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Performance of a Containment Vessel Closure for Radioactive Gas Contents

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ABSTRACT

This paper presents a summary of the design and testing of the containment vessel closure for the Bulk Tritium Shipping Package (BTSP). This 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 containment vessel closure incorporates features specifically designed for the containment of tritium when subjected to the normal and hypothetical conditions required of Type B radioactive material shipping Packages. The paper discusses functional performance of the containment vessel closure of the BTSP prototype packages and separate testing that evaluated the performance of the metallic C-Rings used in a mock BTSP closure.

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 packaging consists of two primary assemblies: a drum assembly and a containment vessel (CV) assembly. The stainless steel drum assembly includes materials contained within a liner that provide thermal insulation and impact protection for the CV assembly. The containment vessel assembly consists of three primary components fabricated from stainless steel: a weldment, a lid and a protective cap. Other separate components that comprise the BTSP assembly include an aluminum honeycomb cylinder, a silicone pad, aluminum foam spacers, and an insulating pad. These BTSP assembly is depicted in Figure 1.

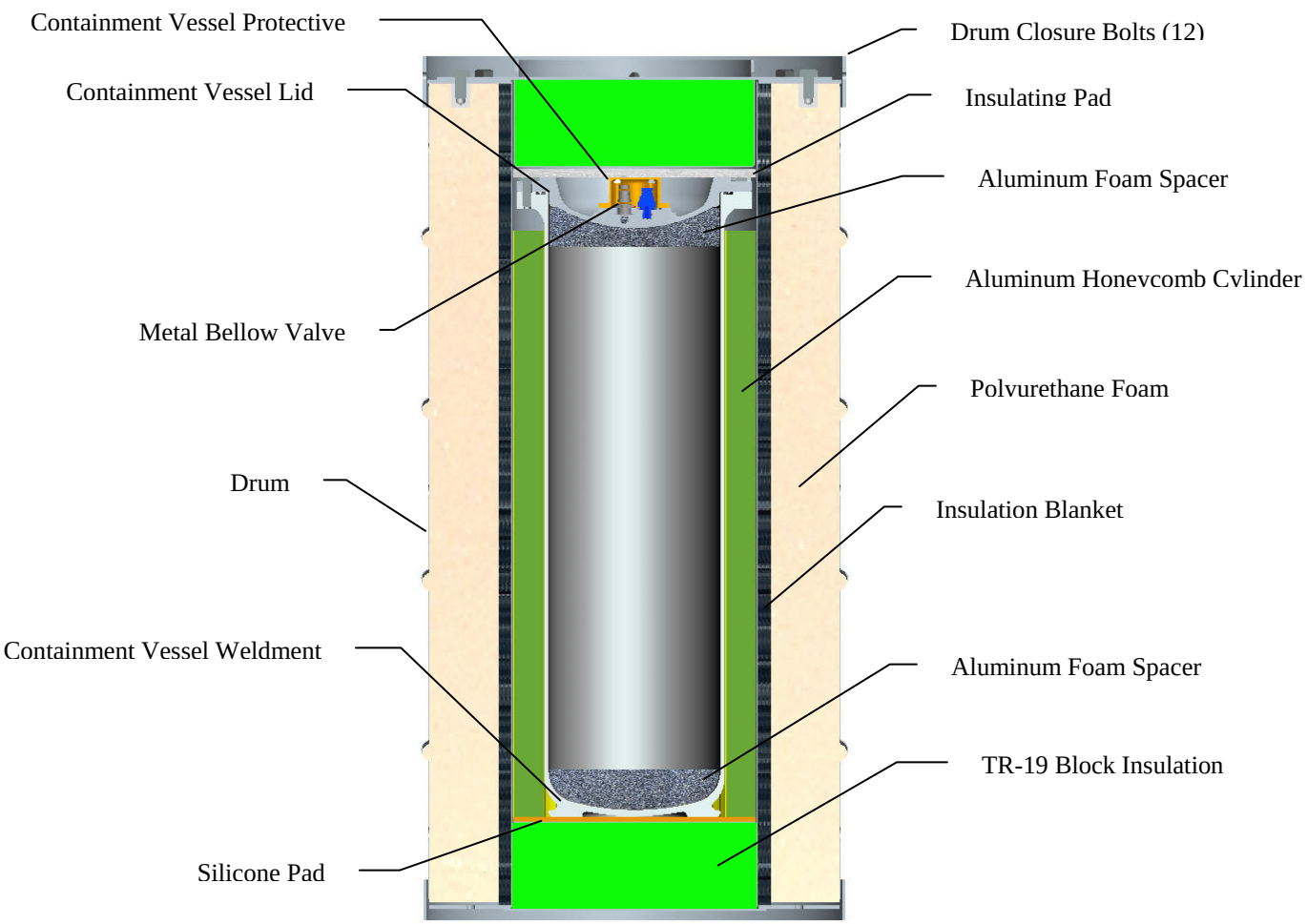

Figure 1 BTSP Assembly

Containment Vessel Closure Design Overview

The BTSP CV assembly provides containment of radioactive material (tritium) during shipping. To comply with the federal regulations that govern Type B shipping packages, the BTSP is designed so that it will not release tritium at a rate greater than the limits stated in 10CFR 71.51 of 10^{-6} A2 per hour for the "Normal Conditions of Transport" (NCT) and an A_2 in 1 week under "Hypothetical Accident Conditions" (HAC).

The CV assembly components that comprise the containment boundary are the lid, weldment, protective cap, metal bellow valve and a large spring-energized metal C-Ring. The Protective Cap seals to the CV lid with a smaller metal C-Ring, similar to the one used between the CV weldment and lid, and includes a stainless steel pressure plug. The inclusion of the protective cap (and C-Ring and pressure plug) in the BTSP CV closure design protect against gas leakage past the valve and inadvertent operation of the valve as required by 10CFR71.43(e). This protective cap enclosure is designed to provide the same level of containment as the CV assembly containment boundary when subjected to the HAC and NCT criteria.

The sealing performance of the C-Rings, valve and pressure plug are confirmed by leakage testing prior to shipment. A leak-test plug in the CV lid and an elastomeric o-ring between the

CV weldment flange and lid facilitate leakage testing of the large C-Ring. The BTSP CV assembly is depicted in Figure 2.

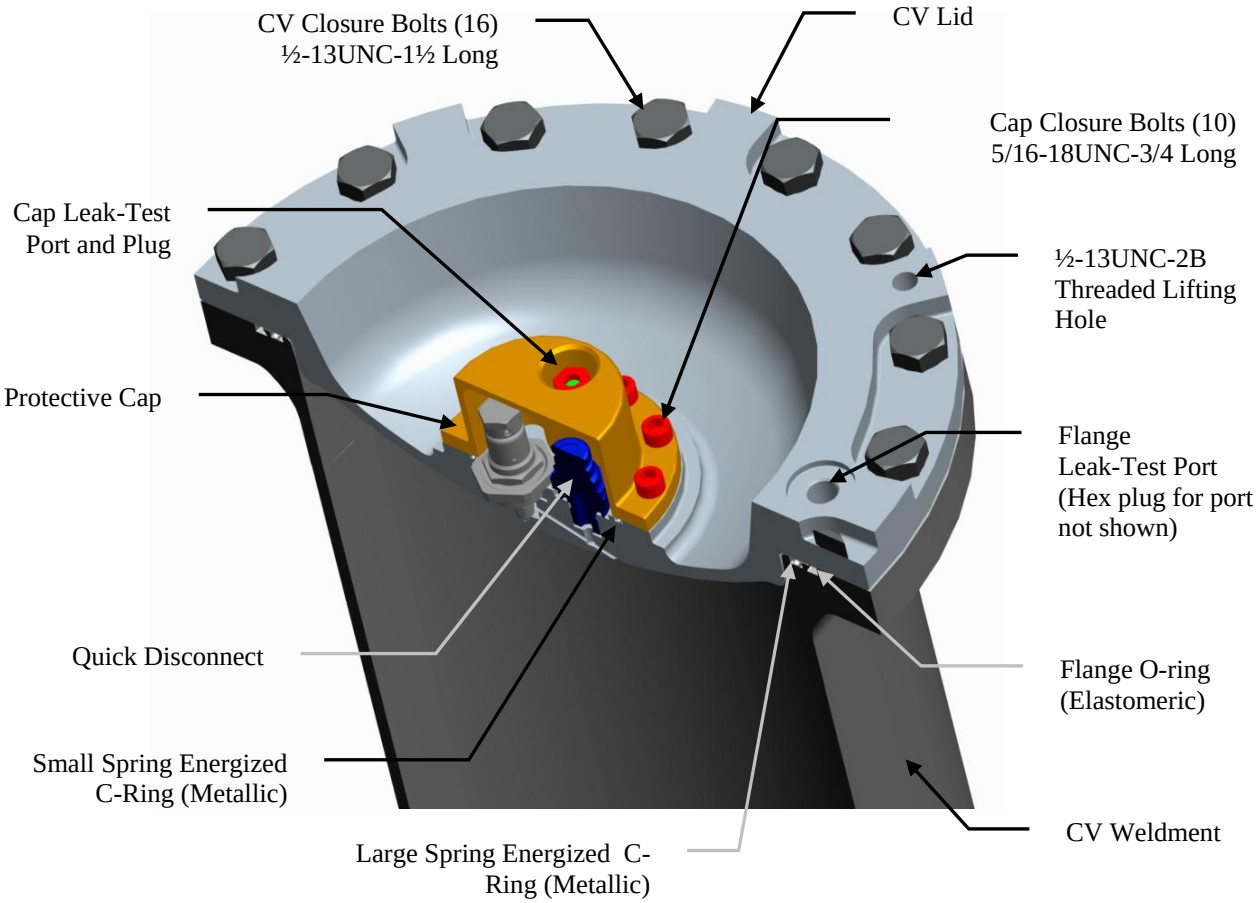

Figure 2 BTSP CV Assembly

Design Features of the CV Closure

The following is a list of design features incorporated in the BTSP containment vessel closure design:

- The CV is 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 400 °F and 500 psig, respectively.
- The CV design includes features that enable leak tests to be performed that satisfy ANSI N14.5-1997.
- The CV includes spring-energized inconnel (Alloy 718) C-Ring seals that provide containment of tritium at levels acceptable per applicable regulations.
- The CV include a valve and fittings to allow helium leak testing, inert gas back-filling, and testing for tritium prior to opening the CV.

- A protective cap covers the valve to prevent unauthorized operation and to retain any leakage as described in 10CFR 71.43(e). The protective cap is designed to enable the performance of leak tests satisfying ANSI N14.5-1997.
- Materials of construction minimize tritium permeation.
- Features incorporated in the CV closure to protect its sealing surfaces.
- Fitting are incorporated that allow for attachment of leak test apparatus.
- The CV complies with all applicable requirements of 10CFR 71.41 through 10CFR 71.47.
- The 'inverted head' design of the CV lid allows the valve and fittings to be protected below the top surface of the CV.
- The heads of the CV closure bolts are recessed below the top surface of the CV lid.

Testing Summary of the CV Closure

Prototypes of the BTSP packaging were fabricated and the containment vessels were leakage tested in accordance with ANSI N14.5-1997. The leak-tight containment vessels, filled with helium, were then tested under 10CFR71 NCT and HAC conditions according to the guidance described in SG-600. The NCT and HAC testing included 4-foot and 30-foot drop tests, vibration tests, water spray tests, compression tests, penetration tests, crush tests and thermal tests. The test matrix that defined the tests performed is included in Figure 3.

Subsequent to the regulatory tests, the containment vessels were extracted from the damaged drum assemblies and tested to confirm that the helium had not escaped and that they remained leak-tight. A specialized procedure was developed to confirm leak-tightness of the tested prototypes and included steps that first checked for any helium detection from the outside of the containment vessel assembly, then verify that helium was still contaioned within the containment vessel and then verified that the containment boundary was still leak-tight by repeating the tests originally performed when the vessels were tested during fabrication.[2]

Testing of the Metal C-Ring

Separate from the regulatory testing of the BTSP prototypes and subsequent leakage-rate testing of the containment vessels, the spring-energized C-Rings were subjected to tests to verify their performance during hot and cold conditions and to evaluate their performance under repeatetive use. The C-Ring tests were performed using a Test Fange that simulated the BTSP lid and flange geometry and were also performed on a BTSP prototypes C that was not damaged during the regulatory tests. The Test Flange, shown in Figure 4, was designed to mimic functionally the BTSP CV flange and lid so that the in situ performance of the C-Rings and other components could be accurately evaluated during the test program. The only design difference between the Test Lid and the actual BTSP CV lid is that the Test Lid profile is flatter than the actual CV lid, i.e., the Test Lid does not incorporate the spherical concave feature of the CV Lid. The Test Flange only differs from the BTSP CV flange in that the Test Flange does not include the full cylinder and base since it is machined from a flat plate. All other physical features of the Test Flange Assembly are dimensionally controlled to the BTSP CV design.

The two inconnel (Alloy 718) C-Ring designs evaluated in the test flange were the same as those used in the BTSP prototype CV design: the smaller C-Ring used under the cap has a nominal outside diameter (OD) of 3.1 inches and the C-Ring used between the CV flange and lid has a nominal 10.9-inch OD; the C-Ring heights are 0.125 inches and 0.188 inches, respectively. Both sizes of C-Rings are specified with 0.001-0.002 inches silver plating on the sleeve, (the surface of the c-section). The manufacturers documented values for maximum service temperature and maximum working pressure for the C Rings is >1,000 °F and > 50,000 psi, both significantly

greater than the design pressure and temperature of BTSP. The vendor documented springback for the Metal C-Rings is good and is in the range of 0.006-0.009-inches for the specified C-Rings. The seating load for the small and large BTSP C-Rings per liner inch is 1,000 pounds and 1,600 pounds, respectively.

		Initial Conditions		Normal Conditions of Transport									Hypothetical Accident Conditions of Transport							
Drum Serial Number	CV Serial Number	Package Pressure	Package Temperature (°F) (Note 1)	Heat (Solar, 100°F) 10CFR71.71(c)(1)	Cold (-40°F, no solar) 10CFR71.71(c)(2)	Pressure Variations (External) 10CFR71.71(c)3&4	Vibrations 10CFR71.71(c)(5) (See Note 8)	Water Spray 10CFR71.71(c)(6)	4-ft Free Drop 10CFR71.71(c)(7)	Corner Drop 10CFR71.71(c)(8) (See Note 2)	Compression 10CFR71.71(c)(9)	Penetration 10CFR71.71(c)(10)	30-ft Drop 10CFR71.73(c)(1)	Crush 10CFR71.73(c)(2)	Puncture 10CFR71.73(c)(3)	Thermal 10CFR71.73(c)(4) (Note 3)	3-ft Immersion – fissile 10CFR71.73(c)(5) (See Note 4)	50-ft Immersion – all 10CFR71.73(c)(6)	290-psi 10CFR71.61 (See Note 5)	Leak Test ANSI N14.5 (Note 6)
1	1	This BTSP Prototype to be tested at SRNL.																		
2	2	A	75	-	-	-	-	-	-	na	-	-	CGT	H	X	VT	na	-	na	na
3	10	A	75	-	-	-	-	-	-	na	Only CV to be tested.						na	X	na	na
4	4	A	75	-	-	-	X	X	BD	na	-	X	BD	VB	X	VT	na	-	na	na
5	5	A	150	-	-	-	-	-	-	na	-	-	H	H	X	VT	na	-	na	na
6	6	A	-20	-	-	-	-	-	TD	na	-	-	H	H	X	H	na	-	na	na
7	7	A	75	-	-	-	-	-	TD	na	-	-	TD	H	X	H	na	-	na	na
8	8	A	75	-	-	-	-	-	H	na	-	-	SD	H	X	H	na	-	na	na
9	9	A	75	-	-	-	-	X	CGT	na	X	-	CGT	CGB	X	VT	na	-	na	na
10	3	A	75	-	-	-	-	-	-	na	-	-	CGT	H	X	VT	Note: This is the practice package.			

Abbreviations:
X – Applicable to SOW; na or "-" – Not applicable to SOW; A – Ambient
BD – Bottom Down; CGT – CG over Top Corner; VB – Vertical, Bottom Up; VT – Vert., Top Up
H – Horizontal; TD – Top Down; SD – Slap Down/Bottom Impact; CGB – CG over Bottom Corner

Notes:
1. Initial temperature conditions to be ± 5 °F.
2. Corner Drop per 10CFR71.71(c)(8) not applicable. BTSP approx. weight is 600 lbs.
3. Thermal Test per 10CFR71.73(c)(4) not applicable to this SOW; included for reference only.
4. 3-ft Immersion- fissile per 10CFR71.73(c)(5) not applicable. BTSP does not transport fissile material.
5. 290-psi evaluation per 10CFR71.61 not applicable. A_2 in BTSP is less than 1000.
6. Leak Test per ANSI N14.5 not applicable to this SOW; included for reference.
7. Actual orientation of Test Package subject to change
8. NCT Vibration Tests shall be performed using a vibration table in accordance with SG-600, Rev. 2.

Figure 3 BTSP Package Test Matrix

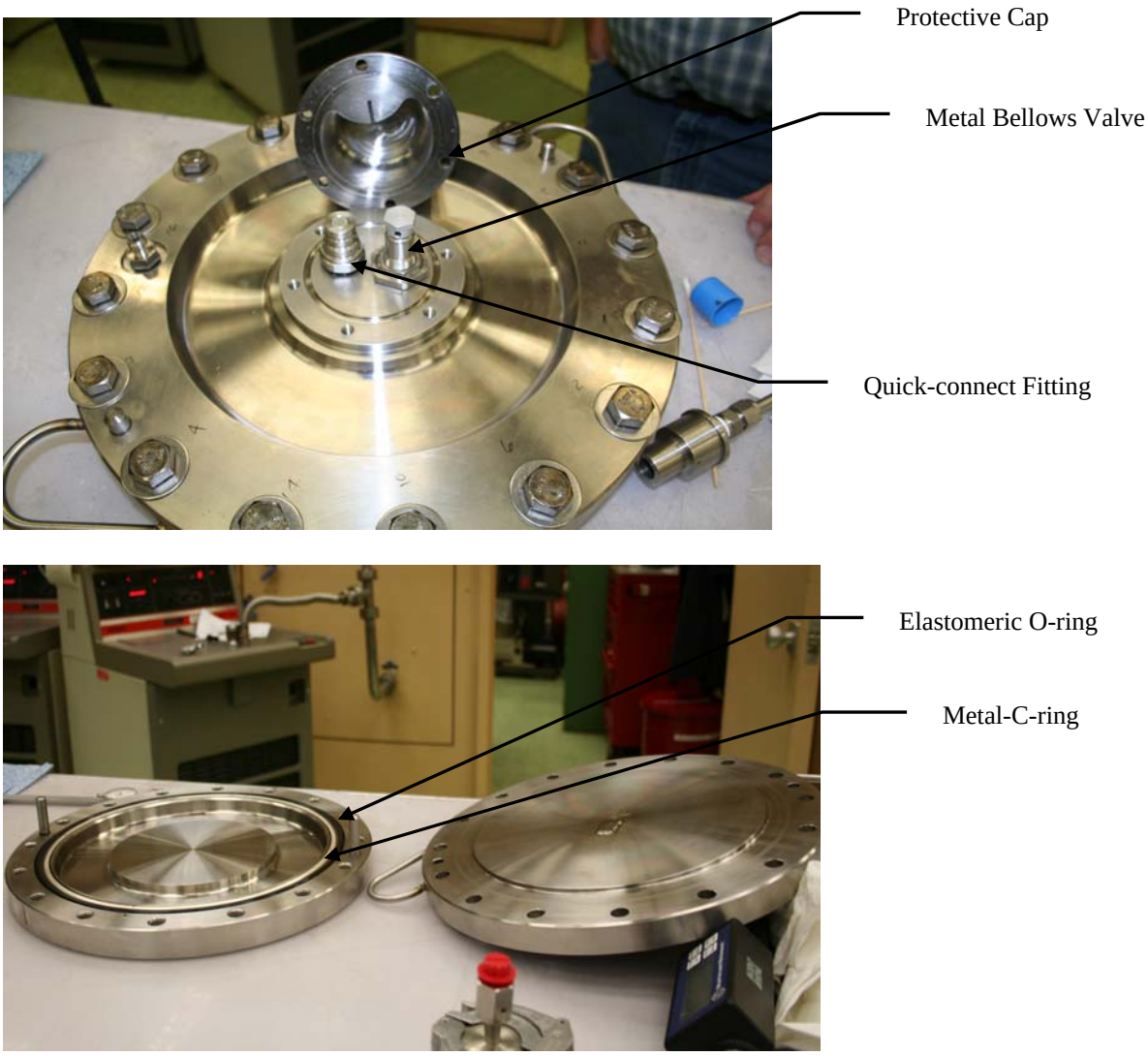

Figure 4 BTSP Test Flange

Test Results of the BTSP Closure and C-Rings

Summary of the Leak Test Results after the Regulatory Tests[3]

Package ID	Protective Cap		Fill Valve		Flange Seal
	As Rec'd	After Backfill	As Rec'd	After Backfill	
PSN 02	<7.7E-10	3.3E-09	<7.9E-10	1.3E-08	1.6E-08
PSN 03	<8.5E-10	1.4E-08	5.5E-09	2.1E-08	4.3E-09
PSN 04	<8.6E-10	4.2E-08	2.6E-09	<8.7E-10	<8.7E-10
PSN 05	<8.8E-10	1.4E-08	2.0E-09	1.1E-08<	3.8E-09
PSN 06	<7.9E-10	2.8E-08	9.0E-10	1.9E-08	4.7E-09
PSN 07	<7.2E-10	1.5E-08	1.2E-09	<7.4E-10	2.0E-09
PSN 08	8.2E-10	<8.2E-10	2.7E-09	1.5E-09	<8.6E-10
PSN 09	<7.6E-10	9.1E-09	1.3E-08	3.8E-09	2.3E-09

Summary of Test Results for the C-Rings

Test Type	**Gas Medium**	**Pressure (psig)**		**Test Temperature**	**Maxiumum acceptable test leak rate $1x10^{-7}$ref cm3 He/sec**
		Internal	**External**	**(F)**	
MSLT*	Helium	15 psig	Vacuum	RT**	passed
Pneumatic Pressure Test	Dry Nitrogen	154 psig	1 atm	RT	Passed: no leak/damage
MSLT	Helium	100	Vacuum	RT	Passed 1.1 x 10^{-9}
MSLT	Helium	Vacuum	100 psig		Passed <2.2 x 10^{-9}
MSLT	Helium	15 psig	Vacuum	RT	-
The following tests determine the re-seal capability of the metallic C-Rings; For each test the Test Flange is opened, seal removed, location marked and seal height measured and then replaced. Bolt torque is applied as required in a "star" pattern. Repeat for the prescribed number of tests or until failure.					
MSLT	Helium	15 psig	Vacuum	RT**	Passed 10^{-9}
Replace with new C-Ring. Install 10 mil thick shims adjacent to bolts, torque and test - repeat increments of 5 mils until seal failure. On each Test Flange disassembly the C-Ring is removed and measured. Repeat for the prescribed number of tests or until failure.					
MSLT	Helium	15 psig and 100 psig	Vacuum	RT	-
Replace with new C-Ring. Install lid 15 degrees off position and rotate to true position while sliding on C-Ring. Torque Bolts in "star" pattern; Repeat for the prescribed number of tests or until failure.					
MSLT	Helium	15 psig	Vacuum	RT	-
MSLT [4] 24 hr test	Helium	15 psig 100 psig	Vacuum	-40 °F	1.7 x 10^{-8}
MSLT (24 hr test)	Helium	15 psig 100 psig	Vacuum	300 °F 370 °F	<1.5 x 10^{-9} <1.1 x 10^{-9}
MSLT[5]	Deuterium	15 psig	Vacuum	RT	No Detectable permeation

* Mass Spectrometer Leak Test

** RT – Room Temperature (Approximately 72 degrees Fahrenheit)

Torque Sequence: Tests using the Test Flange confirmed the torque sequence of the BTSP Test Flange bolts did not effect the performce of the C-Ring seal. The application of torque in a circumferential sequence versus the assigned "star" pattern were compared and the results were comparable.

Pressure from Outside- Pressure testing was performed to verify that pressure scenarios that indicate a pressure to the outside of a C-Ring yield acceptable performance. Regulatory water submersion tests require application of external pressure; the BTSP C-Ring with the opening of the "C" toward the center is specified for internal pressure. Test results indicated the BTSP C-Rings are leak-tight with the application of external pressure as well as with internal pressure.

Seal Re-use - The re-use of metallic seals is not recommended by the manufacturer nor will their re-use in the BTSP be permitted for shipping tritium. Re-use testing was performed to determine the failure threshold of the C-Ring so necessary quality assurance controls may be established on its handling and use on the BTSP CV assembly. The testing showed that re-use of the BTSP C-Rings can provide a leak-tight seal even when re-used up to ten times. Testing to failure was discontinued due to the repeated C-Ring successes.

Permeation - Gaseous tritium will permeate through the seals and stainless steel components of the BTSP CV, permeation tests using deuterium were performed to determine the permeation rate of tritium through the silver-plated inconnel C-Ring seal. These results are reported in a separate paper.

Gland depth/C-Ring height tolerance – The manufacturer suggests a specific gland design for optimal C-Ring seal. The critical feature of the design is its depth which, along with the C-Ring height, determines C-Ring compression. Through the use of shims placed between the test lid and flange these geometric variations, seal height and gland depth, were evaluated. Measured results of C-Ring springback following regulatory testing showed a nominal springback of greater than .014 inches (greater than the vendor reported springback of 6 to 9 mils).[3]

Conclusions

The design of the Containment Vessel closure of the Bulk Tritium Shipping Package satisfies the performance requirements imposed by federal regulations for Type B packaging and incorporates design features that optimize space and simplify operations.

References:

1 Packaging and Transportation of Radioactive Material, Code of Federal Regulations, Title 10, Part 71, Washington, DC (December 2006).

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