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DEVELOPMENT OF THE STANDARDIZED DOE SPENT NUCLEAR FUEL CANISTER DESIGN AND PRELIMINARY DESIGN SPECIFICATION[1]

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ABSTRACT

The Department of Energy (DOE) has developed a set of standard canisters for the handling, interim storage, transportation, and disposal in the national repository of DOE spent nuclear fuel (SNF). The Department's National Spent Nuclear Fuel Program (NSNFP) and Office of Civilian Radioactive Waste Management (OCRWM) worked together along with DOE sites to develop the canister design. The standardized DOE SNF canister had to be capable of handling virtually all of the DOE SNF in a variety of potential storage and transportation systems and also be acceptable to the repository, based on current and anticipated future requirements.

Since specific design details regarding storage, transportation, and repository disposal of DOE SNF are not yet finalized, the NSNFP recognized that it was necessary to specify a complete DOE SNF canister design. This design had to be flexible enough to be incorporated into various storage and transportation systems and yet standardized so that the canister would be acceptable to the repository for disposal. This paper discusses the efforts taken to gain DOE complex consensus, the reasons for various design decisions, the steps taken to demonstrate the robustness of the proposed canister design, and other insights associated with the development of the standardized DOE SNF canister design and the preliminary design specification.

INTRODUCTION

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

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

However, by itself, the DOE SNF canister is not a storage cask or storage facility per 10 CFR Part 72, a transportation cask per 10 CFR Part 71, or a repository waste package per 10 CFR Part 60.

Current federal regulations and other regulatory requirements do not yet specifically address a SNF canister with such a variety of uses. This made it very difficult to identify the design acceptance criteria and requirements that had to be satisfied. In addition, all of the required functions of the canisters have not yet been identified because the various DOE SNF custodians are still determining the best alternatives regarding the disposition of the SNF under their jurisdiction.

DESIGN CRITERIA

The first issue to be considered was the selection of design criteria for the standardized DOE SNF canisters. However, the selection of the proper design criteria heavily depends upon the intended use of the DOE SNF canisters and its required design functions. The two most important questions that required an answer were:

- Does the DOE SNF canister have to perform a containment function?

and

- Does the DOE SNF canister have to provide criticality control?

The initial effort to address these two questions was to let the DOE SNF canister be just a handling envelope and let smaller cans which would be placed inside of the DOE SNF

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DISCLAIMER

canister provide the containment and criticality control functions This would permit the selection of virtually any design criteria for the standardized canister However, in order to provide basic assurances of sound, reasonable construction and to address the potential for internal pressure, the decision was made to identify the ASME Boiler and Pressure Vessel (B&PV) Code, Section VIII, Division 1 (ASME, 1995a) as the design criteria for the DOE SNF canister In addition, special enhancements were identified that, in essence, tried to emulate nuclear pressure vessel standards These enhancements included additional (beyond Section VIII, Division 1 requirements) material examinations before and after fabrication, large mill purchases by the NSNFP of fabrication materials in order to easily provide for traceability, a simplified canister design, and full penetration weld joints on the pressure boundary This was believed to be more simple and economical than specifying ASME B&PV Code, Section III criteria (ASME, 1995b) and would also open the fabrication of the canisters to a larger number of manufacturing shops However, numerous objections were noted about using cans internal to the DOE SNF canister to provide containment and criticality control functions The major concern noted was the lack of easy surveillance of cans internal to the standardized DOE SNF canister Therefore, this design approach was rejected

Next, the philosophy identified in ANSI/ANS-57 9-1992 (ANS, 1992) regarding acceptable design criteria for sealed container pressure boundaries for fuel unit handling areas was considered This ANSI/ANS document recommended that either Section III *or* Section VIII of the ASME B&PV Code could be used as acceptable design criteria However, Table A-3 (on page A-92) of NUREG-1567 (USNRC, 1996) indicates that the U S Nuclear Regulatory Commission (NRC) took exception to the reference to ASME B&PV Code, Section VIII for sealed container pressure boundaries Since acceptance by the NRC was desired by the NSNFP, it became apparent that Section VIII, Division 1 was not an acceptable design criterion for the standardized DOE SNF canister The NSNFP wanted to gain NRC acceptance of the standardized DOE SNF canister on its initial submittal The NSNFP did not want to spend excessive time and funding attempting to justify to the NRC the appropriateness of Section VIII design criteria for the DOE SNF canister

Finally, the issuance of the draft version of NUREG-1617 (USNRC, 1998) in March of 1998 provided clarification to this issue Section 4 5 1 3 of NUREG-1617 states

> "Verify that packages designed for the transport of damaged SNF include packaging of the damaged fuel in a separate inner container (second containment system) that meets the requirements of 10 CFR 71 63(b) "

Since the goal of a standardized DOE SNF canister is to have only one basic design, it became incumbent on the standardized DOE SNF canister to be able to accept intact as well as damaged SNF Damaged SNF, as defined in NUREG-1617, is SNF with defects greater than hairline cracks or pinhole leaks Therefore, assuming that the standardized DOE SNF canister provided the second containment system function for damaged fuel during transportation, the specified design criteria for the DOE SNF canister became Section III, Division 3 (ASME, 1997) Specifying Section III construction also institutes material traceability and other quality enhancements that were initially deemed necessary, especially since the NSNFP decided to let each individual DOE SNF custodian site contract for the DOE SNF canisters to be built on an as-needed basis

The specification of Section III, Division 3 enhances the acceptance of the DOE SNF canister in many areas Section III, Division 1 is applicable to nuclear pressure systems that are stationary Section III, Division 3 can address situations where the standardized DOE SNF canister is being transported It is believed that it is the transportation phase of use that will impose the most stringent regulatory criteria onto the DOE SNF canister At this time, SNF storage at acceptable DOE sites is believed to impose less restrictive criteria because the SNF storage is within fenced facilities that already have certain physical controls in place However, this is not the case for transportation, during which the DOE SNF canister would be on public highways or railways (although still within a certified transportation cask) and subject to less physical control

Hence, using the DOE SNF canisters to transport damaged SNF was identified as the basis for specifying its design criteria If double-containment transportation casks are ultimately used for transportation of damaged DOE SNF, the standardized DOE SNF canister can still be used If double-containment casks are not used, the standardized DOE SNF canister can still be used to transport damaged fuel Options for transportation of DOE SNF are increased if Section III, Division 3 design criteria are invoked

Section III, Division 3 addresses situations that the DOE SNF canister may actually experience, for example, accidental drops during movement However, satisfaction of the ASME Code stress criteria for hypothetical accident conditions is required only when the standardized DOE SNF canister is inside of another container (either for storage, transportation, or repository disposal where appropriate) Whenever the DOE SNF canister is being handled by itself, satisfaction of ASME Code, Section III, Division 3 requirements is not required However, the standardized DOE SNF canister must be handled within an acceptable HEPA-filtered facility in order to satisfy off-site dose limit regulations

Being a Section III, Division 3 containment system also makes it easier in case future design requirements change A Section III construction effort is still the "best effort" now possible regarding fabrication of these canisters Proposed ASME Code changes are currently being considered that would require SNF storage canisters to be built to new criteria to be included in Section III, Division 3 If this change is indeed implemented, the standardized DOE SNF canisters should be much more easily adapted to a variety of interim storage systems Finally, specifying Section III, Division 3 as the canister design criteria means more-willing acceptance by the repository and the NRC Issues such as containment and criticality control (if required) are addressed best when the design basis is Section III of the ASME B&PV Code By making the standardized DOE SNF canister a Section III containment system, many more uses become available, increasing the versatility of the standardized DOE SNF canister

DESIGN DEVELOPMENT

While the final determination of the design criteria for the DOE SNF canister was being made, progress on the design development of the canister was also being achieved In order to adequately address such a wide variety of required uses (but still not knowing all of the desired canister functions), the NSNFP recognized that the standardized DOE SNF canister had to have a robust design Obviously, wall thickness in excess of that required for pressure loading alone or for stable lifting is one approach However, for the standardized DOE SNF canister, the goal was to develop a robust canister design concept that would contain the DOE SNF after an accidental drop event (from a 30-foot drop height) onto a flat surface This was believed to be an achievable goal and still satisfy the large number of constraints imposed by the various desired uses of the canister

Obviously, potential puncture targets could increase the possibility of not maintaining containment on the DOE SNF canister during potential drop events However, facilities handling the DOE SNF canister by itself, outside of other containers, should be designed or modified to eliminate or at least minimize such potentially troublesome targets

The NSNFP also recognized that in light of changing requirements, it was necessary for the NSNFP to specify a complete standardized DOE SNF canister design In this way, rather than having many organizations trying to design a canister to satisfy various changing requirements, a single specified design could be adopted by the repository as being acceptable and eliminate future concerns of whether a canister would be acceptable to the repository

In order to support the development of such a robust canister design, the successful conclusion of three efforts was deemed necessary

These three tasks were

- Establish a viable canister design concept by using finite element analysis methods to predict the deformations, material strains, etc , for a variety of drop orientations and drop heights onto a rigid, flat surface,
- Validate the final design concept and finite element analyses by performing limited drop testing on actual test specimens and representative canisters, and follow up with pressure testing to demonstrate the pressure boundary integrity,
- Show that the final design concept maintains factors of safety against rupture during an accidental drop event through analysis and other testing

These three tasks were successfully concluded during FY98 and are discussed in detail in two other 1999 PVP papers The Snow paper (Snow, et al , 1999) discusses details associated with the finite element analyses and the associated drop testing results used to develop the DOE SNF canister design The Rahl paper (Rahl, et al , 1999) discusses the lessons learned during the actual drop testing performed The three issues are briefly summarized below for convenience

The results of the three tasks yielded the design concept shown in Figures 1 and 2, for the DOE SNF canisters Two different nominal diameters and two different nominal lengths result in a total of four unique DOE SNF canister geometries The canisters are either 18-inch or 24-inch nominal diameter with nominal lengths of either 10 feet or 15 feet

Development of Proposed Design Using Finite Element Analyses

A number of potential canister designs were initially considered Figure 3 illustrates the various canister end configurations that were evaluated using finite element analyses After a number of analyses that considered impact angle, minimization of strain levels in the pressure boundary region of the canister, and affects on the volume where the DOE SNF would be placed, a shallow head with a skirt end configuration was chosen for the canister design If a potential accidental drop event did occur, the deformed skirt could be removed, leaving the canister pressure boundary intact and still useable

The final design is symmetrical about the canister midpoint In this way, a drop resistant end would be viable for either end of the canister Due to the manner in which these canisters are to be lifted, it was assumed that if a low-probability accidental drop event were to occur, the initial (and most damaging) impact would most likely be on a canister end Therefore, the final design reflected this assumption Additional canister protection for side drops would interfere with the projected uses or reduce the useable volume of the canister too much

Design Validation Using Actual Drop Testing

Once the initial design was formalized, a series of drop tests was planned All test specimens were dropped onto a 6-foot by 8-foot flat steel plate, 2-inches thick This large steel plate was placed onto a flat reinforced concrete slab Pressure testing was performed before and after all drop tests The pressure test consisted of holding 25 psig of normal air steady for one hour

The first drop test performed used a 5-inch outer diameter (OD) tube (nominal wall thickness of 0 109 inches) approximately 36 inches long that was loaded to 115 lbs total weight The drop height was 15 feet Finite element analyses accurately predicted the resulting canister deformation This drop test resulted in maximum surface peak equivalent plastic strains of 41% (16% at mid thickness), based on the finite element analysis predictions Even though this specimen experienced these high plastic strain levels, the post-drop pressure test successfully held 25-psig air pressure steady for one hour

One medium-sized test specimen was dropped from 30 feet in order to demonstrate the energy-absorbing action of the proposed skirt design This medium-sized test specimen was 18-inch OD pipe with a nominal 3/16-inch wall thickness The overall height was 5 feet and the total weight was 1000 lbs Finite element analyses again predicted the overall skirt deformation with good accuracy The skirt plastically deformed, absorbing much of the impact energy, and the pressure boundary was not adversely affected The lower head pressure boundary did not touch the impact surface nor did the skirt adversely impact the lower head pressure boundary The skirt performed as desired The post-drop pressure test successfully held 25-psig air pressure steady for one hour

With the successful completion of the medium-sized test specimen, two full-scale representative DOE SNF canisters were fabricated An 18-inch and a 24-inch test canister were fabricated (15 feet long) and loaded such that the total test specimen weights were 5690 and 9790 lbs respectively The full-scale representative canisters were dropped from 30 feet onto the steel plate The test canisters were supported in order to achieve an orientation that reflected a center-of-gravity over the corner impact As with the other drop testing, finite element analyses were performed that accurately predicted the resulting deformations The analyses also predicted maximum surface peak equivalent plastic strains of approximately 4% or less in the pressure boundary portions of the canister Obviously, much higher strains were predicted for the skirt The post-drop pressure test for each canister successfully held 25-psig air pressure steady for one hour

The last drop was to take the 18-inch representative test canister and to again drop it 30 feet but orient it such that the impact resulted in a full side drop (longitudinal canister axis parallel to the impact surface) Even after being dropped twice from 30 feet onto a hard flat surface, the canister still successfully held 25-psig air pressure steady for one hour

Demonstration of Factors of Safety Against Rupture

An additional series of five drop tests were performed The intent of these tests was to demonstrate pressure retention capability even at extremely high strain levels Five identical test specimens were fabricated from 5-inch OD tube (nominal wall thickness of 0 083 inches) and each specimen weighed 111 lbs The drop heights varied from 10 feet through 30 feet, with each subsequent test drop height increasing by 5 feet

As with the other drop tests, finite element analyses accurately predicted the general deformations Analyses-predicted maximum surface equivalent plastic strains varied from 42% (10-foot drop) up to 86% (30-foot drop) while the associated mid-thickness strain values ranged from 20% (10-foot drop) up to 26% (30-foot drop)

For every test specimen dropped, a post-drop pressure test was conducted Each of these test specimens successfully passed the holding 25-psig air pressure steady for one hour test

Actual strains experienced by the canisters during accidental drop events will depend on drop height, impact orientation, weight and geometry of the internals and SNF, etc However, the greatest strains are expected to occur during a potential side drop since the skirt absorbs so much of the impact energy on end drops During 30-foot side drops onto a flat surface, current expectations are for maximum strains to not exceed 20% over relatively large areas in the DOE SNF canisters This gives a safety factor margin of over four based on plastic strain comparisons to the 5-inch OD test specimens which still held pressure Localized surface strains may near the 45% range but even this indicates a margin of approximately two based on plastic strain comparisons

More importantly, in terms of something measurable and controllable, for the 5-inch test specimens, 42% plastic strain related to a 10-foot drop height while 86% plastic strain related to a 30-foot drop height This 20-foot difference in drop height means that a small increase in drop height will not result in a significant jump in plastic strains in a DOE SNF canister Standardized DOE SNF canister lifting heights can be easily controlled so that significant safety margins can indeed be maintained when handling the DOE SNF canisters by themselves

Although, time and budget constraints did not permit extensive leak testing, all of the successful pressure tests did provide the clear indication that the standardized DOE SNF canisters could indeed provide containment of the DOE SNF if an anticipated accidental drop event were to occur

PRELIMINARY DESIGN SPECIFICATION

It was recognized that the DOE SNF canister's final design must be integrated in with its entire specified use, including interim storage, transportation, and repository disposal requirements Different groups of standardized DOE SNF canisters may be built by differing fabricators at different times, may be placed into interim storage in a variety of facilities, and these same various groups of standardized DOE SNF canisters may even be transported in a variety of different transportation casks But there needed to be a way to formally establish a single common design basis for all standardized DOE SNF canisters so that they could become acceptable for repository disposal Hence, a document was prepared in order to establish a common design basis for all of the standardized DOE SNF canisters so that they can be accepted for disposal at the repository

The ASME Code Section III, Division 3 requires that the official Design Specification for a containment system be prepared, certified, and issued by the Design Owner who has (among other things) obtained a Design Owner's Certificate of Accreditation from the Society Therefore, the document prepared was identified as the preliminary design specification (DOE, 1998), with the intent of providing pertinent canister information to the Design Owner Acceptable materials, canister weight capacities, pressure and temperature limitations, and other canister design constraints are listed in this document Once details for interim storage or transportation become finalized, a complete and proper Design Specification can be prepared for each unique group of standardized DOE SNF canisters, incorporating the common information contained in this preliminary design specification Following this, a proper Design Report can then evaluate all of the imposed loads identified for that specific group of standardized DOE SNF canisters

In order to obtain DOE complex-wide consensus, many meetings were held where discussions regarding the standardized DOE SNF canister were held The draft release of the preliminary design specification was forwarded to all of the cognizant DOE sites and other appropriate personnel

Comments received from this review process were addressed and the document was then formally issued.

Most important to this review process was the effort to gain acceptance of the standardized DOE SNF canister by the repository. Numerous meetings were held in order to gain a mutual understanding of the requirements from both the canister and the repository perspective. After many exchanges of information, the repository officially accepted the proposed design of the standardized DOE SNF canister for disposal at the national repository.

CONCLUSIONS

This effort has resulted in a design concept for the standardized DOE SNF canister that is robust and drop resistant. The canister is able to withstand a drop from 30 feet onto a flat, rigid surface, sustaining only minor damage - but no rupture - to the pressure (containment) boundary. A preliminary design specification was prepared that allowed a common design basis to be established for all standardized DOE SNF canisters, even if unique groups of canisters experience different interim storage or transportation systems. The final proposed standardized DOE SNF canister design has been found to be acceptable to the repository. This provides DOE with a SNF canister that can be used with confidence in many different applications.

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NOTICE

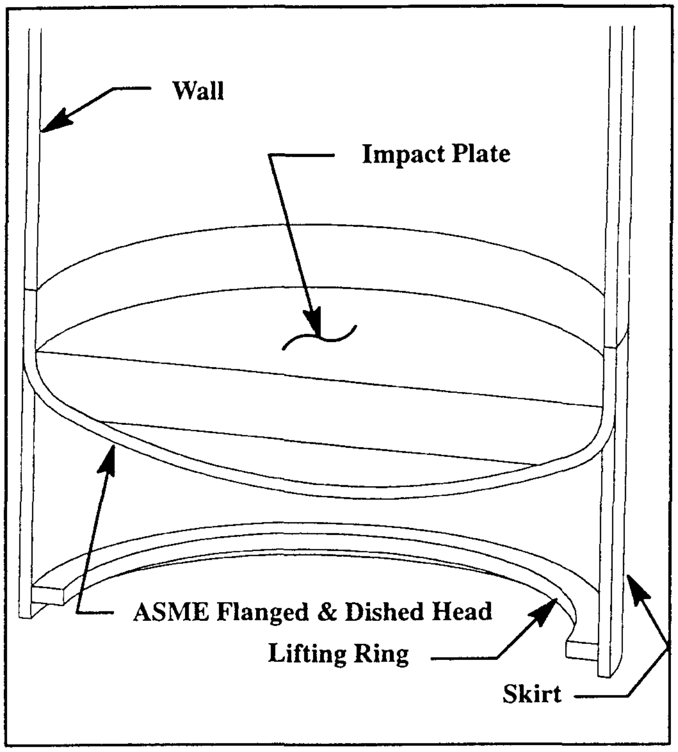

Figure 1. SNF Canister End Configuration (Section View)

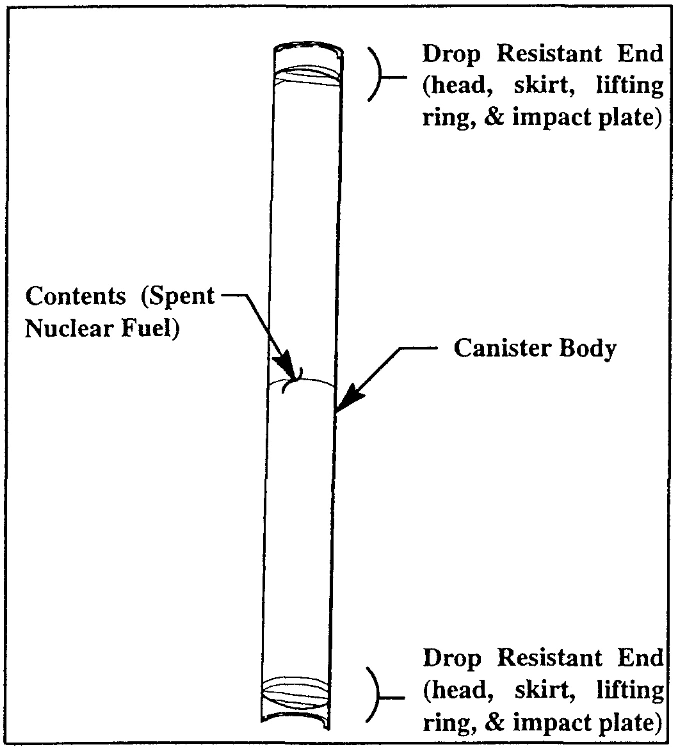

Figure 2. SNF Canister Overall Design (Section View)

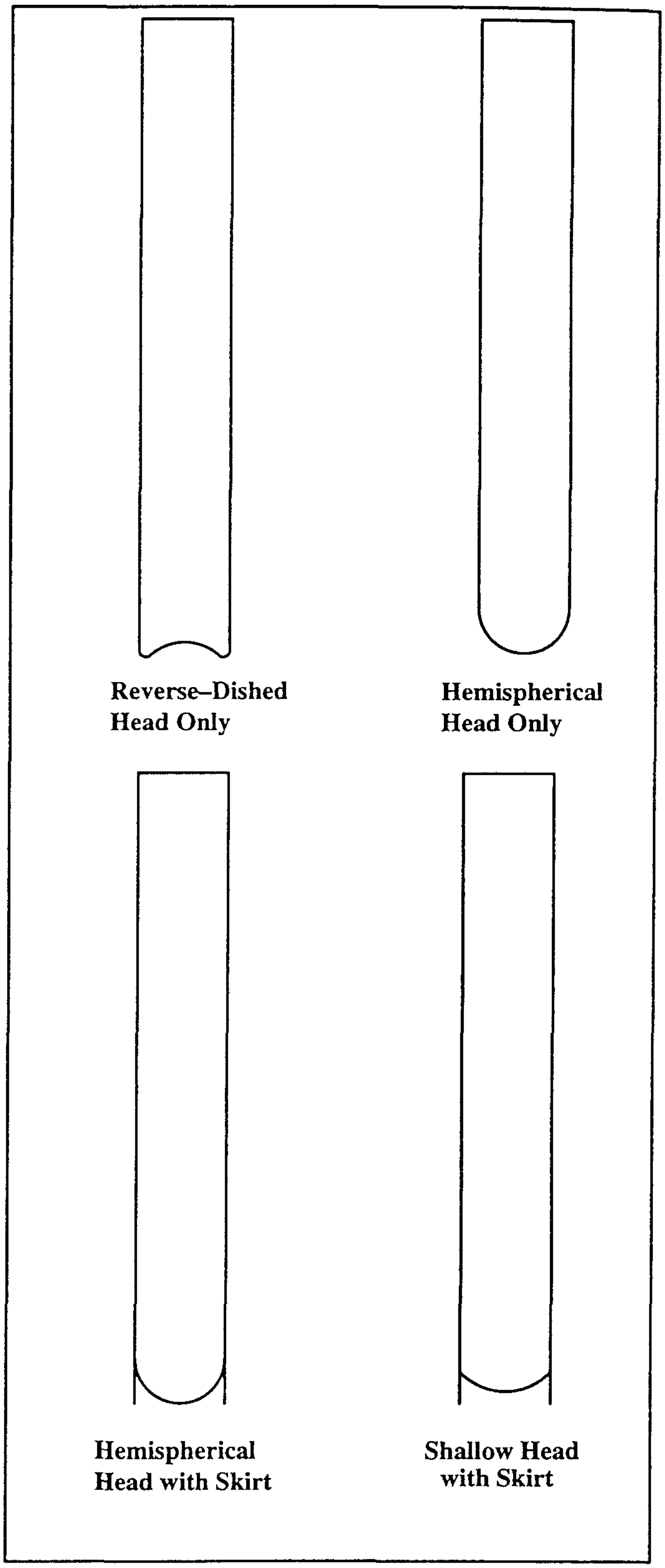

Figure 3. Preliminary Canister End Configurations Considered