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DESIGN OF A CONTAINMENT VESSEL CLOSURE FOR SHIPMENT OF TRITIUM GAS

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ABSTRACT

This paper presents a design summary of the containment vessel closure for the Bulk Tritium Shipping Package (BTSP). This new package is a replacement for a package that has been used to ship tritium in a variety of content configurations and forms since the early 1970s. The new design is based on changes in the regulatory requirements. The BTSP design incorporates many improvements over its predecessor by implementing improved testing, handling, and maintenance capabilities, while improving manufacturability and incorporating new engineered materials that enhance the package's ability to withstand dynamic loading and thermal effects. This paper will specifically summarize the design philosophy and engineered features of the BTSP containment vessel closure.

The closure design incorporates a concave closure lid, metallic C-Ring seals for containing tritium gas, a metal bellows valve and an elastomer O-Ring for leak testing. The efficient design minimizes the overall vessel height and protects the valve housing from damage during postulated drop and crush scenarios. Design features will be discussed.

INTRODUCTION

Packages designed for the shipment of radioactive materials are required by the Code of Federal Regulations (CFR) and the Department of Energy (DOE) to comply with specific regulatory safety requirements. Packages used for the shipment of Type B quantities of radioactive materials, defined by Title 49 of the Code of Federal Regulations as being greater than an A_2 of material, must also comply with the Type B packaging safety requirements of Title 10 of the Code of Federal Regulations, specifically 10CFR71. These regulations, and other applicable DOE Orders and Guides, govern design requirements for the vessels used to contain the radioactive contents being shipped. The Bulk Tritium Shipping Package (BTSP) is designed to ship 150 grams of tritium, which is greater than an A_2 (1.1×10^3 Ci or .113 grams). 10CFR71 applies to and governs many of the design requirements of the package.

DESIGN REQUIREMENTS

The BTSP incorporates design features and components to provide containment of tritium to acceptable regulatory levels and includes features that satisfy facility operational loading, handling, and maintenance requirements.

To comply with the federal regulations that govern Type B shipping packages, the BTSP is designed so that it will not lose tritium at a rate greater than the limits stated in 10CFR 71.51 of 10^{-6} A_2 per hour for the "Normal Conditions of Transport" (NCT) and an A_2 in 1 week under "Hypothetical Accident Conditions" (HAC). Additionally, since the BTSP design incorporates a valve as part of the tritium containment boundary, secondary containment features are incorporated in the CV Lid to protect against gas leakage past the valve as required by 10CFR71.43(e). This secondary containment boundary is designed to provide the same level of containment as the primary containment boundary when subjected to the HAC and NCT criteria.

The following is a list of design requirements, criteria and objectives that have been addressed in the BTSP containment vessel (CV) closure design:

- The CV shall be designed, fabricated, and tested in accordance with requirements of the Boiler and Pressure Vessel Code (B&PVC) Section III, Division 1, Subsection NB requirements. The design temperature and pressure for the BTSP are 300 °F and 500 psig, respectively.
- The CV design shall include features that enable leak tests to be performed that satisfy ANSI N14.5-1997.
- The CV shall include seals that provide containment of tritium at levels acceptable per applicable regulations.
- The CV shall include a valve and fittings to allow helium leak testing, inert gas back-filling, and testing for tritium prior to opening the CV.
- A cap shall cover the valve to prevent unauthorized operation and to retain any leakage as described in 10CFR 71.43(e). The protective cap shall be designed to enable the performance of leak tests satisfying ANSI N14.5-1997.
- Materials of construction shall be used to minimize tritium permeation.
- The CV materials shall be rated for maximum design temperatures.
- The CV contents shall able to be removed while the CV is in the drum overpack.
- CV lid shall have a lifting device rated for the CV and its contents.
- CV Lid shall be configured for lifting.
- Features shall be incorporated in the CV to protect its sealing surfaces.
- Seals shall be commercially available and easily replaceable.
- Fitting shall be incorporated that allow for attachment of leak test apparatus.
- The CV shall comply with all applicable requirements of 10CFR 71.41 through 10CFR 71.47.
- The CV shall have inside dimensions that accept the contents of the predecessor package.

DESIGN FEATURES

A BTSP design has been completed and the package will be tested to assure compliance to all applicable federal regulations. Operators and users of existing tritium shipping packages have been consulted during the design process and, when possible, fittings and other commercially available hardware currently being used have been incorporated in the BTSP design.

The BTSP is similar in size and weight to its predecessor. The BTSP packaging weighs approximately 500 pounds and is 50 inches high by 24.5 inches in outside diameter. The drum overpack structure is fabricated from 304L stainless steel and several specifically engineered materials are used and contained within the stainless steel structure to provide the thermal insulation and structural protection against the NCT and HAC conditions as required by the federal regulations. Figure 1 is a sectioned view of the BTSP assembly.

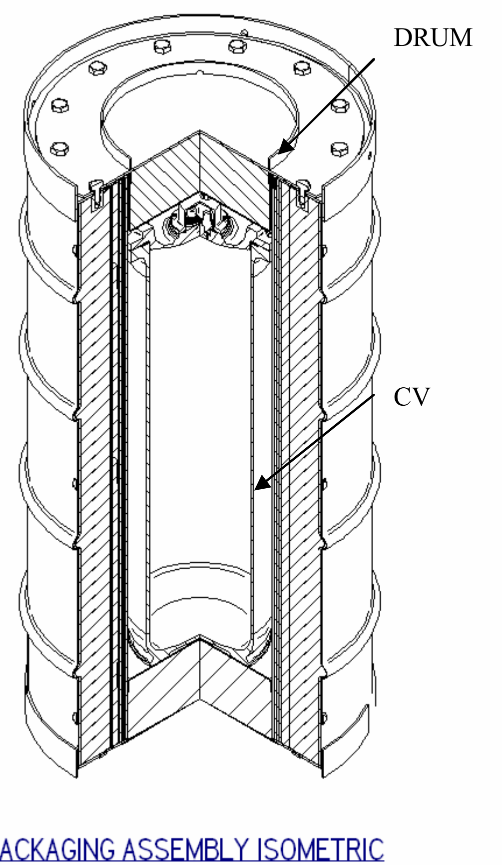

Figure 1

The BTSP Containment Vessel Assembly includes machined and welded stainless steel components, a metal bellow valve, bolts, metal and elastomer seals, and fittings. The CV body is a 304/304L stainless steel pressure vessel designed, analyzed, and to be fabricated in accordance with Section III, Subsection NB of the ASME Code, with a design pressure of 500 psig at 300 °F. The CV assembly weighs approximately 150 pounds and is 37.5 inches high by 14 inches in outside diameter. The CV contains three primary machined parts: the CV Body, the CV Lid and the Protective Cap. Two metal C-Ring seals, a stainless steel plug and the Stellite® stem tip of a bellows valve, along with the three machines parts form the containment boundary for the tritium content. The necessary preload for the metal seals is achieved through proper torquing of the high strength stainless steel screws (SA-453, Grade 660) used to join the three parts; sixteen heavy hex ½-13 UNC screws are used to join the Body and Lid and six ¼-20 UNC socket head screws secure the Protective Cap to the Lid. To provide an attachment feature for leak-rate testing of the primary C-Ring seal and for back-filling the CV, a quick-connect coupling is attached to the Lid and an elastomer O-Ring and a leak-test port are also incorporated in the design. The configuration of these components is shown in Figures 2, 3 and 4.

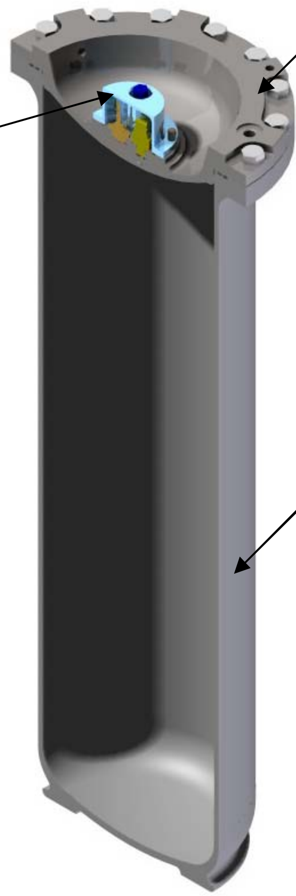

Figure 2 CV Assembly

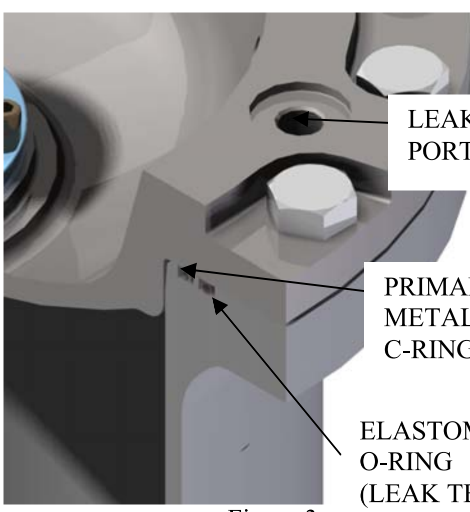

Figure 3

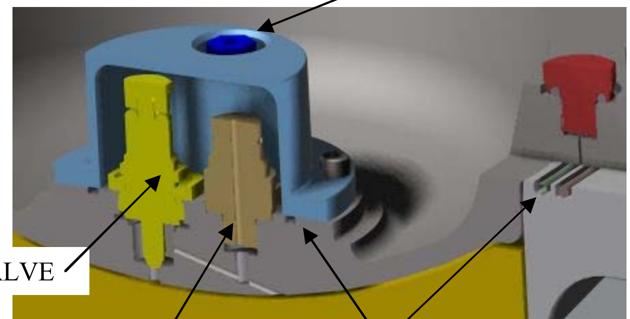

Figure 4 CV Protective Cap

The BTSP CV is designed to enable contents to be loaded and unloaded and for the CV to be leak-tested while the CV remains within the drum overpack. A lifting bail, not shown in these figures, is used to lift the Lid assembly from the CV Body after the sixteen bolts are removed. The lifting bail can also be used to remove the CV Assembly from the overpack.

The BTSP CV Body is designed with a minimum number of welded joints to ease fabrication and to reduce the susceptibility to stress corrosion cracking and hydrogen embrittlement at the weld heat affected zones. The CV Body consists of three subparts welded together using full-penetration circumferential butt welds: the CV Base, the CV Cylinder, and the CV Flange. The Flange and Base are machined from 304L stainless steel bar (ASME SA-479) and the Cylinder is either machined from 304L pipe (ASME SA-312) or rolled and welded from plate (ASME SA-240).

The CV Flange has two machined seal grooves to retain the inner metal C-Ring and the outer elastomer O-Ring. The metal C-Ring is composed of an Inconel 718 spring housed within a "C"-shaped ring which is plated with a thin layer of silver. The silver provides a permeation barrier to tritium and helps to provide a "leak-tight" seal. Figure 5 shows a picture of the BTSP C-Ring. A nominal surface finish of 16 micro-inches is defined for the bottom of each groove and 63 micro-inches for the sides. A current test program will determine the optimum surface finish for the metal C-Ring groove. The Flange has sixteen ½-13 UNC-2B threaded holes to accommodate the bolts. It also has two .40 diameter holes for alignment pins. The pins assure proper alignment of the Lid when assembled to the Body, minimizing movement once the silver-plated Inconel 718 stainless metal seal contacts the Lid. A conical taper is also machined into the top inside of the Flange allowing the Lid and Flange to assemble without binding. A detail of the CV Flange is shown in Figure 6. Figure 7 shows a picture of the test flange being machined.

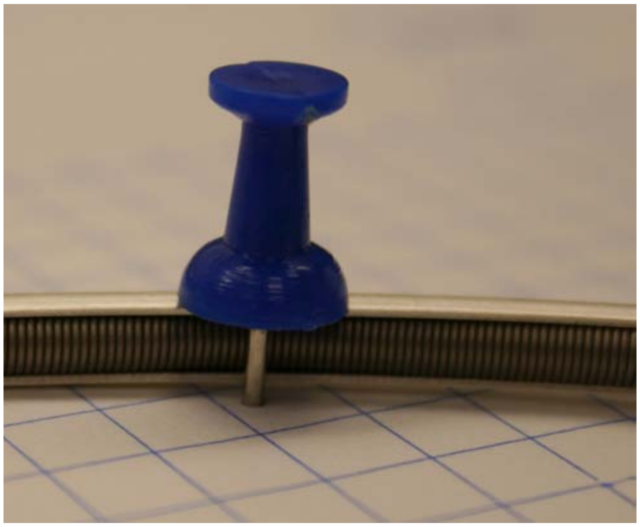

Figure 5 C-Ring

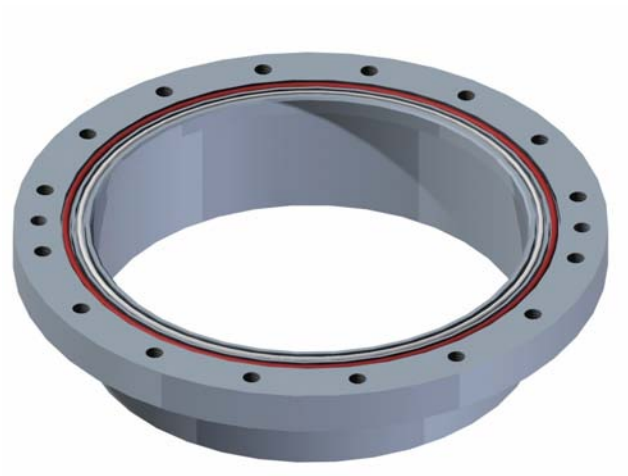

Figure 6 CV Flange

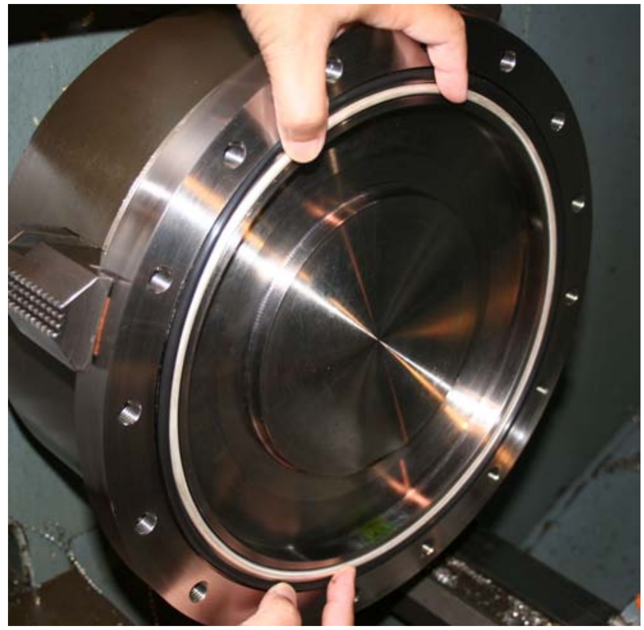

Figure 7 CV Test Flange

The CV Lid is designed to maximize strength, optimize volume, and provide for leak-testing. The Lid is machined from 304L stainless steel bar (ASME SA-479). An "inverted lid" design has been engineered to provide structural stiffness to resist deformation when subjected to the NCT and HAC scenarios and provide protection to the valve and the coupling, locating them below the Flange. The spherical web of the Lid allows impact loads from the contents in the center of the Lid bottom to be absorbed with minimal impact to the sealing region. The "inverted lid" has additional benefits in that the 16 micro-inch sealing surface on the underside of the Lid is protected from damage during handling. Its conical taper provides an efficient way to transfer lateral loads to the CV Body Flange during NCT and HAC scenarios. A small hole connects the quick-connect coupling and the bellows valve and thus to the CV interior. The open end of the hole is closed with a plug weld (using stabilized weld wire) after machining. A three-inch diameter gland is machined into the top of the Lid to allow for the secondary containment boundary C-Ring and a machined step is included in the CV Lid to allow a leak-test belljar (not shown in the figures) to be temporarily seal to the CV Lid to leak-test the Cap. To reduce weight and to minimize the overall height of the package, the CV bolts are recessed in the Lid flange. A detail of the CV Lid is shown in Figure 8.

Figure 8 CV Lid

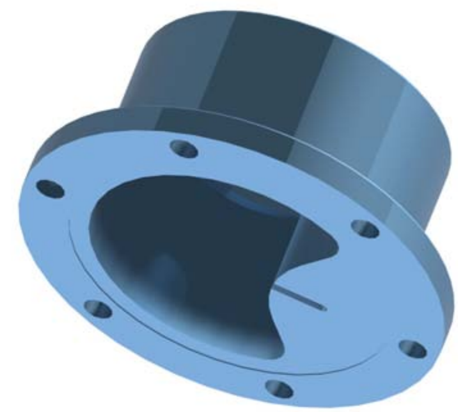

Figure 9 CV Protective Cap

The CV Protective Cap is also designed with features that optimize space and provide connections for leak-testing. The four-inch diameter Cap attaches to the top of the CV Lid and sits below the top surface of the CV Flange. The Cap is machined from 304L stainless steel bar (ASME SA-479) with features that allow for the attachment of leak-test apparatus or a metallic plug on the outside and space within the Cap for the Lid metal bellows valve and quick-coupling. The hole that connects the leak-test port in the Cap with the inside of the Cap is design to minimize the loss of helium during leak-testing. A "leaktight" joint is made between the Cap and the Lid with a silver-plated Inconel 718 C-Ring. A region of the bottom of the Cap is recessed slightly to protect the C-Ring sealing surface during handling. A test program will determine whether the 16 micro-inch surface finish is the optimum finish for this feature. Details of the CV Protective Cap are shown in Figures 9 and 10.

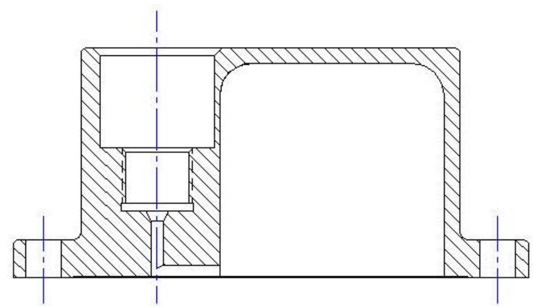

Figure 10 CV Protective Cap (Section View)

To verify that the CV design contains the tritium content to within regulatory limits extensive advanced non-liner finite element analysis has been performed that simulate the regulatory HAC and NCT scenarios on a finite element model of a BTSP package. Internal vessel pressure, package temperature, bolt preload and dynamic loading conditions are incorporated in the analysis to assure that the design requirements are met. Figure 11 is a representative plot from one of the analyses.

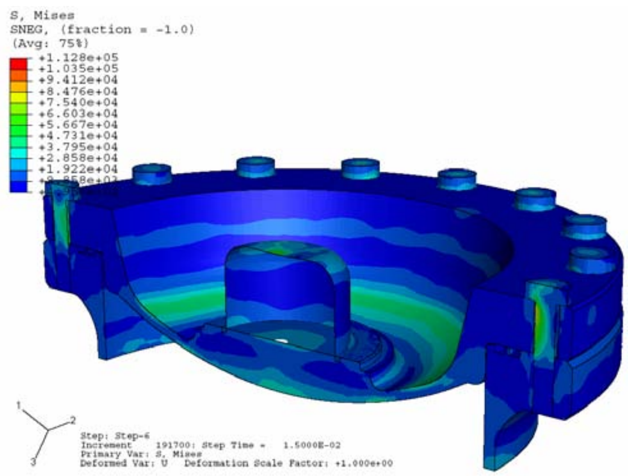

Figure 11
Stress Distribution in CV after a 30-Foot Drop followed by a 30-Foot Crush Scenario (recessed bolts not shown)

The internal volume of a closed CV is approximately 1.5 cubic feet. The nominal assembly weight of the CV Lid Assembly is 35 lb and usable cavity within the CV is approximately 31 inches high and 10 inches in diameter. This internal space is large enough to accommodate all contents shipped in the predecessor package.

CONCLUSIONS

The design of the Containment Vessel closure of the Bulk Tritium Shipping Package satisfies the design requirements imposed by federal regulations and incorporates design features that optimize space and simplify operations. The location of the valve and fittings provide for protection during the regulatory damage scenarios and are designed to simplify the user interface. The minimal number of welds and the overall design of the CV provide for a straight forward fabrication and assembly. This new CV design along with the BTSP drum overpack will provide the tritium users a new and improved package in the near future.

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