an accidental drop event. Starting in 2002 and carrying over into 2003, the NSNFP is funding a preliminary scientific investigation to evaluate the ability of a standardized canister with a flaw to maintain a containment system after an accidental drop event at the repository. The 1999 drop testing effort used test canisters that are expected to reflect the actual condition of the standardized canisters since the ASME Code, Section III fabrication requirements should produce a canister without significant flaws. However, if for any reason (after fabrication or during use), a flaw does develop in a standardized canister, this testing would address such an unexpected situation.

The maximum anticipated acceptable flaw size, determined using analytical fracture mechanics methods and past metallurgical test results, used worst-case stress values resulting in a standardized canister dropped vertically 23 feet (7 m), a repository defined drop event. The result was an elliptical-shaped flaw of significant size, approximately 2 inches (5.1 cm) long and 0.20 inches (0.51 cm) deep. This size of flaw or crack, more than halfway through the nominal 0.375-inch (9.53-mm) wall thickness, can be easily detected using a variety of nondestructive examination techniques. If it can be shown through demonstration testing that flaws of this detectable size, in either base or weld metal, do not propagate through the wall under the expected drop event loads, the robust design of the standardized canister has once again been demonstrated.

FUTURE EFFORTS

The NSNFP has initiated efforts to understand standardized canister aging mechanisms that could adversely affect performance over its design life. Studies are underway to examine hydrogen generation that might affect standardized canister pressurization and material embrittlement. The NSNFP is working with the American Society for Testing and Materials (ASTM) to define a drying standard for SNF that will significantly reduce the amount of water to levels that would be of no concern for aging issues. Detrimental effects from the SNF and fission products are also being investigated.

Even with the robust design of the standardized canister, during certain accident scenarios, ASME Code Level D stress limits can be exceeded. However, no containment failures have been observed or measured during standardized canister drop tests. The standardized canister can experience high strains but still maintain a containment. A white paper is being developed jointly by OCRWM and the NSNFP this year, providing an acceptance basis for canister integrity with high strain values. Future meetings are planned with the NRC to fully discuss the use of strain criteria to determine the suitability of a canister after a drop accident.

CONCLUSIONS

The past few years have seen a number of changes in the ASME B&PV Code, federal regulations, and repository requirements that could affect the standardized canister. However, the standardized canister is still expected to provide the DOE complex with a viable tool to address the handling, storage, transportation, and repository disposal of DOE SNF and other radioactive materials. All accomplishments to date continue to indicate that the standardized canister can indeed perform its intended functions with safety margins.

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NOTICE