SRNL-STI-2010-00654
Rev. 0

DESTRUCTIVE EXAMINATION OF SHIPPING PACKAGE 9975-02168

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Publication Date: November 2010

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This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy.

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Revision Log

Document No. SRNL-STI-2010-00654 **Rev. No.** 0

Document Title Destructive Examination of Shipping Package 9975-02168

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Nomenclature

ASTM – American Society for Testing and Materials

DSA – Documented Safety Analysis

FT-IR – Fourier Transform Infrared Spectroscopy

ID – Inside Diameter

KAC – K-Area Complex

OD – Outside Diameter

PCV - Primary Containment Vessel

RH – Relative Humidity

SAT – Satisfactory

SCV – Secondary Containment Vessel

SEM – Scanning Electron Microscope

SPA – Surveillance Program Authority

SRNL – Savannah River National Laboratory

SRS – Savannah River Site

UNSAT – Unsatisfactory

WME – Wood Moisture Equivalent

Destructive Examination of Shipping Package 9975-02168

Summary

Destructive and non-destructive examinations have been performed on specified components of shipping package 9975-02168. For those attributes that were also measured during the field surveillance, no significant changes were observed. Two conditions were identified that do not meet inspection criteria. These conditions are subject to additional investigation and disposition by the Surveillance Program Authority. The conditions include:

- The lead shield was covered with a white corrosion layer.
- Fiberboard thermal conductivity in the axial direction exceeded the specified range.

The Surveillance Program Authority was notified of these conditions and will document the findings by surveillance report. All other observations and test results met identified criteria, or were collected for information and trending purposes.

Introduction

The Savannah River Site (SRS) stores packages containing plutonium (Pu) materials in the K-Area Complex (KAC). The Pu materials are packaged per the DOE 3013 Standard and stored within Model 9975 shipping packages in KAC.

The KAC facility DSA (Document Safety Analysis) [1] credits the Model 9975 package to perform several safety functions, including criticality prevention, impact resistance, containment, and fire resistance to ensure the plutonium materials remain in a safe configuration during normal and accident conditions. The Model 9975 package is expected to perform its safety function for at least 12 years from initial packaging. The DSA recognizes the degradation potential for the materials of package construction over time in the KAC storage environment and requires an assessment of materials performance to validate the assumptions of the analysis and ultimately predict service life.

As part of the comprehensive Model 9975 package surveillance program [2-3], destructive examination of package 9975-02028 was performed following field surveillance in accordance with Reference [4]. Field surveillance of the Model 9975 package in KAC included nondestructive examination of the drum, fiberboard, lead shield and containment vessels [5]. Results of the field surveillance are provided in Attachment 1.

Package History

Fabrication of package 9975-02168 was completed by Accurate Machine Products Corporation on April 15, 2003. The package contained plutonium oxide material from Rocky Flats packaged in accordance with DOE-STD-3013. RFETS loaded and shipped this package to KAC, where it was received on August 8, 2003. Routine field surveillance was performed on July 7, 2010. SRNL received the package on July 13, 2010 and performed destructive examination activities between July 15 and October 7, 2010.

Discussion

The results of the field surveillance [6] were reviewed. No unsatisfactory conditions were noted. As the package was opened, and components removed, each component was marked to identify its orientation within the package. For components that were removed during the field surveillance, their orientation at the time of this examination probably bears no relation to their orientation while stored in KAC. However, the bottom fiberboard subassembly and lead shield would likely have remained in the same orientation they occupied in KAC.

Examination activities are documented through photographs, data sheets, and other documents. This documentation is maintained in a laboratory notebook [7]. The following examination activities were performed:

Fiberboard physical properties:

The weight and dimensions of the top and bottom fiberboard subassemblies were measured. The weight of the top subassembly was 12.138 kg (26.76 lb). During the field surveillance, the measured weight of the top subassembly was 26.8 lb. These two values are in good agreement. Weight and dimension data are recorded in Table 1.

The air shield was cut and peeled back at four locations to permit accurate measurement of the top fiberboard subassembly dimensions. In order to calculate the density of each subassembly, nominal dimensions were assumed for the aluminum bearing plate and air shield. The calculated densities (0.27 g/cc top subassembly, 0.28 g/cc bottom subassembly) meet the limit for the criticality control function, 0.20 g/cc minimum [4]. The volume and density were calculated using the following equations (see the Table 1 sketch for dimension nomenclature).

Top subassembly fiberboard volume,

$$V_U = (UD1)^2\,(UH1)\,(\pi/4) + [(UD1) - 2\,(UR2)]^2\,(UH2)\,(\pi/4) - (UD2)^2\,(UH3)\,(\pi/4) - 59.96\ \text{inch}^3$$

Top subassembly fiberboard weight, W_U = upper subassembly weight – 9.773 lb

Top subassembly fiberboard density, $\rho_U = W_U / V_U$

Bottom subassembly fiberboard volume,

$$V_L = (LD1)^2\,(LH1)\,(\pi/4) - [(LD2) + 2\,(LR1)]^2\,(LH3)\,(\pi/4) - (LD2)^2\,(LH2)\,(\pi/4) - 59.96\ \text{inch}^3$$

Bottom subassembly fiberboard weight, W_L = bottom subassembly weight – 4.827 lb

Bottom subassembly fiberboard density, $\rho_L = W_L / V_L$

Fiberboard dimensions measured during field surveillance are summarized in Attachment 1, and are consistent with drawing requirements and destructive examination measurements. For each of the five dimensions measured in both the field surveillance and destructive examination, the measured values are similar. The dimensions were measured twice during destructive examination, 8 and 51 days after the field surveillance. Although the changes in measured fiberboard dimensions vary, they are generally in a consistent direction from field surveillance through the two destructive examination measurements. No significant observations were found with the fiberboard physical measurements.

Fiberboard visual appearance:

No significant material or physical damage was observed, and layers were well bonded. The lower subassembly came out smoothly without interference, and gaps exist against the drum.

Following removal of both the top and bottom fiberboard subassemblies from the outer drum, both were inspected visually. No anomalous conditions were observed.

Fiberboard moisture content:

The moisture content of the fiberboard will affect its properties, including density, mechanical strength and thermal properties. Measuring the moisture content of the top and bottom subassemblies, and the relative humidity inside the package, provides reference data to potentially correlate laboratory test results with behavior in KAC. The fiberboard moisture content was measured twice during destructive examination activities – upon receipt of the package, and again approximately 7 weeks after field surveillance. Measurements were also taken during field surveillance to the extent the fiberboard was accessible.

A GE Protimeter Surveymaster moisture probe was used to measure the moisture content of the top and bottom fiberboard subassemblies. This probe identifies the wood moisture equivalent (WME), or the weight % of moisture that would produce the same electrical conductivity in wood. Moisture measurements of both the upper and lower subassemblies were made soon after opening the drum. Moisture content data are presented in Figure 1.

Moisture measurements were compared to those taken during previous destructive examinations [8 – 12]. The readings on 9975-02168 are higher on average than seen on previous packages, although most of the readings fall within the range previously observed. The moisture content of the 9975-02168 fiberboard most closely resembles than of 9975-02028 (among the packages previously examined destructively); both have similar patterns of moisture distribution, although the moisture content at most locations is slightly higher in 9975-02168. Despite the higher moisture content of 9975-02168, no mold was observed, while mold was present in 9975-02128.

Fiberboard moisture measurements were made during field surveillance for both 9975-02168 and 9975-02028 (examined in FY09). In both cases, the moisture gradient across the fiberboard sidewall decreased significantly between field surveillance and subsequent moisture measurements (6-7 weeks later). The initial measurements made on 9975-02168 after receipt in

SRNL indicate most of this decrease in moisture gradient occurred within the first week after the internal heat load was removed during field surveillance.

Consistent with recent efforts to correlate moisture content of fiberboard with humidity in the surrounding air, several sets of data were taken to correlate these two parameters. The fiberboard was placed back in the drum with a narrow channel cut down the side. A humidity probe was placed in this channel such that it could be raised and lowered with the drum closed. The edge of the drum lid was taped to seal around the gap created by the humidity probe cable. After the humidity came to equilibrium, humidity readings were taken at several elevations along the fiberboard, and the fiberboard was then removed to measure the moisture content at those same locations. This process was repeated several times to show the consistency in the results. These data are summarized in Figure 2, and compared to similar data from 9975-02028 and laboratory samples. All the data show a similar trend, although the data for the two 9975 packages are offset slightly from that for laboratory samples.

Fiberboard thermal and mechanical properties:

Samples of fiberboard were removed from the bottom fiberboard subassembly to measure compressive strength, specific heat capacity and thermal conductivity. The source location(s) of these samples is illustrated in Figure 3. The thermal conductivity sample from the bottom center of the subassembly is oriented for heat flow in the axial direction (perpendicular to the glue joints). The thermal conductivity sample from the side is oriented for heat flow in the radial direction (parallel to the glue joints). Testing on each sample was performed at a nominal (mean) temperature of approximately 25ºC (77ºF), with no environmental conditioning. Physical data on the fiberboard samples are recorded in Table 2.

The compression test data are shown in Figures 4 and 5, along with select baseline data. For both the perpendicular and parallel orientations, the compression strength of the 9975-02168 samples is similar to the baseline samples conditioned at 77ºF and 70% RH. A series of photographs showing typical compression behavior under parallel loading is shown in Figure 6.

A total of six samples were prepared from the side and base of the lower subassembly for measuring the specific heat capacity of the fiberboard. The specific heat capacity was calculated in accordance with ASTM C351 at a mean temperature of ~25ºC (77ºF). This ASTM Standard specifies test temperatures that would produce a mean test temperature of 60ºC, but allows alternate test temperatures to be substituted as needed. Data were collected for a sample target temperature of 45ºC, and a water temperature of ~5ºC. The sample moisture content was 10.6 – 12.3 % WME (wood moisture equivalent). Each sample was tested three times, and all results were averaged. The average value was 1290 J/kg-K. Multiplying this value by the density of the lower subassembly (281 kg/m^3) gives a heat capacity of 362,000 J/m^3-K (5.39 Btu/ft^3-F). This meets the required minimum value of 3 Btu/ft^3-F. The specific heat capacity value is consistent with typical baseline laboratory data.

The thermal conductivity of the fiberboard was measured with a Lasercomp Inc. Fox 300 thermal conductivity instrument at a mean temperature of 25ºC (77ºF). For the sample with axial heat flow (perpendicular to the fiberboard layers), the measured thermal conductivity is 0.0628

W/m-K (0.0363 Btu/hr-ft-ºF). This value falls outside the acceptance range identified for destructive examinations (0.025 – 0.035 Btu/hr-ft-ºF [4]), but is consistent with values measured for typical unaged lab samples [13]. For the sample with radial heat flow (parallel to the fiberboard layers), the measured thermal conductivity is 0.1006 W/m-K (0.0581 Btu/hr-ft-ºF). This value falls within the identified range of 0.053 – 0.067 Btu/hr-ft-ºF [4]. The thermal conductivity values are consistent with typical baseline laboratory data.

Lead shield visual examination:

The entire surface of the lead shield was visually examined. It was found to be free from significant deformation and physical damage, but much of the outside surface (in contact with the fiberboard) was covered with a white corrosion product (Figure 7). Areas of corrosion product near the bottom of the shield were flaking off when handled. Reference 4 identifies the presence of corrosion on the shield as an unsatisfactory condition. In contrast, current field surveillance criteria allow the presence of corrosion product, so long as there is no flaking, blistering or spalling [6]. The flaking observed near the bottom of this shield during destructive examination would not have been noted during field surveillance since the shield was not removed from the package at that time. From prior examination of the shield from package 9975-02234, the corrosion product was identified as basic lead carbonate (hydrocerrusite), $Pb_3(CO_3)_2(OH)_2$. No further characterizations of the corrosion product were performed.

Lead Shield Dimensions:

Several lead shield dimensions were measured (Table 3) and all are consistent with drawing requirements.

The radial thickness was measured near the top of the shield, and was calculated from diametral data taken near the bottom of the shield. The calculated thickness from near the bottom (0.5455 inch) is essentially the same as the measured thickness near the top (0.550 inch). While lead is known to creep at ambient temperatures, these data suggest that no significant creep deformation has occurred thus far, since creep would tend to reduce the thickness near the top relative to the bottom.

O-ring examination and testing:

Prior surveillance testing of the four O-rings from this package included visual examination, dimensional and hardness measurements. Three of these O-rings (SCV outer, PCV outer and PCV inner) received additional testing. All three were submitted for FT-IR spectroscopy to confirm material composition, and the two outer O-rings received optical and SEM microscopic examination of the cross section. The dimensions and weight of the SCV outer and PCV outer O-rings were recorded to calculate their density. The PCV inner O-ring was tensile tested, including a hold point at 50% strain to visually examine the O-ring.

FT-IR spectroscopy generically identified the composition of each O-ring as consistent with a Viton® type fluoroelastomer (Figure 8). Viton® A produces a spectrum nearly identical to Viton® GLT, the base polymer for the specified O-ring compound (Parker Seals V0835-75) and the two are difficult to distinguish by FT-IR analysis alone. Additional test techniques (e.g. dynamic mechanical analysis, DMA) would be required to uniquely verify the GLT composition. These results are similar to those from previous destructive examination packages [8 – 12] and are consistent with baseline data [14].

As with previous destructive examinations, visual (Figure 9) and SEM (Figure 10) examination of the cross sections identified a distribution of very small particles throughout each O-ring. Aside from carbon and fluorine (which are the primary constituents of Viton®) the SEM identified aluminum, silicon, oxygen, zinc, calcium and bromine. These elements are present in small amounts, and are generally associated with the particles. Though the actual compound is proprietary, zinc, calcium and oxygen are consistent with Viton®-type fluoroelastomer compounds, which typically contain MgO, CaO, $Ca(OH)_2$, ZnO or lead compounds as acid acceptors and heat stabilizers [15]. Aluminum is present in hydrotalcite, which is used in both GLT and GLT-S compounds as a filler reinforcing agent Silicon may be present as a trace contaminant.

Weight and dimension data for the two outer O-rings are presented in Table 4. The average minor diameter for each O-ring is within the specified tolerances for new O-rings, but the major inside diameter for each O-ring (calculated from the length measured after the O-ring was cut) is greater than specified for new O-rings. This is consistent with a permanent stretch due to the lid diameter. Leak testing during the field surveillance was successful.

The PCV inner O-ring was tensile tested in accordance with ASTM D1414, using a cut (single strand) sample. The test was interrupted at 50% strain to visually examine the O-ring for signs of cracking or other degradation. None were observed. The stress-strain curve for the PCV inner O-ring is shown in Figure 11 along with curves from a new O-ring and from previous destructive examinations. The O-ring from package 9975-02168 displayed tensile properties (strength and elongation) consistent with that observed in previous examinations. The elongation (333%) of this O-ring exceeds the minimum value specified in AMS-R-83485 for new O-rings (120%), while the tensile strength (1.6 ksi) matches the minimum value specified (1.6 ksi) [14]. While Parker Seals does not change the formulation of these O-rings, there are batch variations.

General:

A general visual examination was performed on all metallic components. Aside from the corrosion of the lead shield (discussed above) no significant damage or degradation was observed, although there was light corrosion on some of the drum closure bolts (Figure 12). A similar observation of rust staining of the top drum surface was made during field surveillance. Several components were observed to have fabrication markings. Various markings were stamped or engraved on the containment vessels and lids (Figure 13). These markings appear to be identification numbers used during manufacture, prior to association of the parts with a final package number.

The distance from the drum flange to the top of the air shield was measured, and ranged from 0.974 to 1.047 inch. The average value was 1.009 inch. The drum drawing [16] identifies a reference value for this dimension as 0.8 inch, and notes that it may vary over time due to variations in fiberboard properties. Pre-operational verification requirements, consistent with fire and drop test qualifications for the 9975 package, specify this dimension be no greater than 1 inch. During field surveillance, the average value of this dimension (0.982 inch) met this requirement. The increase in this dimension likely resulted during transport of the package to SRNL - the dynamic conditions of transport may have caused some compaction.

The data from the examination activities described above are compared with field surveillance data in Attachment 1. Two conditions were observed that do not meet specified criteria. The Surveillance Program Authority (SPA) was notified of these conditions, and will direct further investigation and analysis as appropriate. They are summarized as follows:

- The lead shield was partially covered with a white corrosion layer.
- Fiberboard thermal conductivity in the axial direction exceeded the specified range.

Two additional conditions were noted, although they did not violate destructive examination criteria. These are the dimension from the drum flange to the air shield, and superficial rust on some of the closure bolts. All other observations and examination results are consistent with expectations. All findings will be reviewed by NMM for potential impact on the continued storage of other packages in KAC.

Measurement Uncertainties:

Numerous measurements were made with a variety of instruments during the destructive examination of package 9975-02168. Some of the measurements were specifically compared to inspection criteria, while others were taken for information / trending purposes. All measurements which are compared to inspection criteria were made with calibrated instruments, or were verified against calibrated instruments. The uncertainties associated with measurements and calculated results required to meet inspection criteria are discussed below.

<u>Weight</u> – The weight of each fiberboard subassembly was measured to the nearest 2 grams. The balance used was M&TE, and the calibration data shows an accuracy within 4 grams over the range of interest. A conservative net uncertainty of 6 grams will be used.

<u>Calipers</u> – Three different calipers were used to measure component dimensions. All three calipers are M&TE, and calibration data show an accuracy within 0.001 inch. In addition, operator bias can affect measurement accuracy through the contact load applied when making a measurement. A degree of give exhibited by the fiberboard will lead to different results as the contact load changes. The larger calipers are judged to be more susceptible to this bias. Metallic components are significantly more rigid than the fiberboard, but operator bias may also exist for those components. While not characterized explicitly, it is judged that the total uncertainty (instrument uncertainty plus operator bias) for fiberboard measurements is no greater than +/- 0.003 inch for the 6 inch calipers, +/- 0.005 inch for the 24 inch calipers, and +/- 0.007 inch for the 40 inch calipers. It is further judged that total uncertainty when measuring metallic components is no greater than +/- 0.003 inch for 6 and 24 inch calipers, and +/- 0.005 inch for the 40 inch calipers.

Manual calipers – Dimension ID2 on the lead shield was captured with manual swing calipers, which was then locked in that position and measured with 24-inch calipers. It is judged that the accuracy of capturing this dimension with the manual calipers is within +/- 0.002 inch, and the measurement of that dimension is then within +/- 0.002 inch, for a (conservatively) combined accuracy of +/- 0.004 inch.

Thermal conductivity instrument – The specifications for the Fox300 thermal conductivity instrument include a stated accuracy of ~1%. Measurement of the thermal conductivity of a calibration standard was accurate to within 1.1%. Prior test reports of fiberboard samples from an independent laboratory, using the same model instrument, identified an overall 3% uncertainty. An uncertainty of 3% will be conservatively assumed for the current measurements.

Heat capacity – The specific heat capacity is derived from temperature and weight measurements, using calibrated instruments. The thermocouple and balance precisions are high. The greatest contribution to error in the specific heat capacity is considered to be consistency of operator technique. The total uncertainty is reflected in the range of results for multiple trials. The heat capacity was measured three times on each of six samples. The variation for each sample ranged from 5 to 22%. The combined uncertainty on the average of 6 samples is 6%.

Where measurement results are used in subsequent calculations, the uncertainty values identified above are assumed to be random. A standard error propagation formula for random errors is used to calculate the final result uncertainty. In some cases, the calculated uncertainty may be less than the potential error from rounding off the result, and the higher variation associated with round-off is reported as the uncertainty. These calculations are documented in the Laboratory Notebook [7]. Calculation results and their uncertainties are summarized as follows:

- Top fiberboard subassembly volume = 28761 +/- 26 cm^3
- Top fiberboard subassembly density = 0.268 +/- 0.001 g/ cm^3
- Bottom fiberboard subassembly volume = 86523 +/- 73 cm^3
- Bottom fiberboard subassembly density = 0.281 +/- 0.001 g/ cm^3
- Shield radial thickness at bottom = 0.5455 +/- 0.003 inch
- Thermal conductivity (radial) = 0.0581 +/- 0.002 Btu/hr-ft-ºF
- Thermal conductivity (axial) = 0.0363 +/- 0.001 Btu/hr-ft-ºF
- Heat capacity = 4.9 +/- 0.3 Btu/ft^3-ºF

References

[1] WSRC-SA-2002-00005, Rev. 1CN-7, "K-Area Material Storage Facility Documented Safety Analysis", June 2008.

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[3] WSRC-TR-2001-0286, Rev. 4, "The Savannah River Site Surveillance Program for the Storage of 9975/3013 Plutonium Packages in KAC", July 2008

[4] WSRC-TR-2005-00135, "Task Technical and Quality Assurance Plan for Destructive Examination of a 9975 Package from Field Surveillance Activities", W. L. Daugherty, April 2005

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[6] SOP-CSS-207-K, Rev. 7, Attachment 2 "9975 Surveillance Data Sheet" for surveillance SRNS-SRV-2010-011

[7] WSRC-NB-2008-00002, Laboratory Notebook "9975 Shipping Package Celotex Testing Book III"

[8] WSRC-TR-2005-00273, Rev. 1, "Destructive Examination of Shipping Package 9975-02234", W. L. Daugherty, September 2005

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[12] SRNL-STI-2009-00763, "Destructive Examination of Shipping Package 9975-02028", W. L. Daugherty and T. M. Stefek, December 2009

[13] SRNL-MST-2008-00038, "Properties of Un-Aged Cane Fiberboard for Thermal Modeling", W. L. Daugherty, February 22, 2008

[14] WSRC-TR-2004-00162, "Baseline Characterization of Model 9975 Shipping Package O-Rings", T. E. Skidmore, March 2004

[15] Rubber Technology Handbook, W. Hofmann, Hanser Publishers, New York, 1989, page 122

[16] Drawing R-R2-F-0025, Rev. 5, "9975 Drum with Flange Closure Subassembly & Details"

Table 1. Fiberboard physical measurements and calculated density

Top Subassembly						
Weight	12.138 kg					R-R2-F-0019 Rev 5
	0/180 deg.		90/270 deg.		Avg.	Nominal value (inch)
UD1 (in)	17.678		17.670		17.674	17.7
UD2 (in)	8.550		8.562		8.556	8.55
	0 deg.	90 deg.	180 deg.	270 deg.	Avg.	
UR1 (in)	3.058	3.050	3.051	3.052	3.053	3.075
UR2 (in)	1.451	1.503	1.566	1.499	1.505	1.5
UH1 (in)	7.126	7.118	7.092	7.071	7.102	7.1
UH2 (in)	2.085	2.096	2.120	2.095	2.099	2.1
UH3 (in)	5.006	5.011	4.997	5.001	5.004	5.0

Top subassembly calculated density = 0.268 g/cc

Bottom Subassembly						
Weight	26.460 kg					R-R2-F-0019 Rev 5
	0/180 deg.		90/270 deg.		Avg.	Nominal value (inch)
LD1 (in)	18.093		18.100		18.096	18.1
LD2 (in)	8.467		8.478		8.472	8.45
	0 deg.	90 deg.	180 deg.	270 deg.	Avg.	
LR1 (in)	3.248	3.272	3.283	3.268	3.268	3.275
LR2 (in)	1.493	1.489	1.497	1.491	1.492	1.55
LH1 (in)	26.658	26.664	26.570	26.596	26.622	26.7
LH2 (in)	20.293	20.283	20.283	20.303	20.290	20.4
LH3 (in)	2.074	2.052	2.037	2.048	2.053	2.0

Bottom subassembly calculated density = 0.281 g/cc

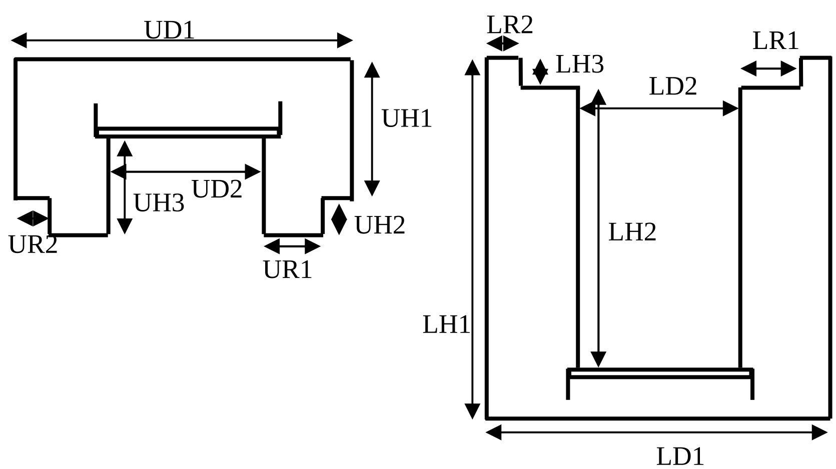


Table 2. Physical data for fiberboard test specimens

Compression Test Sample	Moisture Content (%WME)	Weight (g)	Length (inch)	Width (inch)	Height (inch)	Density (g/cc)
Compression Test Samples						
Side 1 (parallel)	12.5	35.774	1.969	2.034	2.056	0.265
Side 2 (parallel)	12.1	37.632	2.034	2.039	2.055	0.269
Side 3 (perpendicular)	12.3	36.703	2.013	2.051	2.056	0.264
Side 4 (perpendicular)	13.3	36.124	2.050	1.984	2.054	0.264
Base 1 (parallel)	13.3	37.246	2.047	2.052	2.061	0.263
Base 2 (parallel)	13.2	37.594	2.041	2.058	2.053	0.266
Base 3 (perpendicular)	13.4	37.375	2.052	2.062	2.044	0.264
Base 4 (perpendicular)	13.4	38.105	2.033	2.052	2.050	0.272
Thermal Conductivity Samples						
Side (radial)	13.3	304	6.835	7.032	1.442	0.268
Base (axial)	15.3	321	6.993	6.994	1.501	0.267

Table 3. Lead shield dimensions

Dimension	0/180 deg. (inch)		90/270 deg. (inch)		Avg. (inch)	Requirement (inch)
OD (in)	8.341		8.343		8.342	8.252 – 8.35
ID1 (in)	7.256		7.272		7.264	7.25 – 7.26
ID2 (in)	7.218		7.239		7.251	7.24 – 7.26
	0 deg.	90 deg.	180 deg.	270 deg.		
R (in)	0.557	0.548	0.544	0.550	0.550	0.506 min
H (in)	24.671	24.693	24.688	24.681	24.683	24.556 – 24.7

(OD – ID2) / 2 = 0.5455 inch

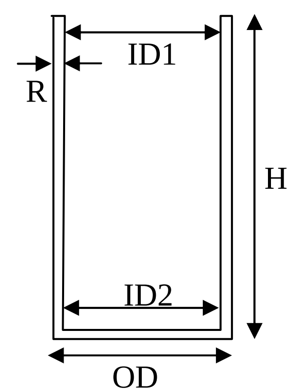


Table 4. O-ring physical data

30 Days after Field Surveillance	PCV Outer O-Ring Thickness		SCV Outer O-Ring Thickness	
	Radial (inch)	Axial (inch)	Radial (inch)	Axial (inch)
Minor Dia. 0 deg	0.1350	0.1350	0.1415	0.1315
Minor Dia. 45 deg	0.1375	0.1335	0.1420	0.1345
Minor Dia. 90 deg	0.1375	0.1340	0.1380	0.1335
Minor Dia. 135 deg	0.1330	0.1370	0.1335	0.1330
Minor Dia. 180 deg	0.1360	0.1365	0.1330	0.1340
Minor Dia. 225 deg	0.1380	0.1350	0.1370	0.1305
Minor Dia. 270 deg	0.1360	0.1360	0.1370	0.1335
Minor Dia. 315 deg	0.1360	0.1350	0.1355	0.1325
Avg. Minor Dia.	**0.1357 inch**		**0.1350 inch**	
Minor Dia. (new)	0.138 +/- 0.006 inch		0.138 +/- 0.006 inch	
Length (after cut)	13 15/16 inch		17 5/32 inch	
Calculated Major Dia.	4.436 inch avg		5.461 inch avg.	
Major Inside Dia. (new)	4.234 +/- 0.030 inch		5.234 +/- 0.035 inch	
Weight	5.909 g		7.137 g	
Calculated Volume	0.2016 $inch^3$ (3.303 cm^3)		0.2458 $inch^3$ (4.027 cm^3)	
Calculated Density	**1.79 g/cm^3**		**1.77 g/cm^3**	

22 Days after Field Surveillance	PCV Outer O-Ring Thickness		SCV Outer O-Ring Thickness	
	Radial (inch)	Axial (inch)	Radial (inch)	Axial (inch)
Minor Dia. 0 deg	0.1345	0.1345	0.1425	0.1300
Minor Dia. 45 deg	0.1380	0.1325	0.1410	0.1330
Minor Dia. 90 deg	0.1375	0.1340	0.1365	0.1340
Minor Dia. 135 deg	0.1335	0.1370	0.1350	0.1340
Minor Dia. 180 deg	0.1365	0.1365	0.1350	0.1340
Minor Dia. 225 deg	0.1375	0.1360	0.1370	0.1300
Minor Dia. 270 deg	0.1355	0.1355	0.1380	0.1330
Minor Dia. 315 deg	0.1345	0.1345	0.1370	0.1305
Avg. Minor Dia.	**0.1355 inch**		**0.1338 inch**	

90 Days after Field Surveillance	PCV Outer O-Ring Thickness		SCV Outer O-Ring Thickness	
	Radial (inch)	Axial (inch)	Radial (inch)	Axial (inch)
Minor Dia. 0 deg	0.1365	0.1340	0.1360	0.1305
Minor Dia. 45 deg	0.1365	0.1345	0.1325	0.1345
Minor Dia. 90 deg	0.1350	0.1340	0.1355	0.1340
Minor Dia. 135 deg	0.1355	0.1340	0.1385	0.1325
Minor Dia. 180 deg	0.1365	0.1365	0.1350	0.1345
Minor Dia. 225 deg	0.1345	0.1365	0.1350	0.1345
Minor Dia. 270 deg	0.1325	0.1355	0.1370	0.1345
Minor Dia. 315 deg	0.1365	0.1355	0.1385	0.1335
Avg. Minor Dia.	**0.1352 inch**		**0.1349 inch**	

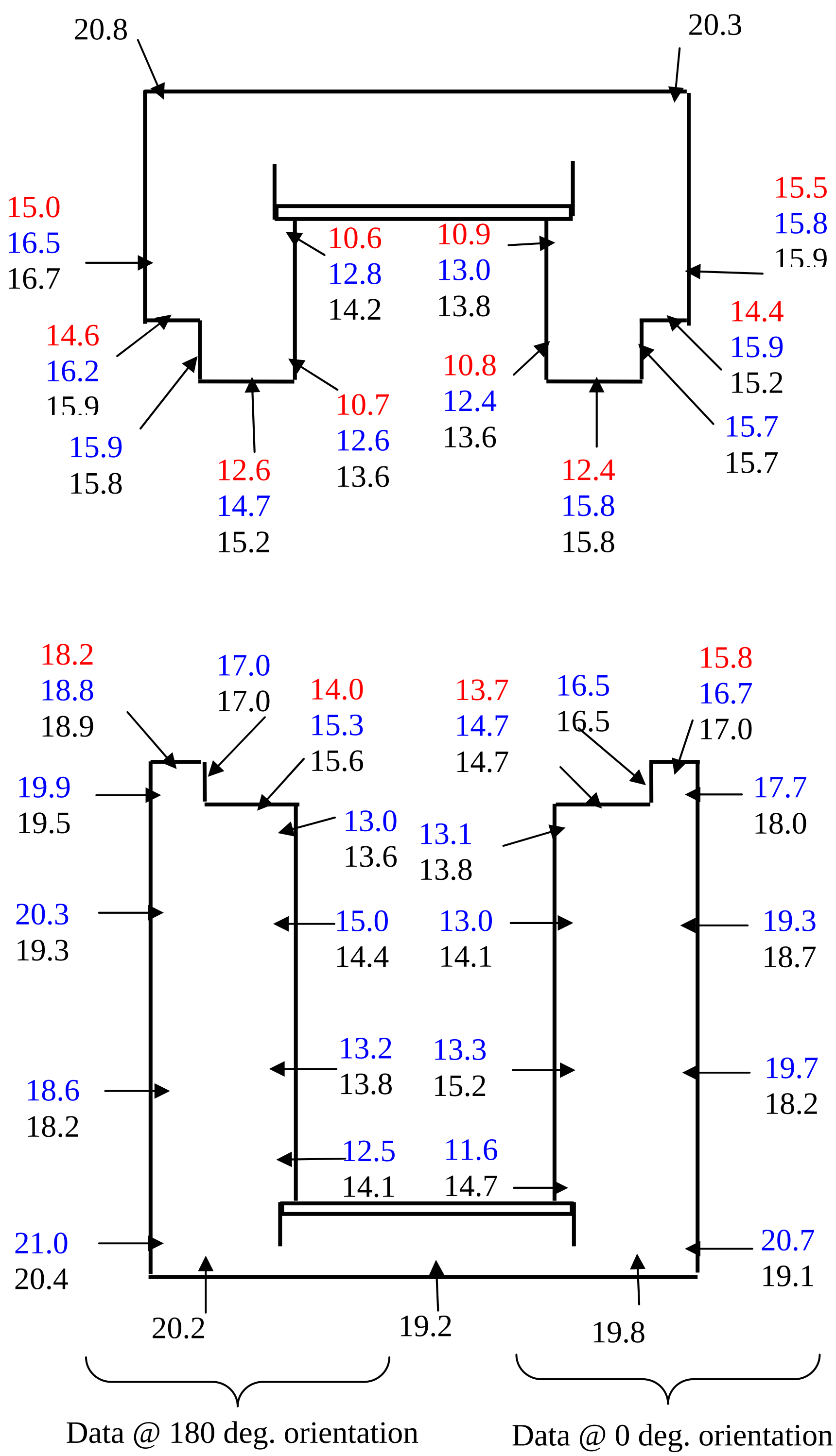


Figure 1. Fiberboard moisture content data. The values in red were measured during field surveillance. The values in blue were measured 8 days later, while the values in black were measured 51 days after field surveillance. All values are % wood moisture equivalent.

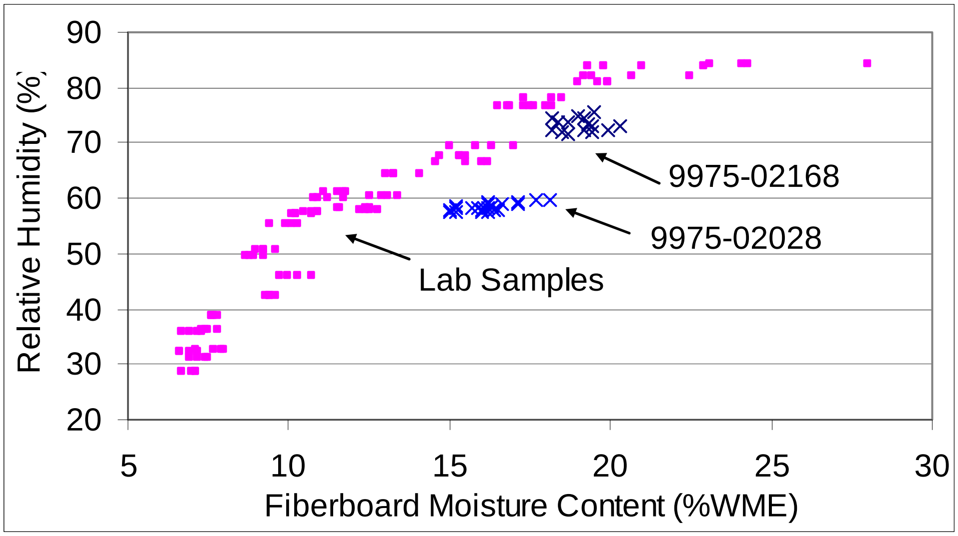


Figure 2. Correlation between fiberboard moisture content and relative humidity of the adjacent air. Data from 9975-02168 are shown with comparable data from 9975-02028 and laboratory samples. Measurements were taken along the fiberboard OD surface.

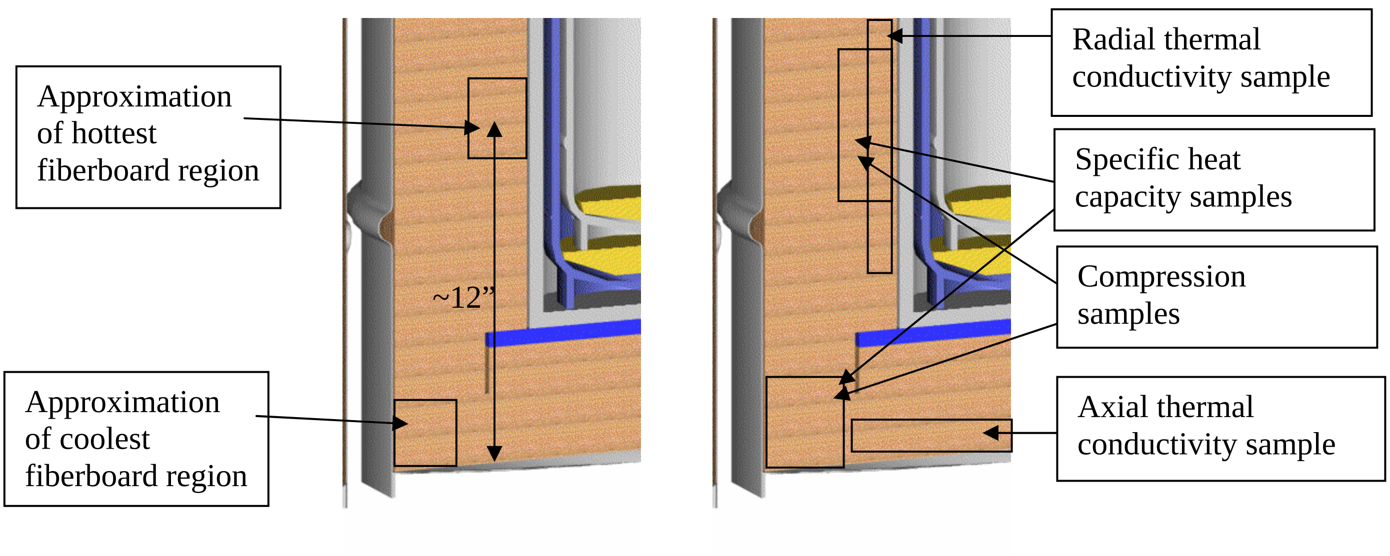


Figure 3. Illustration of fiberboard regions of the bottom subassembly to be tested. Multiple samples (where used) were removed from the illustrated locations at different circumferential positions. Not to scale.

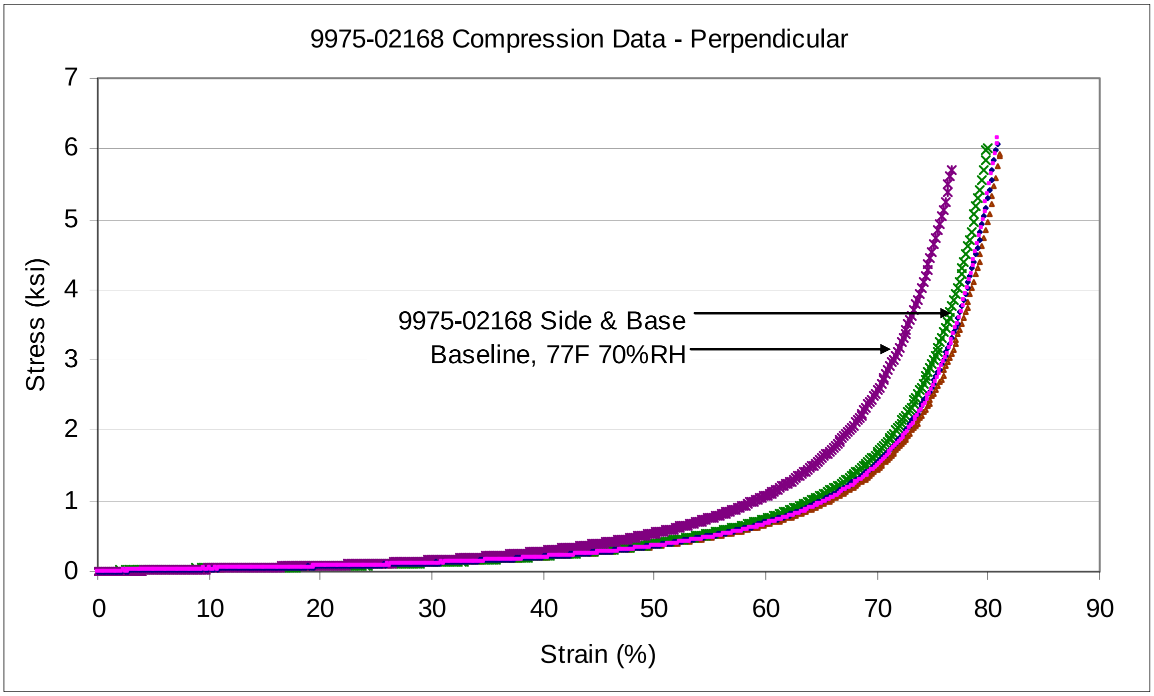


Figure 4. Fiberboard compression test data, compared with typical baseline (77°F, 70% RH) data, in the perpendicular orientation (i.e. load applied perpendicular to the fiberboard layers).

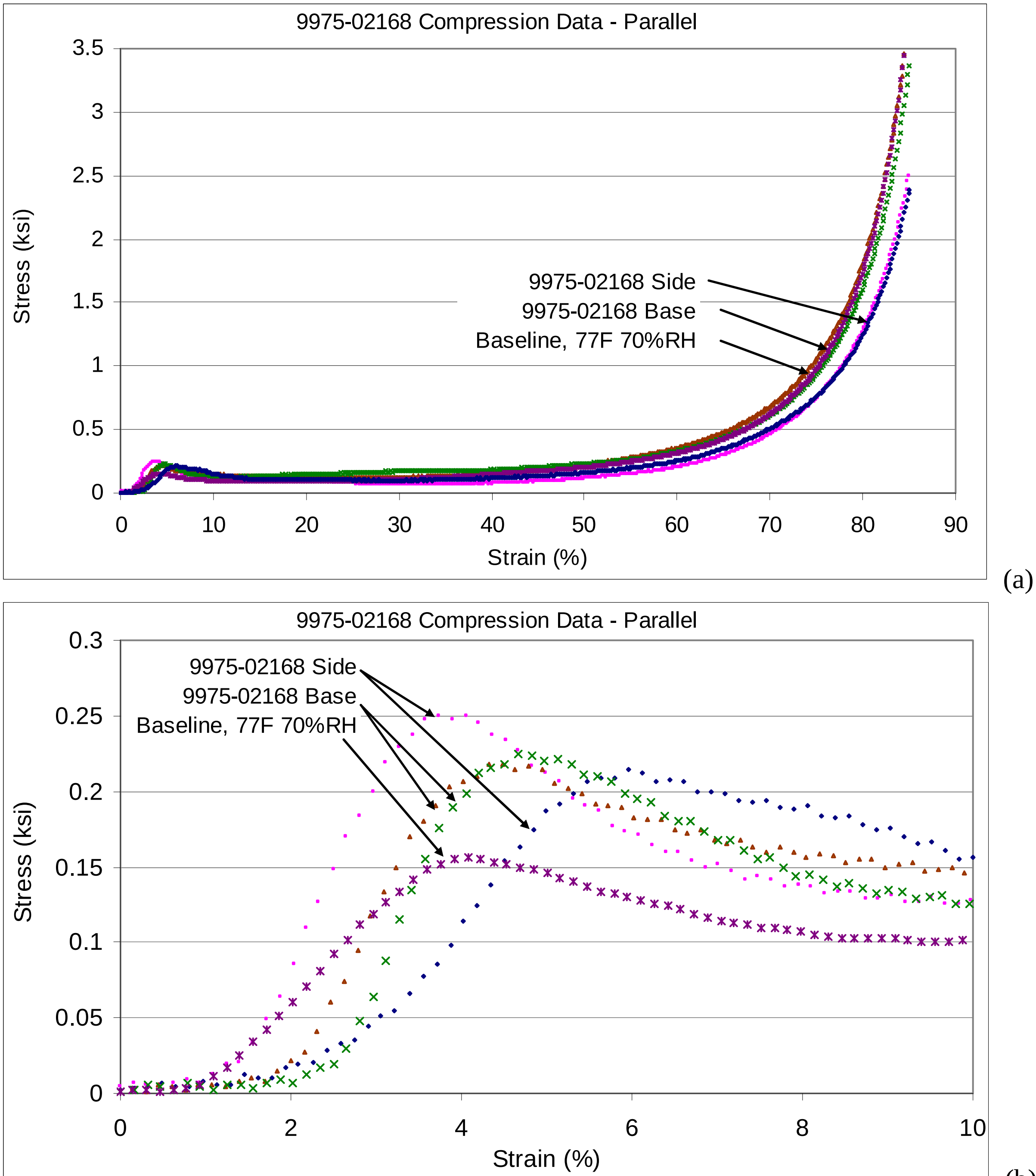
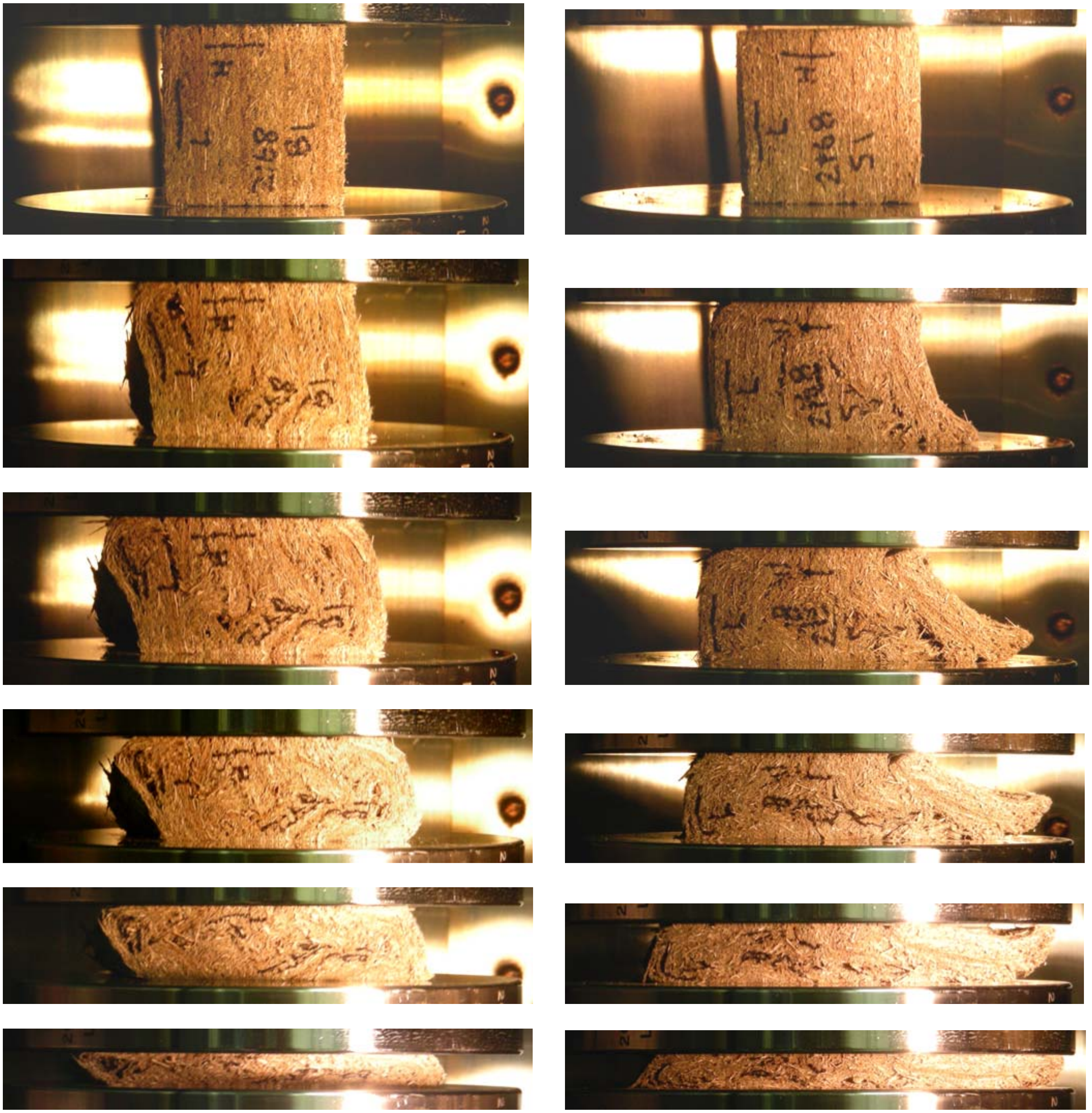


Figure 5. Fiberboard compression test data, compared with typical baseline (77°F, 70% RH) data, in the parallel orientation (i.e. load applied parallel to the fiberboard layers). The full curves are shown in (a), while the initial buckling region is expanded in (b).

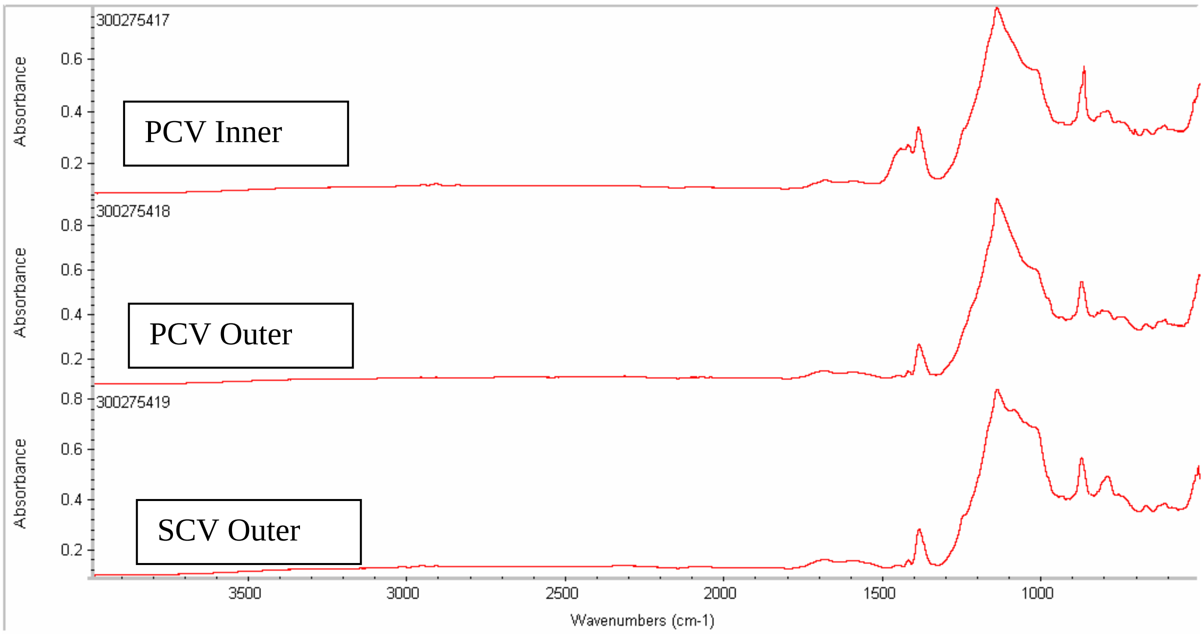


(a) Sample B1 from base of subassembly

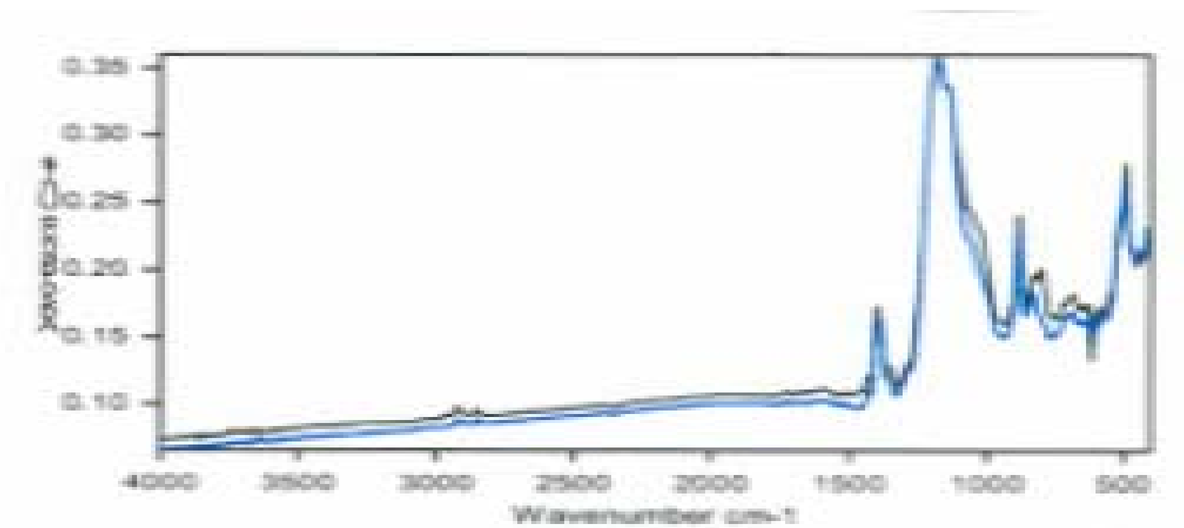
(b) Sample S1 from side of subassembly

Figure 6. Photographs of fiberboard samples during compression testing, parallel orientation

Figure 7. Lead shield with corrosion product.

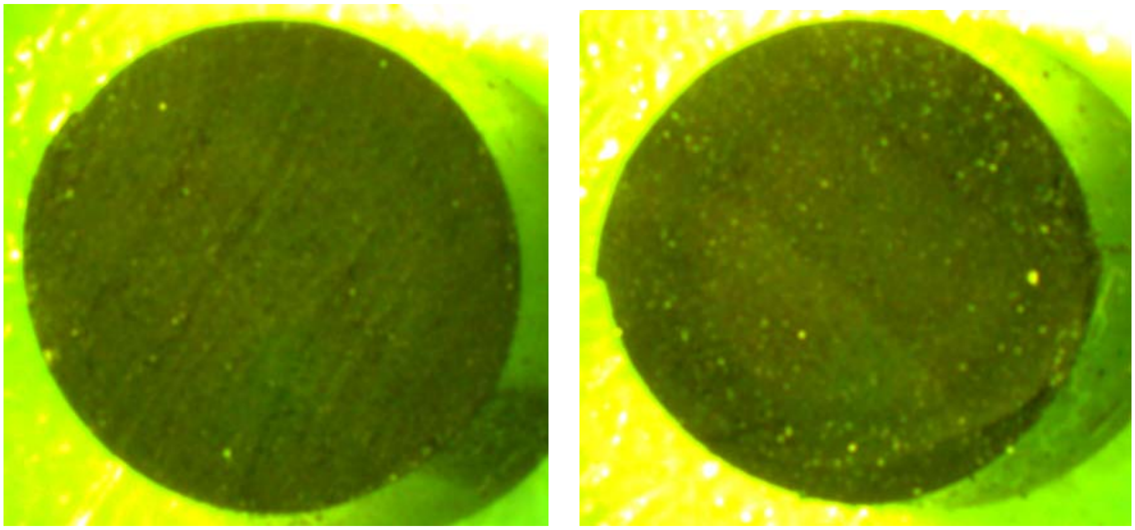


(a)



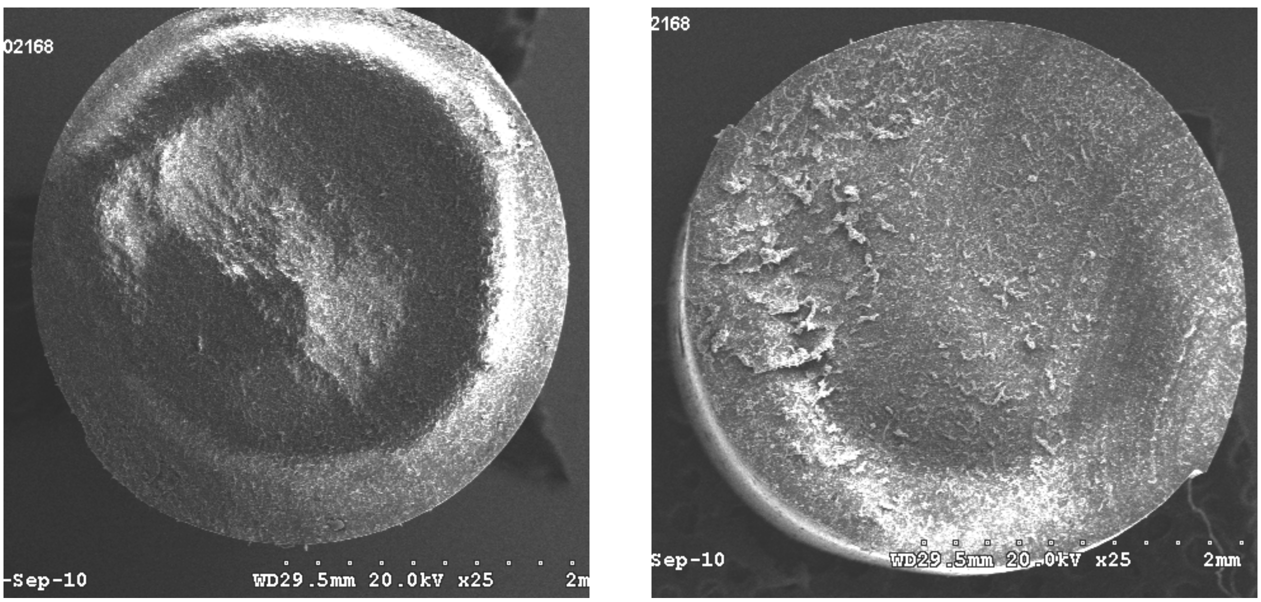
(b)

Figure 8. FT-IR spectra for the three tested O-rings (a). Each spectrum is consistent with a Viton® type fluoroelastomer (b).



(a) (b)

Figure 9. Optical cross section of the (a) PCV outer and (b) SCV outer O-rings.



(a) (b)

Figure 10. SEM cross section of the (a) PCV outer and (b) SCV outer O-rings.

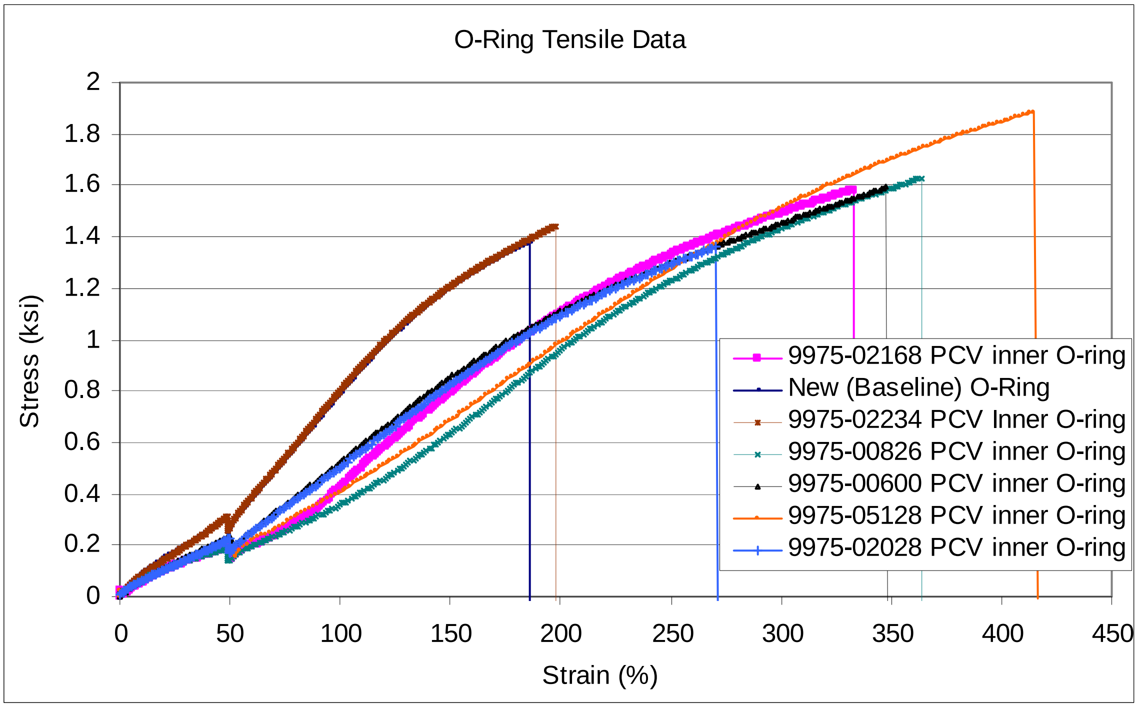


Figure 11. Tensile data for PCV inner O-ring from 9975-02168, compared to a new O-ring and the PCV O-rings from previously examined packages.

Figure 12. Light corrosion on some of the drum closure bolts.

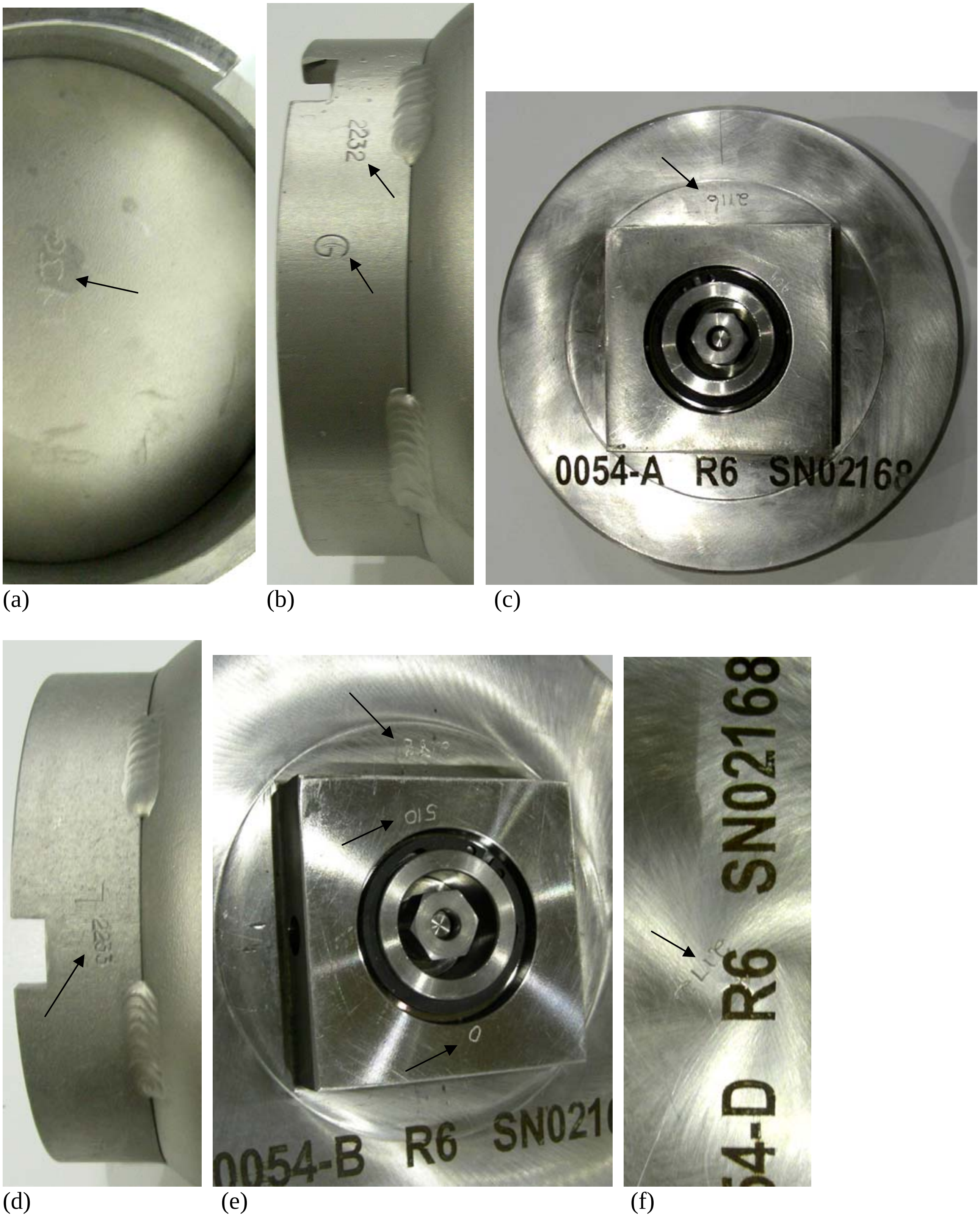


Figure 13. Fabrication markings (at arrows) on PCV (a, b), PCV lid (c) SCV (d) and SCV lid (e, f)

Attachment 1 9975-02028 Field Surveillance Results, with Comparison to Destructive Examination Results

Section I

Drum Exterior Examination

Item	Field Surveillance Result	Destructive Exam. Result
Drum vent plugs are specified and are in place as required	SAT	SAT
Drum surface is not dented beyond 0.25 inch	SAT	SAT
Drum Dents adjacent to the air shield are not deeper than 0.125 inch	SAT	SAT
Drum surface is free from corrosion, swelling/bulging and other physical damage	SAT	SAT

Comment – Rust staining on drum surface (top)

Section II

Humidity Measurements

Humidity at top of the drum 98.8 %RH

Section III

Temperature Measurements

[These data not repeated in this report.]

Section IV

Celotex® Inspection

Upper Celotex® Assembly Weight: <u>26.8 lb (field surv.)</u> <u>12.138 kg / 26.76 lb (destructive exam)</u>

Visual:

Item	Field Surveillance Result	Destructive Exam. Result
Inspect all exposed Celotex® surfaces for significant damage and ensure layers are well bonded	SAT	SAT
Upper Celotex® came out smoothly, without interference	SAT	SAT
All visible Celotex® surfaces are free from staining and variation in coloration	SAT	SAT
Celotex® is free from significant swelling (e.g. gap exists against drum), shrinkage and other significant physical damage	SAT	SAT
Lead shield interior is free from significant deformation and physical damage	SAT	SAT
Lead shield Go/No Go gauge went smoothly into the lead shield and reached all the way to the bottom of the lead shield	SAT	NA

Comments: Slight lead carbonate noted on exterior of lead shield (field surv.). Bands of corrosion on shield – some bands heavier than others (DE).

Attachment 1 9975-02028 Field Surveillance Results, with Comparison to Destructive Examination Results

Celotex® Dimensions (all results reported in inches)

Dimensions		0°	90°	180°	270°	Field Surveillance Average	Destructive Exam. Average
1	Upper Assembly OD	17.658	17.670			17.664	17.674
2	Upper Assembly lower step OD	14.684	14.682			14.683	14.662
3	Upper Assembly ID	8.557	8.538			8.548	8.556
4	Upper Assembly inside height	5.020	4.999	5.001	5.010	5.008	5.004
5	Lower Assembly step height	2.060	2.085	2.073	2.053	2.068	2.053
6	Lower Assembly height from lower step to top of lead shield	4.376	4.012	4.025	4.410	4.206	NA

Dimension	Result	Criteria	Field Surveillance Result	Destructive Exam. Result
Dimension #6 average	4.206	$\leq$ 4.65 ”	SAT	NA
Dimension #1 average – Dimension #3 average	9.117	$\geq$ 8 3/16”	SAT	SAT

Section V

O-Ring Inspection

Test	SAT/UNSAT
O-ring seal test performed on SCV	SAT
SCV O-rings were removed intact	SAT
SCV O-rings have no excess accumulation of grease	SAT
O-ring seal test performed on PCV	SAT
PCV O-rings were removed intact	SAT
PCV O-rings have no excess accumulation of grease	SAT

Comments: Grease noted on SCV lid. Grease noted on PCV lid.

Attachment 1 9975-02028 Field Surveillance Results, with Comparison to Destructive Examination Results

(all dimensional results reported in inches)

Action	0°	90°	180°	270°	Time	Destructive Exam. Average Result
Loosen SCV lid					2250	NA
Outer SCV O-Ring						
Measure OD (while on plug)	6.279	6.281			2259/2259	NA
Measure radial thickness	0.1255	0.1260	0.1260	0.1235	2302/2304	0.1372
Measure vertical thickness	0.1370				2305	0.1329
Inner SCV O-Ring						
Measure OD (while on plug)	6.185	6.186			2305/2306	NA
Measure radial thickness	0.1300	0.1325	0.1265	0.1260	2306/2307	NA
Measure vertical thickness	0.1265				2308	NA
Loosen PCV lid					2326	NA
Outer PCV O-Ring						
Measure OD (while on plug)	5.234	5.237			2338/2340	NA
Measure radial thickness	0.1335	0.1245	0.1260	0.1260	2341/2342	0.1361
Measure vertical thickness	0.1350				2342	0.1353
Inner PCV O-Ring						
Measure OD (while on plug)	5.126	5.125			2345/2346	NA
Measure radial thickness	0.1270	0.1350	0.1350	0.1360	2348/2350	NA
Measure vertical thickness	0.1300				2350	NA

Attachment 1 9975-02028 Field Surveillance Results, with Comparison to Destructive Examination Results

SRNL Receipt Examination of O-Rings

VISUAL EXAMINATION

PCV	PCV Outer	PCV Inner
Grease present	yes	yes
Color (normal or explain)	Normal	Normal
Cross-sectional shape	round	round
Nicks, Scratches, Cracks	none	none
Other Damage (Note extent/size)	none	none
Picture (Note if taken)		

SCV	SCV Outer	SCV Inner
Grease (type, amount)	yes	yes
Color (normal or explain)	Normal	Normal
Cross-sectional shape	round	round
Nicks, Scratches, Cracks	none	none
Other Damage (Note extent/size)	none	none
Picture (Note if taken)		

THICKNESS (all results reported in inches)

PCV	PCV Outer		PCV Inner	
	Axial	Radial	Axial	Radial
Thickness 1 (in)	0.1325	0.1315	0.1360	0.1360
Thickness 2 (in)	0.1350	0.1330	0.1370	0.1325
Thickness 3 (in)	0.1360	0.1340	0.1335	0.1380
Thickness 4 (in)	0.1360	0.1375	0.1325	0.1360
Field Surv. Average	**0.1349**	**0.1340**	**0.1348**	**0.1356**
Destructive Exam Average	**0.1353**	**0.1361**		

SCV	SCV Outer		SCV Inner	
	Axial	Radial	Axial	Radial
Thickness 1 (in)	0.1335	0.1305	0.1325	0.1345
Thickness 2 (in)	0.1315	0.1325	0.1370	0.1400
Thickness 3 (in)	0.1295	0.1390	0.1375	0.1390
Thickness 4 (in)	0.1315	0.1315	0.1355	0.1340
Field Surv. Average	**0.1315**	**0.1334**	**0.1356**	**0.1369**
Destructive Exam Average	**0.1329**	**0.1372**		

Attachment 1 9975-02028 Field Surveillance Results, with Comparison to Destructive Examination Results

SRNL Receipt Examination of O-Rings (Continued)

HARDNESS

	PCV O-Rings		SCV O-Rings	
	Outer	Inner	Outer	Inner
Hardness 1, M-Scale	71.5	77.0	71.0	74.0
Hardness 2, M-Scale	73.0	72.0	74.5	72.0
Hardness 3, M-Scale	73.0	75.0	71.5	69.0
Hardness 4, M-Scale	71.5	72.0	71.0	71.0
Hardness 5, M-Scale	69.0	75.0	73.5	71.0
Average	**71.6**	**74.2**	**72.3**	**71.4**

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