SAND--88-1015
DE89 007296

Distribution
Category UC-71

COMPILATION OF CURRENT LITERATURE ON SEALS, CLOSURES, AND LEAKAGE FOR RADIOACTIVE MATERIAL PACKAGINGS*

by

M. M. Warrant
C. A. Ottinger
Transportation Systems Technology
and Analysis Division
Sandia National Laboratories**
Albuquerque, NM 87185

ABSTRACT

This report presents an overview of the features that affect the sealing capability of radioactive material packagings currently certified by the U.S. Nuclear Regulatory Commission. The report is based on a review of current literature on seals, closures, and leakage for radioactive material packagings. Federal regulations that relate to the sealing capability of radioactive material packagings, as well as basic equations for leakage calculations and some of the available leakage test procedures are presented. The factors which affect the sealing capability of a closure, including the properties of the sealing surfaces, the gasket material, the closure method and the contents are discussed in qualitative terms. Information on the general properties of both elastomer and metal gasket materials and some specific designs are presented. A summary of the seal material, closure method, and leakage tests for currently certified packagings with large diameter seals is provided.

---

*This work performed at Sandia National Laboratories, Albuquerque, New Mexico, supported by the U. S. Department of Energy under Contract DE-AC04-76DP00789.

**A United States Department of Energy Facility.

DISCLAIMER

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Concluded)

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENT

The authors wish to thank Nancy C. Benson for technical writing and editing assistance, and her compilation of data on seals and closures for currently certified casks.

GLOSSARY

A_2 (Activity Limit). The maximum activity of a radioactive material, other than special form radioactive material, permitted in a Type A package.

ANSI. American National Standards Institute, Inc.

Bolt. A threaded fastener which passes through clear holes in the parts to be joined, has a square, round, or hexagonal head at one end and receives a nut at the other end.

Bolted joint. The assembly of two or more parts by threaded bolts and nuts, by cap screws that pass through one member and thread into another, by studs with two nuts, or by studs with one nut that pass through one member and thread into another.

By-pass leakage. Gas which escapes around the seal from a RAM package containment cavity through unfilled surface roughness of the seal face, or through defects in the seal surface or seal material.

Cap screw. A threaded fastener which passes through a clear hole in one part to be joined, screws into a threaded hole in the other part, and has a head which holds the parts together.

Closure. That which closes or shuts a RAM package, confining the material within the package during normal conditions of transport and limiting the release of activity from the package under accident conditions.

Compression force. Force required to squeeze a seal between mating surfaces for purposes of sealing a juncture.

Compression set. The percent of deflection by which an elastomer fails to recover after a fixed time under specified squeeze and temperature [(original diameter-recovered diameter)/(original diameter-compressed diameter)] or $[(D_o - D_R)/(D_o - D_c)]$.

Containment system. The components of the packaging intended to retain the radioactive material during transport.

Curie (Ci). A unit of radioactivity which is the quantity of any radioactive nuclide which has 3.7×10^{10} disintegrations per second.

Elasticity. The property whereby a solid material changes its shape and size under action of opposing forces, but recovers its original configuration when the forces are removed.

Elastomer. A polymer that can be or has been modified to a state exhibiting little plastic flow and quick or nearly complete recovery from an extending force.

GLOSSARY
(Continued)

Extrusion. Extreme distortion under pressure of an elastomer gasket, causing it to flow into the clearance between mating parts.

Gasket. A deformable material, usually in the form of a sheet or ring, used to make a pressure-tight joint between stationary parts.

Groove. A channel produced in a closure system with the purpose of accepting a gasket.

Hardness. The localized resistance to plastic indentation measured by the relative resistance of the material to an indentor point of a standard hardness testing instrument.

IAEA. International Atomic Energy Agency.

Leak. Any opening in an enclosure that permits the escape of a gas, liquid, powder, slurry, or solid.

Leakage rate. The rate of flow through a leak of a specific gas at specific temperature, inlet pressure, and exit pressure.

Leakage testing. A form of nondestructive testing used for the detection and location of leaks, and typically for the measurement of gas or liquid leakage in either pressurized or evacuated systems and components. (The quantity used to describe the leakage is the measured leakage rate.)

Leaktightness. A leakage rate of less than or equal to 10^{-7} std-cm^3/s, for dry air at 25°C at an upstream pressure of 1 atm absolute and a downstream pressure of 0.01 atm absolute or less, is considered to represent leaktightness.

Maximum normal operating pressure (MNOP). The maximum gauge pressure that would develop in the containment system in a period of one year under the heat test specified in 10 CFR 71.71(c)(1), in the absence of venting, external cooling by an ancillary system, or operational controls during transport.

Maximum permissible leakage rate (MPLR). The maximum leakage rate for the medium present during transport, to allow the package to meet the regulatory containment requirements.

NRC. U.S. Nuclear Regulatory Commission.

Outgassing. The release of adsorbed or absorbed volatile constituents in the form of vapor or gases, usually by heating or in a vacuum.

Package. The packaging together with its radioactive contents as presented for transport.

GLOSSARY
(Continued)

Packaging. The assembly of components necessary to ensure compliance with the packaging requirements of 10 CFR 71.

PATRAM. International Symposium on Packaging and Transportation of Radioactive Material.

Permeation. The movement of atoms, molecules, or ions through a porous or permeable substance such as an elastomer.

Permeation leakage. Gas which escapes through the seal material from a RAM package containment cavity.

Permeation constant. The equilibrium leakage rate from gas permeation.

Polymer. A material formed by the joining together of many individual units of one or more monomers.

RAM. Radioactive materials.

SARP. Safety Analysis Report for Packaging.

Seal. Any device or system that creates a tight union between elements in the containment system of a radioactive materials packaging.

Sensitivity of a leakage test procedure. The minimum detectable leakage rate that the test procedure is capable of detecting.

Stud. A threaded rod without a head. One end screws into a threaded hole and the other receives a nut or both ends can be used with nuts.

Tear resistance. Resistance to growth of a cut or nick when tension is applied to the cut specimen. Commonly expressed as pounds per inch thickness.

Temperature range. Highest and lowest temperatures a seal will experience in a given application and provide a satisfactory seal.

Tensile strength. The maximum stress a material can withstand without tearing when subjected to a stretching load.

Type B package. A package containing a quantity of radioactive material greater than A_1 for special form radioactive material or A_2 for normal form radioactive material.

EXECUTIVE SUMMARY

This report presents an overview of the features that affect the sealing capability of radioactive material packagings currently certified by the U.S. Nuclear Regulatory Commission. The report is based on a review of current literature on seals, closures, and leakage for radioactive material packagings.

Chapter 1 presents federal regulations that relate to the sealing capability of radioactive material packagings. It discusses the regulatory test environments and performance requirements that determine the closure design and seal material selected for use in a packaging. It also discusses the regulatory guides and standards that apply to leakage tests for packaging containment systems. The regulatory guidance is to use ANSI N14.5.

Chapter 2 summarizes the basic equations for leakage calculations presented in the ANSI N14.5 standard and elsewhere, and describes some of the available leakage test procedures.

Chapter 3 describes the factors that affect the sealing capability of a closure. There are four major categories of factors: properties of the sealing surfaces, properties of the gasket material, properties of the closure method, and properties of the contents. In addition, experience with large diameter seals has shown that the size of a closure affects its sealing capability, primarily in fabrication of the sealing surfaces. While the factors that affect sealing capability can be discussed qualitatively, no quantitative analysis method exists as yet to accurately calculate leakage from a closure or seal design. This chapter also describes efforts to develop analytical tools for predicting leakage from a full-scale packaging, and tests that have been performed on full- or scale-model packagings to verify the containment system design.

Chapter 4 discusses the properties of gasket materials appropriate for use in radioactive material transport packagings. This discussion covers all gasket materials currently in use in NRC-certified Type B, large-diameter Type A, and irradiated fuel transport packagings in the U.S. The principal gasket materials currently used in these packagings are elastomers and metals. The properties of both general types of gasket material are summarized. This chapter on gasket materials includes information on physical properties affecting sealing capabilities, material and replacement interval specifications, and specific materials and designs.

Chapter 5 contains selected record segments from the TRACCS (Transport Cask Closures & Seals) computerized data base being developed at Sandia. This letter report summarizes TRACCS records for 1) packagings that have large diameter seals [defined as packages with a gross weight of 18,000 kg (40,000 lbs) or greater], and 2) packagings for irradiated fuel as of October 1986.

1.0 INTRODUCTION

This document is a compilation of current literature on seals, closures, and leakage. Seal data are summarized for radioactive materials packagings in the U.S. certified by the NRC as of August 1986. The seal creates a tight union between elements of the closure system of a packaging, thereby limiting the release of radioactive materials from the packaging. The closure provides access to the packaging cavity and confines the radioactive material within the packaging.

Chapter 1 presents the regulatory test environments and performance requirements that determine the closure design and seal material selected for use in a radioactive materials packaging. Chapter 1 also describes guidance for demonstrating compliance with regulatory guides and standards.

1.1 Regulatory Requirements for Seals, Closures, and Leakage

The purpose of a radioactive materials packaging is to enable radioactive materials to be transported without posing a threat to health or property. To this end, regulations have been written (Ref. 1.1-1) establishing general design or test performance requirements for radioactive materials packages that establish containment requirements for the radioactive material and limit the dose rate measured at various distances from the package during transport (10 CFR 71.51). The test performance requirements must be met under specified test environments for normal transport (10 CFR 71.71) and accident conditions (10 CFR 71.73).

The containment system of the package is defined as the components of the packaging intended to retain the radioactive material during transport (10 CFR 71.4). The containment system typically consists of a packaging body (that may consist of parts welded together), a closure (lid), any fasteners used to secure the closure onto the packaging body, one or more penetrations into the closure (e.g., cavity gas sampling port), and one or more seals at each interface where radioactive material could otherwise escape.

A Type B package must satisfy the requirements of 10 CFR 71.41-47, which include general standards, lifting and tie-down standards, and external radiation standards for all packages. Included in the general standards are the following requirements applicable to the containment system:

1. the containment system must be securely closed by a positive fastening device which cannot be opened unintentionally;

2. a package must be of materials and construction which assure that there will be no significant chemical, galvanic, or other reaction among the packaging components or between the packaging components and the package contents, including possible reaction resulting from the in leakage of water to the maximum credible extent;

3. a package valve or other device, the failure of which would allow radioactive contents to escape, must be protected against unauthorized operation and, except for a pressure relief device, must be provided with an enclosure to retain any leakage.

A Type B package must also satisfy additional requirements for Type B packages given in 10 CFR 71.51. For normal conditions of transport, there must be no loss or dispersal of radioactive contents as demonstrated to a sensitivity of 10^{-6} A_2 per hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging. For hypothetical accident conditions, there must be no escape of Krypton-85 exceeding 10,000 curies in one week, no escape of other radioactive material exceeding a total amount A_2 in one week, and no external radiation dose rate exceeding one rem per hour at one meter from the external surface of the package.

The A_2 values have been established considering the various pathways in which the nuclides may affect health, including deposition on the skin, ingestion, and inhalation. Appendix A of 10 CFR 71 describes how A_2 (in units of curies) may be determined for a single nuclide or for a mixture of nuclides.

The normal conditions of transport for which a package design must be evaluated are stated in 10 CFR 71.71, and the hypothetical accident conditions of transport in 10 CFR 71.73. These initial conditions and tests are listed in Appendix A of this document.

The requirements of 10 CFR 71 provide a range of environments under which the containment system of the package must contain the radioactive material as specified in 10 CFR 71.51. The initial conditions for both normal and hypothetical accident evaluations are an ambient air temperature of the value between -29°C (-20°F) and 38°C (100°F) which is most unfavorable for the package, and an internal pressure equal to the package maximum normal operating pressure (MNOP) unless a lower internal pressure is more unfavorable.

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 incident to 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 free drop of 9 m (30 ft), puncture, thermal, and immersion. Performance of the package must be evaluated by test or analysis for a test sequence of a free drop of 9 m (30 ft), 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.

In addition, 10 CFR 71.85(b) requires that before the first use of any packaging which has a MNOP greater than 34.3 kPa (5 psi) gauge, the containment system must be tested at an internal pressure at least 50 percent higher than the MNOP to verify the capability of the containment system to maintain its structural integrity at that pressure.

Choice of a seal material and/or closure design is determined by the environments specified above and by the containment criteria.

Reference

1.1-1. "Packaging and Transportation of Radioactive Material," U.S. Nuclear Regulatory Commission, 10 CFR, Part 71, Appendix A, Federal Register 48, No. 152, August 5, 1983; corrected Vol 48, No. 165, August 24, 1983.

1.2 Regulatory Guides and Standards for Leakage Tests

NRC Regulatory Guides are issued to provide instruction on acceptable methods that may be used to demonstrate compliance with NRC regulations, and reference applicable standards.

1.2.1 Regulatory Guide 7.4

NRC Regulatory Guide 7.4, "Leakage Tests on Packages for Shipment of Radioactive Material," (Ref. 1.2-1) refers to the ANSI (American National Standards Institute) N14.5 standard (Ref. 1.2-2), and states that the guidance contained in the standard constitutes a procedure generally acceptable to the NRC staff for assessing the containment properties of a radioactive material package to satisfy the provisions of 10 CFR 71. Alternative methods that satisfy the requirements in the regulations are also considered acceptable. The maximum permissible leakage rate calculated using this standard or other methods serves as one of the important criteria for the design of the closure and the choice of seal material.

1.2.2 ANSI N14.5

ANSI N14.5 specifies methods for demonstrating that Type B packages comply with the package containment requirements for design verification, fabrication verification, assembly verification, and periodic verification. It also specifies (1) package containment requirements; (2) methods for relating package containment requirements to measured release and leakage rate; and (3) minimum requirements for release and leakage rate measurement procedures. The standard is written to address the 1983 edition of 10 CFR 71 and the 1985 edition of the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Materials, Safety Series No. 6 (Ref. 1.2-3), which specify containment requirements in terms of activity per unit time.

The ANSI N14.5 standard describes methods for converting containment requirements in terms of activity per unit time to maximum permissible release or leakage rates to determine how to test a Type B package. It also provides guidance for taking into account the physical form of the escaping medium (gas or liquid), its physical properties (viscosity), and its conditions (pressure and temperature). The medium may contain radioactive material in gaseous, liquid, or solid forms. Appendices to the standard describe some of the leakage test procedures available, and list the nominal sensitivities of the test methods and their applicability. The package designer must estimate or determine the concentration of radioactive material that might escape from the package under shipping conditions so that a leakage test procedure with adequate sensitivity can be selected.

Before the maximum permissible activity leakage rates can be established, the following must be determined for both normal and accident conditions of transport:

1. the activity of the medium that could escape from the containment system,
2. the maximum permissible leakage rates for the medium,
3. the pressure and temperature of the medium within the containment system.

The activity of the medium that could escape from the containment system is calculated for normal and accident conditions in Ci/cm^3. These activities are determined by the performance of tests on prototypes or models, reference to previous demonstrations, calculations, or reasoned argument. In determining the activities, factors to be considered include: (1) the chemical and physical forms of the radioactive materials within the containment system; (2) the possible ways for this activity to mix with the medium, such as diffusion of gases, airborne transportation of particulates, reactions with water or other materials present in the system, and solubility; and (3) the maximum temperature, pressure, vibration, and other conditions to which the contained material would be subjected for normal and accident conditions of transport.

The maximum permissible leakage rates L_N and L_A for the medium for normal conditions or hypothetical accident conditions, respectively, are then given by the package containment requirements (in Ci/s) divided by the activity of the medium that could escape from the containment system as a result of the conditions of transport (in Ci/cm^3). Air leakage rates, expressed in std-cm^3/s and which are equivalent to the maximum of L_N and L_A, are established by calculation. (Note that ANSI N14.5 considers 25°C as "standard temperature." "Standard pressure" is 101 kPa [14.7 psi] absolute.) The determination of the reference air leakage rates must account for the relationship between the leakage rate of air and that of a different gas, liquid, or aerosol, and the relationship between leakage rates at different sets of pressure and temperature conditions.

The standard provides methods for demonstrating that packages comply with containment requirements at four different phases: (1) design, (2) fabrication, (3) assembly for each use, and (4) periodically in service.

Containment system design verification may be accomplished by assembling as for shipment and testing full-size packages or full-size models to the normal and hypothetical accident conditions, and verifying that the containment system is either leaktight or it has leakage or release rates equal to or less than the maximum permissible rates. Other common methods of containment system design verification are to establish the leakage rate of the assembled containment system by mock-up, reference to containment assessments for other packagings, or reference to technical literature to show that the maximum permissible leakage rates for normal and accident conditions would not be exceeded. Calculations, tests on scale models, or other techniques are used to show that closure parts are neither deformed abnormally (except for nonreusable gaskets that are designed to permanently deform in order to function properly), nor excessively displaced, and that recognized temperature limits for the closure type are not exceeded. Calculations appear to be the most common method of demonstrating that a packaging will not exceed its maximum permissible leakage rate.

Before a reusable Type B package is used for actual shipments, the containment system is assembled as for shipment, except that the radioactive contents may be simulated by nonradioactive contents, and is tested to show that either it is leaktight or it has a release or leakage rate equal to or less than the maximum permissible rate for normal or accident conditions of transport, whichever is the more restrictive. To the extent possible, all joints and seams on the containment system must be tested.

When closure parts of reusable Type B package containment systems are modified, or when replacement is made of components not routinely replaced, the affected part of the containment system is leakage tested as before first use.

As part of the preparation for each actual shipment, the containment system of each Type B package is assembly checked and leak tested to verify that it has been properly assembled and containment established. A check list is completed recording that all containment system parts comply with applicable requirements, and all parts such as gaskets, flanges, seals, etc., are in place and properly secured. Except for packages which have maximum permissible leakage rates greater than 1×10^{-1} cm^3/s for both normal and accident conditions, a leakage test is completed on the containment system together with its radioactive contents. The leakage test procedure, when applied to the containment system, must have a sensitivity of 4200 multiplied by the maximum permissible leakage rate for normal conditions of transport. The sensitivity must be at least 1×10^{-1} std-cm^3/s but no greater than 1×10^{-3} std-cm^3/s.

The assembly leak test requirement is not a relaxation of the allowable leakage rate, but is a relaxation only of the test sensitivity. Accepting an inadequate containment system knowingly violates the intent of the test (Ref. 1.2-4). For example, a cask that is required to be leaktight (leakage rate less than or equal to 1×10^{-7} std-cm^3/s) for normal conditions of transport is acceptable for transport if it demonstrates no measurable leakage using a pressure rise leakage test that has sensitivity of 1×10^{-3} std cm^3/s. However, if an actual leakage rate of more than 1×10^{-7} std-cm^3/s is measured, the cask cannot be transported.

The containment systems of Type B packages that are reusable must be periodically leakage tested to show they do not exceed their maximum permissible leakage rates. Leakage testing is required after a "shakedown" period (normally after third use), and within the preceding 12-month period for any shipment.

The sensitivity of the leakage test procedure, as determined by reference to applicable literature or by performance of tests, is considered adequate when it is equal to or less than one-half of the maximum permissible leakage rate for the tracer liquid or gas. The permissible leakage rate for the tracer is determined by considering the relationship between the leakage rates for different gases and the relationship between the leakage rates for tests that are conducted at different sets of conditions. The test procedure must be designed to preclude false acceptance. For leakage tests, this might include assuring the presence of a tracer material and a driving pressure. For release tests, this might include collection of and accounting for all escaped material.

References

1.2-1. "Regulatory Guide 7.4, Leakage Tests on Packages for Shipment of Radioactive Materials," U. S. Nuclear Regulatory Commission Office of Standards Development, June 1975.

1.2-2. "American National Standard for Radioactive Materials--Leakage Tests on Packages for Shipment," ANSI N14.5-1987, American National Standards Institute, January 1987.

1.2-3. "Regulations for the Safe Transport of Radioactive Materials," 1985 Edition, IAEA Safety Series No. 6, International Atomic Energy Agency, Vienna, 1985.

1.2-4. Lake, W. H. "Containment System Evaluation," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 633-637.

2.0 LEAKAGE OF GASES, LIQUIDS, AND PARTICLES

Regulations limit the release of activity from a radioactive materials package. This activity may be present in the form of a gas, a liquid, a slurry, a powder, a solid, or combinations thereof. As described in Section 1.2, the regulatory guidance is to use ANSI N14.5, which recommends leakage test procedures that measure gas leakage from the test item or a release test (the swipe test) that measures release directly. The standard provides equations that may be used for correlating leakage rates between different gases, between different liquids, and between gases and liquids; and correlating leakage rates at different pressure and temperature conditions. This section summarizes basic equations for leakage calculations presented in the ANSI N14.5 standard and elsewhere, and describes some of the available leakage test procedures.

2.1 Gas Leakage

An assessment of gas leakage forms the basis of the containment analyses of most radioactive materials shipping packages. For shipment of irradiated fuel, the release of fission product gases such as isotopes of krypton, xenon, and iodine must be calculated. As discussed in Section 2.3, leakage of activity in the form of particles can be conservatively assumed to occur at the same rate as gas leakage. Alternatively, experimental data may be used to correlate the mass release of an aerosol with gas leakage. Acceptance and assembly leakage tests are commonly performed by observing the presence of gas released (as in bubble tests) or by measuring the quantity of gas released (as in helium mass spectrometer leakage tests).

There are two components to gas leakage from seals: (1) by-pass leakage and (2) permeation leakage. By-pass leakage flows around the seal through unfilled surface roughness of the seal face or through defects in the seal surface or seal material, and is the primary method of gas leakage of concern for radioactive materials shipping packages. Permeation leakage is gas which passes through the seal material.

2.1.1 Permeation Leakage

Permeation leakage is primarily of interest in determining the time available for making a leakage measurement using a gas such as helium, or in determining the loss of an inert gas from the containment cavity during transport. For example, in the case of silicone, only a few minutes are available for helium leakage testing; the useful time interval is much longer for Viton (Ref. 2.1-1). Measurements of permeation rates and breakthrough times for tracer gases are reported for various seal materials (Refs. 2.1-1 through 2.1-3).

Examination of experimental results for helium, argon, and krypton noble gases diffusing through silicone, Viton, and EPDM seal materials yielded the following general observations (Ref. 2.1-1): (1) the permeation constant increases with increasing temperature (permeation constants are exponentially related to temperature and depend on the activation energy); (2) for silicone, the permeation constant increases with increasing atomic number of the noble gas; (3) in the case of Viton and EPDM, the permeation of helium occurs at a higher rate compared with the heavy noble gases; and (4) Viton has the lowest permeation constant of the three gases and three materials studied. The equilibrium permeation leakage rates observed for krypton at 23°C for the seal materials examined were 5×10^{-4} atm-cm^3/s for silicone (at 1 atm), 1×10^{-7} for Viton (at 0.5 atm), and 3×10^{-6} for EPDM (at 0.5 atm).

Permeation leakage should be considered in assessing activity release when radioactive gases are present in the package. From the results of Ref. 2.1-1, it appears that permeation leakage may be significant if silicone is used as the seal material for shipment of spent fuel or other contents containing krypton or higher atomic number radioactive gases.

2.1.2 By-Pass Leakage

The remainder of this section is devoted to by-pass leakage. Equations for gas leakage through small openings depend on the flow mode. Leakage may occur by unchoked free molecular, transitional, or laminar viscous flow; or by choked flow. The factors that influence gaseous flow through leaks are the molecular weight of the gas, the viscosity of the gas, the gas temperature, the pressure difference causing the flow, the absolute pressure in the system, and the length and cross section of the leakage path (Ref. 2.1-4).

For choked flow, the flow velocity equals the local sonic velocity in the flow field. The critical pressure ratio r_c that determines whether flow is choked or unchoked is given by

$$r_c = \left(\frac{2}{k+1}\right)^{k/(k-1)} \quad , \tag{2.1}$$

where k is the ratio of the specific heat at constant pressure to the specific heat at constant volume (Ref. 2.1-5).

If the ratio $P_d/P_u < r_c$, the flow is unchoked, where P_d is the downstream pressure and P_u is the upstream pressure. If $P_d/P_u \geq r_c$, the flow is choked. For air at 25°C and 101 kPa (1 atm) absolute, the critical ratio has a value of 0.528.

2.1.2.1. Unchoked Free Molecular, Transitional, or Laminar Viscous Flow Modes

Volumetric gas leakage for unchocked free molecular, transitional, or laminar viscous flow modes is estimated by Eqs. B2-B4 of Ref. 2.1-5 as

$$L = (F_c + F_m)(P_u - P_d) \quad , \tag{2.2}$$

where

$$F_c = 2.49 \times 10^6 \frac{D^4}{a\mu} \text{ cm}^3/\text{atm-s} \quad ,$$

$$F_m = 3.81 \times 10^3 \frac{D^3\sqrt{T/M}}{aP_a} \text{ cm}^3/\text{atm-s} \quad ,$$

and

L = gas leakage rate (cm^3/s) at gas temperature T (K),

D = leakage path diameter (cm),

a = leakage path length (cm),

μ = gas viscosity (centipoise, cP),

P_u = upstream gas pressure (atm, abs),

P_d = downstream gas pressure (atm, abs),

T = gas absolute temperature (K),

M = gas molecular weight (g/mole),

P_a = average stream pressure = $1/2(P_u + P_d)$ (atm, abs).

This is an empirical relationship, based on an equivalent hole size. The term F_c in the equation for L pertains to laminar flow and is derived from Poiseuille's law; the second term pertains to free molecular flow and is derived from Knudsen's law. Relationships between leakage at different temperatures and pressures can be derived from the temperature and pressure dependence of the leakage rate in Eq. 2.2, provided the flow mode for the two sets of conditions remains the same and the leakage path geometry remains the same. Temperature occurs explicitly in Eq. 2.2; the gas viscosity is also dependent on temperature.

The use of Eq. 2.2 can overestimate the actual gas leakage for leaks as large as 100 microns and 1 cm long for upstream pressure of 1 atm and a downstream pressure of approximately zero, because the equation does not account for compressibility in the leakage path (Ref. 2.1-6).

The use of Eq. 2.2 also conservatively assumes that all leakage occurs through one hole with a circular cross section, although multiple (smaller) holes are more likely to occur than a single hole. The leakage path length to be used must be estimated by examining the container design to determine the likely mode of bypass leakage (Ref. 2.1-6). For closure seals, this length is most likely the thickness of the gasket in its compressed state.

2.1.2.2 Choked Flow Mode

The leakage rate of a gas in choked flow is estimated by

$$L_u = \frac{\pi D^2}{4}\sqrt{\frac{2k\,R_o\,T_u}{M\,(k+1)}}\left(\frac{2}{k+1}\right)^{1/(k-1)} \text{cm}^2\text{/s at } P_u,\ T_u \quad , \tag{2.3}$$

where

L_u = gas leakage rate (cm^3/s) at upstream pressure and temperature,
D = leakage path diameter (cm),
k = ratio of specific heat at constant pressure to specific heat at constant volume,
R_o = universal gas constant (8.31×10^7 erg/gmole-K),
M = gas molecular weight (g/mole),
P_u = gas upstream pressure (atm, abs),
T_u = gas upstream temperature (K).

Experiments have verified the applicability of the flow relationship in Eq. 2.3 for "thin" orifices 20 to 200 microns in diameter (Ref. 2.1-7). Volumetric air flow was measured through orifices with downstream pressure of approximately 1 atm as upstream pressure increased. Choked flow was observed to occur at pressure ratios of $P_d/P_u = 0.53$, the value expected for air. For pressure ratios above 0.53, the volume flow rate was constant, and the air mass flow increased as a linear function of upstream pressure, as predicted by theory.

2.1.2.3 Mixtures of Gases

If a mixture of gases is present, equivalent properties of the mixtures are used in the volumetric flow equations. The mixture equivalents for pressure, molecular weight, and viscosity are given for ideal gases in terms of component properties weighted by the ratio of the partial to total pressure (see Section B4.5 of Ref. 2.1-5).

If a tracer gas is contained in a mixture and the leakage rate is determined by a procedure that measures only the tracer (such as a helium mass spectrometer leak detector), the total leakage rate is the measured tracer gas leakage rate multiplied by the ratio of the tracer gas partial pressure to the total gas pressure.

References

2.1-1. K. Heumos, et al., "Investigation of Gas Leakage from Sealing Constructions at Containments for Radioactive Materials," Proceedings of the Sixth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '80, Berlin, F.R.G., November 10-14, 1980, pp. 472-478.

2.1-2. W. B. Leisher, et al., "In-Situ Permeation Tests of Elastomeric O-Ring Seals," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 680-685.

2.1-3. "O-Ring Reference Guide," ORD-5703, Parker Seal Group, Lexington, KY, 1985.

2.1-4. Nondestructive Testing Handbook, Second Edition, Volume One-Leak Testing, R. C. McMaster, ed., American Society for Nondestructive Testing, American Society for Metals, 1982.

2.1-5. "American National Standard for Radioactive Materials--Leakage Tests on Packages for Shipment," ANSI N14.5-1987, American National Standards Institute, January 1987.

2.1-6. L. C. Schwendiman, "Supporting Information for the Estimation of Plutonium Oxide Leak Rates Through Very Small Apertures," BNWL-2198 (NRC-12), Battelle Pacific Northwest Laboratories, January 1977.

2.1-7. S. L. Sutter, et al., "Measured Air Flow Rates through Micro-Orifices and Flow Predication Capability," NUREG/CR-0066, U.S. Nuclear Regulatory Commission, Washington, D.C., July 1978.

2.2 Liquid Leakage

Liquid leakage at low flow rates will be laminar and at high flow rates will be turbulent. Liquid leakage for the laminar flow mode is derived from Poiseuille's law (see Ref. 2.2-1) and is given in Eq. 2.4:

$$L = F_c (P_u - P_d) \quad , \tag{2.4}$$

where F_c, P_u, and P_d are defined in Eq. 2.2.

Reference

2.2-1. "American National Standard for Radioactive Materials--Leakage Tests on Packages for Shipment," ANSI N14.5-1987, American National Standards Institute, January 1987.

2.3 Particle Leakage

Particle leakage can occur when solid particles are suspended in an aerosol. An aerosol formed from radioactive materials in a transport package is likely to be nonuniform in both space and time, as particles settle or are resuspended through shocks and vibrations experienced during transport. Calculation of aerosol release is difficult because the characteristics of the aerosol and how particles are removed from the aerosol (through settling or plating out in the leakage path) are not well known (Ref. 2.3-1).

If the particle size distribution of the materials being transported is known, and the particles can only increase in size during transport (through agglomeration, for example), then the mass fraction of particles that can be released is no greater than the mass fraction of the particles with diameters less than the maximum possible leakage hole size. Alternatively, a swipe test can be used to measure the total mass of particles released during a test or portion of a test (Ref. 2.3-1).

If the particle size distribution is not known, and a swipe test cannot be conducted, then an approach can be adopted in which the particles are assumed to be uniformly distributed in the carrier gas, and activity leaks at the same rate as the gas leaks. This is a very conservative assumption for several reasons, and Reference 2.3-2 provides a comprehensive discussion.

First, both Eq. 2.2 and 2.3 assume that leakage occurs through one hole with a flow rate equivalent to the total leakage rate. The actual leakage path is more likely multiple smaller holes. Powders tend to plug small holes, resulting in a lower powder leakage rate through multiple holes. Second, particles may settle from the carrier gas, agglomerate to form larger particles, or attach to the package contents or interior walls, and never reach the leakage path. Third, the particles must pass through the leakage path to reach the environment.

The ability of a leakage path to filter out particles depends on the leakage path geometry. Roughness of the walls of the leakage path, and changes in direction in the leakage path will increase the fraction of particles removed in the passage. Gravitational settling could occur inside the leakage path if the leakage path is horizontal and particles spend enough time in the leakage path for settling to occur. In addition, Brownian diffusion of very small particles may occur, and the particles may stick to the walls of the leakage path (Ref. 2.3-3).

Particles collected in the leakage path will block the entrance of other particles. A particle as large as the leakage path can block the leakage path, and the probability that smaller particles can enter the passage is reduced by the fraction of particles as large as the leakage path. As an example, consider an aerosol consisting of 1 percent "large" particles (large enough to block the leakage path) and 99 percent "small" particles (small enough to pass through the leakage path). The 1 percent "large" particles will not pass through the leakage path. In addition, the first particle to enter the leakage path that is large enough to block it will block the entrance of all other particles. Assuming a well-mixed aerosol, it is probable that only 99 small particles will escape before the leakage path is blocked.

2.3.1 Battelle Powder Leakage Research Program

Battelle, at Pacific Northwest Laboratories and Battelle Columbus Laboratories, has conducted an ambitious theoretical and experimental program outlined in Ref. 2.3-4. The overall objective of the program was to provide experimental data permitting estimation of plutonium oxide leakage rates through small gas leaks in shipping containers. An acceptable particle leakage rate for a powder might be such that the same passageway would permit a fairly large gas leak.

Characterized leakage paths were fabricated, and the relationships of gas flow and fine particle transmission were studied using those leakage paths to investigate the relationships of gas flow rates, leak geometries, pressures, and temperatures. Transmission of well-characterized material (UO_2 powder simulating PuO_2) was measured through the characterized leakage paths under two separate conditions: (1) leak location above the powder level, and (2) leak location below the powder level. Limiting conditions for "blowout" of particles for leaks of a diameter somewhat smaller or larger than the largest particles present were examined. The studies were later expanded to measure fuel grade PuO_2 leakage rates from a leakage path of simple geometry, and then from a simulated leaking container, with a leakage path fabricated to represent failure such as a failed gasket, defective weld, or crack in the wall. Attempts were made to develop analytical techniques to correlate PuO_2 leakage rates with gas leakage at the test conditions.

As part of this research program, several different orifices were created in 0.10 mm-thick platinum disks, 9.5 mm in diameter (Ref. 2.3-5). The particles were contained in a leakage tube having a reservoir volume of about 4 cc, loaded to contain about 25 percent particles by volume. The leakage tube was sealed to the orifice with stainless steel gaskets. Compressed helium was injected into the leakage tube to establish the internal tube pressure. A mechanical vibrator provided agitation of the particles inside the leakage tube. Particles that escaped through the orifice were collected on cascade impactors, so escaped particles could be classified according to size. Radioassay was used to detect the mass of the alpha-emitting powder that escaped. The correlation with a helium leakage rate was established by comparison of the measured particulate leakage rate with the corresponding helium leakage rate, which was measured by pressure drop or volumetric methods using an empty leakage tube. At least two runs were conducted for each experimental condition to check reproducibility of results.

Measured and calculated helium leakage rates for the orifices were compared. The measured rates were determined to be less than the calculated rates by factors from 0.6 to 0.8.*

In general, the total particle release increased with the size of the orifice, and in most cases, particle release increased with increasing pressure. A greater release occurred when particles were piled up on top of the orifice, while the smallest release occurred when the tube was in a sideways position. Vibration was found to increase the emission of particles for the one orifice diameter studied. Data showed that the helium leakage rate was greater than the plutonium leakage rate by factors varying from 1×10^3 to 1×10^8 on an atom/molecule basis, depending on the experimental conditions. Difficulty in duplicating the experimental results was attributed partly to problems in measuring the plutonium released using radioassay.

References 2.3-6 and 2.3-7 report measurements of the transmission of depleted UO_2 through orifices used in the airflow study (Ref. 2.3-5) as a function of upstream pressure, pathway diameter, and leak orientation (whether the leak was above or below the powder level). Statistical correlation suggested a two-state decision rule based on ln(A P) (where A is the cross sectional area of the leak), leak location, and aperture type.

Conclusions reached were: (1) diameter of the leak appeared to be the single most important parameter in powder leakage; (2) the duration of the experimental run had no statistically discernible effect on powder transmission for times up to 24 hr; (3) agitation did not influence the flow from an opening below the bulk powder level; (4) plugging was a frequent occurrence for openings above the bulk powder level, some of which plugged immediately upon pressurization; and (5) efforts to increase powder transmission by other techniques were unsuccessful.

---

*However, data in the report indicate that the leakage rate units should be atm-cm^3/s, rather than cm^3/s. When the leakage rates are recalculated,the values are in excellent agreement with the measured values.

Over two hundred experiments were conducted in another study (Ref. 2.3-8) to examine the effect on particle leakage of parameters such as leak size/type, internal system pressure, agitation of the apparatus, leak orientation with respect to the powder location, and run time. Leak types considered were (1) a small orifice in a thin disk, (2) a simulated crack made by machining a 5.6 μm (220-microinch) surface roughness in the mating faces of a split tapered disk, and (3) two lengths of capillary-type leaks 50-μm in diameter. Both a simulant ThO_2 powder and actual PuO_2 powder were used as the source of particles. Nominal helium gauge pressures of 6.9 MPa (1000 psi) were used for most experiments.

The data exhibited a high degree of irreproducibility, which severely limited the ability of the experimenters to draw any firm conclusions concerning the parametric dependency of the data. No single parameter appeared to have any observable effect on the quantities of PuO_2 emitted. In some cases vibration appeared to increase the powder release, while in other cases it did not. In the case of the PuO_2 experiments, vibration appeared to increase the size of the emitted particles, perhaps serving as a mechanism to enhance agglomeration of the particles. Changes in the run time did not result in changes in the quantities of PuO_2 emitted, leading to the conclusion that the majority of PuO_2 observed was emitted during the initial pressurization of the leakage tube. A weak parametric dependence was found between a logarithmic transformation of the total particle release and $\log_{10}(A\ \ P)$.

2.3.2 Curren and Bond Paper

Curren and Bond (Ref. 2.3-9) postulated that for a given leakage path and differential pressure, mass transfer of powder should be proportional to the air flow rate, and the constant of proportionality should be the density of the aerosol. Experiments were performed to measure gas flow rates as a function of pressure differential for different sized orifices, and to correlate the particle mass transfer with the gas flow rate. For each experiment, about 50 g of UO_2 powder were loaded into a metal can, the pressure inside the container was adjusted to the desired value, the container was attached to the vibrating table, and vibration was begun. The UO_2 particles emerging from the orifice were collected on a filter.

The amount of UO_2 transferred through orifices of 200 µm and 100 µm was plotted as a function of differential pressure, and good agreement was found with similar curves of gas flow rate as a function of differential pressure. The experiments were conducted for flows in the turbulent flow regime, and exhibited choked flow for most of the data points. The amount of UO_2 detected was also proportional to time, for orifices 25, 50, 100, and 200 µm in diameter.* Blockage of the orifices was observed even with the intense vibration used in the experiments for orifices 25 and 50 µm in diameter, when the surface of the powder was close to or above the orifice level. The maximum aerosol density available for escape through an orifice was 9×10^{-6} g/cm^3, for the orifice 20 mm above the UO_2 surface.

2.3.3 Measurement of Powder Leakage Past "Leaktight" Seals

Experiments to measure powder leakage past "leaktight" seals have been conducted (Refs. 2.3-10 and 2.3-11). Typical unlubricated face-type O-ring seals (EPDM gaskets) were used in the test fixture (it was thought that a lubricant might trap some particles). Helium leakage rates were measured, and particulate UO_2 leakage was determined. A chemical sampling procedure was used in early experiments (Ref. 2.3-10), but neutron-activated UO_2 powder was used as a radioactive tracer in later experiments (Ref. 2.3-11) to simplify the tests and eliminate the possibility of contamination. Both sets of experiments used a mixed oxide powder, having 50 percent of the particle population less than 1 µm in diameter, and 99 percent less than 4 µm in diameter.

---

*Two data points having substantial experimental error were used to plot each curve.

The experiments were conducted by admitting tracer particles and helium (at test pressure) into an evacuated chamber. A vibrator agitated the fixture during the test, and the temperature of the system was measured. At relatively high pressures and temperatures permeation occurred so quickly that by-pass leakage rates could not be measured. In the first series of experiments, no apparent correlation was found between amount of uranium measured and either helium leakage rate or equivalent capillary tube diameter. These results were confirmed by the second series of experiments. UO_2 definitely leaked past the O-ring in three of the tests. The authors state that the particle leakage could have occurred as a result of O-ring movement during temperature or pressure cycling at the beginning or end of a test, but could not verify that hypothesis because the time dependence of the particle leakage was not investigated.

2.3.4 Powder Leakage Research to Support the PAT-2 Package

The leakage path in a typical seal between two flat surfaces is more likely to be a flat crack-like opening that exists over some region of the seal than a capillary tube. References 2.3-12 and 2.3-13 present estimates of the space available for particle leakage from such a crack-like opening. The following assumptions are made: (1) the faulted region or crack is isolated to a specific region having a finite dimension, which is conservative because the calculated aperture is maximized; (2) the configuration of the fault is crack-like, having rectangular dimensions; (3) the rectangular cross section of the crack is equal in cross sectional area to the area of the calculated capillary (conservative because particle flow through a narrow crack will be less than the particle flow through a smooth-wall capillary of the same cross-sectional area).

Assuming rectangular dimensions for the "crack-like" aperture, the area of the "crack-like" aperture is related to the area of a circular aperture by

$$A = \pi D^2/4 = h \times w \quad ,$$

where

A = cross-sectional area,

D = leakage path diameter for circular leakage path,

h = height of crack,

w = width of crack.

With these assumptions, for a bolted closure, the width of the crack is given by the linear distance between bolts. The particle size that can escape from the "crack-like" aperture is then given by

$$h = \pi(D^2/4)(1/w) \quad ,$$

which can be estimated knowing the measured gas leakage and using the equations for laminar or molecular flow to estimate the equivalent hole size for a leakage path having a circular cross section.

For the Plutonium Air Transportable Model 2 (PAT-2) package, several different plutonium containment vessels containing various powders, salts, and solids of uranium (surrogate for plutonium) in a helium atmosphere were tested to accident environments specified for air transport of plutonium in NUREG-0360 (Ref. 2.3-14), and then examined for leakage rate and loss of contents.

The primary containment vessel in the PAT-2 package is sealed by means of closely spaced bolts in flat flanges, with a formed-in-place copper gasket contained within a groove equipped with knife edge features. The secondary containment vessel is sealed by means of a PTFE (Teflon)-sealed shouldered screw thread. Other laboratory containers were sealed by means of a screw thread and a PVC gasket in compression (hand-tightened).

Tests expected to pose threat to sealing systems were shock, vibration, and high temperature exposure, which results in high internal pressures. Swipe tests were used to detect powder releases. The particle size distribution for UO_2 powder used in the tests contained particles with a mean diameter of 0.99 µm, and 43 percent of the particles were less than 0.6 µm.

No powder release was detected (< 10^{-8} g) up to leakage rates as great as 10^{-3} cm^3/s of air (STP) (corresponding to a crack width of 6 µm). Additional considerations, such as blockage of the aperture or loss of particles inside the leakage path, could have prevented the particles from escaping from the containers.

2.3.5 Powder Leakage Research to Support the 6M Container

Similar results were found in testing of the 6M container, which is used to transport plutonium powders (Ref. 2.3-15). The powder is placed in at least two mechanically crimped, sealed cans which are packaged inside a sealed vessel (the 2R vessel). Therefore, there are at least three sealed barriers from which the powder must escape in order to reach the environment.

Depleted uranium dioxide (UO_2) powder with a mean particle diameter of about 2 µm was used to simulate plutonium dioxide (PuO_2). The minimum particle size measured was 0.4 µm. Impact testing of the 2R vessels inside the 6M packages showed no effect on the metal cans containing the powder. The only effect was from the thermal test, in which the 2R containers were heated in a tube furnace to simulate the hypothetical thermal accident environment. The furnace was rotated and vibrated during the test. Measurements were made during the time required to cool down to ambient conditions to detect any leakage of UO_2.

Higher gas leakage rates were measured after the thermal test, which resulted from deformation of the can lids from gas pressurization [greater than 105 kPa (15 psi) gauge] during the heating and cooling cycle. Metal cans that had gas leakage rates between 1.6 to 3.2 cm^3/s did not leak any detectable amount of UO_2. This is attributed in part to the complicated leakage path geometries expected for leakage of powder from metal cans with crimped lids. It is concluded that particle-tight seals can be maintained even when gross gas leaks occur under accident conditions.

References

2.3-1. "American National Standard for Radioactive Materials--Leakage Tests on Packages for Shipment," ANSI N14.5-1987, American National Standards Institute, January 1987.

2.3-2. L. C. Schwendiman, "Supporting Information for the Estimation of Plutonium Oxide Leak Rates Through Very Small Apertures," BNWL-2198 (NRC-12), Battelle Pacific Northwest Laboratories, January 1977.

2.3-3. W. E. Browning Jr., and R. D. Ackley, "Decontamination Factors for Particle Deposition in Containment Vessel Leaks," in "Nuclear Safety Program Semiannual Progress Report for Period Ending June 30, 1963," Oak Ridge National Laboratory Report ORNL-3483, September 13, 1963, pp. 39-42.

2.3-4. L. C. Schwendiman, et al., "Research Progress on Particle Transmission through Very Small Openings," Proceedings of the Fifth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '78, Las Vegas, NV, May 7-12, 1978, pp. 279-286.

2.3-5. D. C. Drennen, "Study of Plutonia Leak Rates from Simulated Container Leaks," Proceedings of the Fifth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '78, Las Vegas, NV, May 7-12, 1978, pp. 287-294.

2.3-6. S. L. Sutter, et al., "Depleted Uranium Dioxide Powder Flow Through Very Small Openings," Nuclear Technology 52, January 1981, pp. 100-104.

2.3-7. S. L. Sutter, et al., "Depleted Uranium Oxide Powder Flow Through Very Small Openings," NUREG/CR-1099, U. S. Nuclear Regulatory Commission, Washington, D.C., February 1980.

2.3-8. J. D. Yesso, et al., "Study of Plutonium Oxide Powder Emissions from Simulated Shipping Container Leaks," NUREG/CR-1302, U.S. Nuclear Regulatory Commission, Washington, D.C., August 1980.

2.3-9. W. D. Curren and R. D. Bond, "Leakage of Radioactive Powders from Containers," Proceedings of the Sixth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '80, West Berlin, F.R.G., November 10-14, 1980, pp. 463-471.

2.3-10. W. B. Leisher, et al., "Helium/Solid Powder O-ring Leakage Correlation Experiments," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM'83, New Orleans, LA, May 15-20, 1983, pp. 655-663.

2.3-11. R. W. Bild, et al., "Helium/Solid Powder O-ring Leakage Correlation Experiments Using a Radiotracer," Transactions 1984 Annual Meeting of the American Nuclear Society, New Orleans, LA, June 3-7, 1984, pp. 154-155.

2.3-12. J. A. Andersen, "Correlation between Measured Gas Leaks and Possible Loss of Contents from Radioactive Materials Packagings," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 646-654.

2.3-13. J. A. Andersen, "A Bounding Assessment Method for Correlating Measured Gas Leaks to the Possible Loss of Particulate Contents from Radioactive Materials Packages," Nuclear Technology 72, January 1986, pp. 75-83.

2.3-14. U.S. Nuclear Regulatory Commission, "Qualification Criteria to Certify a Package for Air Transport of Plutonium," NUREG-0360, U.S. Nuclear Regulatory Commission, Washington, D.C., January 1978.

2.3-15. J. M. Taylor and P. J. Raney, "Radioactive Particulate Release Associated with the DOT Specification 6M Container Under Hypothetical Accident Conditions," Battelle Pacific Northwest Laboratory, PNL-5747, February 1986.

2.4 Release and Leakage Test Procedures

Leakage testing is a form of nondestructive testing used (1) for the detection and location of leaks, and (2) for the measurement of gas or liquid leakage in either pressurized or evacuated systems and components (Ref. 2.4-1).

The ANSI N14.5 standard (Ref. 2.4-2), in Appendix A, lists recommended leakage tests and provides their sensitivities as shown in Table 2.4-1. The leakage tests fall into several categories: pressure drop/rise, bubble detection, and detection or measurement of a tracer fluid. The choice of a leakage test method depends on whether the system is accessible from both sides of a pressure boundary.

In the gas pressure drop or pressure rise tests, the test item is pressurized to its design pressure or specified test pressure, and the change of pressure and temperature is measured within the test item during a specified time period. For the pressure drop test, the total

TABLE 2.4-1

LEAKAGE TESTS AND THEIR SENSITIVITIES
(ANSl N14.5-1987)

Test Method	Nominal Test Sensitivity* (std cm^3/s)	Notes
Gas pressure drop	10^{-1}	(†, ‡)
Hot water bubble	10^{-2}	(§, **)
Gas bubble	10^{-3}	(§, **)
Soap bubble	10^{-3}	(§, **)
Gas bubble, vacuum, and glycol	10^{-3}	(§, **)
Gas pressure rise	10^{-4}	(†, ‡)
Halogen detector	10^{-3} - 10^{-6}	(§)
Helium mass spectrometer spray or sniffer	10^{-3} - 10^{-6}	(§)
Helium back pressurizing	10^{-3} - 5 x 10^{-8}	(§)
Helium mass spectrometer envelope	10^{-3} - 10^{-8}	(§)
Tracer gas fill helium or ^{85}Kr	10^{-3} - 10^{-8}	(§)

* For comparison purposes only. The listed values are referred to a common standard of dry air at 25°C and a pressure of 1 atm. Bubble test sensitivities are for 1 atm differential pressure except for the hot water bubble, which is for 0.25 atm differential.

† Depends on volume tested, test time, and instrument sensitivity to pressure differentials.

‡ The listed sensitivity is typical. The actual sensitivity when applied to a containment system should be calculated from Equation B19 of Appendix B.

§ The listed sensitivity applies to test methods under normal field conditions. Under favorable, well-controlled conditions, this sensitivity could be increased by a factor of 10.

** For tests with a liquid-gas interface, take account of surface tension and the hydrostatic head of the liquid bath. Refer to Equation B16 of Appendix B.

leakage rate is calculated using the estimated gas volume within the test item:

$$L = [VT_s/(3600H \times P_s)](P_1/T_1 - P_2/T_2) \quad ,$$

where

L = leakage rate (std-cm^3/s),
V = test volume (cm^3),
H = time (h),
P_1 = pressure in test item at start of test (atm),
P_2 = pressure in test item at end of test (atm),
P_s = standard pressure, 1 atm abs,
T_1 = gas temperature in test item at start of test (K),
T_2 = gas temperature in test item at end of test (K),
T_s = reference absolute temperature of 298K (25°C).

Test sensitivity is low for the pressure drop test, and depends on volume and test duration (usually 2 h or longer). The subscripts (P_1 and P_2, T_1 and T_2) are interchanged to obtain the equation for leakage from the pressure rise test.

The pressure rise test is commonly used to measure the leakage rate of a containment boundary seal by evacuating the space between that seal and a second seal, and measuring the increase in pressure with time in the interseal space.

One problem with this procedure is outgassing, which is the release of gases from the surfaces of the test item when the item is at a low vacuum pressure. Outgassing obscures the actual leakage rate, which may be much lower than the outgassing rate. To minimize outgassing, the test item (metal surfaces, gaskets, etc.) should be kept clean and dry.

In the bubble tests, the test item is pressurized with a tracer gas to its design pressure or specified test pressure for at least 15 min. Then, with the test item pressurized, suspected leakage areas are immersed in a liquid bath. Bubble streams are searched for. Various liquids, such as water, alcohol, mineral oil, or silicone oil can be used in conjunction with various tracer gases, with different combinations producing different sensitivities. For items without pressure connections, a similar test may be conducted by immersing the test item in glycol, evacuating the pressure above the glycol, and searching for air bubble streams coming from within the test item. Specifying a sensitivity greater than 10^{-4} std cm^3/s makes bubble testing exceedingly difficult. When checking for leakages in the 10^{-3} cm^3/s range or lower, the operator must be sure that the test object or component is submerged long enough for any bubbles coming from around crevices to collect and rise (Ref. 2.4-1).

Other test procedures, with greater sensitivity, detect the leakage of a tracer gas (halogen or helium) or measure the concentration of the leaked gas. A helium mass spectrometer leakage detector, for example, compares the rate at which helium leaks from the test item to the rate at which helium leaks from the calibrated leak. Alternatively, the helium can be introduced into the test item by backpressurizing, and then detected as it leaks out, or can be backfilled into an envelope surrounding the test item and detected as it leaks into the evacuated test item.

For any of the gas leakage tests, justification should be given if the direction of leakage for a test procedure differs from the direction of leakage in normal or accident conditions. False acceptance may be a problem with tests which detect and measure the presence of individual leaks. For example, multiple holes may have small leakages which are not detected by a bubble test or a helium sniffer test (Ref. 2.4-3), but which may sum to a leakage rate greater than the maximum acceptable leakage rate.

A release test procedure is included in ANSI N14.5-1987. Care is needed in performing the test to avoid false acceptance, which could occur either from failure of the contents to find existing leakage paths or dispersal and nondetection of the released radioactive material.

References

2.4-1. Nondestructive Testing Handbook, Second Edition, Volume One-Leak Testing, R. C. McMaster, ed., American Society for Nondestructive Testing, American Society for Metals, 1982.

2.4-2. "American National Standard for Radioactive Materials--Leakage Tests on Packages for Shipment," ANSI N14.5-1987, American National Standards Institute, January 1987.

2.4-3. Lake, W. H., "Containment System Evaluation," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983.

3.0 BASIC PRINCIPLES OF SEALS AND CLOSURES

3.1 Introduction

This chapter describes the factors that affect the sealing capability of a closure. There are four major categories of factors: properties of the sealing surfaces, properties of the gasket material, properties of the closure method, and properties of the contents. While the factors that affect sealing capability can be discussed qualitatively, no quantitative analysis method exists as yet to accurately calculate leakage from a closure or seal design. This chapter also describes efforts to develop analytical tools for predicting leakage from a full-scale packaging, and tests that have been performed on full- or scale-model packagings to verify the containment system design.

A seal can be defined as a means to prevent leakage through a joint, but it can also be used to describe the sealed joint itself (Ref. 3.1-1). For transport packagings, the sealed joint consists of the components that make up the closure, including the fasteners. The closure design must be able to provide (1) access to the cavity of the packaging, (2) installation of the gasket (if required) and lid by hands-on or remote handling techniques, (3) reasonably uniform sealing force in order to achieve a seal with the allowable leakage rate, and (4) maintenance of the allowable accident leakage rate with the forces and temperature imposed upon the closure design by the drop and thermal testing requirements (Ref. 3.1-2).

In general, the closure could be welded, brazed, or use a removable gasket to effect the seal. A gasket seal is defined as a seal made by compressing a gasket between the parts to be sealed. (Ref. 3.1-3). Use of a gasket between two sealing surfaces improves the ability to achieve a low leakage rate, and permits lower compressive forces on the flanges than if the gasket were not present (Ref. 3.1-1). The overwhelming majority of Type B packagings are designed with gasket seals (see Chapter 5). Therefore, only gasket seals are discussed in detail in this report.

The basic principle behind operation of a gasket seal is the prevention of gas, liquid or solid loss by the yielding of a softer material wholly or partially confined between two mating surfaces. The gasket is forced to flow into the surface imperfections of the sealing surfaces and any clearances, effecting a positive block to the gas, liquid or solid being sealed (Ref. 3.1-4). The number and sizes of leakage paths are thereby reduced, resulting in a decrease in the leakage rate.

References

3.1-1. A. Roth, Vacuum Sealing Techniques, Pergamon Press, Ltd., 1966.

3.1-2. L. B. Shappert, *et al.*, "Cask Designers Guide -- A Guide for the Design, Fabrication, and Operation of Shipping Casks for Nuclear Applications," Oak Ridge National Laboratory, ORNL-NSIC-68, February 1970.

3.1-3. Glossary of Terms Used in Vacuum Technology, American Vacuum Society, Pergamon Press, Ltd., 1958

3.1-4. "O-Ring Reference Guide," ORD 5703, Parker Seal Group, Lexington, KY, 1985.

3.2 The Sealing Process

Information covering the sealing process is primarily from Refs. 3.2-1 to 3.2-3. If two flanges with high quality surface finishes are brought in contact, a good mechanical union can be made; but under most circumstances, the gaps or channels between the flanges would allow too large a leakage rate. The pressure to close these gaps would be very high since the flanges are stiff and surface irregularities are very hard. In order to seal the gap and any surface irregularities, a third, softer material is placed between the flanges, so that only reasonable compressive forces on the flanges are required (Ref. 3.2-1). This softer material must conform to the sealing surfaces, including any accidental surface distortions or foreign particles (Ref. 3.2-2). In general, the pressures required to effect a seal are moderate for elastomers, higher for plastics, and highest for metals. Some metal seal designs make an effort to reduce the required pressure by using a cross-section design which is more flexible than solid metal (Ref. 3.2-4).

As the closure fasteners are tightened, contact is gradually established between the gasket and sealing surfaces along the entire circumference of the gasket. The initial forces are primarily overcoming the waviness of the sealing surfaces, crushing foreign particles, and pushing small local protrusions of the flanges into the softer material of the gasket. Normal sealing occurs with further tightening. Leakage paths at the interfaces are gradually closed off or throttled by interpenetration of the soft gasket material into the rougher, harder surface of the flange or by flattening of a rough or wavy gasket onto a smoother flange. For a given force, interpenetration permits a lower leakage rate than flattening of the gasket. Local sealing occurs upon even further tightening, in which the soft gasket material fills flaws in the sealing surfaces, such as radial scratches, eccentrically mated concentric machining marks, or grooves of helical machining. The leakage rate decreases very slowly with increasing force for local sealing (Ref. 3.2-2).

There are two parts of the total measured leakage rate from a gasket: by-pass and permeation (see Sections 2.1.1 and 2.1.2). Permeation leakage is that which passes through the gasket itself. By-pass leakage is that which flows around the gasket through unfilled surface roughness and flaws of the sealing surface, and is the major concern of seal designs. Permeation leakage is determined primarily by the gasket material and gas (see Chapter 4).

The equations for calculating by-pass leakage (see Section 2.1.2) include the following environmental parameters: leakage path diameter, leakage path length, absolute temperature, upstream pressure, and downstream pressure. (The remaining parameters deal with properties of the gas itself, such as molecular weight, specific heats, etc.) The equations are derived for leakage from a capillary. It is more likely that the leak passage is similar to a crack, long and narrow, rather than a circular cross section tube (see Section 2.3 for some applications of this assumption to particle leakage). In any case, the leakage rate will depend on the leakage path geometry, and on the number of leakage paths that contribute to the measured leakage rate.

The leakage path length to be used is determined subjectively by examining the container design to determine the likely mode of failure. Typically, the leak path length is taken to be the minimum distance past the gasket in its compressed condition. The cross section of the leakage path(s) is determined by the imperfections in the gasket and sealing surfaces and by any distortion of the sealing surfaces caused by the normal or hypothetical accident tests (primarily from the stresses encountered during the impact or thermal hypothetical accident tests) (Ref. 3.2-5).

References

3.2-1. A. Roth, Vacuum Sealing Technique, Pergamon Press Ltd., 1966.

3.2-2. A. Roth, Vacuum Technology, Elsevier Science Publishing Co. Inc., 1982.

3.2-3. H. H. Buchter, Industrial Sealing Technology, John Wiley and Sons, 1979.

3.2-4. T. C. Chivers, L. A. Mitchell, and M. D. Rowe, "Some Parameters Affecting Static Metallic Seal Design, Selection, and Performance," CEGB Central Electricity Generating Board, Report RD/B/N3589, England, June 1976.

3.2-5. L. C. Schwendiman et al., "Research Progress on Particle Transmission through Very Small Openings," Proceedings of the Fifth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '78, Las Vegas, NV, May 7-12, 1978, pp. 279-286.

3.3 Factors Affecting Sealing Capability

There are many factors which influence the ability to make a seal with as low a leakage rate as possible. The parameters that affect the sealing capability of a closure design include properties of the sealing surface (surface finish and hardness), properties of the gasket material (plasticity and elasticity), properties of the closure method (means of applying force to the gasket, uniformity of applied force, need for lubrication, etc.), and properties of the contents (affecting internal temperature, pressure, radiation, and chemical environments).

3.3.1 Properties of the Sealing Surfaces

3.3.1.1 Surface Finish

Surface finish is used to denote the general quality of a surface. For a given sealing force, the smoother the initial surface, the lower the leakage rate, because fewer and/or smaller leakage paths are available.

Surface texture is the technical term used to describe the characteristics of a surface, and is defined as the repetitive or random deviations from the nominal surface which form the three-dimensional surface topography (Ref. 3.3-1). ANSI B46.1-1978 describes, standardizes, and calls out measuring instrumentation for surface texture. In the ASM Metals Handbook (Ref. 3.3-1), four elements of surface texture are defined: roughness, waviness, lay, and flaws (see Fig. 3.3-1 from Ref. 3.3-2).

3.3.1.1.1 Roughness

Roughness consists of the finer irregularities which generally result from the inherent action of the production process. These include transverse feed marks and other irregularities within the limits of the sampling length (Ref. 3.3-1). The parameter of surface roughness is R_a, which is the arithmetic average (AA) deviation of the surface from the roughness center line, expressed in micrometers or microinches. Still used occasionally is R_q, an average deviation from the roughness centerline which is the root mean square (rms), expressed in microinches ($R_q/R_a = 1.11$) (Ref. 3.3-1).

The smoothness of the surface required depends upon the type of gasket used, as well as the desired leakage rate. A metal gasket requires a smoother surface finish than an elastomer. For example,

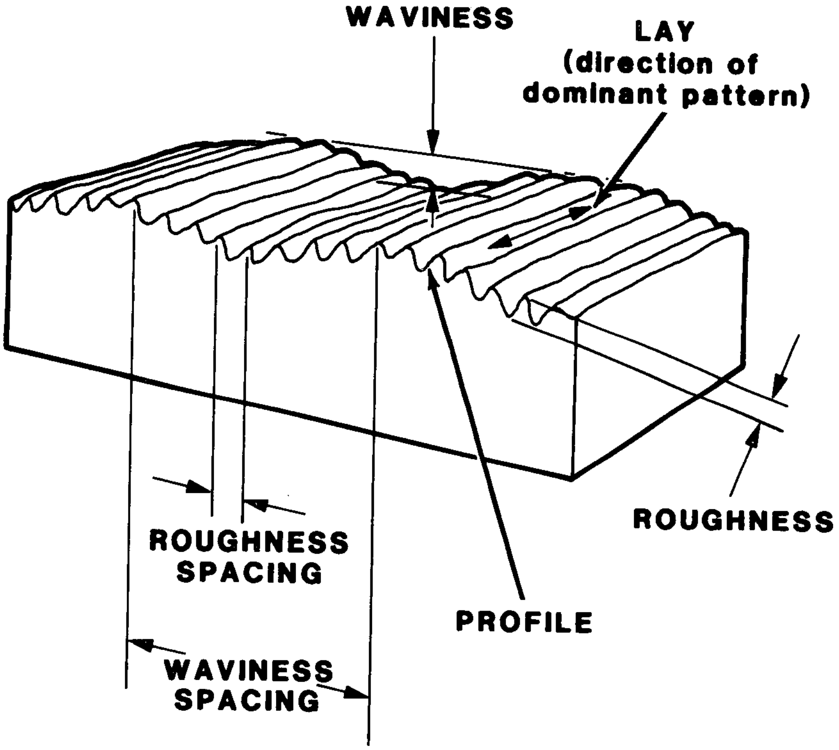


Figure 3.3-1. Elements of Surface Texture (Ref. 3.3-2)

Parker Seal Co. (Refs. 3.3-3 and 3.3-4) recommends a surface finish, for their Gask-O-Seal, of 3.2 μm (125 μin) rms for most applications and 0.81 μm (32 μin) rms for diffusion type leakage of gases, while 0.10-0.20 μm (4-8 μin) rms is recommended for a silver-plated metal O-ring that must meet a leakage rate of 10^{-9} std. cm^3/s.

In a general decreasing order of surface roughness, some production processes are planing or shaping, spark machining or milling, boring or turning, grinding, honing, buffing, lapping and polishing, and super finishing (Ref. 3.3-2). The actual value of surface roughness achieved depends on material and tooling details.

3.3.1.1.2 Waviness

Waviness includes all irregularities whose spacing is greater than the roughness sampling length and less than the waviness sampling length (Ref. 3.3-1). Roughness may be considered superimposed on a "wavy" surface. Waviness may result from machine or work deflections, chatter, vibration, heat treatment, or cutting tool runout.

3.3.1.1.3 Lay

Lay is the direction of the predominant surface pattern, ordinarily determined by the production method used (Ref. 3.3-1).

3.3.1.1.4 Flaws

Flaws are unintentional irregularities which occur at one place or at relatively infrequent or widely varying intervals on the surface. Flaws include cracks, blow holes, inclusions, checks, ridges, scratches, etc. Unless otherwise specified, the effect of flaws is not included in the roughness average measurements. Where flaws are to be restricted or controlled, a special note as to the method of inspection should be included on the drawing or in the specifications (Ref. 3.3-1).

3.3.1.2 Effect of Surface Finish on Sealing Capability

Rough surfaces produce many relatively large leakage paths, and will require considerable plastic flow of the gasket surfaces to seal effectively. Smooth surfaces, on the other hand, produce smaller leakage paths which offer high resistance to leakage flow and require less plastic flow at the gasket surfaces (Ref. 3.3-2).

When the mating surfaces of flanges have significant waviness, and the flanges are bolted together with a gasket interposed between the faces, the compressive stress on the gasket will not be uniform around the circumference. The stress on the gasket will be highest in the regions corresponding to the flange wave peaks, and lowest in the regions corresponding to the wave troughs. When internal pressure reduces the compressive stress on the gasket, the initially low stress regions of the gasket will approach the condition where the residual stress is insufficient to prevent leakage. The usual response is to tighten the bolts in an attempt to increase the compressive stress on the gasket. This will work only when the bolts are still elastic, the flanges are not already completely in contact with each other, and the flanges are sufficiently rigid, or stiff, to transfer the force to the regions of the gasket where it is most required, and when the mechanical properties of the gasket allow such an increase in compression (Ref. 3.3-2).

It is more difficult and requires greater compression to effect a seal when roughness from machining marks or flaws cross the line of the sealing contact area rather than run parallel to the seal, as in circumferential machining. There is also a greater chance that a continuous passage will exist from one side of the gasket contact area to the other, thus increasing the chance of an excessive leakage rate. For example, a piece of dirt or a hair can create a 10^{-6} atm-cm^3/s leak (Ref. 3.3-5). It is also easier to effect a seal if the machining marks are wide and shallow as opposed to being narrow and deep (Ref. 3.3-6).

As the depth to width radio of a flaw or surface defect increases, the gasket material has to be subjected to increasing compression in order to force it to flow into the flaw. Given a sufficiently deep flaw, the available maximum compressive stress may be insufficient to extrude the gasket material into the flaw, and the joint will leak (Ref. 3.3-2).

The shape and dimensions of actual leakage paths have been measured by George and Williams (Ref. 3.3-7). An assembled elastomer O-ring seal was cooled to liquid nitrogen temperature, thereby freezing the deformation impression in the surface of the elastomer O-ring. Profiles of the elastomer and the metal sealing surfaces were compared to yield the cross sectional shape and dimensions of the leakage flow paths. The flow paths were found to be crescent shaped with a length to height ratio of about ten. Good correlation was obtained between leakage rates measured for the seal by the pressure rise method and those calculated using laminar flow equations for a triangular shaped opening, with a correction factor to account for the actual crescent shape of the leakage paths (Ref. 3.3-7).

The concept of the assembly verification leakage test assumes that scratches or other flaws introduced into the surfaces during operation of a packaging will be detectable by visual inspection, or will cause a leakage rate greater than 1×10^{-3} std-cm^3/s for those packages having a more stringent maximum acceptable leakage rate.

3.3.1.3 Hardness

The material of the flanges or sealing surfaces must be locally harder than the gasket material. The harder the sealing surfaces, the less likely it is that the manufacturing process or normal operations will cause scratches. The methods used for measuring the hardness of elastomers and metals are described in Chapter 4. Hardness of the gasket is discussed in Section 3.3.2.1.

When the packaging is subjected to the hypothetical accident impact condition, large forces may occur that distort the flanges or stretch bolts or other fasteners. Thus, the integrity of the seal generally depends upon the design of the flanges and any retaining fasteners. If the lid and cask flanges are stiff and there is no relative movement between the lid and the cask body due to the impact, and the gasket is located near the fasteners, the seal would probably remain intact (Ref. 3.3-8).

3.3.2 Properties of Gaskets

3.3.2.1 Gasket Material

The basic qualities required of gasket materials to satisfactorily perform their sealing function are as follows (Ref. 3.3-2):

1. the surface layers of the material should be plastic,
2. the internal structure of the material should remain elastic,
3. under compression, the time dependent creep properties of the material should be very low and unaffected by temperature changes,
4. the material should not be porous in the compressed state,
5. the physical properties of the material should not be degraded by the material being sealed,
6. the material should not promote corrosion of the flange faces,
7. the material should not tear easily or rupture under compression,
8. the material should be readily available and economical.

In a joint containing an idealized gasket, the plastic surface layers of the gasket ensure that flange surface imperfections are properly sealed (Ref. 3.3-2). The hardness of the gasket material will affect its deformation properties. For the same decrease in leakage rate, soft materials require less sealing force than hard materials.

This can be accomplished by using a soft elastomer such as neoprene or Viton, or by using a soft metal such as indium as the gasket material (Ref. 3.3-9).

The resilient inner structure permits the gasket to track small movements at the flange. This tracking ability is very important since it ensures that the compressive stress on the gasket is maintained at an adequate level in spite of flange deflection under pressure (or impact). Initial internal resilience alone does not guarantee a satisfactory seal. It is also extremely important that the material does not unduly relieve itself of the stress imposed on it, i.e., the stress relaxation of the material should be low (Ref. 3.3-2).

It is difficult to produce a gasket material that possesses all of these characteristics (Ref. 3.3-2). Descriptions of the properties of specific gasket materials are presented in Chapter 4.

3.3.2.2 Contact Width

The shape and size of the gasket are two of the factors (in addition to the compression) which determine the width of the gasket-flange contact area and high stress region, and therefore, the region of deformation. For the same decrease in leakage rate, a narrow seal requires less sealing force than a wide seal (Ref. 3.3-9). This can be accomplished by using a narrow O-ring or a knife edge seal, where the stress is concentrated on a small width of the gasket. Examples of a variety of gasket shapes and their contact widths are shown in Figure 3.3-2 (from Ref. 3.3-10).

The leakage path length used for calculating leakage rates is determined subjectively by examining the closure design to determine the possible failure modes (Ref. 3.3-11). Typically, the leakage path length is taken to be the minimum distance across the width of the gasket in its compressed condition.

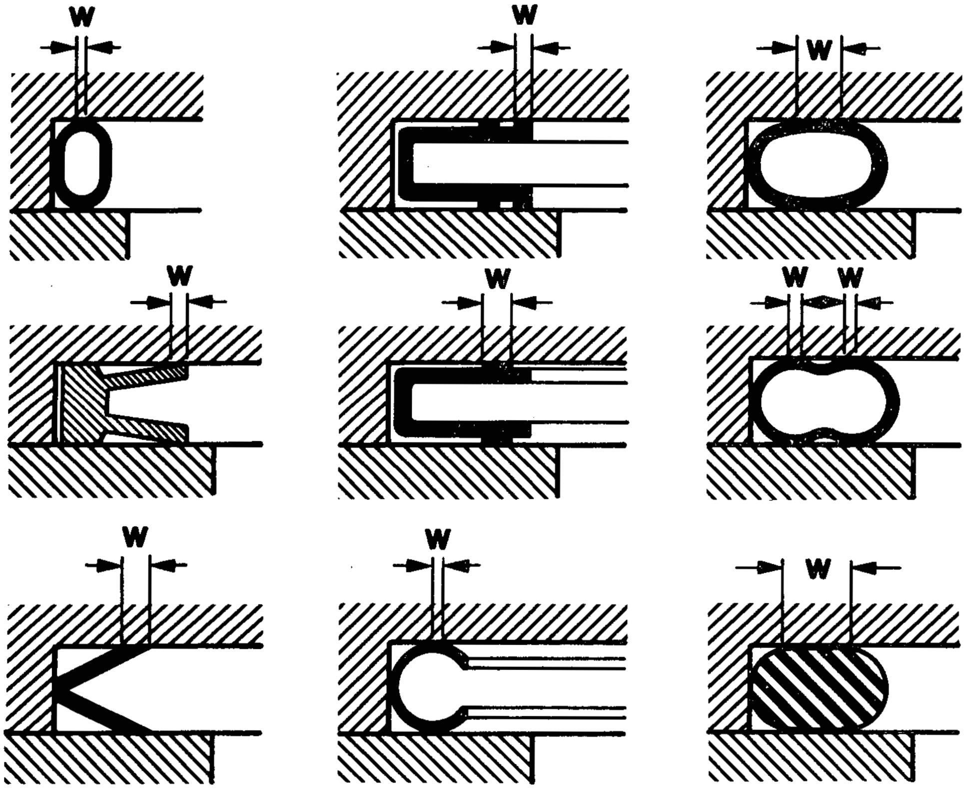


Figure 3.3-2. Contact Width (W) of a Variety of Gasket Shapes (Ref. 3.3-10), reprinted by permission of John Wiley & Sons, Inc. from Industrial Sealing Technology, by H. H. Buchter, copyright ⓒ 1979 by John Wiley & Sons, Inc.)

3.3.3 Properties of the Closure

An acceptable closure design must be able to provide uniform sealing force in order to achieve a seal with the allowable leakage rate, and to maintain the allowable accident leakage rate following the impact and thermal tests when fasteners may be stretched or flanges distorted. See Section 3.4 for descriptions of basic seal designs.

3.3.3.1 Certified Closure Methods

From a catalog (see Chapter 5) of NRC-licensed Type B, large diameter Type A, and irradiated fuel transport packages in the U.S., it was found that the most common method of closure is a threaded fastener, which is listed as bolts, studs and nuts, and cap screws, followed by welds. Studs and nuts and cap screws apply pressure to the seal in the same fashion as bolts. Welding as a method of sealing is outside the scope of this report. Another method of closure, ratchet binders (see Fig. 3.3-3) (Refs. 3.3-12, 3.3-13) is no longer considered an acceptable closure method for Type B packages from a regulatory viewpoint (see Section 5.3.2).

In the following discussions of the properties of closures that affect sealing capability, the closure will generally be assumed to be a bolted closure.

3.3.3.2 Application of Sealing Force

To maintain a low leakage rate across a gasketed joint, it is necessary that the parts containing the mating surfaces are tightly fastened together. The initial forces must be great enough to cause local yielding of the gasket surface when it contacts the metal flange surfaces. Packaging designs use various techniques to lessen the shock of impact and to distribute the impact load over a relatively wide area so the joint can remain tightly fastened together (Ref. 3.3-8).

A certain level of contact stress must be maintained between the gasket and the flanges. This contact stress will vary with time, as a

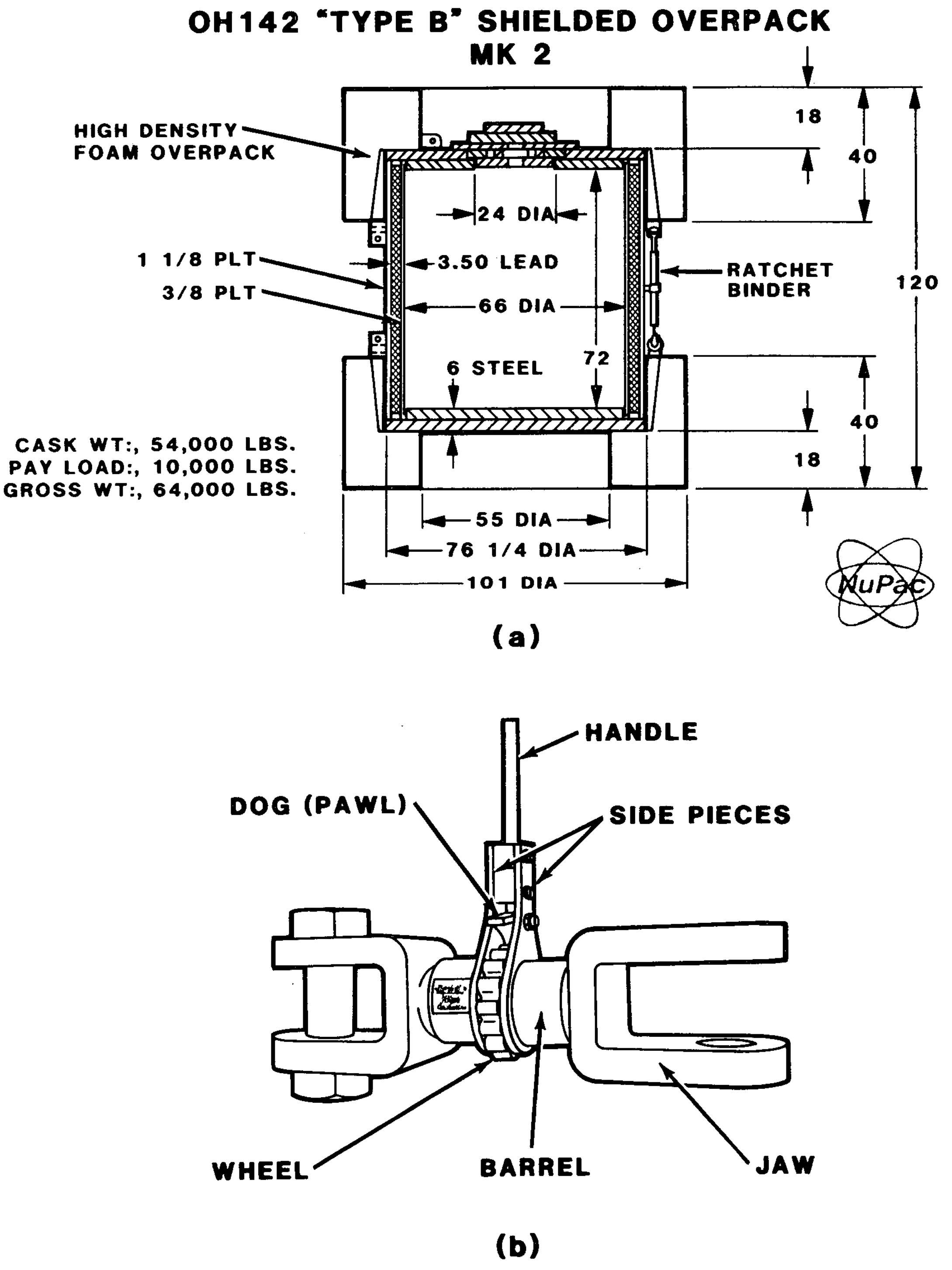


Figure 3.3-3 (a) Transport Packaging With Ratchet Binder (Ref. 3.3-12)

(b) Detail of Ratchet (Ref. 3.3-14)

result of stress relaxation in the gasket material, changes in pressure and temperature with associated flange distortions, and creep in highly stressed regions of the fasteners and flanges. The net effect is normally a reduction in the gasket contact stress, and the joint is likely to seal less effectively. Some means of maintaining the contact stress is necessary. This is achieved by storing elastic strain energy in the joint system. The strain energy is stored as stretch of the fasteners, elastic compression of the gasket, and flange deflection. The fasteners are normally the main source of stored energy, but some types of gaskets (e.g., metallic spiral wound types) also store significant energy (Ref. 3.3-2).

Increasing compression on the gasket results in a lower leakage rate, up to a point. Structural considerations restrict how much the gasket compression can be increased to reduce by-pass leakage. At initial compressions higher than about 20 percent, the effect of small tensile forces have been observed in elastomer O-rings near the edges of the contact area. These forces can increase with increasing temperature because of differential thermal expansion and decreasing tensile strength, which can cause tensile failure in the elastomer when subjected to the hypothetical accident thermal test (Ref. 3.3-6).

The pressure on the gasket required to achieve a given leakage rate depends upon: the gasket material, flange surface finish, and friction between the gasket and flanges. The friction is determined by the lubrication, if any, and the shapes of the gasket and flanges. When a gasket is under pressure, it will deform. The total amount of gasket deformation necessary depends on the shape and material of the gasket and whether the seal design is based on compression, shear, or a combination of these two forces. In compression joints (see Fig. 3.3-4), the pressure is applied perpendicular to the supporting area, while in shear joints, the pressure is applied parallel to the supporting area (Ref. 3.3-15).

The seals that are primarily plastically deformed require high sealing forces or tight machining tolerances and tolerate little

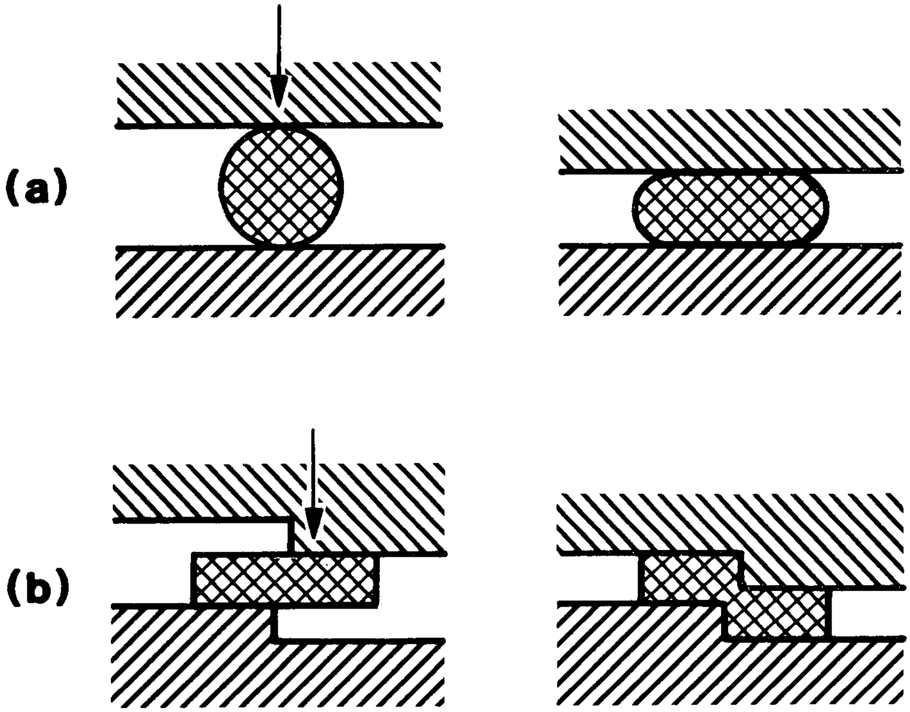


Figure 3.3-4. Example of (a) Compression Joint and (b) Shear Joint (Ref. 3.3-15)

relaxation of sealing forces. Pressure-filled face seals (see Section 4.3.4.2) can compensate for some reduction in sealing force if the bolts used in the closure elongate. Flexible face seals (see Section 4.3.4, Figure 4.3-1) may have small sealing contact areas and require relatively lower sealing loads. These seals require tight tolerances on positioning and surface finishes. The bore seals that plastically deform have the same characteristics as the face seals (Ref. 3.3-15). (See Section 3.4 for definitions of face, flange, gland, and bore seals.)

Elastomer gaskets are commonly lubricated by applying a thin film of grease to the gasket. Lubrication of the gasket sealed between plane flanges allows the seal to be tightened with a relatively lighter pressure. A dry gasket requires higher loadings to seal depending on the hardness of the gasket and the roughness of the surface. The grease may temporarily seal small scratches in a flange or the gasket, but cannot be considered a sealing material, in particular, due to lubricant viscosity changes that may occur due to the thermal testing or decay heating. A greased gasket must be contained in a groove or other centering device, or else it could slide out of position (Ref. 3.3-15). Lubricants are also used to coat the sealing surface for a gland seal, to provide a means for sliding the seal into its required location.

3.3.3.3 Bolted Joint Design

There are many references covering the design of bolted closures for a variety of applications. The information presented here is from reference 3.3-17, which in turn provides a large number of references. In closure designs, bolts act as clamps to hold the flanges and gasket together. Generally, studs, screws, etc., behave in the same manner as bolts, so this discussion on bolts would also apply to these other threaded fasteners. When a bolt is tightened, it is stretched slightly. By turning the nut, tensile stress is induced in the bolt. Due to friction, especially when bolt threads are not lubricated, torsional stress is also introduced. When the flange surfaces are not exactly parallel or the faces of the nut and the bolt head are not exactly perpendicular to the axis of the threads, bending stress is induced. When tightening of the nut ceases, some of the stresses induced in the bolt will disappear or relax due to localized creep or flow. The tensile stress induced in the bolt during tightening results in a tensile force in the bolt, which then results in a clamping force on the closure joint. The initial clamping force, or the tension in the bolt, is called the preload. The preload will in turn generate the contact stress in the gasket. In order to maintain the required leak rate, a sufficient contact stress must be maintained despite relaxation in the bolts and gasket, primarily due to temperature and pressure changes. The elastic behavior of gaskets are generally nonlinear and not well defined in most situations.

Design recommendations by engineering societies and gasket manufacturers are generally based on two experimentally determined gasket factors. The y factor is the initial gasket stress required to preload or seat the gasket. It is given in terms of psi. The m factor is the ratio of residual contact pressure, during operation, to contained pressure and is dimensionless. Both factors are determined experimentally and are different for different gasket designs. Design procedures are given by the ASME Boiler and Pressure Vessel Code. There are both relatively simple (see Ref. 3.8-18) (and more conservative) and more complex procedures (see Ref. 3.3-19) for different types of flange designs. In the simpler analysis for raised face flanges, the designer follows these steps:

1. selects general size and type of flange;

2. determines operating conditions and flange, bolt, and gasket materials and allowable stresses;

3. computes operational loads on the joint;

4. computes bolt loads for both initial seating and operational loading using the published y and m factors and an estimate of the effective gasket contact width;

5. computes the minimum allowable total cross-sectional area of the bolts required for initial gasket seating, operational seating, actual bolt area and flange bolt load;

6. computes the stresses in the flange and determines if these stresses are allowable (if not, the procedure is repeated with different parameters).

This procedure does not guarantee a leak tight joint, but has been a widely used and successful design tool. The m and y factors should be used with caution, since recent studies have indicated that the m and y factors may not be constants, but instead may be functions of the contents, operating temperature, condition of the flanges and other factors (Ref. 3.3-20). The m factor may also be a function of the y factor. In some experiments, the higher the initial seating stress (y), the lower the residual contact pressure (m) required to maintain the leakage rate (Refs. 3.3-20, 3.3-21). In one experiment, the leakage rate of gaskets was dependent on the gasket deformation rather than the contact stress, when the gasket "remembered" a previous higher stress (Refs. 3.3-22, 3.3-23).

3.3.3.4 Uniformity of Applied Pressure

As in the previous section, the information presented here is from reference 3.3-17, which contains many references and suppliers for the instruments discussed. As bolts are tightened, a bending force will be applied to the flange, putting more pressure on the outside diameter of the gasket than on the inside diameter. Contact pressure will then vary from point to point. Due to control problems (for example, the accuracy with which torque creates preload), the amount of preload in each bolt will vary. This can distort the flanges causing more variation in the contact pressure on different portions of the gasket. Suggestions for achieving a relatively uniform preload includes tightening the bolts in an alternating star sequence, tightening several bolts in the star sequence at the same time, and using the best possible method to control the amount of preload to minimize variation in the amount of preload. In some cases, uniform preload may be more important than the actual value of preload.

There are several factors which affect the accuracy with which a desired preload is achieved. These factors include tool accuracy, operator accuracy, control accuracy, short and long-term relaxation, external loads and quality of the parts. When a bolt is tightened, torque is applied to the nut, the nut turns, the bolt stretches and preload is created. The amount of preload can be controlled from any step in this process, that is, through torque, turns or stretch.

It is easiest to control preload by measuring torque, using a torque wrench. Unfortunately, the relationship between torque and preload is not well characterized and therefore not accurately predictable. The main uncertainties are due to variables in surface finishes; hardness; material type; plating thickness, condition and type; lubrication; speed at which the nut is tightened; fit between threads; hole clearance; surface pressures; etc. With these variables, if the same torque is applied to many bolts, the amount of preload in the bolts will not be uniform. Usually, lubricating the bolts will reduce the amount of variation in the preload. However, even perfect input torque (assuming perfect accurate tools) can lead to ± 25 to 30 percent variation in preload. When gasketed joints are tightened in stages, the gasket will generally creep and relax between passes, thereby relaxing the preload slightly with each pass, prior to the next tightening.

The amount of turn on the nut can also be used to control the amount of preload. However, again the relationship between the amount of nut rotation and the amount of stretch in the bolt is not well characterized. It depends on the relative stiffness of joint and bolt; flatness and condition of the joint, washers and threads; and lubrication.

A combination of both torque and turn is used in some bolting applications. In these, the nut is first snugged with an approximate torque and then turned a specific amount which stretches the bolt past its yield point. Once past its yield point, the variation in preload is much smaller than when using torque or turn control alone. This technique produces plastic deformation in the bolt and limits the applications for this technique. A similar procedure, which does not plastically deform the bolts, has been used in the aircraft industry. In this case, the nuts are tightened and loosened twice, then snugged to a relatively low torque and then turned a specific amount. The bolt is not stretched past yield, but preload accuracy is improved. The initial cycling reduces subsequent relaxation and the closure has been pulled together before the official snug torque and turn is applied, providing a more stable initial condition.

Another method for controlling preload is by controlling the stretch in the bolts. The factors which produce scatter in the preload, namely dimensional tolerances and modulus of elasticity, can be measured and controlled if necessary. It is still difficult to analytically predict preload based on stretch, but it can be experimentally determined. The amount of stretch in bolts can be measured using a depth micrometer in the bolt or ultrasonic measurements, which is a relatively new technique.

Ultrasonic measurement instruments can measure either the transit time for the ultrasound pulse or the ultrasonic resonant frequency of the bolt. When a bolt is tightened, it stretches, affecting the length of the transit path; and the stress level in the bolt increases, thereby decreasing the velocity of sound through the bolt. The resonant frequency is reduced by the increased length and decreased sonic velocity. To use an ultrasonic extensometer, a drop of fluid is placed on the bolt for acoustic coupling, the instrument transducer is placed on the fluid and held against the bolt, and the instrument is zeroed for each bolt, since each bolt will have a different acoustic length. As the bolt is tightened, the instrument will indicate the build-up of stress or strain in the bolt. Measurements can also be taken in the future if all necessary information is recorded. Other factors must be compensated for if future measurements are made, including changes in length due to temperature changes or corrosion and velocity changes due to metallurgical and temperature changes. The extensometer must be calibrated very precisely, an acoustic coupling fluid must be used, and the ends of the bolt need to be smooth and parallel.

There are several measurement techniques which can be used to measure preload more directly. One method is to use strain-gauged bolts. Bolts can be purchased with strain gauges mounted in them, but although very accurate, this can be a very expensive and time consuming method of determining preload. Washers can also be instrumented with strain gauges, but like the bolts, are both accurate and expensive. Load-indicating crush washers can be used, but only once and only for the specific preload for which they were designed. They only indicate when a minimum preload has been exceeded and not what maximum preload was achieved. Load-indicating bolts which utilize a color change will show when a specific preload has been achieved. They are similar to the load-indicating washers, except that they can be reused.

In an experiment, using a gasketed reactor steam generator manway cover, the use of lubricants and torquing procedure was studied (Ref. 3.3-24). The joint was bolted in a cross pattern and the results of torquing checked with an ultrasonic extensometer. In a test with three bolting passes, only 30 to 50 percent of the total design load across the joint was produced, there was wide scatter in preload and four of the sixteen bolts were virtually loose. When the bolts were then gauged with the extensometer, and a fourth pass torque calculated and accomplished, the total load was 70 to 90 percent of the design load. One test showed that multiple passes at each successive torque level significantly improved the preload scatter. In this test, nine passes were required to achieve a scatter of ± 15 percent in the stud stretch, with the last three passes aided by extensometer measurements. In these tests, the various lubricants produced different total loads, but the same preload scatter.

3.3.3.5 Effects of Seal Size

Large diameter seals which are used in nuclear fusion machines have some of the same design requirements as seals for transport packagings, including withstanding high temperature and radiation environments, and remote handling capability. Experience with these large diameter seals has shown that the size of a closure also affects its sealing capability, primarily in fabrication of the sealing surfaces (Ref. 3.3-25).

Fixed radial clearances will be proportionately tighter as the gasket size increases. The roundness and flatness tolerances become harder to maintain when the flange cross section is not scaled up in proportion to the diameter. As component sizes increase, the type of manufacturing machine used to fabricate the component can change, thereby changing the method and ease of obtaining the desired surface (Ref. 3.3-25).

If the flanges are subjected to nonuniform heating, the differential expansion between the flanges and the gasket can cause difficulties in maintaining the necessary compression. In the large sized gaskets, the absolute expansion difference can be large, especially when the flanges are relatively less stiff than in small diameter gaskets (Ref. 3.3-25).

3.3.4 Properties of the Contents

The contents affect the temperature, pressure, radiation, and chemical environments of the seal. Radiation and chemicals contained in the contents primarily affect the material properties of the gasket, and are discussed in Chapter 4. The decay heat of the contents contributes to thermal stresses on the closure for normal and accident conditions of transport.

The pressure which forces the gasket to deform is supplied by mechanical pressure determined by the closure design, bolt preload, material selection of the sealing surfaces and gasket material, and by the system pressure transmitted by the gas or liquid itself to the gasket (Ref. 3.3-2).

The pressure transmitted by the contained gas or liquid acts in two opposing ways. First, for many gasket materials, an increase in the system pressure increases the effectiveness of the seal until the physical limits of the gasket are exceeded and the gasket begins to extrude into any clearance gap. For such "self-energizing" seals, the internal pressure will increase the sealing effect without additional applied force from the closure fasteners (a self-energizing seal still requires the fasteners to maintain a tight seal under all the operational pressure and temperature conditions). On the other hand, internal pressure above atmospheric pressure in the package reduces the preload on the closure fasteners (Ref. 3.3-2). Internal pressure also affects the leakage rate and leakage flow regime (see Chapter 2).

References

3.3-1. Metals Handbook, Desk Edition, H. E. Boyer and T. L. Gall, ed., American Society for Metals, 1985.

3.3-2. R. K. Flitney, B. S. Nau, D. Reddy, The Seal Users Handbook, 3rd edition, British Hydromechanics Research Association, the Fluid Engineering Centre, Cranfield, Bedford, England, 1984.

3.3-3. "Gask-O-Seal Handbook," OSD-6411 Parker Seal Group, Culver City, CA, 1983.

3.3-4. "Parker Metal Seals," OSD-6900, Parker Seal Group, Culver City, CA, 1982.

3.3-5. B. J. Benda and R. T. Langland, "Methods for Evaluating the Leak Tightness of Spent Fuel Container Closures," NUREG/CR-1312, U.S. Nuclear Regulatory Commission, Washington, D.C., February 1980.

3.3-6. T. C. Chivers and A. F. George, "Factors Influencing the Design and Assessment of Elastomer Seals for Nuclear Fuel Transport Flasks," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 664-671.

3.3-7. A. F. George and D. Williams, "An Investigation of Leakage Past Static Elastomer Seals," 10th International Conference on Fluid Sealing, Innsbruck, Austria, April 3--5, 1984, pp. 43-53.

3.3-8. L. B. Shappert, et al., "Cask Designers Guide -- A Guide for the Design, Fabrication, and Operation of Shipping Casks for Nuclear Applications," Oak Ridge National Laboratory, ORNL-NSIC-68, February 1970.

3.3-9. A. Roth, Vacuum Technology, Elsevier Science Publishing Co. Inc., 1982.

3.3-10. H. H. Buchter, Industrial Sealing Technology, John Wiley and Sons, 1979.

3.3-11. L. C. Schwendiman et al., "Research Progress on Particle Transmission through Very Small Openings," Proceedings of the Fifth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '78, Las Vegas, NV, May 7-12, 1978, pp. 279-286.

3.3-12. L. J. Hansen, "The Design, Licensing and Fabrication of a 64,000-Pound, Top and Bottom Loading, 'Type B' Shielded Overpack," Proceedings of the Fifth International Symposium on Packaging and Transportation of Radioactive Materials, Las Vegas, NV, May 7-12, 1978, pp. 102-109.

3.3-13. "Consolidated Safety Analysis Report for NUPAC 14D-2.0 Casks to 10 CFR 71 'Type A' and Low Specific Activity Packaging Requirements," Nuclear Packaging Inc., 815 South 28th Street, Tacoma, WA 98409, March 1, 1983.

3.3-14. "Patterson Products," W. W. Patterson Company, Pittsburgh, PA, 1986.

3.3-15. A. Roth, Vacuum Sealing Technique, Pergamon Press Ltd., 1966.

3.3-16. R. E. Lathem and R. T. Brown, "Evaluation of Metal Seal Criteria for Spent Fuel Cask Closures," Proceedings of the Third International Symposium Packaging and Transportation of Radioactive Materials, Richland, WA, August 16-20, 1971, pp. 615-633.

3.3-17. J. H. Bickford, An Introduction to the Design and Behavior of Bolted Joints, Marcel Dekker, Inc., 1981.

3.3-18. "Rules for Bolted Flange Connections with Ring Type Gaskets," ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, Appendix II, American Society of Mechanical Engineers, New York.

3.3-19. "Alternative Rules," ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, American Society of Mechanical Engineers, New York.

3.3-20. H. D. Raut and G. F. Leon, "Report of gasket factor tests," Welding Res. Council Bull., No. 233, December 1977, pp. 1-35.

3.3-21. J. R. Payne, "The PVRC's gasket test program II-A Status Report," Reprint No. 19-80 of a paper presented at the 45th Midyear Refining Meeting of the American Petroleum Institute Tank Update, Houston, TX, May 14, 1980.

3.3-22. A. Bazergui, L. Marchand, and G. Lague, "Analysis of exploratory gasket tests," Interium Report presented to Subcommittee on Bolted Flanged Connections of the Pressure Vessel Research Committee, May 1980.

3.3-23. A. Bazergui, Oral report to Subcommittee on Bolted Flanged Connections of the Pressure Vessel Research Committee, at United Engineering Center, New York, May 1980.

3.3-24. M. E. Looram, H. F. Petsch, and E. A. Merrick, "Steam Generator Manway Assembly," Improved Technology for Critical Bolting Applications, ASME MPC-Vol. 26, American Society of Mechanical Engineers, 1986.

3.3-25. W. R. Wheeler, "The Design of Large Vacuum Seals for Nuclear Fusion Machines," Tencor Instruments Co., Mountain View, CA.

3.4 Basic Seal Designs

The design of a seal is determined by its intended application. Types of seals are separated into the general categories of dynamic and static seals. In dynamic seals, the sealed parts are in motion, which may be rotary (as on a centrifugal pump shaft), or reciprocating (as on a hydraulic cylinder rod). An example of a static seal is a flanged joint, such as the closure of radioactive materials packaging (Ref. 3.4-1).

Different terms may be used in the seal literature to describe the same type of seal. In this report, if the main compression on a seal is exerted radially, the seal is called a gland (or bore) seal. If the main compression is exerted axially, the seal is called a flange seal. Static flange seals are occasionally called "face" seals, which should not be confused with "mechanical face" seals, which are used in dynamic applications. Figure 3.4-1 from Ref. 3.4-2 shows a variety of seal designs for both flange-type and gland-type seals.

Seal designs depend on both the method of providing for gasket retention and for applying the sealing force. Multiple seals may be provided in the seal design either to facilitate leakage testing or to satisfy different design requirements.

3.4.1 Gasket Retention

The simplest gasket configuration is to place the gasket between two flat flanges; however, this does not provide centering, retention or any limit for compression. The gasket can be held in place in a groove, with spacers, on a step, or between shaped flanges forming a conical sealing flange or ring (Ref. 3.4-2). Confining the gasket perpendicular to the compressive force increases the sealing capability because it prevents the seal from slipping away under the force of the contained pressure (Ref. 3.4-3).

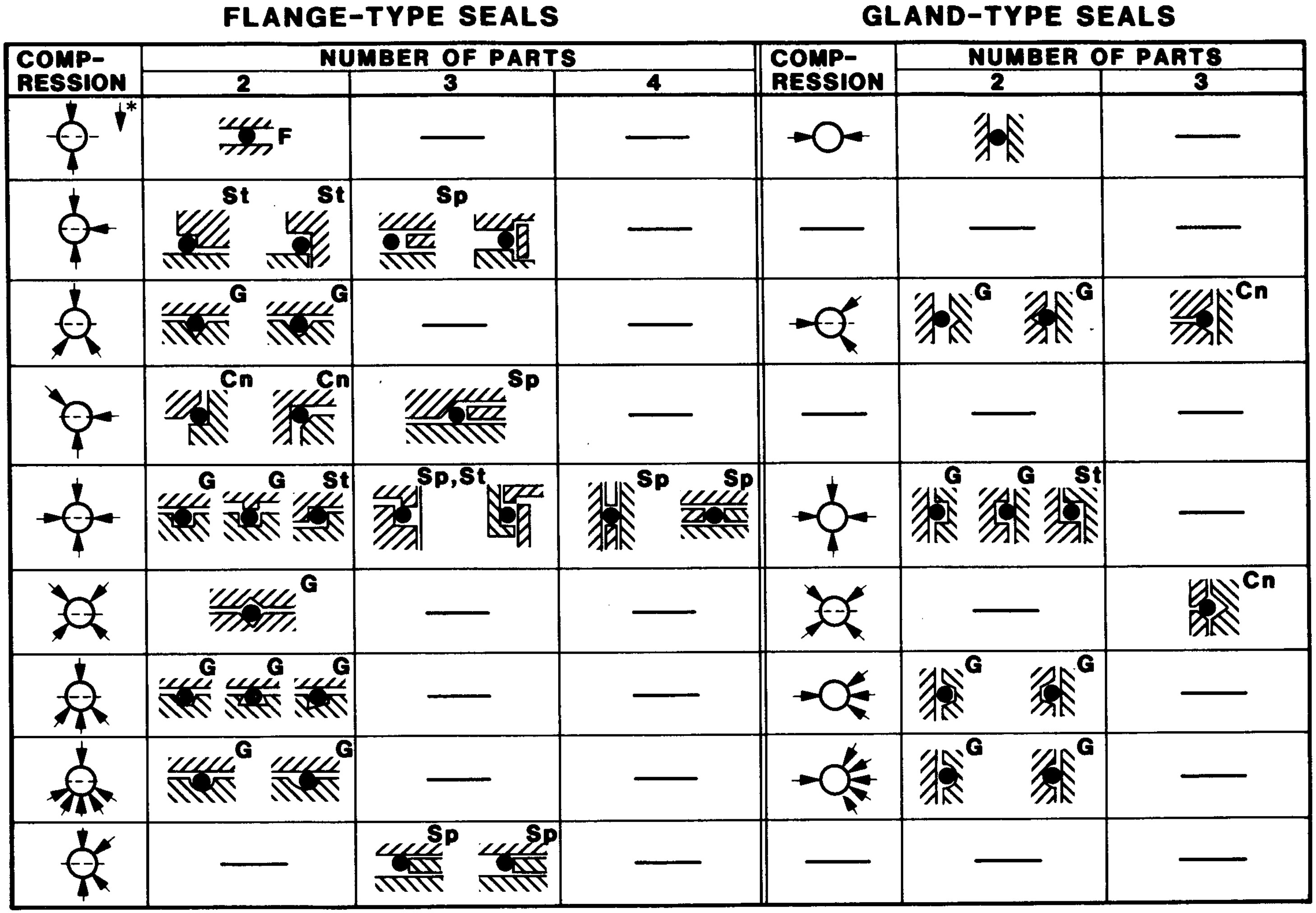


Figure 3.4-1. A Variety of Seal Designs for Both Flange-Type and Gland-Type Seals (Ref. 3.4-2). *The axis of the seal centerline is vertical and in the illustrations is on the right side of the seal. F = flat flange seal; G = groove seal; Sp = spacer seal; Cn = conical seal; St = step seal.

3.4.1.1 Grooves

Conventional practice is to house an O-ring seal in a groove machined into one of the sealing surfaces. The groove provides positive retention of the O-ring during preparation and assembly. The groove can be designed for constant deflection (or limited compression) of the O-ring (Ref. 3.4-2).

The constant deflection seal limits the compression on an elastomer O-ring by having the sealing flanges or a spacer meet in metal-to-metal contact when the correct compression is achieved. The constant load arrangement is used with plastic and metal gaskets where full load must be maintained (Ref. 3.4-2).

Gasket manufacturers generally provide dimensions for the sizes of these grooves. The groove must be designed to contain the total volume of the gasket since elastomers are incompressible (that is, compression in one direction is accompanied by expansion in another direction). An elastomer gasket chosen for a given groove size must have a large enough circumference. Otherwise, the gasket will stretch as it is placed into the grove, all the irregularities on the surface of the gasket will be enlarged, and the gasket will be more likely to leak (Ref. 3.4-2). The cross section is, also, reduced and flattened. Parker Seal Co. advises that stretching of the inside diameter of an O-ring during assembly should not exceed 100 percent and after installation should not exceed 5 percent. When the centerline diameter is stretched more than 2 to 3 percent, the groove depth must be reduced to maintain the necessary compression. O-rings should not be twisted during installation; this occurs more readily when the ratio of diameter-to-cross section diameter becomes large (as in RAM packagings) (Ref. 3.4-4).

Grooves can be of different cross sections, including rectangular or trapezium (see Fig. 3.4-2 from Ref. 3.4-2). The groove may have rounded edges to prevent cutting the gasket when it is forced over the edges.

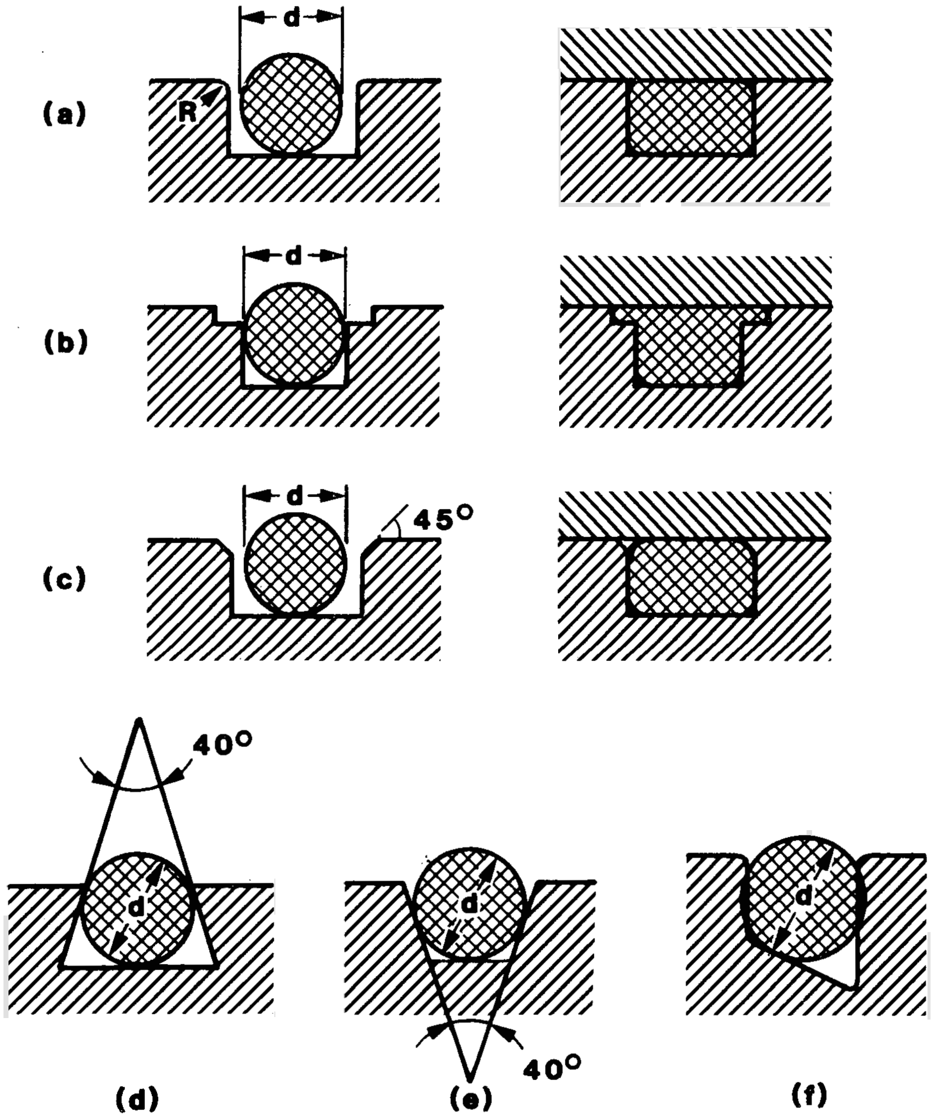


Figure 3.4-2. Rectangular Grooves and Trapezium Grooves for O-Rings (d = O-ring diameter) (Ref. 3.4-2).
(a) Rectangular groove with rounded corner.
(b) Rectangular groove with O-ring retention for vertical flanges.
(c) Rectangular groove with bevelled corner.
(d) Closed trapezium or dovetail groove.
(e) Open trapezium groove.
(f) Trapezium groove with parallel sidewalls.

3.4.1.2 Spacer or Retaining Ring

Since placing a gasket between flat flanges does not provide centering, retention, or any limit for compression, spacers or retaining rings are often used when grooves are not required for the seal design to be effective. For metal gaskets, the main function of a spacer or a retaining ring is to provide centering and retention.

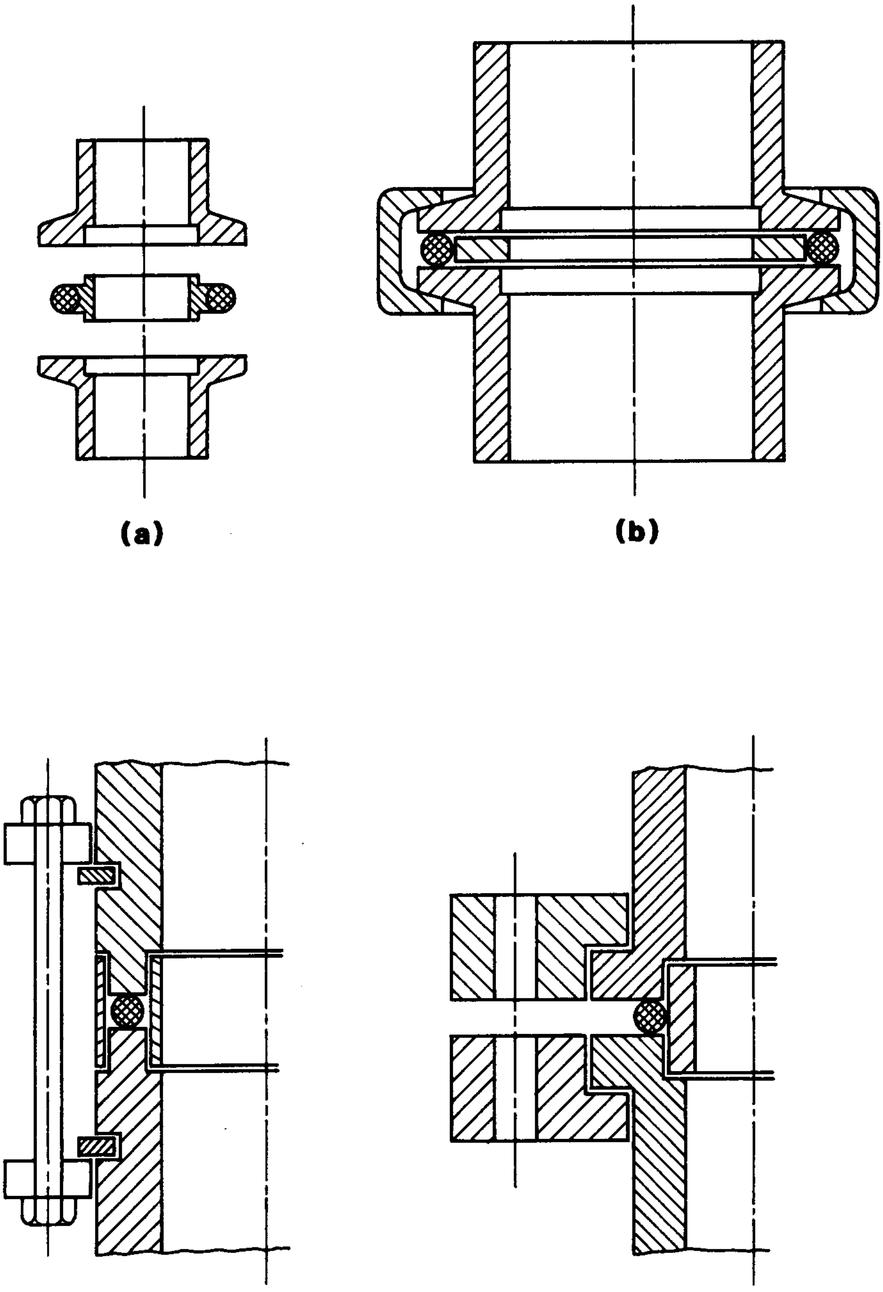
A spacer seal used with a gasket utilizes a retaining ring to hold the gasket in position. The retaining ring can be either flat (see Fig. 3.4-3(b)) or have a V or rounded V groove (see Fig. 3.4-3(a)) for holding the gasket in position (Ref. 3.4-2). The spacer ring can also provide for alignment of the flanges as well as the gasket. Alignment can be on either the inside diameter (see Fig. 3.4-3(d)), the outside diameter, or both (see Fig. 3.4-3(c)).

3.4.1.3 Conical Sealing Flange or Ring

The conically shaped sealing flange or ring uses an angle with the sealing surfaces to be sealed, as shown in Fig. 3.4-4. As with a groove, the dimensions of the angled surface must be optimized in order to have enough compression to seal but not enough to enclose large trapped volumes, which will complicate leak checking (Ref. 3.4-2). An example of a metal O-ring with a conical sealing flange or ring is the Wheeler seal, as shown in Fig 3.4-5 from Ref. 3.4-2 or in Ref 3.4-5. This seal uses an OFHC (oxygen-free high conductivity) copper wire gasket which is captured between angled flanges.

3.4.1.4 Step

A gasket can also be placed in a step machined into one of the sealing flanges and compressed against the other flat flange (see Fig. 3.4-6). The step can maintain either the outer diameter or the inner diameter of the gasket. A corner seal is based on crushing or plastically deforming a metal gasket in the corner of a step on a sealing flange. This gasket is generally made of a gold wire. The surface finish and the radial clearances are critical for this seal (Ref. 3.4-2).



(a)

(b)

(c)

(d)

Figure 3.4-3. O-Ring Seals with Retaining Rings [(a), (b)] or Spacers [(c), (d)] (Ref. 3.4-2)

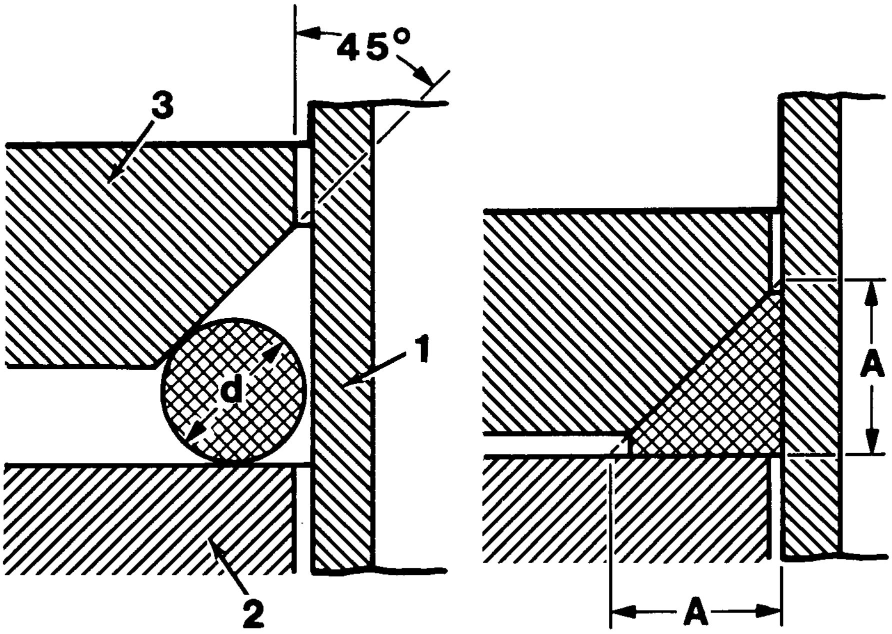


Figure 3.4-4. Conical Flange O-Ring Seal (Ref. 3.4-2).
1, 2 = flanges
3 = conical sealing flange or ring
d = O-ring diameter
A = 1.32 d.

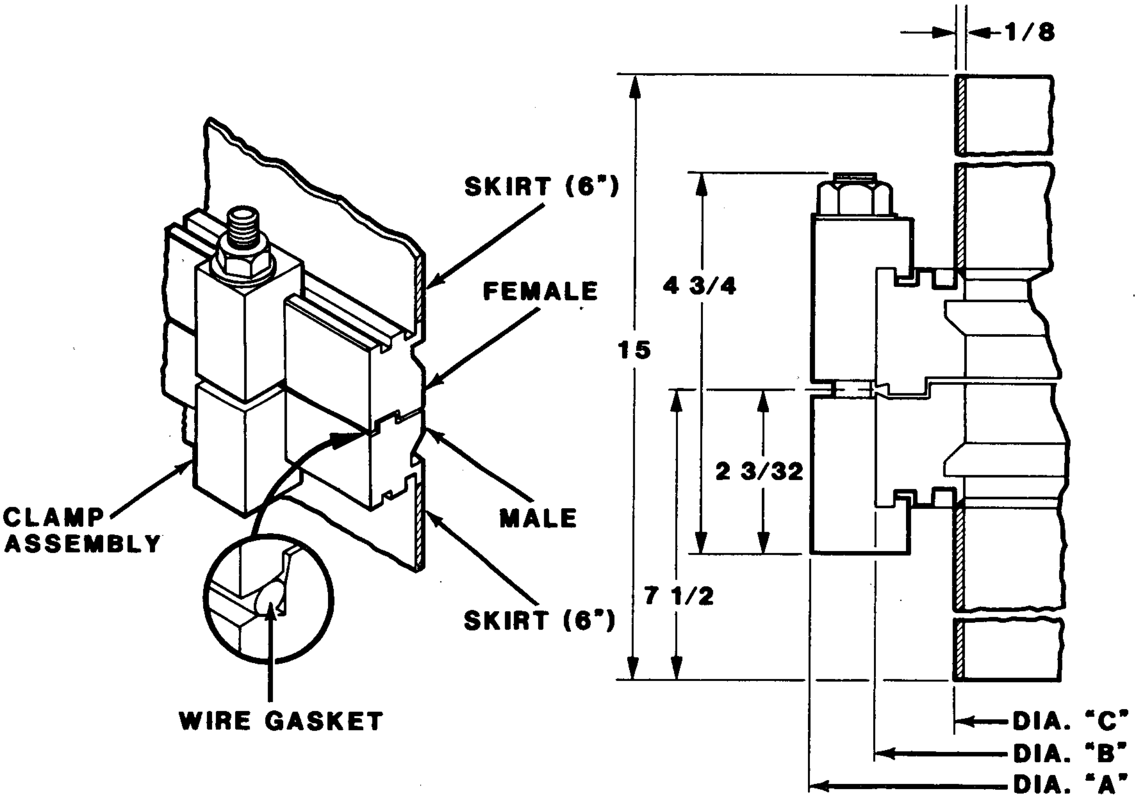


Figure 3.4-5. The Wheeler Wire Gasket Seal (Ref. 3.4-2), reprinted with permission of Macmillan Publishing Company from "Theory and Application of Metal Gasket Seals," Transactions of the Tenth National Vacuum Symposium of the American Vacuum Society, by W. R. Wheeler, edited by G. H. Bancroft. Copyright ⓒ 1964 by American Vacuum Society, Inc.)

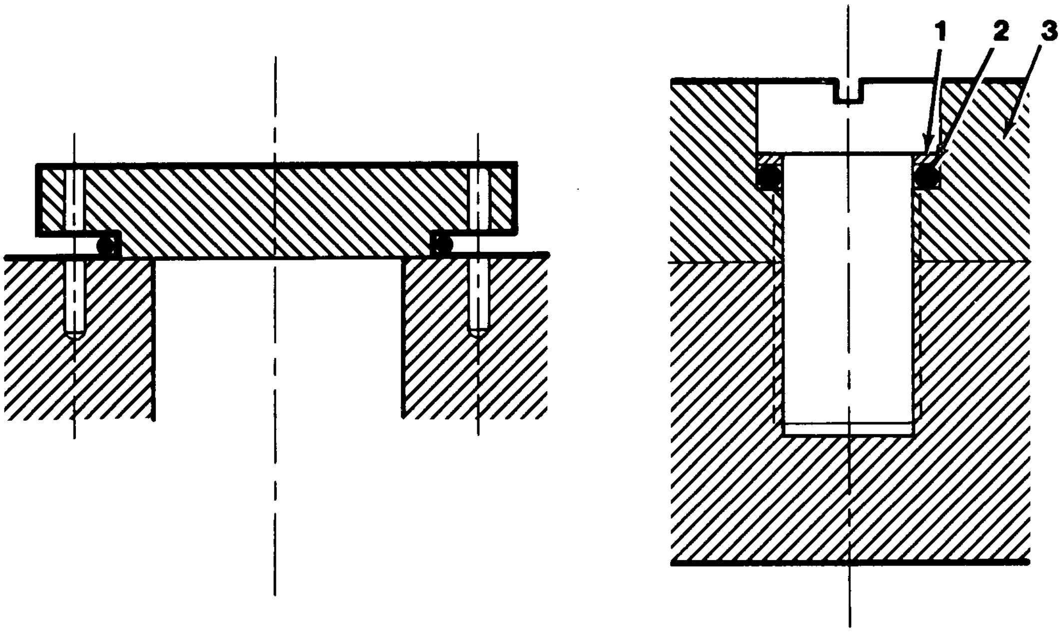


Figure 3.4-6. Step Seals With O-Rings (Ref. 3.4-2).
1 = Washer
2 = O-ring
3 = Flange

3.4.2 Methods of Applying Compression

Most seal designs use a smooth surface to apply compressive force to the soft material of the gasket (such as an O-ring), creating the seal. Other designs, restricted to metal seals, use different techniques, including a knife edge shape on the flanges, or pressure or springs inside a softer sealing material. These designs are discussed in detail in Chapter 4.

Knife edge seals are used to concentrate the tightening force onto a small width. The knife edge must be made of a harder material than the gasket.

The all metal Helicoflex® seal has a built-up structure with inner and outer liners with a central helical energizing spring. Sealing is accomplished by plastic flow of the outer liner against the mating sealing surfaces. The helical spring aids in keeping a sufficient load against the outer liner to follow temperature fluctuations and small deformations (Ref. 3.4-6).

The Grayloc® seal is a flexible bore seal consisting of a metal ring with a T-shaped cross section. The vertical portion of the T provides the main structural support and radial motion control. The flexible arms of the crossbar make contact with the upper and lower hubs or flanges. Axial compression of these arms causes plastic deformation at the contact points (Ref. 3.4-7).

Flexotallic or spirotallic metal gaskets have preformed V-shaped metal strips wound into a spiral. The metal strips are separated by a filler depending upon the application. The seal functions by a combination of the yield and flow of the metal and soft filler plies (Ref. 3.4-1).

3.4.3 Designs with Multiple Seals

Multiple seals can be used for different design approaches. A pair of seals may be used to facilitate leakage testing by providing a fixed volume that may be evacuated for pressure rise testing or for sensing a tracer gas that has leaked past the innermost seal. Leakage from the containment system to the environment would have to pass the innermost seal, then the sealed test port or the outermost seal. While credit for the test port seal or the outermost closure seal is usually not taken (for example, see Ref. 3.4-8), the reliability of the multiple seal system is greater than for a single-seal design (Ref. 3.4-9).

A containment design may use multiple seals which satisfy different design requirements. For example, one seal may provide a high level of containment under normal conditions but fail during accident conditions, while a second seal provides a lower level of containment, but survives the accident conditions. Valid demonstration of such a containment system requires testing each gasket independently (Ref. 3.4-10).

The Federal Republic of Germany requires a second seal for intermediate storage of spent fuel elements. This can be an additional outer lid similar to the inner lid, both on a single containment vessel. Elastomer gaskets may be used for transport; for storage times on the order of ten years, metal gaskets are preferred that contain a spiral spring for elasticity and a thin sheet of ductile metal is used for plasticity at the contact surface (Ref. 3.4-11).

References

3.4-1. R. K. Flitney, B. S. Nau, D. Reddy, The Seal Users Handbook, 3rd edition, British Hydromechanics Research Association, the Fluid Engineering Centre, Cranfield, Bedford, England, 1984.

3.4-2. A. Roth, Vacuum Technology, Elsevier Science Publishing Co. Inc., 1982.

3.4-3. T. C. Chivers and A. F. George, "Factors Influencing the Design and Assessment of Elastomer Seals for Nuclear Fuel Transport Flasks," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 664-671.

3.4-4. "Parker O-Ring Handbook," ORD-5700, Parker Seal Group, Lexington, KY, 1982.

3.4-5. "Varian Vacuum Price List Catalog," VAC 4025 B, Varian Associates, Inc., Vacuum Products Division, Lexington, MA, 1985.

3.4-6. "Resilient Metal Seals and Gaskets," H.001.002, Helicoflex Co., 400 Myrtle Ave., Boonton, NJ 07005.

3.4-7. W. B. Leisher and J. H. Biffle, "Grayloc Seal Static Tests," Sandia National Laboratories, SAND81-1295, February 1983.

3.4-8. "Transuranic Package Transporter (TRUPACT-I) Safety Analysis Report for Packaging," Sandia National Laboratories, SAND 83-7077, May 1986.

3.4-9. W. H. Lake, "Reliability in Maintenance and Design of Elastomer Sealed Closures," Proceedings of the Fifth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '78, Las Vegas, NV, May 7-12, 1978, pp. 790-796.

3.4-10. W. H. Lake, "Containment System Evaluation," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 633-637.

3.4-11. H. Kowalewsky, "Criteria for and Proof of Leaktightness Concerning Casks for Dry Transport and Intermediate Storage of Spent LWR-Fuel Elements," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, pp. 638-645.

3.5 Analytical and Experimental Approaches for Predicting Leakage Rates

The ANSI N14.5 standard (Ref. 3.5-1), states that verification of the closure system design may be accomplished by testing full size packages or models and measuring the resulting leakage rates, or by performing calculations to demonstrate that closure parts are neither deformed abnormally (excluding gaskets, which are designed to deform) nor excessively displaced. Transient conditions during the thermal test may be the most limiting. The standard does not provide guidance for the use of scale model leakage tests.

3.5.1 Analytical Approaches

For many packagings, the design of the closure seal specifies surface finish, gasket material, and bolt preload. The surface finish and gasket material to be used in the design to achieve a given leakage rate are chosen based on the designer's experience and manufacturers' recommendations. The normal or hypothetical accident tests must cause no (1) degradation of the gasket material, (2) deformation of the sealing surfaces, or (3) reduction in the bolt load, that would result in a leakage rate greater than the maximum permissible leakage rate. Demonstrating that the environments experienced by the gasket material are within its specifications, and that the bolts and sealing surfaces remain elastic is one accepted approach.

Leakage itself cannot be predicted at present based on surface finish, compression, and materials data. Instead, measurements must be made (Ref. 3.5-2 and 3.5-3).

A project was funded in the late 1970s by the NRC with the objective of developing methods for assessing the leaktightness of general seal designs for nuclear waste shipping casks. Leakage rates were to be correlated with measured parameters such as temperature, bolt load, pressure differential across the seal, and surface finish; and calculation of contact area and stress. NIKE2D, a finite element code for structural analysis, was used to calculate the contact area and stress for a given seal geometry. The code was successful in predicting the behavior of cask closures under different loading conditions (with limited experimental verification); however, there was insufficient data to develop a general leakage rate model (Ref. 3.5-3).

The authors concluded that assessment of a seal design before it is built is difficult, particularly if a leakage rate less than 10^{-6} std cm^3/s is desired. General design principles that characterize every successful seal design with this level of performance were stated. Closure designs that use elastomer seals and metal flanges have slightly different principles than metal-to-metal seals. For seal designs that have metal-to-metal seals it is necessary to (1) put a soft metal seal against a hard metal closure, (2) obtain as high a seal contact stress as possible, (3) retain some spring-back in the seal to account for unloading. Elastomers are inherently soft and have good spring-back. Additional requirements for elastomer gaskets with metal flanges are (1) good seal deformation (as high as 30 percent strain), (2) good surface finish of 0.81 to 1.6 μm (32 to 64 μin) AA, and (3) resistance to dirt and scratching (Ref. 3.5-3).

3.5.2 Experimental Approaches

Full-scale prototype, full-scale closure mock-up, or scale-model tests may be performed to verify the closure system design. Actual leakage rates may be measured on full-scale packages or full-scale closure mock-ups. From the literature surveyed to date, relationships between the leakage rate measured from a scale-model package and measured from a full-size package have not been developed. Instead, scale-model tests are used to demonstrate that closure parts are not deformed abnormally (excluding gaskets, which are designed to deform) or excessively displaced, and temperature limits for the closure parts are not exceeded.

Scaling relationships have been examined for testing seal designs using laboratory models. Several relationships have been established. The same machining process used on a full-size closure should be used on a scale model in order to reproduce the same surface finish and lay. Other aspects that may not scale linearly include effects of accidental damage, waviness, tolerance changes, and flaws or surface defects (Ref. 3.5-4).

To maintain the same contact stress and deformation characteristics, the seal cross section should be modeled full size. There appears to be a lesser dependence on circumferential stiffness, which depends on seal diameter. For example, a small cross-sectional diameter seal will have a much higher contact stress resulting in greater infilling, and therefore lower leakage, than a large diameter seal at the same compression. If the compression of the small diameter seal is reduced in order to reduce the contact stress, the contact width (and therefore the leakage path length) is also reduced. From Ref. 3.5-4, it does not appear possible to scale both the contact stress (which determines infilling) and the contact width (which determines leakage path length) and therefore, the leakage rate. A model should be as close as possible to the actual unit. As the degree of required seal integrity increases, this becomes more important (Ref. 3.5-4). However, using a full size seal cross section may change the closure stiffness of the scale model.

The following subsections present examples, by no means inclusive, of package designs that have been verified by experiment.

3.5.2.1 Testing of Full-Scale Packages

Testing of full-scale packages is uncommon because of their cost. One example of a package that has been subjected to full-scale testing is the Transuranic Package Transporter, Model I (TRUPACT-I) (Ref. 3.5-5).

3.5.2.2 Testing of Full-Scale Closure Mockups

Leakage testing has been performed on a full-scale mock-up of the Defense High Level Waste Cask (DHLW) design, having a prototype closure and closure interface. Pressure rise and helium mass spectrometer leakage tests were conducted. The maximum deflection of the sealing surfaces was determined by the structural and thermal analyses of the impact and thermal hypothetical accident tests. To simulate a partial reduction in O-ring compression, contact pressure on the seals was reduced in several incremental steps and leakage tests conducted at each step. Measurements of sealing surface deflections obtained from scale-model tests will be correlated with the analysis predictions (Ref. 3.5-6).

3.5.2.3 Scale Model Testing

Scale-model impact and puncture testing was used as part of the design verification for the NuPac 125B packaging (Ref. 3.5-7). Dimensions were scaled linearly from the full-scale package to the scale model, and the materials and material properties remained the same. Leakage rate measurements of the model were conducted to determine any changes in leakage, which would indicate permanent deformations in the closure region. Radial tolerances in the seal area were not fully scaled; however, surface finishes of the sealing surfaces were held identical to full scale. There were no detectable deformations in the closure area, and there was no detectable change in leakage rate for either the inner or outer containment vessel.

References

3.5-1. "American National Standard for Radioactive Materials--Leakage Tests on Packages for Shipment," ANSI N14.5-1987, American National Standards Institute, January 1987.

3.5-2. T. C. Chivers and A. F. George, "Factors Influencing the Design and Assessment of Elastomer Seals for Nuclear Fuel Transport Flasks," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 664-671.

3.5-3. B. J. Benda and R. T. Langland, "Methods for Evaluating the Leak Tightness of Spent Fuel Container Closures," NUREG/CR-1312, U.S. Nuclear Regulatory Commission, Washington, D.C., February 1980.

3.5-4. T. C. Chivers and R. P. Hunt, "Scaling of Gas Leakage from Static Seals," 8th International Conference on Fluid Sealing, University of Durham, England, September 11-13, 1978.

3.5-5. "Transuranic Package Transporter (TRUPACT-I) Safety Analysis Report for Packaging," Sandia National Laboratories, SAND83-7077, May 1986.

3.5-6. M. M. Madsen, et al., "Testing of the DHLW Truck Shipping Cask," Proceedings of the Eighth International Symposium on the Packaging and Transportation of Radioactive Materials: PATRAM '86, Davos, Switzerland, June 16-20, 1986, to be published.

3.5-7. M. M. Warrant, et al., "Drop and Puncture Testing of 1/4 Scale Model of NuPac 125B Rail Cask," Nuclear Materials Management, Vol. XIV, No. 3, July 1985, pp. 357-362.

4.0 PROPERTIES OF GASKETS APPLICABLE TO TRANSPORT PACKAGES

4.1 Introduction

The requirements of 10 CFR 71 specify a wide range of environments in which the seals and closures of radioactive material packages must function reliably for the useful life of the packaging for both normal and accident conditions (see Chapter 1 and Appendix A).

The environments include:

- minimum normal operating temperature of -40°C (-40°F),
- maximum normal operating temperature considering 38°C (100°F) ambient air, solar insolation, and heat generated by the contents,
- external pressures ranging from 3.5 psia to 20 psia,
- internal pressure equal to the maximum normal operating pressure of the packaging,
- vibration normally incident to transport,
- shock (free drop and drop onto a puncture bar),
- radiative heat flux simulating a fire accident,
- immersion in water,
- radiation,
- chemical attack.

This chapter discusses gasket materials and gasket designs that might be used in Type B RAM packages. A catalog of the gasket materials used in all currently NRC-licensed Type B, large-diameter Type A, and irradiated fuel transport packages in the U.S. reveals that elastomers and metals are the principal gasket materials currently used for closure seals of these packages (see Chapter 5).

Terms describing gasket materials were found in either a packaging's NRC Certificate of Compliance, listed in Ref. 4.1-1, or its Safety Analysis Report for Packaging (SARP). The terms include (1) elastomers: silicone, polyurethane, Viton, Neoprene, Buna-N, fluoroelastomer, styrene-butadiene rubber, rubber; (2) metals: copper, pressure-filled metallic, silver-plated metallic, spiral-wound/graphite filled, spiral-wound/asbestos filled; and (3) other: asbestos and plastic (polytetrafluoroethylene). Some older SARPs, particularly those for power unit and core cartridge transport containers, do not specify a seal material. SARPs published before 1980 tend to be nonspecific in describing seal materials [e.g., "rubber" and "elastomer"], and to list gasket brand names [e.g., "Gask-O-Seal" (1976), "Garlock" (1979)] rather than specific materials.

The selection of an appropriate gasket material is based on consideration of the environments to which the gasket will be exposed, such as temperature, pressure, radiation, chemicals, and abrasion. Temperature generally governs the selection. A comparison of the characteristics of elastomer, plastic, and metal gaskets intended for use in vacuums for temperatures ranging from that of liquid nitrogen to ~400°C is shown in Table 4.1-1 (Ref. 4.1-2). Almost all of the information is also applicable to low pressure systems.

The major advantages of elastomer gaskets are that they are less expensive, require less maintenance of the sealing surface, and perform better under a wide range of flange movement than metals. The major advantage of metal gaskets is their performance at high operating temperatures where elastomers may undergo decomposition and higher thermal expansion than the sealing surfaces or emplacement groove, and at high operating pressures where elastomers may extrude into the clearance between mating surfaces (Ref. 4.1-3). Elastomer gaskets generally may be re-used many times, while metal gaskets are often used only once, or possibly just a few times.

References

4.1-1. "Directory of Certificates of Compliance for Radioactive Materials Packages," NUREG-0383, Vol. 2, Rev. 8, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, D.C., October, 1985.

4.1-2. A. Roth, Vacuum Sealing Techniques, Pergamon Press Ltd., 1966, pp. 326-327.

4.1-3. T. C. Chivers and A. F. George, "Factors Influencing the Design and Assessment of Elastomer Seals for Nuclear Fuel Transport Flasks," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 664-671.

TABLE 4.1-1

COMPARISON OF THE CHARACTERISTICS OF ELASTOMER, PLASTIC, AND METAL GASKETS[a,b]

Feature	Rubber gaskets	Plastic gaskets	Metal gaskets
Compressibility	Incompressible; the seal should allow for its constant volume deformation.	Compressible; higher local pressures required; flanges with ridges indicated.	Compressible; Very high pressures required; sealing surfaces should be kept to a minimum.
Elasticity	Very elastic; the seal requires less pressure and maintains it.	Inelastic; the pressure on the seal must be often increased, bolts retightened or elastic (spring) loading used. Equal torque on all the bolts required.	
Permanent set	Small permanent set if the compression ratio is limited by flange-flange contact. Grooves or spacers required; gasket may be re-used.	Cold flow occurs under sealing load; small compression ratio used; to be used without flange-flange contact. Gaskets may be re-used after annealing.	Hardens under load. Gasket cannot be re-used many times.
Hardness	Very soft; the seal does not require very high surface finish of flanges.	Soft; The seal is based on parallel grooves and ridges on surface of the flanges.	Harder than other gaskets. Very good surface finish of flanges required.
Bonding	Easy to bond to itself or other materials; gaskets can be made from cord.	Teflon very difficult to bond to itself or other materials; gasket should be cut from a single piece.	Cold welding or welding and brazing may be used.
Outgassing	High; the surface exposed to vacuum should be kept minimum; heating limited.	Teflon has very low vapour pressure.	Very low vapor pressure even at high temperatures.
Permeability	Fair, excepting silicone rubber.	Teflon has a very low permeability.	Very low.
High temperature behaviour	Use limited to moderate temperatures; hardening accelerated by temperature.	Fair, especially Teflon. High expansion; the seal should be tightened at lowest service temperature.	Some metal gaskets may be used for bakeable seals. Seal should allow for differential expansion.
Low temperature behaviour	Becomes brittle; cannot be used at low temperatures.	Teflon can be used at low temperatures; seal should be tightened at low temperature.	May be used at low temp. if differential expansion allowed for
Chemical behaviour	Resistant to oils and mercury.	Teflon is chemically inert.	Some oxidize, others are attacked by vapours (mercury).

a. Reference 4.1-2.
b. Considering temperatures ranging from that of liquid nitrogen to ~400°C.

4.2 Elastomer Gaskets

Parker Seal Company literature (Ref. 4.2-1) defines an elastomer as "any synthetic or natural material which has resilience or memory sufficient to return to its original shape after minor or major distortion." When nearly all rubber was of natural origin and synthetics were first being explored, it became normal practice to refer to materials with physical properties similar to natural rubber as "synthetic rubber." Many special synthetic rubbers which far exceed certain physical and chemical properties of natural rubber have since become available, and are included with natural rubber under the generic term "elastomer" in current usage.

The ASTM definition of an elastomer is summarized in Ref. 4.2-1. In order to be called an elastomer, a basic polymer that has been converted (without the addition of plasticizers or other diluents) to an essentially nonplastic state and tested at room temperature, must meet the following requirements: (1) capable of being stretched 100 percent, (2) after being stretched 100 percent, held for five minutes and then released, it is capable of retracting to within 10 percent of its original length within five minutes after release.

Under the broad category of elastomers fall a wide range of compounds, which are mixtures of base polymers and other chemicals that form a finished rubber material. To the base polymer are added reinforcing agents, such as carbon black; curing or vulcanizing agents, such as sulfur; activators, plasticizers, accelerators, anti-oxidants, anti-ozonants, etc., until the elastomer has been tailored into a seal compound with its own distinct properties.

4.2.1 Physical Properties of Elastomers

The discussion of elastomer material properties in this section follows the discussion found in Ref. 4.2-2. Elastomer properties are affected by compounding. In order of decreasing dependence on compounding, these properties are: modulus and hardness, resistance to abrasion, tear strength, tensile strength, bonding, elasticity, electrical properties, resistance to light, weathering, and thermal expansion. Other properties, such as liquid absorption, permeability, temperature range, etc. can also be modified to some extent by suitable compounding. Some of these properties are discussed below.

4.2.1.1 Hardness and Young's Modulus

Squeeze type seals such as O-rings rely on being deformed in the assembled state, and the designer is interested in how much force is obtained for a given deformation, which will affect both the sealing ability and assembly of the seal. For small deformations, Young's modulus can be related to the hardness (although different methods of measuring Young's modulus result in different values). Hardness helps to prevent extrusion at the low pressure edge of the seal, which can be a problem for high pressure applications. Softer materials will flow more easily into the sealing surface roughness but tend to abrade, wear and extrude (Ref. 4.2-3). Usually a compromise needs to be achieved between pressure, clearance, and elastomer hardness (Ref. 4.2-2).

Hardness of most elastomers is measured using the Type A durometer, an instrument manufactured by the Shore Instrument Co. The instrument is calibrated to read 100 if there is no indention, as on a glass surface. For most applications, elastomers having a Type A durometer hardness of 70 to 80 are suitable (Ref. 4.2-3).

4.2.1.2 Tensile Strength and Tear and Abrasion Resistance

These properties are interrelated. Tensile strength is the load in pounds per square inch required to rupture a specimen of elastomer material (Ref. 4.2-3). High tensile strength and tear resistance usually implies a high degree of abrasion resistance. Good abrasion (or scraping) resistance reduces wear. High tensile strength and tear resistance helps minimize extrusion damage (Ref. 4.2-2). If tear resistance is very low, the seal is more likely to be cut or nicked during assembly, especially if it passes over sharp corners or edges. Elastomers with low tear resistance will fail rapidly under additional stress or flexing once a crack has been initiated (Ref. 4.2-3).

4.2.1.3 Elasticity

Elastic strains may exceed 100 percent for elastomers, compared to 1-2 percent for metals. An ideal elastomer would recover its original shape and size after deformation. The amount of elastic recovery is time and temperature dependent (Ref. 4.2-2).

4.2.1.4 Stress Relaxation and Compression Set

When an elastomer is deformed, molecular rearrangements occur which make a portion of the deformation permanent. The decline in sealing contact stress with time and temperature is referred to as stress relaxation (Ref. 4.2-2). Compression set or permanent set is complementary to stress relaxation, and is the percent of deflection by which elastomers fail to recover to their original shape when released after a given time under specified temperature and stress, and results in loss of compression on the seal (Ref. 4.2-3). While it is possible for seals to function adequately even with 100 percent compression set provided flanges remain undisturbed, the effects of impact and thermal cycling have to be considered if the deflections of the flanges is comparable with the height of the surface roughness (Ref. 4.2-4).

Compression set occurs slowly at low temperatures but accelerates with exposure to high temperature and radiation. For some elastomers, compression set is accentuated by the presence of water. When given conditions are maintained for a period of time, the compression set accumulates rapidly at first and then the rate of accumulation decreases with time (Ref. 4.2-4).

4.2.1.5 Thermal Expansion Coefficients

Thermal expansion coefficients are higher for elastomers than for metals. The linear thermal expansion coefficient is generally in the range of 1.1 to 3.1 x 10^{-4} per °C for elastomers, versus 0.11 x 10^{-4} per °C for steel (Ref. 4.2-2). The relative expansion or contraction of the gasket material with respect to the sealing surfaces must be considered in closure designs.

4.2.1.6 Low Temperature Behavior

At low temperatures, elastomers lose their elastic properties (reversibly) and become more brittle and glasslike. If the low temperature causes crystallization, the stiffening may be irreversible. The point at which this occurs is known as the brittle point, and is the temperature at which the elastomer will fracture when given a sharp blow (Ref. 4.2-2).

4.2.1.7 High Temperature Behavior

If an elastomer is exposed to high temperature, the molecular structure undergoes a chemical change due to oxidation, which is not reversible. Also, there is often excess unused vulcanizing agent in the elastomer and the vulcanizing process can continue over a long period causing progressive hardening of the elastomer. The result of these high temperature effects is that the seal takes on a hard, brittle character and may begin to crack and disintegrate (Ref. 4.2-2). For elastomers, the Arrhenius relationship between lifetime (τ) and temperature (T) is commonly used. However, considering data for silicone, fluorocarbon, and ethylene propylene, it appears to be only an approximation, and any extrapolation will be optimistic (Ref. 4.2-5):

$$\tau = \alpha e^{\gamma/T}, \text{ where } \frac{\partial\tau}{\partial T} < 0, \text{ and } \alpha \text{ and } \gamma \text{ are constants.}$$

Non-Arrhenius behavior was particularly noted in elastomers affected by oxidation and other degradation mechanisms (Ref. 4.2-6).

4.2.1.8 Swell

Elastomers can absorb lubricants or some of the liquid or vapor that they are sealing. The amount of swell depends on the environmental conditions. If swelling occurs in an undersize groove, considerable force can be exerted by the seal. Shrinkage of the elastomer is also a possibility, and is caused by the sealed liquid or vapor, or lubricant leaching plasticizer. Usually elastomers are compounded to give positive swell when used with compatible liquids (Ref. 4.2-2).

4.2.1.9 Permeability

Permeation is the flow of a gas or vapor through the elastomer material, and is governed by solubility of the gas or vapor in the elastomer and by diffusion of gas or vapor molecules through the molecules of the elastomer (Ref. 4.2-7). Several parameters are of interest, including the "breakthrough" time for initial permeation to occur, the time required to reach equilibrium, and the equilibrium leakage rate of gas or vapor permeation (permeation constant). Permeability increases as temperature rises, different gases and vapors have different permeability rates; and the more a gasket is compressed, the greater is its resistance to permeation (Ref. 4.2-3).

Experimental results for He, Ar, and Kr in silicone, Viton, and EPDM provided the following general observations: (1) the permeation constant increased with increasing temperature (usually exponentially related to temperature), and (2) for silicone, the permeation constant increased with increasing atomic number of the noble gas, while for Viton and EPDM, the permeation of He was favored compared with the heavy noble gases (Ref. 4.2-7). The correct cross sectional geometry and compression should be used for permeation coefficient measurements, in order to maintain the exposed area, exhaust area, and diffusion path length (Ref. 4.2-5).

4.2.1.10 Outgassing

Outgassing is the release of adsorbed or absorbed volatile constituents in the form of vapor or gases. The outgassing rate may affect the choice of leakage testing procedure, because outgassing may obscure the actual leakage rate. Outgassing occurs from several mechanisms, including: (1) the loss of additives that are not chemically bonded, such as plasticizers; (2) exposure to temperature and radiation, which can break chemical bonds and release degradation products; (3) release of solvents during the curing process; and (4) exposure to vacuum (Refs. 4.2-8, 4.2-9). Absorbed water may also be released.

A comparison of outgassing rates from Ref. 4.2-10 is shown in Figure 4.2-1. This figure does not, however, indicate what is being outgassed.

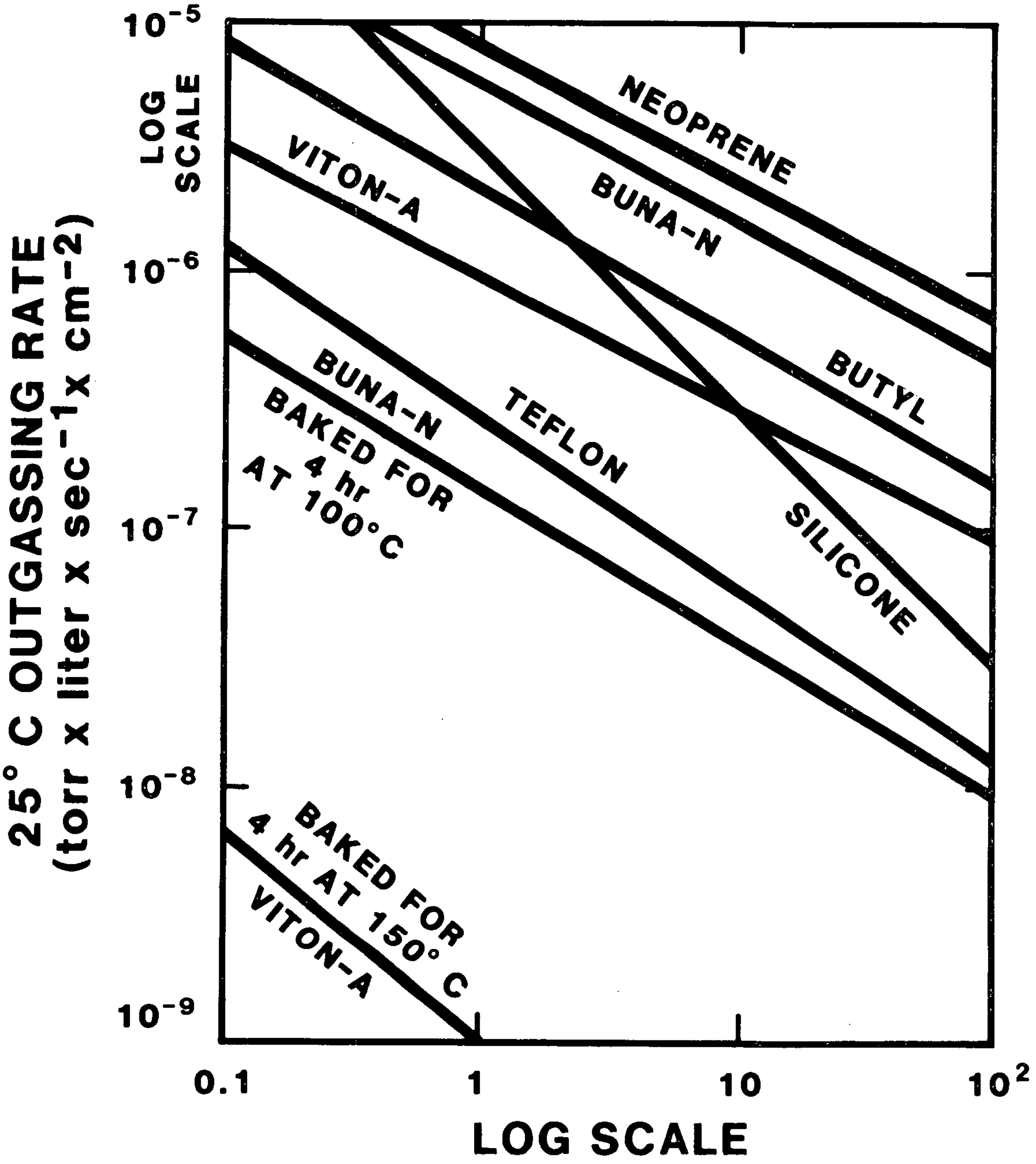


Figure 4.2-1. Comparison of Outgassing Rate of Typical Gasket Materials (from Ref. 4.2-10, reprinted by permission of John Wiley & Sons, Inc. from Industrial Sealing Technology, by H. H. Buchter, copyright © 1979 by John Wiley & Sons, Inc.)

4.2.1.11 Radiation Resistance

The sealing force exerted by a compressed elastomer gasket will decay with time. This is caused by a physical rearrangement of the molecules which becomes permanent when crosslinking occurs. This effect is accelerated by both temperature and radiation (Ref. 4.2-11) and these effects can be synergistic (Ref. 4.2-6). Very large dose-rate effects can exist in oxygen environments (Ref. 4.2-6). Results of testing by Parker Seal Co. indicate that most elastomers can maintain a seal after experiencing 10^6 rads of gamma radiation at room temperature. At 10^7 rads, differences in compression set of different elastomers becomes significant; and some elastomers will still maintain a seal while others will not (Ref. 4.2-3).

4.2.1.12 Friction

For static seals, friction values depend on surface finish, seal pressure, the sealed material, lubrication, and especially the seal design. Friction coefficients vary with the normal load. Unlubricated coefficients of friction can reach values well above unity, but friction for lubricated gaskets is an order of magnitude less. A lubricated gasket absorbs some of the lubricant in the film between the gasket and the sealing surface. The amount of lubricant in the film, thus, decreases with time, and the breakout friction, or the force to initiate sliding, increases correspondingly. The maximum friction, or the force to initiate sliding, attainable is for the dry contact case (Ref. 4.2-2). The lubricant must be compatible with the gasket material.

4.2.2 Specification of Elastomer Gaskets

4.2.2.1 Gasket Material

An elastomer material is usually specified by citing a name like "Viton" or "silicone" which describes only a general type or class of elastomer, not the quantitative spectrum of ingredients of a specific compound. This makes the problem of comparing the properties of different types of elastomers difficult. The material characteristics and performance characteristics of a gasket made of "Viton," for example, may vary considerably because a large number of compounds share that same base elastomer.

An illustration of this difficulty is presented in Table 4.2-1, which compares values found in the literature for the temperature ranges for types of elastomers commonly used for closure seals of RAM transport packages. As Table 4.2-1 demonstrates, the performance characteristics claimed by different sources are not in wide agreement, due in part to the fact that there is no quantitative basis for the comparison. Also, the acceptance criteria used by each source in determining the temperature limit of a given material are not known. The limit depends upon the application, the environment, and the time. Short temperature excursions beyond these limits may also be possible and still maintain acceptable seal performance (Refs. 4.2-14, 4.2-15). One compound of an elastomer "family" may provide acceptable performance, while another may not. For example, Ref. 4.2-16 reports that in low temperature studies some Viton seals were observed to start becoming stiff at -20°C, and failed to seal at -40°C, although one cask developer who has used Viton reported its acceptable performance at -40°C. The conclusion reached was that unsuccessful performance of one member of the "Viton" elastomer family should not eliminate all members of the family from consideration.

A qualitative comparison of properties of elastomer families is presented in Section 4.2.3.9.

The Bundesanstalt fur Materialprufung (BAM), the competent authority for the Federal Republic of Germany, has proposed a data sheet which contains appropriate testing information to ensure the compliance of the elastomer gaskets to be installed into the transport packaging with the ones of the approved design in the SARP (Ref. 4.2-17). The tests to be performed depend on the environments experienced under normal and hypothetical accident conditions and the properties of the radioactive contents. Test results would be required for the elastomer compound, a sample of the batch, and the individual gasket. Table 4.2-2 lists the proposed data to characterize a batch of gaskets for applications having a temperature range of -40°C to 127°C, small differential pressure

TABLE 4.2-1

A COMPARISON OF TEMPERATURE RANGES FOR ELASTOMER GASKET MATERIALS FROM FOUR SOURCES IN THE SEAL LITERATURE (°F)

Polymer	(a) Parker	(b) Seal Users	(c) Buchter	(d) Murray
Silicone	-65 to 450	-76 to 392	-120 to 450	-178 to 450
Neoprene	-45 to 300	--	-65 to 300	-65 to 300
Fluorocarbon	-15 to 500	+5 to 347	--	-50 to 450
Nitrile	-65 to 250	-49 to 266	-65 to 300	-60 to 300
Polyurethane	--	-58 to 212	--	-65 to 240
Natural Rubber	--	-76 to 176	-65 to 300	--
Fluorosilicone	-100 to 400	-76 to 392	--	-90 to 400
Ethylene-Propylene	-70 to 400	-49 to 284	--	-60 to 350

---

a. Reference 4.2-12.
b. Reference 4.2-2.
c. Reference 4.2-10.
d. Reference 4.2-13.

TABLE 4.2-2

PROPOSED TEST DATA TO BE REQUIRED OF A BATCH OF ELASTOMER GASKETS BY THE BUNDESANSTALT FUR MATERIALPRUFUNG (BAM)[a,b,c]

Tests	Test Standard
Tensile strength and elongation at break	ISO 37
Hardness	ISO 48
Compression set	ISO 815
Chemical analysis (percent of carbon black, polymer extraction constant, etc.)	ISO 1408, 1407, 247
Accelerated aging	ISO 188
Ozone resistivity	ISO 1431 (E)
Density	ISO 1183
Low temperature behavior	ISO 3387, 1653

---

a. Bundesanstalt fur Materialprufung (BAM), the competent authority of the Federal Republic of Germany

b. Reference 4.2-17.

c. For applications having a temperature range of -40°C to 127°C, small differential pressure (about 1 atm), and no essential influence from radiation and chemical contents.

(about 1 atm), and no essential influence from radiation and chemical contents. Each batch would be identified by marking, method of delivery, manufacturer, and date of manufacturing. Because the O-rings themselves are not able to bear identification markings, each individual gasket would be required to be enclosed in an envelope showing the proper identification marks. If gaskets were glued, nondestructive testing of the joint would also be required.

The Parker Seal Company, one of the major elastomer gasket manufacturers in the U.S., performs tests on each lot of elastomer O-rings, providing traceability of the material properties of the O-rings purchased, including hardness, tensile strength, ultimate elongation, and specific gravity (Ref. 4.2-12). Parker has developed colored compounds that clearly identify the elastomer family, and that have physical properties which in some cases actually exceed those of their black rubber counterparts (Ref. 4.2-12).

4.2.2.2 Replacement Interval

The required replacement interval for reusable gaskets is determined by the gasket material and the service history of the closure system. W. H. Lake has identified the need for reliability and life test data for RAM containment seals (Refs. 4.2-18, 4.2-19, 4.2-20).

The failure rate is defined as the conditional instantaneous probability of failure, given that failure has not yet occurred. Mortality curves, of failure rate vs. component age, commonly have a "bathtub" shape (Ref. 4.2-18), with the different portions of the curve determined as follows. The first part of the curve (with negative slope) is called early mortality and is determined by faulty components. The level part of the curve shows the performance of the good components during their useful life. The last part of the curve (with positive slope) shows the rate at which components wear out. The use of components that fall in the level part of the curve involves screening to eliminate potential early failures, and replacement of components in service prior to the expected wearout period (Ref. 4.2-18).

For elastomer O-ring seals, it is reasonable to assume that early failure is not a problem because of the quality assurance programs of the O-ring manufacturers. Reference 4.2-18 cites data in the literature for static seals that yields a life expectancy of 4 years. The U.S. NRC has used replacement after one year as the typical requirement for elastomer seals (Ref. 4.2-18).

4.2.3 Descriptions of Types of Elastomers

The predominant closure seal material in currently certified, large Type B packages is silicone, which has been in general use since the mid-seventies. Neoprene is a close second in high usage, followed by Viton and Buna-N.

Descriptions of the various types of elastomers used in closure seals of currently certified, large Type B RAM transport packages are provided, followed by descriptions of several other materials which show promise for this application.

4.2.3.1 Silicone

The silicones are a group of elastomer materials made from silicon, oxygen, hydrogen, and carbon (Ref. 4.2-12). Silicones have outstanding high temperature properties due to the silicon-oxygen linkage in their main chain, instead of the carbon-carbon linkages that exist in organic polymers (Ref. 4.2-21). They have poorer tensile strength, tear resistance, and abrasion resistance than other elastomers, but may have exceptional heat and compression set resistance (Ref. 4.2-12). They have a relatively low rate of outgassing, but have a relatively high permeability (Refs. 4.2-10, 4.2-2). Silicones are useful for temperature operations ranging from approximately -54°C to 232°C (-65°F to 450°F), and their retention of properties over a wide temperature range is superior to other elastomers. Parker Seal Co. claims to have compounded silicone materials which will resist temperatures to 371°C (700°F) for short periods (Ref. 4.2-1).

Original silicone elastomers required an oven cure, but some later types require no oven cure. Some types can cure at room temperature (RTV grades), some of which are squeezed from tubes and can be provided with adhesive or release properties (Ref. 4.2-2).

4.2.3.2 Neoprene

"Neoprene" is an E.O. duPont de Nemours Co. trade name for chloroprene rubbers, homopolymers of chloroprene (chloro-butadiene) (Ref. 4.2-1). They were among the earliest of the synthetic rubbers available to seal manufacturers, and are closer to natural rubber than the other synthetics. Neoprenes are not vulcanized with sulfur, which is useful in applications where the corrosion properties of sulfur on the sealing surfaces is important (Ref. 4.2-10).

Tensile strength and abrasion resistance properties are nearly as good as natural rubber, but tear resistance is not as good. Dynamic properties are excellent and are retained at higher temperatures. Neoprenes have excellent resistance to oils, but have the highest outgassing rates of the most commonly used gasket materials (Ref. 4.2-10). Neoprenes can be compounded to be serviceable over an approximate temperature range of -54°C to 149°C (-65°F to 300°F) (Ref. 4.2-12).

4.2.3.3 Viton

"Viton" is an E.O. duPont de Nemours Co. trade name for a fluorocarbon elastomer, also known as "Fluorel" (Minnesota Mining and Manufacturing Co. trade name) (Ref. 4.2-1). The high proportion of combined fluorine in these compounds gives them unusual chemical stability. Therefore they can be used to seal liquids or vapors in which other elastomers would be unsuitable (Ref. 4.2-1). Fluorocarbons are useful for temperature operations ranging from approximately -23°C to 204°C (-10°F to 400°F) and are capable of withstanding temperatures to

371°C (700°F) for short periods (Ref. 4.2-1). They have relatively poor low temperature properties compared to other elastomers, but have been known to seal at -54°C (-65°F) in some static applications (Ref. 4.2-12). Viton gaskets have been observed to become stiff at about -20°C (-5°F) and have failed at -40°C (-40°F) in other tests (Ref. 4.2-16).

Measurements of permeation constants for several combinations of gases and elastomer gasket materials (silicone, Viton, EPDM) demonstrated that Viton has the lowest permeation constant of the materials studied (Ref. 4.2-7). Viton has a lower outgassing rate than neoprene or Buna-N (see Fig. 4.2-1), and this rate can be improved by a vacuum bakeout. However, any exposure to the atmosphere following the bakeout will cause gases to be reabsorbed and will negate the effect of the bakeout (Ref. 4.2-10).

4.2.3.4 Buna-N

Buna-N is a copolymer of butadiene and acrylonitrile (the "N" in the name stands for "nitrile"). The acrylonitrile content is varied in most products from 18 percent to 48 percent (Ref. 4.2-1). Nitrile compounds are superior to most elastomers with regard to compression set, and tear and abrasion resistance. They are the most widely used elastomers in the seal industry today (Ref. 4.2-12). Buna-N compounds may be soluble in benzene, toluene, naphthalene and trichloroethylene (Ref. 4.2-10). Buna-N has a high outgassing rate, but vacuum baking can reduce this rate. The gases removed during the vacuum bakeout are primarily plasticizers and not water, so exposure to the atmosphere following bakeout does not negate the effects of the bakeout (Ref. 4.2-10). Nitriles are useful for temperature operations ranging from approximately -54°C to 121°C (-65°F to 250°F). However, one type of nitride-butadiene tested failed at -32°C (-25°F) (Ref. 4.2-16).

4.2.3.5 Styrene-butadiene Rubber

Styrene-butadiene rubber is a synthetic polyisoprene, and is slightly better than natural rubber with respect to natural aging and resistance to attack from vegetable and animal oils (Ref. 4.2-2).

4.2.3.6 EPDM

Ethylene/propylene terpolymers (EPDMs) are saturated copolymers of ethylene and propylene. Due to the saturation of the main polymer chain, there are no double bonds or weak points as in other organic synthetic rubbers. This saturation improves EPDM's resistance to degradation by light, heat, and oxygen (Ref. 4.2-21). EPDM has been in continuous use as a seal at temperatures to 121°C (250°F) in solar applications (Ref. 4.2-21). Ethylene-propylenes are useful for temperature operations ranging from approximately -54°C to 149°C (-65°F to 300°F) for most applications (Ref. 4.2-12). Other tests have confirmed the low temperature limit of at least one EPDM compound to be -54°C (-65°F) (Ref. 4.2-16).

4.2.3.7 Fluorosilicone

Fluorosilicones are a more recent development in the silicone family that combine the good high and low temperature properties of silicones along with basic fuel and oil resistance now lacking in plain silicones (Ref. 4.2-12). High-strength type fluorosilicones are available, and certain of these exhibit much improved resistance to compression set (Ref. 4.2-12). Fluorosilicones are useful for temperature operations ranging from approximately -34°C to 177°C (-30°F to 350°F).

4.2.3.8 Polyurethane

Polyurethanes have a good resistance to fuels, oils, oxygen, ozone, and weathering. They are susceptible to hydrolysis, but improvements can be made to increase their resistance. They have high strength and good abrasion resistance which is useful if there is a reciprocating, high pressure, or abrasive application (Ref. 4.2-2). Polyurethanes can be used over the temperature range of -54°C to 93°C (-65°F to 200°F) (Ref. 4.2-3).

4.2.3.9 Summary of Elastomer Properties

Table 4.2-3 is a comparison of the properties of commonly used elastomers, derived from Ref. 4.2-12. Chapter 5 provides information about elastomer gaskets used in specific Type B RAM transport packages.

4.2.4 Gasket Designs

Most elastomers are used in the form of circular O-rings, but they can also be used in other cross sections or designs. One proposed Type B packaging uses rectangular elastomer gaskets (Ref. 4.2-22). The AP-101 shipping cask uses a Parker Gask-O-Seal closure seal.

4.2.4.1 O-Ring

An O-ring is an elastomer gasket, generally with a circular cross section. The O-ring is compressed between two sealing faces. The O-ring can be held in place in a groove, with spacers, on a step, between flat flanges, or with a conically shaped sealing ring (see Section 3.4.1). O-ring manufacturers generally provide dimensions for the size of the groove.

4.2.4.2 Gask-O-Seal

The Parker Gask-O-Seal is used in the AP-101 shipping cask. In this seal design, an elastomer is permanently molded into a plastic or metal retaining ring. When assembled, the round crown is deformed into a square or oblong shape, as shown in Fig. 4.2-2. The retaining ring provides the strength and rigidity for the seal and limits compression of the elastomer (Ref. 4.2-1).

4.2.4.3 Dual Hardness

Reference 4.2-4 discusses dual hardness elastomer gaskets, which have a layer of soft elastomer on the outside of a relatively hard elastomer core. This design leads to greater roughness infilling. The effect of the hard core is to cause high contact stress at the seal face,

TABLE 4.2-3

SUMMARY COMPARISON OF ELASTOMER PROPERTIES[a,b]

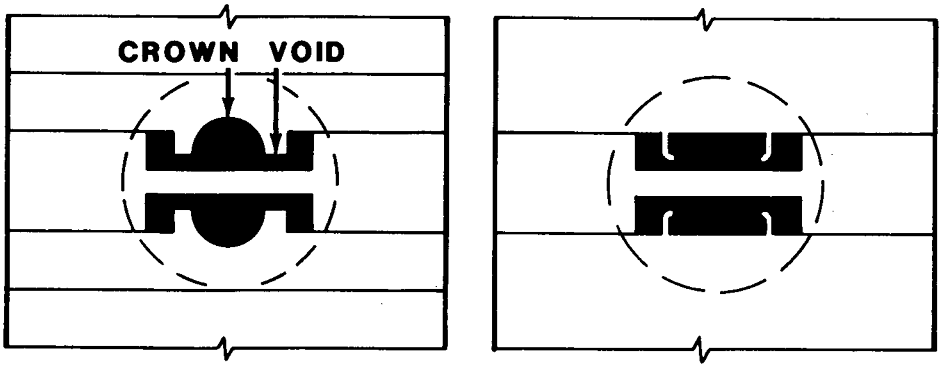
A = Silicone
B = Neoprene
C = Fluorocarbon
D = Nitrile
E = Fluorosilicone
F = Ethylene Propylene

	A	B	C	D	E	F
Ozone resistance	7	6	7	1	7	7
Weather resistance	7	7	7	3	7	7
Heat resistance	7	5	7	5	7	7
Chemical resistance	6	4	7	4	7	7
Oil resistance	3	4	7	7	5	1
Impermeability	1	5	5	5	1	5
Cold resistance	7	4	2	5	6	6
Tear resistance	1	4	3	4	1	6
Abrasion resistance	1	5	5	5	1	6
Set resistance	6	3	6	6	6	6
Acid resistance	4	4	7	3	4	5
Tensile strength	1	5	6	6	3	6
Electrical properties	7	3	3	3	7	5
Water/steam resistance	3	3	4	4	3	7
Flame resistance	3	5	7	1	5	1

---

a. Reference 4.2-12.

b. Properties are ranked on a scale of 7 to 1, 7 being highest (excellent) and 1 being lowest (poor).



BEFORE FASTENING.

AFTER FASTENING.

Figure 4.2-2. Gask-O-Seal (Ref. 4.2-1)

while the soft surface gives greater infilling than a uniformly hard gasket material. A uniformly soft elastomer could not raise the initial high contact stress. As of 1983, this gasket design had not yet been developed for practical use.

References

4.2-1. "Gask-O-Seal Handbook," OSD-6411, Parker Seal Group, Culver City, CA, 1983.

4.2-2. R. K. Flitney, B. S. Nau, and D. Reddy, The Seal Users Handbook, 3rd Edition, British Hydromechanics Research Association, The Fluid Engineering Centre, Cranfield, Bedford, England, 1984.

4.2-3. "Parker O-Ring Handbook," ORD-5700, Parker Seal Group, Lexington, KY, 1982.

4.2-4. T. C. Chivers and A. F. George, "Factors Influencing the Design and Assessment of Elastomer Seals for Nuclear Fuel Transport Flasks," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 664-671.

4.2-5. T. C. Chivers and R. P. Hunt, "Scaling of Gas Leakage from Static Seals," 8th International Conference on Fluid Sealing, University of Durham, England, September 11-13, 1978.

4.2-6. L. L. Bonzon, F. J. Wyant, L. D. Bustard, and K. T. Gillen, "Status Report on Equipment Qualification Issues Research and Resolution," Sandia National Laboratories, SAND85-1309, November 1986.

4.2-7. K. Heumos, et al., "Investigation of Gas Leakage from Sealing Constructions at Containments for Radioactive Materials," Proceedings of the Sixth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '80, West Berlin, F.R.G., November 10-14, 1980, pp. 472-478.

4.2-8. Solar Heating Materials Handbook, Sandia National Laboratories, DOE/TIC-11374, UC-11-59-59c, January 1981, pp. 6-6 to 6-10.

4.2-9. M. A. Mendelsohn, R. M. Luck, F. A. Yeoman, and F. W. Navish, Jr., "Collector Sealants and Breathing," Westinghouse Electric Corporaton, DOE/CS/15362-1, February 1980.

4.2-10. H. H. Buchter, Industrial Sealing Technology, John Wiley & Sons, 1979.

4.2-11. S. G. Burnay and J. W. Hitchon, "Prediction of Service Lifetimes of Elastomeric Seals During Radiation Aging," Journal of Nuclear Materials, Vol. 131, 1985, pp. 197-207.

4.2-12. "O-Ring Reference Guide," ORD-5703, Parker Seal Group, Lexington, KY, 1985.

4.2-13. M. G. Murray, Jr., "Select O-Rings Carefully," Hydrocarbon Processing, Vol. 55, No. 4, 1976.

4.2-14. T. C. Chivers and R. P. Hunt, "Thermal Degradation of Elastomers and a Criterion for Predicting Useful Life During a Temperature Transient," Central Electricity Generating Board, CEGB Report RD/B/N3433, England, July 1975.

4.2-15. T. C. Chivers and R. P. Hunt, "Problems, Properties, and Performance of Static Seals," CEGB Research, No. 6, January 1978, pp. 26-35.

4.2-16. H. Kowalewsky, "Leak Testing and Activity Leakage Rate Evaluation -- Practical Experiences, First Approaches to Some Systemization and Outstanding Problems," Proceedings of the Sixth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '80, West Berlin, F.R.G., November 10-14, 1980, pp. 446-453.

4.2-17. K. E. Wieser, K. Tobisch, U. Probst, "The Elastomer Gasket -- A Black Sheep for Quality Assurance Measures?," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 1366-1369.

4.2-18. W. H. Lake, "Reliability in Maintenance and Design of Elastomer Sealed Closures," Proceedings of the Fifth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '78, Las Vegas, NV, May 7-12, 1978, pp. 790-796.

4.2-19. W. H. Lake, "Containment Seal Reliability Testing," Proceedings of the Sixth International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '80, West Berlin, F.R.G., November 10-14, 1980, pp. 1199-1204.

4.2-20. W. H. Lake, "Containment System Evaluation," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 633-637.

4.2-21. R. V. Gallagher, "Elastomeric Seals for Solar Collectors," Solar Glazing: Topical Conference, Stockton State College, Pomona, NJ, June 22-23, 1979, pp. C-29 to C-31.

4.2-22. "Transuranic Package Transporter (TRUPACT-I) Safety Analysis Report for Packaging," Sandia National Laboratories, SAND83-7077, May 1986.

4.3 Metal Gaskets

Metal gaskets are used for closure of a relatively small number of currently certified Type B RAM transport packages, primarily for large irradiated fuel casks such as the M-130 and IF-300, which have been in service since before 1980. The particular metals used in the package closure often are not specified in the SARPs. In general usage, gasket metals include lead, copper, aluminum, brass, Monel, nickel, stainless steel, Inconel, silver and platinum. Metal gaskets are available in a wide variety of configurations.

4.3.1 Physical Properties of Metals Used for Gasket Materials

Metal gaskets can accommodate significantly higher temperature requirements (in excess of 1000°C) than elastomer gaskets, and do not deteriorate with age, but require smoother sealing surfaces than elastomers. Metals are also used when high pressure, corrosive, or radiation environments are encountered. Certain properties of elastomers, such as permeation, outgassing, and swell, are not of concern for metal gaskets.

4.3.1.1 Hardness

Metal gaskets are harder than other gasket materials and require a very good surface finish. Hardness is the localized resistance of the metal to plastic indention, and is generally determined by a static loading test of a penetrator and measurement of the resulting indentation. The most common static hardness tests are: (1) Rockwell, using a diamond cone or hardened steel sphere; (2) Brinell, using a 10-mm steel or tungsten carbide sphere; (3) Vickers, using a square-base diamond pyramid; and (4) Knoop, using an elongated diamond pyramid. The hardness numbers are read from a table based on one dimension of the indention (Ref. 4.3-1). For example, a "soft" metal such as 99.6 percent pure annealed aluminum has a hardness of B-16 (on the Brinell scale), while "hard" stainless steel has a hardness in the range of B-160 (Ref. 4.3-2).

When the main body of a gasket must be hard and stiff (for structural strength or to match thermal expansion coefficients), the efficiency of sealing can be improved by plating the contact surface of the gasket with a soft metal or coating with a plastic, such as Teflon. Gaskets can be plated with soft metals including silver, copper, nickel, lead, indium, and gold. Plating allows for better infilling of surface irregularities and reduces contact force. The plating generally deforms without affecting the base material, thereby, reducing the force required to establish seal contact. Nickel is used in high temperature applications and where liquid sodium is present. The thickness of the plating depends upon the particular application, varying from 0.05 to 0.15 mm (0.002 to 0.006 inches) (Ref. 4.3-3).

4.3.1.2 Compression Set

Metals can be compressed; however, high stresses are required. The gaskets can harden under loading and limit the number of times a metal gasket can be reused (see Table 4.1-1).

4.3.1.3 Thermal Expansion Coefficients

The thermal expansion coefficients for metals are much smaller than for elastomers (see Section 4.2.1.5), so a groove used to hold a metal O-ring in place does not need to allow for the large expansion that an elastomer O-ring experiences during deformation and temperature increases. The differential expansion of the flanges and the gasket must still be accounted for in the design and choice of gasket material, by considering the operating temperature range.

4.3.1.4 Low and High Temperature Behavior

Metal gaskets can be used at both lower and higher temperatures than elastomers. Table 4.3-1 from Ref. 4.3-4 indicates the range of metals used for gaskets, as well as the upper temperature limit for each metal.

TABLE 4.3-1

TEMPERATURE LIMITS OF METAL GASKET MATERIALS[a]

Material	Maximum Temperature (° C)
Lead	100
Common brasses	260
Copper	320
Aluminium	430
Stainless steel type 304	540
Stainless steel type 316	540
Soft iron, low carbon steel	540
Titanium	540
Stainless steel type 502	620
Stainless steel type 410	650
Silver	650
Nickel	760
Monel	820
Stainless steel type 309 SCB	870
Stainless steel type 321	870
Stainless steel type 347	870
Inconel	1090
Hastelloy	1090

---

a. Reference 4.3-4.

4.3.1.5 Radiation Resistance

Metals have high resistance to radiation compared to elastomers. Metal gaskets are generally required in environments where the radiation exposure exceeds 10^7 rads. Gamma radiation and fast moving ions have little effect on metals. Detectable changes in the mechanical properties of metals are generally not evident until fast neutron fluxes reach about 10^{19} n/cm^2. Radiation effects in metals are similar to cold working and result in an increase in tensile and yield strength, hardness, and electrical resistivity, while decreasing ductility, impact strength, density, thermal conductivity, corrosion resistance and creep (Ref. 4.3-5).

4.3.2 Specification of Metal Gaskets

4.3.2.1 Gasket Material

Seal manufacturers specify the metals for gaskets by the metal or type of alloy desired. A vast number of specifications exist covering chemical composition, manufacturing, physical and mechanical properties, testing, inspection, reporting and marking. These specifications include: AA (Aluminum Association), ACI (Steel Founders Society of America), AISI (American Iron and Steel Institute), AMS (SAE/Aerospace Materials Specifications), ASME (American Society of Mechanical Engineers), ASTM (American Society for Testing and Materials), CDA (Copper Development Association), Federal Specifications, MIL (Military Specifications), SAE (Society of Automotive Engineers), and trade designations. Inconel 600 is an example of a trade designation (or name), while stainless steel 304 is covered by many AISI, ASME, ASTM, FED, MIL, and SAE specifications.

4.3.2.2 Replacement Interval

The service life of metallic seals may depend on the number of times they are loaded and unloaded (packaging opened and closed), so replacement may be stated in terms of the number of uses (Ref. 4.3-6). Many metallic gaskets are not considered to be reusable.

4.3.3 Descriptions of Types of Metal Gaskets

Metal gaskets are made of metal tubing or solid rod, which is formed into circular or other shapes and the two ends welded together. Metal gaskets can be electroplated with silver, copper, indium, nickel, gold, lead, or other metals, or coated with Teflon. The flow of the finish material improves the sealing capability, especially under high contact pressure (Ref. 4.3-7).

4.3.4 Gasket Designs

Chapter 5 provides information about the types of metal gaskets in use in specific Type B RAM transport packagings. Metal O-rings, Grayloc® seals, and Flexotallic gaskets are currently in use. The Helicoflex® seal shows promise for this application.

4.3.4.1 O-Rings

Metal O-rings can be either hollow or solid. Hollow metal O-rings are available in a variety of cross sections other than circular. These include elliptical, diamond, and double diamond cross sections (see Figure 4.3-1). They can be vented (self-energizing) or pressurized. Pressurized rings are used to offset the loss of strength at high temperatures. O-rings are often made of stainless steels and Inconels. Their sealing efficiency is improved if they are plated with a softer material (see Section 4.3.1.1). Tests have demonstrated that some hollow metal O-rings have very little spring-back and are very sensitive to unloading (Ref. 4.3-8). A metal O-ring is used in the FSV-1 packaging, and a silver-plated Inconel O-ring is used in the NLI-1/2 packaging, both of which are used for transport of irradiated fuel.

4.3.4.2 Pressure-Filled Gaskets

Hollow pressure-filled metal gaskets are designed for a temperature range of 427°C to 1093°C (800°F to 2,000°F). The gasket is filled with an inert gas at about 4.1 MPa (600 psi). At elevated temperatures, gas

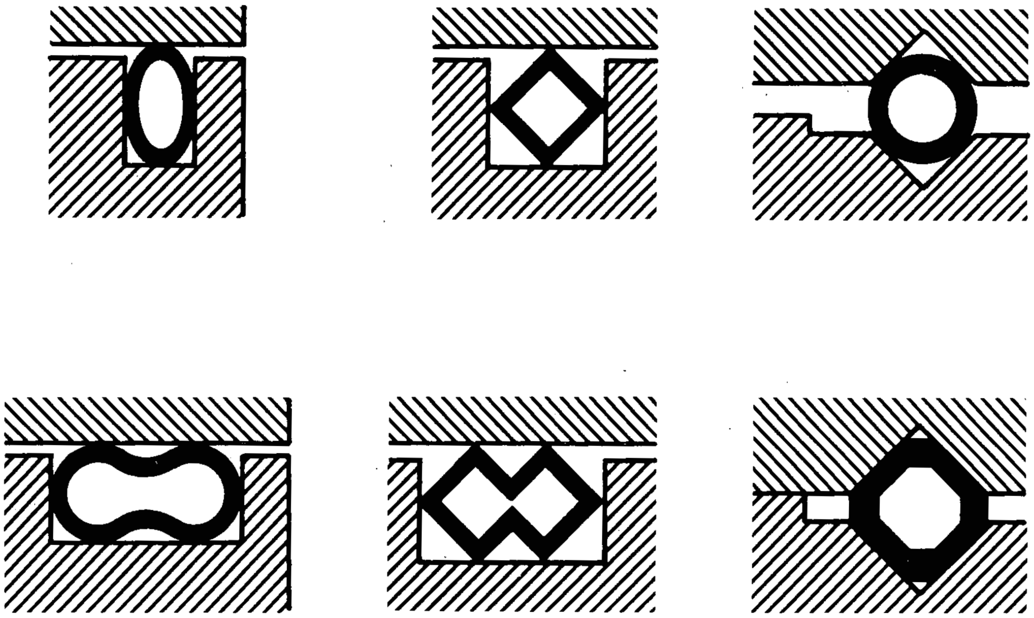


Figure 4.3-1. Variety of Shapes of Hollow Metal O-Rings (from Ref. 4.3-3, reprinted by permission of John Wiley & Sons, Inc. from <u>Industrial Sealing Technology</u>, by H. H. Buchter, copyright © 1979 by John Wiley & Sons, Inc.)

pressure increases, which partially offsets the loss of strength in the tubing at elevated temperatures and increases sealing stress (Ref. 4.3-7).

4.3.4.3 Self-Energizing Gaskets

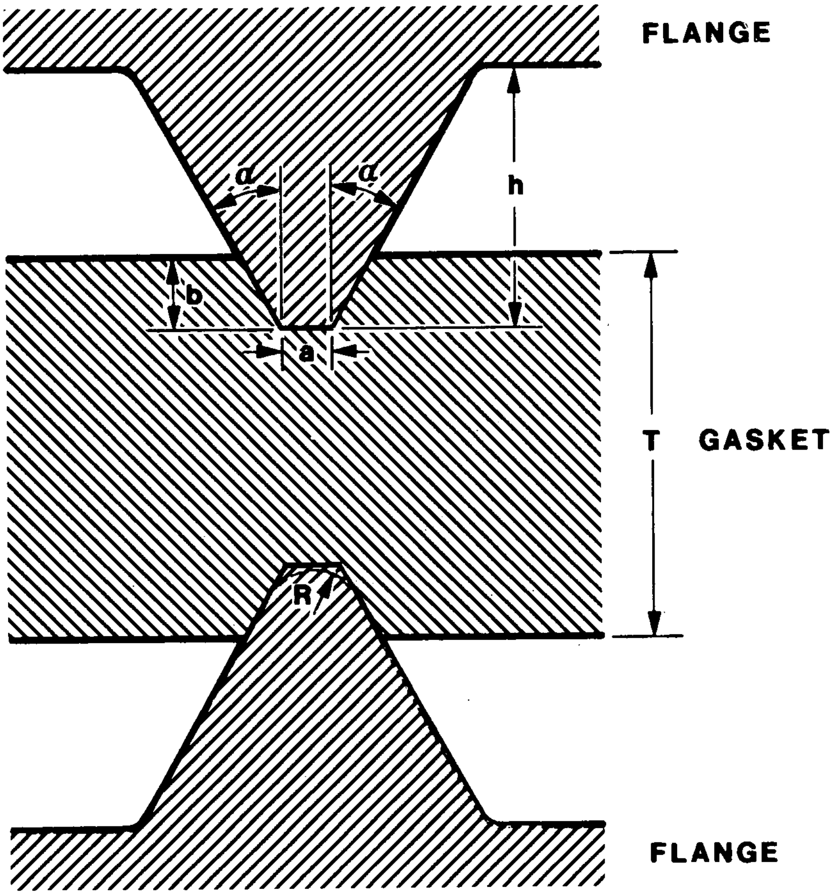
The inner periphery of a hollow metal gasket can be vented by small holes or a slot to allow the pressure of the gas or liquid inside a container to pressurize the gasket. This energizes the gasket and increases the sealing effectiveness. Self-energizing gaskets can be used at higher pressures than pressure-filled gaskets (Ref. 4.3-7).

4.3.4.4 Knife Edge Seals

Knife edge seals (Ref. 4.3-9) are used to concentrate the compression force onto a small part of the gasket width (see Figure 4.3-2). The knife edge must be made of a harder material than the gasket. Common gasket materials used with knife edge seals include OFHC copper, nickel, silver, silver-plated copper, and indium-plated copper. An example of this type of seal is the Conflat® seal made by Varian for vacuum applications (see Figure 4.3-3). A formed-in-place copper gasket contained within a groove equipped with knife edge features is incorporated in the primary containment vessel of the PAT package (Ref. 4.3-10).

4.3.4.5 Helicoflex® Seals

The all-metal Helicoflex® seal has a built-up structure with inner and outer liners, and a central helical energizing spring (see Figure 4.3-4). Sealing is accomplished by plastic flow of the outer liner against the mating sealing surfaces. The helical spring aids in keeping a sufficient load against the outer liner to follow temperature fluctuations and small deformations. Helicoflex® seals can be manufactured to meet leaktight or better sealing criteria (Ref. 4.3-11). Leakage rates of less than 1×10^{-9} atm-cm^3/s (helium) can be met using seals with a slightly larger wire gauge for the internal spring than those for "standard" sealing. The seal is not generally considered reusable.



$\alpha = 30\text{–}45^{\circ}$

apex of knife edge: flat edge a = 0.1–0.2 mm or rounded R = 0.1–2.5 mm

height of knife edge = h = 0.7–2 mm

gasket thickness = T = 1–1.5 mm

depth of bite = b = 0.2–0.4 mm

Figure 4.3-2. Knife Edge Seal (Ref. 4.3-9)

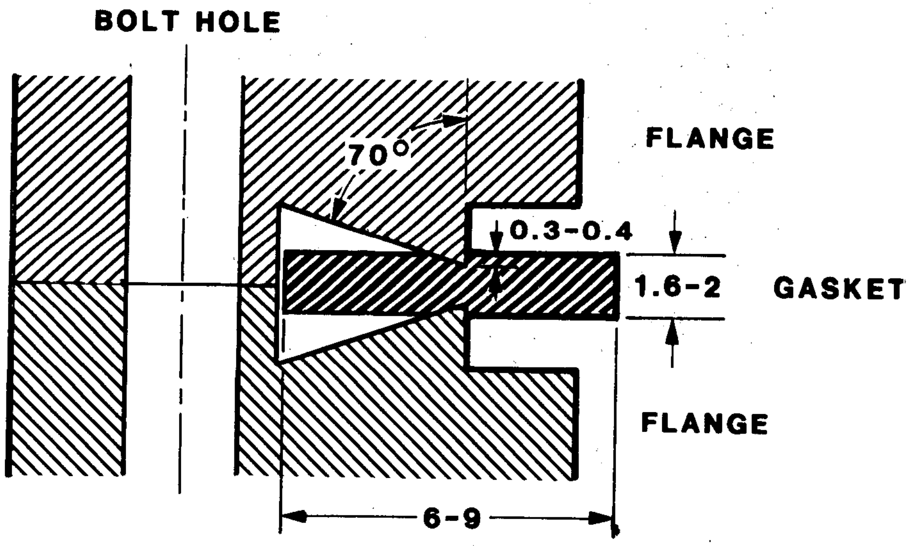


Figure 4.3-3. The Varian Conflat® Seal (Ref. 4.3-9)

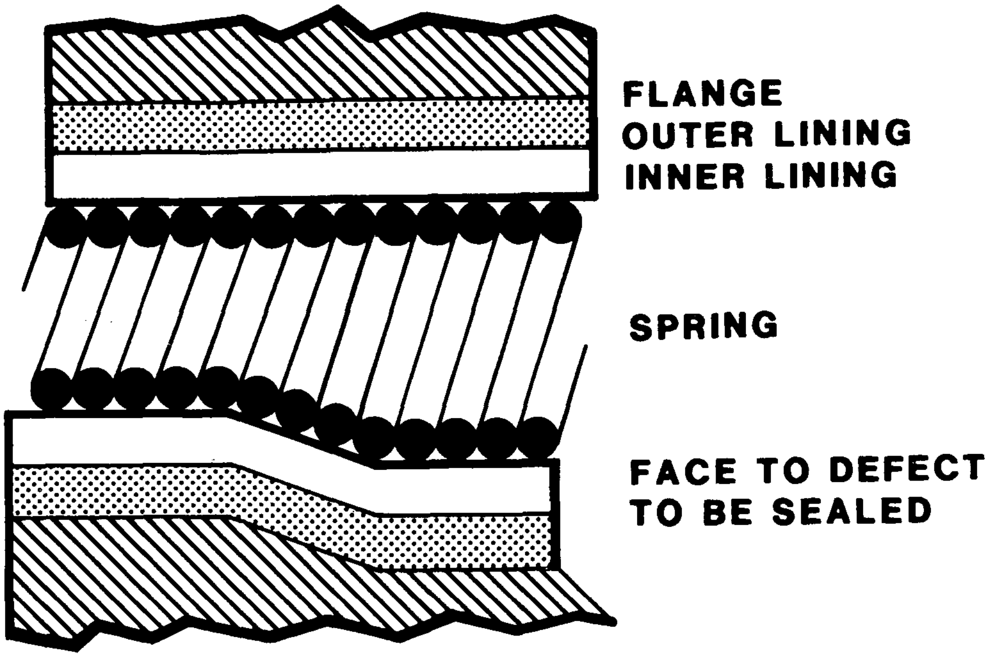


Figure 4.3-4. The Helicoflex® Seal (Cross Section) (Ref. 4.3-11)

4.3.4.6 Grayloc® Seals

The Grayloc® seal is manufactured by the Gray Tool Company (Ref. 4.3-12) and consists of a metal ring with a T-shaped cross section (see Figure 4.3-5 from Ref. 4.3-13). The vertical portion of the T provides the main structural support and motion control. The flexible arms of the crossbar of the T make contact with the tapered sealing surfaces on upper and lower hubs or flanges. Compression of these arms causes plastic deformation at the contact points. Grayloc® seals are used in the IF-300 and the NLI-10/24 rail casks for transport of irradiated fuel.

A static test program using these seals was conducted at Sandia National Laboratories, where a model was used to describe seal loading and actual seals [with an inner diameter of 0.74 m (29.25 inches)] were tested and leakage checked (Refs. 4.3-13 and 4.3-14). Given acceptable sealing surface dimensions and finishes, air leakage rates of 10^{-6} to 10^{-5} atm-cm^3/s were achieved. The seals could be reused if the seals and the sealing surfaces remained undamaged and free of foreign material.

4.3.4.7 Flexotallic/Spirotallic Seals

Flexotallic or spirotallic metal gaskets have preformed V-shaped metal strips wound into a spiral. The metal strips are separated by a filler which depends on the application. Fillers include Teflon, asbestos, and graphite (for ultra-high temperature ranges). Metals used in fabrication include carbon steel, stainless steel, Inconel, Hastelloys, Carpenter 20, titanium, Monel, nickel, copper, aluminum, and silver. For corrosion resistance, stainless steel may be used, but for high temperature operation, materials such as Inconel are preferred (Ref. 4.3-4).

The seal can be made with and without a centering device or inner and outer compression-control rings (see Fig. 4.3-6). The seal functions by a combination of the yield and flow of the metal and soft filler plies. Metal-to-metal plies forming the inner and outer edges must be in compression (Ref. 4.3-3). The resiliency of the metal plies allows

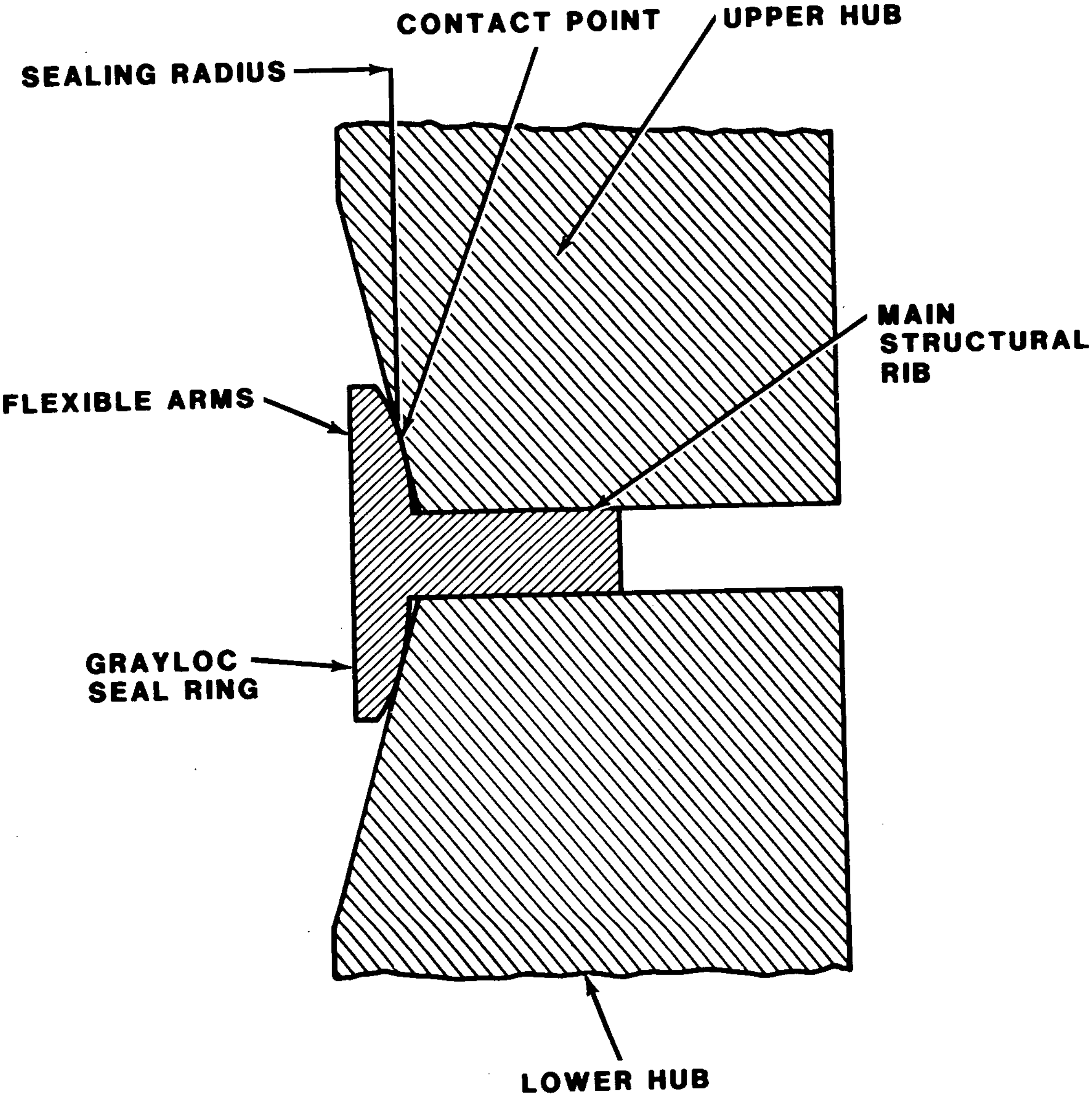
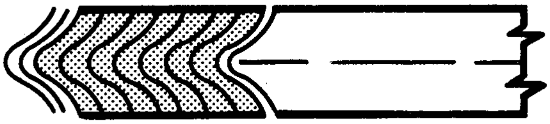
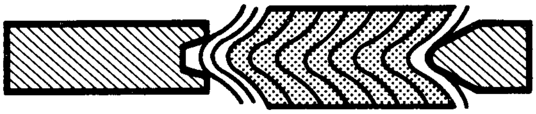


Figure 4.3-5. The Grayloc® Seal (Ref. 4.3-13)



GENERAL PURPOSE SPIRAL WOUND GASKET.



SPIRAL WOUND GASKET WITH INNER AND OUTER RINGS FOR CENTERING AND COMPRESSION LIMITING.

Figure 4.3-6. Spiral Wound Gaskets (Ref. 4.3-4) spiral-wound gaskets to tolerate flange distortions (Ref. 4.3-4). A spiral-wound graphite-filled gasket is used in the closure of a very large RAM transport package, the PWR-2 Lower Core Barrel Shipping/Disposal Container. A Flexotallic gasket is used in the M-130 packaging.

4.3.4.8 Other Designs

Metal gaskets are available in a wide variety of configurations including plain, profiled (in many cross-sections), serrated, and corrugated as single or multiple piece designs. See Ref. 4.3-3 for examples of the variety of metal gaskets in general use.

References

4.3-1. Metals Handbook, Desk Edition, H. E. Boyer and T. L. Gall, ed., American Society for Metals, 1985.

4.3-2. A. Roth, Vacuum Sealing Techniques, Pergamon Press Ltd,. 1966.

4.3-3. H. H. Buchter, Industrial Sealing Technology, John Wiley and Sons, 1979.

4.3-4. R. K. Flitney, B. S. Nau, D. Reddy, The Seal Users Handbook, 3rd edition, British Hydromechanics Research Association, the Fluid Engineering Centre, Cranfield, Bedford, England, 1984.

4.3-5. M. van de Voorde, K. P. Lambert, H. Schonbacher, "Resistance of Organic and Inorganic Materials to High-Energy Radiation," CERN Laboratory, Prevessin, France, 1974. (In "Evaluation de L'Action de L'Environment Spatial sur les Materiaux.")

4.3-6. W. H. Lake, "Containment System Evaluation," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 633-637.

4.3-7. "Metallic O-Rings," Fluorocarbon Co., 2620 The Boulevard, Columbia Industrial Park, P.O. Box 9889, Columbia, S.C. 29290, 1983.

4.3-8. B. J. Benda and R. T. Langland, "Methods for Evaluating the Leak Tightness of Spent Fuel Container Closures," NUREG/CR-1312, U.S. Nuclear Regulatory Commission, Washington, D.C., February 1980.

4.3-9. A. Roth, Vacuum Technology, Elsevier Science Publishing Co., Inc. 1982.

4.3-10. J. A. Andersen, "Correlation Between Measured Gas Leaks and Possible Loss of Contents from Radioactive Materials Packagings," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 646-654.

4.3-11. "Resilient Metal Seals and Gaskets," H.001.002, Helicoflex Co., 400 Myrtle Ave., Boonton, NJ 07005.

4.3-12. "Grayloc Industrial Catalog," Gray Tool Co., 7135 Ardmore St., P.O. Box 2291, Houston, TX, 77001.

4.3-13. W. B. Leisher and J. H. Biffle, "Grayloc Seal Static Tests," Sandia National Laboratories, SAND81-1295, February 1983.

4.3-14. W. B. Leisher and A. A. Trujillo, "Metallic Seal Testing," Proceedings of the Seventh International Symposium on Packaging and Transportation of Radioactive Material: PATRAM '83, New Orleans, LA, May 15-20, 1983, pp. 686-693.

4.4 Other Gasket Materials and Their Physical Properties

Other materials used in closure seals of Type A and Type B RAM transport packages include Teflon and asbestos.

4.4.1 Teflon

Polytetrafluoroethylene (trade name Teflon) is a plastic polymer of tetrafluoroethylene. It can be used over an approximate temperature range of -184°C to 232°C (-300°F to 450°F) and maintain high mechanical strength. Teflon gaskets require higher sealing pressures than elastomers. To achieve these higher pressures, narrower grooves are used and flanges have ridges or small grooves that act in a similar fashion to the knife edge. Teflon is incompressible and will deform with time at any temperature unless the material is placed in a restrained cavity which does not allow for expansion (Ref. 4.4-1). A Teflon gasket tends to flatten upon repeated use, so it is not generally considered reusable unless the gasket is made with an elastomer or spring core. Teflon has very low permeability to gases (Ref. 4.4-2) and is inert against the absorption of moisture and resistant to many chemicals (Ref. 4.4-1). A Teflon gasket is used in the closure seal of the NAC-1 cask, which transports irradiated fuel.

4.4.2 Asbestos

Asbestos is used as a gasket material because it has excellent temperature and chemical resistance. Because of its low strength and high porosity, it is not generally applied as pure asbestos. Instead, it is mixed with rubber or plastic compounds such as neoprene, nitrile, butadiene, and styrene, and included in materials known as "compressed asbestos fibers" (Ref. 4.4-3). An asbestos gasket is used in the closure seal of the KKP-20-4950, a large Type A cask transporting low specific activity materials. Metal gaskets, such as spirotallic-wound or metal-jacketed, can be filled with asbestos.

References

4.4-1. H. H. Buchter, Industrial Sealing Technology, John Wiley and Sons, 1979.

4.4-2. A. Roth, Vacuum Sealing Techniques, Pergamon Press Ltd,. 1966.

4.4-3. R. K. Flitney, B. S. Nau, D. Reddy, The Seal Users Handbook, 3rd edition, British Hydromechanics Research Association, the Fluid Engineering Centre, Cranfield, Bedford, England, 1984.

5.0 CHARACTERIZATION OF SEALS AND CLOSURES CURRENTLY CERTIFIED FOR RADIOACTIVE MATERIALS PACKAGES

5.1 Introduction

This section contains information from the TRACCS (Transport Cask Closures & Seals) computerized data base being developed at Sandia National Laboratories to describe features that affect the sealing capability of packages currently certified by the NRC. Records in the data base include the following: certificate number/model, gross weight, method of closure, seal material(s), number of seals, length of seal(s), shape of seal(s), number of bolts (if applicable), cask diameter, issue date of first Safety Analysis Report for Packaging (SARP), contents, frequency of seal replacement, leakage test information, and additional closure/seal information.

Included in the data base are: (1) packages that have large diameter seals [those packages with a gross weight of 18,000 kg (40,000 lbs) or greater], and (2) packages of irradiated fuel. Fifty-eight packages were identified for initial inclusion in the data base.

5.2 Development of Data Base

Information was entered directly into TRACCS from the NRC's 1984 Directory of Certificates of Compliance (Ref. 5.2-1) and updated to reflect the 1985 Directory (Ref. 5.2-2). The most current editions of SARPs for the packages of interest were ordered from the NRC Public Documents Room so that data not usually listed in the certificate, such as leakage test method, could be included in the data base. Inspection of the SARPs shows that no detailed containment analyses are present in SARPs dating earlier than the mid-'70s.

References

5.2-1. "Directory of Certificates of Compliance for Radioactive Materials Packages," NUREG-0383, Volume 2, Revision 7, U.S. Nuclear Regulatory Commission, Division of Fuel Cycle and Material Safety, Washington, D.C., November 1984.

5.2-2. "Directory of Certificates of Compliance for Radioactive Materials Packages," NUREG-0383, Volume 2, Revision 8, U.S. Nuclear Regulatory Commission, Division of Fuel Cycle and Material Safety, Washington, D.C., October 1985.

5.3 Summary of TRACCS Data for Packages of Immediate Interest

Information about irradiated fuel packages and packages with large diameter seals in the TRACCS data base has focused on seal material(s) and method of closure. The specific terms (for example, "bolts," "cap screws," etc.) used by each manufacturer are reported for seal material and closure method. A summary of the compiled data follows.

5.3.1 Seal Material

The predominant closure seal material is silicone. Neoprene is a close second (high usage), followed by Buna-N and Viton (moderate usage). A small number of packagings use seal materials (or brands) described as: polyurethane, Garlock, metallic, elastomer, Gask-O-Seal, ethylene propylene, polytetrafluoroethylene, spiral-wound/graphite-filled, metal and asbestos, or silver plated metallic.

5.3.2 Method of Closure

The predominant method of closure is threaded fasteners, which include bolts, cap screws, high strength studs, and studs and nuts. However, regulatory concerns about the structural integrity of ratchet binders, including failure mechanisms, safety factors, and load paths, have resulted in elimination of that closure method from Type B packaging designs, at least for the present. Welds are only rarely used in closures.

5.4 Listing of Selected TRACCS Record Segments for Packages of Immediate Interest

Following is a listing of selected TRACCS record segments compiled as of August 1986 for currently certified radioactive material packages that have large diameter seals, and packages of irradiated fuel.

- Weight is in pounds.
- Inner seal material/outer seal material are listed respectively for concentric seals.
- Cask diameter is in inches, and indicates outside diameter unless otherwise noted.
- Leakage rates are in atmospheric cubic centimeters per second (air).
- MPLR is "maximum permissible leakage rate," the maximum leakage rate for the medium present during transport, to allow the package to meet the regulatory containment requirements.
- Acceptance leakage rate is the fabrication acceptance leakage rate; assembly is the assembly leakage rate.

Some of the SARPs for certified packages were not available for this document.

Package ID: 5059/AF
Model: NFS Uranyl Nitrate Tank Trailer
Weight: 45,600
Diameter:
First SARP: March 1981
Seal Material:
Method of Closure:
Contents: fissile uranium
Leakage Tests:

Package ID: 5580/B()F
Model: S5W Power Unit
Weight: 127,900
Diameter: 95
First SARP: August 1968
Seal Material:
Method of Closure:
Contents: fissile uranium
Leakage Tests:

Package ID: 5607/B()F
Model: T-2
Weight: 18,400
Diameter: 6.07 (ID)
First SARP: April 1980
Seal Material:
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:

Package ID: 5758/B
Model: S5W Core Barrel Disposal Cask
Weight: 180,000
Diameter: 111
First SARP: February 1968
Seal Material:
Method of Closure: weld
Contents: by-product, normal form; high-level waste
Leakage Tests:

Package ID: 5805/B
Model: CNS 3-55
Weight: 70,000
Diameter: 50.50
First SARP: April 1982
Seal Material: silicone/silicone
Method of Closure: bolt
Contents: waste, B
Leakage Tests:
  Acceptance: 1.0E-03 (1985)
    "Cask pressurized to 4 psig with air and bubble testing of all closures in accordance with ANSI Standard N14.5" (1982), "Or hydrostatic test" (1982)
  Assembly: 1.0E-01 (1985)

Package ID: 5914/B()F
Model: 57.5 x 108 Core Cartridge
Weight: 48,000
Diameter: 61
First SARP: May 1968
Seal Material:
Method of Closure: bolt
Contents: fissile uranium
Leakage Tests:

Package ID: 5926/B()F
Model: GE-100
Weight: 4,800
Diameter: 20.25
First SARP: January 1980
Seal Material: silicone
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:

Package ID: 5942/B()F
Model: GE-700
Weight: 40,200
Diameter: 37
First SARP: March 1980
Seal Material: silicone
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:
  Assembly: 1.0E-03, except for special form radioactive material (1985)

Package ID: 5957/B()F
Model: BMI-1
Weight: 23,660
Diameter: 33.37
First SARP: June 1980
Seal Material:
Method of Closure: studs
Contents: irradiated fuel
Leakage Tests:

Package ID: 5971/B()F
Model: GE-200
Weight: 10,000
Diameter: 20.25
First SARP: February 1980
Seal Material: silicone
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:
  Assembly: 1.0E-03, except for special form radioactive material (1985)

Package ID: 5980/B()F
Model: GE-600
Weight: 23,300
Diameter: 34
First SARP: October 1979
Seal Material: silicone
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:
  Assembly: 1.0E-03

Package ID: 6003/B()F
Model: M-130
Weight: 228,000
Diameter: 84
First SARP: December 1968
Seal Material: metal & asbestos (Flexitallic)/ethylene-propylene
  (access plug = Flexitallic in series with silicone)
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:
  Acceptance: 1.0E-03, soap bubble test, 60 psig

Package ID: 6144/B
Model: B-2
Weight: 42,000
Diameter: (double walled steel box)
First SARP: December 1979
Seal Material: Garlock Model 23 Split Klozure (inner box)
Method of Closure: bolt
Contents: waste, B
Leakage Tests:

Package ID: 6244/B
Model: CNS 4-85
Weight: 46,000
Diameter: 58
First SARP: May 1984
Seal Material: polyurethane
Method of Closure: bolt
Contents: waste, B
Leakage Tests: "The cask has no mechanical provision for any type of quantitative leak test to be performed." (1984)

Package ID: 6346/B()F
Model: FSV-1 and FSV-1A
Weight: 47,600 and 51,790
Diameter: 31
First SARP: August 1980
Seal Material: silicone/silicone (FSV-1 primary seal is 2 O-rings, one metallic and the other silicone; FSV-2 primary and secondary seals are dual concentric silicone O-rings)
Method of Closure: bolt
Contents: irradiated material
Leakage Tests:

Package ID: 6385/AF
Model: S1W Unirradiated Core
Weight: 45,200
Diameter: 53
First SARP: July 1969
Seal Material:
Method of Closure: bolt
Leakage Tests:

Package ID: 6400/B()F
Model: Super Tiger
Weight: 45,000
Diameter: (square)
First SARP: August 1981
Seal Material: silicone
Method of Closure: bolt
Contents: PU, normal form; waste
Leakage Tests: No leakage test performed.
(Protective overpack only.)

Package ID: 6441/AF
Model: D2G Power Unit
Weight: 270,000
Diameter: 102
First SARP: August 1969
Seal Material:
Method of Closure: bolt
Contents: fissile uranium
Leakage Tests:

Package ID: 6568/A
Model: LL-60-150
Weight: 73,000
Diameter: 82.50
First SARP: August 1976
Seal Material: silicone
Method of Closure: bolt
Contents: low specific activity; waste
Leakage Tests:

Package ID: 6574/B
Model: HN-200
Weight: 50,000
Diameter: 66.25
First SARP: December 1979
Seal Material: Viton
Method of Closure: bolt
Contents: waste, B
Leakage Tests: MPLR: 4.3E-02
Acceptance: glycol or water bubble tests
Assembly: 1.0E-05 (glycol test) or 1.0E-03 (hot water bubble test) (1985)

Package ID: 6601/B
Model: CNS 8-120
Weight: 70,000
Diameter: 73.50
First SARP: November 1979
Seal Material: silicone
Method of Closure: bolt
Contents: waste, B
Leakage Tests:

Package ID: 6722/A
Model: BS-33-180
Weight: 51,100
Diameter: 84
First SARP: July 1975
Seal Material: silicone
Method of Closure: bolt
Contents: low specific activity
Leakage Tests:

Package ID: 6771/B
Model: SN-1
Weight: 60,000
Diameter: 80
First SARP: April 1981
Seal Material: silicone
Method of Closure: bolt
Contents: waste, B
Leakage Tests:
  Acceptance: 1.0E-01 nominal leakage, gas pressure drop test, 15 psig for 2-4 hrs (1981)

Package ID: 9001/B()F
Model: IF-300
Weight: 140,000
Diameter: 49.50
First SARP: October 1979
Seal Material: metallic (Grayloc)
Method of Closure: studs & nuts
Contents: irradiated fuel
Leakage Tests:

1.0E-01 nominal leakage, gas pressure drop test, 200 psig for 10 min. (for irradiated hardware). "Close supply valve and observe the pressure gage for an appropriate period of time (e.g. 10 minutes)." (1984)

For irradiated fuel: "Leakage test meeting requirements of ANSI N14.5 1977, as appropriate to design of the cask, will be performed prior to each shipment." (1984)

Package ID: 9010/B()F
Model: NLI-1/2
Weight: 49,250
Diameter: 47.13
First SARP: March 1980
Seal Material: elastomer
(containment vessel has silver-plated metallic Inconel O-ring)
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests: MPLR 1.24E-04 (1983)
Acceptance: 1.0E-06, helium leakage test
Assembly: 1.0E-01 (gas pressure drop); 1.0E-03 (gas bubble) for cask without inner container

---

Package ID: 9015/B()F
Model: TN-8 and TN-8L
Weight: 84,200 and 78,660
Diameter: 67.60
First SARP: April 1980
Seal Material: silicone or Viton/silicone or Viton
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests: MPLR 1.46E-03 (1985)
Assembly: 1.0E-02, pressure rise test (1985)

Package ID: 9016/B()F
Model: TN-9
Weight: 79,400
Diameter: 67.60
First SARP: April 1980
Seal Material: silicone or Viton/silicone or Viton
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests: MPLR 1.46E-03 (1985)
Assembly: 1.0E-02, pressure rise test (1985)

Package ID: 9023/B()F
Model: NLI-10/24
Weight: 194,000
Diameter: 96
First SARP: February 1976
Seal Material: Viton or silicone
(inner closure head has Grayloc metallic O-ring) ("high temperature polymer sheet positioned between inner and outer closure heads at top end")
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:

Package ID: 9044/B()F
Model: GE-1600
Weight: 25,500
Diameter: 38.50
First SARP: February 1982
Seal Material: silicone
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:

Package ID: 9071/B
Model: AP-101
Weight: 62,000
Diameter: 40
First SARP: June 1976
Seal Material: Gask-O-Seal (design: elastomer & metal or plastic)
Method of Closure: bolt
Contents: waste, B
Leakage Tests:
Acceptance: "Prior to first use the containment vessel will be checked at a pressure of 41 psia in order to ascertain that it will not leak." (1980)
Assembly: 1.0E-03, soap bubble test.

Package ID: 9073/B
Model: OH-142, OH-142MKI, OH-142MKIB, OH-142MKII, NUS 10-135
Weight: 64,000
Diameter: 76.25
First SARP: October 1982
Seal Material: silicone (secondary lids have silicone, Neoprene, or silicone/Neoprene seals)
Method of Closure: ratchet binder, or studs & nuts
Contents: waste, B
Leakage Tests:

Package ID: 9079/A
Model: NUPAC 14D-2.0
Weight: 49,000
Diameter: 81.75
First SARP: November 1982
Seal Material: Neoprene
Method of Closure: ratchet binder
Contents: low specific activity, waste
Leakage Tests:

1.0E-03, low pressure soap bubble test, 8-9 psi for 5 min. (1982)

Package ID: 9080/A
Model: HN-600, NUPAC 100, and CNS 7-100
Weight: 48,000
Diameter: 84
First SARP: February 1984
Seal Material: Neoprene
Method of Closure: ratchet binder
Contents: low specific activity
Leakage Tests:
  Acceptance: 1.0E-03, soap bubble test, pressurize to 8 psig (1984)

Package ID: 9086/A
Model: HN-100 Series 1
Weight: 50,000
Diameter: 81.50
First SARP: March 1983
Seal Material: Viton or Buna-N
Method of Closure: studs & nuts
Contents: low specific activity
Leakage Tests: none

Package ID: 9089/A
Model: HN-100S
Weight: 43,000
Diameter: 81.63
First SARP: March 1984
Seal Material: Buna-N
Method of Closure: studs & nuts
Contents: low specific activity, waste
Leakage Tests:
  Acceptance: 1.0E-03, bubble test, pressurize to 8 psig for 15 min. (1984)

Package ID: 9094/A
Model: CNS 14-195-H
Weight: 56,500
Diameter: 83.13
First SARP: March 1980
Seal Material: silicone
(secondary lid has Neoprene gasket)
Method of Closure: cap screw
Contents: low specific activity
Leakage Tests:

Package ID: 9096/A
Model: CNS 21-300
Weight: 57,450
Diameter: 86.75
First SARP: April 1980
Seal Material: silicone (secondary lid has Neoprene gasket)
Method of Closure: cap screw
Contents: low specific activity
Leakage Tests:

Package ID: 9100/A
Model: KKP-20-4950
Weight: 55,000
Diameter: 82.50
First SARP: March 1978
Seal Material: (asbestos-gasketed access ports)
Method of Closure:
Contents: low specific activity
Leakage Tests:

Package ID: 9103/B()F
Model: NLI-6502
Weight: 45,300
Diameter: 33.50
First SARP: September 1977
Seal Material: Buna-N
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:
Acceptance: Hydrostatic test at 30 psig
Assembly: "Air bubble leak check of containment boundary before shipment." Soap bubble test at 10 psig (1977)

Package ID: 9105/A
Model: CNS 6-101
Weight: 58,400
Diameter: (rectangular)
First SARP: March 1983
Seal Material: none
Method of Closure: bolt
Contents: low specific activity
Leakage Tests: "no containment capability"

Package ID: 9108/A
Model: CNS 6-75
Weight: 41,300
Diameter: 62
First SARP: May 1983
Seal Material: Neoprene
Method of Closure: bolt
Contents: low specific activity
Leakage Tests:
  Acceptance: 1.0E-03, soap bubble test at 14 psig (1983)

Package ID: 9111/A
Model: CNS 6-80-2 and CNS 6-80-2A
Weight: 51,500
Diameter: 70.50
First SARP: June 1983
Seal Material: silicone (CNS 6-80-2)
  (silicone/Neoprene secondary lid seals)
  silicone/silicone (CNS 6-80-2A)
  (silicone/silicone secondary lid seals)
Method of Closure: bolt, or stud & nut
Contents: low specific activity
Leakage Tests:
  Acceptance: 1.0E-01, gas pressure drop test, 14 psig for 10 min.

Package ID: 9132/B(M)F
Model: T-3
Weight: 38,000
Diameter: 52
First SARP: October 1978
Seal Material: Viton/Viton
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:
  Acceptance: "The leak test to satisfy ANSI N 14.5 and Regulatory Guide 7.4 must be a test having sufficient sensitivity to detect a leak rate of 1.0E-07."

Package ID: 9139/A
Model: 589
Weight: 50,000
Diameter: 79
First SARP: March 1980
Seal Material: Buna-N
Method of Closure: ratchet binder
Contents: low specific activity
Leakage Tests:

Package ID: 9144/A
Model: SGC-1 (steam generator)
Weight: 722,000
Diameter: 187
First SARP: January 1981
Seal Material: Neoprene
Method of Closure: bolt
Contents: low specific activity
Leakage Tests: none

Package ID: 9151/A
Model: HN-100 Ser. 3, CNS 14-170 Ser. 3, NUS 14-170 Ser. 1
Weight: 53,005
Diameter: 81.50
First SARP: April 1982
Seal Material: Neoprene
Method of Closure: ratchet binder
Contents: low specific activity
Leakage Tests:

Package ID: 9159/A
Model: NUPAC 14/190L, 14/190M, 14/190H
Weight: 65,200
Diameter: 83.25
First SARP: October 1982
Seal Material: Neoprene
Method of Closure: ratchet binder
Contents: low specific activity
Leakage Tests:
  Acceptance: 1.0E-03, soap bubble test to 8 psi for 5 min. (1982)

Package ID: 9168/B(U)
Model: CNS 8-120B
Weight: 74,000
Diameter: 74
First SARP: June 1984
Seal Material: silicone/silicone
(secondary lid has double silicone O-rings)
Method of Closure: bolt
Contents: waste, B; by-products, normal form
Leakage Tests:

Package ID: 9176/A
Model: NUPAC 14/210L, 14/210H, and CNSI 14-215H Ser. A
Weight: 58,400
Diameter: 83.80
First SARP: October 1982
Seal Material: Neoprene
Method of Closure: ratchet binder
Contents: low specific activity
Leakage Tests:

Package ID: 9177/A
Model: NUPAC 10/140
Weight: 56,500
Diameter: 66
First SARP: October 1982
Seal Material: Neoprene
Method of Closure: ratchet binder
Contents: low specific activity
Leakage Tests:

Package ID: 9178/A
Model: NUPAC 7/100
Weight: 48,900
Diameter: 75.50
First SARP: October 1982
Seal Material: Neoprene
Method of Closure: ratchet binder
Contents: low specific activity
Leakage Tests:
  Acceptance: 1.0E-03, soap bubble leakage test

Package ID: 9179/A
Model: NUPAC 6/100L, 6/100H
Weight: 53,900
Diameter: 71.37
First SARP: October 1982
Seal Material: Neoprene
Method of Closure: ratchet binder
Contents: low specific activity
Leakage Tests:

Package ID: 9183/B()F
Model: NAC-1
Weight: 49,000
Diameter: 50
First SARP: June 1984
Seal Material: polytetrafluoroethylene (Teflon)/Teflon
Method of Closure: bolt
Contents: irradiated material
Leakage Tests:
  Acceptance: 1.0E-01, pressure drop, 30 psig for 10 min.
  Annual: 1.0E-01, pressure drop, 100 psig for 10 min.

Package ID: 9186/AF
Model: S-6213 Power Unit Shipping Container
Weight: 490,000
Diameter: 129
First SARP: June 1975
Seal Material:
Method of Closure: stud
Contents: fissile uranium
Leakage Tests:

Package ID: 9193/B(U)
Model: NES-5
Weight: 51,000
Diameter: 49.13
First SARP: June 1984
Seal Material: silicone
Method of Closure: bolt
Contents: waste, B
Leakage Tests:
  Acceptance: 1.0E-03, soap bubble test, 10 psig for 15 min. (1984)

Package ID: 9200
Model: NUPAC 125-B
Weight: 181,500
Diameter: 65.50
First SARP: 1985
Seal Material: Neoprene/Neoprene
Method of Closure: bolt
Contents:
Leakage Tests:
  Acceptance: 1.0E-07, helium sniffer test (6 tests -- 3 for inner vessel and 3 for outer cask)
  Assembly: "Leak detection equipment shall not detect a leak within the range of 1.0E-03 to 1.0E-07"; argon, nitrogen or helium test

---

Package ID: 9781/B()F
Model: M-160
Weight: 237,000
Diameter: 79
First SARP: October 1968
Seal Material:
Method of Closure: bolt
Contents: irradiated fuel
Leakage Tests:

Package ID: 9787/B(U)F
Model: A1W-3 Power Unit Shipping Container
Weight: 397,000
Diameter: 134
First SARP: August 1980
Seal Material:
Method of Closure: bolt
Contents: fissile uranium; reactor parts
Leakage Tests:

Package ID: 9788/B()L
Model: S5W Reactor Compartment
Weight: 2,016,000
Diameter: 396
First SARP: July 1981
Seal Material:
Method of Closure:
Contents: by-product, normal form; reactor parts
Leakage Tests:

Package ID: 9791/B(U)
Model: PWR-2 Lower Core Barrel Shipping/Disposal Container
Weight: 400,000
Diameter: 127
First SARP: January 1982
Seal Material: spiral-wound, graphite-filled gasket
Method of Closure: bolt
Contents: waste, B; irradiated material
Leakage Tests:

APPENDIX A

INITIAL CONDITIONS AND TESTS FOR NORMAL CONDITIONS OF TRANSPORT AND HYPOTHETICAL ACCIDENT CONDITIONS

A.1 Normal Conditions of Transport

Separate specimens may be used for the free drop test, the compression test, and the penetration test if each specimen is subjected to the water spray test before being subjected to any of the other tests.

A.1.1 Initial Conditions for Normal Conditions

Initial conditions of temperature and internal pressure are specified.

A.1.1.1 Temperature

The temperature preceding and following the tests must remain constant at that value between -29°C (-20°F) and 38°C (100°F) which is most unfavorable for the feature under consideration.

A.1.1.2 Internal Pressure

The initial internal pressure within the containment system must be considered to be the maximum normal operating pressure unless a lower internal pressure consistent with the ambient temperature considered to precede and follow the tests is more unfavorable.

A.1.2 Conditions and Tests for Normal Transport

The conditions and tests to which the package must be subjected are shown in Table A-1.

TABLE A-1

CONDITIONS AND TESTS FOR NORMAL CONDITIONS OF TRANSPORT

Test	Description
Heat	An ambient temperature of 38°C (100°F) in still air, and insolation according to Table A-2
Cold	An ambient temperature of -40°C (-40°F) in still air and shade
Reduced external pressure	An external pressure of 24.5 kPa (3.5 psi) absolute
Increased external pressure	An external pressure of 140 kPa (20 psi) absolute
Vibration	Vibration normally incident to transport
Water spray	A water spray that simulates exposure to rainfall of approximately five cm (two in.) per hour for at least one hour
Free drop	Between 1.5 and 2.5 hrs after the conclusion of the water spray test, a free drop through 0.3 m (1 ft) onto a flat essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected
Corner drop	Not applicable for large Type B packages[a]
Compression	Not applicable for large Type B packages[b]
Penetration	Impact of the hemispherical end of a vertical steel cylinder of 3.2 cm (1.25 in.) diameter and six kg (13 lb) mass, dropped from a height of one m (40 in.) onto the exposed surface of the package which is expected to be most vulnerable to puncture. The long axis of the cylinder must be perpendicular to the package surface.

---

a. This test is applicable only to wood or fiberboard packages.
b. This test is applicable only to packages weighing up to 5000 kg.

TABLE A-2

INSOLATION DATA

Form and Location of Surface	Total insolation for a 12-hr period (g-cal/cm^2)
Flat surface transported horizontally:	
-- Base	None
-- Other surfaces	800
Flat surfaces not transported horizontally	200
Curved surfaces	400

A.2 Initial Conditions and Tests for Hypothetical Accident Conditions

10 CFR 71.73 states the hypothetical accident conditions of transport for which a package design must be evaluated. Evaluation is based on sequential application of the tests in the order indicated to determine their cumulative effect on a package or array of packages. An undamaged specimen must be used for the water immersion test required for all packages.

A.2.1 Initial Conditions

Initial conditions of temperature and internal pressure are specified for all tests except the water immersion tests.

A.2.1.1 Temperature

The temperature preceding and following the tests must remain constant at that value between -29°C (-20°F) and 38°C (100°F) which is most unfavorable for the feature under consideration.

A.2.1.2 Internal Pressure

The initial internal pressure within the containment system must be considered to be the maximum normal operating pressure unless a lower internal pressure consistent with the ambient temperature assumed to precede and follow the tests is more unfavorable.

A.2.2 Tests

The tests to which the package must be subjected (by physical test or analysis) are shown in Table A-3.

TABLE A-3

TESTS FOR HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

Test	Description
Free Drop	A free drop of the specimen through a distance of 9 m (30 ft) onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected
Puncture	A free drop of the specimen through a distance of one m (40 in.) in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 15 cm (six in.) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (1/4 in.) and of a length as to cause maximum damage to the package, but not less than 20 cm (8 in.) long. The long axis of the bar must be vertical.
Thermal	Exposure of the whole specimen for not less than 30 min to a heat flux not less than that of a radiation environment of 800°C (1475°F) with an emissivity coefficient of at least 0.9. For purposes of calculation, the surface absorptivity must be either that value which the package may be expected to possess if exposed to a fire or 0.8, whichever is greater. In addition, when significant, convective heat input must be included on the basis of still, ambient air at 800°C (1475°F). Artificial cooling must not be applied after cessation of external heat input and any combustion of materials of construction must be allowed to proceed until it terminates naturally. The effects of solar radiation may be neglected prior to, during, and following the test.
Immersion--Fissile Material	For fissile material, in those cases where water inleakage has not been assumed for criticality analysis, the specimen must be immersed under a head of water of at least 0.9 m (three ft) for a period of not less than eight hours and in the attitude for which maximum leakage is expected.
Immersion--All Packages	A separate, undamaged specimen must be subjected to water pressure equivalent to immersion under a head of water of at least 15 m (50 ft) for a period of not less than eight hours. For test purposes, an external pressure of water of 147 kPa (21 psi) gauge is considered to meet these conditions.

DISTRIBUTION

No. of
Copies

187 U.S. Department of Energy
Office of Scientific & Technical Information
Oak Ridge, TN 37830
Attn: DOE/OSTI-4500-R74 UC-71

6 U.S. Department of Energy
Routing RW-30
1000 Independence Ave., SW
Washington, DC 20585
Attn: R. Stein
K. Klein
C. Kouts
W. Lake (3)

1 U.S. Department of Energy
Naval Reactors
Routing NE-60
Washington, DC 20585
Attn: R. Kulbitskas

4 U.S. Department of Energy
Attn: M. Heiskell
Routing DP-123
Washington, DC 20545
Attn: T. Hindman
L. Harmon
F. Falci
R. Garrison

2 Office of Security Evaluations
Defense Programs - DP-4, GTN
Washington, DC 20545
Attn: Dr. J. L. Torres
C. Mauck

2 U.S. Department of Energy
Albuquerque Operations Office
Albuquerque Headquarters
P.O. Box 5400
Albuquerque, NM 87115
Attn: J. E. Bickel
C. E. Garcia
K. G. Golliher

2 U.S. Department of Energy
Nevada Operations Office
P.O. Box 14100
Las Vegas, NV 89114-4100
Attn: E. L. Wilmot
W. Dixon

No. of
Copies

1 U.S. Department of Energy
Richland Operations Office
Post Office Box 550
Richland, WA 99352
Attn: J. Peterson

6 U.S. Department of Energy
Chicago Opertions Office
9800 S. Cass Avenue, Bldg. 350
Argonne, IL 60439
Attn: T. Haugen
J. Holm
S. Kouba
S. Mann
J. Roberts
R. Rothman

7 U.S. Department of Energy
Idaho Operations Office
550 Second Street
Idaho Falls, ID 83401
Attn: N. Burrell (2)
S. Hinschberger
W. Lattin
T. Rowland

1 U.S. Department of Energy
Oak Ridge Operations Office
P.O. Box E
Oak Ridge, TN 37831
Attn: M. Heiskell

3 Battelle Columbus Division
505 King Avenue
Columbus, OH 43201-2693
Attn: J. Allen
W. Pardue
R. Peterson

6 EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83145
Attn: I. Hall (4)
B. DaBell
W. Mings

1 Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
Attn: G. Popper

5 Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830
Attn: R. B. Pope
R. Rawl
T. Rowe
L. Shappert
R. Westfall

1 University of California
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550
Attn: L. E. Fisher

2 Battelle Pacific Northwest Laboratory
Battelle Boulevard
Richland, WA 99352
Attn: G. Beeman
J. Creer

1 Westinghouse Hanford Co.
Post Office Box 1970
Richland, WA 99352
Attn: J. D. Berger

2 Roy F. Weston, Inc.
995 L'Enfant Plaza SW
Washington, DC 20024
Attn: P. Bolton
E. Livingston-Behan

1 ANEFCO, Inc.
904 Ethan Allen Hwy
P.O. Box 433
Ridgefield, CT 06877
Attn: J. Murphy

1 Babcock and Wilcox
Nuclear Equipment Division
91 Stirling Avenue
Barberton, OH 44203
Attn: T. Stevens

1 Chem-Nuclear Systems, Inc.
220 Stoneridge Drive
Columbia, SC 29210
Attn: R. Anderson

1 Combustion Engineering
CE Power Systems
1000 Prospect Hill Road
Windsor, CT 06095
Attn: R. Ng

1 GA Technologies, Inc.
P.O. Box 85608
Building 2, Rm 644
San Diego, CA 92138
Attn: R. Burgoyne

1 Nuclear Assurance Corporation
6251 Crooked Creek Rd.
Norcross, GA 30092
Attn: C. Johnson

3 Nuclear Packaging, Inc.
1010 S. 336th, Suite 220
Federal Way, WA 98003
Attn: G. Quinn
J. R. Schornhorst
C. J. Temus

1 Transnuclear, Inc.
Two Skyline Drive
Hawthorne, NY 10532-2120
Attn: Bill R. Teer

1 Westinghouse Electric Corp.
Waste Technology Services Div.
Box 286
Madison, PA 15663-0286
Attn: C. Little

1 MITRE Corporation
Metrek Division
1820 Dolley Madison Boulevard
McClean, VA 22102
Attn: L. Ettlinger

1 Westinghouse Electric Corp.
Bettis Atomic Power Laboratory
Mail Stop 36E
Post Office Box 79
West Mifflin, PA 15122-0079
Attn: M. J. Schneider

1 Program Executive Office
Program Manager for
Chemical Demilitarization
Aberdeen Proving Ground, MD
21010-5401
Attn: A. McKinney

1 Science Applications International Corporation
Nevada Nuclear Waste Storage Investigations
Valley Bank Center
101 Convention Center Drive
Las Vegas, NV 89109
Attn: W. B. Andrews

1 Applied Science & Technology
16630 Sagewood Lane
Poway, CA 92064
Attn: R. E. Nickell

3 Bundesanstalt fur Materialforschung und Prufung (BAM)
Laboratory 1.52
Unter Den Eichen 87
1000 Berlin 45
FEDERAL REPUBLIC OF GERMANY
Attn: Burkhard Guenther (3)

1 Ontario Hydro
800 Kipling Avenue
Toronto, Ontario M8Z 5S4
CANADA
Attn: M. Adam Habayeb

2 Mr. Douglas Larson
Executive Director
Western Interstate Energy Board
3333 Quebec Street
Denver, CO 80207
Attn: L. E. Friel

1 Mr. Ken Nemeth, Executive Director
Southern States Energy Board
3091 Governors Lakes Drive
Suite 400
Norcross, GA 30071

1 Ms. Barbara Foster
National Conference of State Legislatures
Energy Science and Natural Resources
1050 17th Street, Suite 2100
Denver, CO 80265

1 Ms. Gail Chehak
National Congress of American Indians
804 D Street, NE
Washington, DC 20002

1 U.S. Council for Energy Awareness
1776 I Street, NW
Washington, DC 20006
Attn: J. Siegel

1 Edison Electric Institute
1111 19th Street, NW
Washington, DC 20036
Attn: J. Kearney

10 Electric Power Research Institute
P.O. Box 10412
3412 Hillview Avenue
Palo Alto, CA 94304
Attn: R. Lambert
R. Williams (9)

5 LeBoeuf, Lamb, Leiby, and McRae
1333 New Hampshire Avenue, NW
Washington, DC 20036
Attn: L. Trosten (5)

1 Utility Nuclear Waste Management Group
1111 19th Street, NW
Washington, DC 20036
Attn: J. Davis

3 JNT, Inc.
P.O. Box 1510
Los Gatos, CA 95031-1510
Attn: R. Jones

7 U.S. Nuclear Regulatory Commission
Office of Nuclear Materials
Safety and Safeguards
Washington, DC 20555
Attn: R. Chappell
A. Grella
R. Odegaarten
C. MacDonald
C. Marotta
J. Roberts
L. Rouse
E. Easton

2 U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555
Attn: D. Hopkins
W. Lahs

1 U.S. Department of Transportation
Federal Rail Administration
Office of Research and Development
400 7th Street, SW
Washington, DC 20590
Attn: C. Orth

1 U.S. Department of Transportation
Office of Materials Transportation
400 7th Street, SW
Washington, DC 20590
Attn: M. Wangler

1 Yankee Atomic Electric Co.
1617 Worcester Rd.
Framington, MA 01701
Attn: V. Pareto

1 Northern States Power Co.
414 Nicollet Mall
Minneapolis, MN 55401
Attn: L. McCarten

1 Wisconsin Electric Power Co.
231 West Michigan St.
Milwaukee, WI 53201
Attn: H. Shimon

1 Southern Company Services
P.O. Box 2625
Birmingham, AL 35202
Attn: K. Folk

2 Duke Power Co.
P.O. Box 33189
Charlotte, NC 28242
Attn: D. Frech
B. Rasmussen

1 Florida Power & Light Co.
P.O. Box 14000
Juno Beach, FL 33408
Attn: D. Brodnick

2 Virginia Power Co.
P.O. Box 2666
Richmond, VA 23261
Attn: J. Fisher
M. Smith

1 Southern California Edison Co.
2244 Walnut Grove Ave.
Rosemead, CA 91770
Attn: J. Ladesich

1 Parker Hannifin Corp.
O-Seal Division
10567 Jefferson Boulevard
Culver City, CA 90232
Attn: M. Murray

1 Helioflex Company
400 Myrtle Avenue
Boonton, NJ 07005
Attn: J. Simon

1	1513	D. W. Larson
1	1521	R. D. Krieg
1	1832	R. J. Salzbrenner
5	3141	S. A. Landenberger
3	3151	W. I. Klein
5	5165	J. M. Freedman
1	6000	D. L. Hartley
1	6300	R. W. Lynch
1	6320	J. E. Stiegler
1	6320	R. E. Luna, acting Attn: TTC Master File
50	6320	TTC Library
1	6321	M. G. Vannoni, acting
1	6322	G. C. Allen, Jr.
1	6322	N. N. Brown
1	6322	R. G. Eakes
1	6322	R. E. Glass
1	6322	D. L. Humphreys
1	6322	B. J. Joseph
1	6322	M. A. Kincy
1	6322	L. E. Romesberg
1	6322	K. B. Sorenson
10	6322	M. M. Warrant
1	6323	P. C. Bennett
1	6323	D. R. Bronowski
1	6323	M. M. Madsen
1	6323	J. D. Pierce
1	6323	T. L. Sanders
1	6323	W. L. Uncapher

1	6323	H. R. Yoshimura
1	6323	K. R. Edwards
1	6323	J. L. Moya
1	6323	D. R. Stenberg
1	6442	D. B. Clauss
15	6512	C. A. Ottinger
1	7241	W. B. Leisher
1	8524	J. A. Wackerly