**SUMMARY DOCUMENT**

# Evaluation of Nonmetallic Components in the Hanford Waste Transfer

**Date submitted:**

March 31, 2017


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Work supported by: U.S. Department of Energy
Office of Environmental Management
Under Cooperative Agreement # DE-EM0000598



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# Introduction

Nonmetallic materials are utilized in the waste transfer system at the Hanford tank farms; these include the inner hose of the hose-in-hose transfer lines (HIHTLs), Garlock® gaskets and ethylene propylene diene monomer (EPDM) O-rings. These materials are exposed to simultaneous stressors including β and γ radiation, elevated temperatures, caustic supernatant as well as high pressures during normal use. In 2011, the Defense Nuclear Facilities Safety Board recommended to the U.S. Department of Energy (DOE) to conduct post service examination of HIHTLs and Garlock® gaskets to improve the existing technical basis for component service life. Suppliers of the nonmetallic components often provide information regarding the effects of some of the stressors, but information is not provided for simultaneous exposure. An extensive test plan was developed by Sandia National Laboratories to understand the simultaneous effects of the aforementioned stressors [1]; however, this test plan was never executed. Additional studies conducted by Lieberman provides information on HIHTLs at elevated temperature and pressure but little information is gained regarding the synergistic effects with the caustic supernatant [2]. Florida International University (FIU) has been tasked with supporting this effort by conducting multi stressor testing on typical nonmetallic materials used at the Hanford tank farms.

This summary provides results from mechanical property testing of EPDM and Garlock® material coupons as well as the blowout/leak testing for HIHTL, EPDM O-rings and Garlock® gaskets after a 6-month aging period. In addition, the experimental test loop used to age the test specimens is described.

# Experimental Testing

## *Baseline Testing*

All material samples had baseline mechanical performance and properties tested prior to any exposure. Once the baseline properties were obtained, each material sample was aged, which involved exposure to a chemical simulant at ambient (38°C), operating (54°C) and design temperatures (79°C) for durations of 180 and 365 days. Tests were conducted on both material coupons as well as in-service configuration assemblies. After aging/conditioning, the mechanical/material properties of the samples were again measured to identify any degradation in the properties.

To assess the baseline material properties of EPDM and Garlock®, sheets of the material were obtained and coupon specimens were cut using a D412-C die. The specimens were used to determine hardness values obtained using a LECO LMV 50 Series hardness tester. To determine the material hardness, a load of 500 grams was used to create an indention in the sample and hardness values according to the Rockwell scale and Vickers scale were obtained. Multiple measurements were taken from 3 different Garlock® specimens. The average Vickers and

Rockwell Hardness measurements were 4.09 and 54.0, respectively. Since EPDM material is a soft material, hardness readings were unable to be obtained with existing equipment.

Baseline coupon tensile testing was conducted for both un-aged EPDM coupons and un-aged Garlock® coupons. All procedures used for testing were derived from the ASTM D412-16 standard [3] and were recorded to provide consistency throughout all tensile testing experiments, for both EPDM and Garlock® material coupons.

Table 1 shows the average test results for peak stress, peak load, strain at break and modulus of elasticity for the un-aged EPDM coupons. The average test results for the un-aged Garlock® coupons are provided in Table 2.

**Table 1. Average Test Results from EPDM**

| Average Test Run Results - EPDM | | |
|---|---|---|
| Display Name | Value | Unit |
| Peak Stress | 0.002 | $kN/mm^2$ |
| Peak Load | 0.13133 | kN |
| Strain at Break | 0.76367 | mm/mm |
| Modulus | 0.00833 | $kN/mm^2$ |
| Width | 6.14 | mm |
| Thickness | 2.381 | mm |

**Table 2. Average Test Results from Garlock® Coupons**

| Average Test Run Results - Garlock® | | |
|---|---|---|
| Display Name | Value | Unit |
| Peak Stress | 0.003 | $kN/mm^2$ |
| Peak Load | 0.17367 | kN |
| Strain at Break | 0.0167 | mm/mm |
| Modulus | 3.03967 | $kN/mm^2$ |
| Width | 6.6 | mm |
| Thickness | 2.381 | mm |

In order to quantify how each sample was affected by the exposure to the caustic stressor, pre-exposure mechanical testing was conducted. Mechanical testing included hose burst and O-ring/gasket leak tests as per ASTM D380-94 [4] and ASTM F2378-05 [5], respectively. The tests were conducted on the 9 test samples (3 from each material). These results will be compared to post-exposure testing to be conducted on samples exposed for 6-months and 12-months.

Baseline pressure tests were conducted on hose-in-hose transfer lines (HIHTL), ethylene propylene diene monomer (EPDM) O-rings and Garlock® gaskets. HIHTL pressure tests involved pressurizing each test section at a constant rate until the hose ruptured. Baseline hose pressure testing was conducted on three hose specimens. The results are shown in Table 3.

**Table 3. Baseline HIHTL Pressure Test Results**

| | H-00-1 | H-00-2 | H-00-3 | H-00-4 | Averages |
|---|---|---|---|---|---|
| Water Temperature (°C) | 22.22 | 22.22 | 24.11 | 22.89 | 22.86 |
| Ambient Temperature (°C) | 19.44 | 18.89 | 27.22 | 30.00 | 23.89 |
| Humidity % | 37.00 | 36.00 | 67.00 | 60.00 | 50.00 |
| Burst Pressure (Pa) | 1.89E+07 | 2.02E+07 | 1.94E+07 | 1.89E+07 | 1.93E+07 |
| Type of Failure | Rupture | Rupture | Rupture | Rupture | N/A |
| Time Until Failure (s) | 320.50 | 216.00 | 203.50 | 145.50 | 221.38 |
| Start Length (m) | 0.76 | 0.77 | 0.77 | 0.76 | 0.76 |
| End Length (m) | 0.80 | 0.79 | 0.79 | 0.77 | 0.79 |
| Deformation Length (m) | 0.04 | 0.02 | 0.02 | 0.01 | 0.02 |
| Test Date | 3/21/2016 | 3/21/2016 | 3/25/2016 | 3/25/2016 | N/A |

Each specimen experienced a rupture type failure, with the average maximum pressure at 1.93 x $10^7$ Pa. Each specimen also experienced a permanent deformation in their lengths, which averaged 0.02 m. A photo of a typical failed hose specimen is shown in Figure 1.

**Figure 1. Ruptured HIHTL test specimen.**

The baseline O-ring pressure testing was conducted for three EPDM O-ring specimens. The test rig and the results of the testing are shown in Figure 2 and Table 4, respectively.

Figure 2. O-ring pressure test rig.

Table 4. Baseline O-ring Pressure Test Results

| | O-00-1 | O-00-2 | O-00-3 | Average |
|---|---|---|---|---|
| Water Temperature (°C) | 22.89 | 25.28 | 24.56 | 24.24 |
| Ambient Temperature (°C) | 27.78 | 29.44 | 29.44 | 28.89 |
| Humidity (%) | 68.00 | 59.00 | 59.00 | 62.00 |
| Holding Pressure (Pa) | $1.76 \times 10^6$ | $1.69 \times 10^6$ | $1.83 \times 10^6$ | $1.76 \times 10^6$ |
| Pressure Maintained? | Yes | Yes | Yes | N/A |
| Time Until Failure (s) | N/A | N/A | N/A | N/A |
| Test Date | 3/29/2016 | 3/29/2016 | 3/29/2016 | N/A |

Each specimen maintained the allotted pressure for the 5 minute time interval. The average pressure at which the O-rings were maintained was $1.76 \times 10^6$, which was $1.38 \times 10^5$ over the original desired pressure. The change in the prescribed pressure was due to the large variations in the hand-pump used.

The baseline Garlock® gasket pressure testing was conducted for three gasket specimens. The test rig and the results of the testing are shown in Figure 3 and Table 5, respectively.

Figure 3. Gasket baseline pressure test rig.

**Table 5. Baseline Gasket Pressure Test Results**

| | G-00-1 | G-00-2 | G-00-3 | Average |
|---|---|---|---|---|
| Water Temperature (°C) | 23.89 | 23.89 | 23.89 | 23.89 |
| Ambient Temperature (°C) | 26.11 | 25.56 | 25.56 | 25.74 |
| Humidity % | 50.00 | 54.00 | 52.00 | 52.00 |
| Holding Pressure (Pa) | $1.15x10^6$ | $1.03x10^6$ | $1.02x10^6$ | $1.07x10^6$ |
| Pressure Maintained? | Yes | Yes | Yes | N/A |
| Time Until Failure (s) | N/A | N/A | N/A | N/A |
| Test Date | 4/4/2016 | 4/4/2016 | 4/4/2016 | N/A |

Each specimen maintained the allotted pressure for the 5 minute time interval. The average pressure at which the gaskets were held was 154.98 psig, which was only 5 psig over the desired pressure.

## *In-Service Configuration Aging*

The in-service configuration aging experimental setup consisted of 3 independent pumping loops with two manifold sections on each loop (Figure 4). Each of the 3 loops was run at a different temperature (38°C, 54°C and 79°C). Each manifold section holds three test samples and was used for a corresponding exposure time of 6 months and 1 year. Each test sample consists of a HIHTL hose section, an EPDM O-ring and a Garlock® gasket placed in a series configuration. Isolation valves on each manifold allowed for removal of samples without affecting the main loop and the rest of the samples. The temperature of the chemical solution circulating within each loop was maintained at a preset temperature by an electronically controlled heater. A 25% sodium hydroxide solution was used as a chemical stressor that circulated in each of the loops. The chemical stressor's pH was checked every 30 days to ensure that the concentration levels were consistent over time.

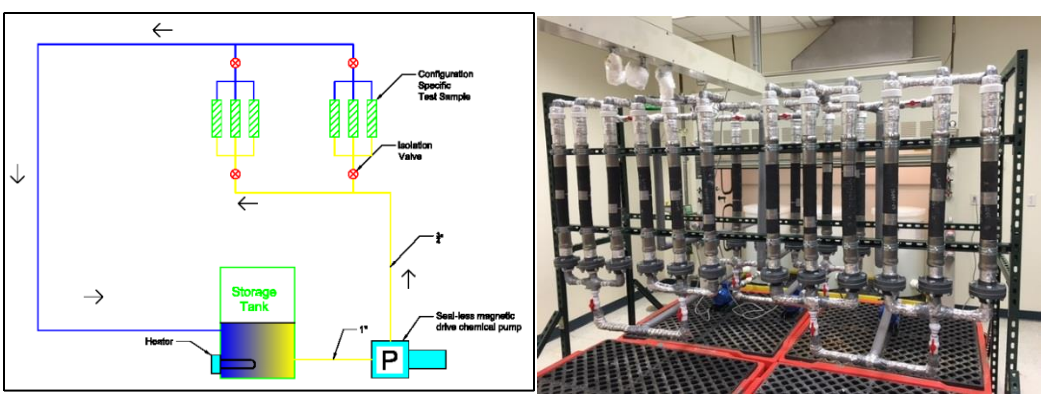



**Figure 4. In-service component aging loop.**

The coupon aging experiment setup consisted of one coupon aging vessel (Figure 5) submerged in each of the three test loop's storage tanks. This resulted in exposing the coupons to the same conditions as the in-service configuration tests; the circulating fluid is the same 25% sodium hydroxide solution. Each vessel contained 12 coupons (6 of each type of EPDM and Garlock®

materials) and was submerged in the bath for a duration of 180 and 365 days. Table 6 shows the test coupon aging matrix and Figure 5 shows a coupon aging vessel.

**Table 6. Coupon Aging Matrix**

| Days Exposure | Ambient Temperature (38°C) | Operating Temperature (54°C) | Design Temperature (79°C) | Baseline |
|---|---|---|---|---|
| 0 | | | | 3 coupons |
| 180 | 3 coupons | 3 coupons | 3 coupons | |
| 360 | 3 coupons | 3 coupons | 3 coupons | |

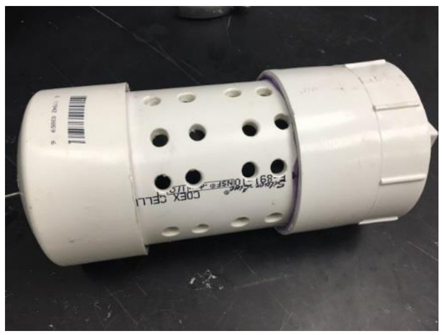


**Figure 5. Coupon aging vessel.**

## 6-Month Testing Results

### *Hose-In-Hose*

Three aged sample hoses from each loop were pressurized until rupture. Their pressure profiles as well as initial and final lengths were measured. The rupture pressure was compared to the baseline values. Figure 6 shows the results of the 6-month aged hose burst pressure tests and Figure 7 shows a ruptured hose section.

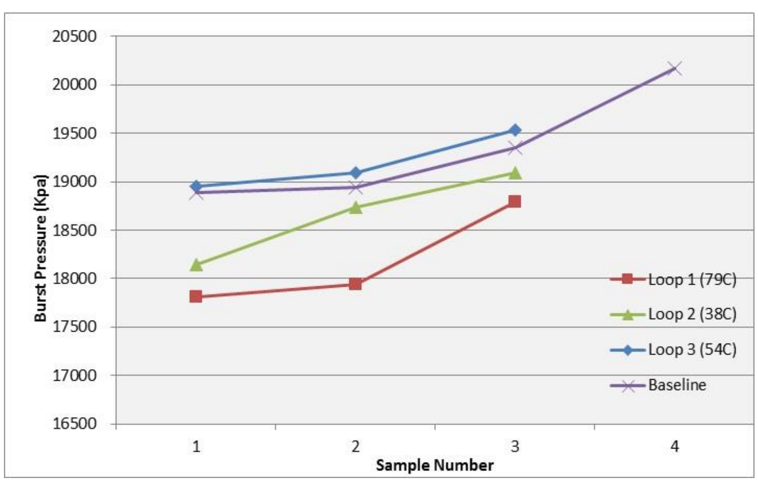



**Figure 6. HIHTL burst pressure profiles.**

Figure 7. Ruptured hose section.

## *EPDM O-Ring Testing*

The aged O-ring pressure testing was conducted for nine EPDM O-ring specimens (three from each loop). Table 7 shows the results of the testing. An average pressure of 1650 KPa was maintained for five minutes without any leaks.

Table 7 . 6-month O-Ring Pressure Test Results

| Sample Number | O-01-4 | O-01-5 | O-01-6 | O-02-4 | O-02-5 | O-02-6 | O-03-1 | O-03-2 | O-03-3 | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| Water Temperature (°C) | 23.00 | 23.00 | 22.00 | 22.00 | 22.00 | 22.00 | 22.00 | 22.00 | 22.00 | 22.22 |
| Ambient Temperature (°C) | 26.00 | 26.00 | 24.00 | 24.00 | 24.00 | 24.00 | 26.00 | 26.00 | 26.00 | 25.11 |
| Humidity (%) | 65.00 | 66.00 | 85.00 | 85.00 | 85.00 | 85.00 | 76.00 | 76.00 | 76.00 | 77.67 |
| Holding Pressure (Pa) | 1.63E+06 | 1.61E+06 | 1.61E+06 | 1.65E+06 | 1.61E+06 | 1.63E+06 | 1.68E+06 | 1.72E+06 | 1.75E+06 | 1.65E+06 |
| Pressure Maintained? | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | N/A |
| Time Until Failure (s) | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

## *6-Month Garlock® Gasket Testing*

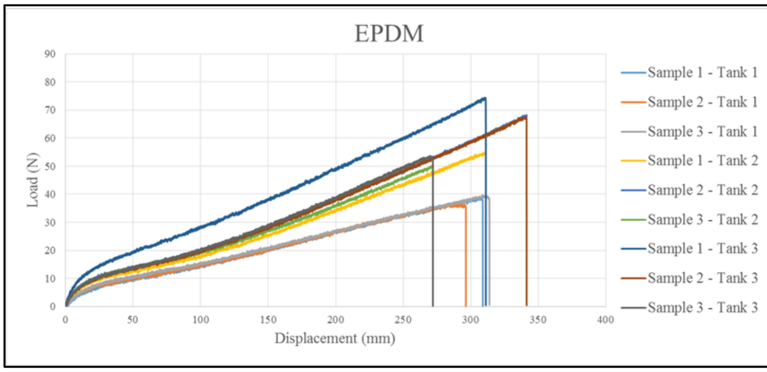
The aged Garlock® gaskets pressure testing was conducted for nine Garlock® gasket specimens (three from each loop). Table 8 shows the results of the testing. Of the nine specimens, only four gaskets were able to maintain the pressure. Of the four that maintained pressure, an average pressure of 487 KPa was maintained for five minutes without any leaks. The leaks are believed to be due to the gaskets being compressed when they were installed in the aging loop. Since the Garlock® material maintains a memory after it has been compressed, when it is reinstalled into the pressure test rig, it does not always create a good seal.

Table 8. 6-Month Garlock® Gasket Testing Results

| Sample Number | G-01-4 | G-01-5 | G-01-6 | G-02-4 | G-02-5 | G-02-6 | G-03-1 | G-03-2 | G-03-3 | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| Water Temperature (°C) | 22.44 | 22.44 | 22.44 | 22.44 | 22.44 | 22.44 | 22.44 | 22.44 | 22.44 | 22.44 |
| Ambient Temperature (°C) | 26.67 | 26.67 | 26.11 | 26.11 | 26.11 | 26.11 | 26.11 | 26.11 | 26.11 | 26.23 |
| Humidity (%) | 50.00 | 50.00 | 54.00 | 54.00 | 54.00 | 54.00 | 54.00 | 48.00 | 53.00 | 52.33 |
| Holding Pressure (Pa) | 1.09E+06 | 1.12E+06 | 1.12E+06 | 0.00E+00 | 1.05E+06 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.87E+05 |
| Pressure Maintained? | Yes | Yes | Yes | No | Yes | No | No | No | No | N/A |
| Time Until Failure (s) | N/A | N/A | N/A | 0.00 | N/A | 0.00 | 0.00 | 0.00 | 0.00 | N/A |

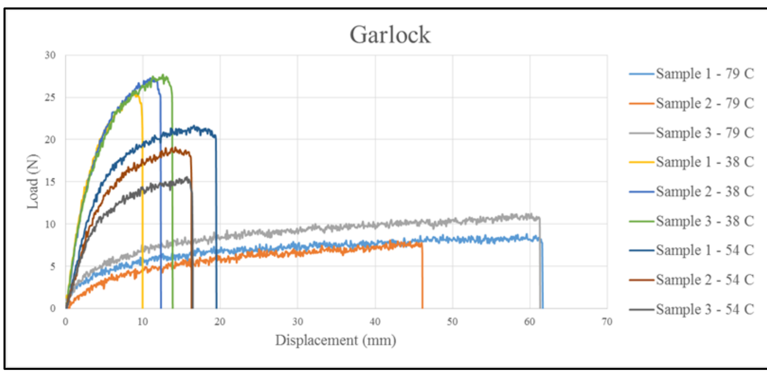
## *6-Month Coupon Testing*

Three each of the EPDM and Garlock® samples were aged in each of the three loop tanks maintained at 38°C, 54°C and 79°C, respectively. All procedures used for testing were derived from the ASTM D412-16 standard [3]. Figure 8 and Figure 9 show results from the tensile strength tests for the EPDM and Garlock® coupons, respectively, while Figure 10 shows a comparison of the results to the baseline data.




| EPDM | |
|---|---|
| Tank | Average Tensile Strength (MPa) |
| Baseline | 8.98 |
| (38°C) | 3.94 |
| (54°C) | 3.83 |
| (79°C) | 2.30 |
| Average | 3.89 |
| Std. Dev | 0.08 |

Figure 8. EPDM coupon tensile strength.




| Garlock | |
|---|---|
| Tank | Average Tensile Strength (MPa) |
| Baseline | 11.05 |
| (38°C) | 1.49 |
| (54°C) | 1.09 |
| (79°C) | 0.58 |
| Average | 1.29 |
| Std. Dev | 0.29 |

Figure 9. Garlock® coupon tensile strength.

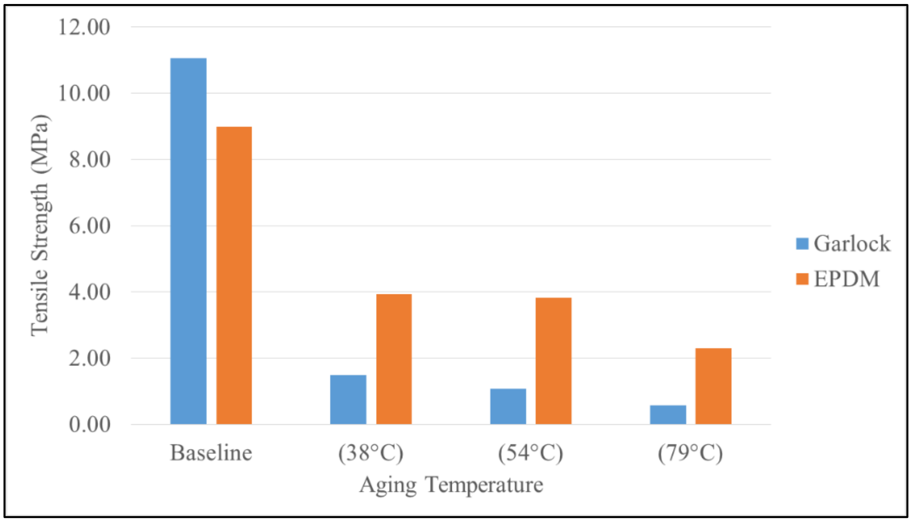



Figure 10. Coupon tensile strength comparison to baseline data.

## Discussion and Summary

A test plan and loop have been developed to evaluate the synergistic effects of elevated temperature and exposure to caustic material for 6 months and 1 year of EPDM and Garlock® components in the waste transfer system. Baseline material properties were obtained for coupon samples and mechanical properties were obtained for in-service configuration components. After 6 months of aging, the tests were repeated to determine if degradation in the properties were observed.

Data from the aged HIHTL coupons (Figure 6) provided inconsistent results. Coupons aged with the higher temperatures did have lower burst pressures but burst pressures associated with the operating temperature conditions (54°C) were higher than the room temperature specimens (38°C) and very close to the baseline pressures. However, it should be noted that changes in the burst pressures were minimal and all were well above the minimum requirement for operation of 4 x the pressure rating (425 psi).

In-service performance of the O-rings demonstrated that the aged specimens (6-months) could hold the required pressure. Note, due to limitations in the components of the test rig, the specimens were not tested to failure. In-service performance of the Garlock® gaskets demonstrated that 4 aged specimens (6-months) could hold the required pressure, but the remaining 5 could not. This is likely due to the initial compression of the gaskets during aging and re-installment into the test rig. The gasket was unable to create the appropriate seal as a result of material memory due to compression during the aging process.

Tensile testing of the Garlock® and EPDM coupons demonstrated a significant change in elastic modulus and tensile strength. Figure 10 clearly shows that as the aging temperature is increased, the strength was reduced as compared to the baseline data. Changes in the elastic modulus can be observed in Figures 8 and 9. Data show that the highest temperature had the greatest reduction in the modulus with the room and operating temperatures having similar moduli.

Although changes were noted in these properties, the HIHTL obtains a majority of its strength from the two woven fabrics compressed between the three layers of EPDM. The EPDM limits the ability of the caustic fluid to alter the properties of the woven fabric. If the caustic fluid is able to penetrate and diffuse through the EPDM, the strength of the fabric could be comprised. Future analysis will include investigating the aged EPDM using SEM-EDX to evaluate changes in the microstructure and chemistry.

After the specimens have been aged for 12 months, testing will be repeated and results will be compared with the baseline and 6 month data.

# Works Cited

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