USED FUEL DISPOSITION CAMPAIGN

Preliminary Report: Effects of Irradiation and Thermal Exposure on Elastomeric Seals for Cask Transportation and Storage

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign

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EXECUTIVE SUMMARY

A testing and analysis approach to predict the sealing behavior of elastomeric seal materials in dry storage casks and evaluate their ability to maintain a seal under thermal and radiation exposure conditions of extended storage and beyond was developed, and initial tests have been conducted.

The initial tests evaluate the aging response of EPDM elastomer O-ring seals. The thermal and radiation exposure conditions of the CASTOR® V/21 casks were selected for testing as this cask design is of interest due to its widespread use, and close proximity of the seals to the fuel compared to other cask designs leading to a relatively high temperature and dose under storage conditions.

Samples of EPDM elastomeric seal material were exposed to thermal and irradiation conditions listed in Table 1 below. Additional exposure of the EPDM material is being performed.

Table 1. Initial Exposure Conditions for EPDM E0740-75 Seal Material

Set Name : Description	Radiation Conditions	Thermal Conditions
A: Exposure-to-Failure: Extremely High Temperature Only	None	Air at 350°F
B : Exposure-to-Failure: Cask Design Load Temperature (at O-ring location) with High Dose Rate Irradiation to Doses through Extended Storage	Exposure up to 100 Mrad - 240 kRad/hr	Air at 240°F

*A dose of 6 Mrad is the calculated integrated dose for a 100-year time at the gasket seal location in a CASTOR® V/21 cask at design cask spent fuel load conditions.

A novel test fixture was developed to enable compression stress relaxation measurements for the seal material at the thermal and radiation exposure conditions.[1] The compression stress relaxation results for the tested conditions are plotted below in Figure 1.

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[1] A primary parameter used to evaluate seal lifetime is compression stress relaxation (CSR), a common seal industry method. A modified CSR method was developed to enhance existing test capabilities, and to allow for irradiation of test samples without degrading CSR jig performance. A failure criterion of a 90% loss of sealing force (10% retained) was selected.

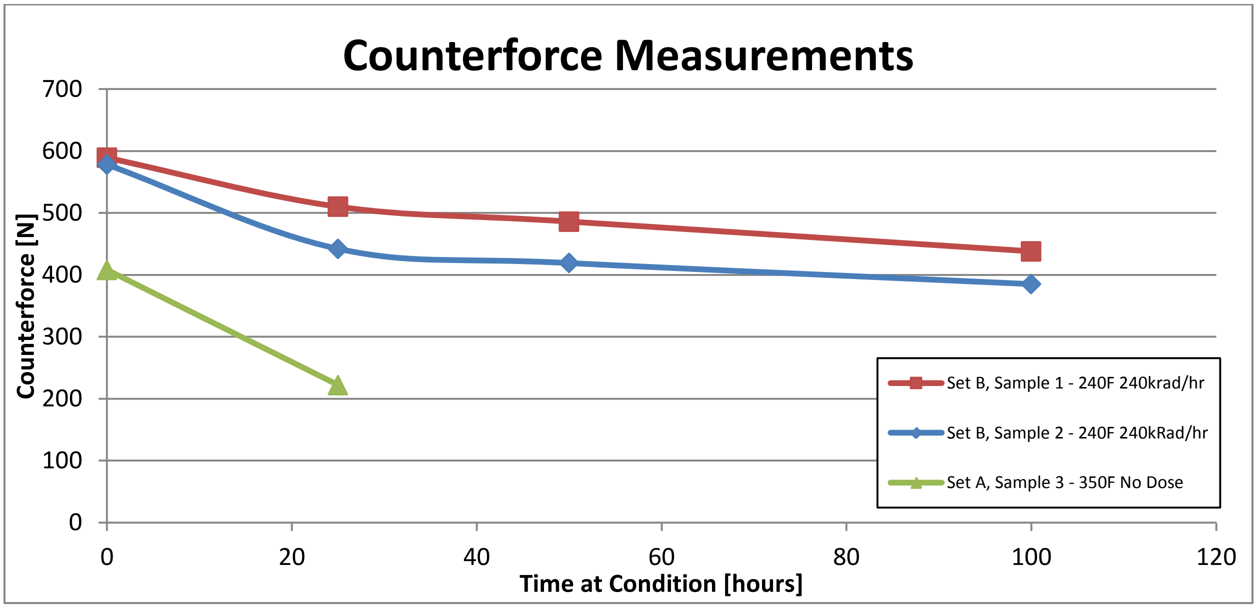


Figure 1. Sealing force decay (compression stress relaxation) of E740-75 EPDM seal material

A loss of compression stress of 90% is suggested as the threshold at which sealing ability of an elastomeric seal would be lost. Previous studies have shown this value to be conservative to actual leakage failure for most aging conditions. These initial results indicate that the seal would be expected to retain sealing ability throughout extended storage at the cask design conditions, though longer exposure times are needed to validate this assumption.

The high constant dose rate used in the testing is not prototypic of the decreasingly low dose rate that would occur under extended storage. The primary degradation mechanism of oxidation of polymeric compounds is highly dependent on temperature and time of exposure, and with radiation expected to exacerbate the oxidation.

Additional data will be developed in FY14 using this approach to allow an estimation of compression stress relaxation loss for time/temperature/dose/dose rate conditions. That information, and literature information on the expected corrosion of the bolts and metallic seals, will be compiled in a report to be issued later in FY14 to give an overall assessment of the bolted closure to maintain its seal function under extended storage and transportation conditions. Recommendations for an Aging Management Program for the bolted closure joint will be developed and reported to fulfill M3 milestone M3FT-14SR0805063, Degradation Evaluation and Aging Management of Bolted Closure Joints.

This report fulfills the M3 milestone M3FT-14SR0805062, Effects of Irradiation on Polymeric Seals.

1. Introduction

The components of a bolted closure joint (includes lids, bolting, metallic seals, and polymeric seals) of a dry storage cask are vulnerable to degradation under stressors of thermal and mechanical loads, and also radiation and corrosion conditions. The bolted closure joint provides a confinement function in a cask dry storage system. The bolted closure joint has been ranked as a high priority in the technical data gaps for extended storage and transportation [1].

Elastomer seals provide secondary seals in bolted closure joints in fuel dry storage casks and in dual-purpose storage and transportation casks. Their degradation and failure could possibly lead to exposure of the primary metallic seals and bolting to corrosive conditions. Thermal (thermo-oxidation) and radiation exposures cause polymeric breakdown [2], and although polymeric seals, as are the bolting, metallic seals, and polymeric seals in a bolted closure joint replaceable, it would be cost prohibitive as a routine maintenance item. Therefore, there is a motivation to identify the likely conditions at which a loss of sealing function may be expected under extended storage.

This report describes the development and initial application of a testing and analysis approach to evaluate the time/temperature/dose conditions at which a polymeric seal may lose its ability to provide a seal function. Initial testing with this approach has been performed for a specific elastomer seal compound, Parker Seals EPDM E740-75, as used in other cask designs [3]. This compound is currently being used as a surrogate for the specific EPDM compound in the CASTOR® V/21 cask, which is in process of being procured. Initial testing at temperature and gamma dose conditions at the location of the seal in the cask, relevant to extended dry storage, was completed and the results are reported herein.

Additional testing using this approach is underway to develop a data set with a mechanistically-based empirical model. The objective is to enable prediction for time/temperature/dose conditions for the EPDM material. This information, and literature information on the expected corrosion of the bolts and metallic seals, will be compiled in a report to be issued later in FY14 to give an overall assessment of the bolted closure to maintain its seal function under extended storage and transportation conditions. Recommendations for an Aging Management Program for the bolted closure joint will be developed.

2. CASTOR®/V21 Elastomeric Seals and Service Conditions

The general configuration of the bolted closure joint is shown in Figure 2 below.

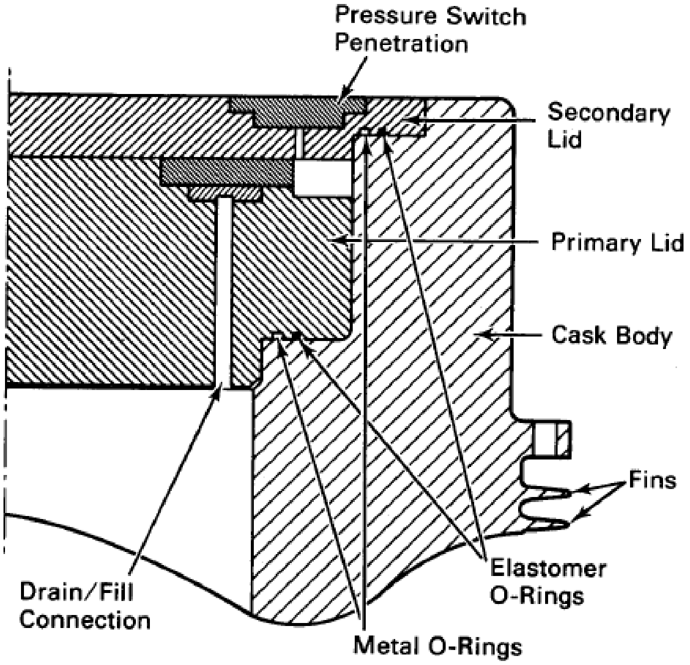


Figure 2 – CASTOR®–V/21 Cask Lid System

In Reference 4, the CASTOR® V/21 cask elastomer seals are described as 1580 mm (5.19 ft) outside diameter x 1560.2 mm (5. 12 ft) inside diameter x 9.9 mm (0.39 in.) cross section diameter, EPDM type 50049-2.2. supplied by the Helicoflex Company. Columbia, SC.

Reference 4 describes examination of these seals after 14 years of service. Due to size, the O-rings are fabricated with a 45 degree splice joint. The O-rings examined were still resilient with no evidence of embrittlement, stiffness, or depolymerization. Bending, pulling, twisting, and coiling the elastomer into a 30 cm (12 in.) diameter coil did not cause fracture or stress failure. The elastomer surface exhibited a satin matte sheen and was free of breaks, cuts, scratches, cracks, or craze defects. There was no evidence of oxidation or physical degradation of the elastomer. Remote camera and visual inspection revealed that the splice joint was slightly misaligned and partially open, suggestive that the elastomer adhesive did not completely fill the joint gaps in the joint. However, the joint retained good strength and could not be pulled apart manually.

The crushed dimensional configuration taken along a segment of the elastomer O-ring after removal suggests an average degree of compression of ~ 13%, assuming no elastic recovery before measurement, metal-to-metal contact (zero gap between mating surfaces) and an initial O-ring thickness of 0.39” (9.9 mm). The manufacturing tolerances and shrinkage factors for the specific O-ring compound are not known at this time. The actual degree of compression is dictated by actual O-ring part thickness, groove dimensions and relevant tolerances, and any gap that may exist between mating surfaces after O-ring installation. It is noted that for most static seals, compression of 15-30% is typically desired, with 25% used in most test standards for comparison unless otherwise specified [5-7]. Too little compression can lead to more extensive or rapid compression set, while higher compression values can overstress the elastomer. ID stretch is also an important factor, with minimal stretch values (<3-5%) preferred to minimize tensile stress on the elastomer after installation. The ID stretch for the CASTOR® V/21 seals has not yet been established, but is not believed to be excessive.

SRNL has made attempts to identify and obtain O-ring material of the same compound/thickness as specified in the CASTOR® V/21 cask. The description provided in Reference 4 is not sufficient for O-ring compound identification. For example, the 50049-2.2 appears to only indicate that the part meets DIN 50049-2.2, a German inspection standard for material testing and certificate types (now European Standard EN10204 or BSEN 10204). Helicoflex is now part of the Technetics Group. Helicoflex/Technetics personnel contacted by SRNL were not familiar with seals provided or specified for the CASTOR® V/21 cask.

SRNL also contacted Gesellschaft für Nuklear-Service mbH (GNS), manufacturer of the CASTOR® line of nuclear fuel/radioactive material shipping/storage casks, for details on the seal compound and its availability. GNS personnel (Dr. Romina Krieg, 0201/109-1320) indicated that the CASTOR® V/21 seal compound was provided by two seal manufacturers in Germany (Fa. Kempchen, a subsidiary of The Klinger Corporation, and Max Werth GmbH & Co. KG). Max Werth representatives have recently stated that their EPDM compound 804003 has previously been supplied to GNS for the CASTOR® V/21 seals and that O-rings of this compound can be procured. INL personnel were also contacted to determine details on the seal compound and availability, possibly of spare parts for test purposes.

The primary modes of degradation anticipated for elastomeric seals in spent fuel storage casks is thermo-oxidation in combination with radiation damage (chain scission, cross-linking), with the dominant mechanism possibly to vary depending on specific service conditions within a particular cask. In absence of chemical exposure. the most likely degradation mechanisms and behaviors to result in seal leakage include: antioxidant depletion, oxygen consumption/oxidation, compression stress-relaxation (CSR) and compression set.

Ethylene-propylene diene monomer (EPDM) compounds are known to be quite resistant to ozone and oxidation relative to some elastomers, but most formulations require antioxidants for long-term protection. Once antioxidants are consumed, degradation will likely occur at a faster rate. EPDM compounds are generally useful in the temperature range of -60 °F to 250-300 °F, depending on the service environment and specific compound However, it is important to recognize that “continuous” service temperatures as often indicated or quoted by seal manufacturers are typically based on limited data and relatively short time periods (1000 hrs). Therefore, such values should not necessarily be used to establish long-term service temperature limits. In some cask designs, the seals may see temperatures much closer to the service limit or design limit than in other designs.

2.1 Radiation Dose Estimation

The dose accumulation over time of a CASTOR® V/21 storage cask loaded with commercial PWR assemblies at the design conditions was evaluated to determine dosimetric test conditions. A fully loaded CASTOR® V/21 cask was modelled by the Monte Carlo transport code, MCNP. The model (Figure 3) was simulated to store its maximum allowable fuel loading as per the CASTOR® V/21 license requirements. This consists of 21 W17x17 assemblies burned to 23 GWD/MTU during three 550 day cycles allowing 30 days of cooling in between cycles. Additionally, the spent fuel was allowed to cool 5 years before being loaded into the cask.

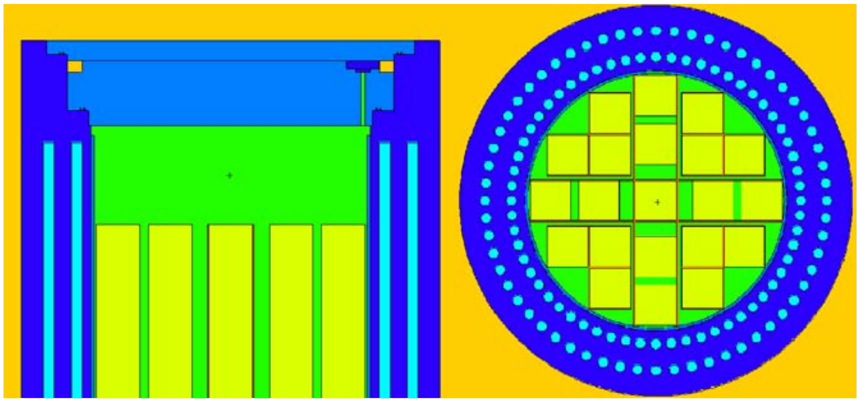


Figure 3. Model of CASTOR® V/21 Cask with 21 PWR Assemblies

Dose detector tallies were used in the MCNP model to determine gamma dose rates at the polymeric O-ring location in the primary lid. The dose rate was calculated at 5, 10 15, 30, 50, and 100 years after fuel discharge, and integrated over time to yield the total accumulated dose between 5 and 100 years after discharge. Note that the fuel is stored in spent fuel pools for the first 5 years after leaving the reactor. The absorbed dose rate profile estimated for the seals in a CASTOR® V/21 cask loaded as described is shown in Figure 4.

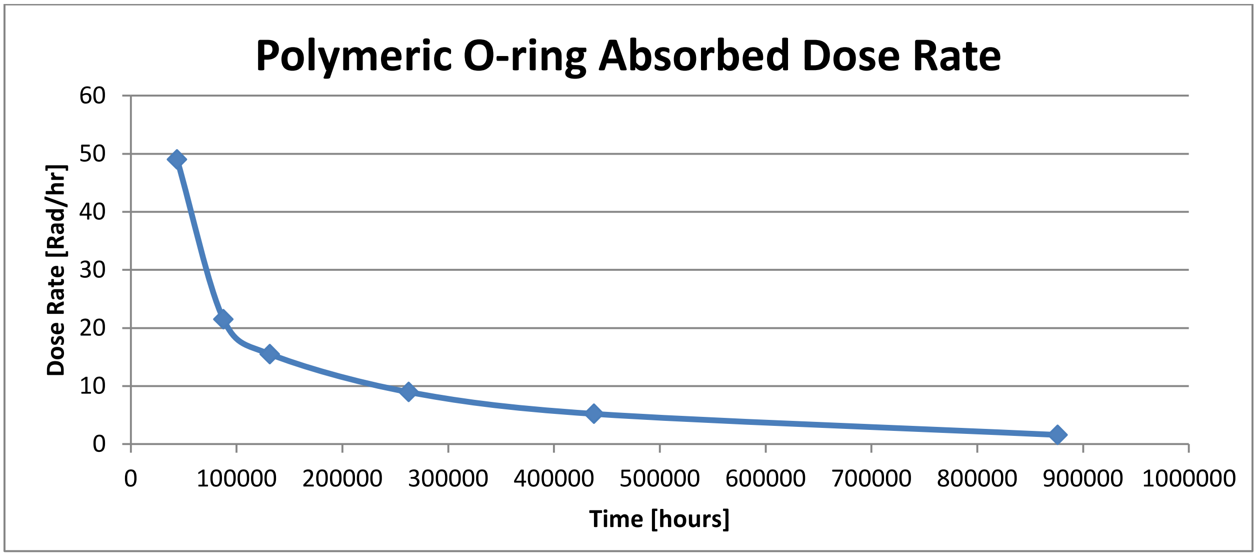


Figure 4. Dose Rate at Elastomeric Seal Location for CASTOR® V/21 Cask

The absorbed radiation dose profile for secondary elastomeric seals in the CASTOR® V/21 cask during the first 95 years of storage is a cumulative dose of 5.87×10^6 rad (5.87E+04 Gy or 58.7 kGy).

2.2 Estimation of Temperature

The aging temperatures chosen for polymeric testing conditions were based on reasonable assumptions and conclusions drawn from the CASTOR® V/21 opening & examination performed by Idaho National Laboratory and documented in NUREG/CR-6745. [4]. Thermocouple readings taken from various locations in the cask in 1985 and 1999 suggest that a freshly loaded cask may experience temperatures between 200°F and 250°F at the location of the primary lid elastomer seal. These values represent the initial inputs for the proposed test matrix thermal conditions.

A more rigorous evaluation of the O-ring temperature is currently underway to verify the thermal boundaries of this test plan. The thermal power of a fully loaded CASTOR® V/21 basket was estimated using SCALE6 to generate actinide and fission product inventory of 21 PWR assemblies burned to 23 GWD/MTU. This heat source term is being used to develop thermal models which can accurately predict temperature at specified locations as a function of time.

Basket Heat

Time Since Discharge	0 [years]			5 Yr	10 Yr		50 yr	100 yr
Cooling Time [Days]	1 [days]	100	1000	1825	3650	10000	18250	36500
Fission Products [Watts]	1.24E+06	1.69E+04	2.80E+03	1.47E+03	9.28E+02	5.61E+02	3.24E+02	9.81E+01
Actinides [Watts]	7.10E+04	1.43E+03	2.69E+02	2.49E+02	2.57E+02	2.64E+02	2.54E+02	2.20E+02
Total per MTU [Watts]	1.31E+06	1.83E+04	3.07E+03	1.72E+03	1.18E+03	8.26E+02	5.78E+02	3.18E+02
Total per Cask [Watts]	1.28E+07	1.79E+05	3.01E+04	1.69E+04	1.16E+04	8.10E+03	5.67E+03	3.12E+03
Total per m^3 [Watts]	3.03E+06	4.24E+04	7.10E+03	3.99E+03	2.74E+03	1.91E+03	1.34E+03	7.37E+02

3. Test Approach

There is no perfect substitute for real-time aging for predicting material performance. However, real-time aging is rarely practical for life prediction purposes unless failures can be observed within reasonable time periods (months to a few years). Therefore, accelerated-aging methods are commonly employed to develop aging models for service life prediction. However, no accelerated-aging methodology is perfect as all methods and parameters/metrics used to predict material performance have limitations and disadvantages.

One limitation is that the true parameter of interest for elastomeric seals (typically time to leakage, gas or liquid) can require extensive assemblies and fixturing to represent a particular design. The results (time to failure) for one design may or may not represent the time to failure of the same seal compound in another design. In addition, the failure criteria (leak rate) may vary from one component or design to another. The time to failure for a leak-tight (i.e. < 1E-07 cc/sec ref per ANSI N14.5) design may be far less than the time to reach a less stringent criteria. Another limitation is that the time to failure at meaningful or realistic test conditions can often require significantly long test periods. Some investigators have used time to leak failure as the only measure of seal performance [8-9]. While this approach has merit, the data are generally limited to leak failures at high temperatures with extensive extrapolations needed to estimate time to leakage at lower, more realistic temperatures.

The approach proposed and used in this preliminary report to evaluate seal performance is to use compression stress-relaxation (CSR) or sealing force decay. This approach is commonly used to evaluate seal performance in many industries including automotive, aerospace, chemical/petrochemical and nuclear power/radioactive waste and material transportation. While not as directly relevant as time to leakage, CSR testing allows direct comparison of seal behavior under a specific set of conditions. CSR data can be evaluated for various failure criteria (10% loss, 25% loss, 50% loss, etc.) and the collective data can be translated to any temperature of interest using time-temperature superposition principles, as long as the degradation mechanism remains constant across the extrapolation range (Arrhenius theory).

In absence of chemical exposure, CSR testing is relatively straightforward, exposing materials to different thermal/radiation conditions and monitoring sealing force decay over time until a failure point is reached. There are different CSR methods and devices used in the seal industry, each with advantages and limitations. Ideally, the failure parameter should be reached at 3-4 or more conditions to establish a failure prediction model. This approach has been used for life prediction of elastomeric seals in many applications, including critical seals such as nuclear weapon components and Pu storage containments [10-13].

No direct correlation has been established between CSR behavior and O-ring service life based on leak-tightness. While it is intuitive that a significantly reduced sealing force should correlate to an increased likelihood of leakage (especially for a dynamic application), very little data are available to indicate the actual sealing force needed to maintain leak-tightness. The criterion of 90% loss in initial sealing force has been adopted in some studies as a failure parameter [10-13], which should generally be a conservative limit for a relatively static seal such as the CASTOR® V/21 cask O-rings. Examples of this approach are given in Figures 5-6.

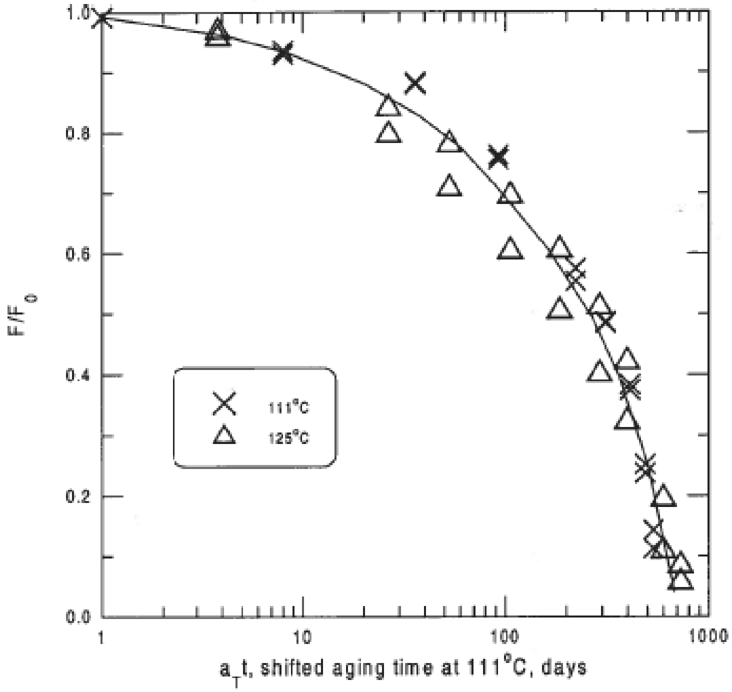


Figure 5 Time-temperature superposition of CSR data for EPDM O-rings [10]

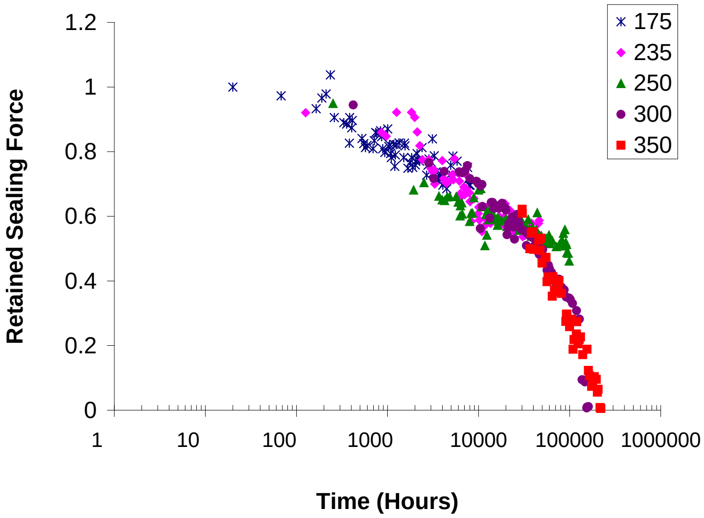


Figure 6. Time-temperature superposition of CSR data for 9975 shipping package O-rings [12]

The time-temperature superposition method shown above is based on the principle of determining shift factors that provide best agreement (either derived or empirically determined) for all CSR data at various temperatures to be combined into a master curve at a reference temperature (typically the lowest test temperature).

Each of the shift factors represents the relative difference in time scale between the average degradation rate at that temperature and the reference temperature. Together, they provide a means for extrapolating CSR behavior to other temperatures, assuming they follow an Arrhenius relationship as described by the equation:

$$t = A \exp(-E_a / RT)$$

where t = time to reach failure criterion
A = constant
E_a = activation energy
R = ideal gas constant, 8.3145 J/K-mol
T = absolute temperature (K)

When the shift factors are plotted on a log scale versus the inverse temperature (1/K), the slope of the plot gives the activation energy (Ea) of the degradation process as the slope * ideal gas constant (8.3145 J/K-mol) = activation energy (typically expressed in J/mol or kJ/mol. An example of this is shown in Figure 7.

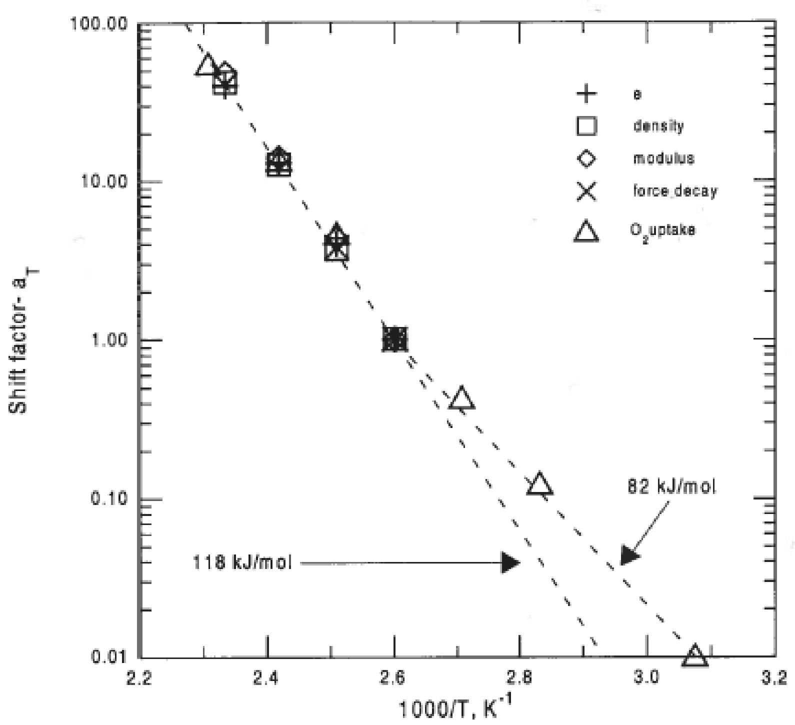


Figure 7. Shift factors for various degradation parameters for EPDM O-ring material vs. inverse temperature [10]. Non-Arrhenius aging behavior indicated by oxygen uptake data, below 110°C

If the shift factors provide reasonable alignment (single trend line), then the behavior can be considered to follow an Arrhenius relationship. However, if the best fit shift factors cannot be aligned or show a deviation, then it is possible (likely) that the aging behavior is non-Arrhenius, at least for part of the overall extrapolation range. It is sometimes the case that materials (polymers in particular) can show Arrhenius behavior over one range of temperatures (usually higher values) but non-Arrhenius aging behavior at lower temperatures. This is often attributed to diffusion-limited oxidation effects (possibly due to sample geometry), oxygen consumption or antioxidant depletion or other mechanisms [10-11]. Making life predictions assuming Arrhenius aging behavior over the complete extrapolation range can lead to overly optimistic and non-conservative lifetimes. Therefore it is important to determine the time to failure or end-of-life for as many temperatures as possible, preferably those as close to realistic service temperatures as possible within reasonable test periods.

A limitation of this approach is that very few investigators have attempted to determine the relationship between CSR and leak rate, which may vary with a given seal design. Reference 11 details an attempt to measure sealing force decay and leakage in the same device, using an insert compressed in the CSR jigs that could also be leak tested. The authors of Reference 11 concluded that the sealing force had to drop below ~1 N/cm before leakage became significant in that particular design. Though this was not proposed as a universal value, the value of 1 N/cm is generally much lower than 10% of initial sealing force in CSR studies.

The experimental test matrix was designed to evaluate seal responses to a variety of dose and temperature combinations which range from conservative representations of realistic conditions within a cask to absolute overkill. The conditions for each sample set may include irradiation at a prescribed dose rate, exposure to high temperatures or a combination of both. For each temperature considered, several accompanying dose rates will be applied simultaneously. The variations in these combinations should provide insight into the quantitative damaging effect of radiation on polymeric O-rings when compounded with extreme temperatures.

Additionally, the degradation consequences of radiation alone and its dependence on dose rate will be tested in ambient temperature. Similarly, several samples will experience high temperature with zero radiation exposure. These data will reveal whether the effects of radiation are additive or multiplicative with the oxidizing effect of extreme temperature. The proposed Test Matrix is displayed in Table 2**.** These conditions may be revised as data are obtained over time.

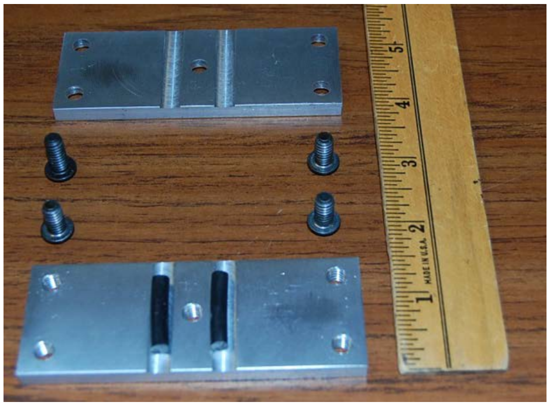
Table 2. Test Matrix for EPDM O-ring Aging Conditions (Radiation/Temperature)

Set Name : Description	Radiation Conditions	Thermal Conditions
A : Absolute Failure , Extremely High Temperature Only	None	350°F
B : Absolute Failure , Extremely High Dose Rate, High Temperature	100 Mrad - 240 kRad/hr	240°F
C : Absolute Failure , High Dose Rate, High Temperature	100 Mrad - 100 kRad/hr	240°F
D : Target Dose, High Temp, Low Dose Rate	6 MRad – 10 kRad/hr	240 °F
E : Target Temp , High Temperature Only	None	240°F
F : Absolute Failure , Extremely High Dose Rate, Med Temp	100 Mrad - 240 kRad/hr	200°F
G : Absolute Failure , High Dose Rate, Med Temp	100 Mrad - 100 kRad/hr	200°F
H : Target Dose, Med Temp, Low Dose Rate	6 MRad – 10 kRad/hr	200 °F
I : Target Temp , Med Temperature Only	None	200°F
J : Absolute Failure , Extremely High Dose Rate, Low Temperature	100 Mrad - 240 kRad/hr	100°F
K : Absolute Failure , High Dose Rate, Low Temperature	100 Mrad - 100 kRad/hr	100°F
L : Target Dose, Low Dose Rate, Low Temperature	6 MRad – 10 kRad/hr	100 °F
M : Target Dose, Extremely Low Dose Rate, Low Temperature	6 MRad – 1 kRad/hr	100 F

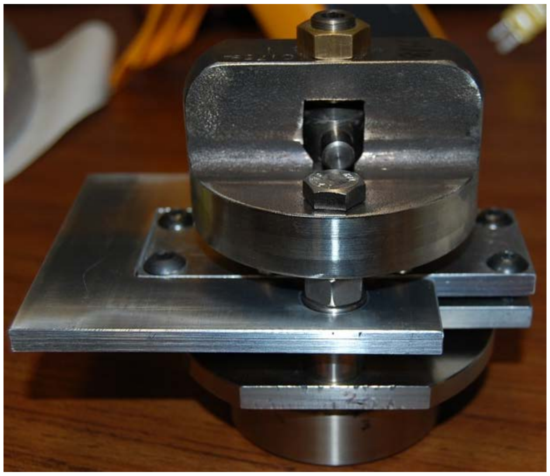
4.0 Compression Stress-Relaxation Test Modification and Results

Due to concern about radiation damage to the CSR jigs (Shawbury-Wallace type), a modified CSR approach was developed. This approach is believed to a first of its type. For thermal-only exposures, such modifications are not likely necessary, though could conceivably still be of benefit by limiting the number of CSR jigs that need to be procured (which can be expensive with procurement lead-times). Back-up or duplicate CSR jigs are still needed, but this approach minimizes the number of jigs that actually need to see thermal/radiation exposure conditions. The Shawbury-Wallace jigs are being used in this study as they are currently being used in other studies at SRNL and have been used in similar studies on critical components. Alternative CSR jigs and methods may be evaluated for future use, but were not considered or readily available for this study.

The modified CSR approach is shown in the following collective figures.

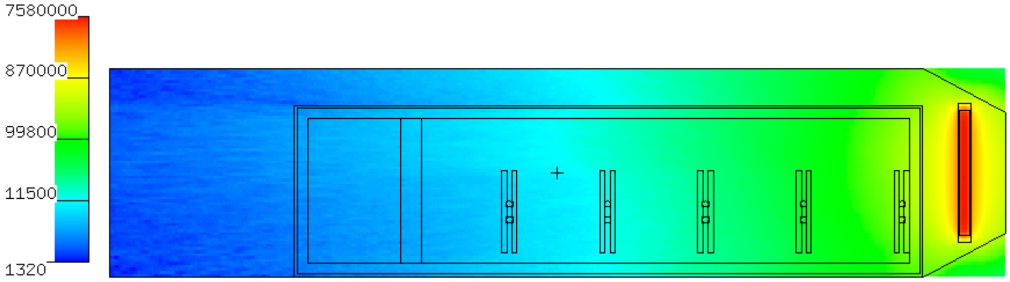


Counterforce measurements of tested O-ring segments are taken to determine loss of sealability. O-ring segments are initially appraised for dimensional and hardness values using a snap gauge and Durometer. Segments are then loaded into custom aluminum inserts designed to hold O-ring segments in place and under a constant compression of 25% during the tests.

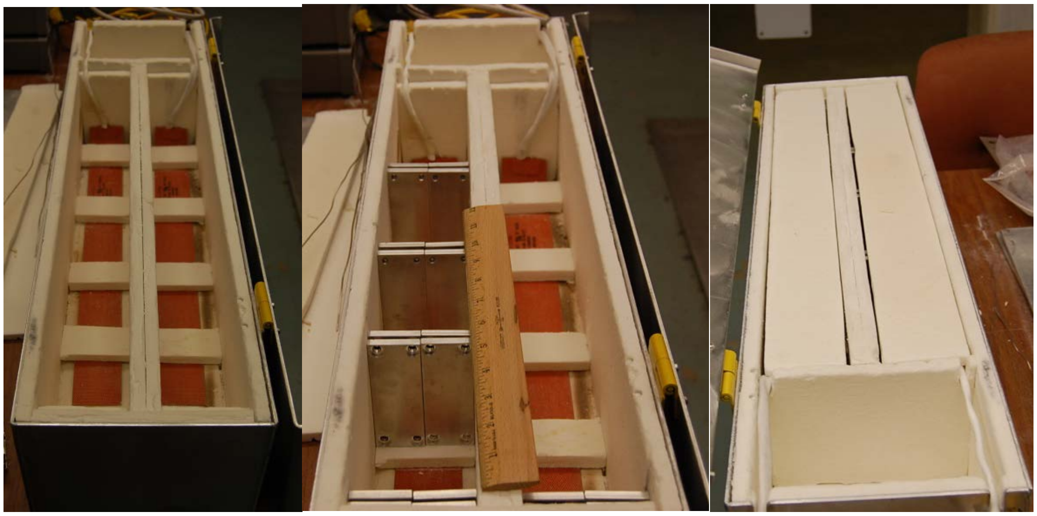


The counterforce measurements are made using a Wallace Mark IV relaxometer with Shawbury-Wallace C11 jigs per ASTM D6147. The jig is modified to accept an insert, allowing aging of the samples without compromising jig integrity. After cooling to room temperature, the aluminum inserts are placed in a CSR jig which is then loaded into the relaxometer to determine the force necessary to further compress the tested O-rings beyond 25%. This force is equal to the counterforce of the sample. The aluminum insert design ensures that the sample remains compressed while under irradiation and heat treatment while also assisting with consistent placement and loading of the CSR jig.

Irradiation is performed using the Model 484 Co-60 irradiator, capable of delivering 250,000 Rad/hr to a target within its expansive chamber. The chamber spans 8”W x 8”H x 40”L which allows users to obtain variable dose rates down to 1,000 Rad/hr by adjusting the target’s distance from the Co-60 sources. A dose map of the irradiation chamber has been developed to assist with placement of O-ring samples in order to obtain desired dose rates.



Because several of the sample sets require simultaneous irradiation and heating, an insulated portable chamber was built to house the samples during irradiation. This heated box uses two 200 Watt heat tape strips to bring the samples to the desired temperature while the box itself sits within the irradiation chamber. Several thermocouples are used to monitor the chamber and sample temperatures and control the heat tape output. The setup of the oven box is shown below.



Following intial baseline counterforce measurements, compressed samples are loaded into the oven box at specified locations corresponding to the dose rates outlined in the the test matrix. The heat tape controllers are set to respective temperatures and the box is closed and loaded into the irradiator. The time and duration of irradiation/heating is recorded for every test. Samples are periodically removed from the irradiator and allowed to cool in order to take CSR measurements at regular cumulative dose intervals. The measurements recorded to date are given in the next table.

Table 3. Compression Stress Relaxation Measurements for Test Sets A and B to Date

Set : B **Sample: 1** Dose Rate: 240,000 rad/hr

Temperature: 240 ˚F / 115 ˚C Anticipated Total Dose: N/A (Until Failure)

Measurement Number	Date	Unadjusted Counterforce			Average	Breakforce	Adjusted Counterforce	Cumulative Dose
		1st	2nd	3rd				
Baseline	5 / 20 / 14	601	592	589	586	5	581	None
1	5 / 22 / 14	522	512	508	514	4	510	6 Mrad
2	5 / 27 / 14	490	485	495	490	4	486	12 Mrad
3	5 / 29 / 14	439	448	438	442	4	438	18 Mrad

Set : B **Sample: 2** Dose Rate: 240,000 rad/hr

Temperature: 240 ˚F / 115 ˚C Anticipated Total Dose: N/A (Until Failure)

Measurement Number	Date	Unadjusted Counterforce			Average	Breakforce	Adjusted Counterforce	Cumulative Dose
		1st	2nd	3rd				
Baseline	5 / 20 / 14	574	595	579	583	5	578	None
1	5 / 22 / 14	448	447	443	446	4	442	6 Mrad
2	5 / 27 / 14	431	418	420	423	4	449	12 Mrad
3	5 / 29 / 14	396	393	377	389	4	385	18 Mrad

Set : A **Sample: 3** Dose Rate: None

Temperature: 350 ˚F / 177 ˚C Anticipated Total Dose: None

Measurement Number	Date	Unadjusted Counterforce			Average	Breakforce	Adjusted Counterforce	Time at Temperature
		1st	2nd	3rd				
Baseline	5 / 27 / 14	412	413	398	408	5	403	None
1	5 / 29 / 14	218	222	227	222	4	218	25 Hrs

4. References

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