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Performance Testing of Spring Energized C-Rings for use in Radioactive Material Packagings Containing Tritium

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ABSTRACT
This paper describes the sealing performance testing and results of silver-plated inconnel Spring Energized C-Rings used for tritium containment in radioactive shipping packagings. The test methodology used follows requirements of the American Society of Mechanical Engineers (ASME) summarized in ASME Pressure Vessel Code (B&PVC), Section V, Article 10, Appendix IX (Helium Mass Spectrometer Test - Hood Technique) and recommendations by the American National Standards Institute (ANSI) described in ANSI N14.5-1997. The tests parameters bound the predicted structural and thermal responses from conditions defined in the Code of Federal Regulations 10 CFR 71. The testing includes an evaluation of the effects of pressure, temperature, flange deflection, surface roughness, permeation, closure torque, torque sequencing and re-use on performance of metal C-Ring seals.

Background
The programmatic need of the Department of Energy (DOE) to ship bulk quantities of tritium has been satisfied since the late 1970s by the UC-609 shipping package. The current Certificate of Conformance for the UC-609, USA/9932/B(U) (DOE), will expire in late 2011. Since the UC-609 was not designed to meet current regulatory requirements, it will not be recertified and thereby necessitates a replacement Type B shipping package for continued DOE tritium shipments in the future. A replacement tritium packaging called the Bulk Tritium Shipping Package (BTSP) is currently being designed by Savannah River National Laboratory (SRNL).

BTSP Package Overview
The BTSP consists of an 85-gallon drum with a welded inner liner. The drum inner liner houses a 304L stainless steel Containment Vessel (CV) in which tritium storage containers (contents) are loaded. The interstitial space between the liner and drum is filled ceramic and polyurethane material engineered to provide structural and thermal protection for the CV. A separate insulated lid inserts into the liner and bolts to the top of the drum. Figure 1 shows a computer rendering of the BTSP assembly.

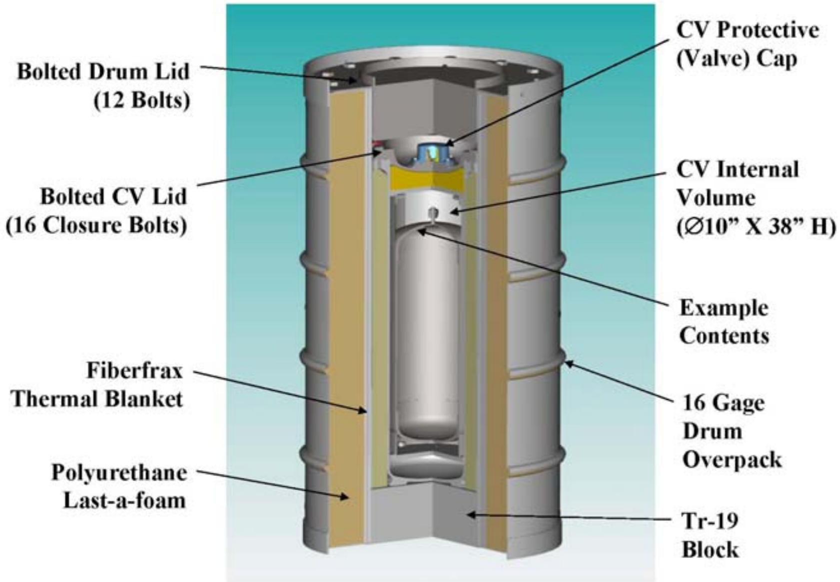


Figure 1 BTSP Package Cross-Sectional Overview

The BTSP CV lid is sealed to the CV body with a silver-plated Spring Energized inconnel C-Ring. The CV lid design incorporates a bellows valve and a quick-connect coupling to be used for leak test operations. A protective cap is bolted to the lid to protect the valve and coupling. The primary tritium containment boundary of the BTSP CV includes the lid C-Ring and the stellite stem tip of the bellows valve. A second, smaller C-Ring between the cap and the lid creates the secondary containment boundary. The sealing performance of the metallic C-Rings are the focus of testing summarized in this paper. The performance of the Stellite tipped valve will be documented separately. Figure 2 shows an exploded view of the BTSP CV assembly and a sectioned view of the lid with valve and coupling and the protective cap.

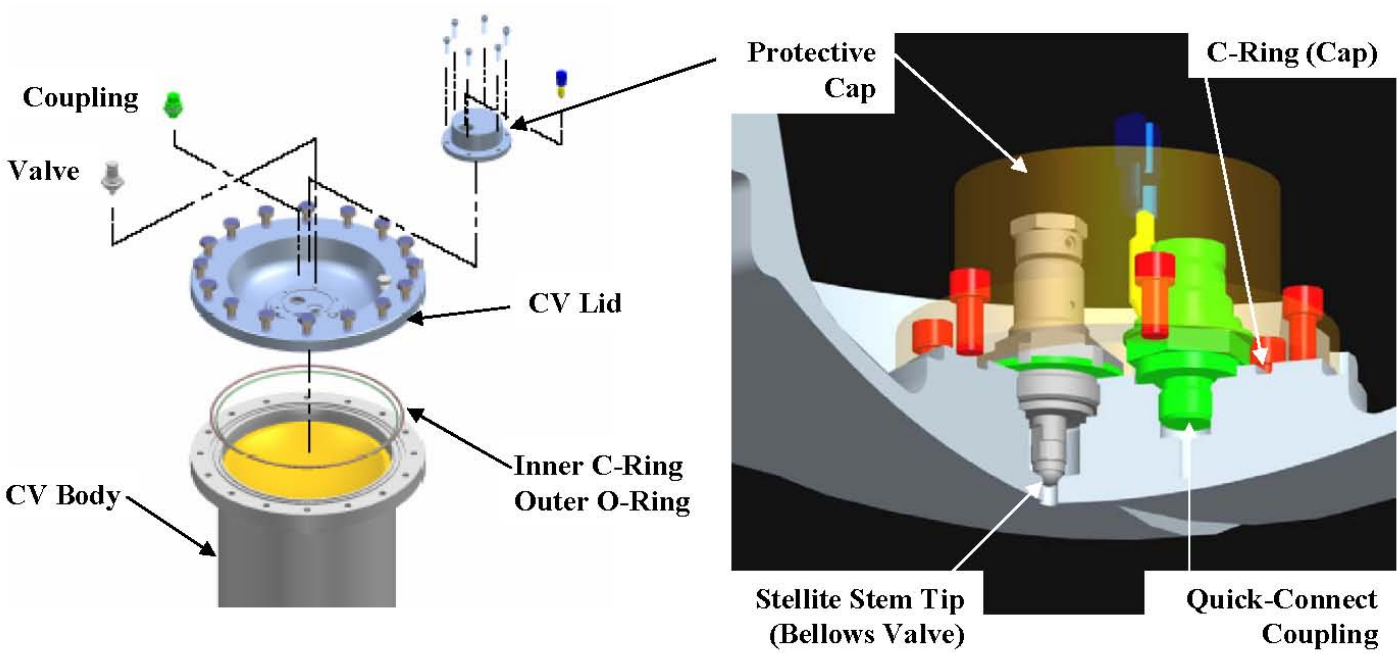


Figure 2 BTSP CV Assembly with CV Lid Cross-Sectional View

The BTSP has been designed to ship up to 200 grams of tritium which would produce up to 66 watts of thermal load within the CV. Silver-plated inconnel Spring Energized C-Rings were specified for the two CV containment boundary seals to resist permeation of tritium gas at the expected temperature and pressure environments for this quantity of tritium. Elastomer O-rings, as are commonly used in other shipping packages, do not have the permeation resistance or thermal properties required of the BTSP seals. However, an elastomer (Viton) O-ring is used as an outer seal between the CV lid and body flange for leak test purposes, but is not part of the containment boundary of the CV. The C-Ring is comprised of an inner inconnel helical spring surrounded by an outer silver-plated inconnel "C" shaped sleeve. The C-Ring selected has the spring-back properties to provide a reliable and robust tritium containment seal when compressed between facing surfaces. The BTSP C-Ring seal is fabricated by Advanced Products Company, Inc. Figure 3 shows the interior view of the inconnel C-Ring being used for the BTSP CV flange closure. Figure 4 shows the response to compressing the C-Ring seal and the expected springback. (Reference 4)

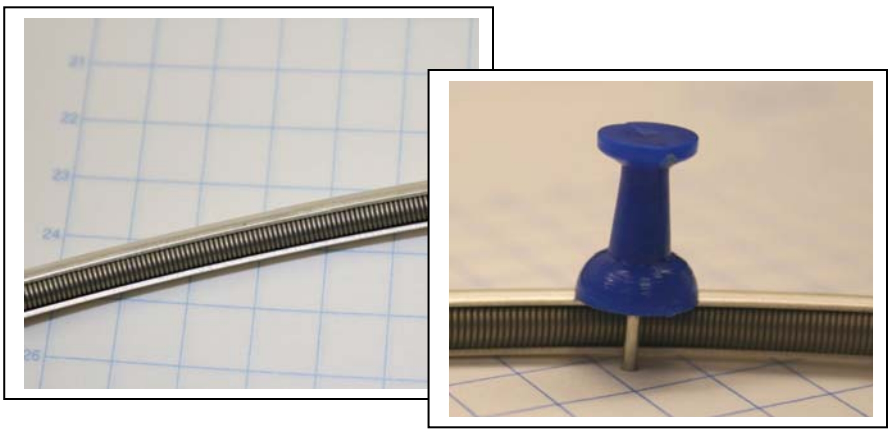
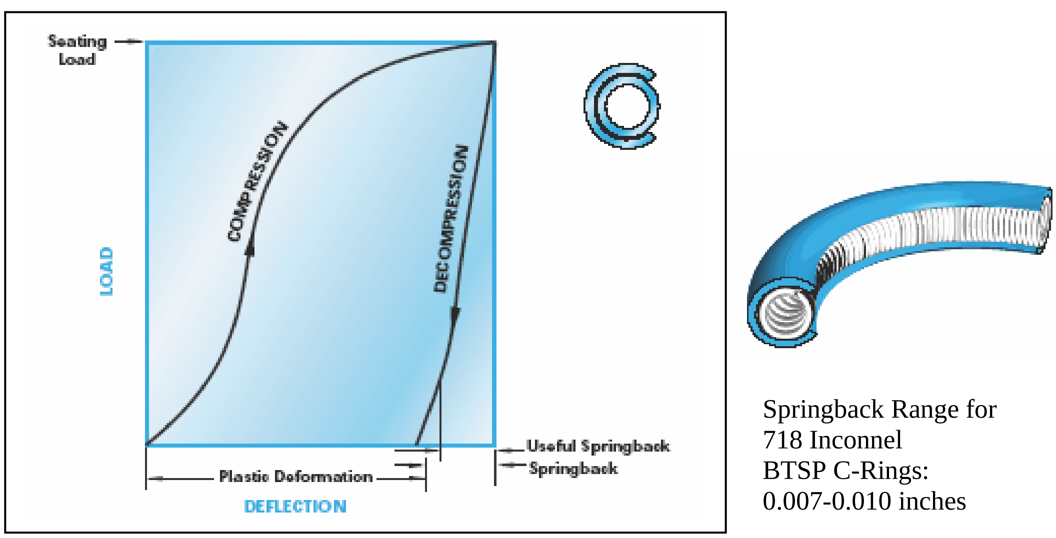


Figure 3 Silver-plated Inconnel Spring Energized C-Ring



Springback Range for
718 Inconnel
BTSP C-Rings:
0.007-0.010 inches

Figure 4 C-Ring Response to Compression

Test Overview

Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material', describes the design loading that must be considered for certification of a Radioactive Material Packaging. These loading conditions include temperature, vibration, pressure, and other less demanding conditions, such as a water spray, etc. The acceptance criteria for the containment vessel after the package is subjected to the most severe combinations of loadings are defined in 10 CFR 71 and can be summarized as follows:

For Normal Conditions of Transport (NCT) there shall be no loss or dispersal of radioactive contents as demonstrated to a sensitivity of 1x 10^{-6} A_2 per hour. For Hypothetical Accident Conditions (HAC) there shall be no escape of radioactive material exceeding a total amount of A_2 in one week. An A_2 of tritium is 1.1 x 10^{-3} Ci. Given these conditions the test results must demonstrate that the leak-rate is less than 2×10^{-7} ref cm^3 helium/sec with a sensitivity of 1×10^{-7} ref cm^3 helium/sec or less in accordance with the ANSI N14.5 definition of leak-tight.

The response of the C-Rings to regulatory loading conditions tests described above is summarized in this paper. Results from the BTSP C-Ring testing will validate the use of the inconnel Spring Energized C-Ring for sealing in radioactive material packagings. Metallic seals similar to the BTSP C-Rings are in use in tritium storage containers at the Savannah River Site; it is believed that test data from the BTSP C-Ring Tests will provide useful information for the continued use of these and other metallic seals used in tritium storage and other applications.

Test Flange Hardware

The Test Flange hardware for the C-Ring testing, shown in Figure 5, 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 identical to the BTSP CVs.

The two inconnel (Alloy 718) C-Rings being evaluated are specified to be the same as those used in the BTSP 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. The silver plating on the sleeve is specified to be 0.001-0.002 inches for both sizes. 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 documented springback is in the range of 0.007-0.010-inches. The seating load for the small and large BTSP C-Rings per inch of circumference is 1000 pounds and 1600 pounds, respectively.

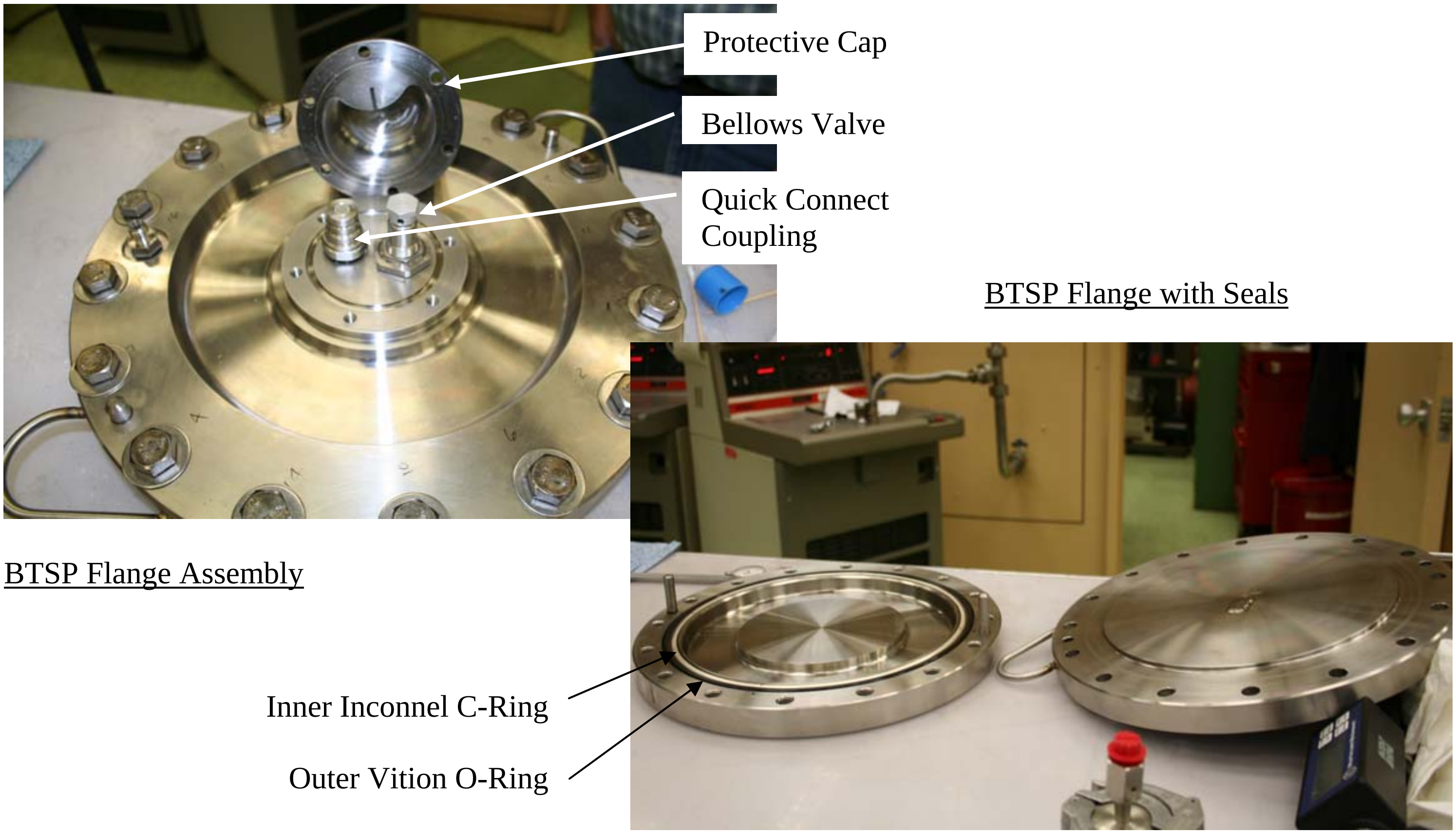


Figure 4 Bulk Tritium Shipping Packaging Test Flange

Test Matrix
The following test matrix partially summarizes the individual tests that are included in the BTSP Test Flange Program. Available results at the time of this publication are included in the test matrix table. The basis of each test parameter is provided below. This series of tests will be repeated at the minimum and maximum temperatures prescribed by Normal Conditions of Transport - (approximately 300°F) and -40°F.

Test No.	**Test Type**	**Gas Medium**	**Pressure (psig)**		**Test Temperature**	**Data Recording**	**Maximum acceptable test leak rate 1×10^{-7} ref cm^3 He/sec**
			Internal	**External**	**(F)**	**(minutes)**	
1	MSLT*	Helium	15 psig	Vacuum	RT**	5,10, 30, 60	passed
2	Pneumatic Pressure Test	Dry Nitrogen	154 psig	1 atm	RT	15	Passed: no leak/damage
3	MSLT	Helium	100	Vacuum	RT	60	Passed 1.1 x 10^{-9}
4	MSLT	Helium	Vacuum	100 psig		60	Passed <2.2 x 10^{-9}
5	MSLT	Helium	15 psig	Vacuum	RT	60	-
-	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.						

6 -10	MSLT	Helium	15 psig	Vacuum	RT**	60	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.						
11- 16	MSLT	Helium	15 psig and 100 psig	Vacuum	RT	10	
-	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.						
17-21	MSLT	Helium	15 psig	Vacuum	RT	60	
22	MSLT	Helium	15 psig 100 psig	Vacuum	-40 °F	5,10, 30, 60	
23	MSLT	Helium	15 psig 100 psig	Vacuum	300 °F	5,10, 30, 60	
24	MSLT	Deuterium	15 psig	Vacuum	RT	As required	

* Mass Spectrometer Leak Test
** RT – Room Temperature (Approximately 72 degrees Fahrenheit)

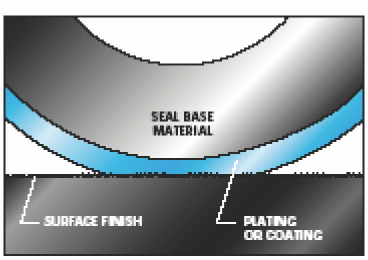
Test Parameters

Bolt Torque/Bolt Torque Sequence – Tests will be performed to determine the effect of NOT torquing the BTSP Test Flange bolts in accordance with the assigned pattern. For these tests, the application of torque in a circumferential sequence versus the assigned "star" pattern will be performed to determine if sequencing is important to the performance of the C-Ring seal.

Pressure from Outside- A test is 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.

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 is being 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.

Seal Surface Finish – The manufacturer recommends a sealing surface finish for use with the C-Ring. Previous laboratory testing at SRNL has determined that the manufacturing suggested finishes may not be the optimal finish and that rougher finishes may be provide better sealing. Tests will be performed on progressively better surfaces to baseline this finding.



(Reference 4)

Permeation - Gaseous tritium will permeate through the seals and stainless steel components of the BTSP CV, permeation tests using deuterium will be used to determine the permeation rate of tritium through the silver-plated inconnel C-Ring seal.

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, will be evaluated.

Vibration/Lateral Sliding – The effect of vibration associated with 10CFR71 Normal Conditions of Transport along with the potential of lateral sliding of the lid against the CV flange during assembly operations will be evaluated.

Conclusions

Testing to document the performance of silver-plated 718-inconnel Spring Energized C-Rings for use in the Bulk Tritium Shipping Package is being performed at the Savannah River National Laboratory. Test data indicates that all acceptance criteria have been met or exceeded for the tests completed to date. The 32-microinch surface finish in the C-Ring glands being tested, though rougher than the manufacturer recommends, has not contributed to unacceptable performance. The re-use of the large 10.9-inch OD C-Ring has produces acceptable leak rates ($\sim 10^{-9}$ std cc He/sec) for continued use (greater than 4 times). The C-Ring Tests have shown that application of pressure from the opposite side as specified by the manufacturer, i.e., pressurized from the outside for C-Ring with the open side of the “C” facing toward the center, is acceptable.

Acknowledgements

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Don Trapp, Greg Sides, Wayne Good

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