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HELIUM LEAKAGE TESTING OF SAFSHIELD® 2773A WITH SILICONE O-RINGS

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ABSTRACT

The Croft Associates SAFSHIELD® 2773A is designed as a Type B(U) Package to the IAEA Regulations for the Safe Transport of Radioactive Materials [1].

The SAFSHIELD® 2773A packaging comprises of a high integrity lead shielded stainless flask (Design No 2774) which provides containment and shielding of the contents. The flask is carried within a double skinned carbon steel outer casket (Design No 2773) providing regulatory impact and thermal protection.

The 2774 flask has a conventional double O-ring closure design incorporating silicone O-ring seals. It is a regulatory requirement to verify the containment system i.e., the O-rings and flask closure at manufacture and periodically during annual maintenance. The containment verification, depending on product form and State Variations, requires helium leakage testing to ANSI N14.5 [2] or ISO 12807 [3] against a leakage rate acceptance criteria of: 1.0×10^{-7} ref-cc.s^{-1} or 1.0×10^{-8} Pa.m^{3}.s^{-1} SLR respectively.

The operational temperature range of silicone O-ring seals is very desirable for transportation packages, however, the permeability coefficient of helium through silicone is up to 10 times greater than that of ethylene propylene and fluoroelastomer (Viton) O-rings. This high permeation creates challenges for the helium leakage testing and consequently, despite their performance characteristics, silicone O-ring seals are seldom utilised in high integrity containment applications where helium leakage testing is required.

In response to this issue Croft, with the support of Leak Testing Specialists Inc, have developed a test methodology which provides for accurate timed release of helium into the containment system and a test configuration that significantly reduces the System Response Time (SRT), i.e., the time taken for the Mass Spectrometer Leakage Detector (MSLD) to reach a steady state reading from release of helium, before the onset of permeation. The methodology utilises a fine capillary from the helium quartz reference leak to the test port and then a high conductance, multi-port arrangement to maximise the helium conductance to the MSLD.

This paper explains the problems associated with helium leakage of high integrity enclosures utilising silicon O-rings and how these problems were resolved, validated, and verified through a dedicated test programme.

INTRODUCTION

The SAFSHIELD® 2773A package is a general-purpose Type B packaging for the transport of non-fissile radionuclides under non-exclusive use. In the package's latest configuration, the contents are in solid form, and transported by road, rail, sea and air.

DEVELOPMENT OF THE SAFSHIELD® 2773A

SAFSHIELD® package design No 2773A was originally developed primarily to cover the shipment of bulk quantities of Cobalt-60 for the treatment of cancer through focused gamma irradiation of malignant tumours.

The packaging design consists of an inner lead shielded flask (design 2774) encased in a stainless steel skin, with impact and thermal protection provided by an outer casket (design 2773), as depicted in Figure 1 and Figure 2 respectively. Inner and outer Silicone O-rings are fitted to the top flange in the flask body to provide a verifiable leak tight closure.

The containment boundary of the 2774 flask consists of the cavity liner, top flange, closure flange (lid), and the inner O–ring fitted to the flask closure. The outer O-ring of the flask closure is not part of the containment boundary (the containment boundary is shown in Figure 3).

Figure 1. 2773A Packages within their transport pallets

Figure 2. Flask 2774 within the 2773 casket base assembly, with a cross section depicting the internal structure and lead shielding

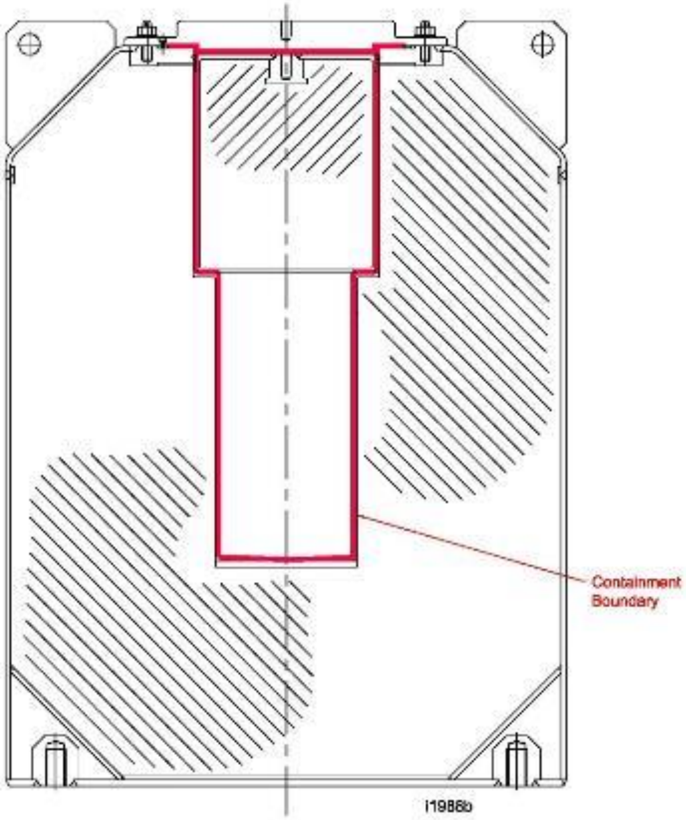

Figure 3. Flask 2774 Containment Boundary

CONTAINMENT VERIFICATION TESTS

The packaging is designed to provide containment for non-special form solid material under normal and accident conditions of transport. The leak tightness standard is that there shall be no leakage greater than 5 x 10^{-5} Pa.m^{3} s^{-1} SLR (5 x 10^{-4} bar.cm^{3} s^{-1} SLR) through the containment boundary. The 2774 flask features a double O-ring seal to facilitate leak testing and there is a test port that provides access to the interspace volume between the two seals.

Based upon the above leakage test criteria the packaging is tested by gas pressure drop or pressure rise to verify the leak tightness to meet the IAEA SSR-6 [1] regulations. However, with the package now being used in the USA, a helium leakage test was required with a pass rate of 1.0 x 10^{-7} ref-cc.s^{-1} or 1.0 x 10^{-8} Pa.m^{3}.s^{-1} SLR to meet the US 10 CFR 49 Regulations [4] .

LEAK TESTING ISSUES

Helium leakage testing with Silicone O-rings is notoriously difficult due to the rapid rate of helium permeation through silicone. This means that there is a very short period of time in which to measure the leakage between introducing helium into the system and the commencement of helium permeating through the inner O-ring seal.

The design of the O-ring groove and interspace provides a small path of conductance. The Figure below shows the cross-section area to be approximately 1mm^{2} giving a volume of less than 10 cc. In a worst-case scenario, the length of a leakage path would be 466 mm (π297/2), where the leak is assumed to occur 180° opposite the test port connected to the MSLD. This gives an estimated conductance of 10^{-6} m/s.

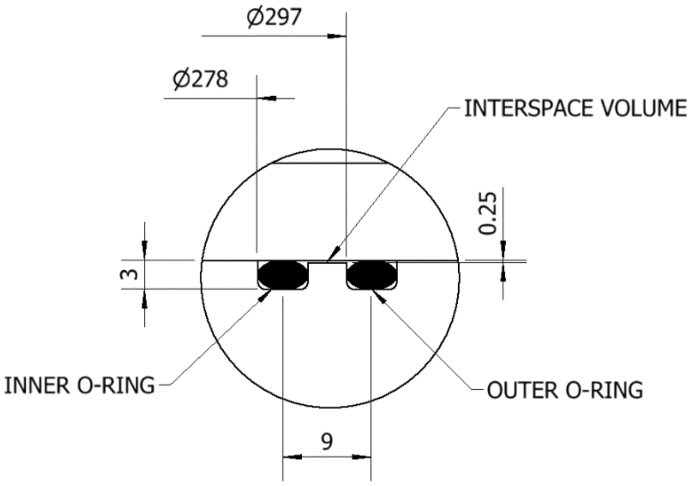

Figure 4. O-ring Groove Detail

For the closure test, a reservoir is charged with helium and placed inside the flask before closing the lid. The reservoir has a timer which releases the helium at a set time. The timer is set to a convenient time to allow the reservoir to be placed inside the flask, close the lid, torque the eight closure nuts to 19Nm lid, connect the vacuum hoses to the Mass Spectrometry Leakage Detector (MSLD) and time for the MSLD to pump down to a background - typically to the 10^{-9} atm. cc.s^{-1} or 10^{-10} Pa.m^{3}.s^{-1} decade.

It is general practice to perform a qualification test in advance of the closure test to determine the System Response Time (SRT) and correction factors to be applied to the closure test results.

The SRT is the time it would take until the MSLD yielded a steady state reading and true measurement if a real leak were to exist through the inner O-ring or closure hardware. The SRT is established by creating an artificial leak in the O-ring interspace with a known helium leakage rate from a calibrated reference leak.

The Permeation Time (PT) is the time at which permeation commences before increasing exponentially.

The Test Duration Time is the time period during which a leakage measurement is taken once a steady state MSLD reading (SRT) has been reached and before the onset of permeation (PT).

System Response Time < Test Duration Time < Permeation Time

With ethylene propylene or fluoroelastomer O-rings, which are the traditional materials used to seal Containment Vessels (CVs), permeation occurs after several minutes which provides adequate time to achieve the SRT and measure the leakage rate before the onset of permeation. However, with silicone O-rings the permeation can commence within less than one minute which means a very short SRT is required.

ORIGINAL DESIGN

The original design of 2774 Flask had one interspace test point to connect to the MSLD (see Figure 5) for the closure test using the helium reservoir with timer. Traditionally a test lid with an additional interspace test point at 180 degrees to the original test point (see Figure 6) is used for the SRT qualification test. A calibrated reference leak with a known leakage rate is connected to the additional test point and the time is recorded from release of helium until the MSLD records a steady state reading, (SRT). The additional test port is positioned at 180 degrees to the original test point as it is the furthest position away from the original test point, which would yield the worst-case condition in the case of a leak.

With the two test port set up, with the reference leak at 180 degrees to the MSLD connection, it took approximately 7 minutes 40 seconds to achieve a steady state reading which was greater than the permeation time.

To achieve a useable test, the SRT needed to be reduced. Positioning the reference leak closer to the MSLD test port at 45 degrees (see Figure 7) reduced the system response time to reach steady state to approximately 3 minutes 40 seconds.

Figure 5. Calibrated leak 180 degrees from MSLD Test port

The reference leak is also connected to a high vacuum pump via a hose and switchable valves which exhausts the helium to the vacuum pump prior to helium being introduced into the system to determine the SRT. If this was not the case, then helium would build up upstream of the reference leak valve which, when released, would cause a burst of helium (relatively speaking) which would artificially increase the time to stablise thus increasing the SRT. Therefore, the valve to the vacuum pump is closed and the valve to the system is opened simultaneously, which enables the reference leak to release helium as close as possible to the known calibrated leak rate.

If the reference leak were to be connected directly to the MSLD then it could be expected that the MSLD would measure very close to the specified calibrated leakage rate and the SRT to be very short in the absence of any hoses. However, in this system the reference leak is positioned some distance from the MSLD. The more tortuous the flow path to the MSLD and the bigger the system volume the bigger the system losses which can be measured by the difference between the specified reference leakage rate value and the actual leakage rate measured by the MSLD. The test procedure includes correction factors to take account of these losses along with temperature, altitude, and helium concentration correction factors.

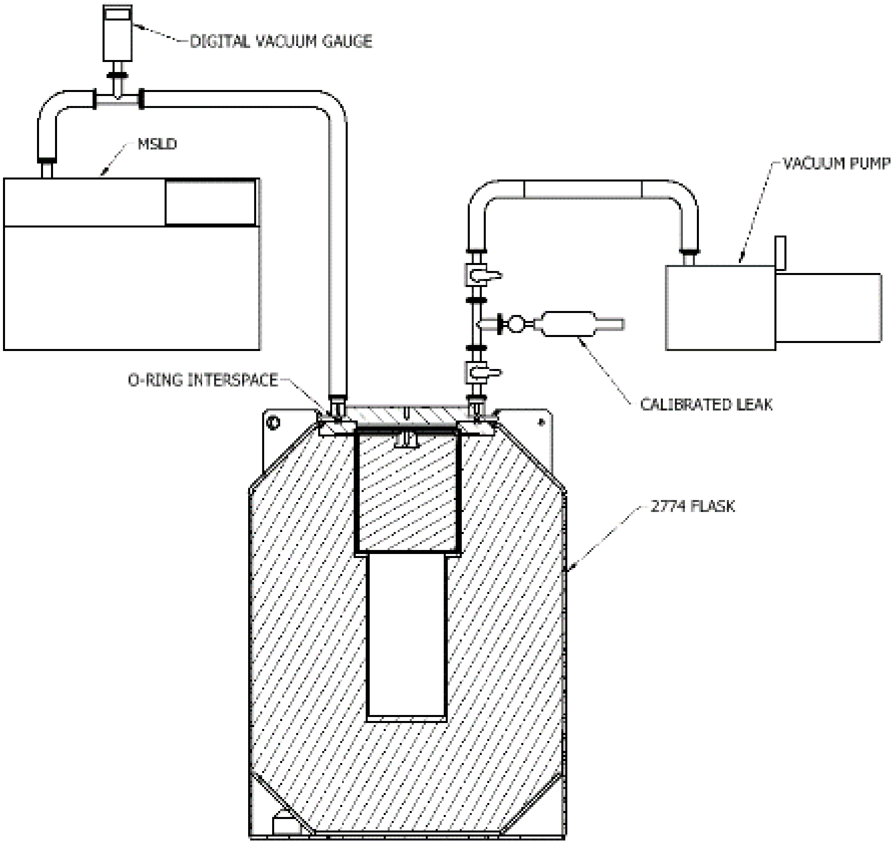

Figure 6. System Response Test Setup

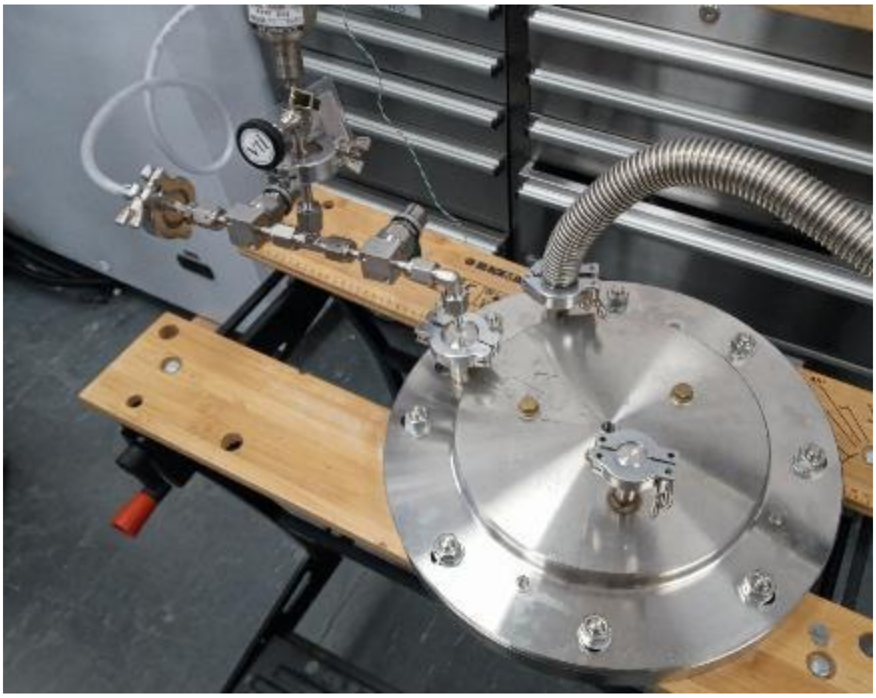

Figure 7. Calibrated leak 45 degrees from Mas Spec Test port

DESIGN SOLUTION

It was proposed that if four test ports were used at 90 degrees to each other in the lid and all connected to the MSLD, the reference leak could not be more than 45 degrees from the MSLD test port thus improving the SRT [5], the leakage path would now be no longer than 116 mm (466/4). This increases the estimated conductance to the test ports to approximately 10^{-5} m/s.

In addition, it was recommended that the SRT could be improved further by decreasing the volume of the pipework upstream of the MSLD test port to the reference leak and increasing the helium conductance downstream of the test port towards the MSLD by using a manifold made of four large bore vacuum hoses in parallel (see Figure 8). The helium conductance is directly proportional to the bore size of the hoses and hose length, e.g. the larger the bore and shorter the hose the greater the helium conductance to the MSLD which will yield a shorter SRT.

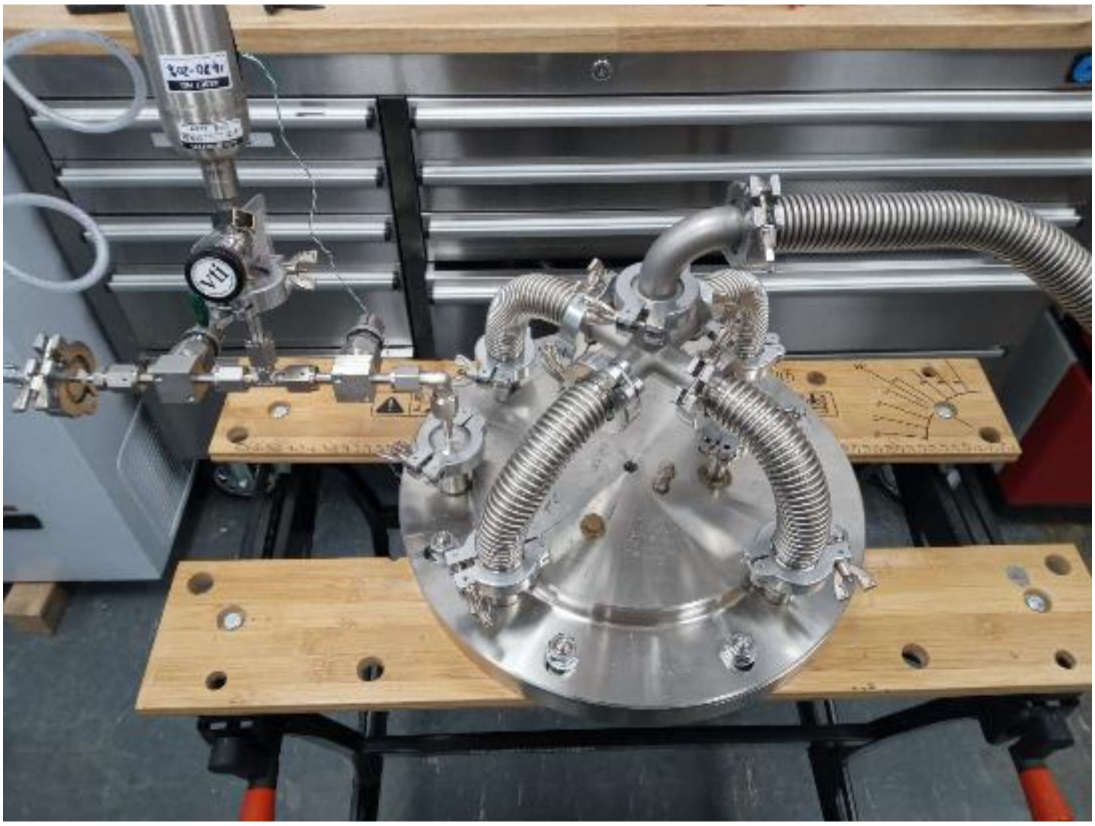

Figure 8. Four test ports at 90 degrees, all get connected to MSLD

RESULTS

With this new setup, tests were carried out to determine its effectiveness. The SRT was reduced to 17 seconds to reach equilibrium at 7.30 x 10^{-8} atm.cc.s^{-1} (see Figure 9). Helium was first detected by the MSLD in less than 1 second.

Additional tests were performed to determine the time for the helium to permeate across the inner silicone O-ring. With 100% helium in the evacuated cavity the O-ring permeation starting at approximately 24 seconds.

Further tests were undertaken to determine the time for the helium to permeate across the inner silicone O-ring when the self-releasing reservoir is used. This produced a concentration of 56% helium and a permeation time of 30 seconds (see Figure 10).

With this information the system response time was known and the permeation time so a suitable test duration could be determined:

System Response Time < Test Duration Time < Permeation Time
17 seconds < Test Duration Time < 30 seconds

A test duration of 22 seconds was selected as this provides a suitable margin between the system response (SRT) and permeation time (PT).

If there was a real leak in the system, helium would be detected before the test measurement time.

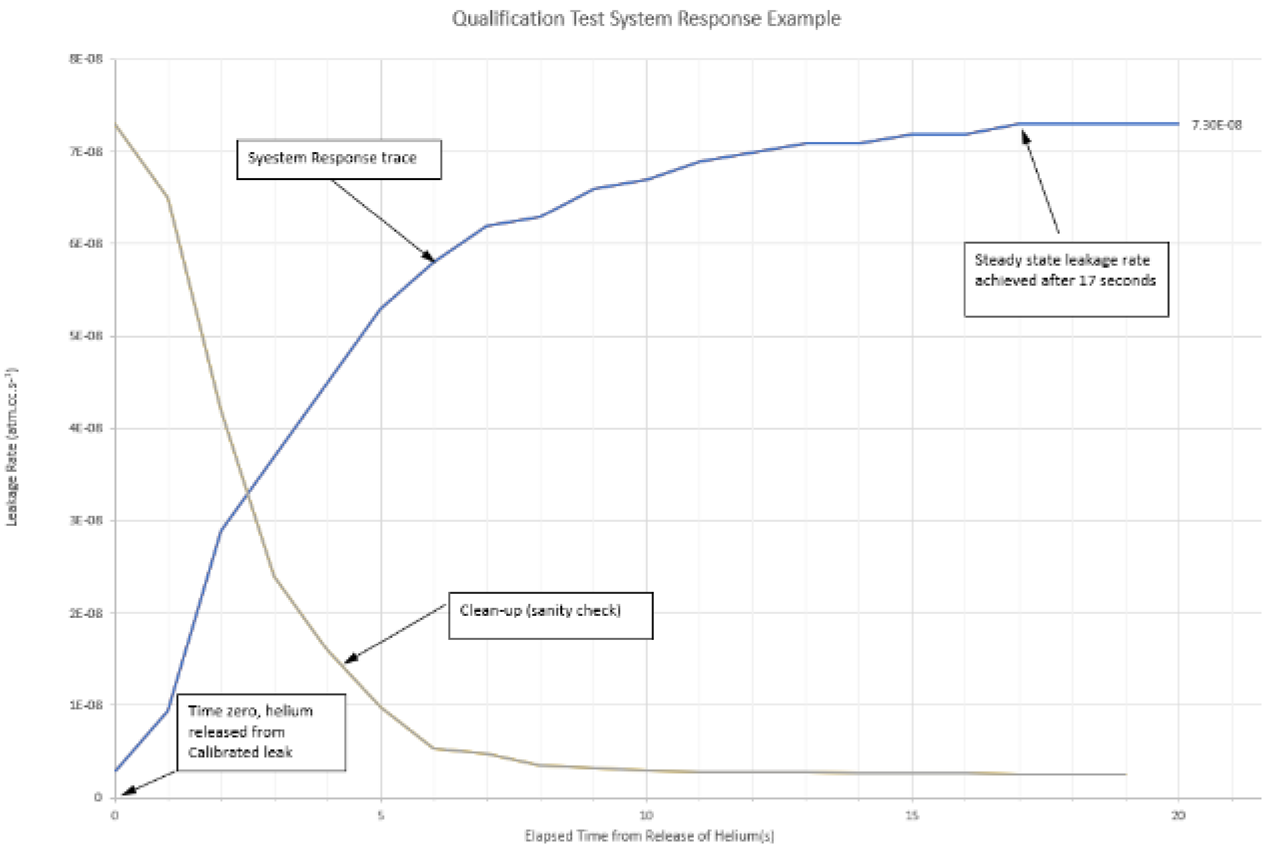

Figure 9. Qualification system response test example

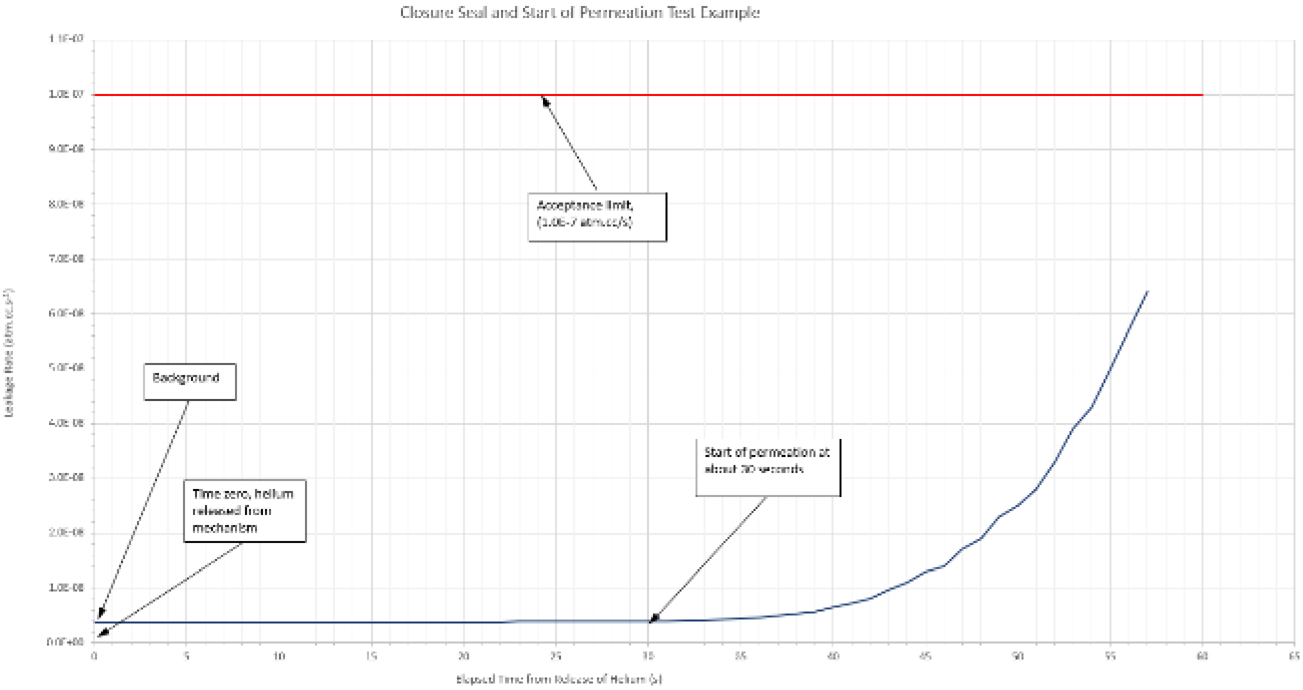

Figure 10. Containment seal and start of permeation

CONCLUSIONS

The work undertaken has demonstrated that with use of a multi-test port system and appropriate selection of leakage testing hardware i.e. the use of high conductance hoses downstream of the interspace, that the system response time (SRT) can be significantly reduced. These changes enabled helium leakage testing of SAFSHIELD® 2773 closure to ANSI N14.5 to be successfully completed. It is believed that the methodology could be utilised on other transport packaging designs fitted with silicone O-ring seals and which require high integrity containment versification using helium MSLD methods.

ACKNOWLEDGMENTS

The authors would like to extend thanks to the technical teams at Croft and Leak Test Specialists for their contributions to the development of the successful testing methodology.

REFERENCES

[1] IAEA Safety Standard, “Specific Safety Requirements No. SSR-6: Regulations for the safe Transport of Radioactive Material 2012 Edition”.

[2] “ANSI N14.5-2014, American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment”.

[3] International Standard, Safe transport of Radioactive Materials, Leakage testing on packages, ISO 12807:2018.

[4] Title 49, Code of Federal Regulations, Parts 100-199, United States of America.

[5] Croft Associates, 2774 Helium Leakage Tests, CTN 2019/05.