PARAMETERS INFLUENCING RAM TRANSPORT PACKAGE SEAL BEHAVIOR*

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ABSTRACT

Several design or test performance requirements for radioactive materials (RAM) transportation packages are specified in Title 10 of the U.S. Code of Federal Regulations Part 71 (10 CFR 71). Seals that provide the containment system interface between the packaging body and the closure must function in all environments specified in 10 CFR 71. This paper will discuss parameters to be considered during design of a packaging that influence the sealing capabilities of a packaging.

INTRODUCTION

The normal and hypothetical accident conditions of 10 CFR 71 provide a range of environments under which the containment system of the package must contain the RAM. The tests for normal conditions include heat, cold, reduced external pressure, increased external pressure, vibration, water spray, free drop, corner drop, compression, and penetration. Performance of the package must be evaluated by test or analysis for the maximum normal operating temperature considering 38°C (100°F) ambient air temperature, solar insolation, and heat generated by the contents, and for a minimum temperature of -40°C (-40°F) in still air in the shade. External pressures to be evaluated are from 24.5 kPa (3.5 psi) to 140 kPa (20 psi) absolute. Other environments that may affect package performance include vibration normally associated with transport and a 0.3 m (1 ft) free drop. These tests must not substantially reduce the effectiveness of the packaging.

The tests for hypothetical accident conditions include a free drop, puncture, thermal, and immersion tests. Acceptance of the package is based on radiological performance in terms of containment, shielding, and subcriticality. This paper focuses on package containment. Performance of the package must be evaluated by test or analysis for a test sequence of a free drop of 9 m (30 ft) on an unyielding target, a free drop of 1 m (40 in.) onto a puncture bar, and exposure of the package for 30 min to a heat flux specified in terms of a thermal radiation environment of 800°C (1475°F). A separate test addresses immersion of the package under a head of water of at least 15 m (50 ft) for 8 h. The practice for determining the acceptability of RAM packages following hypothetical accident conditions has been to assure no permanent deformation of the seal area following the hypothetical accident sequence; thereby, allowing leak testing of each package, as built, to demonstrate containment adequacy.

The containment system of a RAM package is defined in 10 CFR 71.4 as the components that retain the RAM during transport. This system typically consists of a cask body, closure, fasteners to secure the closure onto the cask body, one or more penetrations into the closure (e.g., for cavity gas sampling), and one or more seals at the closure and penetrations. Figure 1 illustrates a schematic of a representative cask with seals positioned in grooves in the closure.

The Nuclear Regulatory Commission's (NRC) Regulatory Guide 7.4, "Leakage Tests on Packages for Shipment of Radioactive Material" (1) refers to the American National Standards Institute (ANSI) N14.5 standard (2) and states the guidance in the standard is generally acceptable to the NRC certification staff for assessing the containment adequacy of a RAM package. The standard provides methods for demonstrating that packages comply with containment requirements at four phases: (1) design, (2) fabrication, (3) assembly for each shipment, and (4) periodically during service.

Regulations limit the release of activity from a RAM package. ANSI N14.5 recommends leakage test procedures that measure gas leakage from the package or a release test such as a swipe test that measures release directly. The gas leakage measurement most frequently forms the basis for the Type B package containment analysis.

Gas leakage from seals is comprised of two components: (1) by-pass leakage and (2) permeation leakage. By-pass leakage flows around the seal through unfilled surface roughness of the seal surface or material. Permeation leakage is gas which passes through the seal material. The primary method of RAM release is through by-pass leakage. Permeation leakage is an important consideration in determining the time available for making a leakage measurement using a tracer gas such as helium or in determining the loss of an inert gas during shipment.

The majority of Type B packagings are designed with gasket seals (3). The basic principle of a gasket seal is the yielding of a softer material. Confined between two surfaces as the closure fasteners are tightened, the gasket is

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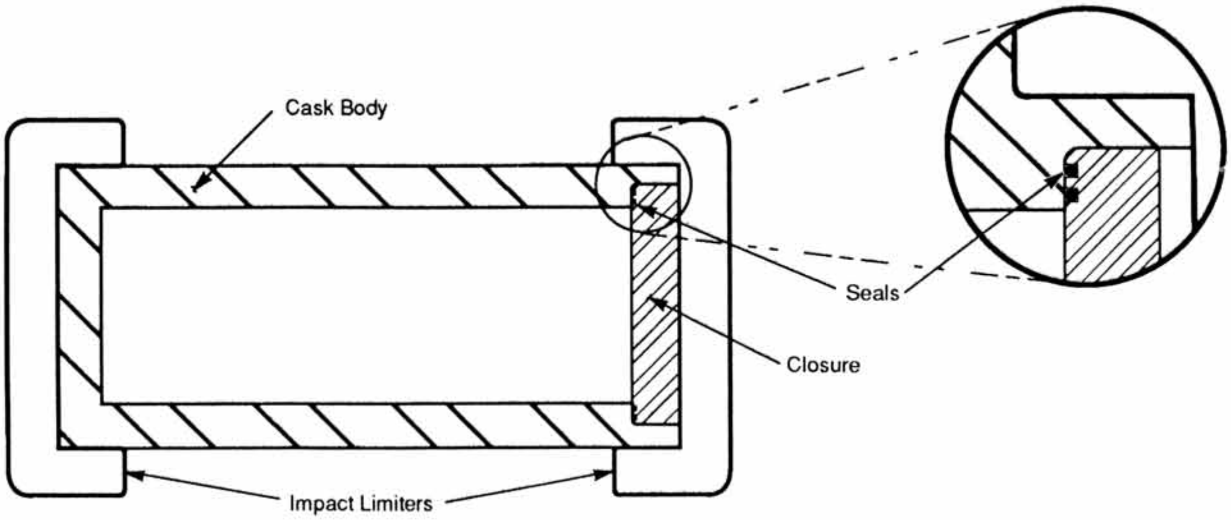

Fig. 1. Representative RAM Transportation Cask Schematic.

forced to flow into the surface imperfections of the sealing surfaces causing a positive block to the media being sealed. Figure 2 illustrates the compressive deformation of an elastomer gasket.

SEALING CAPABILITY PARAMETERS

Numerous factors influence the design of a seal system which will function reliably for the life of the packaging under both normal and accident conditions. These factors, as applicable to transport packages, include properties of the closure design, sealing surfaces, gasket material and contents. The following discussion is intended to provide an understanding of factors which should be considered when designing a seal system.

Closure Design

The design of a seal system is determined by its intended application. Types of seal systems are separated into the general categories of dynamic and static. In a dynamic system, the sealed surfaces are in motion. Static systems with stationary sealing surfaces are used in RAM packages. A static face seal system compresses a gasket on the top and bottom; a static bore seal system compresses a gasket between the inner and outer diameters.

In order to position the gasket, it is conventional practice to install the gasket in a groove. Frequently the gasket for a static face seal system is held in place by a square or dovetail groove, as shown in Fig. 3. Although the dovetail groove holds the gasket more securely, it is far more expensive to fabricate. Dimensions for grooves are recommended by seal manufacturers. Rounded edges on grooves

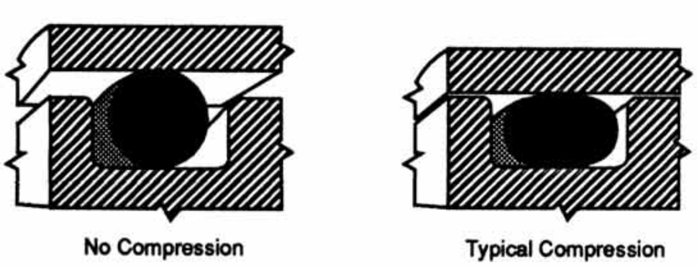

Fig. 2. Compressive deformation of an elastomer gasket.

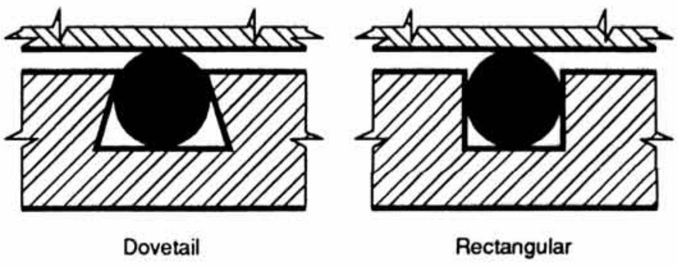

Fig. 3. Gasket groove shapes.

protect the gasket during installation. A narrow slot perpendicular to the groove facilitates removal of the gasket.

The choice of standard diameter and cross-section diameter gaskets provides economy and enhanced delivery schedules. Selection of a cross section involves analyzing several factors, and some of these are contradictory. Larger cross sections are less sensitive to scratches, allow larger fabrication tolerances, and better compression set properties. Advantages of smaller cross sections include lower cost and smaller space (4).

When an elastomer is stretched for installation, its cross section is reduced and flattened. Parker (4) recommends that standard groove designs should be modified if the installed stretch exceeds 2 or 3%. Larger assembled stretches cause more rapid aging.

Compression is an important consideration in seal system design. Manufacturer recommendations for elastomers generally range from 10 to 30%. A 30% compression may be difficult to assemble in a static bore seal design. Higher compressions may produce lower leak rates for some designs; however, the extra stress may contribute to seal deterioration. Exposure to temperatures at the maximum manufacturer recommendation should be carefully considered. Thermal expansion differences of the gasket and sealing surface could cause damage to closure fasteners.

Gasket Material

Choosing an effective gasket for a specific RAM transportation cask involves an investigation of gasket properties based on design requirements. Gasket properties which will be discussed are compression set, temperature, permeation, and thermal expansion coefficient.

Elastomers, which are rubber-like polymers, and metals are the principal gasket materials used for currently NRC licensed Type B packages (3). Elastomeric gaskets are less expensive than metal gaskets and require less maintenance of the seal surface. The major advantage of metal gaskets is their performance at high temperatures where elastomers often undergo decomposition. Elastomeric gaskets generally may be re-used many times; in contrast, metal gaskets are often used only once.

Inconel and stainless steel are often used for metal gaskets. Elastomeric materials frequently used for RAM transportation casks include butyl, neoprene, ethlylene propylene, fluorosilicone, silicone, and fluorocarbons. The compression set, temperature, and permeation properties of these materials show wide variations (4,5,6). For example, several silicone compounds have excellent temperature ranges but permeate easily. Butyl resists permeation; however, the maximum operating temperature is 108°C (225°F).

Compression Set

Compression set is a measure of the ability of an elastomer to return to its original shape after being compressed. It is a reliable predictor of an elastomer's ability to maintain the required force for prolonged operating periods. Compression set (Fig. 4) is usually expressed as a percentage of the seal deflection unrecovered when the compressive load is removed, compared to the original deflection. It occurs slowly at low temperatures but accelerates with exposure to radiation and high temperatures. The amount of compression set is time dependent (6).

Temperature

RAM transportation cask seals must function through the temperature range of -40°C (-40°F) to the hypothetical accident condition maximum that frequently exceeds 149°C (300°F). Metal gaskets can be used at both higher and lower temperatures than elastomers. For example, the maximum temperature limit of Inconel is an excess of 1000°C (1832°F). In contrast, the manufacturer rating for one silicone elastomer is 232°C (450°F).

High temperature affects the properties of elastomers. Some changes are physical which will reverse when the temperature drops. Softening is a first effect of high temperature. This should be considered in high pressure applications since a material that may resist extrusion at lower temperatures may begin to flow through clearances and cause leakage.

Chemical changes, which are irreversible, occur with increasing exposure time at high temperatures. These changes result in hardening, cracking, and ultimate leakage.

At low temperatures, elastomers lose their elastic properties and become brittle and glasslike. Unless the temperature becomes low enough to cause crystallization, the stiffening is reversible (6). The temperature at which crystallization occurs is known as the brittle point.

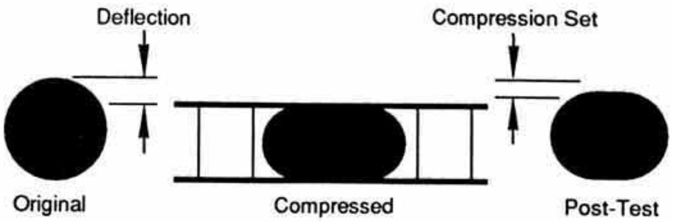

Fig. 4. Compression set.

Manufacturer high-temperature ratings often are based on continuous operating performance of 1000 hours in the media the compounds are designed to contain. The American Society for Testing Materials (ASTM) procedure, D1414-78 Standard Test Methods for Rubber O-Rings (7), details a low- temperature retraction test. This procedure, referred to as temperature retraction at 10% (TR-10), requires cooling a specimen that has been elongated 50% and raising the temperature until it returns 10% of the amount it was stretched. Manufacturer low-temperature ratings for elastomers frequently are based on temperatures approximately 8.4°C (15°F) below the TR-10 values.

Because most elastomer applications are for hydraulic systems, manufacturer low-temperature ratings are based on methods that simulate this use. Eighteen elastomeric materials were tested in a fixture similar to a RAM closure (8). The helium leak test commonly used in RAM transportation is very stringent and apparently different from the low-temperature basis, since only one silicone material was leak tight (1.0×10^{-7} std cm^3/s) at the manufacturer low-temperature rating.

Permeation

Gases diffuse into and through elastomers, depending on the density of the base polymer molecule, the amount of fillers, and the state of cure. Generally, denser elastomers have lower diffusion rates. Permeability of a gasket depends on the amount of compression, area, pressure, temperature, and molecular weight of the gas being sealed (6). As temperature rises, permeability increases; and the more a gasket is compressed, the greater is its resistance to permeation (4).

Room temperature permeation was measured for the 18 materials tested in Ref. 8. Permeation occurred in about 2 minutes for the silicones. In contrast, approximately 140 minutes are required to measure butyl permeation.

Coefficient of Thermal Expansion

Elastomers have coefficients of thermal expansion approximately 10 times that of steel (4). Marginal compression at low temperatures or grooves nearly filled with the gasket at high temperatures may pose problems.

The thermal expansion coefficients for metals are much smaller than for elastomers; therefore, the groove for metal gaskets requires smaller allowances for expansion. However, the differential expansion of the gasket and the sealing surfaces must be considered for the temperature range of the design.

Sealing Surfaces

Surface finish describes the general qualities of the cask body and closure surfaces. The ASM Metals Handbook (9) defines four elements of surface finish: roughness, waviness, lay, and flaws. Roughness consists of irregularities resulting from the manufacturing process and is measured by R_a, which is the arithmetic average deviation of the surface from the roughness center line, expressed in micrometers or microinches. The surface finish required depends upon the type of seal used, as well as the desired leakage rate. A metal seal requires a smoother sealing surface than an elastomer. Typical recommended surface finishes (4,5,6) for elastomers range from 3.2 μm (125 μin.) to 0.40 μm (16 μin.) while metal seals require finishes ranging from 0.20 μm (8 μin.) to 0.40 μm (16 μin.).

The smoother finishes are more expensive to machine during fabrication and maintain during operation of the cask.

Lay is the direction of the predominant surface pattern produced during machining. Figure 5 shows a schematic illustrating circular and radial lay which are frequently specified in RAM transport casks. If a machining pattern, such as radial lay, creates a continuous path across the cross section of the seal, leakage can occur more easily.

Waviness includes all irregularities with spacing greater than the roughness sampling length. It may result from machine vibration or heat treatment. Flaws are irregularities that occur at widely varying intervals on the surface. They include cracks, inclusions, and scratches.

Contents

The temperature, pressure, and radiation environments of the gasket are influenced by the contents of the cask. The effects of temperature and pressure were previously discussed.

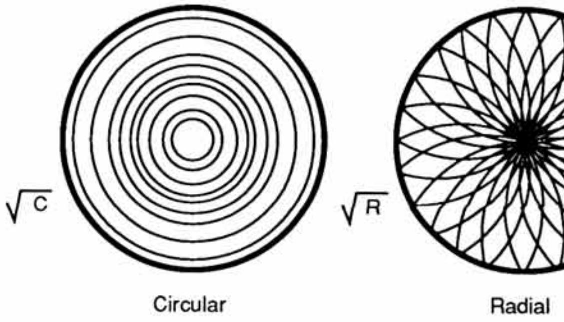

Fig. 5. Sealing surface lay.

Tests conducted on various seal materials for radioactive material transport indicate no elastomer can be expected to give lengthy service after a total dosage of 10^7 Gy (10^9 rad) of gamma radiation. Radiation and elevated temperatures produce compression set and physical degradation of the elastomer (4,6). Testing by Parker indicates most elastomers maintain sealing capabilities after exposure to 10^4 Gy (10^6 rad) of radiation at room temperature. Metals have high resistance to radiation compared to elastomers. Gamma radiation has little effect on metals.

During the design of spent fuel casks, radiation dosages are evaluated to assure that levels are below those which would affect performance of gaskets. Additionally, radiation exposure of gaskets is evaluated when length of service for this component is determined.

SUMMARY

During the design of a seal system, numerous parameters relating to the gasket material and closure design should be considered. Because of the need to provide the best seal compatible with a group of varied requirements using nonideal materials, the seal choice is nearly always an engineering compromise.

Following selection of a design and gasket material, testing is encouraged. Much of the manufacturer temperature data is based on hydraulic applications. Application to the stringent transportation environment may produce very different results.

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