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FOURTH INTERIM STATUS REPORT: MODEL 9975 PCV O-RING FIXTURE LONG-TERM LEAK PERFORMANCE

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Fourth Interim Status Report: Model 9975 PCV O-Ring Fixture Long-Term Leak Performance (U)

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Summary

A series of experiments to monitor the aging performance of Viton GLT O-rings used in the Model 9975 package has been ongoing for five years at the Savannah River National Laboratory. Sixty-two mock-ups of 9975 Primary Containment Vessels (PCVs) were assembled and heated to 200 or 300 ºF. They were leak-tested initially and have been tested at nominal six month intervals to determine if they meet the criterion of leaktightness defined in ANSI standard N14.5-97. To date, all of the original O-ring fixtures have maintained a leaktight seal at room temperature following up to three years exposure at temperature. It is expected that the actual 9975 O-rings in KAMS storage will maintain a leaktight seal for a significantly longer period of time than demonstrated by these fixtures, based on the less severe service conditions in KAMS.

An additional five mock-up fixtures were more recently assembled and exposed to higher temperatures (350 – 450 ºF) in an attempt to produce failures within the timeframe of this effort and to improve the predictive capability of the leak tests. Three of the five higher temperature fixtures have failed to remain leaktight. Predictive models being developed by SRNL compression stress relaxation tests will attempt to quantify the expected equivalent storage lifetime at actual storage conditions. The failure intervals from these fixtures will be considered in developing the overall confidence of these predictive models.

Background

This is an interim status report for experiments carried out per Task Technical Plan WSRC-TR-2003-00325, “TTQAP for Characterization and Surveillance of Model 9975 Package O-Rings and Celotex™ Materials [1]”, which is part of the comprehensive 9975 package surveillance program [2].

PCV test fixtures were assembled with Parker Seals V0835-75 (hereafter referred to as Viton GLT) O-rings and are being aged in environments that provide varying degrees of margin over KAMS storage conditions. Newer O-rings based on a Viton GLT-S formulation are the subject of separate efforts, and will be reported on separately. The purpose of these experiments is to characterize the performance of the Viton GLT O-ring seals, and then correlate the data to lifetime predictions of PCV and SCV O-ring seals in 9975 packages being stored in KAMS. O-ring performance in these tests is defined by leak-tightness.

The data from these fixtures are scoping in nature, although most of the controls under which they were collected are typical of baseline data. Accordingly, care should be used to assess the overall quality of the data prior to use in baseline applications. Within the 9975 surveillance program, these data will be used for information only, to compare to baseline data from other testing and build confidence in the overall predictions of O-ring seal service life.

Experimental Method

Test Matrix

A test matrix was developed to determine the importance and effect of several variables on the condition of the PCV O-rings over time inside the KAMS storage facility. The variables believed to be the most relevant to O-ring performance in storage were O-ring temperature, radiation/dose rate, O-ring lubrication, and internal PCV atmosphere. Two different dose rates were selected to evaluate potential dose rate effects. A total of 62 tests, with 22 separate sets of conditions were developed. Replicates of tests were developed based on a modified full-factorial statistical design. The test variables and the basis for variable selection are given in Table 1.

Several fixtures have been taken out of test since the initiation of the study. Eleven were removed from test based on leak test performance while at their conditioning temperature of 200 °F or 300 °F and they were disassembled and examined. Fourteen more were taken out of test after a power failure caused a temperature excursion severe enough to invalidate the tests. One additional fixture was removed from test in 2007 for reasons that were not documented. Fixtures that remain in test for each set of parameter values are summarized in Table 2.

In addition to the original test matrix, several fixtures (removed from test as noted above) were placed back into test with new O-rings. Fixture 62 was returned to service with new O-rings in June 2007, and designated 62-2007. After 20 days at 300 °F, it was removed from service for unknown reasons. In October 2008, 5 fixtures were dimensionally verified and returned to service with new O-rings for aging at temperatures ranging from 350 to 450 °F. These fixtures were intended to provide some O-ring failures in a shorter time frame to enhance the predictive value of the original test matrix. The predictive model assumes that the time to leakage at all temperatures is a function of a common mechanism. With the expectation that these would fail in a much shorter time than the original fixtures, they have been leak tested on a nominal 3 week frequency. All of these fixtures were assembled with the normal O-ring lubricant and contained no backfill gas (i.e. they remained filled with air). Three of them (one each at 350, 400 and 450 °F) were irradiated to 2E5 rad at a high dose rate.

Initial Assembly and Setup

The two-piece lid of the mock-up PCV, consisting of the cone seal nut and cone seal plug, was machined to be identical to the actual PCV lid. The body of the mock-up PCV was shortened to 3.5 inches from the original design of 18.6 inches and a threaded hole was machined in the bottom to provide a port for evacuating and filling the vessel with gas and for in-situ leak testing of the O-rings. A PCV test fixture with the O-rings installed in the lid is shown in Figure 1.

The mock-up PCV fixtures were assembled per the requirements described in the 9975 Safety Analysis Report for Packaging (SARP) [3]. After installation of the O-rings and assembly of the mock-up PCV test fixture, an initial leak test was performed while the fixture was at room temperature. If the fixture required irradiation, it was placed in a Co-60 gamma cell and irradiated at one of two dose rates to reach a total dose of 2E5 rad. This is equivalent to a ten year dose at the bounding dose rate expected for the PCV O-rings (2 rad/hr). The fixture was irradiated at either a "slow" dose rate of approximately 667 to 830 rad/hr or a faster rate of ~1.7E5 rad/hr. After irradiation, the fixture was leak tested again while at room temperature, filled with an air/CO_2 mixture if required per the test matrix, and heated to test temperature.

The vessels are heated with a flexible, wound-wire heater wrapped around the vessel circumference. Ceramic fiberboard and fiber batting are used to insulate the exposed ends of the fixtures. Stainless steel tubing is attached to the port on the top of the fixture lid via a high-pressure fitting and to the hole machined into the bottom of the PCV body. Both sets of tubing are capped until needed for leak testing. A thermal fuse was added to each heater to prevent excessive temperature excursions. The heaters are controlled by a desktop computer running LabView™ software, with feedback via a type-K thermocouple attached to the PCV body. The final assembled fixture is shown in Figure 2.

Initially, there was a plan to raise the temperature of the O-rings in some of the mock-up PCV fixtures to 400 °F for a half hour period to simulate what might occur during an accident after the O-rings had aged. 400 °F is the maximum allowable SCV/PCV O-ring temperature for short term conditions [4]. The excursions have been delayed as a result of the loss of several of the fixtures to disassembly and overheating. The objective of predicting lifetime at the specified conditioning temperatures currently takes precedence.

Fixture Leak Testing

The mock-up PCV O-ring fixtures are leak-tested after initial setup, after irradiation, and approximately every six months thereafter to the same leaktight criterion as the 9975 PCV and SCV. The outer O-rings of the 9975 PCV and SCV are credited with being leaktight while in transport and are credited with maintaining containment while in storage in the KAMS facility [3, 5].

A room temperature leakage rate of no more than 1E-7 ref·cc/sec air (2E-7 cc/sec He) demonstrates leaktightness when measured according to the requirements outlined in ANSI Standard N14.5-97 [6]. In addition to a room temperature leak test, the fixtures were initially tested at their conditioning temperature as well. While not required by ANSI N14.5-97, the elevated temperature leak tests were intended to show whether additional margin to leakage exists at storage temperatures. However, these additional tests were dropped due to difficulties in obtaining repeatable, valid results.

Leak testing is conducted using a helium mass spectrometer leak detector of the same make and model as that currently used in annual certification testing of the 9975 PCV and SCV, although the method used has been adapted to the O-ring fixtures. A Gas Filled Envelope Test, as defined in ANSI N14.5-97 Section A.5.3 is used for the mock-up PCV fixtures. Both O-rings are tested simultaneously, with failure of either O-ring causing a failure of the test. Although this approach differs from annual certification testing, it gives results that are valid and comparable [6], and accommodates the difference in set up of the actual PCV and SCV and the mock-up PCV fixture. If a leak is found, it is possible to determine which O-ring is leaking by re-directing the helium to either the fixture body or the closure weep hole, rather than to both at the same time.

The O-ring fixture leak test program was reviewed in December 2008, prompting reconsideration of the methodology used for leak testing the mock-up PCV fixtures. One important change was made in the conduct of the leak test, as well as minor changes in the data analysis used to correct the measured leak rates. These changes are described in Reference [7].

Previously, the leak rate was recorded after 3 minutes exposure to helium, and the leak test was terminated. This duration is sufficient to identify true leakage while avoiding helium saturation of the O-rings and decreasing leak test productivity. Based on Reference 7, the tests have been extended beyond a 3 minute duration until an increase in helium concentration is recorded by the detector, indicating helium has permeated through the O-rings. Typically, the test will be extended for up to 30 minutes, although permeation is often seen within 15 minutes. Observing a permeation signal for each test provides positive evidence that the fixture and test setup are capable of transmitting a helium signal (i.e. no part of the flow path is blocked), and that helium was actually introduced into the fixture. This satisfies ANSI N14.5, Section 8.1 requirements such that leakage rate tests shall be designed to preclude false acceptance; this includes assuring the presence of a tracer gas and a driving pressure.

Results

Sixty-eight mock-up PCVs have been assembled and aged, including conditions of temperature, irradiation, and internal gas atmosphere. To date, all of the initial 62 O-ring fixtures have satisfied the leaktight criterion by passing helium leak tests at room temperature. There are 36 of these original O-ring fixtures left in test and they have been at temperature for 26 to 38 months, with the exception of two fixtures that have not yet reached 2 years. Three of the recently added high temperature fixtures have aged to the point that they failed to pass a room temperature leak test, and have been removed from service. In the 450 °F fixture, the first O-ring failed the leak test after 8 days at temperature. In the two 400 °F fixtures, O-ring failure was noted after 28 and 45 days at temperature. The two high temperature fixtures aging at 350 °F remain leaktight after 4 months. Note that 400 °F is the upper "continuous" service temperature often quoted for the O-rings, typically based on 1000 hours (42 days) exposure.

Eleven of the original 62 fixtures were disassembled in 2006 and 2007 and examined following difficulties with leak testing at elevated conditioning temperature of 200 °F (one) or 300 °F (ten). Note that all 11 of these fixtures were leaktight at room temperature prior to removal from testing. In 2007, fourteen additional fixtures were taken out of test after a computer controller failure resulted in a temperature excursion severe enough to invalidate the tests. Later in 2007, 1 additional fixture (28) was removed from service for unknown reasons. Twenty fixtures remain in test at 200 ºF and sixteen at 300 ºF. During 2007, fixture 62 (removed from service previously) was placed back into service with new O-rings. It operated for about six months, to compare the effect of heating from the strip heaters vs heating in an oven.

Table 3 contains room-temperature leak rate data for all the tests. These data are also summarized in Figure 3. None of the fixtures conditioning at 350 °F or less have failed to pass a room temperature leak test. The two O-rings in the one fixture conditioning at 450 ºF failed the room temperature leak test after 8 and 12 days at temperature, respectively. Both O-rings in one fixture conditioning at 400 °F failed the room temperature leak test after 27 days at temperature, and both O-rings in the second fixture conditioning at 400 °F failed the room temperature leak test after 45 days at temperature.

The fixture temperatures are controlled and documented by computer, which supplies power to each fixture rack location to establish and maintain the programmed temperature setpoint for that fixture. Over the course of this task, some of the fixtures have been moved from one rack location to another. This has been done in part to bypass hardware problems that arose with specific test locations. In addition, following removal of some fixtures from service, some of the remaining fixtures were moved to rack locations that were easier to access for leak testing. As a result, the computer data files do not accurately attribute all temperature data to the appropriate fixture. The available documentation and data files have been reviewed, and the history of fixture movements has been reconstructed to the extent practical. The history of each fixture, including the leak test schedule, is provided in Appendix 1. One observation from this history and reconstruction effort is that the leak test frequency for some fixtures deviates from the nominal interval (e.g. 6 months or 3 weeks). The actual intervals for each leak test are indicated in Table 3.

Eleven O-ring fixtures were disassembled after failing a high-temperature leak test. Examination of these was summarized in previous reports [8 - 10].

Fourteen fixtures were taken out of test after a computer controller failure resulted in a temperature excursion. Computer communication with the heaters was lost for a period of two hours, with the result that fourteen fixtures overheated and their thermal fuses melted. During that period, the maximum temperature recorded for each of these fixtures ranged from 342 to 768 ºF. With the temperature recorded at 30 minute intervals, actual peak temperatures could have greatly exceeded the recorded values. Most of the overheated fixtures were opened and the O-rings discarded without examination. Four of them (16, 23, 24 and 34) were disassembled in September 2008. Fixtures 28 and 62-2007 were also disassembled, and their O-rings examined in September 2008. The following observations were made at that time.

- Fixtures 16 and 24: no findings
- Fixture 23: lots of excess grease on / around O-rings
- Fixture 34: significant amount of O-ring material extruded out of grooves, brown (grease) residue on bottom of plug. O-ring residue adhering to body and plug surfaces. See Figures 4 and 5.
- Fixtures 28 and 62-2007: small white specks on the O-rings

The three fixtures conditioning at 400 and 450 °F were disassembled in January – February 2009 after failing the room temperature leak test. For each fixture, both O-rings were verified to have failed to maintain leak-tightness. The following observations were made during disassembly:

- The O-rings were stuck to the body and/or plug to varying degrees in each fixture.
- The body and plug retained black deposits from the O-rings to varying degrees in each fixture.
- White and brown deposits were observed on the metal and O-rings for each fixture, indicative of oxidized grease.

- One O-ring from fixture 21D (400 °F) had minor scuff marks in one spot.
- Both O-rings from fixture 23D (450 °F) were more squared than round after removal. The lower O-ring had regions of “raised” brown stain (baked grease) and a small bump on the OD surface. The upper O-ring had a more uniform layer of baked grease mainly on the OD.

All of the O-rings removed during these examinations received dimensional and hardness measurements. Average hardness readings for each O-ring varied from 74 to 78 Durometer M. The hardness of new O-rings is specified as 75 +/- 5 Durometer A. In a few areas where an O-ring was twisted, individual readings varied significantly beyond this range. While there is no exact conversion between the A and M scales, they are generally very similar in value. Therefore, these O-rings do not show any significant degradation in hardness.

The dimensional measurements were used to calculate compression set. The measurements were taken at different times following removal of the O-rings, but generally fall into 2 time intervals. Measurements were taken either within 4 hours of removal, or at least 9 days after removal, with some O-rings being measured during both time intervals. Some O-rings were measured multiple times (at less than 4 hours and after 9 days or more). Of these, most of the relaxation that was seen occurred prior to the first longer-term measurement (around 10 days). Compression set results are summarized in Table 4 and Figure 6.

A number of the fixtures removed from service were dimensionally checked to verify compliance with drawing requirements (this had not been done on all fixtures initially). Only fixtures that met all critical drawing dimension requirements (or could be re-machined to meet requirements) were selected for the additional high temperature fixtures. Results from the dimensional checks are documented in References 11 and 12, and are summarized in Table 5. In some cases, such as dimensions and surface finish of the O-ring grooves, the observed deviations could have had some impact on O-ring performance.

Discussion

With the most recent set of leak tests, each fixture was tested for permeation. In cases where no permeation was seen, the fixture was re-tested. Permeation results are summarized in Table 6. Permeation was eventually seen in all but 4 fixtures. There is considerable variation in the time to permeate among the fixtures, and among multiple trials for the same fixture. Some tests permeated in as little as 5 minutes, while other tests showed no permeation for 60 minutes. There is no apparent trend in this variation. Reasons for the variation are unknown, although limited testing has shown that the amount of vacuum grease on the O-ring can affect permeation performance [7]. It was observed that the detector background was somewhat higher than normal during many of these tests due to degradation of the vacuum pump seals. After steps were taken to improve the detector background, permeation was seen in a greater percentage of tests. However, this step alone did not show permeation in all fixtures.

Extending the leak test to demonstrate a permeation signal provides two functions; it demonstrates an open flow path from the fixture to the detector, and that helium was actually introduced to the fixture. Based on the permeation results to date, an open flow path has been demonstrated for all but 4 fixtures. These 4 fixtures will be tested similarly in the future until they show permeation or until they fail. If they fail before showing permeation, their validity will be assessed based on all available data. The remaining fixtures have shown an open flow path for permeation. In general, they will not be tested to permeation in future leak tests. The test method provides sufficient assurance that helium is provided to each fixture since the bag around the fixture is seen to inflate with helium after it is evacuated.

Reference 7 recommended several corrections to the measured leak rates. These include:
- The leak detector correction factor should be 1.
- The helium concentration correction factor should be 1.3.
- The leak standard reference temperature correction factor should be 1.1.
- These 3 factors lead to an overall correction factor of 1.4.

Leak tests performed by the High Pressure Lab (HPL) are adjusted in accordance with the standard assumptions built into their analysis software. This includes a greater overall correction factor, giving a conservative result. The HPL analysis software did not include the leak standard reference temperature correction factor prior to November 2006 [13]. Therefore, all HPL results from prior to November 2006 have been adjusted from previously reported values to include this factor. Leak tests performed by MS&T have been adjusted to include all the above factors. MS&T data that has been reported in previous status reports have been re-analyzed with these correction factors, and the new values are included in this report.

For those fixtures with multiple O-ring measurements following removal (to provide multiple compression set results), the compression set results follow either of 2 general trends. For the 3 high temperature fixtures and fixture 47, the compression set values remain roughly constant from the initial measurement within 4 hours of removal through the latest measurements a month or more after removal. In contrast, the other fixtures with multiple results show a distinct decrease in compression set from the initial 4 hour period in subsequent measurements. It might be postulated that the extended exposure to 400 ºF and higher led to material degradation such that the high temperature fixture O-rings were no longer capable of stress relaxation (and therefore recovery of compression set). However, this explanation would not explain why fixture 47 also displays this constant compression set behavior.

In contrast, fixture 34 experienced the greatest short-term overheating excursion of the fixtures that were examined (reaching at least 721 ºF), although it's O-rings were able to relax an appreciable amount during the 10 days following removal. The short-term compression set values for this fixture of approximately 120% are explained by the fact that some O-ring material was ejected from the grooves. After cooling, the remaining O-ring material was not sufficient to fill the normal groove depth. Because of the lost material, the actual compression set is less than indicated by the calculation based on the original O-ring thickness.

Compression set data for the eleven fixtures which were disassembled based on their leak test results at elevated temperature were presented previously [10]. O-rings from five of these fixtures were measured within an hour of removal, O-rings from another five were measured approximately 1 month after removal, and the O-rings from the eleventh (fixture 47) were measured in both time frames. The compression set values were higher for the earlier set of measurements than for the delayed set of measurements, as would be expected. However, specific changes over time can only be described for fixture 47, which showed relatively little change in compression set.

The previous status report [10] compared the compression set observed from the O-ring fixtures with that from O-rings removed during field surveillance activities in KAMS. It cited compression set values of less than 11% based on measurements within 30 minutes of removal. However, these compression set values were not calculated in the same manner as the values cited for the O-ring fixtures. Specifically, compression set values for the O-ring fixtures have been calculated as follows:

$$\text{Comp Set} = (\text{final } t_r - \text{initial } t_r) / (\text{initial } t_r - \text{average O-ring groove depth}) * 100$$
with t_r = radial O-ring thickness

In contrast, compression set values for the field surveillance O-rings were calculated as follows:

$$\text{Comp Set} = (\text{final } t_r - \text{initial } t_r) / (\text{initial } t_r) * 100$$
with t_r = radial O-ring thickness

In both cases, where an initial O-ring thickness is not known, a nominal value of 0.139 inch is assumed. The benefit of using the first equation is that it will give a compression set of 100% for an O-ring with no recovery after removal. The second equation will give a compression set of 28% for the same case, which does not convey the extent of physical degradation of the O-ring.

If the compression set values for the field surveillance O-rings were calculated with the first equation, the resulting values would be increased by a factor of approximately 3.5. A sample of 15 surveillance packages were reviewed, and the compression set calculated (with the first equation) from the measurements made within 30 minutes of removal. Individual compression set values ranged from 12 to 42%, with an average of 30%. Though higher than 11%, this is still considered a highly tolerable value for a robust, static seal design. The average value is a more meaningful result to consider, since the individual measurements include the uncertainty introduced by assuming a nominal initial thickness. With a large enough population, this uncertainty will tend to cancel out for the average.

Most of the fixtures removed from service were measured to verify critical dimensions. In many cases, one or more dimensions were found to not meet drawing requirements. Some of these deviations are not judged to significantly impact leak-tightness of the O-ring seal. For example, the test port cone angle on the plug (the sole deviation noted for 6 plugs) has no impact on the O-rings. Minor deviations of the body or plug taper angle will affect slightly the degree of compression of the O-ring, but would not otherwise alter its capability to seal. On the other hand, deviations such as surface finish could have a significant impact on the O-ring seal. Intermediate to these examples, conditions such as variation in the O-ring groove width or depth may change the degree of compression of the O-ring enough to affect its long-term performance.

To gain perspective on the dimensional deviations observed in the fixtures, several containment vessels were also checked by the same QC lab and personnel. This included 4 secondary and 1 primary containment vessels that had seen prior service. Three of these five vessels also had dimensional deviations, including O-ring groove width and plug diameter at the bottom of the taper. Although the rate of deviations in this limited sampling is less than seen in the fixtures, it indicates that the conditions observed in the fixtures are not inconsistent with containment vessels in service. A larger population may show a different deviation rate. While the results from the O-ring fixtures might be influenced to some extent by these conditions, they are consistent with the influences that could also be present in packages within KAMS.

Conclusions

To date, all O-ring fixtures conditioning at 200 and 300 ºF have maintained a leaktight seal at room temperature following up to 3 years at temperature. Fixtures at 350 ºF are leaktight after aging for 4 months. Three QC-verified fixtures conditioning at 400 or 450 ºF have reached a failure condition within 45 days and did not maintain a leaktight seal at room temperature. The actual onset of failure is unknown. Failure within shorter periods at higher aging temperatures is not unexpected. These extended high temperature exposures bound the worst case fire exposure in KAMS, which is postulated to complete in less than one day. It is expected that the actual 9975 O-rings in storage will maintain a seal for a significantly longer period of time than any of the O-ring fixture tests because they have not been at bounding conditions (e.g. 200 ºF or higher) for a significant period of time, if at all. Predictive models being developed by SRNL from compression stress relaxation data will attempt to quantify the equivalent storage lifetime period at lower temperatures. The observation of failures for fixtures conditioning at the higher temperatures will provide a point of comparison for these models.

These results apply to 9975 O-rings based on a Viton GLT formulation. Newer O-rings based on a Viton GLT-S formulation are the subject of separate efforts, and will be reported on separately. Periodic leak testing will continue for the 38 remaining fixtures. Leak testing will be carried out with the fixtures at room temperature only, as allowed by the ANSI Standard that defines leaktightness.

References

[1] WSRC-TR-2003-00325, Rev. 4, "Task Technical and Quality Assurance Plan for Characterization and Surveillance of Model 9975 Package O-Rings and Celotex® Materials (U)", January 2009.

[2] WSRC-TR-2001-0286, Rev. 4, "SRS Surveillance Program for Storage of Pu Material in KAMS", July 2008.

[3] WSRC-SA-2002-00008, Rev. 0, "Safety Analysis Report for Packaging – Model 9975", December 2003.

[4] S-CLC-K-00198, Rev. 0, "KAMS 9975 Shipping Package Thermal Sensitivity Analysis", S. Chow, October 2004.

[5] L9.4-10500, Rev. 2, "Annual Maintenance and Leak Testing for the 9975 Shipping Package," Instrumentation and Equipment Systems Section, SRNL, August 29, 2007.

[6] ANSI Standard N14.5-97, "American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment", American National Standards Institute, New York, NY, February 1998.

[7] SRNL-L1400-2008-00038, "Characterization of Leak Test System for O-Ring Studies", D. J. Trapp, December 18, 2008.

[8] WSRC-TR-2006-00443, "Examination of O-rings from Mock 9975 Primary Containment Vessels (PCVs)," E. B. Fox et al., February 2007.

[9] WSRC-TR-2007-00073, "Second Interim Status Report: Model 9975 PCV O-Ring Long-Term Leak Performance", K. M. Counts, E. B. Fox and T. E. Skidmore, June 2007.

[10] WSRC-TR-2007-00497, "Third Interim Status Report: Model 9975 PCV O-Ring Long-Term Leak Performance", K. M. Counts, T. E. Skidmore and E. B. Fox, February 2008.

[11] 2008-IR-33-7053, "PCV Cone Seal Plug and Body Weldments", D. B. Hudson, September 4, 2008.

[12] 2008-IR-33-7060, "PCV Cone Seal Plug and Body Weldments", D. B. Hudson, October 28, 2008.

[13] SRNL-IES-2006-00100, "Temperature Correction for Helium Standard Leaks Prepared by SRS Analytical Labs", D. J. Trapp, November 15, 2006.

[14] SRNS-TR-2008-00290, Rev. 0, "Summary and Matrix 9975 Shipping Package Qualification Program for Extended Storage of Plutonium in the K Area Complex", J. A. Radder, Savannah River Nuclear Solutions, Aiken, SC, November 2008.

[15] M-CLC-K-00729, Rev. 0, "Thermal Analysis of the 9975 Package with Softwood-Based Fiberboard during KAMS Facility Fire", N. K. Gupta, June 11, 2008, and
M-CLC-K-00727, Rev. 0, "Thermal Model Study for the 9975 Package in KAMS during Facility Fire", N. K. Gupta and D. Tamburello, June 11, 2008

Table 1. Test Matrix Variables for O-Ring Experiment

Test Variable	Values Tested	Basis for Values Tested
Temperature	200 °F (93 °C)	With loss of ventilation in the KAMS facility, the maximum ambient temperature is 137 °F [14], and the corresponding PCV O-ring temperature is 199 °F [15].
	300 °F (149 °C)	The maximum allowable temperature for the PCV O-rings for continuous operation is 300 °F [4].
	350, 400, 450 °F (177, 204, 232 °C)	Elevated temperatures added to increase the likelihood of seeing O-ring failures in a timely manner.
Radiation Dose	2E5 Rad in 72 min	The bounding dose rate for the PCV is 2 rad/hr. A total dose of 2E5 rad represents ten years of storage.
	2E5 Rad in >200hr	Longer-term exposure may reveal the added effect of diffusion-limited oxidation (DLO) that only occurs with long-term exposure.
	None	Many packages will have little radiation exposure. This also serves as an experimental control.
Internal Atmosphere	75% CO_2 with a balance of Air	The free volume of the PCV is filled/diluted with CO_2 as a cover gas. A small portion of the air originally in the vessels may remain.
	Air	It supplies comparative data and acts as a control.
O-Ring Lubrication	Silicone high-vacuum grease	It is specified in assembly of the 9975 package [3].
	Krytox® 240AC	It has been used on 9975 O-rings at DOE facilities. It is used on lid components of the 9975 PCV and SCV [3].
	None	It supplies comparative control data. Also, it is possible that the O-rings may be mistakenly installed without grease.

Table 2. Summary of test parameters for fixtures remaining in test

Test Parameters					Fixtures Still in Test	Fixtures No Longer in Test
Temp. °F	**Gamma Dose**	**Dose Rate**	**Environ-ment**	**O-Ring Lubricant**		
200	~2E5 rad	High	CO_2	Normal	5, 6, 36, 40, 41, 53, 54	15, 23, 24
200	~2E5 rad	Low	CO_2	Normal	10	
200	~2E5 rad	High	Air	Normal	9, 27, 37, 42, 55	16
200	~2E5 rad	Low	Air	Normal	11	
200	no		CO_2	Normal	3, 43, 56	28
200	no		Air	Normal	1, 44, 57	13, 29
300	~2E5 rad	High	CO_2	Normal	7, 8, 26, 51	17, 22, 25, 39, 45, 46, 58, 59
300	~2E5 rad	Low	CO_2	Normal	18, 30	
300	~2E5 rad	High	Air	Normal	12, 31, 52	47, 60
300	~2E5 rad	Low	Air	Normal	32	21, 38
300	no		CO_2	Normal	4, 33, 61	14, 48, 50
300	no		Air	Normal	49	2, 62
300	~2E5 rad	High	Air	No lubricant		19
300	no		Air	No lubricant		34
200	no		CO_2	Krytox lubr.	35	
300	~2E5 rad	Low	Air	Krytox lubr.	20	
350	~2E5 rad	High	Air	Normal	18D	
350	no		Air	Normal	19D	
400	~2E5 rad	High	Air	Normal		14D
400	no		Air	Normal		21D
450	~2E5 rad	High	Air	Normal		23D

Table 3. Room temperature leak rate data for fixtures

Test Conditions				Helium Hood Leak Test Results, std cc/sec He 200 and 300 ºF Fixtures Tested at Room Temperature							Notes
				Leak Rate after Indicated Time (months) at Temperature for Nominal Intervals of							
Test	**T (°F)**	**Fill Gas**	**Rad Dose**	**Baseline**	**6 Mon**	**12 Mon**	**18 Mon**	**24 Mon**	**30 Mon**	**36 Mon**	
1 A	200	Air	None	<1.3E-9	6 <9.0E-10		17 8.0E-9		30 <1.2E-8	36 <1.2E-8	
2 B	300	Air	None	<2.8E-9	6 1.3E-8	12 <1.1E-8					Fixture disassembled after 392 days in test based on high temp leak tests
3 C	200	CO2	None	<2.9E-9	6 1.0E-7	15 2.7E-8	18 <1.2E-8		31 <1.3E-8	37 <2.0E-9	
4 D	300	CO2	None	<1.8E-9	6 1.6E-8	12 2.5E-8	19 <8.0E-9		32 <1.0E-8	38 <8.0E-9	
5 E	200	CO2	2E5 in 72 mins	<2.3E-9	6 1.1E-7	11 2.0E-8	18 <1.2E-8		31 <1.0E-8	37 <6.0E-9	
6 E	200	CO2	2E5 in 72 mins	3.3E-9	6 4.0E-8	11 5.5E-8	18 <1.2E-8		31 <1.8E-8	37 <2.2E-8	
7 F	300	CO2	2E5 in 72 mins	4.2E-8	6 8.6E-8	14 <1.1E-8	17 <1.0E-8		33 <1.2E-8		
8 F	300	CO2	2E5 in 72 mins	2.0E-8	6 1.1E-7	12 <1.1E-8	18 <1.0E8			37 <1.2E-8	
9 G	200	Air	2E5 in 72 mins	5.6E-9	6 9.9E-8	12 4.2E-8	18 <1.8E-8		28 <1.6E-8		
10 H	200	CO2	2E5 in 240 hrs	7.4E-8	6 1.2E7	13 <1.2E-8		26 5.6E-9	33 <8.0E-9		
11 I	200	Air	1.4E5 in 479 hrs	<1.5E-9	8 <1.3E-8	14 <8.8E-9		25 <1.0E-8	31 <4.0E-9		
12 J	300	Air	2E5 in 72 mins	<1.3E-8	5 2.0E-8	9 <1.4E-8	20 <1.4E-8				
13 M	200	CO2	None	6.3E-9	6 <1.2E-9	11 2.3E-8	17 <8.0E-9				Overheated; removed from test (12/29/06)

Table 3. (continued) Room temperature leak rate data for fixtures

Test Conditions				Helium Hood Leak Test Results, std cc/sec He 200 and 300 ºF Fixtures Tested at Room Temperature							Notes
Test	**T (ºF)**	**Fill Gas**	**Rad Dose**	**Leak Rate after Indicated Time (months) at Temperature for Nominal Intervals of**							
				Baseline	**6 Mon**	**12 Mon**	**18 Mon**	**24 Mon**	**30 Mon**	**36 Mon**	
14 N	300	CO2	None	4.0E-9	6 <1.2E-9	11 2.1E-8	17 <1.2E-8				Overheated; removed from test (12/29/06)
15 O	200	CO2	2E5 in 72 mins	<1.1E-9	6 <1.1E-8	13 <2.4E-8					Overheated; removed from test (12/29/06)
16 P	200	Air	2E5 in 72 mins	<1.3E-9	7 <1.2E-9	11 3.0E-8					Overheated; removed from test (12/29/06)
17 Q	300	CO2	2E5 in 72 mins	<1.8E-9	7 <1.2E-9	12 1.6E-8	17 <1.4E-8				Overheated; removed from test (12/29/06)
18 R	300	CO2	2E5 in 246 hrs	<1.5E-9	7 <1.1E-8	10 <6.0E-9		26 <1.8E-8			
19 S	300	Air	1.75E5 70 mins	<1.1E-9		14 <1.6E-8					No O-ring lubricant used. Overheated; removed from test (12/29/06)
20 T	300	Air	1.75E5 562 hrs	<1.2E-8	6 3.0E-8	13 <4.8E-8		27 <1.8E-8	33 <6.0E-9		Krytox O-ring lubricant used
21 U	300	Air	2.0E5 571 hrs	1.9E-8	7 1.8E-8	13 <1.8E-8					Overheated; removed from test (12/29/06)
22 V	300	CO2	2E5 in 72 mins	<1.2E-9	7 1.8E-8	12 1.7E-8					Overheated; removed from test (12/29/06)
23 E	200	CO2	2E5 in 72 mins	1.4E-9	7 2.3E-8	13 <2.0E-8					Overheated; removed from test (12/29/06)
24 E	200	CO2	2E5 in 72 mins	<8.2E-10	8 1.7E-8	13 <1.8E-8					Overheated; removed from test (12/29/06)
25 F	300	CO2	2E5 in 72 mins	<7.4E-10	8 2.0E-8	13 2.0E-8					Overheated; removed from test (12/29/06)
26 F	300	CO2	2E5 in 72 mins	Invalid Baseline	6 1.8E-8	12 <1.0E-8			29 <2.0E-8		

Table 3. (continued) Room temperature leak rate data for fixtures

Test Conditions				Helium Hood Leak Test Results, std cc/sec He 200 and 300 ºF Fixtures Tested at Room Temperature							Notes
				Leak Rate after Indicated Time (months) at Temperature for Nominal Intervals of							
Test	**T (ºF)**	**Fill Gas**	**Rad Dose**	**Baseline**	**6 Mon**	**12 Mon**	**18 Mon**	**24 Mon**	**30 Mon**	**36 Mon**	
27 G	200	Air	2E5 in 72 mins	1.6E-9	6 1.5E-8	12 <1.0E-8	19 <3.2E-8				
28 C	200	CO2	None	<7.9E-10	6 3.1E-8	11 <1.2E-8					Removed from test (~11/07) after 630 days. Reason unknown.
29 A	200	Air	None	Invalid Baseline	6 5.1E-8						Fixture disassembled after 284 days in test based on high temp leak tests
30 K	300	CO2	2E5 in 300 hrs	5.6E-8	6 1.5E-8	11 <1.8E-8		24 <2.0E-8	32 <3.0E-8		
31 J	300	Air	2E5 in 72 mins	Invalid Baseline	6 1.5E-8	11 <1.2E-8		24 <1.6E-8			
32 L	300	Air	2E5 in 300 hrs	<1.3E-9	6 5.9E-8	11 <8.0E-9		25 <3.0E-8	32 <1.8E-8		
33 D	300	CO2	None	Invalid Baseline	6 1.3E-8	10 <2.0E-8		22 <1.8E-8	29 <2.6E-8		
34 B	300	Air	None	1.1E-8	6 3.7E-8	12 1.3E-8	18 <1.2E-8				No O-ring lubricant used. Overheated; removed from test (12/29/06)
35 M	200	CO2	None	Invalid Baseline	6 1.3E-8	11 <1.4E-8		24 <1.6E-8	31 <3.2E-8		Krytox O-ring lubricant used
36 O	200	CO2	2E5 in 72 mins	<1.5E-9	6 1.3E-8	11 <8.0E-9		25 <1.8E-8	32 <2.8E-8		
37 O	200	Air	2E5 in 72 mins	Invalid Baseline	8 1.9E-8	11 <8.0E-9		24 <1.8E-8	32 <2.2E-8		
38 U	300	Air	2E5 in 342 mins	6.3E-8	7 1.2E-8	11 <1.4E-8					Fixture disassembled after 474 days in test based on high temp leak tests
39 V	300	CO2	2E5 in 72 mins	<1.5E-9	6 1.8E-8	11 1.5E-8					Fixture disassembled after 458 days in test based on high temp leak tests
40 E	200	CO2	2E5 in 72 mins	7.7E-9	6 1.5E-8	12 <1.0E-8			28 <2.6E-8		

Table 3. (continued) Room temperature leak rate data for fixtures

Test Conditions				Helium Hood Leak Test Results, std cc/sec He 200 and 300 ºF Fixtures Tested at Room Temperature							Notes
				Leak Rate after Indicated Time (months) at Temperature for Nominal Intervals of							
Test	**T (ºF)**	**Fill Gas**	**Rad Dose**	**Baseline**	**6 Mon**	**12 Mon**	**18 Mon**	**24 Mon**	**30 Mon**	**36 Mon**	
41 E	200	CO2	2E5 in 72 mins	Invalid Baseline	6 1.3E-8	11 <1.0E-8		24 <1.9E-8	32 <1.8E-8		
42 G	200	Air	2E5 in 72 mins	Invalid Baseline	6 1.5E8	11 <1.0E-8		24 <1.8E-8	32 <1.8E-8		
43 C	200	CO2	None	Invalid Baseline	6 2.0E-8	12 <1.0E-8		24 <1.8E-8	33 <3.0E-8		
44 A	200	Air	None	Invalid Baseline	6 1.5E-8	12 <1.6E-8		24 <1.8E-8	32 <2.0E-8		
45 F	300	CO2	2E5 in 72 mins	Invalid Baseline	6 1.5E-8						Fixture disassembled after 292 days in test based on high temp leak tests
46 F	300	CO2	2E5 in 72 mins	Invalid Baseline		10 2.5E-8					Fixture disassembled after 496 days in test based on high temp leak tests
47 J	300	Air	2E5 in 72 mins	Invalid Baseline	8 5.8E-8	11 <1.6E-8					Fixture disassembled after 395 days in test based on high temp leak tests
48 D	300	CO2	None	Invalid Baseline	8 1.6E-8	11 <1.8E-8					Fixture disassembled after 491 days in test based on high temp leak tests
49 B	300	Air	None	Invalid Baseline	6 1.6E-8	11 <6.0E-9			30 <1.8E-8		
50 N	300	CO2	None	Invalid Baseline	6 1.8E-8						Fixture disassembled after 266 days in test based on high temp leak tests
51 Q	300	CO2	2E5 in 72 mins	4.3E-8	6 5.2E-8	11 <8.0E-9	21 <2.0E-9		28 <3.2E-8		
52 S	300	Air	2E5 in 72 mins	Invalid Baseline	6 1.8E-8	11 <1.0E-8	21 <2.4E-8	27 <2.8E-8			
53 E	200	CO2	2E5 in 72 mins	Invalid Baseline	6 1.8E-8	11 <1.0E-8		25 <1.8E-8	32 <1.8E-8		

Table 3. (continued) Room temperature leak rate data for fixtures

Test Conditions				Helium Hood Leak Test Results, std cc/sec He 200 and 300 ºF Fixtures Tested at Room Temperature							Notes
				Leak Rate after Indicated Time (months) at Temperature for Nominal Intervals of							
Test	**T (°F)**	**Fill Gas**	**Rad Dose**	**Baseline**	**6 Mon**	**12 Mon**	**18 Mon**	**24 Mon**	**30 Mon**	**36 Mon**	
54 E	200	CO2	2E5 in 72 mins	Invalid Baseline	6 1.8E-8	11 <1.2E-8		25 <1.8E-8	32 <1.2E-8		
55 G	200	Air	2E5 in 72 mins	Invalid Baseline	6 1.6E-8	11 <1.4E-8		24 <1.6E-8	32 <8.0E-9		
56 C	200	CO2	None	Invalid Baseline	6 1.3E-8	11 <1.8E-8		23 <1.8E-8	30 <1.0E-8		
57 A	200	Air	None	Invalid Baseline	6 1.6E-8	11 <1.2E-8		23 <2.4E-8	31 <1.2E-8		
58 F	300	CO2	2E5 in 72 mins	<1.1E-9	6 1.6E-8	10 <8.0E-9					Overheated; removed from test (12/29/06)
59 F	300	CO2	2E5 in 72 mins	<2.9E-9	6 1.8E-8	11 <1.4E-8					Overheated; removed from test (12/29/06)
60 J	300	Air	2E5 in 72 mins	1.6E-8	6 1.8E-8	10 <1.0E-8					Fixture disassembled after 455 days in test based on high temp leak tests
61 D	300	CO2	None	Invalid Baseline	6 1.8E-8	11 <1.0E-8		23 <1.6E-8	30 <2.0E-8		
62 B	300	Air	None	Invalid Baseline	6 4.2E-8						Fixture disassembled after 283 days in test based on high temp leak tests

Table 3. (continued) Room temperature leak rate data for fixtures

Test Conditions				Helium Hood Leak Test Results, std cc/sec He 350 to 450 °F Fixtures Tested at Room Temperature							Notes
Test	**T (°F)**	**Fill Gas**	**Rad Dose**	**Time Zero**	**Leak Rate after Indicated Time (days) at Temperature**						
14 D	400	Air	2E5 in 72 mins	<2.2E-8	8 <9.4E-9	28 1.0E-8	45 1.5E-4				Both O-rings leaking at 45 days.
18 D	350	Air	2E5 in 72 mins	<8E-9	8 1.6E-8	28 3.2E-8	46 <8.1E-9	67 <1.9E-9	91 5.0E-8	107 6.1E-9	
19 D	350	Air	None	2.8E-8	8 <7.9E-9	28 2.3E-8	45 <8.6E-9	66 <1.9E-9	90 2.2E-8	107 <2.8E-9	
21 D	400	Air	None	1.4E-8	8 <9.9E-9	28 > E-5					Both O-rings leaking at 28 days.
23 D	450	Air	2E5 in 72 mins	8.0E-9	8 2.1E-4	10 6.4E-8	12 8.6E-7				Outer O-ring leaked after 8 days. Subsequent leak rates are for inner O-ring only. Inner O-ring leaked after 12 days.

Table 4. Summary of compression set data from O-ring fixtures

Fixture ID & History	Time since Opening	Comp. Set – Inner / Outer O-ring	Time since Opening	Comp. Set – Inner / Outer O-ring	Time since Opening	Comp. Set – Inner / Outer O-ring
Fixtures reported previously with high temperature leak test difficulties						
2 (392 days at 300 ^{o}F)					30 days	62%
						59%
29 (283 days at 200 ^{o}F)					30 days	30%
						18%
38 (473 days at 300 ^{o}F)	<30 min.	85%				
		87%				
39 (456 days at 300 ^{o}F)	<30 min.	77%				
		81%				
45 (291 days at 300 ^{o}F)					30 days	60%
						71%
46 (493 days at 300 ^{o}F)	<30 min.	76%				
		75%				
47 (394 days at 300 ^{o}F)	1 hour	80%	5 days	77%	34 days	68%
		81%		73%		72%
48 (490 days at 300 ^{o}F)	<30 min.	84%				
		84%				
50 (265 days at 300 ^{o}F)					30 days	42%
						38%
60 (454 days at 300 ^{o}F)	<30 min.	88%				
		89%				
62 (282 days at 300 ^{o}F)					30 days	50%
						54%
Fixtures removed due to overheating						
16 (522 days at 200 ^{o}F)	4 hours	72%	10 days	31%	230 days	29%
Overheated to >430 ^{o}F		46%		28%		23%
23 (490 days at 200 ^{o}F)	4 hours	70%	11 days	33%	230 days	29%
Overheated to >432 ^{o}F		89%		37%		32%
24 (486 days at 200 ^{o}F)	4 hours	75%	10 days	23%	230 days	17%
Overheated to >342 ^{o}F		58%		31%		24%
34 (654 days at 200 ^{o}F)	4 hours	123%	10 days	101%	230 days	101%
Overheated to >721 ^{o}F		115%		86%		87%
High temperature fixtures removed after failing room temperature leak test						
14D (45 days at 400 ^{o}F)	21 minutes	51%	9 days	54%	80 days	51%
		77%		74%		66%
21D (27 days at 400 ^{o}F)	27 minutes	65%	9 days	57%	80 days	52%
		77%		69%		66%
23D (12 days at 450 ^{o}F)	21 minutes	65%	14 days	53%	85 days	52%
		70%		63%		60%
Fixtures removed for other reasons						
28 (630 days at 200 ^{o}F)	4 hours	68%	10 days	31%	230 days	28%
		62%		28%		24%
62-2007 (~6 months at 300 ^{o}F)	4 hours	66%	11 days	35%	230 days	32%
		77%		35%		31%

Table 5. Summary of dimensional inspections on disassembled fixtures [15, 16]

Fixture #	Body ID	Body findings *	Plug ID	Plug findings *
2	7	Q3 – 62 µin	13	Q12 – 0.143” (4 places) Q13 – 5.061”
13	25	None	25	Q5 - 66º33’, 66º24’
14	4	None	4	Q5 - 69º15’, 69º9’ Q13 – 5.048” (1 place)
15	2	None	2	Q5 - 70º10’, 70º37’
16	19	None	19	None
17	11	None	1	Q5 – 69º26’, 69º28’
19	1	None	3	Q5 – 68º59’, 68º30’
21	13	None	5	Q5 - 69º20’, 68º30’
22	66	Q1 – 5.262” (1 place)	66	Q5 - 66º25’, 65º48’
23	35	None	65	Q4 – 56, 58 µin
24	69	Q1 – 5.277”	69	Q4 – 65 µin (2 places)
25	29	Q1 – 5.262”, 5.264”	56	Q5 - 65º51’, 66º34’ Q8, Q9 – 0.079, 0.080 (4 places each)
28	41	None	28	Q4 – 45, 56 µin
34	24	None	24	Q4 – 34 µin (1 place)
38	37	None	41	Q4 – 39 µin (1 place)
39	36	None	58	Q4 – 53, 55 µin
45	47	None	45	Not checked
46	55	None	43	Q4 – 54 µin (2 places) Q10 – 36 – 39 µin (4 places)
47	43	None	46	Q4 – 66, 68 µin
48	62	None	52	Q4 – 57, 61 µin
50	52	None	63	Q4, Q10 – 36 µin (1 place each)
58	70	None	26	None
59	71	None	31	Q8, Q9 – 0.080 (4 places each)
60	50	None	37	Q4 – 37 µin (1 place) Q11 – 0.148, 0.149” (3 places) Q12 – 0.149 (2 places)
62	72	None	53	Q4 – 37 µin (1 place)

* “Q” numbers refer to specific drawing dimensions, as follows:
- Q1: body ID at top of taper, 5.270 +/- 0.005”
- Q3: body ID taper surface finish, 32 µin
- Q4: plug taper surface finish, 32 µin
- Q5: plug test port cone angle, 60º +/- 30’
- Q8, Q9: plug lower and upper O-ring groove depth, 0.086 +/- 0/005”
- Q10: plug O-ring grooves surface finish, 32 µin
- Q11, Q12: plug upper and lower O-ring groove width, 0.150 – 0.155”
- Q13: plug OD at bottom of taper, 5.054 +/- 0.005”

Table 6. Summary of testing for permeation signal

Fixture Number	Test Date	Permeation Seen? / Time to Permeate *	Re-test Date	Permeation Seen? / Time to Permeate *	Re-test Date	Permeation Seen? / Time to Permeate *
1	2/9/09	Y / 10 min				
3	2/9/09	Y / 30 min				
4	2/10/09	N	3/12/09	N (45 min)		
5	2/10/09	N	3/12/09	N		
6	2/10/09	N	3/18/09	Y / 5 min		
7	2/10/09	Y / 10 min				
8	2/10/09	Y / 16 min				
9	2/10/09	Y / 7 min				
10	2/10/09	N	2/25/09	Y / 11 min	3/18/09	N
11	2/10/09	Y / 10 min				
12	2/17/09	N	3/18/09	Y / 35 min		
18	3/4/09	Y / 11 min				
20	2/17/09	Y / 30 min				
26	2/19/09	Y / 9 min				
27	2/19/09	N	4/2/09	Y / 8 min		
30	2/12/09	Y / 8 min				
31	2/18/09	Y / 10 min				
32	2/12/09	Y / 13 min				
33	2/12/09	N (40 min)	4/2/09	Y / 9 min		
35	2/12/09	N	2/17/09	N	4/1/09	Y / 12 min
36	2/11/09	N	2/18/09	N (60 min)	4/1/09	Y / 6 min
37	2/11/09	N	2/18/09	N (60 min)	4/1/09	Y / 18 min
40	3/4/09	N	4/6/09	Y / 14 min		
41	3/4/09	Y / 10 min				
42	3/4/09	Y / 8 min				
43	3/4/09	N	4/6/09	N		
44	3/4/09	Y / 12 min				
49	2/19/09	Y / 7 min				
51	2/18/09	N (45 min)	4/6/09	Y / 4 min		
52	2/18/09	N	4/6/09	Y / 7 min		
53	2/19/09	Y / 30 min				
54	2/11/09	Y / 12 min				
55	3/5/09	Y / 11 min				
56	3/5/09	Y / 10 min				
57	3/5/09	Y / 13 min				
61	3/4/09	N	4/6/09	N		

* In cases with no observed permeation, leak testing was performed for 30 minutes unless indicated otherwise.

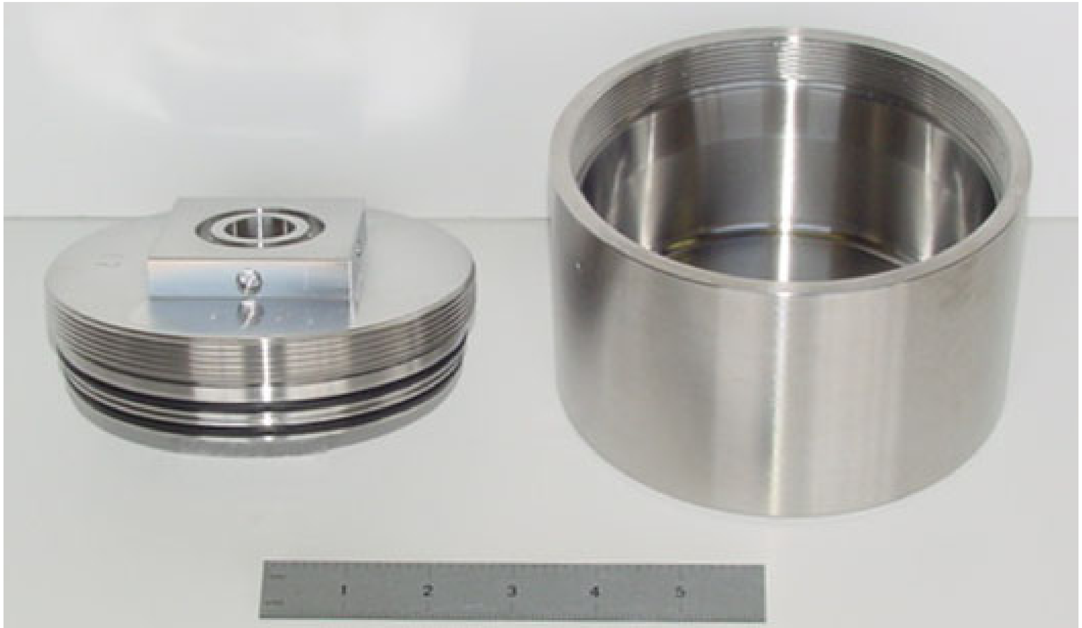


Figure 1. Mock-up PCV test fixture lid and body

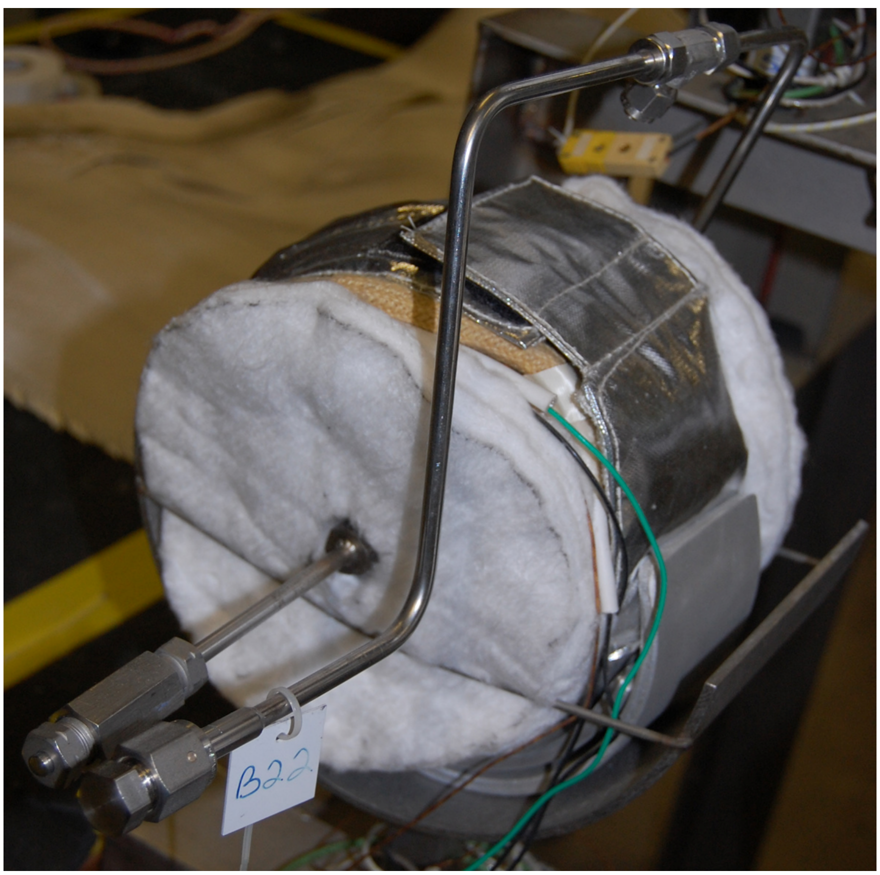


Figure 2. Assembled mock-up PCV

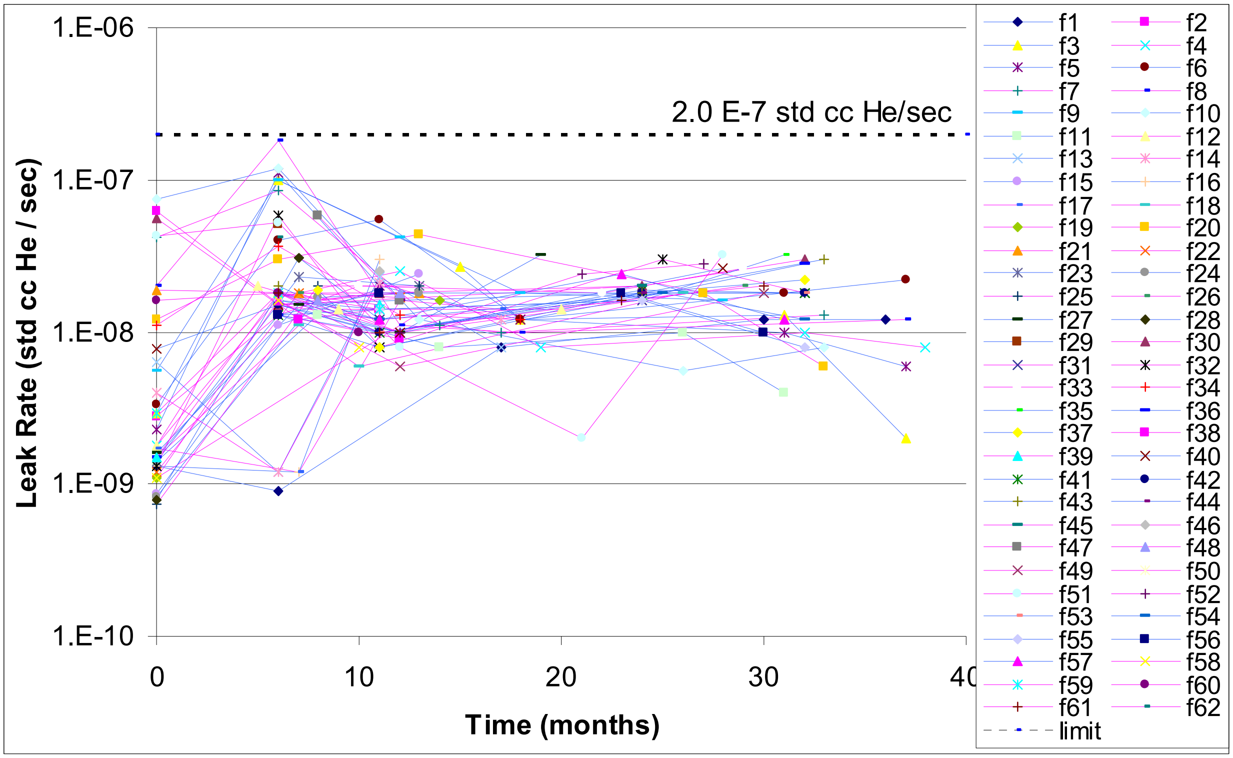
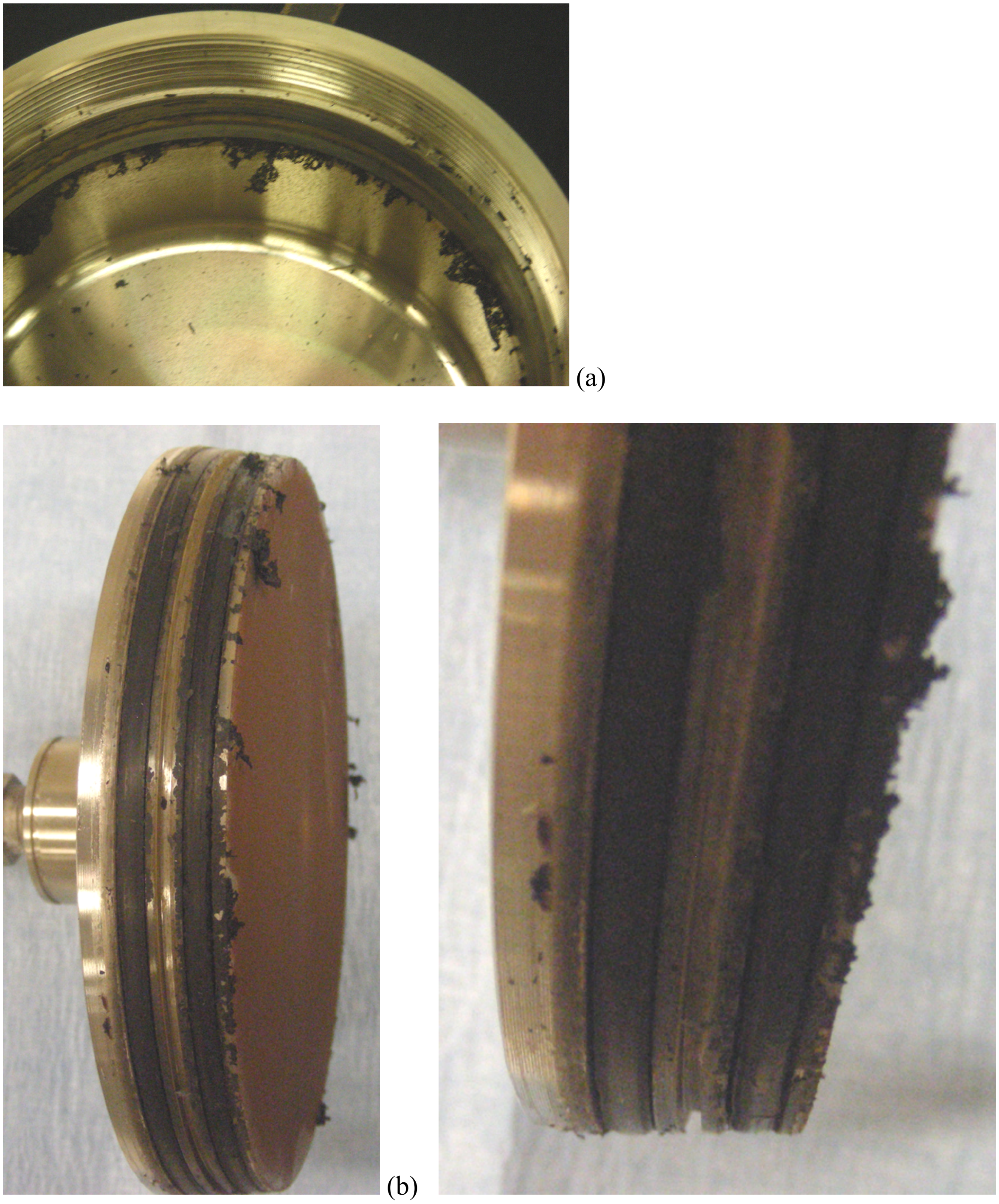
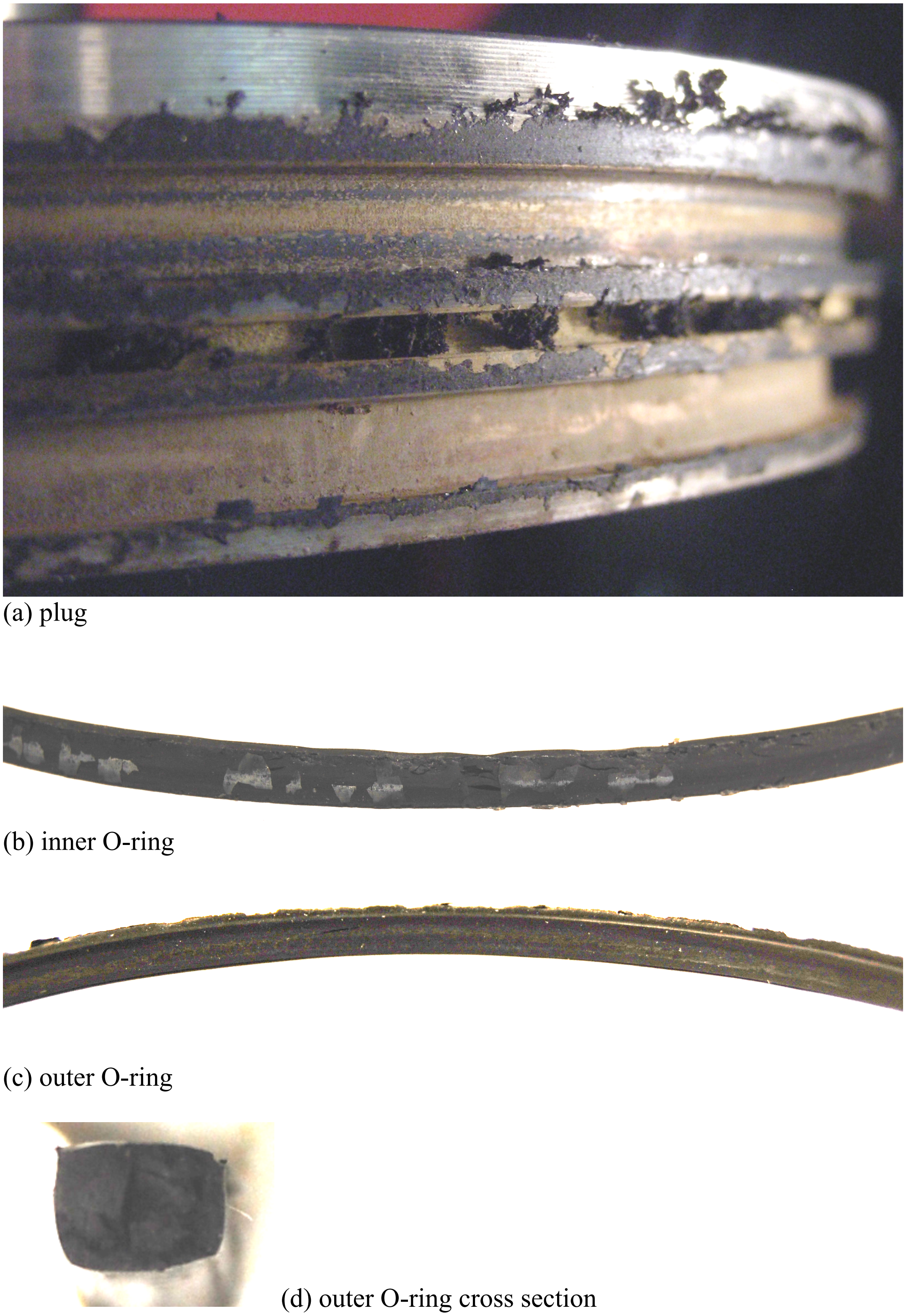


Figure 3. Summary of room temperature leak rate data for the original fixtures. The red lines represent fixtures aged at 300 ºF, and the blue lines represent fixtures aged at 200 ºF.



(a) (b) (c)

Figure 4. Fixture 34 body (a) and plug (b, c) disassembled following unplanned high temperature excursion. Portions of both O-rings extruded into the plug / body gap.



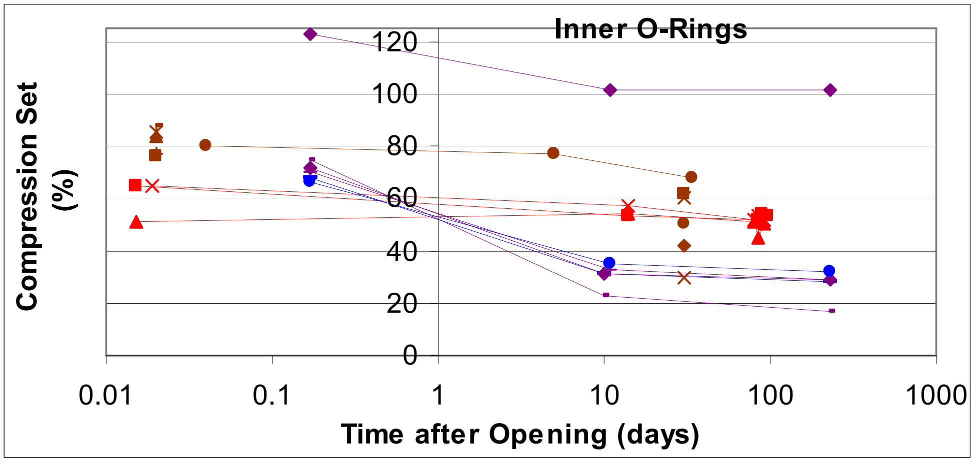
(a) plug

(b) inner O-ring

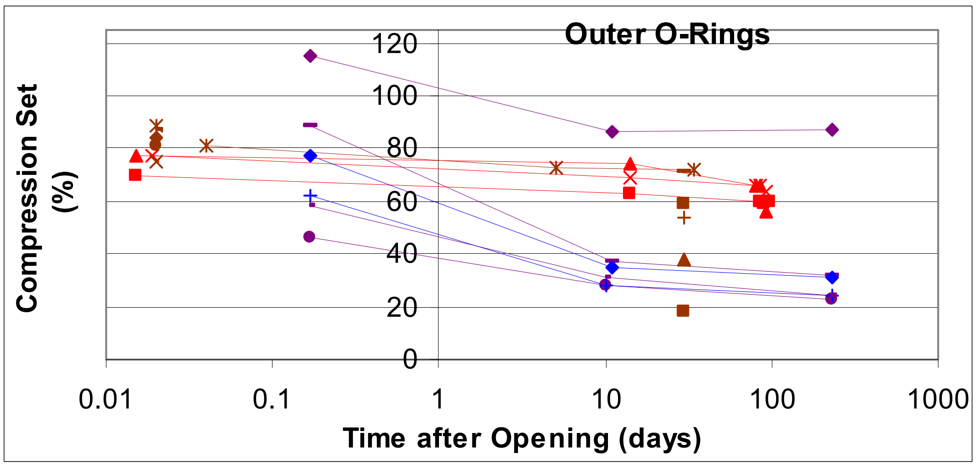
(c) outer O-ring

(d) outer O-ring cross section

Figure 5. Fixture 34 plug and O-rings after O-ring removal.



(a)



(b)

Figure 6. Compression set values for O-rings after removal from fixtures. Although values are similar, results are plotted separately for inner (a) and outer (b) O-rings. The color indicates the fixture source:

- brown: fixtures removed based on high temperature leak test results
- purple: fixtures removed after overheating
- red: high temperature fixtures removed following room temperature leak test failure
- blue: fixtures removed for other (unknown) reason

Appendix 1. Operational Summary of Each O-Ring Fixture

Fixture 1
Assembled 5-17-04
Baseline leak test 5-17-04
Began aging in Rack 1 at 200ºF on 5-18-04
Leak test on 12-3-04 after 6 months
Leak test on 9-25-06 after 17 months
Leak test on 7-29-08 after 30 months
Leak test on 2-9-09 after 36 months
Still in test (rack 1) as of 4-15-09

Fixture 2
Assembled 5-17-04
Baseline leak test 5-17-04
Began aging in Rack 2 at 300ºF on 5-18-04
Leak test on 12-3-04 after 6 months
Leak test on 1-12-06 after 12 months
Removed from test (rack 2) as of 8-22-06 due to high temp leak test problems

Fixture 3
Assembled 5-13-04
Baseline leak test 5-17-04
Began aging in Rack 3 at 200ºF on 5-18-04
Leak test on 11-15-04 after 6 months
Leak test on 5-1-06 after 15 months
Leak test on 9-25-06 after 18 months
Leak test on 7-29-08 after 31 months
Leak test on 2-9-09 after 37 months
Still in test (rack 3) as of 4-15-09

Fixture 4
Assembled 5-11-04
Baseline leak test 5-17-04
Began aging in Rack 4 at 300ºF on 5-18-04
Leak test on 12-3-04 after 6 months
Leak test on 1-25-06 after 12 months
Leak test on 9-25-06 after 19 months
Leak test on 7-29-08 after 32 months
Leak test on 2-10-09 after 38 months
Leak test on 3-12-09 after 38 months
Still in test (rack 4) as of 4-15-09

Fixture 5
Assembled 5-1-04
Baseline leak test 6-10-04 6-29-04
Began aging in Rack 5 at 200ºF on 7-1-04
Leak test on 4-19-05 after 6 months
Leak test on 1-25-06 after 11 months
Leak test on 9-25-06 after 18 months
Leak test on 7-29-08 after 31 months
Leak test on 2-10-09 after 37 months
Leak test on 3-12-09 after 37 months
Still in test (rack 5) as of 4-15-09

Fixture 6
Assembled 6-1-04
Baseline leak test 6-10-04 6-29-04
Began aging in Rack 6 at 200ºF on 7-1-04
Leak test on 4-19-05 after 6 months
Leak test on 1-25-06 after 11 months
Leak test on 9-25-06 after 18 months
Leak test on 7-29-08 after 31 months
Leak test on 2-10-09 after 37 months
Leak test on 3-18-09 after 37 months
Still in test (rack 6) as of 4-15-09

Fixture 7
Assembled 6-1-04
Baseline leak test 6-10-04 6-29-04
Began aging in Rack 7 at 300ºF on 7-1-04
Leak test on 4-19-05 after 6 months
Leak test on 5-2-06 after 14 months
Leak test on 9-25-06 after 17 months
Leak test on 2-10-09 after 33 months
Still in test (rack 7) as of 4-15-09

Fixture 8
Assembled 6-1-04
Baseline leak test 6-10-04 6-29-04
Began aging in Rack 8 at 300ºF on 7-1-04
Leak test on 4-19-05 after 6 months
Leak test on 2-8-06 after 12 months
Leak test on 9-25-06 after 18 months
Moved to Rack 19 on ~6-27-07
Moved to Rack 8 on ~10-20-08
Leak test on 2-10-09 after 37 months
Still in test (rack 8) as of 4-15-09

Fixture 9
Assembled 6-1-03
Baseline leak test 6-10-04 6-29-04
Began aging in Rack 9 at 200ºF on 6-30-04
Leak test on 4-19-05 after 6 months
Leak test on 2-8-06 after 12 months
Leak test on 9-25-06 after 18 months
Location unknown ~12/28/06 to ~1/30/08
Leak test on 2-10-09 after 28 months
Still in test (rack 9) as of 4-15-09

Fixture 10
Assembled 7-26-04
Baseline leak test 7-15-04
Began aging in Rack 10 at 200ºF on 3-17-05
Leak test on 1-25-06 after 6 months
Leak test on 8-28-06 after 13 months
Leak test on 7-29-08 after 26 months
Leak test on 2-10-09 after 33 months
Leak test on 2-25-09 after 33 months
Leak test on 3-18-09 after 33 months
Still in test (rack 10) as of 4-15-09

Fixture 11
Assembled 7-13-04
Baseline leak test 7-15-04 9-29-04
Began aging in Rack 11 at 200ºF on 11-17-04
Leak test on 4-19-05 after 2 months
Leak test on 2-8-06 after 8 months
Leak test on 8-28-06 after 14 months
Leak test on 7-30-08 after 25 months
Leak test on 2-10-09 after 31 months
Still in test (rack 11) as of 4-15-09

Fixture 12
Assembled 7-22-04
Baseline leak test 8-5-04 10-14-04
Began aging in Rack 34 at 300ºF on 5-2-05
Leak test on 1-25-06 after 5 months
Leak test on 8-30-06 after 9 months
No time at temp from ~6-4-07 to 7-1-08
Moved to Rack 12 on ~10-20-08
Moved to Rack 2 on ~12-1-08
Leak test on 2-17-09 after 20 months
Leak test on 3-18-09 after 20 months
Still in test (rack 2) as of 4-15-09

Fixture 13
Assembled 7-20-04
Baseline leak test 8-5-04
Began aging in Rack 13 at 200ºF on 8-18-04
Leak test on 6-29-05 after 6 months
Leak test on 3-15-06 after 11 months
Leak test on 9-25-06 after 17 months
Removed from test 1-2-07 due to overheating

Fixture 14
Assembled 7-21-04
Baseline leak test 7-26-04 8-5-04
Began aging in Rack 14 at 300ºF on 8-18-04
Leak test on 6-29-05 after 6 months
Leak test on 3-15-06 after 11 months
Leak test on 9-25-06 after 17 months
Removed from test 1-2-07 due to overheating

Fixture 15
Assembled 6-1-04
Baseline leak test 6-10-04 9-29-04
Began aging in Rack 15 at 200ºF on 11-16-04
Leak test on 1-12-06 after 6 months
Leak test on 8-28-06 after 13 months
Removed from test 1-2-07 due to overheating

Fixture 16
Assembled 7-13-04
Baseline leak test 7-15-04 7-26-04
Began aging in Rack 16 at 200ºF on 8-18-04
Leak test on 6-29-05 after 7 months
Leak test on 3-15-06 after 11 months
Leak test on 9-25-06 after 14 months
Removed from test 1-2-07 due to overheating

Fixture 17
Assembled 7-14-04
Baseline leak test 7-15-04 7-26-04 8-5-04
Began aging in Rack 17 at 300ºF on 8-18-04
Leak test on 6-29-05 after 7 months
Leak test on 3-16-06 after 12 months
Leak test on 9-25-06 after 17 months
Removed from test 1-2-07 due to overheating

Fixture 18
Assembled 7-21-04
Baseline leak test 8-5-04 11-9-04
Began aging in Rack 18 at 300ºF on 11-16-04
Leak test on 1-25-06 after 7 months
Leak test on 8-13-06 after 10 months
Leak test on 8-31-06 after 11 months
12-26-06 until 2-20-07 status unknown
2-20-07 to 11-3-07 in Rack 12
11-3-07 to 11-9-07 status unknown
11-9-07 to 4-29-08 rack 18
Not heated 11-16-07 to 4-29-08
8-13-08 to present, rack 59
Leak test on 2-25-09 after 26 months
Still in test (rack 59) as of 4-15-09

Fixture 19
Assembled 7-22-04
Baseline leak test 7-26-04 9-29-04
Began aging in Rack 19 at 300ºF on 11-16-04
Leak test on 8-28-06 after 14 months
Removed from test 1-2-07 due to overheating

Fixture 20
Assembled 7-27-04
Baseline leak test 8-5-04 10-14-04 1-10-05
Began aging in Rack 20 at 300ºF on 3-17-05
Leak test on 1-25-06 after 6 months
Leak test on 8-30-06 after 13 months
Leak test on 7-30-08 after 27 months
Leak test on 2-17-09 after 33 months
Still in test (rack 20) as of 4-15-09

Fixture 21
Assembled 7-27-04
Baseline leak test 8-5-04 1-10-05
Began aging in Rack 21 at 300ºF on 3-17-05
Leak test on 2-21-06 after 7 months
Leak test on 8-29-06 after 13 months
Removed from test 1-2-07 due to overheating

Fixture 22
Assembled 11-22-04
Baseline leak test 12-2-04 (pre-irradiation)
Baseline leak test 3-9-05, invalid (post-irradiation)
Began aging in Rack 22 at 300ºF on 12-2-04
Leak test 2-21-06 after 7 months
Leak test 8-30-06 after 12 months
Removed from test 1-2-07 due to overheating

Fixture 23
Assembled 12-9-04
Baseline leak test 1-11-05 (pre-irradiation)
Baseline leak test 3-9-05, invalid (post-irradiation)
Began aging in Rack 23 at 200ºF on 3-17-05
Leak test 2-21-06 after 7 months
Leak test 8-29-06 after 13 months
Removed from test 1-2-07 due to overheating

Fixture 24
Assembled 12-9-04
Baseline leak test 1-11-05 (pre-irradiation)
Baseline leak test 3-9-05, invalid (post-irradiation)
Began aging in Rack 24 at 200ºF on 3-17-05
Leak test 3-17-06 after 8 months
Leak test 8-29-06 after 13 months
Removed from test 1-2-07 due to overheating

Fixture 25
Assembled 12-6-04
Baseline leak test 1-10-05 (pre-irradiation)
Baseline leak test 3-10-05, invalid (post-irradiation)
Began aging in Rack 25 at 300ºF on 3-17-05
Leak test 3-17-06 after 8 months
Leak test 8-30-06 after 13 months
Removed from test 1-2-07 due to overheating

Fixture 26
Assembled 12-6-04
Baseline leak test 1-10-05 (pre-irradiation)
Baseline leak test 3-10-05, invalid (post-irradiation)
Began aging in Rack 26 at 300ºF on 4-28-05
Leak test 2-22-06 after 6 months
Leak test 8-20-06 after 12 months
Leak test 8-30-06 after 12 months
In R26 until 6-28-07
6-28-07 to 12-7-07 in Rack 9
1-7-08 to 10-21-08 in Rack 50
10-21-08 to present in Rack 26
Leak test 2-19-09 after 29months
Still in test (rack 26) as of 4-15-09

Fixture 27
Assembled 12-6-04
Baseline leak test 1-10-05 (pre-irradiation)
Baseline leak test 3-10-05, invalid (post-irradiation)
Began aging in Rack 27 at 200ºF on 4-28-05
Leak test 2-22-06 after 6 months
Leak test 8-30-06 after 12 months
In R27 until 12-13-06
12-06 to 1-08 location unknown
1-25-08 to 10-21-08 in Rack 60
10-21-08 to present in Rack 27
Leak test 2-19-09 after 19 months
Leak test 4-2-09 after19 months
Still in test (rack 27) as of 4-15-09

Fixture 28
Assembled 12-7-04
Baseline leak test 1-10-05
Began aging in Rack 28 at 200ºF on 5-2-05
Leak test 2-22-06 after 6 months
Leak test 8-22-06 after 11 months
In R28 until 6-26-07
6-26-07 to 11-16-07 in Rack 14
(11-7-07 to 11-16-07 includes 6.3 days @ 149 C)
Removed from test 11-07 for unknown reasons

Fixture 29
Assembled 12-8-04
Baseline leak test 3-10-05, invalid
Began aging in Rack 29 at 200ºF on 5-3-05
Leak test 2-22-06 after 6 months
Fixture disassembled after 284 days in test due to high temperature failure

Fixture 30
Assembled 11-29-04
Baseline leak test 1-10-05 (pre-irradiation)
Baseline leak test 3-10-05, invalid (post-irradiation)
Began aging in Rack 30 at 300ºF on 4-28-05
Leak test on 2-22-06 after 6 months
Leak test on 8-22-06 after 11 months
Leak test on 7-30-08 after 24 months
Leak test on 2-12-09 after 32 months
Leak test on 2-19-09 after 32 months
Still in test (rack 30) as of 4-15-09

Fixture 31
Assembled 1-13-05
Baseline leak test 2-10-05, invalid (pre-irradiation)
Baseline leak test 3-22-05, invalid (post-irradiation)
Began aging in Rack 31 at 300ºF on 5-2-05
Leak test on 2-22-06 after 6 months
Leak test on 8-22-06 after 11 months
Leak test on 7-30-08 after 24 months
Still in test (rack 31) as of 4-15-09

Fixture 32
Assembled 11-29-04
Baseline leak test 12-2-04 (pre-irradiation)
Baseline leak test 3-9-05, invalid (post-irradiation)
Began aging in Rack 32 at 300ºF on 5-2-05
Leak test on 2-22-06 after 6 months
Leak test on 8-22-06 after 11 months
Leak test on 7-31-08 after 25 months
Leak test on 2/12/09 after 32 months
Still in test (rack 32) as of 4-15-09

Fixture 33
Assembled 1-13-05
Baseline leak test 2-10-05, invalid
Began aging in Rack 33 at 300ºF on 5-2-05
Leak test on 2-22-06 after 6 months
Leak test on 8-29-06 after 10 months
Leak test on 7-30-08 after 22 months
Leak test on 2-12-09 after 29 months
Leak test on 4-2-09 after 29 months
Still in test (rack 33) as of 4-15-09

Fixture 34
Assembled 5-27-04
Baseline leak test 6-10-04 6-29-04
Began aging in Rack 12 at 300ºF on 6-30-04
Leak test 4-20-05 after 6 months
Leak test 2-22-06 after 12 months
Leak test 9-25-06 after 18 months
Removed from test 1-2-07 due to overheating

Fixture 35
Assembled 1-24-05
Baseline leak test 2-10-05, invalid
Began aging in Rack 35 at 200ºF on 5-2-05
Leak test 2-22-06 after 6 months
Leak test 8-22-06 after 11 months
Leak test 7-30-08 after 24 months
Leak test 2-12-09 after 31 months
Leak test 2-19-09 after 31 months
Leak test 4-1-09 after 31 months
Still in test (rack 35) as of 4-15-09

Fixture 36
Assembled 1-24-05
Baseline leak test 5-10-05
Began aging in Rack 36 at 200ºF on 5-2-05
Leak test 2-23-06 after 6 months
Leak test 8-24-06 after 11 months
Leak test 7-31-08 after 25 months
Leak test 2-12-09 after 32 months
Leak test 2-19-09 after 32 months
Leak test 4-1-09 after 32 months
Still in test (rack 36) as of 4-15-09

Fixture 37
Assembled 1-24-05
Baseline leak test 2-15-05, invalid (pre-irradiation)
Baseline leak test 3-9-05, invalid (post-irradiation)
Began aging in Rack 37 at 200ºF on 5-2-05
Leak test 5-8-06 after 8 months
Leak test 8-24-06 after 11 months
Leak test 7-30-08 after 24 months
Leak test 2-12-09 after 32 months
Leak test 2-18-09 after 32 months
Leak test 4-1-09 after 32 months
Still in test (rack 37) as of 4-15-09

Fixture 38
Assembled 1-25-05
Baseline leak test 2-23-05 (pre-irradiation)
Baseline leak test 4-4-05, invalid (post-irradiation)
Began aging in Rack 38 at 300ºF on 5-2-05
Leak test 4-3-06 after 7 months
Leak test 8-24-06 after 11 months
Fixture disassembled after 474 days in test due to high temperature failure

Fixture 39
Assembled 1-25-05
Baseline leak test 2-23-05 5-10-05
Began aging in Rack 39 at 300ºF on 5-2-05
Leak test 2-23-06 after 6 months
Leak test 8-30-06 after 11 months
Fixture disassembled after 458 days in test due to high temperature failure

Fixture 40
Assembled 1-25-05
Baseline leak test 2-23-05 (pre-irradiation)
Baseline leak test 3-22-05, invalid (post-irradiation)
Began aging in Rack 40 at 200ºF on 5-2-05
Leak test 2-23-06 after 6 months
Leak test 8-22-06 after 11 months
Leak test 8-29-06 after 12 months
Leak test 3-4-09 after 28 months
Leak test 4-6-09 after 28 months
Still in test (rack 40) as of 4-15-09

Fixture 41
Assembled 1-25-05
Baseline leak test 2-16-05, invalid (pre-irradiation)
Baseline leak test 3-22-05, invalid (post-irradiation)
Began aging in Rack 41 at 200ºF on 5-2-05
Leak test 2-23-06 after 6 months
Leak test 8-22-06 after 11 months
Leak test 7-31-08 after 24 months
Leak test 3-4-09 after 32 months
Still in test (rack 41) as of 4-15-09

Fixture 42
Assembled 1-25-05
Baseline leak test 2-16-05, invalid (pre-irradiation)
Baseline leak test 3-9-05, invalid (post-irradiation)
Began aging in Rack 42 at 200ºF on 5-2-05
Leak test 2-23-06 after 6 months
Leak test 8-22-06 after 11 months
Leak test 7-31-08 after 24 months
Leak test 3-4-09 after 32 months
Still in test (rack 42) as of 4-15-09

Fixture 43
Assembled 1-25-05
Baseline leak test 2-16-05, invalid
Began aging in Rack 43 at 200ºF on 5-2-05
Leak test 2-23-06 after 6 months
Leak test 8-22-06 after 11 months
Leak test 8-29-06 after 12 months
Leak test 7-31-08 after 24 months
Leak test 3-4-09 after 32 months
Leak test 4-6-09 after 33 months
Still in test (rack 43) as of 4-15-09

Fixture 44
Assembled 1-25-05
Baseline leak test 2-16-05, invalid
Began aging in Rack 44 at 200ºF on 5-2-05
Leak test 2-23-06 after 6 months
Leak test 8-29-06 after 12 months
Leak test 7-31-08 after 24 months
Leak test 3-4-09 after 32 months
Still in test (rack 44) as of 4-15-09

Fixture 45
Assembled 1-25-05
Baseline leak test 2-16-05, invalid (pre-irradiation)
Baseline leak test 3-23-05, invalid (post-irradiation)
Began aging in Rack 45 at 300ºF on 5-2-05
Leak test 2-23-06 after 6 months
Fixture disassembled after 292 days in test due to high temperature failure

Fixture 46
Assembled 1-25-05
Baseline leak test 2-16-05, invalid (pre-irradiation)
Baseline leak test 3-23-05, invalid (post-irradiation)
Began aging in Rack 46 at 300ºF on 5-2-05
Leak test 8-1-06 after 10 months
Leak test 8-24-06 after 10 months
Fixture disassembled after 496 days in test due to high temperature failure

Fixture 47
Assembled 1-25-05
Baseline leak test 2-16-05, invalid (pre-irradiation)
Baseline leak test 3-10-05, invalid (post-irradiation)
Began aging in Rack 47 at 300ºF on 5-2-05
Leak test 5-8-06 after 8 months
Leak test 8-24-06 after 11 months
Fixture disassembled after 395 days in test due to high temperature failure

Fixture 48
Assembled 1-25-05
Baseline leak test 2-17-05, invalid
Began aging in Rack 48 at 300ºF on 5-3-05
Leak test 5-8-06 after 8 months
Leak test 8-29-06 after 11 months
Fixture disassembled after 491 days in test due to high temperature failure

Fixture 49
Assembled 1-25-05
Baseline leak test 2-17-05, invalid
Began aging in Rack 49 at 300ºF on 5-3-05
Leak test 3-1-06 after 6 months
Leak test 8-30-06 after 11 months
??? until 6-26-07 in Rack 49
6-26-07 to 10-21-08 in Rack 23
10-21-08 to present in Rack 49
Leak test 2-19-09 after 30 months
Still in test (rack 49) as of 4-15-09

Fixture 50
Assembled 1-26-05
Baseline leak test 2-22-05, invalid
Began aging in Rack 50 at 300ºF on 5-2-05
Leak test 3-1-06 after 6 months
Fixture disassembled after 266 days in test due to high temperature failure

Fixture 51
Assembled 1-26-05
Baseline leak test 5-11-05
Began aging in Rack 51 at 300ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-24-06 after 11 months
Leak test 7-31-08 after 21 months
Leak test 2-18-09 after 28 months
Leak test 4-6-09 after 29 months
Still in test (rack 51) as of 4-15-09

Fixture 52
Assembled 1-26-05
Baseline leak test 2-17-05, invalid (pre-irradiation)
Baseline leak test 3-10-05, invalid (post-irradiation)
Began aging in Rack 52 at 300ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-23-06 after 11 months
Leak test 7-31-08 after 21 months
Leak test 2-18-09 after 26 months
Leak test 4-6-09 after 27 months
Still in test (rack 52) as of 4-15-09

Fixture 53
Assembled 1-26-05
Baseline leak test 2-22-05, invalid (pre-irradiation)
Baseline leak test 3-23-05, invalid (post-irradiation)
Began aging in Rack 53 at 200ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-23-06 after 11 months
Leak test 7-30-08 after 25 months
Leak test 2-19-09 after 32 months
Still in test (rack 53) as of 4-15-09

Fixture 54
Assembled 1-24-05
Baseline leak test 2-17-05, invalid (pre-irradiation)
Baseline leak test 3-23-05, invalid (post-irradiation)
Began aging in Rack 54 at 200ºF on 5-3-05
Leak test 2-28-06 after 6 months
Leak test 8-22-06 after 11 months
Leak test 7-30-08 after 24 months
Leak test 2-11-09 after 32 months
Still in test (rack 54) as of 4-15-09

Fixture 55
Assembled 1-24-05
Baseline leak test 2-22-05, invalid (pre-irradiation)
Baseline leak test 4-4-05, invalid (post-irradiation)
Began aging in Rack 55 at 200ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-22-06 after 11 months
Leak test 7-31-08 after 24 months
Leak test 3-5-09 after 32 months
Still in test (rack 55) as of 4-15-09

Fixture 56
Assembled 2-24-05
Baseline leak test 3-23-05, invalid
Began aging in Rack 56 at 200ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-22-06 after 11 months
Leak test 7-30-08 after 23 months
Leak test 3-5-09 after 30 months
Still in test (rack 56) as of 4-15-09

Fixture 57
Assembled 2-24-05
Baseline leak test 3-23-05, invalid
Baseline leak test 5-11-05
Began aging in Rack 57 at 200ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-23-06 after 11 months
Leak test 7-31-08 after 23 months
Leak test 3-5-09 after 31 months
Still in test (rack 57) as of 4-15-09

Fixture 58
Assembled 2-24-05
Baseline leak test 5-11-05
Began aging in Rack 58 at 300ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 10-3-06 after 10 months
Removed from test 1-2-07 due to overheating

Fixture 59
Assembled 2-24-05
Baseline leak test 5-10-05
Began aging in Rack 59 at 300ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-29-06 after 11 months
Removed from test 1-2-07 due to overheating

Fixture 60
Assembled 2-24-05
Baseline leak test 4-28-05
Began aging in Rack 60 at 300ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-29-06 after 10 months
6-1-07 Fixture disassembled after 455 days in test due to high temperature failure

Fixture 61
Assembled 2-24-05
Baseline leak test 3-23-05, invalid
Began aging in Rack 61 at 300ºF on 5-2-05
Leak test 2-28-06 after 6 months
Leak test 8-24-06 after 11 months
Leak test 7-31-08 after 23 months
Leak test 3-4-09 after 29 months
Leak test 4-6-09 after 30 months
Still in test (rack 61) as of 4-15-09

Fixture 62
Assembled 2-24-05
Baseline leak test 3-23-05, invalid
Began aging in Rack 62 at 300ºF on 5-2-05
Leak test 2-28-06 after 6 months
Fixture disassembled after 283 days in test due to high temperature failure

Fixture 62-2007
Re-assembled 62 with new O-rings 6-4-07
Baseline leak test – no record of leak test
Began aging in Rack 62 at 300ºF on 6-8-07
Stop aging in rack on 6-28-07 after 20 days at temperature
Aged in oven for ~6 months
Fixture disassembled 9-5-08

High Temperature Fixtures

Fixture 14D
Assembled 10-30-08
Baseline leak test 11-4-08
Began aging in Rack 14 at 400ºF on 11-4-08
Leak test 11-13-08 after 8 days
Leak test 12-5-08 after 28 days
Leak test 12-30-08 after 45 days (both O-rings failed)
45 days at temperature
Fixture disassembled 2-2-09

Fixture 18D
Assembled 10-16-08
Baseline leak test 10-16-08
Began aging in Rack 18 at 350ºF on 10-28-08
Leak test 11-10-08 after 8 days
Leak test 12-5-08 after 28 days
Leak test 12-30-08 after 46 days
Leak test 1-22-09 after 67 days
Leak test 2-23-09 after 91 days
Leak test 3-24-09 after 108 days
Still in test (rack 18) as of 4-15-09

Fixture 19D
Assembled 10-30-08
Baseline leak test 11-4-08
Began aging in Rack 19 at 350ºF on 11-4-08
Leak test 11-13-08 after 8 days
Leak test 12-5-08 after 28 days
Leak test 12-30-08 after 45 days
Leak test 1-22-09 after 66 days
Leak test 2-23-09 after 90 days
Leak test 3-24-09 after 107 days
Still in test (rack 19) as of 4-15-09

Fixture 21D
Assembled 10-30-08
Baseline leak test 11-4-08
Began aging in Rack 21 at 400ºF on 11-4-08
Leak test 11-13-08 after 8 days
Leak test 12-5-08 after 28 days (both O-rings failed)
28 days at temperature
Fixture disassembled 2-2-09

Fixture 23D
Assembled 10-16-08
Baseline leak test 10-16-08
Began aging in Rack 23 at 450ºF on 10-27-08
Leak test 11-10-08 after 8 days (outer O-ring failed)
Leak test 12-5-08 after 10 days (inner O-ring only)
Leak test 12-17-08 after 12 days (inner O-ring failed)
12 days at temperature
Fixture disassembled 1-28-09

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