SUMMARY DOCUMENT

Baseline Testing Results of Nonmetallic Materials in Hanford's HLW Transfer System

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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© Blue-Gard 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 HIHTL nonmetallic components to improve the existing technical basis for component service life (LH Brush, 2013). 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 (LH Brush, 2013); however, this test plan was never executed. Additional studies conducted by Lieberman provide information on HIHTLs at elevated temperature and pressure but little information was added regarding the synergistic effects with caustic supernatant (Lieberman, 2004). 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 document provides the results of the baseline material and mechanical testing of the EPDM and Garlock© components. After the materials have been aged, the tests will be repeated to determine the long term effect of multiple stressors on the nonmetallic materials.

Scope

The current phase of testing will utilize caustic fluid at various temperatures as stressors to determine the combined effect on EPDM and Garlock© materials. A detailed test plan has been developed for this phase and provided to site engineers and DOE EM HQ for their review (Awwad, 2015). The test plan details the performance objectives, the types of tests, the control parameters and the data to be collected and analyzed. Material samples will be aged as coupons as well as in a specific system configuration setup. The effects of aging due to various stressor combinations on each sample and material will be quantified.

EPDM was selected as one of the materials for this phase of testing due to its use in multiple applications within the Hanford waste transfer system. The EPDM material tested will consist of EPDM material coupons, EPDM HIHTL inner hoses and EPDM O-rings. In addition to the HIHTLs and O-rings, we will also be evaluating gaskets made from Garlock©. Coupons manufactured with EPDM and Garlock© will be used to obtain a fundamental understanding of the relationship of the stressors with the materials. Components (inner hoses, gaskets and O-rings) will be used to determine the effect on the component being evaluated in an environment similar to its operational environment.

Experimental Approach

All material samples will have their mechanical performance and properties tested as per ASTM standards prior to any stressor exposure. Once the baseline properties have been determined, each material sample will be aged, which will involve exposing each sample to a chemical simulant at ambient (85°F), operating (130°F) and design temperatures (180°F) for a duration of 180 and 360 days. Tests will be conducted on both material coupons as well as in-service configuration assemblies. After aging/conditioning, the mechanical properties of the samples will again be measured as per ASTM standards.

In-Service Configuration Aging

The in-service configuration aging experimental setup will consist of 3 independent pumping loops with two manifold sections on each loop (Figure 1). Each of the 3 loops will be run at a different temperature (85°F, 130°F and 180°F). Each manifold section can hold up to three test samples and be used for a corresponding exposure time of 180 and 360 days. Three samples of the EPDM inner hose and three samples of the O-rings and gaskets will be placed in a parallel manifold configuration. Isolation valves on each manifold will allow removal of samples without affecting the main loop and the rest of the samples. The temperature of the chemical solution circulating within each loop will be maintained at a preset temperature by an electronically controlled heating system. This configuration requires 6 test samples (for the inner hose, gaskets and O-rings) for each of the three test loops, requiring a minimum of 18 test samples of each the inner hose, gaskets and O-rings. A 25% sodium hydroxide solution will be used as a chemical stressor that will circulate in each of the loops. The chemical stressor will be sampled every 30 days to ensure that the concentration levels remain constant.

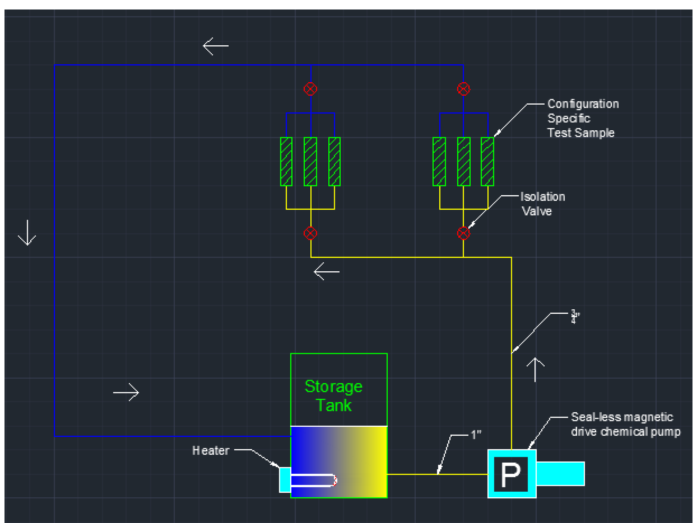

Figure 1. In-service component aging loop.

Coupon Aging

The coupon aging experiment setup will consist of 3 temperature controlled circulating fluid baths. The three fluid baths will be maintained at the same temperatures as the test loops (85°F, 130°F and 180°F). As with the in-service configuration tests, the circulating fluid will be a 25% sodium hydroxide solution. Each bath will have two sacks with five coupons placed in each. One sack will be submerged in each bath for a duration of 180 days and the second sack for 360 days. In addition, samples will be tested that are not exposed or aged to generate a set of baseline data for comparison. Table 1 shows the test coupon aging matrix.

Table 1. Coupon Aging Matrix

Days Exposure	Ambient Temperature (85°F)	Operating Temperature (130°F)	Design Temperature (180°F)	Baseline
0				5 coupon samples
180	5 coupon samples	5 coupon samples	5 coupon samples	
360	5 coupon samples	5 coupon samples	5 coupon samples	

Quantification of Material Degradation

In-Service Configured Components

In order to quantify how each sample was affected by the exposure to the caustic stressor, post-exposure mechanical testing will be conducted. Post-exposure mechanical testing will include hose burst tests as per ASTM D380-94 and O-ring/gasket leak tests. The tests will be conducted on the 18 aged test samples (6 from each test temperature with 3 at each exposure time). These results will be compared to the baseline mechanical testing results from un-aged samples.

Coupons

Post-exposure mechanical testing of coupons will provide baseline durometer hardness, elastic modulus, maximum strain, maximum stress and maximum load values. These properties/values will be evaluated using standardized test methods developed by ASTM International (ASTM D412 –EPDM and ASTM D638 - Garlock©). Before the coupons are placed in the tanks for exposure, specific gravity measurements will be conducted in accordance with ASTM D792 and dimensions and mass measurements will also be obtained. After exposure, these values will be obtained again and compared with the initial values. For hardness measurements, tests will be conducted in accordance with ASTM D2240 for EPDM and ASTM D785 for Garlock©.

Experimental Test Loop

The experimental test loop was designed to simultaneously age both in-service components as well as material coupons. The test loop consists of schedule 40 PVC and schedule 80 CPVC piping attached to the HIHTL coupons. As mentioned previously, there are three separate loops that will each have a different temperature bath (85, 130, 180°F). Each loop will have 6 coupons, 3 that will be exposed for 180 days and 3 that will be exposed for 1 year.

The sodium hydroxide solution is supplied to each loop from 30-gallon polyethylene tanks. Each tank has a 1500 watt heater to maintain the desired fluid temperature within each loop. One-half (½) horsepower magnetic drive chemical pumps are used to circulate the fluid within each loop. Each pump is capable of delivering 30 gallons-per-minute of flow at an operating pressure of 13 psi. The two loops that operate at 85°F and 130°F are fabricated from PVC pipes while the loop operating at 180°F is fabricated from CPVC pipes in order to withstand the high operating temperature. The loops are completely insulated with foam insulation tape except for the test sections.

Each loop also has six in-configuration test sections on it that are connected by a common manifold. In-configuration test sections are oriented vertically and are comprised of a HIHTL inner hose with a Garlock© gasket in a 2" PVC 150-lbs flange on the bottom and an EPDM O-ring in a 2" PVC coupling on top. Figure 2 shows the in-configuration test sections. Each test loop is also instrumented with electronic flow meters and pressure transducers as well as a thermocouple to measure the flow rate, pressure and temperature with the loop. The completed aging set up is shown in Figure 3.

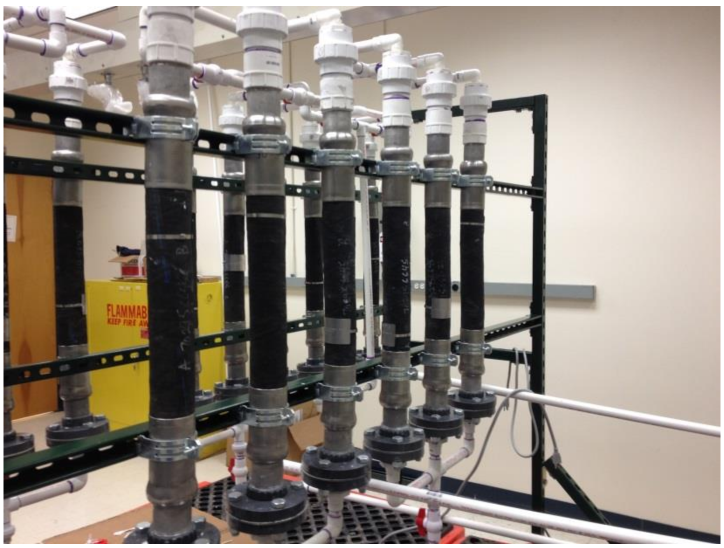

Figure 2. In-configuration test sections.

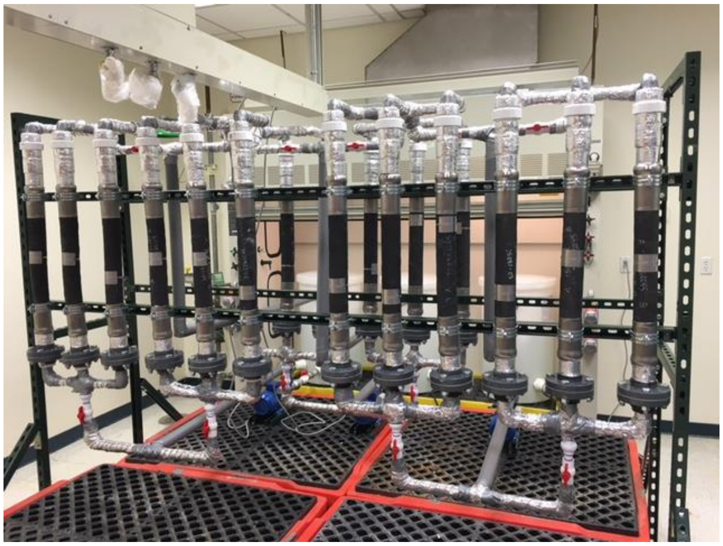

Figure 3. Aging test loop.

Baseline Testing

In order to evaluate the mechanical and material properties of the nonmetallic materials, a number of initial tests were conducted to determine baseline values that will be used to assess the effects of aging from the test loop. This includes samples in the in-service configuration as well as the coupons for material testing. In the following sections, results from the baseline tests are provided and will be used in the future to compare with the same tests conducted on the aged specimens.

In-Service Configuration Testing

HIHTLs

For the HIHTL coupons, burst pressure tests were conducted on four specimens to establish a baseline for the nominal pressure the coupons can withstand. As shown in Figure 4, a hydraulic pump capable of pressurizing the coupon to 10,000 psi was connected to the coupon which was enclosed in a containment structure manufactured from Plexiglas. Pressure data was acquired using a Barksdale model 425H3-17 pressure transducer, which measures pressures between 0 and 7500 psi at an accuracy of ±0.25%. The pressure data was acquired via a data acquisition system that acquires and logs the data at intervals of 500 ms. Additional data such as water temperature and ambient temperature, was determined prior to testing each hose specimen and transcribed onto its own *Burst Pressure Verification Data Sheet* (see Appendix).

Figure 4. Hose rupture pressure testing assembly.

After each hose specimen was securely fastened to the testing assembly, any remaining air was purged from the system. After verifying that no air remained in the system, pressure testing, data acquisition and video recording began, simultaneously. Pressure was increased at a rate between 800-1200 psi/min. The specimen burst pressure and type of failure (rupture, hose split, termination failure, ply separation) was recorded on the *Burst Pressure Verification Data Sheet*. Table 2 provides all the measurements obtained, including the burst pressures, for four specimens.

Table 2. Hose Rupture Pressure Test Results

	H-00-1	H-00-2	H-00-3	H-00-4	Averages
Water Temperature (°F)	72.00	72.00	75.40	73.20	73.15
Ambient Temperature (°F)	67.00	66.00	81.00	86.00	75.00
Humidity %	37.00	36.00	67.00	60.00	50.00
Burst Pressure (psig)	2740.21	2925.95	2807.25	2747.90	2805.33
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 (in.)	29.75	30.25	30.25	30.00	30.0625
End Length (in.)	31.50	31.00	31.00	30.25	30.94
Deformation Length (in.)	1.75	0.75	0.75	0.25	0.875
Test Date	3/21/2016	3/21/2016	3/25/2016	3/25/2016	N/A

The average burst pressure obtained for the four specimens was 2805 psi. After discussions with site engineers at Hanford and the representatives at Riverbend, these values were similar to tests conducted on other hose samples. Figure 5 shows the rupture from specimen H-00-2. The other three specimens failed in the same manner.

Figure 5. Failed hose specimen H-00-2.

O-rings and Gaskets

To evaluate O-ring in-service configuration specimens, a pressure testing rig was assembled (Figure 6). The assembly included the same hydraulic pump, pressure transducer and data acquisition system used in the HIHTL testing. Similar system data (water temperature, ambient temperature, etc.) was also measured and recorded in the *Holding Pressure Verification Data Sheet* (see Appendix).

Figure 6. O-ring pressure testing assembly.

Each O-ring specimen was placed in the testing union, which was securely fastened, and any air was purged from the system. After verifying that no air remained in the system, pressure testing, data acquisition and video recording began, simultaneously. Pressure was increased until reaching approximately 235 psi, where it was maintained for 5 minutes, or until failure. The 235 pressure limit was determined by limitations of the schedule 80 PVC unions used for the in-configuration testing. Determination of leakage in the system was verified from examining the pressure data as well as observation of the testing assembly. If the specimen failed to maintain pressure, the time until failure was recorded. Results from the three O-ring tests are provided in Table 3. The results of the testing show that each of the O-rings were able to maintain the desired pressure for the duration of the testing. It should be noted that the pressure applied to the system had slight variations due the limitations of the large range of the hydraulic pump being utilized.

Table 3. O-ring Pressure Test Results

	O-00-1	O-00-2	O-00-3	Averages
Water Temperature (°F)	73.20	77.50	76.20	75.63
Ambient Temperature (°F)	82.00	85.00	85.00	84.00
Humidity %	68.00	59.00	59.00	62.00
Holding Pressure (psig)	255.00	245.00	265.00	255.00
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

A pressure testing rig, similar to the O-ring rig, was assembled for the Garlock© gaskets (Figure 7). As before, each gasket was placed in a flange, which was securely fastened, and air was purged from the system. After verifying that no air remained in the system, pressure testing, data acquisition and video recording began, simultaneously. Pressure was increased until reaching approximately 150 psi, where it was maintained for 5 minutes, or until failure. The 150 pressure limit was determined by limitations of the schedule 80 PVC flanges used for the in-configuration testing. Determination of leakage in the system was again verified from examining the pressure data as well as observation of the testing assembly. If the specimen failed to maintain pressure, the time until failure was recorded. Results from three gasket tests are provided in Table 4. The results of the testing showed that each of the gaskets were able to maintain the desired pressure for the duration of the testing.

Figure 7. Gasket pressure testing assembly.

Table 4. Gasket Pressure Test Results

	G-00-1	G-00-2	G-00-3	Averages
Water Temperature (°F)	75.00	75.00	75.00	75.00
Ambient Temperature (°F)	79.00	78.00	78.00	78.33
Humidity %	50.00	54.00	52.00	52.00
Holding Pressure (psig)	166.75	149.89	148.30	154.98
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

Coupon Testing

To assess the baseline material properties of EPDM and Garlock© sheets of each material were obtained and coupon specimens were cut using a D412-C die. The specimens were used to determine the material properties obtained from tensile and hardness testing.

The data for the coupon tensile testing was acquired directly from the MTS machine (Figure 8). To accurately measure the tensile properties/ values, the correct width, thickness and grip separation needs to be entered into the MTS software. For the current specimens, the width was 25 mm and the thickness was 2.38125 mm. The displacement rate for the EPDM was 500 mm/min and was 5 mm/min for the Garlock©.

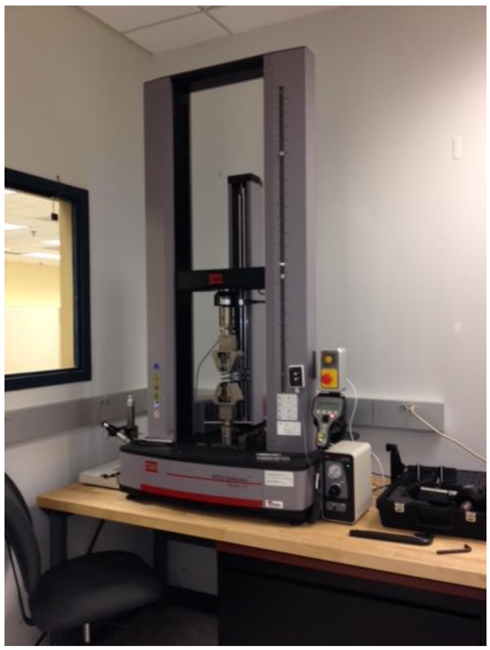

Figure 8. MTS tensile testing machine.

Results below show the average values obtained from the tensile tests for both the Garlock© and the EPDM coupons. The values will be re-obtained for the exposed coupons to evaluate any degradation in the material. Figure 9 and Figure 10 shows typical tests using Garlock© and EPDM specimens, respectively.

Table 5. Tensile Test Results

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	25	mm
Thickness	2.381	mm

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	25	mm
Thickness	2.381	mm

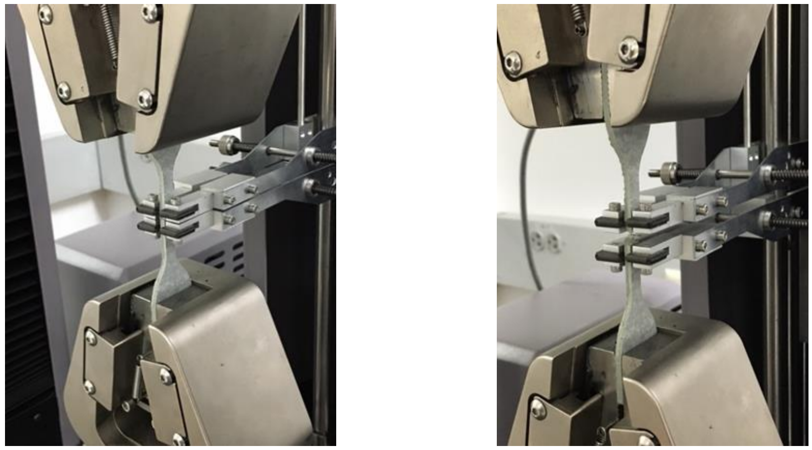

Figure 9. Garlock© MTS testing.

Figure 10. EPDM MTS testing.

The data for the coupon hardness testing was obtained using a LECO LMV 50 Series hardness tester (Figure 11). 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. These results and the corresponding averages are provided in Table 6. To obtain hardness measurements for the EPDM material, a different indenter probe is required and is currently being procured. Results these tests will be provided when the probe is obtained.

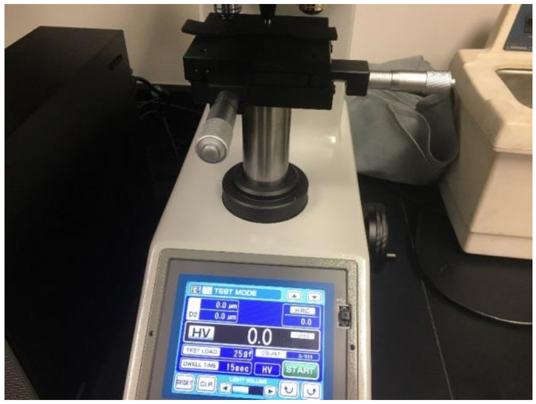

Figure 11. Hardness testing machine.

Table 6. Garlock© Hardness Testing Results

GARLOCK© DATA	
Vickers	**Rockwell HRB/HRC**
4	54
3	54
4	54
4	54
4	54
4	54
4	54
4	54
4	54
5	54.1
5	54.1
AVERAGE VALUES	
4.09	**54.01**

Path Forward

The next step for the nonmetallic material testing is to begin the aging process of both the material coupons and the in-service configuration specimens. After 180 and 360 days, the specimens will be removed and tested in the same manner as the baseline specimens. Based on these results, additional testing may be conducted that includes investigating shorter exposure times. Other possible tests include investigating the synergistic effects of temperature, caustic material and elevated pressure. Additional materials may also be added to the test matrix including, Teflon and Tefzel.

Works Cited

LH Brush, C. O. (2013). *Test Plan for the Irradiation of Nonmetallic Materials.* Albuquerque, New Mexico: Sandia National Laboratories.

Lieberman, P. (2004). *Banded (Band-It) and Swaged Hose-In-Hose (HIHTL) Assembly Service Life Verification Program.* Santa Clarita, California: National Technical Systems.

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Appendix

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Burst Pressure Verification Data Sheet

Date: ____________ Hose Size: 2”

Hose Coupon # ________________ **Specimen #** ________________

Pressure Gauge Calibration Information:

Brand/Model #	425H3-17
Serial #	N/A
Calibration Expiration:	3/21/17

Initials ________ Date __________

Test Data:

Water Temperature __________ °F Humidity _________

Ambient Temperature __________

______________ psig

Burst Pressure

____

Type of Failure

Time until Failure ________________

Start Length ______________

After Length ______________

Acceptance Criteria:

- 2” Minimum Burst Pressure is 1700 psig

_________ Pass _________ Fail

Verify that testing was performed in accordance with the Hose Pressure Testing Procedures.

Exceptions/Comments:

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Holding Pressure Verification Data Sheet

Date: ____________

Specimen Type ________________ Specimen # ________________

Pressure Gauge Calibration Information:

Brand/Model #	425H3-17
Serial #	N/A
Calibration Expiration:	3/21/17

Initials ________ Date __________

Test Data:

Water Temperature __________ °F
Ambient Temperature __________

Humidity __________

______________ psig
Holding Pressure

____
Was Pressure Maintained

If No, Time until Failure ______________

Acceptance Criteria:

- Desired Pressure was maintained for 5 minutes.

_________ Pass _________ Fail

Verify that testing was performed in accordance with the Gasket/O-Ring Pressure Testing Procedures.

Exceptions/Comments: