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Deployment of the Bulk Tritium Shipping Package

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ABSTRACT

A new Bulk Tritium Shipping Package (BTSP) was designed by the Savannah River National Laboratory to be 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 BTSP was certified by the National Nuclear Safety Administration in 2011 for shipments of up to 150 grams of Tritium. Thirty packages were procured and are being delivered to various DOE sites for operational use. This paper summarizes the design features of the BTSP, as well as associated engineered material improvements. Fabrication challenges encountered during production are discussed as well as fielding requirements. Current approved tritium content forms (gas and tritium hydrides), are reviewed, as well as, a new content, tritium contaminated water on molecular sieves. Issues associated with gas generation will also be discussed.

Introduction

The Bulk Tritium Shipping Package design complies with the packaging safety requirements of Title 10, Part 71, of the Code of Federal Regulations for the shipment of Type B quantities of tritium.[1] The BTSP contents are Type B quantity, normal-form radioactive material per 10 CFR 71.4. The BTSP packaging consists of two primary components: a containment vessel (CV) assembly and a drum assembly. The containment vessel assembly consists of three primary components fabricated from stainless steel: a weldment, a lid and a protective cap. The stainless steel drum assembly includes materials contained within a liner that provide thermal insulation and impact protection for the CV assembly. Additional components present in the BTSP package include a composite sleeve, a silicone pad, aluminum foam spacers, and an insulating pad. The BTSP package is depicted in Figure 1. The BTSP package net weight is approximately 530 lbs with a corresponding gross weight (with 120 maximum content weight) of 650 lbs. Package dimensions are 50-1/2 inches high by 24-1/2 inches in outside diameter.

The BTSP is certified by the National Nuclear Safety Administration Office of Packaging and Transportation, NA-00-40. The associated Offsite Transportation Certificate, DOE/NNSA/201004/b(M), was issued on February 28, 2012 and expires on February 27, 2017.

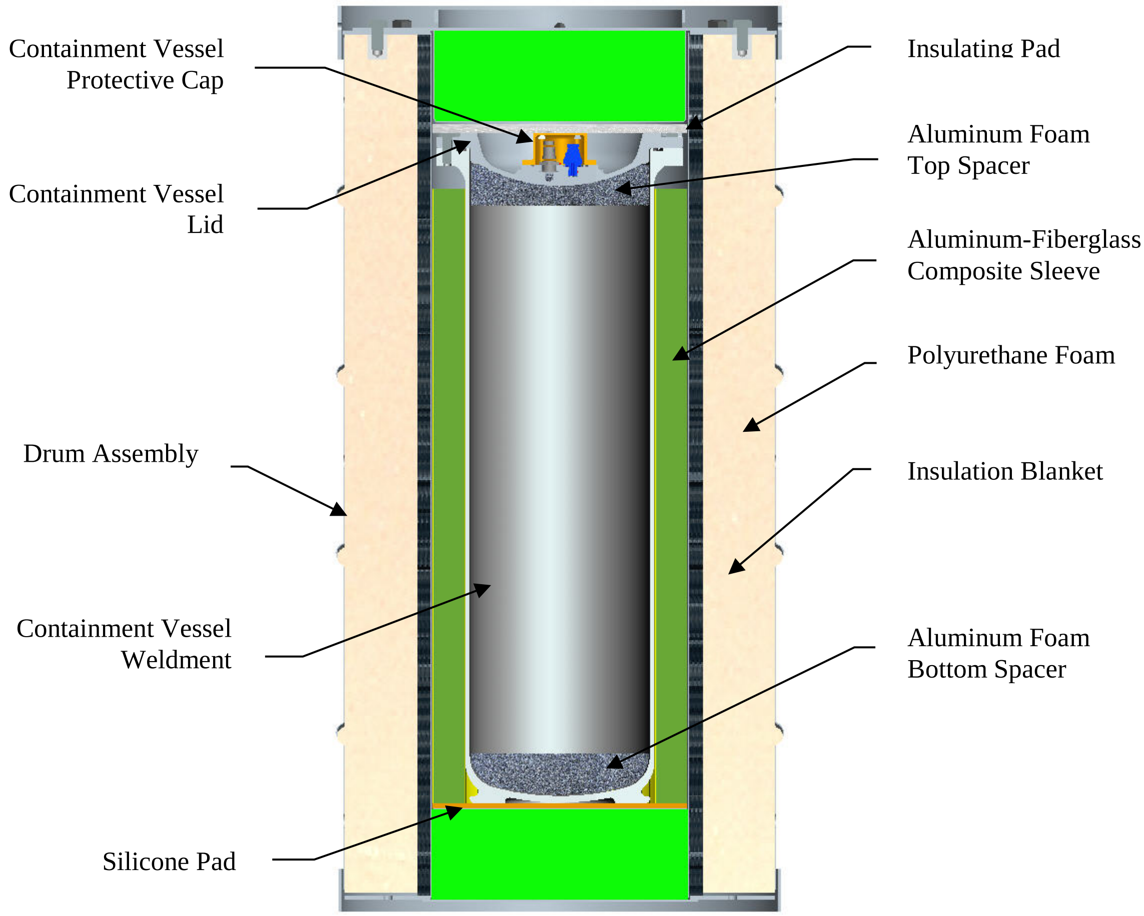


Figure 1 BTSP Package Assembly

Containment Vessel Assembly Design Features

The BTSP CV consists of three primary components, the CV Weldment, Lid, and Protective Cap, Figure 2. The CV is designed, fabricated, and examined in accordance with ASME B&PVC, Section III, Subsection NB requirements to a design pressure of 500 psig and design temperature of 400 °F.

The CV Weldment is a cylindrical vessel with a machined base welded to a 10–inch diameter pipe section at its closed end and a machined flange welded to its closure end. The cylindrical section is fabricated from SA 312 Grade TP-304L SS seamless pipe. Two concentric glands are machined into the top surface of the weldment flange. The inner gland allows placement of an Inconel 718 spring-energized C-Ring to servere as a containment boundary seal. The outer gland allows for placement of an elastomeric O-ring which to serve as a boundary for leak testing the C-Ring.

The CV Lid and associated Protective Cap are fabricated from SA-479 Grade 304L SS bar and are secured closed to the CV weldment by sixteen ½ 13UNC-2A, Class B Heavy Hex bolts. The lid is concave with a concentrically machined flat feature for receiving two fittings; a metal-bellows fill valve and a quick-connect fitting. The bellows valve stem tip serves as a containment boundary seal. The machined flat surface includes ten 5/16 18UNC2B internal threaded holes and a single gland for placement of a smaller diameter Inconel 718 spring energized C-Ring that seals the Protective Cap enclosure. Other design features of the CV Lid include:

- a recessed ½-inch diameter leak-test port that allows access to the volume between the elastomer and the Inconel 718 spring energized C-Ring for pre-shipment leak testing.
- a low-profile hollow hex plug used to close the port during shipping to prevent dirt from entering the volume between the two concentric seals.
- CV closure bolts recessed below the top surface of the CV lid for protection during impacts.

Features of the Protective Cap include:

- Cap flange underside sealing surface (raised) that matches with the CV Lid gland to protect the seal surface,
- A recessed port in the top of the Cap that accepts a high pressure plug and gland nut to facilitate leak testing.

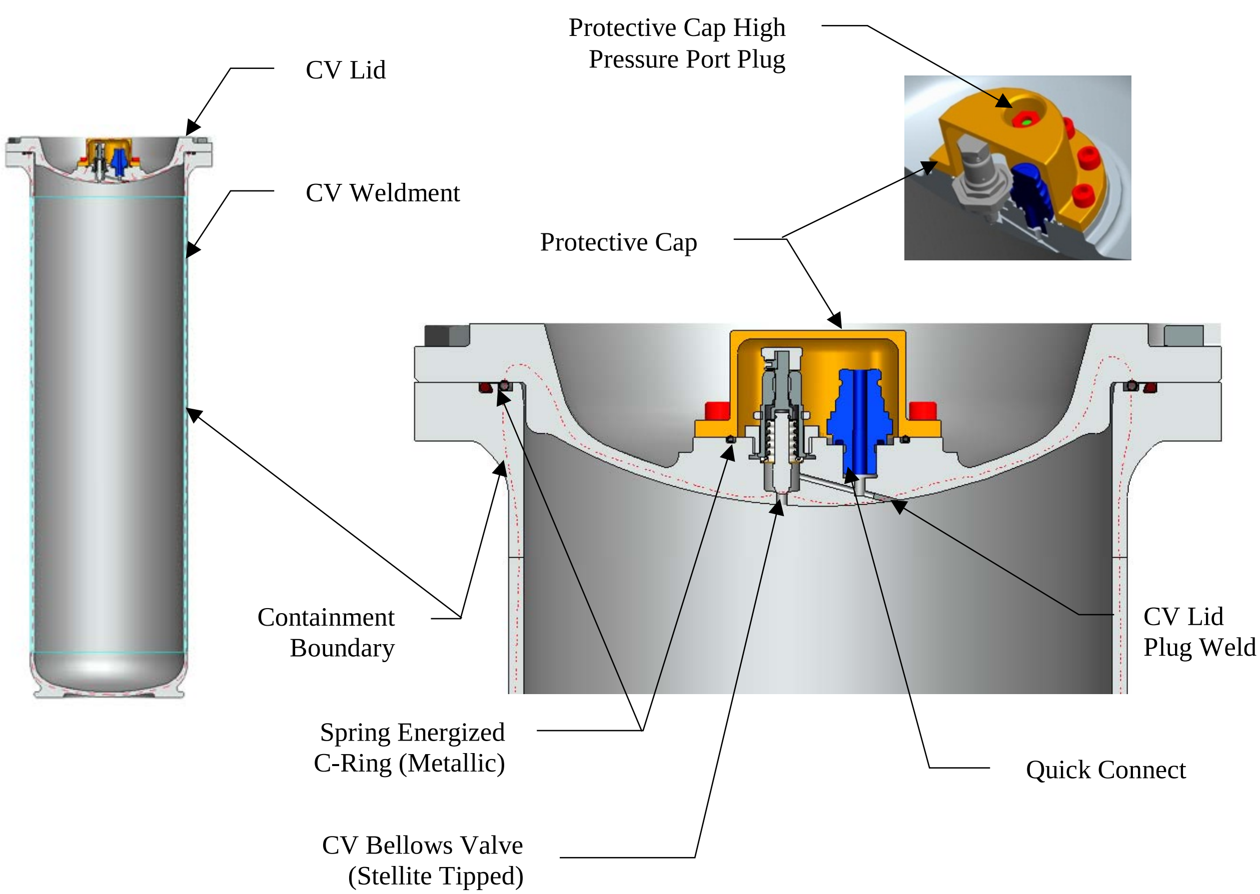


Figure 2 BTSP Containment Vessel Assembly

Drum Assembly Design Features

The Drum Assembly consists of two welded stainless steel structures, a drum body with an integral liner, and a lid, Figure 3. The drum and lid are insulated to provide structural and thermal protection to the CV. A 3/16-inch diameter elastomeric gasket between the drum lid and body is included as a weather seal to prevent water ingress into the drum liner.

The drum body is fabricated from 16-gauge stainless steel (SS) outer shell with four integral rolled hoops. Twelve ¾ inch diameter plastic plugged vent holes are located around the drum; four positioned at 90-degree intervals for each of three elevations. The vents permit decomposition gases from the foam to escape during HAC fire testing. The top and bottom of the drum are reinforced with rolled and welded SS bands. The top band has four equally spaced holes that facilitate water drainage and lifting. The bottom band provides stiffness and a wear surface during normal handling.

The drum liner is fabricated from a 16-gauge SS cylinder welded between two nominally 24 inch diameter by 3/16 inch thick SS plates. The liner inner dimension is 14.25 inches. A 12 gauge SS CV support shelf is welded within the cylinder approximately 5 inches from its bottom. The liner top plate is open in the center to receive the Lid Assembly. Twelve ⅝ inch 11UNC-2B blind threaded fittings are welded to the underside of the top liner plate to accept the lid bolts.

The liner bottom plate is open in the center to allow for Thermal Ceramics TR-19™ Block Insulation to be installed into the space below the support shelf. This TR-19™ Block Insulation is secured in place by welding a 15.3-inch diameter, 1/8-inch thick SS drum bottom plate to the liner bottom plate. Four holes are located in the liner bottom plate, a 1 inch diameter hole for filling the drum with polyurethane foam and three ½ inch diameter vent holes.

The drum liner weldment is wrapped with three ½-inch thick quilted insulation blanket layers. The quilted insulation blanket is comprised of a ceramic fiber insulation core backed on both sides with fiberglass cloth held in place by fiberglass thread stitching. The fiberglass cloth adds both mechanical strength and wear resistance, and helps retard gas flow from the foam to the liner wall in the event of a fire.

The drum lid weldment is fabricated from a 23 inch diameter 3/16 inch thick SS plate with a 14 inch diameter by 5.1 inch deep, 16 gauge SS bottom extending from its bottom surface. The drum lid is reinforced with a 1 inch high by 3/16 inch thick ring. The ring has four equally spaced slots to permit water drainage and provide attachment points for lifting the lid. The drum lid is filled with TR 19™ Block Insulation. The lid is secured to the drum using heavy hex head bolts threaded into fittings welded beneath the top surface of the drum body. Bolt heads include a 3/32 inch diameter thru hole to facilitate installation of a tamper indicating device.

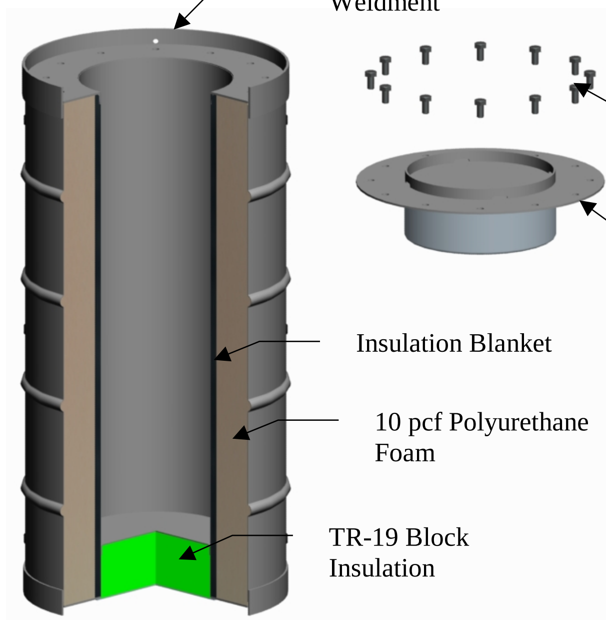


Figure 3 Drum Assembly

Engineered Materials

The BTSP containment vessel and containment sealing features are constructed of materials that minimize permeation and ensure the construction complies with federal regulations for tritium release defined in 10CFR71.51 of 10^{-6} A_2 per hour for the "Normal Conditions of Transport" (NCT) and $1A_2$ in one week for Hypothetical Accident Conditions" (HAC).

Illustrated in Figure 1, the BTSP assembly includes an aluminum-fiberglass composite sleeve, a silicone pad, aluminum foam spacers, and an insulating pad. The sleeve fits around the CV to center it in the liner and prevents radial movement during transportation. It is comprised of multiple aluminum honeycomb core layers rolled into a cylinder and covered with fiberglass epoxy to form a light weight durable composite subassembly. The pad is made from silicone rubber reinforced with fiberglass and it provides a flexible wear surface between the drum liner and the CV. A pair of aluminum foam spacers, that function as impact energy absorbers, fit within the CV above and below each payload configuration, conforming to the CV geometry. Each spacer is covered in a dimpled stainless steel foil. The foil acts as a wear resistant surface and eliminates sharp edges for handling. The insulating pad, similar in construction to the insulation blanket wrapping the drum liner, is made of KAO-Tex Superwool® insulation covered with fiberglass cloth; the pad adds thermal protection during the HAC fire event.

The annular volume between the insulation blanket and the drum wall is filled with General Plastics (GP) Last-A-Foam™. Last-A-Foam™ is poured as a liquid into the drum;, and sets exothermically as it rises and expands to form a rigid, closed-cell polyurethane foam. The closed cell foam helps protect the CV from impact damage during NCT and HAC events, provides thermal insulation, and is unaffected by the presence of water. During the HAC fire event, the intumescing properties of polyurethane consume heat during phase change to help protect package internal components.

The drum assembly includes two cylindrical segments of TR-19™ Block Insulation, one fitted inside the bottom of the liner and one within the drum lid. The engineered material is thermally stable to 2,300 °F and provides protection to the CV from impact damage during NCT and HAC events.

Fabrication Challenges

The containment vessel is designed not to release tritium at a rate greater than the limits stated in 10CFR71.51. Its protective cap is designed to the same code criteria as the primary containment boundary of the package in the event of valve failure. The caps are fabricated from ASME code material, SA479 304L bar, and examined using radiography, ultrasonic and by liquid penetrant methods, per NB 2540 requiring bar stock. During fabrication, multiple caps fabricated from the same bar were demonstrated to meet material inspection criteria as specified by the ASME acceptance standards, including hydrostatic test pressure of 750 psi per ASME NB.

In the course of package testing, 40% of the CV Protective Caps failed the more sensitive helium leak test. Testing was performed in accordance with ANSI N14.5, Radioactive Materials-Leak Tests on Packages for Shipment.[2] Figure 3 illustrates the Protective Cap installed on the CV. Destructive examination of the suspect caps concluded that the code material contained a series of inclusions that were unidentifiable by the standard material examination methods required by ASME for code vessel materials. Figure 4 shows formation of a bubble when a cap was pressurized with helium. Subsequent metallographic cross sections of the caps identified material stringers in the base material causing the leaks. As a result, leak testing of all containment boundary materials was performed at high pressures and with wait times considered sufficient to identify possible mill material manufacturing flaws that could affect the containment function of the BTSP CV.

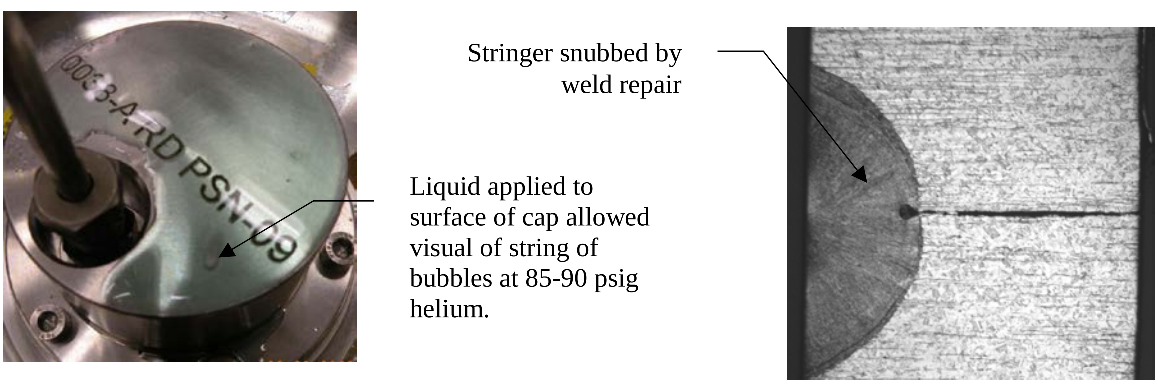


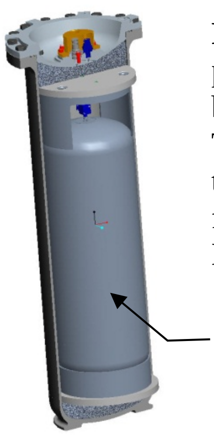
Figure 4 Surface Inspection and Metallographic Cross Section of Leak

Packaging Contents

The authorized contents for the BTSP include tritium as a gas, as a tritide or as contaminate on metal. The BTSP is currently under review by NNSA OPT for a new content configuration; contaminated water vapor on a molecular sieve.   For all content forms, the tritium is contained within a process vessel within the BTSP CV. For some content forms, the process vessel is placed in a Contamination Control Vessel (CCV) within the BTSP CV. The CCV provides additional handling convenience and contamination control. CCVs are also used as process vessels to contain contaminated metals. In some cases, the process vessels/CCV are secured in a Configuration Control Support Structure (CCSS) within the BTSP CV. Although the process vessels are designed to remain leak-tight during handling and storage, no credit is taken for these vessels for containment during transport. Common requirements for all content configurations in the BTSP are:

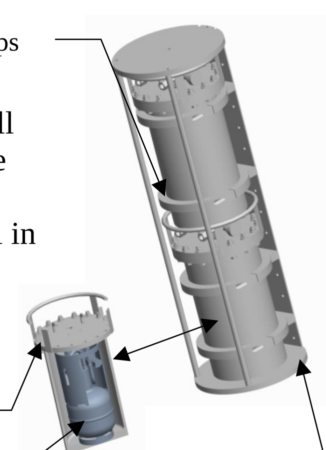
- Maximum tritium content is 150 grams as a solid (on a hydride or as contaminated metal) or 25 gram-moles as a gas (50 watt heat load).
- Maximum A_2s of Tritium is 1,350.
- Maximum content gas (e.g., tritium, deuterium, helium) within the Process Vessels is 25 gram-moles. The maximum A2s of Tritium that may be transported is 1,350.
- Maximum weight of the CV payload is 120 lbs; this includes process vessels, CCVs, packing, CCSS, and aluminum foam spacers.
- Maximum allowed organics restricted by content type.
- Oxygen gas content shall be less than 5% by volume in the CV (to avoid flammable or explosive mixtures).
- Maximum payload dimensional envelop for the CV is 30.625 inches long by 9.95 inches in diameter.

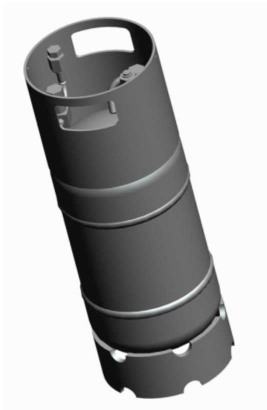
Examples of the various approved content configurations are provided below:



Product Vessel Configuration – The Product Vessel (PV) holds high purity tritium gas or gas mixtures. It is loaded as shown in the BTSP CV between the top and bottom aluminum foam spacers shown in the figure. The PV is principally used to transport tritium gas to be used as DT fuel at the National Ignition Facility (NIF), the laser-based inertial confinement fusion device located at the Lawrence Livermore National Laboratory in Livermore, CA.

Hydride Transport Vessel (HTV) Configuration – The HTV is a small ASME designed pressure vessel containing a uranium tritide (UT_3). The HTV is used to transport larger quantities of Tritium than in the gaseous state. A HTV must be packaged inside a Contamination Control Vessel in which one or two CCVs are held in a Configuration Control Support Structure (CCSS) by C-Clamps around the CCV as illsutrated by the figure.





Hydride Storage Vessel (HSV) - The hydride storage vessel is a somewhat larger version of the HTV both in physical dimensions and quantity of tritium that it may contain. It holds tritium in a solid form as titanium tritide, TiT_2. The HSV is sized such that only one may be shipped at a time in the BTSP. It is retained in a configuration control support structure similar to the HTVs CCV shown in the figure above.

Mound Configuration-5 Process Vessel Configuration (MC5PV) – The MC5PV is **an** ASME pressure vessel designed to capture tritium contaminated water vapor on absorbent molecular sieve materials. The MC5PV is loaded by passing air containing contaminated tritiated water vapor through the absorbent. In November of 1987, the MC5PV was approved as the primary containment vessel under DOE CoC USA/9507/BLF for the transport of tritium contaminated water. When shipped in the BTSP the MC5PV is treated as a process vessel and not credited in the package safety evaluation. 10-grams or Tritium is the maximum loading for the MC5PV. It is retained in a configuration control support structure similar to the HSV and HTVs CCV shown in the figure above.

Packaging Fielding

Ten Bulk Tritium Shipping Package Prototypes, satisfying the performance requirements imposed by federal regulations for Type B packaging for NCT and HAC Regulatory testing, were produced by Major Tool and Machine, located in Indianapolis, Indiana. The results of testing and analysis performed on the packaging design demonstrated the BTSP could be certified as a Type B(M) package for the transport of tritium.

Following certification, thirty packagings were procured through Joseph Oats Corporation, of Camden, New Jersey. These packagings constitute the current DOE inventory of the Bulk Tritium Shipping Package. Prior to use, candidate users of the BTSP must be designated as an authorized user by the NNSA Office of Packaging and Transportation. Authorized users must meet the requirements specified in DOE Order 461.1B.

Conclusions

The design of the Bulk Tritium Shipping Package was designed by the Savannah River National Laboratory. The BTSP was demonstrated to meet the performance requirements imposed by federal regulations for Type B packaging and certified for use by the NNSA. The BTSP is approved for shipment of up to 150 grams of tritium in various configurations. Thirty packages were procured to function as the next generation tritium transport packaging for the Department of Energy.

References:

1. Packaging and Transportation of Radioactive Material, Code of Federal Regulations, Title 10, Part 71, Washington, DC.
2. P.S. Blanton, M. Trosen, Evaluation of Material Flaws Identified During Fabrication Leak Testing of a 304L Containment Vessel, Proceedings of INMM 50th Annual Meeting JW Marriot Starr Pass, Tucson, AZ July 12-16, 2009.