The Use of Dual Material Seals For Packaging

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The use of dual material seals, metal and elastomeric for a transportation package, provides a viable option for packages requiring high temperature seal capability. Allowing the seal area to go to higher temperatures then allowed for all elastomeric seal reduce the necessity of providing thermal protection during a postulated accident condition fire. It also increases the options for impact limiting features that do not also mitigate the affects of accident thermal events. Typically, high temperature seals require the use of metal O-rings. Only one seal (typically identified as the containment seal) needs to survive the hypothetical accident conditions, including the high temperatures that may occur during the prescribed hypothetical thermal event. However, to expedite the assembly leakage rate testing of radioactive material packages, a dual O-ring seal arrangement is often used to allow creation of a relatively small volume test cavity between the seals. For any package that is being used on a frequent basis, the total cost of seals can be significantly reduced by using an elastomeric seal as the secondary seal. The elastomeric seal is not the containment boundary seal and does not need to survive the high temperature condition.

To get the dual material O-ring seals to seat properly, a different approach has to be taken than with closure of a radioactive material package that does not use metallic O-ring(s). A metal O-ring requires an application of a seating force while the elastomeric package requires a certain percentage of deformation. This is further complicated when the seating force is developed using a multi-bolt closure. Because of the nature of multi-bolt closures, elastic interaction prevents the equal application of force. This paper develops the methods involved in properly closing and establishing containment when using dual material seals with a multi-bolt closure. These methods were demonstrated in two production casks requiring testing leak rates of 10^{-7} standard cc/sec.

1 Introduction

Dual seals are often used for packaging for redundancy or more often for ease of operation and testing. These seals often have different performance requirements. Typically there is one containment seal that has the full burden of maintaining containment for all conditions of transport. The other is a test seal with no regulatory requirements, but capable of maintaining a vacuum in the annulus between the two seals. The test seal is used only for verification that the containment seal meets the regulatory leakage rate, as specified by the transportation license. In some cases, it is more economical to select different materials for the two seals when the containment seal is a metallic material. The performance and assembly characteristics of both seal materials must be understood so that proper closure and verification leakage rate testing can be performed. Once the characteristics of both seal materials are understood, a proper design and sealing procedure can be developed.

2 Background

Regulatory rules requiring a high degree of leak tightness for radioactive material packages has lead to demanding requirements on transportation package closure seals. These requirements have continued to evolve as the understanding of leakage and how seals work has developed.

In the US, the term 'leak tight' has been defined by ANSI N14.5 [1] as $1X10^{-7}$ std-cc/sec. A wide variety of O-rings type seal designs are used to accomplish this requirement. A unique feature of most US radioactive packaging seals is that they are not only required to seal to the very high standard of leak tight, but they must also be capable of maintaining this high standard during and following application of severe design conditions. To demonstrate leak tight, usually involves the use of helium leakage rate testing. The typical helium leakage rate testing involves filling the inner cavity of the package with helium and establishing a vacuum between the containment and test seals. The cavity between the seals is than sampled for helium to detect any leakage.

The typical material used for transportation containment boundary closure seals is some type of elastomer. Most elastomeric seal materials have an upper temperature limit in the 400ºF range. This requires that the seal area is protected from the regulatory fire event. Generally this is easily done by the use of impact limiters over the closure end of the package. However there are cases where a package is used where impact limiters are not required for mechanical load mitigation. Additionally, other thermal load protection components are not desired to avoid operational time and radiation exposure affects. One such situation is on site transfers at the US Department of Energy Hanford Reservation in the State of Washington in the United States. Because of the ability to use administrative controls for speed, routes, and traffic, etc, impact limiters are not required. This allows considerable savings in operating the package since impact limiters were not required to be taken off and on. One such cask, shown in Figure 1, does not require impact limiters but must survive the fire accident without loss of seals.

In the case of the example cask, impact limiters were not required to mitigate mechanical loads, and the customer did not wish the use thermal load mitigation devices to save on operation and radiation costs. A seal design using a metallic O-ring in combination with an elastomeric O-ring proved successful. The primary metallic seal has silver C-section cladding energized by an internal spring. The test seal is an elastomeric O-ring. The elastomeric seal is outside of the metallic seal with its only purpose to provide a small vacuum test cavity. The test seal was not required to survive the accident fire conditions.

Figure 1 Transfer Cask without Impact limiters

3 Seal Requirements

The metal O-ring seal was a spring energized metal seal with a ductile jacket. The sealing principle is based on the plastic deformation of a jacket with much greater ductility than the flange materials. This occurs between the cash sealing faces and an elastic core composed of a close-wound helical spring. The jacket/spring combination is selected to have a specific compression resistance. During compression, the resulting pressure forces the jacket to yield and fill the flange imperfections while ensuring positive contact with the flange sealing faces. Each coil of the helical spring acts independently and allows the seal to conform to surface irregularities on the flange surface. However, this combination of spring and jacket makes for a seal that is significantly stiffer than an elastomeric and requires much greater preload to both properly seat the seal, and plastically deform the spring, so that jacket has adequate contact with the sealing surface. The grove depth must be tightly controlled so that the spring is not overly crushed while still achieving the requisite amount of plastic deformation. The depth of grove allows the seal to deform to the optimum combination of resiliency and contact force. Metallic seals are capable of sealing without obtaining the optimum seal load and crush. This allows the seal to gain an initial seal without optimum loading being applied.

The seal provides a high quality seal with a uniform crush and pressure along the full length of the seal. This is assured when metal-to-metal contact is made between the cask lid and the sealing flange. Because of the stiffness of the seal, relatively high compressive loads and adequate seal structural stiffness are required to compress the seal. When the seal is properly deformed it seats against the sealing surfaces generating a leak tight seal. These loads, usually applied by bolting loads, can be difficult to obtain since the preload are applied by one bolt at a time. The relative stiffness of the lid requires each bolt to develop more crush load during tightening phase when not all bolts are tightened equally than the predicted load when the bolts are carrying equal loads. It should be noted here that although the fasteners are used as screws they will be referred to as bolts.

An elastomeric seal requires much less uniformity of load and much lower sealing preload. Elastomeric O-ring seals operate on the bases of self resiliency. As with the metallic seal the stiffness of the flange relative to the seal allows the lid to apply a uniform loading even though the preload may only be applied in a few locations. The lower compressive strength of the seal permits a much lower preload. Face seals as used on this cask rely on the O-ring grove being properly sized. With a properly sized grove, the compression of the O-ring is controlled by the flange to closure lid interaction (metal-to-metal contact). If the lid moves in relation to the flange the elastomeric seal can follow the lid. Seals have been tested to maintain a helium leak tightness with compression from 14%-35 %. It takes very little force for the seal to compress in contrast to the high seating loads for the metallic seals.

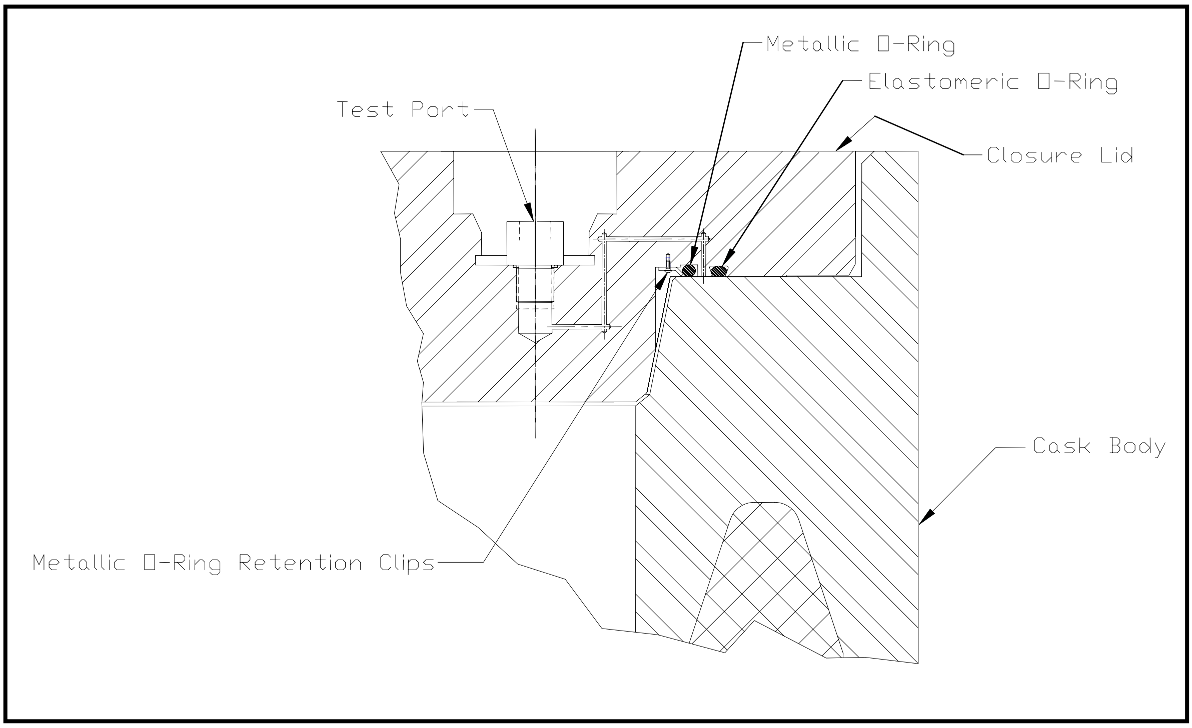

Figure 2 Closure Assembly

4 Design

The metallic O-ring has a specified load per inch value that is required for seating and maintaining the seal. The preload required to plastically deform the seal and obtain an optimum seal can be calculated from the seal manufacturer's data. Metallic seals have very uniform and reproducible force deflection curves. Testing done in the development of this cask verified the required compressive load to obtain the required deformation. The key in this design is to apply the load correctly so that the metallic O-ring will crush sufficiently to allow activation of the elastomeric seal.

The load is obtained by applying torque to the bolts. The applied preload is combined with the postulated accident loads of a transportation cask to determine the size of the bolts. A complete evaluation of the bolts and seals was done in accordance with NUREG/CR-6007 "Stress Analysis of Closure Bolts for Shipping Casks".[2)}

The applied load was initially determined by the use of the standard torque–preload equation.

$T = F (KD)$

Where:

T= Applied Torque

F=Preload
D= nominal diameter of the bolts
K= nut factor

This combined with the bolt evaluation per NUREG CR-6007[2)] provided a range for the torque values for the operator to meet. There is a relatively narrow range of torque values that can be applied. The preload must be high enough to seat the seal, yet have sufficient strength left in the bolt to resist all external loads from the accident conditions. The preload was applied in multiple steps in a star pattern applying a fraction of the preload each step until the maximum torque permitted was obtained. These values proved to be inadequate to obtain a seal with the initial application of the maximum torque load when the acceptance testing was undertaken.

The design requirements were not met by applying a simple application of maximum torque. Although the torque was applied to the bolts the preload was not transmitted to the seals. In the design it is assumed that all pre-loads are equally shared by the bolts. During the preload application this is not the case since each bolt, via the stiffness of the lid is asked to crush a larger portion of the seal than if they were shared equally. Investigation showed that not all twenty-four bolts were carrying equal loads even though they had been tightened in a star pattern up to the upper part of the allowable range in a multi-step process. The bolts were all cleaned, lubricated and reinstalled with the same result. This condition is often referred to elastic interaction of the bolts and is found quiet often with gasketed seals. The lid had adequate stiffness to allow adjacent bolts to carry the load of each other. During disassembly it was found that only about a quarter of the bolts were carrying anywhere near the desired preload.

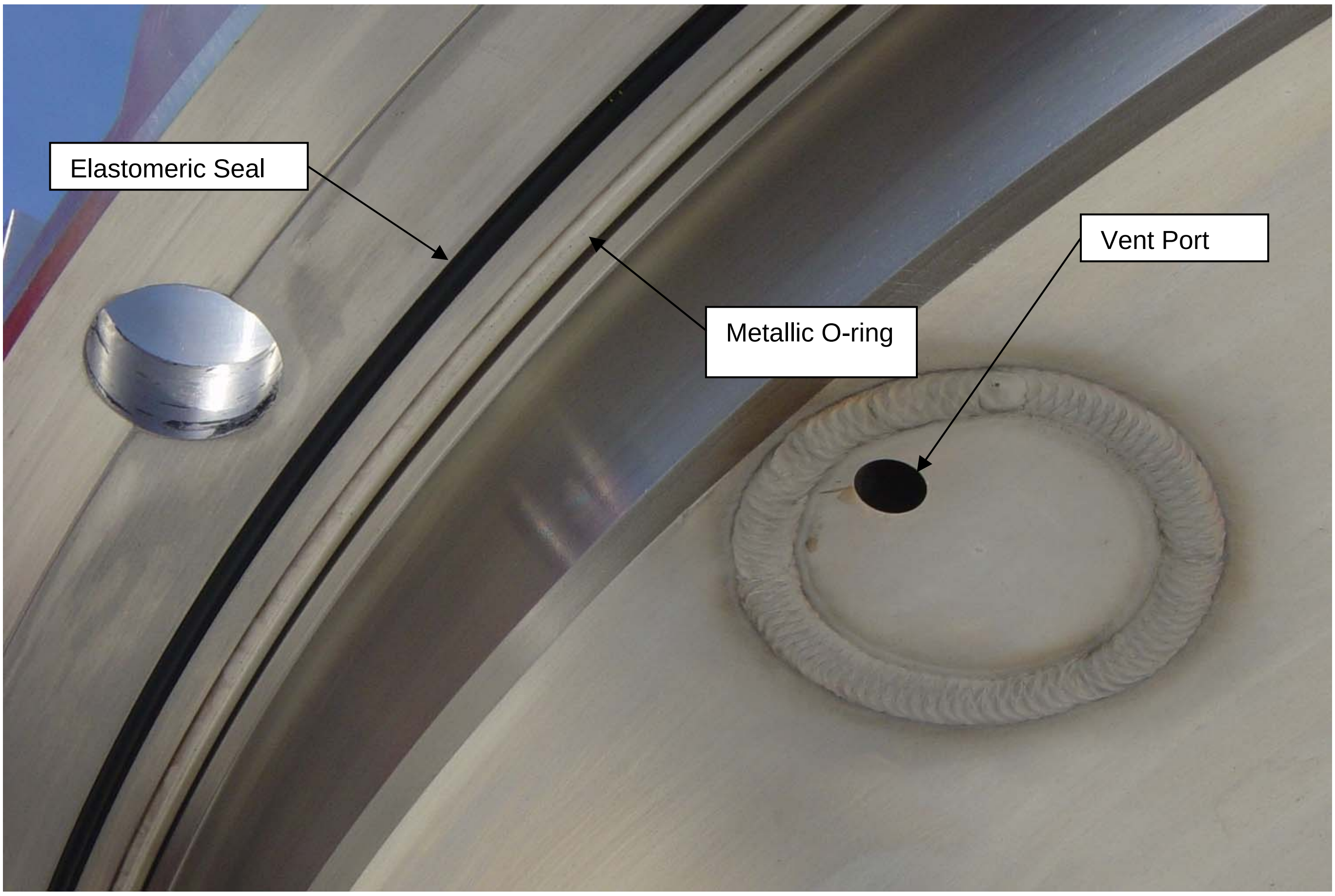

Figure 3 - Seals Installed on Lid

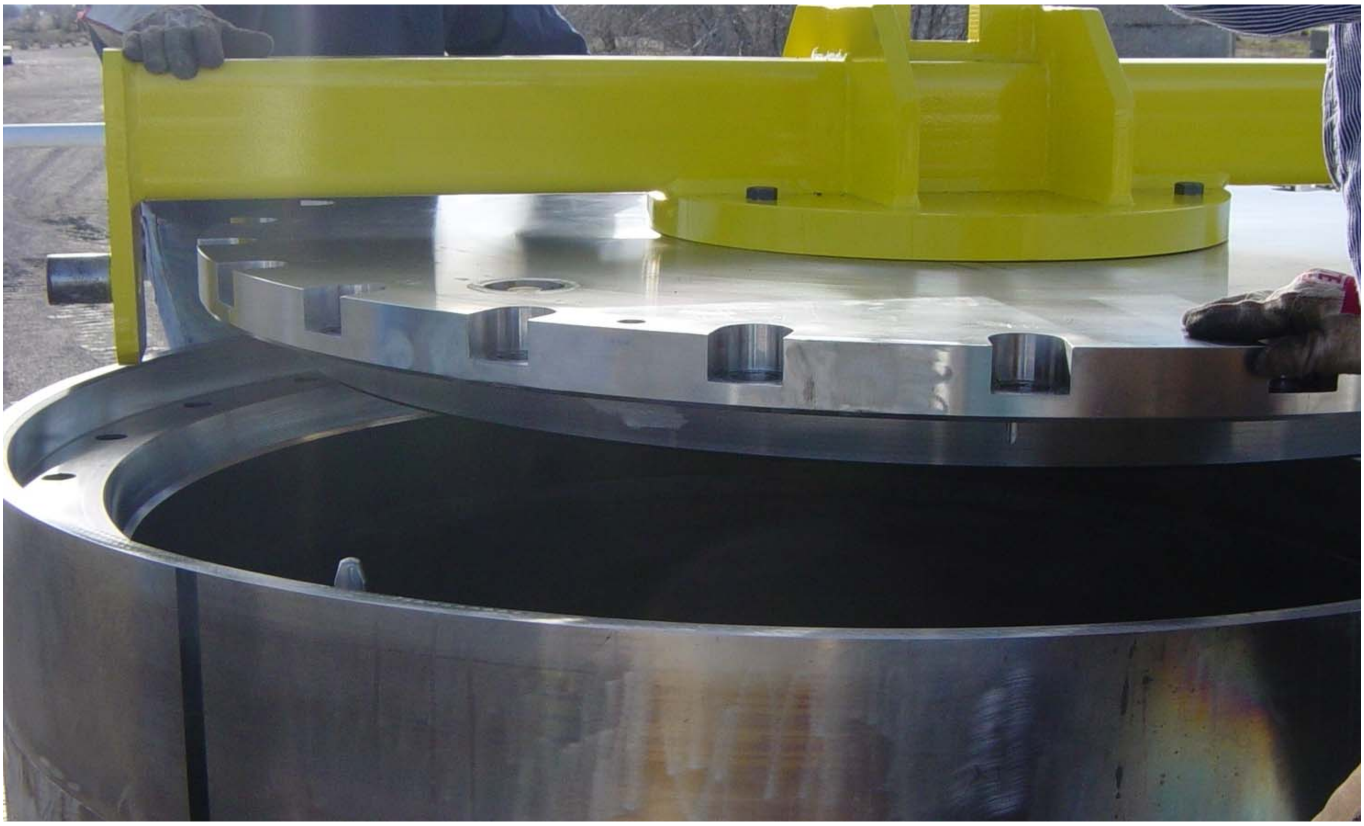

Figure 4 Lid and Cask

5 Sealing Procedure

The situation was corrected by changing the closure criteria from a simple prescribed torque value for each bolt to a position of the lid relative to the sealing surface. As described in the seal criteria both the elastomeric seal and the metallic seals perform optimum when the lid and flange approach metal-to-metal contact. As shown in Figure 2 the lip of the flange is basically the same height as the thickness of the outer edge of the lid. This provides a ready made reference for measuring the proximity of the lid to the flange. Four positions around the cask were marked and measured during the application of the preload through tightening of the bolts**.**

It was found that the initial application of the 93 % of the maximum torque allowed did not apply sufficient preload to the entire gasket to allow energizing of the elastomeric seal. The 93% of the maximum preload was used to ensure that the maximum allowed torque was not exceeded. By repeated applications of the 93% of the maximum permitted torque using different tightening sequences of the bolts, the metallic seal would continue to deform and the lid and flange would approach metal-to-metal contact. Optimum sealing capability for both the metal seal and the elastomeric seal was obtained in this manner. During these repeated applications of torque the torque values were not increased but rather the same amount of torque was used. The applied torque load was approximately 50 % greater than the minimum expected torque load for seating and optimally deforming the metallic seal.

Metal-to-metal was achieved with two to five applications of the 93 % of maximum permitted torque. The varying number of load cycles required demonstrates the variability in applying a predetermined load by the use of multiple bolts. Even thought the bolts were cleaned and lubricated each time they were used there were differences in friction between the bolt and the threaded hole on the cask. There were also differences in the application of the torque by the personnel and the torque wrenches used. There maybe slight differences in the required force to compress the seals between seals.

6 Leak testing

When the seals were properly deformed they successfully passed helium leak testing to better than 1x 10^{-7} cc/sec repetitively.

7 Conclusion

When using two different materials for seals the sealing mechanism of each seal has to be understood. O-ring metallic seals seal with a given load per unit length. Elastomeric seals require a certain amount of compression. To get these to work together adequate compression of both seals must be obtained. Obtaining adequate loading for the stiffest of the seals can only be obtained by allowing for the elastic interaction of the bolts. It has been proven that one way of addressing this is repetitive application of the torque. By repeating the application of the same torque to the bolts a more uniform load between bolts can be obtained ensuring that the seals are adequately compressed. By using measurement of the relative position between the lid and the flange as an acceptance criteria, rather than simple applied torque, leak tight seals can be assured.

8 References

1) ANSI N14.5-1997, *American National Standard for Radioactive Materials - Leakage Test on Packages for Shipment*, American National Standard Institute, Inc. (ANSI).

2) NUREG/CR-6007, *Stress Analysis of Closure Bolts for Shipping Casks*, G. C. Mok, L.E. Fischer, Lawrence Livermore Laboratory, and S.T.HSU, Kaiser Engineering, Prepared for U.S. Nuclear Regulatory Commission, April 1992