Radioisotope Thermoelectric Generator Package O-Ring Seal Material Validation Testing

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Westinghouse
Hanford Company Richland, Washington

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**RADIOISOTOPE THERMOELECTRIC GENERATOR
PACKAGE O-RING SEAL MATERIAL VALIDATION TESTING**

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Abstract

The Radioisotope Thermoelectric Generator Package O-Ring Seal Material Validation Test was conducted to validate the use of the Butyl material as a primary seal throughout the required temperature range. Three tests were performed at (1) 233 K (-40 °F), (2) a specified operating temperature, and (3) 244 K (-20 °F) before returning to room temperature. Helium leak tests were performed at each test point to determine seal performance. The two major test objectives were to establish that butyl rubber material would maintain its integrity under various conditions and within specified parameters and to evaluate changes in material properties.

INTRODUCTION

The Radioisotope Thermoelectric Generator (RTG) packaging uses elastomeric O-rings for the primary containment boundary seals. The elastomer chosen for the RTG packaging is butyl rubber material procured through the Rainier Rubber Company located in Seattle, Washington. The Rainier Rubber Company designation for this material is RR0405-70.

The RR0405-70 material was tested extensively to develop a time/temperature operating envelope for use in the TRUPACT-II packaging. TRUPACT-II packaging is certified to be in compliance with the *Code of Federal Regulations* (10 CFR 71). The seal material in the RTG packaging is subjected to time/temperature conditions outside those tested for defining the TRUPACT-II operating envelope (WHC 1989a). This does not mean that the material is unacceptable for use in the RTG packaging, but that it must be test validated as acceptable for the operational time/temperature envelope of the RTG packaging conditions.

PURPOSE

This test was performed to validate an expanded time/temperature operating envelope of the RR0405-70 butyl rubber material (WHC 1993, 1994). This expanded envelope contains the predicted time/temperature conditions for the RTG packaging, including a margin of safety.

TEST PARAMETERS

The primary interest is in the ability of the elastomer seal to maintain the integrity of the containment boundary. A photograph of the test equipment is shown in Figure 1.

DISCUSSION OF COMPRESSION RANGES

When the O-ring is assembled into the fixture and the inner disc of the fixture is offset by the maximum amount, a condition of minimum compression will be obtained in part of the O-ring. The minimum compression on the O-ring will have a range that depends on the specimen and fixture measurements and is found as follows.

The test fixture has dimensions according to the test plan/procedure drawings are shown in Table 1. These are calculated values and will not be inspected. The inside diameter of the O-ring fixture groove includes a 0.05-mm run-out to the outside diameter of the inner disc.

FIGURE 1. Radioisotope Thermoelectric Generator O-Ring Test Setup.

TABLE 1. Test Fixture Dimensions.

Feature	Dimension (mm)	Sheet
Inside diameter of the outer fixture frame	323.545 ± 0.025	4
Outside diameter of the O-ring fixture groove	322.174 ± 0.025	5
Inside diameter of the O-ring fixture groove	308.762 ± 0.025	5

According to the *Parker O-Ring Handbook*, Figure A4-9, the cross section of the O-ring is reduced by 1.7 percent for a stretch of 2 to 3 percent (Parker 1992). The minimum cross section at room temperature is

$$(9.982 \text{ mm} - 0.178 \text{ mm}) * (25.4 \text{ mm} - 0.432 \text{ mm}) = 9.63 \text{ mm in cross section diameter. (1)}$$

The centered maximum space width for the O-ring is half the difference of the minimum inside diameter (ID) of the O-ring groove from the maximum outside fixture inside diameter, or

$$(323.545 \text{ mm} - 308.712 \text{ mm})/2 = 7.417 \text{ mm. (2)}$$

The fixture was offset by half the difference of the maximum ID of the outer frame diameter minus the minimum outside diameter (OD) of the inner O-ring fixture groove plus half the total run out, or

$$(323.545 \text{ mm} - 322.174 \text{ mm})/2 + 0.025 \text{ mm} = 0.711 \text{ mm; (3)}$$

therefore, the maximum offset condition space for the O-ring is

$$7.417 \text{ mm} + 0.711 \text{ mm} = 8.128 \text{ mm.} \quad (4)$$

The minimum offset side is

$$7.417 \text{ mm} - 0.711 \text{ mm} = 6.706 \text{ mm.} \quad (5)$$

The minimum possible squeeze using O-ring cross section is

$$(9.627 \text{ mm} - 8.128 \text{ mm})/9.627 \text{ mm} = 15.6\%. \quad (6)$$

The maximum side compression in the test fixture is

$$(9.627 \text{ mm} - 6.706 \text{ mm})/9.627 \text{ mm} = 30.3\%. \quad (7)$$

The minimum seal compression in the fixture is the value that results when the inner disc is offset by the maximum amount. This value demonstrates the sealing ability of the material at low compression and high temperatures. The test fixture is constructed of an outer fixture with a central hole in which a disc is located. Clearance exists between the outer fixture and inner disc such that when the disc is offset the O-ring is compressed more on one side than the other side. This value is known as the maximum-minimum or "max-min" compression. These dimensional values are derived from Table 1, Test Fixture Dimensions.

x = Minimum ID of the Outer Fixture Frame	323.494 mm
y = Maximum ID of Fixture Groove	308.762 mm
z = Maximum OD of Fixture Groove	322.224 mm
r = Maximum Radial Run-out, between Groove OD and ID	000.025 mm.

The corresponding space available for the O-ring to occupy is, therefore

$$\frac{(x-y) + (x-z)}{2} - r = 7.976 \text{ mm.} \quad (8)$$

The mounted O-ring cross section will be

$$D = (25.4 \text{ mm} - 0.432 \text{ mm})D_m \quad (9)$$

where D is minimum cross section as mounted, D_m is the free-state measured cross section. The largest value from any O-ring is used. The max-min compression is, then

$$C = \frac{(D - 7.976 \text{ mm})}{D} \quad (10)$$

The smallest space for the O-ring to occupy on the high-compression side of the fixture was found above to be 0.264. The maximum overall compression in the fixture is, then

$$C_{\max} = \frac{(D - 6.706 \text{ mm})}{D} \quad (11)$$

The O-ring, under these conditions of minimum compression, was tested at elevated temperatures for the times listed in Table 2 below. Two O-rings were used in the test fixture.

TABLE 2. Test Time/Temperature Ranges.

Test	Temperature K (°F)	Time	Number of Runs
1	477 (400)	8 h	1
2	463 (375)	24 h	2
3	450 (350)	168 h	2

TEST RESULTS

A summary of the seal test results is shown in Table 3. The seals were tested against a leakage acceptance criteria of 1×10^{-7} atm-cc/s, air (WHC 1989b). All seal tests were shown to be satisfactory and did not show any sign of failure through the test range.

TABLE 3. Summary of Test Results.

Test	O-Ring	Max-Min Comp. (%)	Max Comp. (%)	Test Temp. (K)	Hours at Temp.	Leak Rate (1×10^{-7} atm-cc/s, air) or Lower
1	1	17.7	30.7	477	8	yes
	2	17.5	30.5	477	8	yes
2	3	17.6	30.5	463	24	yes
	4	17.7	30.7	463	24	yes
3	5	17.7	30.7	463	24	yes
	6	17.7	30.7	463	24	yes
4	7	17.6	30.5	450	168	yes
	8	17.5	30.5	450	168	yes
5	9	17.5	30.5	450	168	yes
	10	17.5	30.5	450	168	yes

Seal leak-tightness also is demonstrated at the temperatures and durations shown in Table 3. Compression values ranged from as low as 17.5 percent to as high as 30.7 percent.

During the testing, minor changes in the durometer were noted, and the O-rings took a compression set. These material changes seemed to have little impact on the ability to maintain seal integrity through the range of temperature and time tested. Table 4 is a summary of compiled O-ring information from the test data.

TABLE 4. O-Ring Material Measurement Data.

O-Ring	Test	Measurement Sequence	Cross-Sectional Radial Dimension (mm)				Cross-Sectional Axial Dimension (mm)				Inside Diameter (mm)	Hardness Shore A (Durometer)	
			45°	135°	225°	315°	45°	135°	225°	315°			
1	1	Before	9.855	9.830	9.830	9.830	9.906	9.906	9.881	9.881	299.822	75	75
1	1	After	8.280	7.849	7.645	7.899	10.439	10.973	11.227	10.592	304.000	70	70
2	1	Before	9.804	9.830	9.830	9.830	9.804	9.830	9.830	9.830	299.822	75	75
2	1	After	7.950	8.509	8.357	7.772	10.973	10.490	10.947	10.922	304.241	68	68
3	2	Before	9.804	9.830	9.830	9.830	9.804	9.830	9.830	9.830	299.796	75	76
3	2	After	8.280	7.645	8.153	8.509	10.979	11.201	10.846	10.693	304.622	70	78

TABLE 4. O-Ring Material Measurement Data.

O-Ring	Test	Measurement Sequence	Cross-Sectional Radial Dimension (mm)				Cross-Sectional Axial Dimension (mm)				Inside Diameter (mm)	Hardness Shore A (Durometer)	
			45°	135°	225°	315°	45°	135°	225°	315°			
4	2	Before	9.855	9.830	9.830	9.830	9.855	9.830	9.855	9.830	300.126	75	75
4	2	After	8.306	7.874	7.696	8.306	10.541	11.278	10.947	10.262	304.775	70	73
5	3	Before	9.830	9.830	9.855	9.830	9.830	9.881	9.830	9.830	299.822	75	75
5	3	After	8.255	7.925	7.645	8.230	10.516	10.922	11.125	10.643	304.419	71	72
6	3	Before	9.855	9.855	9.855	9.855	9.855	9.855	9.855	9.855	299.898	75	75
6	3	After	7.798	7.696	8.331	8.280	11.201	11.125	10.465	10.617	303.403	73	73
7	4	Before	9.830	9.830	9.830	9.830	9.830	9.830	9.830	9.830	299.771	75	75
7	4	After	8.331	8.103	7.518	7.595	10.770	10.897	11.074	11.659	304.000	72	74
8	4	Before	9.830	9.830	9.830	9.830	9.830	9.855	9.830	9.830	299.796	75	74
8	4	After	8.280	7.976	7.417	7.950	10.947	11.236	11.532	11.684	307.848	72	72
9	5	Before	9.830	9.830	9.830	9.830	9.830	9.830	9.830	9.830	299.898	75	75
9	5	After	8.357	8.026	7.417	7.950	10.541	11.024	11.049	10.338	305.054	76	73
10	5	Before	9.830	9.830	9.830	9.830	9.830	9.830	9.830	9.830	299.822	75	75
10	5	After	7.849	7.341	7.823	8.306	11.049	10.312	10.668	10.439	304.978	75	75

FIGURE 2. Buytl O-Ring Operating Temperature Envelope.

CONCLUSIONS

The butyl O-ring material has shown to be satisfactory for use in the RTG Transportation System as long as the temperatures in the seal area are within the operating temperature envelope shown in Figure 2. Seal temperature requirements performed by analysis define the temperatures to be within that operating temperature envelope.

Acknowledgments

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