Contract No:

This document was prepared in conjunction with work accomplished under Contract No. 89303321CEM000080 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

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Surplus Plutonium Disposition Sphincter Seal Development & Testing

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April 2021

SRNL-STI-2021-00008, Revision 1

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Printed in the United States of America

Prepared for
U.S. Department of Energy

Keywords: *Sphincter Seal, Leak Test, Surplus Plutonium Disposition, Smoke Test, Testing*

Retention: *Varies*

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REVISION HISTORY

Revision #	Date	Reason for Revision
0	February 2021	Initial Issue
1	April 2021	After Revision 0 of the report was issued, review of the sphincter seal drawings resulted in changes to the sphincter seal design. This revision describes the design changes and the testing performed to confirm that the design changes do not adversely affect the performance of the sphincter seal assemblies.

ACKNOWLEDGEMENTS

SRNL would like to thank those who helped make this testing possible. Specifically; Med Allen for his input regarding what tests to perform; Eric Skidmore for his materials expertise; Daniel Radford, Evan Shealy, and Greg Wunderlich for their technical input that resulted in an improved design; Bridget Miller for securing the materials required for smoke testing; Brandon Walden, Doug Cardosi, Nate Miller, and Linda Gray for critical component purchase and retrieval; Patrick Folk, Cameron Turner, and Corey Hopper for assisting in hands-on work, William Housley for performing the Technical Review; and Greg Sides, Aaron Hubble, Doug Holiday, and Tyler Lyons from the SRNL R&DE High Pressure Laboratory for lending their expertise, and helping run all tests.

EXECUTIVE SUMMARY

The Surplus Plutonium Disposition Project (SPD, Project Y744) requested the Savannah River National Laboratory (SRNL) to perform a series of leak and durability tests on sphincter seals that were designed to process blend cans and shield cans into an SPD glovebox. Each sphincter seal assembly consisted of a stainless-steel outer sleeve weldment that was bolted onto the test enclosure and an aluminum inner sleeve that housed seven to nine Neoprene seals. All tests were executed to determine long term effects from processing approximately a year's worth of blend and shield cans through the sphincter seals.

All testing was performed per the SRNL developed test plan (TTQAP SRNL-RP-2020-00693 [1]). The test plan included a flow chart that detailed and identified the order of execution for all the tests. The first test was a Helium leak test to verify that the test enclosures, without the sphincter seals installed, were free of leaks that could impact testing. A rate-of-rise test was then conducted to evaluate how well each enclosure could hold a vacuum of -1" water column over the course of an hour. The sphincter seals were then installed on each enclosure and an initial rate-of-rise test was performed with one sphincter seal containing a single blend can and the other containing two shield cans. Smoke testing was then performed on each of the sphincter seal assemblies. It is important to note that only this test had an acceptance criterion. The acceptance criteria for the smoke test was no visible disturbance of the smoke where applied and no visible smoke migration into the test enclosure.

The planned throughput in a single SPD glovebox in one year is 4,400 cans, as a result it was determined that the durability testing would consist of passing at least 4,400 cans through each of the sphincter seals. Durability testing commenced by processing an initial batch of 100 cans followed by a smoke test. The smoke test was executed to ensure no leak paths developed during this initial batch of 100 cans. After the acceptance criteria of the smoke test were met, four cycles of 1,100 cans were processed through the blend can and shield can sphincter seals, respectively. Smoke tests and rate-of-rise tests were performed at the end of each cycle to monitor and quantify the integrity of the sphincter seals. The forces required to push cans through the sphincter seal assembly was measured with a load cell before and after durability testing for both the blend can and shield can sphincter seals. The last test consisted of replacing the inner sleeve assemblies. This was done by pushing the currently installed inner sleeve assembly into the test enclosure with a second replacement assembly. The force required to push the second assembly into place was also recorded. Smoke testing was also performed on the inner sleeve assemblies after installation to confirm no leak paths resulted from the replacement process.

Based on this testing, SRNL concludes that both the blend can and shield can sphincter seals demonstrated the ability to withstand a year's worth of operation. Both sphincter seals passed all the smoke tests during and after durability testing. The forces required to push the blend cans and shield cans were under the ergonomic limit of 46 lbf, but the force to push out the inner sleeve was above the limit [2]. Additionally, it was found that Krytox lubricant applied on the inner sleeve's silicone O-rings drastically reduced the force required for insertion by 120 lbf, but the force was still above the ergonomic limit.

The drawings drafted to address the recommendations in Revision 0 of this report underwent a thorough review. This led to a subject matter expert suggestion to remove the end gaskets from the sphincter seal inner sleeve design, modify the end components, and replace the end gaskets with O-rings between the end components and the inner sleeve. This design change results in less variability in flat gasket compression and simplification of the machining and assembly processes, thus resulting in a more repeatable design. This revised design was fabricated and tested and the testing revealed that for the blend can sphincter seal to achieve the leak tightness required to consistently pass a smoke test, the seamless rolled perimeter of the base of the can must be in contact with the outer-most sphincter seal. Photos of the testing documented in Revision 0 of this report indicate that the blend cans were likely in this position for smoke testing during endurance testing. This reinforces the need for a pusher tool not only to reduce the pushing effort required by operators but to ensure proper positioning of cans.

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LIST OF ABBREVIATIONS

AGS	American Glovebox Society
ASME	American Society of Mechanical Engineers
CAD	Computer Aided Design
COTS	Commercial-off-the-shelf
HPL	High Pressure Laboratory
ID	Inner Diameter
IN.	Inches
LBF	Pounds Force
M&TE	Measuring & Testing Equipment
MSLD	Mass Spectrometer Leak Detector
NPT	National Pipe Thread
OD	Outer Diameter
PSI	Pounds per Square Inch
SPD	Surplus Plutonium Disposition
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
TTQAP	Task Technical & Quality Assurance Plan
TTR	Technical Task Request
WC	Water Column

1. Introduction

The SPD project is investigating the use of sphincter seals to introduce blend cans and shield cans into the process gloveboxes during the plutonium down blending process. It is currently estimated that a total of 4,400 blend cans and shield cans will be used during a typical year of processing [3]. Sphincter seals should be able to withstand this workload in order to prevent a breach of containment. A minimum of one blend can or shield can shall always be inside a sphincter seal when not in use. The sphincter seals shall allow workers a safe and efficient means of introducing cans into the gloveboxes.

To date, no commercial off the shelf (COTS) sphincter seals exist for these types of cans and no information is available about effects of long-term wear on sealing surfaces. To address this, the SPD Project issued a Technical Task Request (TTR) to SRNL (M-TTR-K-00028, Rev.1) [3], requesting that SRNL design, fabricate, and test sphincter seals for both blend cans and shield cans. In response to this TTR, SRNL developed Task Technical & Quality Assurance Plan (TTQAP) SRNL-RP-2020-00693 [1] to document the plan for designing and testing the sphincter seals to satisfy the requirements in the TTR [3]. The tests outlined in the TTQAP are intended to document leak tightness, durability, the forces required to push cans during sphincter seal operations, and the force required to replace an inner sleeve assembly. Subsequently, six types of tests were run:

a) Helium leak tests were performed to ensure the test enclosure did not have any leak indications equal to or greater than the calibrated leak standard when the test enclosure was internally pressurized with Helium to at least +4” wc.
    a. The calibrated leak standard was set to $1x10^{-4}$ atm cc/sec Helium.
b) Test enclosure rate-of-rise tests were done to evaluate how well the test enclosure can hold a vacuum of -1” water column (wc) for an hour duration.
c) Sphincter seal rate-of-rise tests provided leak tightness information of how well seals can hold a vacuum of -1” wc for an hour duration before and after multiple cycles of cans have passed through the sphincter seals.
    a. Sphincter seal rate-of-rise test was intended for information about seal wear only.
        i. Rate-of-rise tests are significantly influenced by the surrounding environment’s temperature and atmospheric pressure changes, and due to variations in temperature and pressure the results may not be indicative of the system’s actual leak tightness.
d) Smoke testing at a vacuum of –1" wc to indicate if any major leaks were present after the sphincter seals had processed a batch of cans.
    a. Smoke testing was the only test performed on the sphincter seal assemblies that had an acceptance criterion. Smoke testing is used for leak testing operational SRS sphincter seals. This method of testing was advised by glovebox experts.
e) Durability tests consisted of pushing an initial cycle of 100 cans and then conducting smoke tests to determine if any potential leak paths had occurred. If the smoke test after 100 cans passed, four cycles of 1,100 cans were then performed. A rate-of-rise test and smoke test were then performed at the end of each cycle to evaluate the long-term wear effects on sealing. The forces to insert the cans were also documented before and after durability testing.
f) After durability testing was complete, replacement of the inner sleeves was performed to determine the force required to push the initial inner sleeve into the test enclosure with the replacement. Smoke testing was then performed at –1" wc.

Each test type was run per the Flow Chart of Test Scenarios as shown in Figure 4 of the TTQAP [1]. Experimentation of different sealing materials and inner diameters for the sphincter seal assembly was also done throughout testing.

Following all tests, the sphincter seal designs were modified to address the findings identified during testing. Future recommendations will be discussed in this report. The experimental procedure, data, and more formal conclusions are presented below.

2. Experimental Procedure

Test Setup

Test enclosures were used to house the sphincter seals and to provide an enclosure to facilitate the various leak tests performed. The test enclosures were welded from two bent ¼" thick 3003 aluminum pieces. A 3/8" thick 6061-T6 aluminum flange, which contained a 11.005" diameter hole for the sphincter seal assembly, compressed a ¼" thick 50A Neoprene gasket to the welded body. On the back end of the test enclosure, a 3/8" thick polycarbonate panel with two 6" diameter holes for glove ports compressed another ¼" thick 50A Neoprene gasket to the welded body. Each test enclosure was 19.625" long, 29.5" wide, and 18.5" tall and had an internal void volume of 4.69 ft^3. The test enclosure had four welded ¼" - 20 spacers for feet and three ½ National Pipe Thread (NPT) couplings for a thermometer, vacuum pump and Helium supply connection, and a port for purging the system. Figure 2-1 shows a Computer Aided Design (CAD) model, that highlights the features of the test enclosure with a sphincter seal that contains a shield can inside.

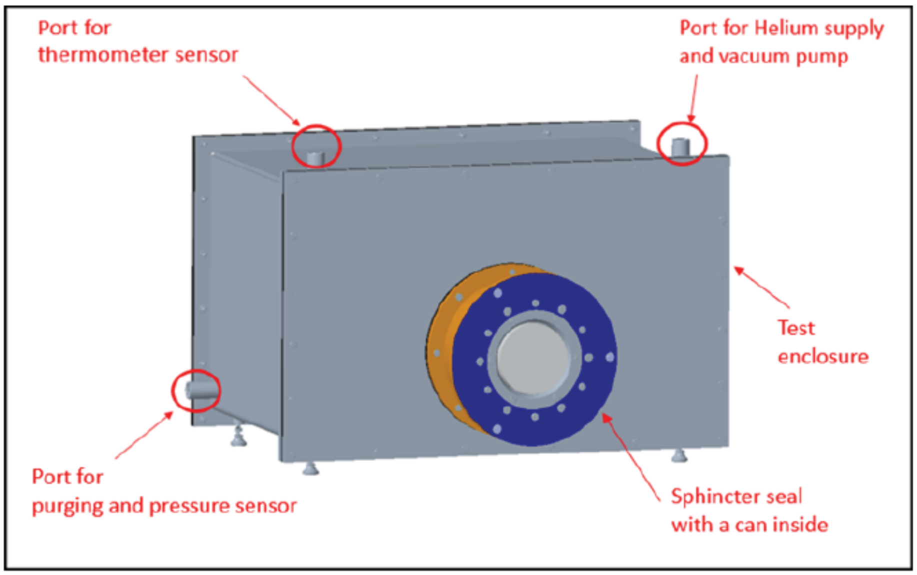

Figure 2-1. CAD Model of Test Enclosure.

Each sphincter seal assembly included a 304 stainless steel outer sleeve that was bolted onto the test enclosure's front panel and a 6061-T6 aluminum inner sleeve that was inserted inside the outer sleeve. The outer sleeve weldment is attached to the enclosure front panel with the same bolt pattern and fastener size as the removable sphincter seal mounting plate designed for the SPD gloveboxes. A ¼" thick 60A Neoprene gasket was put in between the outer sleeve and the front flange on the test enclosure in order to prevent any leak paths and to compensate for the warping caused by the welding on the outer sleeve. O-ring grooves on the inner sleeve provided sealing with the outer sleeve and a means to replace the inner sleeve when required due to sphincter seal wear. Per Parker O-ring standards for high pressure applications, there was initially a .003" to .006" clearance on diameter between the inner sleeve and outer sleeve. Viton 75A and silicone 50A O-rings were examined for applicability and ease of use. During initial assembly, the inner sleeve was difficult to insert due to the tight clearance between the inner sleeve and outer sleeve weldment. To remedy this, the inner sleeve's outer diameter was reduced by .005", thereby increasing the diametral clearance. The inner sleeve's O-ring groove diameter was also reduced by .017". This ensured a nominal O-ring compression of 14%, this is the same O-ring compression specified in the SPD Glovebox 90% design review. It was also observed that the inner sleeve was much easier to install with the softer silicone O-rings rather than the harder Viton O-rings. The Viton O-ring required silicone O-Lube while the silicone O-ring did not require lubrication, although lubricating the silicone O-rings did reduce the pushing force required. The silicone O-rings were chosen for use due to the reduced force needed for insertion as combined with the fact that they could be used without lubricant.

The shield can inner sleeve assembly weighed 29.4 lbs. while the blend can inner sleeve weighed 33.4 lbs. Both inner sleeves, including the locking caps and end caps, were less than 10” in length. Stainless steel thread inserts were installed on each inner sleeve to prevent the aluminum threads on the inner sleeve from stripping. A 6061-T6 aluminum plate bolts the inner sleeve to the outer sleeve during use but can be removed to allow the inner sleeve to be replaced. Inner sleeve replacement is performed by pushing the initial inner sleeve into the glovebox with a replacement inner sleeve.

For these test assemblies, both sphincter seals used common design elements and similar parts with variations in sizes and diameters to account for the differences in the cans to be processed. Six ¼” -20 threaded rods connected the locking cap of the inner sleeve to the end cap of the inner sleeve, providing compression on the internal components when the nuts were torqued. Initially, the internal components for both assemblies included ten 6061-T6 aluminum spacers, one 6061-T6 aluminum end spacer, two 6061-T6 aluminum support spacers, and nine Neoprene seals. The spacers contained female and male ridges that compressed each seal. The support spacer contained a tapered bore that reduced to a smaller inner diameter to provide support and alignment for each can when travelling through the sphincter seal. Two 1/8” 60A seals compressed the end caps and locking caps to the inner sleeve. The default sphincter seals were 1/16” thick and were initially made from 60A Neoprene. The inner diameters of the spacers and seals were calculated based on the ratios used in the FB-Line Bagless Transfer sphincter seal. These diameters can be seen in Table 1 of the TTQAP [1]. Per the SPD Glovebox 90% design review, the end spacers were lengthened by 0.067” to ensure the overall nominal compression of all the inner seals was 16%.

The following Figure 2-2 displays the cross-sectional view of the shield can sphincter seal assembly. This assembly was designed to house two shield cans at a time. The shield can closest to the inside of the test enclosure (right hand side of figure) had 5 inner seals engaged while the other shield can had 4 inner seals engaged with it. In this figure of the initial design, the red circle indicates a larger diameter dust seal that was designed to prevent “flicking” of oxide that could cause oxide migration when the standard sphincter seals relax from a bent state. It was subsequently observed that this relaxation did not occur in the shield can assembly. As a result of this observation, and feedback from the 90% SPD design review the final seal was replaced with a standard diameter seal.

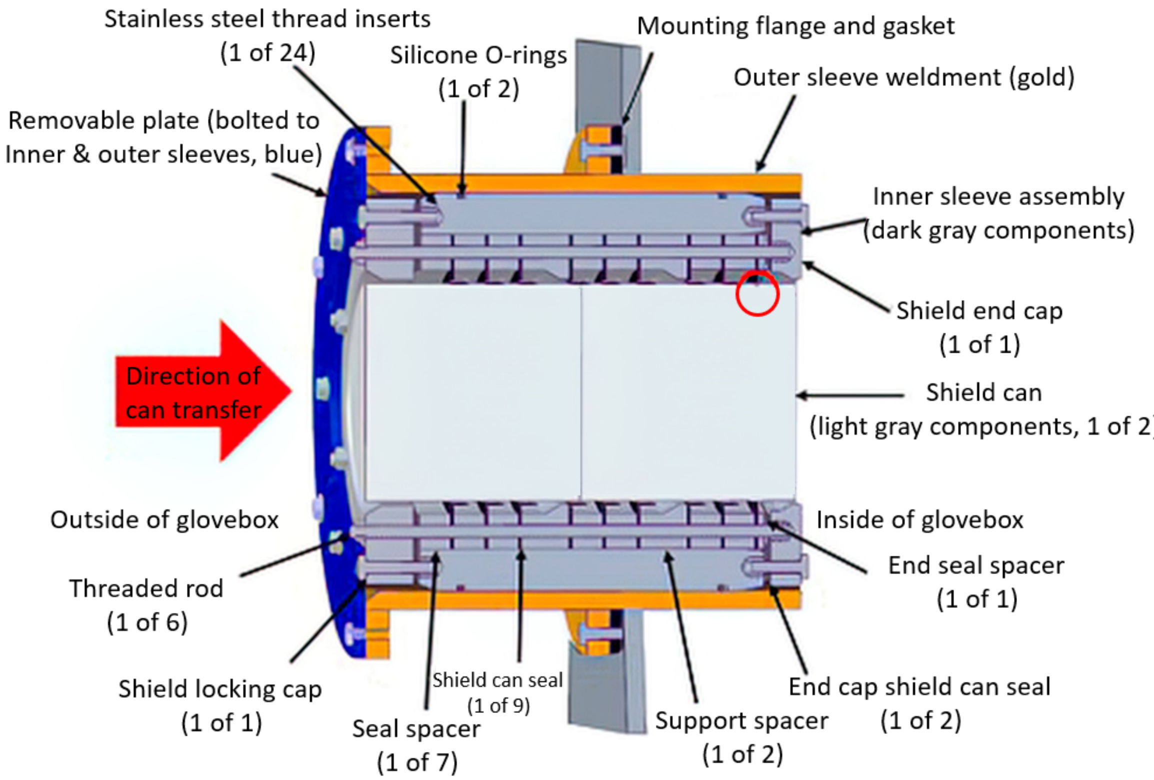

Figure 2-2. Initial Cross-sectional View of Shield Can Sphincter Seal.

Figure 2-3 displays the cross-sectional view of the blend can sphincter seal assembly. This assembly was initially designed to contain 1.5 blend cans. Upon further internal review and in response to the 90% design review, it was concluded that this assembly would be tested with a single blend can. The red circle in Figure 2-3 indicates the two seals that were either unused, or modified to match the diameter of the seal spacers to simulate a reduced length sphincter seal assembly. Similar to the shield can assembly, it was determined that the final larger diameter dust seal would be replaced with a standard diameter seal. This design change was a result of the 90% SPD design review, and because relaxation of the sphincter seals was not sudden and seemed unlikely to cause dust migration. The next revision of the design incorporated this change and can be seen in the right portion of Figure 2-4, which also displays the final concept design for the shield can sphincter seal on the left. These designs also incorporate some revisions that resulted from a drawing review subsequent to Revision 0 of this report. These design revisions are discussed in Section 5 of this report. The blend can sphincter seal assembly will be visually distinguishable from the shield can sphincter seal assembly due to its shorter length. Each assembly will be permanently identified by laser etching its sphincter seal name on the flanges of the outer sleeve weldments and removable plates.

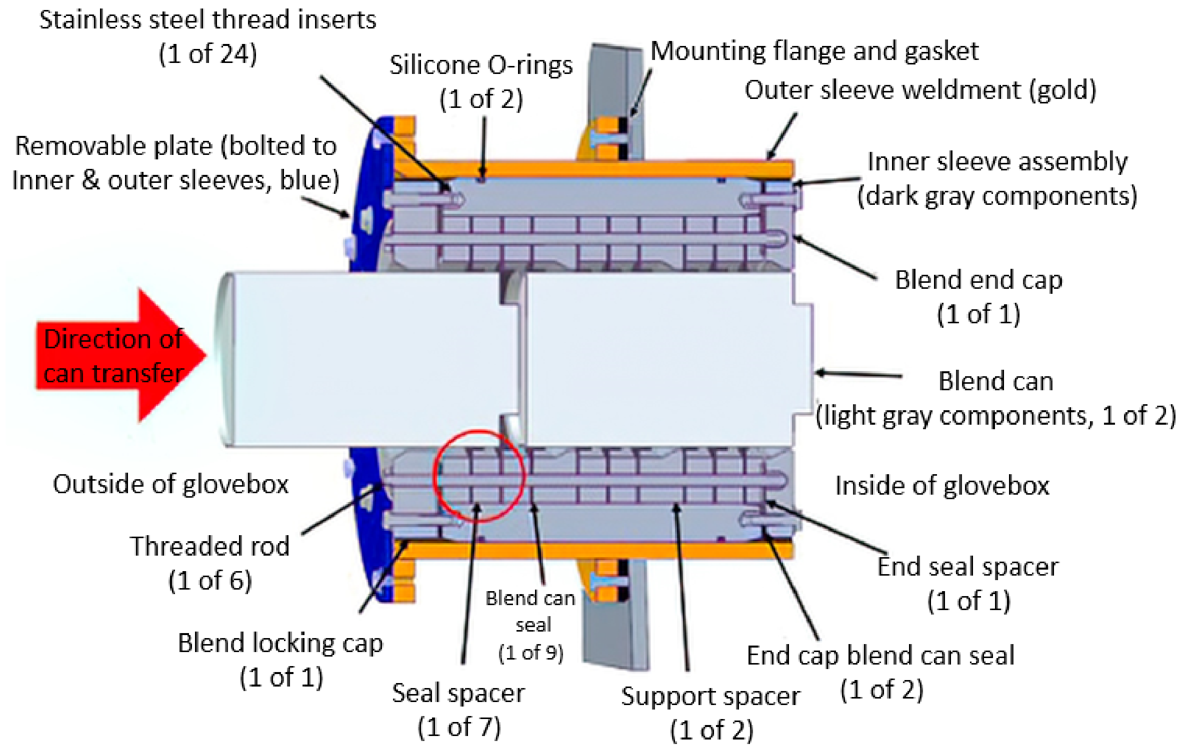

Figure 2-3. Initial Concept Cross-sectional View of Blend Can Sphincter Seal

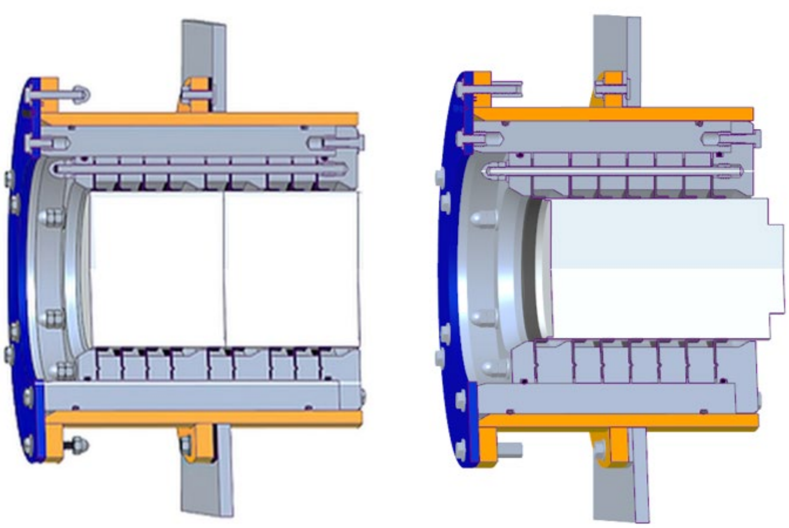

Figure 2-4. (Left): Final Concept Cross-Sectional View of Shield Can Sphincter Seal; (Right): Final Concept Cross-Sectional View of Blend Can Sphincter Seal

A shielding cover will be placed onto the outer sleeve weldment when the sphincer seals are not in operation. Figure 2-5 demonstrates an initial concept design for the removable cover. It has two handles, and two tabs to wrap around the outer sleeve weldment. The sphincter seal assembly will also have laser etched identification markings. Two bolts will protude out of the outer sleeve to prevent the outer sleeve weldment from rotating off the outer sleeve weldment (red arrow on Figure 2-5).

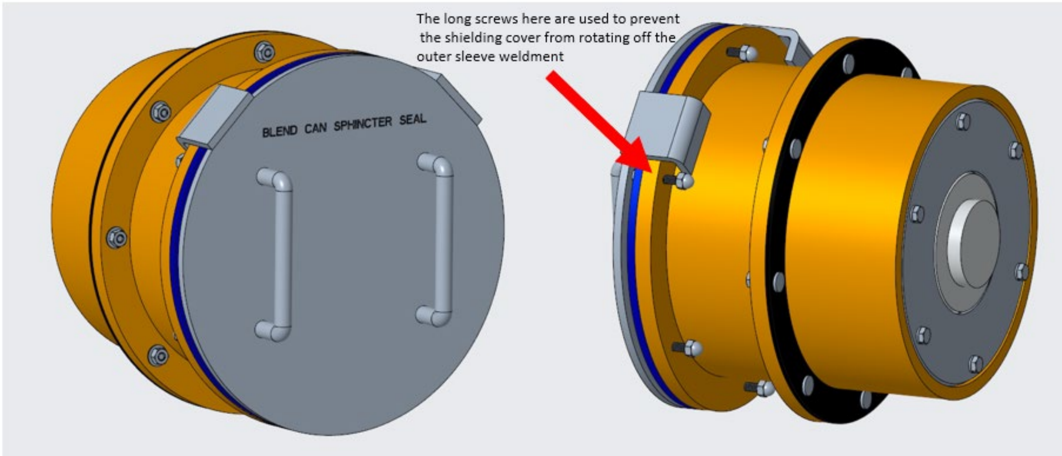

Figure 2-5. Blend Can Sphincter Seal Shielding Cover Concept

The following sensors were used for data acquisition during testing. Each test enclosure had a digital thermometer installed on one of the ½" NPT couplings on top of the enclosure." A Paroscientific pressure sensor was used to measure the ambient atmospheric pressure and a second Paroscientific sensor was used to measure the absolute pressure inside the enclosure being tested. Load cells were also used to measure the forces required to push the cans through the sphincter seals as well as to measure the force required to replace the inner sleeve assembly. Figure 2-6 shows the primary sensors that were used.

Figure 2-6. (Left): Absolute Pressure Sensors; (Middle): Digital Thermometer; (Right): Load Cell

Details concerning all sensors used to collect the data in this report can be found in Table 2-1.

Table 2-1. Test Sensor List and Descriptions

Sensor Type	Manufacturer	Calibrated Range	Accuracy	M&TE Numbers
Atmospheric Pressure	Paroscientific	0 to 23 psi	+/- 0.01 %	3-3874-1
Absolute Pressure	Paroscientific	0 to 23 psi	+/- 0.01 %	3-4580
Force	Omega	0 to 100 lbf	+/- 1 %	EA-393*
Force	Strainsert	0 to 8,000 lbf	+/- 0.1%	3-2125
Force	A E Adams	0 to 440 lbf	+/- 1 %	3-6804
Temperature	Tel-Tru	-75°F to 750°F	+/- 0.5 °F	3-7802 3-7803

*The calibration for this load cell was "As Needed". To verify that the load cell was in calibration, multiple weights were used to characterize the force range required for testing the sphincter seal. The weights used for this test were verified on scale M&TE number 3-6804 as the weights themselves were not M&TE. Testing demonstrated that the load cell was within ±1 lbf for the force range required for sphincter seal testing, indicating that calibration was not needed.

The tubing and valve layout that managed the vacuum and Helium supply can be seen with Figure 2-7. A needle valve was used to throttle the vacuum rate and pressure introduction, one ball valve was used to isolate the test enclosure, a second ball valve was used as a vent to atmosphere, and a 3 psi pressure relief valve ensured the pressure did not exceed the calculated rating of the test enclosure. The absolute pressure sensor was connected immediately upstream of the test enclosure to measure the internal pressure.

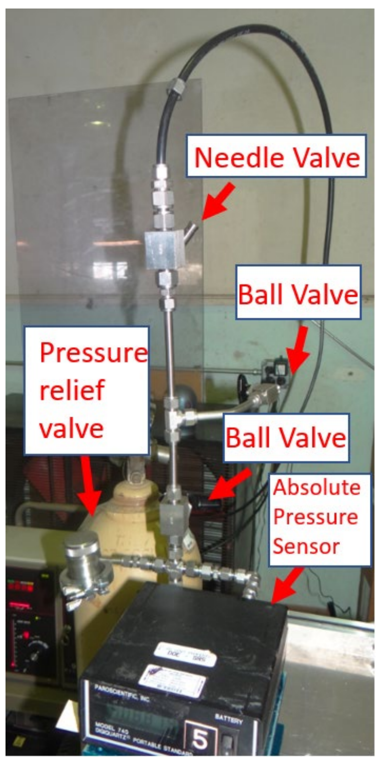

Figure 2-7. Tubing and Valve Layout.

For these tests, both blend cans and shield cans were to be tested. Blend cans, including the threaded top cap, were 6.75” tall. The diameter of the cylindrical portion of the can ranged from 3.89” to 3.91”. Two lips at the top and bottom of the blend can had a slightly bigger diameter than the can’s base diameter. A seam on the cylindrical portion of the can protruded less than 0.01” from the adjacent outer surface and it extended from the upper lip to the bottom lip of the blend can. The seam can be seen by the red rectangle on Figure 2-8. Each blend can had 4.4 lbs. (2 kgs.) of a simulated adulterant inside of it. The shield cans had an outer diameter that was 4.50” and the height of the shield cans was 3.84”. Two variations of shield cans were tested, a welded version made from pipe and a machined version made from bar stock. The machined variant of the can was made from 4.5” diameter 304 stainless bar stock. The welded variant of the shield can was made from 4” 304 stainless steel pipe with a recessed plug welded inside the pipe to form a bottom. The outer diameter (OD) surface of both shield can variants was left in an as received condition and was not modified to improve the surface finish of the commercial bar stock or/pipe. Both variations were evaluated for surface roughness, with the machined can being smoother by having an average Ra value of 67.1 µin and the welded cans having an average Ra value of 104.73 µin.

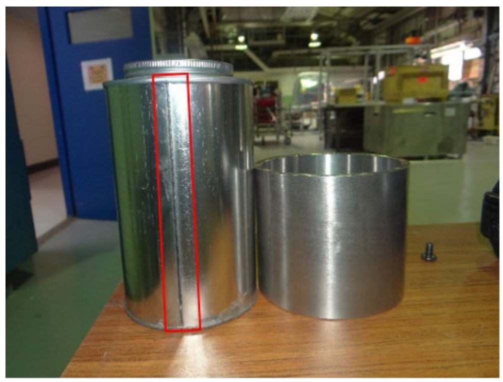

Figure 2-8. Blend Can and a Machined Shield Can

The following Table 2-2 displays the torque values of the fasteners used on the test enclosure and sphincter seal. The glove ports manufacturer, LaCalhene, specified using a minimum torque value of 27 in. lbs. for 6” glove ports set screws [4]. The torque used for the screws on the test enclosure flange used Design Change Form (M-DCF-A-00768) as a general reference to specify a torque of 20 in. lbs [5]. The torque specified for the inner sleeves’ end cap, lock caps’ bolts, and nuts was based on when the end cap gaskets were compressed by 16%. This was done by measuring the thickness of the gasket while being incrementally torqued in a star shaped pattern. The rest of the values, not including the removable face plate fasteners, were met when adequate leak tightness was achieved. The fasteners for the removable face plate were torqued sufficiently to prevent inadvertent loosening as these values were not critical for testing purposes. Anti-seize lubrication was only applied to the removable plate fasteners that bolted to the outer sleeve, since these fasteners must be removed to replace the inner sleeve assembly. Application of anti-seize to the fasteners that attach the removable plate to the inner sleeve will also be specified on the drawings, for the same reason.

Table 2-2. Torque Value Table

Type of Connection	Fastener Used	Torque Value (in. lbs.)
Removable Plate to Lock Cap	¼”-20 UNC-2A, 5/8” LG, SST	65
Removable Plate to Outer Sleeve	¼”-20 UNC-2A, 1-3/8” LG, SST	65
Lock Cap to Inner Sleeve	¼”-20 UNC-2A, 1-1/2” LG, SST	125
Outer Sleeve Flange Screws	¼”-20 UNC-2B, SST	50
Nuts on Threaded Rods	¼”-20 UNC-2B, SST	125
End Cap to Inner Sleeve	¼”-20 UNC-2A, 1” LG, SST	125

Figure 2-9 indicates where the fastener connections that Table 2-2 specifies the torque values for.

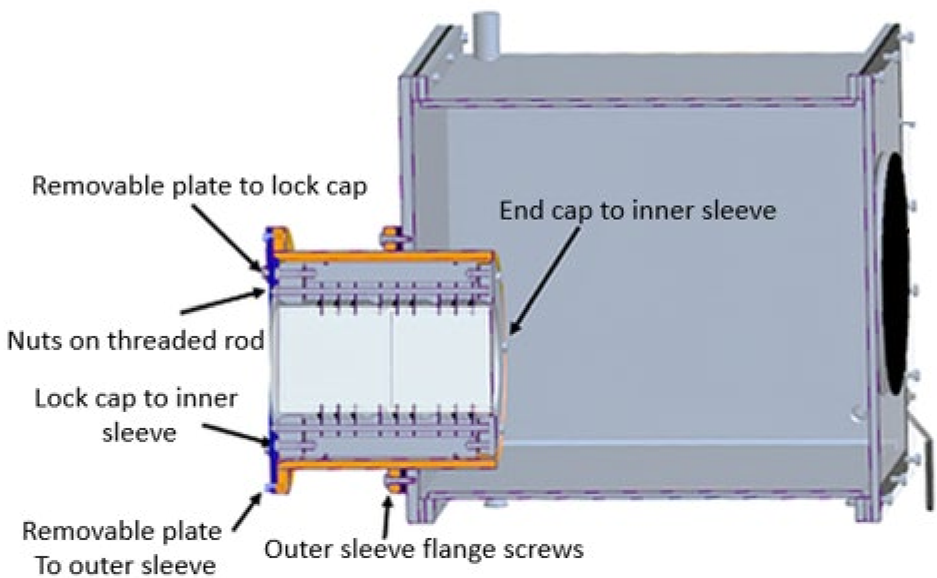

Figure 2-9. Cross Sectional View of Fastener Connections of Shield Can Sphincter Seal Assembly

Test Procedures

The TTQAP includes a flowchart that specifies testing to be performed and the associated acceptance criteria. These tests were performed in accordance with American Glovebox Society (AGS) standards as applicable. Research & Development (R&D) directions (SRNL-L4520-2020-00011) [6] were developed for the leak testing to be performed and were supplied to the High Pressure Laboratory (HPL) personnel assisting with the tests. All equipment used for pressure testing was Measuring & Test Equipment (M&TE) calibrated and are listed in the aforementioned Table 2-1. Testing was performed in 723-A, room 161. All data acquired during these tests were used as design inputs for the final sphincter seal designs for both assemblies.

Enclosure Local Helium Leak Test

Helium leak testing was the first test performed on the test enclosures to confirm that the weld joints, seals, gaskets, etc. had leak rates that were less than or equal to the calibrated leak standard before commencement of sphincter seal testing. The leak rate specified for this test was $1x10^{-4}$ atm cc/sec of Helium at any single leak at an internal pressure of +4” wc.

The Helium leak test utilized a Mass Spectrometer Leak Detector (MSLD) that had a sensitivity of at least $1x10^{-6}$ atm cc/sec. A calibrated Helium leak standard of $1x10^{-6}$ was used to calibrate the MSLD. The MSLD was then set to detect Helium leaks of $1x10^{-4}$ atm cc/sec, or greater, in order to trigger the correct response. A calibrated leak standard of $1x10^{-4}$ atm cc/sec Helium was used during testing to confirm the MSLD was properly calibrated.

Figure 2-10. (Left): Helium MSLD; (Middle): Helium Cylinder and Pressure Regulator; (Right): Calibrated Leak Standard

Test Enclosure Rate-of-Rise Test

After the Helium leak tests were finished, a rate-of-rise test was performed on the test enclosures. The inner sleeve assemblies were not installed for this test, but a 1/2” thick 6061-T6 aluminum plate and a 40A Neoprene gasket were used to blank off the test enclosure instead. The test enclosures’ internal pressure was reduced to at least -1” wc for a minimum of 1 hour using a vacuum pump. The initial pressures and temperatures were monitored over the duration of the test and a leak rate was then computed. This test was intended for information only, hence, no acceptance criteria was specified. Both this test and the Helium test helped ensure that the test enclosures were satisfactory prior to installing the sphincter seals.

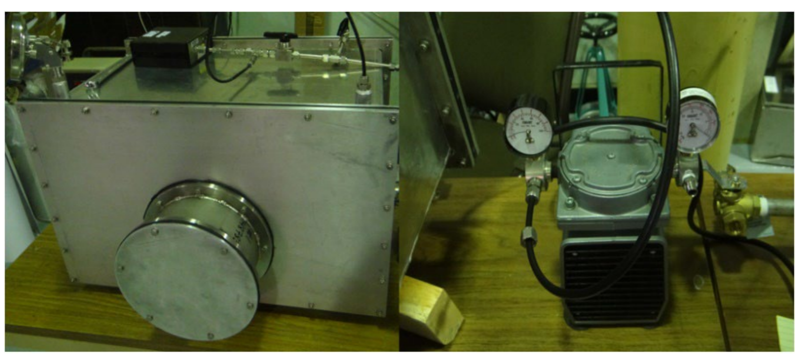

Figure 2-11. (Left): Blanked off Test Enclosure; (Right): Vacuum Pump

The following figure displays the leak equation, which is from section 6.3 of American Glovebox Society (AGS)-G004-2014: Standard of Practice for Leak Test Methodologies for Gloveboxes and Other Enclosures [7]:

$$Q = \frac{60}{\Delta t}\left(1 - \frac{P_1 T_2}{P_2 T_1}\right)V$$

Where:
Q=leak rate, cubic feet/hour
Δt = time interval, minutes
V=volume of enclosure, cubic feet
P_1= initial absolute pressure, inches of water
P_2= final absolute pressure, inches of water
T_1= initial temperature, °R
T_2= final temperature, °R

Figure 2-12. Leak Rate Equation for Rate-of-Rise Tests

Sphincter Seal Smoke Tests

Smoke testing is a qualitative method used to locate leaks by using Draeger smoke tubes that produce a neutral buoyancy smoke. Smoke testing was done with cans installed in the sphincter seals and under a vacuum of at least -1" wc. Testing was done prior to durability testing, and then after every cycle of 1,100 cans that passed through the seal during the durability testing. This was done to determine if any sphincter seal leaks existed, and if so where they had developed. Smoke testing was performed based on the SRNL glovebox structural integrity evaluation procedure [8] and the 235-F Enclosure Integrity Program [9]. Both procedures state that smoke should be applied at 1 inch per second along the evaluation points, this equates to approximately 12 to 15 seconds of smoke application for the sphincter seals. Smoke testing will be used by the SPD Project to qualify the production sphincter seals and was the test method recommended by the glovebox experts for this type of transfer system. For these reasons, the smoke test was selected as the acceptance test for the sphincter seals. The acceptance criterion for the smoke test is no visible disturbance of smoke indicating entry into the sphincter seal, and no presence of smoke in the test enclosure after the prescribed application. For the blend can sphincter seal assembly, smoke testing was performed twice at each inspection, once with the seam oriented down (6 o'clock position) and once with the seam oriented up (12 o'clock position).

Figure 2-13. Smoke Testing

Sphincter Seal Rate-of-Rise Tests

The sphincter seal rate-of-rise was performed with a starting pressure of at least -1" wc and had a duration of 1 hour. Testing was performed with either a single blend can or with two shield cans installed in the sphincter seal. Rate-of-rise tests are not typically used for transfer systems, and this testing was performed for information only. The primary intent was to observe if there was a correlation between rate of rise and long-term sphincter seal use.

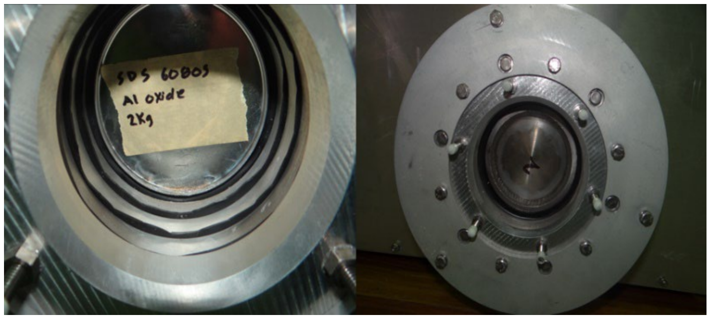

Figure 2-14. (Left): Blend Can Inside Sphincter Seal; (Right): Shield Can Inside Sphincter Seal

Sphincter Seal Durability Tests

Durability testing consisted of pushing multiple cans through the sphincter seals. Per the TTR [3], it is currently expected 4,400 cans will be introduced into a single SPD glovebox each year. For the durability test, an initial cycle of 100 cans was performed. This was the followed by four cycles of 1,100 cans transferred through the sphincter seals. After the initial 100 cans were pushed, the seals were tested for leaks by performing a smoke test and a rate-of-rise test. Due to the high number of cycles needed for this test, a mechanical system was developed to push the cans through. This system consisted of an extruded aluminum frame, a pneumatic cylinder, two bent 3003 aluminum air cylinder supports, one machined piston, one load cell, one 6061-T6 aluminum welded can tray, one four-way valve with a handle, and a pressure relief valve set at 80 psi. This mechanical system can be seen in Figure 2-15.

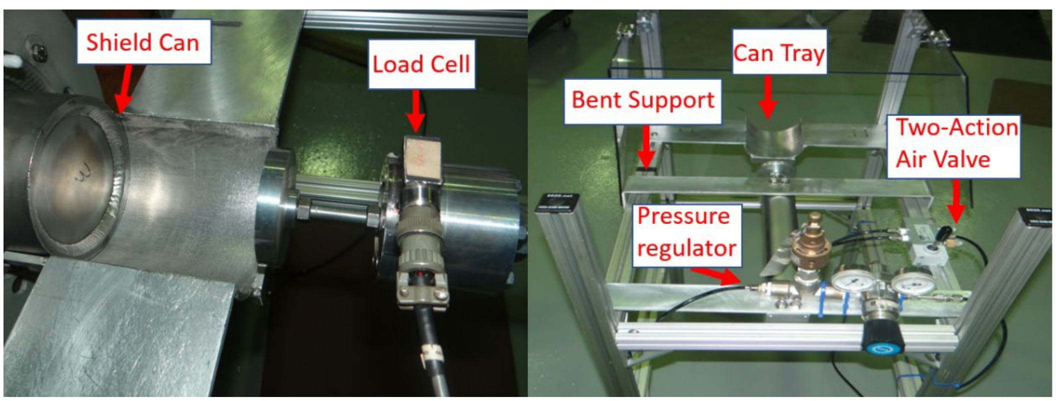

Figure 2-15. (Left): Close Up of the Pusher System; (Right): Wide Shot of Pusher System

Inner Sleeve Replacement Tests

At the conclusion of the durability testing the inner sleeve replacement testing was then conducted. Experimentation was done with both 75A Viton and 50A silicone O-rings. Both materials provided acceptable sealing performance, but after preliminary handling and insertion of the inner sleeves, it was decided to perform the replacement test with two silicone 50A O-rings. This was primarily because the harder Viton O-rings significantly increased the force to install the inner sleeves when the sphincter seals were initially inserted for durability testing. For these tests, the force required to replace the inner sleeves was documented using the setup shown in Figure 2-16. Smoke testing was performed after insertion to confirm that a leak path was not created during replacement.

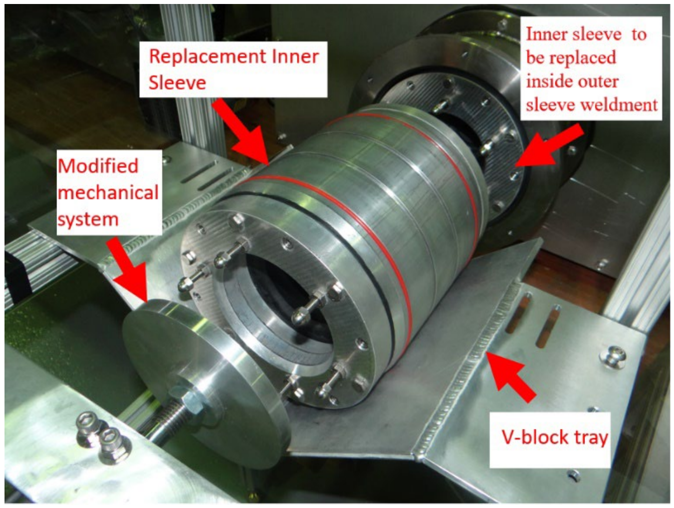

Figure 2-16. Inner Sleeve with 2 Orange Silicone O-Rings Experimental Setup

Quality Assurance

Requirements for performing reviews of technical reports and the extent of review are established in manual E7 2.60. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2 [10]. R&D data sheets with HPL signatures will be in this project's associated SRNL electronic job folder.

3. Results and Discussion

This section discusses and presents the results of each test.

Enclosure Local Helium Test

The shield can sphincter seal test enclosure was first pressurized with Helium at +4" wc and then slowly scanned with the Helium MSLD probe. The Helium probe scanned all the welds, joints, gaskets, and glove ports of the test enclosure with the outer sleeve blanked off (Figure 2-11). Two areas triggered the alarm by detecting activity greater than the acceptance leak rate (10^{-4} atm cc/sec Helium), one additional area displayed minor activity that was at 10^{-6} atm cc/sec Helium. It was then determined that the first leak location in the weld on the top right corner of the test enclosure, where the digital thermometer connection was located. The second was at the bottom left portion of the right glove port. The bottom left portion of the gasket between the outer sleeve and the test enclosure displayed activity of 10^{-6} atm cc/sec Helium.

A dye penetrant test was used to identify the crack in the weld and the crack was then re-welded by the SRNL machine shop. The glove port that triggered the alarm was removed and vacuum grease was applied to the O-ring. The glove port was then put back into the polycarbonate panel. The bolts connecting the outer sleeve to the test enclosure were retorqued as well. After doing this, no leaks were found with a leak rate of more than 10^{-4} atm cc/sec Helium.

The blend can test enclosure did not trigger any alarms during the Helium leak test.

Enclosure Rate-of-Rise Test

After proving both test enclosures contained no significant leaks, a rate-of-rise test was performed on each of the enclosures with both outer sleeves blanked off. Each test enclosure was evacuated to a pressure of at least -1" wc, and then isolated from the vacuum source. This was done to observe how well each test enclosure could hold a vacuum over the course of an hour. Table 3-1 showcases the findings of each test. The shield can test enclosure was evacuated to a pressure slightly lower than the blend can test enclosure, but both had similar results in terms of leak rates and final gage pressures after the hour duration.

The rate-of-rise test on the shield can test enclosure was executed after allowing the enclosure to settle for a day after being blanked. The enclosure held the initial vacuum of –1" wc for the entirety of the one hour. This implies that the Neoprene material conforms to its mating surface over time and could potentially improve its ability to provide a seal. It was observed that many of the final temperatures and atmospheric pressures measured during the leak tests varied from their initial values. When combined with the fact that the leak rate calculation is very dependent on temperature and pressure differential these variations in some cases produced negative leak rates that are inaccurate. The leak equation used to compute leak rates can be found in the R&D Directions [6].

Table 3-1. Rate-of-Rise Test Enclosure Results

Test Enclosure	Test Enclosure Gage (in. wc)		Test Enclosure Absolute (in. wc)		Test Enclosure Atmospheric (in. wc)		Internal Temperature (°R)		Calculated Leak Rate and Propagated Error (ft^3/hr.)
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	
Shield Can (settled for a day)	-1.257	-2.111	401.21	400.35	402.47	402.47	534.87	533.09	+5.64E-03 ±1.36E-04
Shield Can	-1.614	-0.569	402.31	403.3	403.92	403.87	525.37	526.69	-1.37E-04 ±3.29E-06
Blend Can	-1.166	-0.406	401.22	401.51	403.39	401.92	532.87	533.29	-3.18E-04 ±7.64E-06

Initial Sphincter Seal Tests and Modifications

After passing the initial smoke tests with the sphincter seals installed, a rate-of-rise test was done on both assemblies with the 60A Neoprene seals. Significant leaks were observed on both assemblies. The shield can sphincter seal contained two cans with an initial pressure of -1.3" wc. After only 10 minutes, the enclosure pressure was measured to be -0.317" wc. The blend can assembly pressure, with a blend can with the seam down, went from -1.2" wc to -0.226" wc after 10 minutes. In order to locate the leak paths, the same MSLD Helium sniffer was used to locate leaks greater than or equal to 10^{-4} atm cc/sec. The helium sniffer test was executed when the sphincter seal assembly was pressurized to at least +4" wc of Helium. When sniffing around the shield can sphincter seal assembly, an alarm was triggered around the threaded rods, as seen on the left portion of Figure 3-1. This occurred after the assembly was filled with Helium for two hours. The blend can assembly had similar results, but the alarm was triggered around the blend can seam. The alarm occurred both when the seam was oriented up and when it was oriented down. Both times the alarm was triggered at the seam. When the seam was down, it caused the alarm to trigger from the 3 o'clock position to 6 o'clock position as shown by the red curve on the right portion of Figure 3-1.

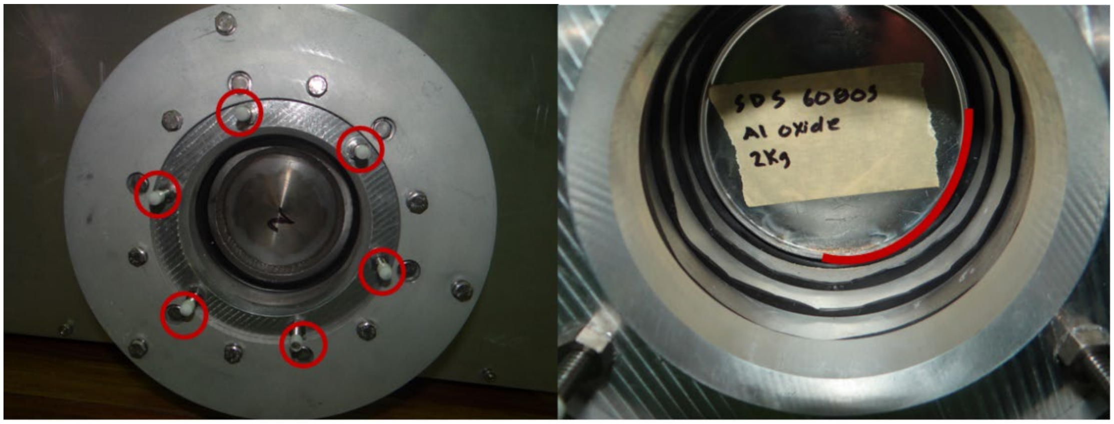

Figure 3-1. (Left): Shield Can Sphincter Seal Threaded Rods Leak Paths; (Right): Blend Can Seam Leak Path

Sealing fasteners were purchased and installed on the sphincter seal assembly in order to close the leak paths. Six ¼"-20 nuts containing silicone O-rings were used on the threaded rods with the same torque values that were specified in Table 2-2. Six ¼"-20 screws with silicone O-rings under the head were used to bolt the end cap to the inner sleeve and the locking cap to the inner sleeve. These screws were also torqued to previously specified values in Table 2-2. The red squares on Figure 3-2 show the fasteners and washers that were replaced with the sealing fasteners. The red lined arrow displays the suspected leak path that was formed around the threaded rods. The chamfer on the inner sleeve on the inside glovebox side may have been the cause of this leak path since it was in proximity to the end cap fastener. It has been decided that this chamfer will be removed in the final design (red circles on Figure 3-2). The chamfer on the "Outside Glovebox" side will be steeper on the final design to allow more room away from the lock cap fastener. After replacement of the fasteners, the Helium MSLD alarm did not trigger when the probe scanned the threaded rods on both assemblies. However, the alarm still triggered at the interface between the blend can seam and the sphincter seal.

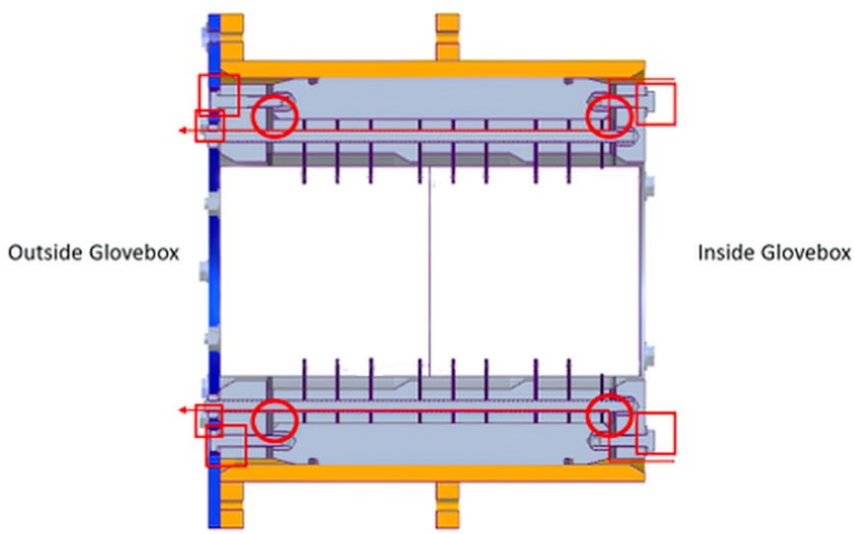

Figure 3-2. Cross-Sectional View of Shield Can Sphincter Seal Leak Paths

Several opportunities for design improvements were discovered during testing. In some cases, parts required immediate modification in order to allow testing to continue. Other improvements were noted for inclusion in the next design evolution and are explained in section 5.

It was observed that the last seal on both assemblies caused interference with the tapered section of the end cap of the sphincter seals as depicted on Figure 3-3. The modified end cap spacer decreased the length between the taper of the end cap and the last seal. This caused the shield can to be misaligned and potentially could have created additional leak paths. Both sphincter seal end caps were modified by increasing the bore length before the tapered section on the end cap piece. It was also observed the end cap gaskets on both assemblies created interference internally and externally when torqued. It would interact with the blend can when the blend can was inserted as well as created additional disturbance when placed inside the outer sleeve. It was determined that the outer diameter and inner diameter on both end cap gaskets needed to be reduced. The threaded rods extend out of the lock cap which could present a safety hazard. Counterboring the lock cap for the nuts to be threaded against the counterbores would reduce how far the threaded rods extend past the lock cap. Cutting the threaded rods flush with the nuts after assembly and initial leak testing would also eliminate the hazard. If the modification requires the threaded rods to extend slightly past the lock cap surface, acorn nuts or rubber boots will be installed over the rod ends. Another modification that will be implemented is removal of the chamfer on the glovebox end of the outer sleeve to make a smaller path for Plutonium oxide to migrate between the inner and outer sleeve.

Figure 3-3. End Cap Sealing Interference

Shield Can Testing

A rate-of-rise test was done on the shield can sphincter seal while containing two shield cans and after installation of the sealing fasteners for the shield can sphincter seal with two shield cans inside. The initial pressure was -1.2” wc which increased to -0.852” wc after 10 minutes, showing an improvement from the initial 10-minute rate-of-rise test without the sealing fasteners. The cans were then left in place overnight, and the full hour rate-of-rise test was done the morning after. After the rate-of-rise test was completed, the durability testing began. Neoprene 60A durometer seals with a 3.76 ID were used during the durability testing. It should be noted that rate-of-rise testing was also done with one shield can inside the sphincter seal, which yielded poor results. The test enclosure reached ambient conditions in around 10 minutes. The enclosure in this configuration also failed a smoke test. Additionally, aligning only one shield can inside the sphincter seal proved to be difficult. These findings indicate that having only one shield can inside the sphincter seal did not pass the acceptance criteria.

The results of all the rate-of-rise tests, smoke tests, configurations, leak rates and testing notes are shown in Table 3-2. The numbers in parenthesis and brackets in the pressure columns represents the absolute and atmospheric pressures. It is believed that the superior leak test performance of tests 1 and 4 are due to the tests being performed with cans being in place for several days. It should also be noted that the leak rate calculations are highly sensitive to temperature changes and could have led to the negative leak rates shown below. For instance, the enclosure temperature rose 1.9°F during test 3, if the temperature had stayed constant and the same pressures recorded, the leak rate would have been positive. However, there was very little temperature change during tests 1 and 4. After 4,500 cans were processed, the final pressure was almost at ambient conditions after one hour. This may indicate that the seals were worn down during the can transferring process. It should be noted that test enclosures passed the smoke tests, despite the change in the rate-of-rise tests. There was evidence that indicated that increased can residence time in the sphincter seal may improve sealing performance. It was found that after two cans had been inside the sphincter seal for six days, the results of the rate-of-rise tests improved. The rate-of-rise tests seem to indicate that the welded cans resulted in a slightly worse seal than the machined cans, which is expected due to the slightly rougher surface finish, but the smoke tests with both welded and machined cans met the acceptance criteria.

Toward the end of testing, it was advised that bar code stickers would be applied to the outside diameter of the shield and blend cans before passing them through the sphincter seals. The last two tests were performed with a sticker on each shield can and both smoke tests still passed.

Table 3-2. Shield Can Leak Test Results

Test #	Number of Cans Pushed Through Sphincter	Configuration		Gage, (Absolute), & [Atmospheric] Pressures (in. wc)		Temp. Difference (°R)	Calculated Leak Rate and Propagated Error (ft^3/hr.)	Smoke Test	Notes
		Seal Durometer	Seal ID (in.)	Initial	Final				
1	0 (2 machined cans)	60A	3.76	-1.321 (407.8) [409.1]	-1.413 (407.7) [409.1]	+.12	-2.13E-03 ±5.13E-05	Passed	Sealing fasteners were installed, and two cans sat overnight, and it held the vacuum over one hour.
2	0 (1 can on last 5 seals)	60A	3.76	-1.549 (409.6) [411.2]	-.091 (411.1) [411.2]	+1.42	+3.83E-03 ±9.23E-05	Failed	It took a minute and a half to get to -.2" wc and gradually went to ambient conditions. This was the only shield can configuration (1 can on last 5 seals) that failed the smoke test.

Test #	Number of Cans Pushed Through Sphincter	Configuration		Gage, (Absolute), & [Atmospheric] Pressures (in. wc)		Temp. Difference (°R)	Calculated Leak Rate and Propagated Error (ft^3/hr.)	Smoke Test	Notes
		Seal Durometer	Seal ID (in.)	Initial	Final				
3	0 (2 welded cans)	60A	3.76	-1.051 (410.2) [411.3]	-.021 (411.1) [411.1]	+1.92	-7.39E-03 ±1.78E-04	Passed	2 welded shield cans were inserted afterwards. It took 50 minutes to reach -.2 " wc and then gradually went to ambient conditions.
4	1200	60A	3.76	-1.3 (401.9) [403.2]	-1.522 (401.7) [403.2]	-.21	-1.03E-03 ±2.49E-05	Passed	Test was done after cans set over the weekend.
5	2300	60A	3.76	-1.046 (397.9) [399.0]	-.568 (398.5) [399.1]	+.2	+4.59E-03 ±1.11E-04	Passed	
6	3400	60A	3.76	-1.305 (402.4) [403.8]	-.646 (402.9) [403.6]	+.6	+4.16E-04 ±1.00E-05	Passed	
7	4500	60A	3.76	-1.045 (405.5) [406.6]	-.041 (406.5) [406.4]	0	+1.09E-02 ±2.63E-04	Passed	The sphincter was almost at ambient conditions 1 hour.
8	4500 (2 machined cans)	60A	3.76	-1.222 (402.8) [404.1]	-.183 (403.8) [404.0]	+0.7	+4.62E-03 ±1.11E-04	Passed	End cap piece was modified to prevent interference and the sphincter.
9	4500 (2 welded cans)	60A	3.76	-1.25 (401.6) [402.9]	-.075 (402.5) [402.6]	+1	+1.39E-03 ±3.34E-05	Passed	Sphincter was almost at atmospheric conditions after the 1 hour
10	4500 (2 welded cans with stickers)	60A	3.76	-1.3 (403.4) [404.7]	-.35 (404.4) [404.7]	+0.8	+4.43E-03 ±1.07E-04	Passed	2 welded cans with barcode stickers at 12 o'clock positions on them.
11	4500 (2 welded cans with stickers)	60A	3.76	-1.3 (406.1) [407.4]	-.292 (407.1) [407.4]	+1.4	-1.54E-03 ±3.71E-05	Passed	2 welded cans with barcode stickers settling inside for 6 days.

The force required to push cans through the sphincter seal was assessed as a separate part of this testing. The welded cans took approximately 39.81 lbf, on average, to push through the sphincter seal by hand before durability testing. The machined cans took about 40.21 lbf on average. These numbers are average maximum loads recorded by the load cell and are representative of the initial static force required to initiate motion. After overcoming the initial static force to move the cans, they moved much more easily through the sphincter seal. After durability testing, the average maximum force required to begin moving the welded cans through the sphincter seal was 38.01 lbf. The machine cans required 40.15 lbf to move through the sphincter seal. The recorded forces are less than the prescribed ergonomic limits per Liberty Mutual's "Tables for Evaluating Lifting, Lowering, Pushing, Pulling, and Carrying Tasks" handling guidelines. The report identifies and recommends a 46 lbf. limit for an SPD glovebox operator at a hand height of 53 inches [2]. The accuracy of the load cell was 1% of the full-scale output which was 100 lbf. Incorporating the propagated equipment error, the push forces were still under the ergonomic limit. The default diameter seals were replaced with 50A Neoprene seals and load cell testing was done to determine if the force required to move a can through the sphincter seal would decrease. The welded shield cans required an average force of 38.23 lbf to be moved through the sphincter seal. The machined shield cans required an average of 46 lbf. These findings were not different from the load cell readings with the 60A Neoprene seals and so conducting durability testing with the 50A Neoprene seals was not warranted. No visible damage was observed on the shield cans after testing. The seals were inspected for wear after testing and no evidence of wear, cracking or cuts were observed. After post-testing disassembly of the shield can sphincter seal, it was observed that the holes in some of the seals were elongated. This is due to misalignment of the holes during fabrication rather than slippage, as evidenced by the round holes in the properly fabricated seal (see Figure 3-4).

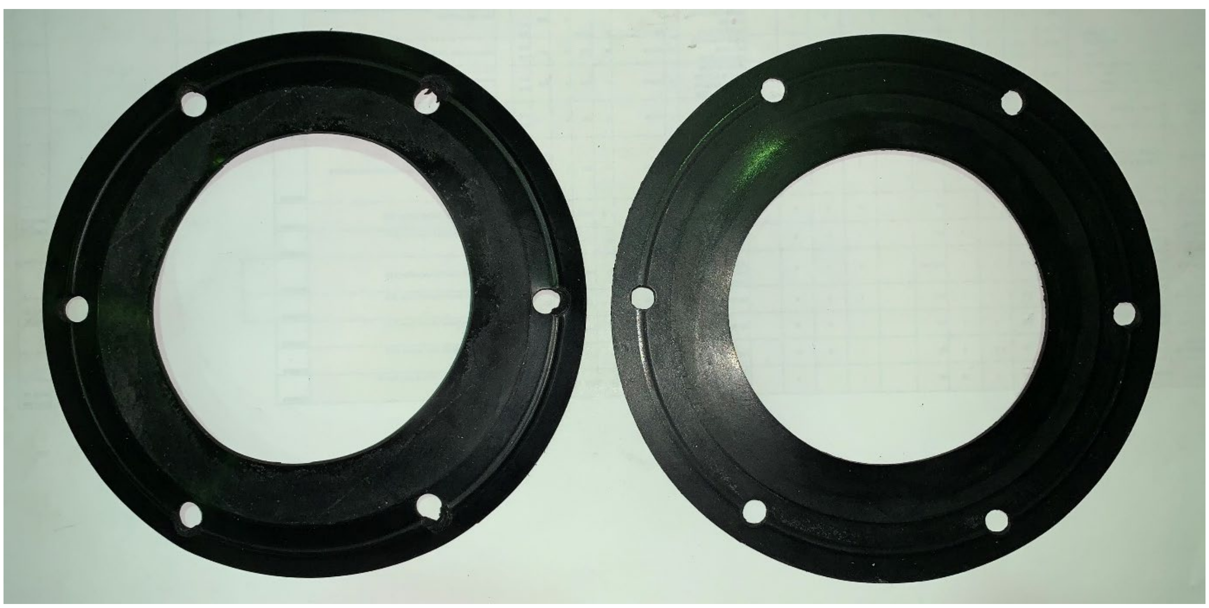

Figure 3-4. (Left): Shield Can Seal with Misaligned Holes After Testing; (Right): Shield Can Seal with Aligned Holes After Testing

<u>Blend Can Testing</u>

Softer and different configuration seals were interchanged within the blend can sphincter seal in order to minimize the loading force required to move a can through the sphincter seal. The goal was to remain below the aforementioned ergonomic limit. It would be beneficial to be able to move cans into the glovebox by hand and not require a pusher system, as there is limited space around an SPD glovebox. Table 3-3 displays the different seal inner diameters and durometers that were tested. The durometer that is labeled "50A/70A" meant that a combination of both durometers was simultaneously used. This setup consisted of all 50A seals with the first seal and second to last seal being a 70A seal "double stacked" behind it. All configurations passed the smoke test according to SRNL glovebox testing protocols; however, smoke was observed if smoke was applied longer than the calculated time limit. Reducing the seal diameter to 3.14", which increased the contact by 25%, resulted in less smoke intrusion than the default diameter of 3.3". It was also observed during hand pushing the cans that the 60A and 70A seals proved to be difficult to push.

Table 3-3. Blend Can Smoke Test Results

Inner Diameter	Seal Durometer	Smoke Test Results
3.30 in	60A	Passed
3.30 in	60A	Passed
3.30 in	60A	Passed
3.30 in	50A	Passed
3.30 in	50A/70A	Passed
3.14 in	60A	Passed
3.14 in	70A	Passed
3.14 in	70A	Passed

Figure 3-5 demonstrates how a failed smoke test looks if smoke was applied significantly longer than what the smoke test procedure prescribed. The location of the seam dictated the leak path of the smoke travelling though the sphincter seal. The reduced diameter seals produced barely visible smoke when tested longer than the time limit, which can be seen on the left portion of Figure 3-5. The right portion of Figure 3-5 shows visible smoke on the 3.30" ID (default sized) seals when the seam was oriented downwards.

Figure 3-5. (Left): Subtle Smoke Around Seam Location (Up) with 3.14" ID Sample Set; (Right): Visible Smoke Around Seam Location (Down) with 3.30" ID Sample Set

The 3.14" ID and 50A sample set was utilized for blend can testing. Subtle smoke was observed after 1 minute and 47 seconds when the seam was oriented up in the blend can sphincter seal. In a separate test, smoke was observed after 3 minutes and 14 seconds when the seam was oriented down. Testing was continued in this configuration because it did not require a high amount of force to push cans and provided subtle smoke if tested for more than the required time constraint of 12 to 15 seconds. Table 3-4 shows the leak rates, notes, smoke tests, temperature difference, and configurations that were tested. The numbers in parenthesis in the gage pressure column represent the absolute pressures. Towards the end of testing, it was advised that bar code stickers would be applied to the outside diameter of the shield and blend cans before passing them through the sphincter seals. For test 7, the blend can sat inside the seal for 6 days. For test 8, the can had 2 kg of steel shot epoxied inside the bottom of the can to simulate compacted dilutant material, which is a worst-case loading scenario on the seals. It was observed during the last two tests, after 4,500 cans had been passed through the sphincter seal, that the pressure went to atmospheric conditions in under an hour. It was also observed that increasing the time period that the blend can was inside the sphincter seal did not improve its ability to be leak tight, unlike the shield can sphincter seal. This might be due to the softer seal set in the blend can sphincter seal. Ultimately, the seam on the blend can caused a leak path that reduced the sphincter seal's performance to be worse than the shield can assembly; however, the seal still passed the smoke tests.

Table 3-4. Blend Can Leak Results

Test #	Number of Cans	Configuration		Gage, (Absolute) & [Atmospheric] Pressure (in. wc)		Temp. Difference (°R)	Calculated Leak Rate And Propagated Error (ft^3/hr.)	Smoke Test	Notes
		Seal Durometer	Seal ID (in.)	Initial	Final				
1	0	60A	3.3	-1.232 (408.1) [409.4]	0.011 (409.2) [409.2]	+1.59	-2.93E-03 ±2.54E-04	Passed	Seam was down and pressures went from -1.2" wc to -.2" wc in 18 minutes. It then gradually went to ambient conditions 12 minutes later.
2	0	50A	3.14	-1.33 (399.4) [400.7]	-.448 (400.8) [401.3]	+.09	+1.60E-02 ±1.38E-03	Passed	Seam was oriented downwards
3	1200	50A	3.14	-1.153 (399.8) [401.0]	-.136 (400.7) [400.8]	-.01	+1.03E-02 ±8.90E-04	Passed	The seam was oriented up.
4	2300	50A	3.14	-1.3 (406.2) [407.5]	0.14 (407.4) [407.3]	+.99	+4.83E-03 ±4.19E-04	Passed	Blend can was sitting in overnight. The seam was oriented up and the can had a sticker on the opposite side of the seam.
5	3400	50A	3.14	-1.3 (401.4) [402.7]	-.231 (402.3) [402.6]	+.09	+9.88E-03 ±8.57E-04	Passed	Seam was oriented down and can had a sticker on the opposite side.
6	4500	50A	3.14	-1.3 (403.6) [404.9]	-.23 (404.8) [405.1]	+.59	+8.26E-03 ±7.17E-04	Passed	Seam was oriented down and can had a sticker on the opposite side. The final vacuum pressure was -.23" wc.
7	4500 (6 days inside of sphincter)	50A	3.14	-1.3 (405.9) [407.2]	0 (407.4) [407.4]	+4.09	-3.00E-02 ±2.60E-03	Passed	Blend can with stickers (seam down) inside sphincter for 6 days. Went to atmospheric in 40 minutes and went to -.2 " wc in 20 mins

Test #	Number of Cans	Configuration		Gage, (Absolute) & [Atmospheric] Pressure (in. wc)		Temp. Difference (R°)	Calculated Leak Rate And Propagated Error (ft³/hr.)	Smoke Test	Notes
		Seal Durometer	Seal ID (in.)	Initial	Final				
8	4500 (2 kgs of steel shot epoxied to bottom of can)	50A	3.14	-1.3 (405.4) [406.5]	0 (406.4) [406.5]	+.99	+7.85E-03 ±6.81E-04	Passed	Went to -.2 in 35 min. and ambient conditions 12 min. after

The blend can seals were inspected for noticeable wear after durability testing. Figure 3-6 displays a blend can seal that was used for durability testing and an unused seal. No noticeable wear was observed on the used seal. The bolt circle holes were not deformed, which demonstrated adequate compression was achieved. It is also evident that compression was achieved by the indentation pattern caused by the ridges on the seal spacers.

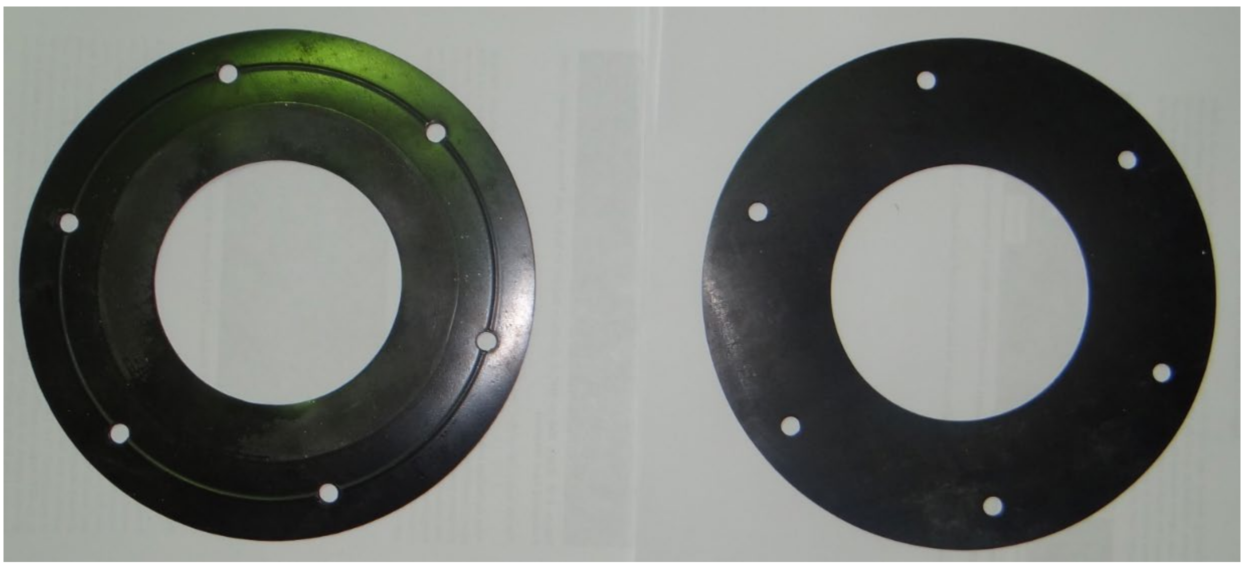

Figure 3-6. (Left): Used Blend Can Seal; (Right): Unused Blend Can Seal

One of the blend cans that was used during testing acquired a dent during durability testing. It did not negatively affect the rate-of-rise tests and smoke tests. The dent did not create a leak path when smoke tested. Figure 3-7 compares the dented blend can that was processed 2200 times to a blend can that was not used during durability testing. The red circle on the left blend can shows the dent that occurred during testing and it was also observed that the thin lacquer coating on the dented blend can was starting to wear down. The right portion of Figure 3-7 is a close-up of the dent, which depicts a depth that was less than 0.010".

Figure 3-7. Comparison of Blend Cans

The force required to move blend cans through the sphincter seal was observed before and after durability testing by utilizing a load cell. The average maximum force before durability testing was 32.8 lbf and the average maximum force after durability testing was 23.8 lbf. The seals may have become softer and worn during durability testing, while the harder shield can seal force values stayed almost constant. Both numbers were below the ergonomic limit of 46 lbf. even when including the accuracy of the equipment, which was ±1% of the full-scale output (100 lbf).

The application of tape along the blend can seam was done to observe if it can smoothen the discontinuity of the seam and thus improve the leak rate. It should be noted that one end of the tape was folded into a tab for easy removal once inside the glovebox. Table 3-5 shows the different tapes that were applied to blend cans and the smoke test results. The clear packing tape did not create a leak path which was determined by applying smoke for 5 minutes and monitoring for leaks. The taped can passed the smoke test twice, once with the seam up and once with the seam down on two blend cans. The nuclear grade tape (Figure 3-8), performed the worst amongst the different types of tape. This was due to the textured surface of the nuclear grade tape.

Figure 3-8. Nuclear Grade Tape on Blend Can Seam

Table 3-5. Blend Can with Tape Smoke Results

Tape	Seam Orientation	Smoke Observed in Enclosure	Time
Clear Packing Tape	Bottom	No	5 min
Clear Packing Tape	Up	No	5 min
Clear Packing Tape	Bottom	No	5 min
Clear Packing Tape	Up	No	5 min
Vinyl	Down	Yes	1 min 42 seconds
Nuclear Grade Tape	Up	Yes	47 sec
Nuclear Grade Tape	Down	Yes	59 sec
Green Tape	Down	No	5 min
Green Tape	Up	Yes	3 minutes 9 sec
Electrical	Down	Yes	2 min 30 sec

Table 3-6 demonstrates that the clear packing tape also improved the leak rate and sealing capabilities when compared to a blend can without tape. The leak rate data on this test was accurate due to the temperatures and pressures not fluctuating drastically during the 10-minute testing time interval.

Table 3-6. Blend Can with Tape Rate-of-Rise Results

Blend Can Configuration	Seal Durometer	Seal Inner Diameter (in.)	Gage, (Absolute), & [Atmospheric] Pressure (" wc)		Temperature (°R)		Leak Rate & Propagated Error (ft^3/hr)
			Initial	Final	Initial	Final	
Blend (seam up) with no tape	50A	3.14	-1.3 (404.4) [405.7]	-0.782 (404.90 [405.7)	521.77	521.89	+4.58E-03 ±3.97E-04
Blend (seam up with tape	50A	3.14	-1.3 (404.4) [405.7]	-0.917 (404.8) [405.7]	522.07	522.39	+1.63E-03 ±1.41E-04

Inner Sleeve Replacement Test

A V-block tray was used to hold the replacement inner sleeve that was pushed in to replace the currently installed inner sleeve inside the sphincter seal. A cradle was also built and placed inside the test enclosure to prevent the inner sleeve from deflecting downward when entering the test enclosure and binding with the outer sleeve. A larger diameter piston was machined for the pneumatic pusher to allow it to push the inner sleeve. However, alignment and binding issues occurred when using the v-block tray and pusher system. Because of this, all the tests were then done manually, and the force required to replace an inner sleeve can be seen in Table 3-7. The propagated error was the accuracy of the load cell (.1%) times the full-scale value of calibration range (8,000 lbf). This equated to be ±8 lbf. Tests 1 and 8, both with and without Krytox 240AC lubrication, show the results of pushing an inner sleeve into an empty outer sleeve. The tests with lubricant averaged 103 lbf. while the tests without averaged 224 lbf. Smoke tests were conducted on both inner sleeves after they had been installed. Both of the newly installed sleeves passed the smoke test.

Table 3-7. Replacing Inner Sleeve Results

Test	Inner Sleeve	Force (lbf)	O-Ring Lubrication
1	Blend	180	None
2	Shield	277	
3	Blend	177	
4	Shield	223	
5	Blend	187	
6	Shield	275	
7	Blend	207	
8	Blend	77	Krytox 240AC
9	Shield	146	
10	Blend	109	
11	Shield	92	
12	Blend	66	

4. Conclusions

Overall, both sphincter seal assemblies were able to remain leak tight after withstanding the transfer of a year's worth of blend cans and shield cans. This was determined through smoke testing before, during, and after durability testing. Smoke testing was the only test that had an acceptance criterion associated with it. The sphincter seals met or exceeded the smoke test acceptance criteria in all cases.

It should be noted that the leak rate decreased the longer the cans were inside the higher durometer sphincter seal. However, this relation was not seen in the lower durometer sphincter seal. The amount of force required to push blend cans through the sphincter seal decreased over time, this implies that the softer seals became worn during durability testing. Though the seals did seem to wear, no reduction in performance of the sphincter seal was observed. Since no visible deformation was noticed, the seals could be used longer than a year. The application of packing tape did appear to improve the leak-tightness of the blend can sphincter seal. However, conversations with the SPD customer led to agreement that the performance of the seal without tape is adequate and the operational concerns caused by application of tape outweigh the benefit. The welded and machined shield cans both had similar push forces, but the welded cans increased the leak rate of the sphincter seal. The support spacers that were inside the inner sleeves were shown to not have any wear after durability testing. The cans did not appear to have any contact the cans. The support spacers are included in the design to provide support to the cans if the seals were to sag after long term use, but sagging was not evident after a year's worth of cans have been processed. The support spacers can also be used as an indicator to replace the inner sleeves if the seals are worn and there is evidence that the cans are scraping against them. The leak rate data obtained was dependent on room's 161 temperature and pressure, which fluctuated due to its large volume and doors being opened to the outside.

Below is a list of modifications made to the sphincter seal assemblies to facilitate testing and these modifications will be applied to the final design:

1. The end cap components were modified to have a longer bore section before the tapered section to prevent interference with the adjacent sphincter seal.

2. The inner sleeves will have two O-ring grooves that will have a diameter of 8.011”. The inner sleeve OD will be 8.242”. These were the dimensions tested.
3. Application of lubrication of the silicone O-rings help reduce the inner sleeve replacement push force by more than half the loading. It is recommended to use Krytox or any equivalent silicone compatible lubricant.

5. Recommendations, Path Forward or Future Work

It is recommended to use 60A Neoprene seals with an inner diameter of 3.76” for the shield can sphincter seal and 50A Neoprene seals with an inner diameter of 3.14” for the blend can sphincter seals. It is also recommended to perform periodic smoke testing during normal operations to confirm the that sphincter seals remain adequately leak tight. The sphincter seal inner sleeve assembly should be replaced after a failed smoke test.

The following modifications are recommended for the final design:

1. The end cap gaskets will be removed from the assembly. This will improve the assembly in several ways:
   - Elimination of differential compression due to the greater thickness of the end cap seals than the sphincter seals and greater hardness of the end cap seal material than the blend can sphincter seals.
   - The initial design required complex measurement of the tolerance stack-up of the spacers and subsequent machining of a spacer, and the threaded rods had to be shortened after assembly. The final design concept in Figure 2-4 does not require these actions. The design also ensures that all components, including the acorn nuts, will be contained inside the inner sleeve.
   - Only one torqueing sequence will be critical for gasket compression instead of having to rely on three torqueing sequences.
2. The inner sleeve end cap will be modified so that it will contain a longer bored section in which the thread inserts will be installed. The drill depth for the thread inserts will have a ¼” clearance from the outer surface of the end cap. An O-ring groove will be fabricated on the bored section to accommodate a 259 size silicone O-ring that will eliminate the leak path demonstrated in Figure 3-2.
3. The inner sleeve lock cap will be removed and will be replaced by a spacer inside the inner sleeve. This spacer will have an O-ring groove for a 259 size silicone O-ring and will contain a lead-in chamfer for both sphincter seal assemblies. This spacer will be referred to as the end seal spacer in the final drawings.
4. The seal and support spacers’ ODs will be reduced by 0.010” to ensure ease of insertion inside the inner sleeve. The ODs on the inner sleeve end cap and end seal spacer will not be reduced to ensure proper O-ring sealing.
5. The blend can sphincter seal assembly will be shortened to house only one blend can. It will also contain only seven seals.
6. The outer sleeve weldment will have a small inner chamfer and the inner sleeves will not have an outer chamfer on either side to avoid contamination build up.
7. The inner ID chamfer in the inner sleeve will be removed to avoid a potential leak path. The outer ID chamfer will have a steeper angle to have more sealing surface area.
8. The removable plate will have six bolts to bolt onto the outer sleeve weldment.
9. A removable shielding cover will be placed onto the assemblies when the assemblies are not in operation.
10. The assemblies’ names will be laser etched onto the outer sleeve weldment’s flange, removable plates, and shielding covers.

11. Stronger stainless-steel fasteners may be used to ensure no yielding or galling will occur when torqued.
12. All clearance holes' diameters for ¼" fasteners will be increased to .281" to account for tolerance stack-up and ensure all components fit.
13. All surfaces that seal against flat gaskets will have a 0.005" flatness specification per American Society of Mechanical Engineers (ASME) PCC-1-2019 [11].
14. Wear was noticed on the locking cap and end cap components after durability testing. The wear on the locking cap was due to the pneumatic pusher being misaligned and the wear on the end cap was caused by the cans scraping against it while they were being pushed out. It is recommended to hard anodize the support spacers, inner sleeve end cap, and end seal spacers.
15. The seals shall not be cut by hand but rather fabricated by water jetting or any other seal cutting methods. All the seals used were cut by hand and many were discarded due to having defects because of human error.
16. The seal ODs will be reduced to prevent contact with the inner sleeve's ID when the seals are compressed.
17. Coupling nuts will be installed on the threads of the screws that protrude out of the outer sleeve weldment's flange.
18. All fasteners will have Loctite N-5000 anti-seize applied to their threads to prevent galling.
19. The outer sleeve gasket, or sphincter assembly gasket, will be a thinner and harder gasket described in the Merrick drawing package (P-PB-K-00054) [12].
    - Merrick's sphincter assembly gasket was fabricated and installed, using a torque specification of 25 in. lbs, and passed both a Helium sniffer and smoke test.

<u>Proof-of-Concept Tests of Final Sphincter Seal Designs</u>

The drawings drafted to address the recommendations in Revision 0 of this report underwent a thorough review. This led to a subject matter expert suggestion to remove the end gaskets from the sphincter seal inner sleeve design, modify the end components, and replace the end gaskets with O-rings between the end components and the ID of the inner sleeve. This design change eliminated the differential compression between the end gaskets and the sphincter seals and simplified the machining and assembly processes, thus resulting in a more repeatable design. No changes were made to the number, materials, or inner diameters of the sphincter seals or the inner diameters of the seal spacers, so additional endurance testing was not required.

In order to prove the final concept design would be effective, SRNL modified both tested sphincter seals assemblies and smoke tested both assemblies. Figure 5-1 showcases the tested sphincter seal assemblies that were modified to represent the final design concepts. For both sphincter seals, one of the support spacers was modified to become the end seal spacer component. The red circles in Figure 5-1 represent the new O-rings that were leak tested.

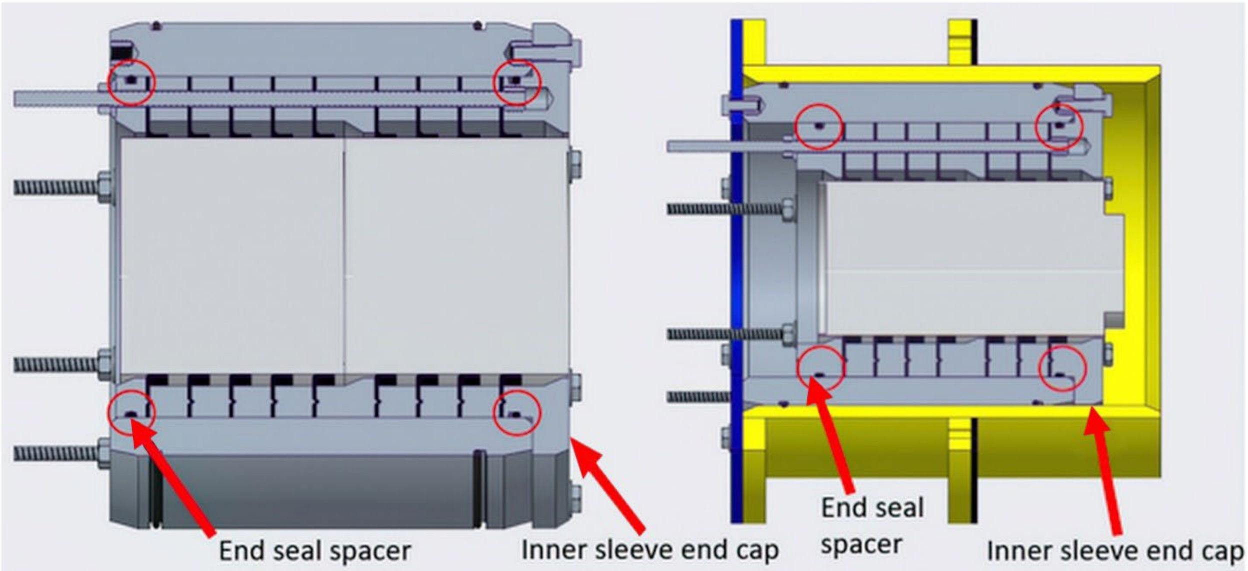

Figure 5-1. (Left): Modified Tested Shield Can Inner Sleeve; (Right): Modified Tested Blend Can Inner Sleeve Inside Outer Sleeve Weldment

First the inner seals' compression was measured while being torqued. This was done by torqueing the assemblies without the inner sleeves constraining them. The recommended compression range for neoprene gaskets is between 16-30%. For the blend can sphincter seal, this range was achieved when the assembly was torqued to a range of 35±3 in. lbs. and the shield can sphincter seal achieved this compression range when it was torqued to 25±3 in. lbs. After achieving the desired seal compression, it was noted that the sphincter seals protruded outside the OD of the spacers. The blend can inner seals protruded past the spacer OD by up to .17" and the shield can seal protruded up to .125". Both the shield can and blend inner seals were then trimmed and the ODs were reduced in the final drawings. Figure 5-2 displays both sphincter seal assemblies torqued down without the inner sleeves. The red circles show the seals that were cut so their compression could be measured while being torqued.

Figure 5-2. Sphincter Seal Assemblies Torque Test

After trimming the shield can seals and obtaining the modified end seal spacer and inner sleeve end cap, the shield can sphincter seal assembly was tested first. All fasteners' threads were lubricated with Loctite N-5000 anti-seize. All fasteners that were not critical to sealing were torqued between 28-31 in. lbs, which is the range specified in the SPD glovebox procurement specification document (M-SPP-K-00069) [13]. New EZ-lok thread inserts were used because they have a higher yield strength than the original thread inserts (60,000 psi to 35,000 psi). The thread inserts had to be threaded into the inner sleeve end cap an extra 1/8" due to it interfering with the male ridge on the adjacent seal spacer. Krytox 240-AC was applied to the inner O-rings in addition to the inner sleeve O-rings. The nuts at the end of the threaded rods, with the sealing washers in place, were torqued down to the nominal value of 25 in. lb. Per the Loctite N-5000 manufacturer's instructions, the fasteners were retorqued after 24 hours. The nuts were measured before retorquing and had loosened by a range of 9-12 in. lbs. Two shield cans were placed inside the sphincter seal and passed a smoke test in which smoke was applied around the can perimeter and at all the sealing fasteners. It also passed the Helium sniffer test at these locations as no leaks were greater than 1x10-4 atm cc/sec. The two-inner O-rings sealed the leak path that occurred during initial testing. It was decided that the sealing washers will remain in the final design as a precautionary measure.

The blend can sphincter seal was assembled in a similar fashion as the shield can sphincter seal assembly, but the nuts on the threaded rods were torqued to 35 in. lbs. per the results of the compression test. This series of testing was done with a newer blend can design that had a seam that was at least 0.005" greater in depth than the original seam. After retorquing the nuts after 24 hours, smoke testing was performed with the seam up on both new and old blend cans. Smoke was instantly observed inside the test enclosure for these tests. Helium sniffer testing showed that the location of the seam on the blend can produced a leak that was greater than $1x10^{-4}$ atm cc/sec. Smoke testing was also performed on the cans used during endurance testing and smoke was observed during some of these tests as well.

Upon further investigaton to determine why the blend cans and shield can did not pass the smoke test using the new design, it was noticed that the seamless rolled perimeter at the base of the cans tested with the initial design was in direct contact with the first inner seal as seen in Figure 2-13. Coincidently, the mechanical assist device used for durability tested placed the blend can in this position during testing. With the blend can in this position with the seam up, it passed the smoke test. This new finding demonstrates that a few of the blend cans may not have been in the optimal position inside the sphincter seal, which caused the test enclosure to rise to atmospheric conditions quickly in Table 3-4. In addition to testing a new blend can, a new blend can that had slight damage at the base was also tested along with the counter weighted blend can. These tests produced passing tests and the tests were repeated eleven more times with a combination of the seam up and down. All smoke tests were successful with the blend cans in this preferred position, which confirmed repeatability. While conducting every test, the distance from the front spacer (end seal spacer) to the sealing lip on the blend can was measured to determine a tolerance range for a push assist device and the distance range was between 1.25-1.5".

A suggestion was made to design the blend can sphincter seal assembly to ensure both ends of the can are in contact with a sphincter seal; however, tolerance stack-up concerns make fabrication of this design complex. Each neoprene seal has a thickness tolerance of ±0.016" and all the inner seal spacers have a thickness tolerance of ±0.005". Summing the tolerances of all these components results in a stack-up of at least ±0.152". Assuming the base of the can is perfectly centered in contact with a sphincter seal, the sphincter seal that would seal against the top of the can must be located within ±0.125" of its designed location to ensure a seal on this part of the can. Thus, designing the assembly to seal on both ends of a can was not be pursued. A pusher assist device shall be designed to repeatably insert each blend in a position that ensures passing smoke test results.

The torque ranges on both assemblies ensured that the stainless-steel fasteners are torqued to less than 90% of yield, which demonstrates that 304 stainless-steel fasteners can be used. The reduction in torque relative to the initial design was due to having no differential compression from the end cap gaskets and not requiring to work two complex torqueing sequences on the inner sleeve locking cap and end cap. Trimming the ODs on the inner seals prevented any interference with the IDs of the inner sleeves when torqued, which also aided in reducing the torque relative to the initial design.

Path Forward

All drawings of the final sphincter seal designs incorporating the recommended changes will be provided to SPD.

K-Area Operations personnel evaluated the force required to push cans through both assemblies and for replacing the inner sleeves. It was determined that a mechanical assist system must be developed to push in both the blend and shield cans. The assist device to push cans through may be a mechanical linkage device that attaches to the outer sleeve. This tool will also push in the cans a set distance to ensure all the inner seals are having constant contact with the cans. This is especially important for the blend cans, as noted in the section above. This will promote seal longevity and will prevent the operators from putting their hands inside the sphincter assemblies. Operations personnel concluded that an assist device for replacing the inner sleeves is not required. Operations personnel did recommend replacing the inner sleeve with the removable plate attached to it. A cradle or v-block component is recommended to catch both the shield cans and blend cans, as well as preventing the inner sleeve from binding when replaced. In addition, it is recommended that a sacrificial shield can, or blend can plug be used during inner sleeve replacement. This would allow for removal of the serialized process cans before replacement of the inner sleeve and prevent the need to recover cans once the inner sleeves are loaded into the glovebox. This sacrificial component can also be used as a spacer to prevent the inner sleeves from contacting each other during inner sleeve replacement.

A full-scale mock-up of the final sphincter seal assemblies will be fabricated and assembled in the SPD glovebox.

Lastly, any future leak rate testing should be done in a more controlled environment where ambient temperatures and pressures can be better maintained. This will help prevent the variability seen in the leak rate calculations at the low pressures that were tested.

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