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Characterization of Glovebox Gloves for the Savannah River Site

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Characterization of Glovebox Gloves for the Savannah River Site

Abstract

A task was undertaken to characterize glovebox gloves that are currently used in the facilities at Savannah River Site (SRS) as well as some experimental and advanced compound gloves that have been proposed for use. Gloves from four manufacturers were tested for permeation in hydrogen and air, thermal stability, tensile properties, puncture resistance and dynamic mechanical response. The gloves were compared to each other within the type and also to the butyl rubber glove that is widely used at the SRS. The permeation testing[1] demonstrated that the butyl compounds from three of the vendors behaved similarly and exhibited hydrogen permeabilities of .52-.84 x10^{-7} cc H_2*cm / (cm^2*atm). The Viton® glove performed at the lower edge of this bound, while the more advanced composite gloves exhibited permeabilities greater than a factor of two compared to butyl. Thermogravimetric analysis[2] was used to determine the amount of material lost under slightly aggressive conditions. Glove losses are important since they can affect the life of glovebox stripper systems. During testing at 90, 120, and 150°C, the samples lost most of the mass in the initial 60 minutes of thermal exposure and as expected increasing the temperature increased the mass loss and shortened the time to achieve a steady state loss. The ranking from worst to best was Jung butyl-Hypalon® with 12.9 %, Piercan Hypalon® with 11.4 %, and Jung butyl-Viton® with 5.2% mass loss all at approximately 140°C. The smallest mass losses were experienced by the Jung Viton® and the Piercan polyurethane. Tensile properties[3] were measured using a standard dog bone style test. The butyl rubber exhibited tensile strengths of 11-15 MPa and elongations or 660-843%. Gloves made from other compounds exhibited lower tensile strengths (5 MPa Viton) to much higher tensile strengths (49 MPa Urethane) with a comparable range of elongation. The puncture resistance[4] of the gloves was measured in agreement with an ASTM standard[5]. The Butyl gloves exhibited puncture resistance from 183 – 296 lbs/in for samples of 0.020 – 0.038" thick. Finally, the glass transition temperature and the elastic and viscoelastic properties as a function of temperature up to maximum use temperature were determined for each glove material using Dynamic Mechanical Analysis[6]. The glass transition temperatures of the gloves were -60°C for butyl, -30°C for polyurethane, -16°C Hypalon®, -16°C for Viton®, and -24°C for polyurethane-Hypalon®. The glass transition was too complex for the butyl-Hypalon® and butyl-Viton® composite gloves to be characterized by a single glass transition temperature. All of the glass transition temperatures exceed the vendor projected use temperatures.

Introduction

General

Savannah River Site handles tritium, a radioactive isotope of hydrogen in numerous gloveboxes. An incident occurred in which a Radiological Buffer Area (RBA) was upgraded to Contamination Area (CA) due to excessive tritium permeation out of a glovebox. The resultant tritium permeation into the air created tritiated water. This tritiated water is readily assimilated by workers and could pose a significant health problem. This facility contamination event prompted an assessment of the practices and

materials for gloveboxes. A root cause analysis for the event determined that the presence of vacuum grease, glove damage from abrasion, and poor housekeeping all contributed to the contamination event. These findings, in turn, precipitated a evaluation of gloves to determine baseline characteristics and the properties of potential alternative glove materials.

In addition to tritium release from glove permeation, oxygen from air may permeate through the gloves and seals to form tritiated water which requires stripping from the glovebox atmosphere. SRS Facilities use magnesium beds in which the magnesium is oxidized to release the tritium. The Mg beds in the stripper system are fairly expensive, are used only once and then must be disposed as contaminated waste. Consequently, reducing oxygen ingress will result in reduced magnesium bed usage and a concomitantly reduced cost.

This task characterized the permeability of air and dry hydrogen, the thermal stability, the mechanical properties, the puncture resistance, and the dynamic mechanical behavior of 15 polymeric glovebox gloves from 4 different manufacturers. The gloves by manufacturer, type and thickness are listed in Table 1. This testing establishes baseline data that can be utilized for glove specifications. Through this characterization, it will also be possible to assess the performance of the current gloves in use in the facility

Table 1. Description of gloves and ID used for the testing.

Vendor	Composition	Thickness (mils)	ID		Vendor	Composition	Thickness (mils)	ID
North	Butyl	15	NB15		North	Butyl	30	NB30
Piercan	Butyl	15	PB15		Piercan	Butyl	30	PB30
Piercan	Electrostatic Discharge Butyl	15	PESDB15		Piercan	Electrostatic Discharge Butyl	24	PESDB24
Guardian	Butyl	15	GB15		Guardian	Butyl	30	GB30
Jung	Butyl-Hypalon®	27	JBH27		Jung	Butyl-Viton®	20	JBV20
Jung	Viton®	24	JV24		Jung	Viton®	31	JV31
Piercan	Polyurethane	15	PU15		Piercan	Polyurethane-Hypalon®	20	PUY20
Piercan	Hypalon®	25	PY25					

Gloves for this task were provided by suppliers North, Piercan, Guardian, and Jungitec. North 15 and 30 mil butyl and Piercan 15 and 30 mil butyl are the gloves currently approved for use in Tritium Operations.

Permeability

Permeability is a material property that indicates the rate at which a certain phase, typically gas, of matter passes through the material in question. The flux J is the amount of gas exiting a given

permeation barrier per unit area per unit time. The flux of a gas permeating a membrane is related to the permeability by.

$$J = P\,(p_1 - p_2) / L$$

in which p_1 is the high partial pressure on the entrance side of a membrane, p_2 is the partial pressure on the opposite (exit) side, and L is the thickness of the membrane. Q is the quantity of permeating material. It is the flux times the surface area (A) of the sample times the time (t).

$$Q = J * A * t$$

Permeability (P) is equal to the Diffusivity (D) multiplied by the Solubility (S) of the material, P = SD. $Diffusivity = \frac{L^2}{6*\theta}$. The variable L is the thickness of the material and θ is the time at which break through is achieved. For this study

$$Permeability\ (P) = \frac{V(cm^3)*L\ (in)*MV\ @STP*slope\ \ of\ test\ (\frac{Torr}{\sec})}{SA\ (in^2)*R*T(K)*P(cmHg)}\ .$$

Where V = expansion volume (cm^3), L = sample thickness (cm), MV = slope of permeation curve at steady state (Torr/s), SA = surface area (in^2), R = universal gas constant (6236 cmHg*cm^3/gmol*K), T = temperature (K) and P = test pressure difference (P_{source} - $P_{expansion}$ ~ P_{source}).

$$(1\ Barrers = \frac{10^{-10} cm^3 gas\ @\ STP*cm}{cm^3*s*cmHg})$$

The measured and calculated values can be used to determine the potential for contamination in the facility by gas permeating the various glove materials.

Dynamic Mechanical Analysis

DMA measures stiffness and damping, which are reported as storage modulus (stiffness) and loss modulus and tan delta (damping). Because a sinusoidal force is applied, it is possible to express the modulus as an in-phase component, the storage modulus, and an out of phase component, the loss modulus, see Figure 1. The storage modulus, either E' or G', is the measure of the sample's elastic behavior. The ratio of the loss to the storage is the tan delta (tan δ) and is often called damping. It is a measure of the energy dissipation of a material.

Modulus values change with temperature and transitions in materials can be seen as changes in the E' or tan delta curves. This includes not only the glass transition and the melt, but also other transitions that occur in the glassy or rubbery plateau, shown in Figure 2. These transitions indicate more subtle changes in the material. The samples were prepared and tested so that the properties from below the glass transition to the maximum use temperature were examined.

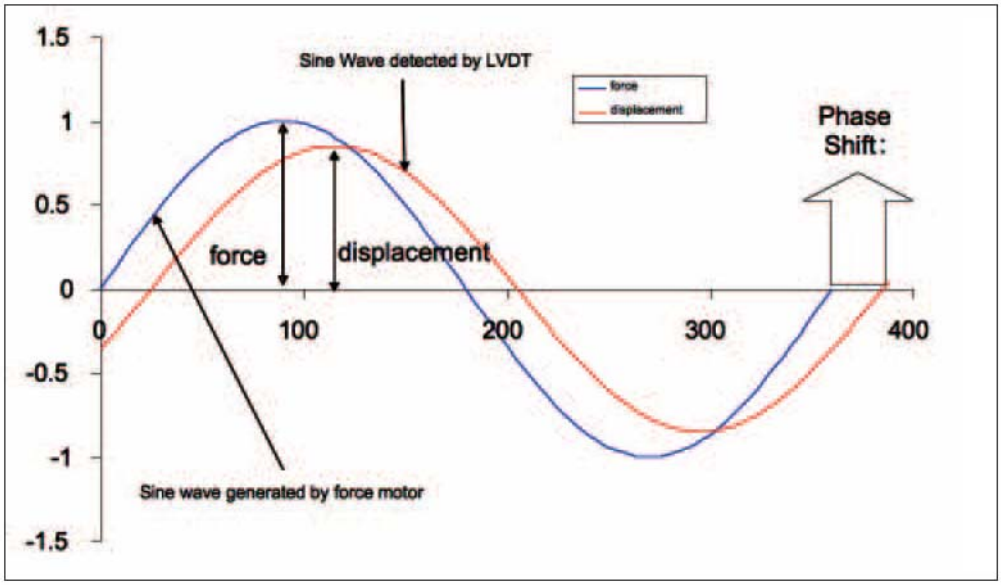

Figure 1. Schematic of output for a DMA showing phase shift[8].

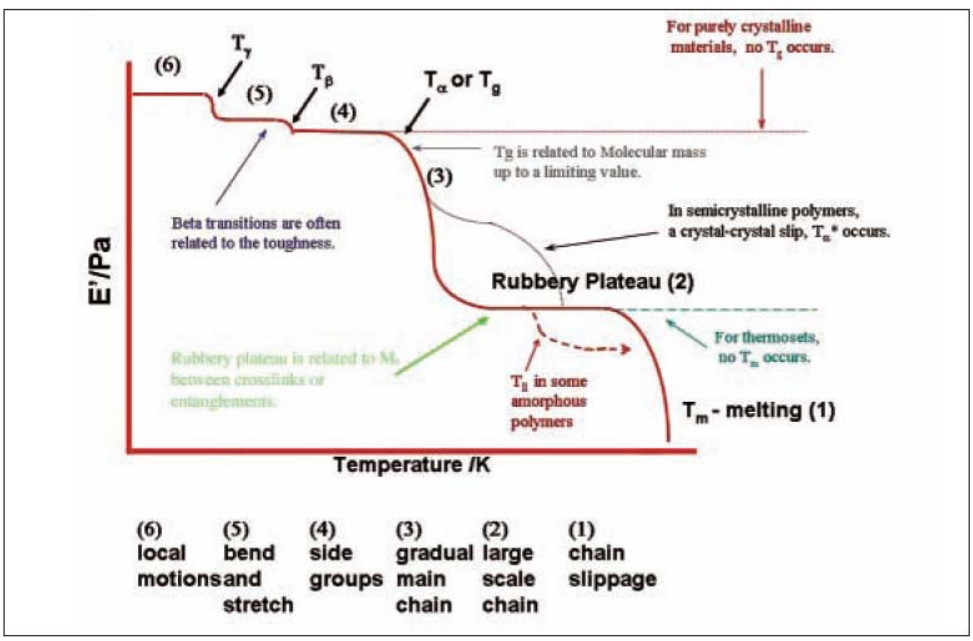

Figure 2. Schematic of DMA output indicating several physical changes in a polymer[8].

Experimental

Permeability

Each glove sample was cut out using a 2 7/8" circular die. The samples were cut from the sleeve portion of the glove to unsure a flat uniform thickness sample. The top of the glove was labeled with a T to indicate the sample orientation in the apparatus. The sample was inserted into the sample holder in the

middle of the permeation rig. A modified centering ring with a Viton®/silicon O-ring was used clamped between two flanges to create the seal.

The apparatus is designed so the sample separates the source side of gas stream from the permeant side. The disk sample thickness was measured and recorded then it was placed between the O-ring and the upper flange in the sample holder. The clamp was tightened and the entire volume was evacuated to a pressure below 5 x 10^{-6} Torr. Often the system was baked (heated) between 90 and 120°C to ensure suitable pressures were achieved. A leak test was conducted before the first test was performed to establish a baseline rate of rise (ROR) for the specific test. This ROR ensured that a suitable seal was achieved in the apparatus and the ROR from permeation was sufficiently high to allow interpretation of the results. After the leak test was completed, the system was evacuated for about two hours to pressures comparable to the pressure achieved prior to the leak test, i.e., 5 x 10^{-6} Torr or lower. A permeation test at the first test pressure test was performed by isolating the source and permeant sides, and increasing the source side of the apparatus to either 70 or 140 Torr depending on material thickness. The time, permeant and source pressures, and sample temperature were monitored and digitally recorded. Air Liquide Research grade hydrogen and Air Liquide industrial grade dry air were used for the tests. The hydrogen tests were terminated after reaching a pressure of at least $5.0X10^{-2}$ Torr in the permeant side of the apparatus, and the air tests were terminated at a pressure of $3.0X10^{-2}$ Torr. These final pressures were determined based on the curve fitting of the data. Several of the earlier tests were not run long enough to reach these pressures and resulted in correlation coefficient (R^2) of 0.99 rather than the 0.999 R^2 that is attained for the higher pressures listed above. All but one test was conducted at room temperature.

Thermogravimetric Analysis

Thermogravimetric Analysis (TGA) was conducted using a TA Instruments TGA 951. Isothermal tests were run at 90, 120, and 150°C with argon purge gas for times up to 8 hours. TGA samples were prepared by cutting rectangular samples that weighed nominally 20 mg from each glove; the dimensions were measured and the surface area was calculated. The sample was placed on the TGA pan, heated to the isothermal exposure temperature at a rate of 10°C/min and held for the programmed exposure time, usually between 8-10 hours. Argon at a flow rate of 40 sccm was purged through the balance and furnace tube. The mass and temperature data were recorded electronically at a frequency of 0.5 or 1 Hz and analyzed in MS Excel spreadsheets. The nominal percent weight loss, weight loss as a function of time, and the specific weight loss (mg/cm^2) were determined at the end point of the test or after a specified exposure time.

Mechanical Properties Testing

ASTM D412[7] was used as a guideline for this experiment. Three “dog bone” shaped tensile samples were cut along the sleeve axis from each glove represented. Two sample sizes were used. The longer gauge length sample was used for the majority of the tests, but two glove compounds required the use of a shorter test sample. The die geometry and select dimensions are shown in Figure 3. The glove material was placed on a piece of Teflon® and cut with a die with the aid of a manual press. The samples were pulled to failure with an Instron Model 4507 test machine including a MTS Systems Renew Package

at a constant crosshead rate of 20 inches/ minute. The elongation of each sample was assumed to be the applied elongation of the crosshead (no independent elongation gages were used.) The loads, percent elongation and peak stress were recorded on a computer using Testworks software. A 200 lb capacity load cell calibrated to ASTM E4[9] was used during this experiment.

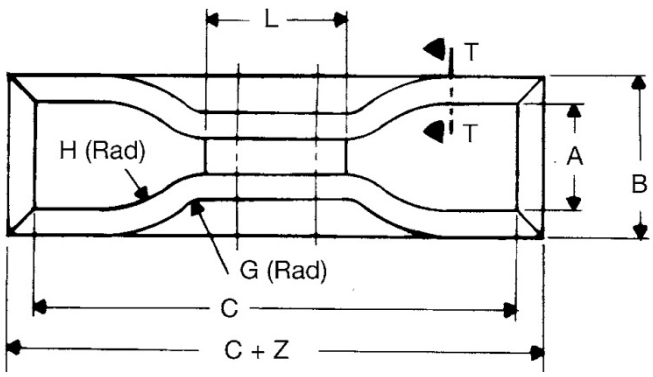

Figure 3. Die geometry for gauge width of 0.5 inch, and L of 3 or 2.25 inches, and C of 6.5 or 5.5 inches for long and short tensile samples, respectively.

Puncture Testing

Portions of ASTM D120[5] were used as a guideline for this experiment. Disk samples were die cut from the hand portion of the glove to simulate the most likely scenario where a sharp will have the opportunity to penetrate a glove in the facility. The sample disk was mounted in a compression holder and probe A was driven into the sample at a cross head speed of 20 in/min. A 200 lb capacity load cell calibrated to ASTM E4[9] was used for this experiment. The samples were tested to failure with an Instron Model 4507 test machine including a MTS Systems Renew Package. The load and deflection were recorded on a computer using Testworks software. The tests were completed in triplicate rather than 12 times due to time constraints.

Dynamic Mechanical Analysis

A TA Instruments 2950 Dynamic Mechanical Analyzer was used for this study. It is a forced oscillation, non-resonant, constant amplitude instrument. A tensile clamp, or sample holder was used due to the thickness of the sample and broad temperature range of interest.

Rectangular test samples were cut from each glove. The samples were 6.4 mm (0.25”) wide and 44.4 mm (1.5”) long. Each sample being tested was installed on the tensile clamp. The test temperature was stabilized at the sub-ambient starting temperature (-90°C for most of the tests—but this was adjusted based on the observed T_g), holding for ten minutes, and then increasing the temperature at 1°C/min to 120°C or the vendor recommended maximum temperature. The dynamic mechanical properties were continuously measured during the controlled heating. The TA 2980 has both electrical resistance heating and liquid nitrogen evaporative cooling using the Gas Cooling Accessory (GCA) and is controlled by the DMA software. The samples were loaded at frequencies of 1, 3, and 10 Hz. Up to three replicate tests were run, depending on the fidelity of the data. The DMA amplitude was set to be 40 microns, and the force track was 125%. The instrument was calibrated both at the beginning and the end of testing.

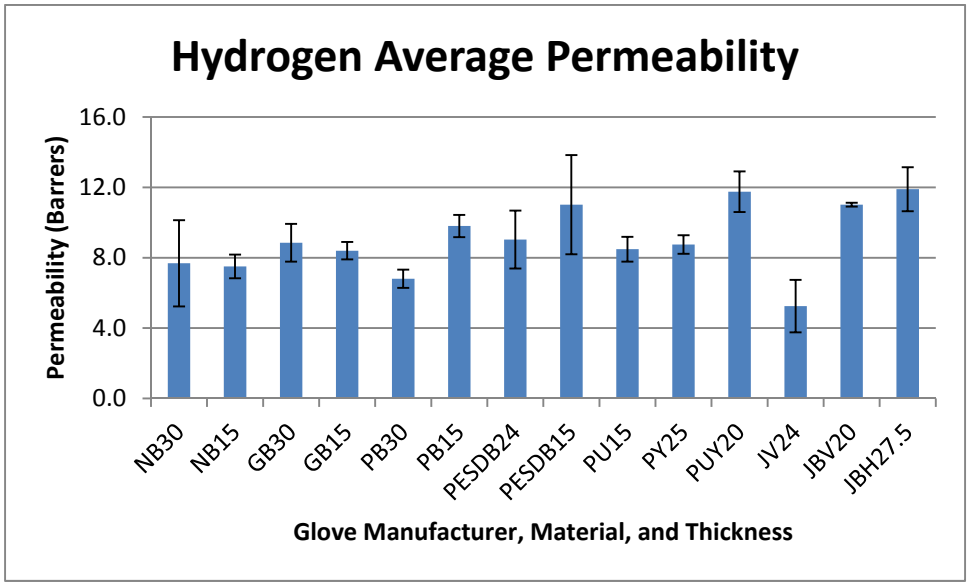

Figure 4. Hydrogen Average Permeability.

Results and Discussion

The measured permeability of hydrogen and air are summarized in Table 2, Figure 4 and Figure 5, respectively. The individual test results for hydrogen permeability testing are listed in Table 3. It is apparent from the summary data that the room temperature permeability of the butyl rubber gloves varies between 7 and 11 barrers (10^{-10}) cc H_2 * cm / (cm^2 *cm Hg), regardless of glove manufacturer. The data in Figure 4 indicates that the permeability of butyl gloves, regardless of curing treatment, have similar values. A statistical analysis of the hydrogen permeability indicates that all these values are consistent with each other and these determined values for the butyl rubber are consistent with literature data[10].The polyurethane and Hypalon® gloves exhibit comparable permeabilities to the butyl gloves with values of 8.5 and 8.7 barrers, respectively. The Jung Viton® glove exhibits the lowest hydrogen permeability of the materials tested with a value of about 5 barrers. This permeability value was determined to be statistically significantly lower than the butyl gloves. The composite gloves, i.e., Piercan Polyurethane-Hypalon®, Jung Butyl-Hypalon®, and Butyl-Viton®, all exhibit higher permeabilities than the pure compound gloves. The hydrogen permeability varies between 11 and 12 barrers for these compositions.

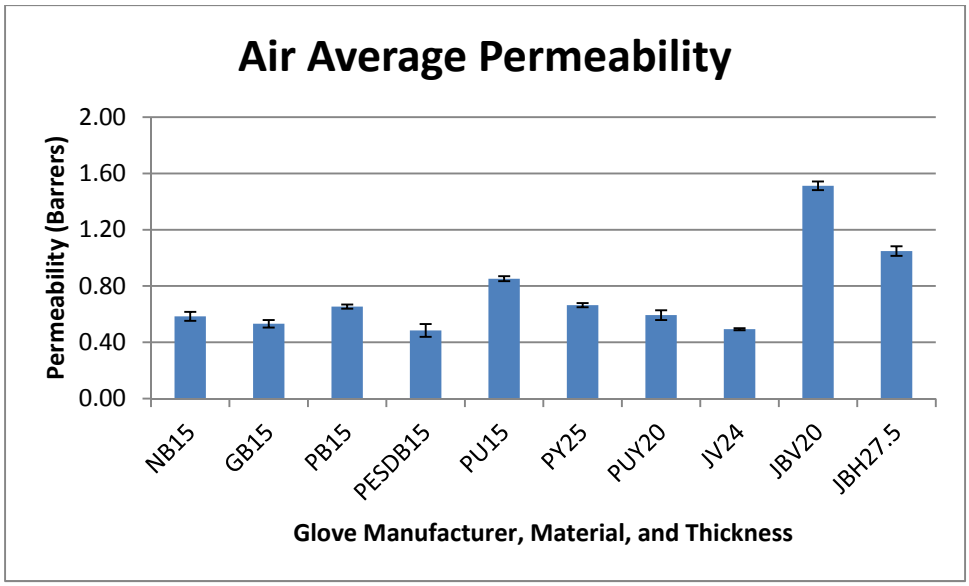

Figure 5. Air Average Permeability

The dry air permeability data, Figure 5, showed similar trends. The air permeability through each butyl glove varied between 0.48-0.65 barrers. There is not a significantly lower or higher performing glove from the butyl materials tested. The Viton® glove had a dry air permeability of about 0.49 barrers, a value at the lower end of the butyl range. The polyurethane and Hypalon® gloves were at the high end or above the Butyl rubber range, as was the Piercan polyurethane-Hypalon®. The Jung Butyl-Viton® and Jung Butyl-Hypalon® exhibited air permeabilities about twice the Butyl rubber gloves.

A more practical assessment tool for SRS to observe the effect of different permeabilities is to calculate the amount of tritium expected to permeate through the gloves. A calculation using the following assumptions and constants provides a comparative basis. A glove has a surface area of 3375 cm^2, the tritium content is 0.5 µCi/cm^3 (2.1×10^{-7} cm^3 T_2/cm^3), the internal glovebox pressure is -0.5 in H_2O, the glove descriptions accurately reflect the nominal thickness, e.g., a North 15 mil is nominally 0.015" thick, and the glovebox and room are at 25°C. The results of this calculation are shown in Figure 6 for a 24 hour exposure using the average permeability for hydrogen that was measured for each glove. The calculations for permeation through each glove indicates, obviously, that lower permeabilities result in lower overall permeation events and that thicker gloves of the same compound will exhibit lower total permeation.

Table 2. Average Hydrogen and Air Permeability.

Average Permeability 10^{-10} cc H_2 * cm / (cm^2 *cm Hg) -- Barrers					Permeability *10^{-7} cc H_2 * cm / (cm^2 *atm)	
ID	H_2	Stdev.	Dry Air	Stdev.	H_2	Air
NB30	7.7	2.5	NA	NA	0.58	NA
NB15	7.5	0.67	0.58	0.03	0.57	0.044
GB30	8.9	1.1	NA	NA	0.68	NA
GB15	8.4	0.50	0.53	0.03	0.64	0.040
PB30	6.8	0.52	NA	NA	0.52	NA
PB15	9.8	0.64	0.65	0.01	0.74	0.049
PESDB24	9.0	1.6	NA	NA	0.68	NA
PESDB15	11	2.8	0.48	0.05	0.84	0.036
PU15	8.5	0.70	0.85	0.02	0.65	0.065
PY25	8.7	0.53	0.66	0.01	0.66	0.052
PUY20	12	1.2	0.59	0.03	0.91	0.044
JV24	5.2	1.5	0.49	0.01	0.39	0.037
JBV20	11	0.11	1.5	0.03	0.84	0.11
JBH27.5	12	1.3	1.0	0.03	0.91	0.076

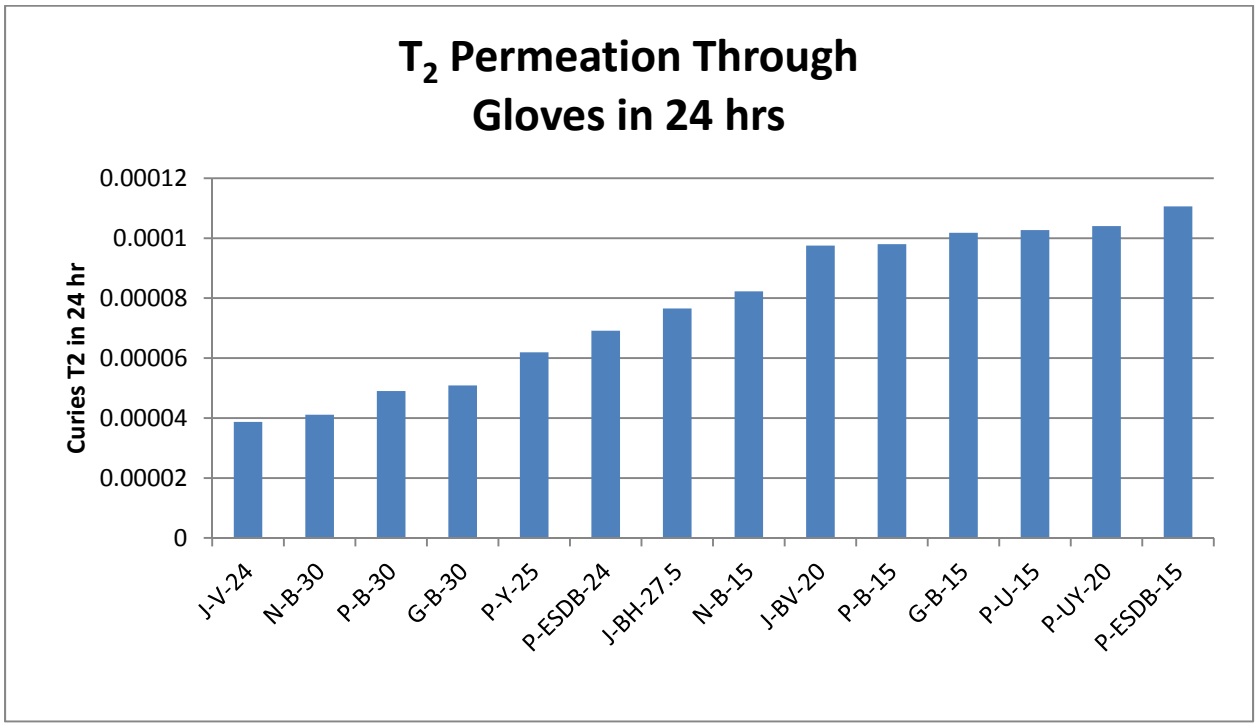

Figure 6. Graphical representation of tritium permeation in 24 hours for each glove type and thickness tested.

Table 3. Measured hydrogen permeabilities for the gloves tested.

Hydrogen Permeability (Barrers)												
Man.	Mat'l	Thick (mil)	Perm70	Sat70	Perm140	Sat140	Perm350	Sat350	Perm700	Sat700	Ave.	Stdev.
NORTH	Butyl	30	NA	NA	12	14	6.2	7.9	6.5	7.3	8.9	3.1
NORTH	Butyl	30	NA	NA	8.0	8.1	5.4	5.9	5.4	5.8	6.4	1.3
NORTH	Butyl	15	7.6	8.3	6.6	7.2	7.0	8.4	NA	NA	7.5	0.71
Guardian	Butyl	30	NA	NA	9.71	11	7.8	8.7	7.5	8.7	8.9	1.2
Guardian	Butyl	15	8.0	8.0	8.2	8.6	8.3	9.4	NA	NA	8.4	0.53
Piercan	Butyl	30	NA	NA	6.9	7.8	6.7	6.8	6.1	6.6	6.8	0.57
Piercan	Butyl	15	9.5	10	10	11	9.0	9.3	NA	NA	9.8	0.60
Piercan	ESDB	24	NA	NA	10	12	8.9	9.4	7.0	7.1	9.0	1.8
Piercan	ESDB	15	14	17	11	12	7.9	8.4	NA	NA	12	3.5
Piercan	ESDB	15	13	NA	10	NA	7.8	NA	NA	NA	10	2.36
Piercan	U	15	8.0	NA	7.8	NA	7.6	NA	NA	NA	7.8	0.18
Piercan	U	15	8.9	9.3	8.9	9.6	9.1	9.1	NA	NA	9.2	0.3
Piercan	Y	25	NA	NA	8.1	8.3	9.0	8.9	9.1	9.1	8.7	0.4
Piercan	UY	20	8.5	9.2	7.9	7.9	18	19	NA	NA	12	5.2
Jung	V	24	NA	NA	5.7	6.2	4.9	5.1	4.8	4.8	5.2	0.6
Jung	BV	20	NA	NA	11	12	9.4	9.8	11	13	11	1.26
Jung	BH	27.5	NA	NA	14	NA	11	NA	11	NA	12	1.8

Thermogravimetric Analysis

For the Thermogravimetric Analysis, the specific mass loss for the gloves tested at 90°C is presented in Figure 7. The largest mass losses occurred in the following samples Jung BH27.5 146°C 12.9% mass loss, Piercan Y25 144°C 11.4% mass loss, and Jung BV 140°C 5.2% mass loss, or 3.70 mg/cm^2, 2,79 mg/cm^2, and 1.38 mg/cm^2, respectively. The gloves that showed the least amount of off-gassing were the Jung V24 and the Piercan U15. Neither of them exhibited greater than a 0.6% mass loss. For the butyl gloves Guardian B15 and Piercan B15 showed the least off-gassing, staying below 0.8% mass loss. The North B15 and the Piercan ESDB15 showed a higher amount of off-gassing from 0.5 to around 3.0% mass loss. The Piercan production is considering changing over their manufacturing line to this new electrostatic butyl and the amount of off gassing will increase; however, since these ranges fall within the current off-gas values of the gloves in the facility (North B15) they may be viable product.

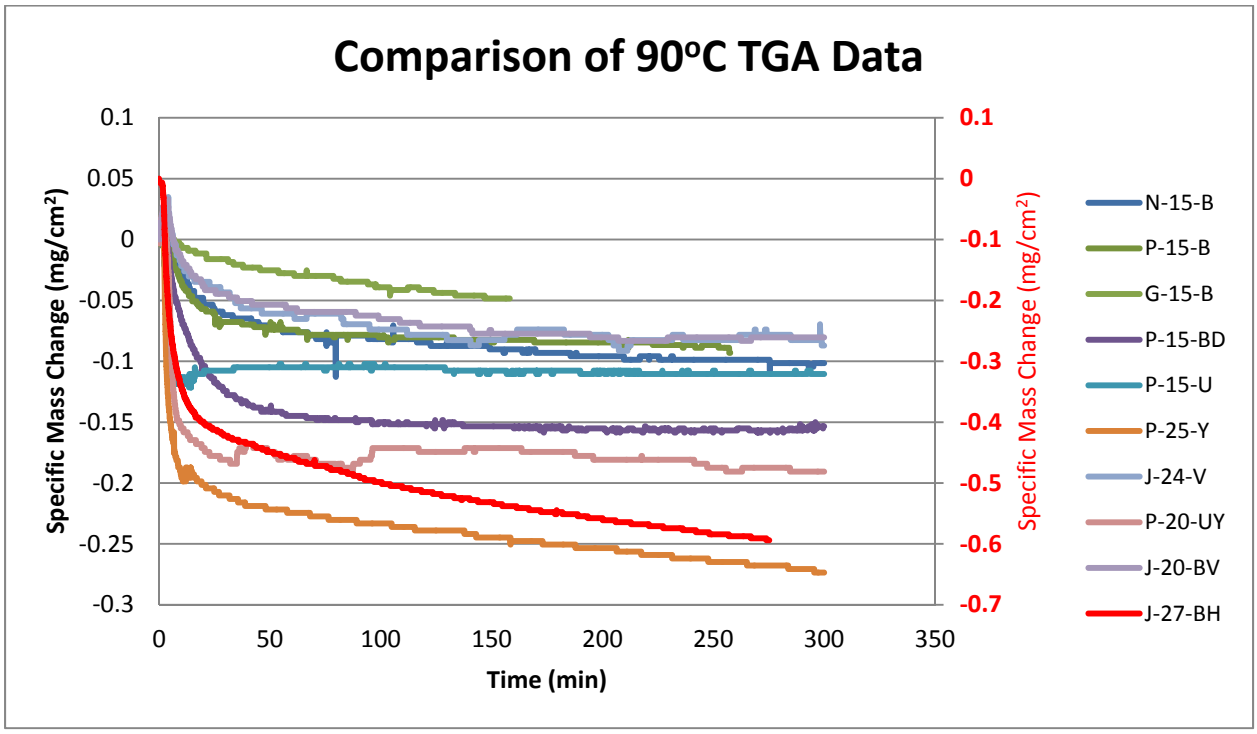

Figure 7. Specific mass change for glove samples exposed at 90°C to argon, J-27-BH is read on the right hand axis.

Data at the end of the test is summarized in Table 4 and lists the test temperature, duration, final mass loss %, and specific mass loss. From a practical viewpoint, the mass loss per unit area, i.e., specific mass loss, is more useful for extrapolating to the facility. For instance, to estimate the amount of off-gas in the facility, one can use the 3375 cm^2 surface area per glove and the number of gloves, i.e., 4400 gloves, and simply multiply. This amount of material may be expected to be evolved from the gloves after the time period for the estimate rate. Extrapolating the values to lower temperatures is possible but this action requires the understanding that there may be changes in mechanism or non-Arrhenius behavior over the extrapolation range.

Table 4. Summary of Weight Change Data

TGA Test % Weight Loss				
Glove	Temp. °C	Time (Min)	% Weight Loss	Specific mass (mg/cm2)
North B15	80	536	0.9	0.19
North B15	92	493	0.7	0.15
North B15	93	526	0.6	0.12
North B15	124	546	1.4	0.30
North B15	152	533	2.5	0.49
Piercan B15	93	258	0.5	0.09
PiercanB15	90	612	0.5	0.04
Piercan B15	122	474	0.3	0.06
Piercan B15	153	546	1.2	0.21
Piercan ESDB15	92	529	1	0.16
Piercan ESDB15	123	309	1.1	0.16
Piercan ESDB15	113	546	1.7	0.27
Piercan ESDB15	147	615	1.9	0.28
Piercan ESDB15	148	519	3	0.50
Guardian B15	92	159	0.2	0.05
Guardian B15	91	612	**-0.6**	**-0.13**
Guardian B15	90	612	0.4	0.09
Guardian B15	119	511	0.6	0.13
Guardian B15	151	546	1.5	0.27
Piercan U15	96	425	0.5	0.11
Piercan U15	119	486	0.6	0.11
Piercan U15	145	518	**-0.9**	**-0.17**
Piercan Y25	91	612	1.1	0.27
Piercan Y25	113	613	1.7	0.47
Piercan Y25	144	615	11.4	2.79
Piercan UY20	91	439	0.6	0.17
Piercan UY20	92	497	0.7	0.20
Piercan UY20	119	614	1.4	0.31
Piercan UY20	150	615	5.5	1.20
Jung V24	90	523	0.2	0.08
Jung V24	121	546	0.3	0.09
Jung V24	153	511	0.4	0.14
Jung BV20	75	496	0.3	0.07
Jung BV20	115	546	2.5	0.69
Jung BV20	140	554	5.2	1.38
Jung BH27.5	85	551	1.9	0.59
Jung BH27.5	118	614	5.4	1.55
Jung BH27.5	146	615	12.9	3.70

Note: Bold values are weight gains, all other changes are losses.

Mechanical Properties

These tensile strength (TS) results for all the gloves are listed in Table 5. The strength ranges from a low of 5.4 MPa for Viton to a high of 49 MPa for Polyurethane. The rankings are Viton® at 5.4 MPA for a 31 mil thick glove as the lowest, the butyl-Hypalon®, butyl-Viton®, and 24 mil Viton® are second lowest with about 8 MPa, then Butyl at 8-11 MPa, followed by Hypalon® at 19 MPa, Hypalon®-Polyurethane with 24

MPa and finally, Polyurethane at 49 MPa. Graphically these data can be seen in Figure 8 for both tensile strength and elongation. All of the samples exhibit at least 400% elongation with all of the butyl gloves being over 600%.

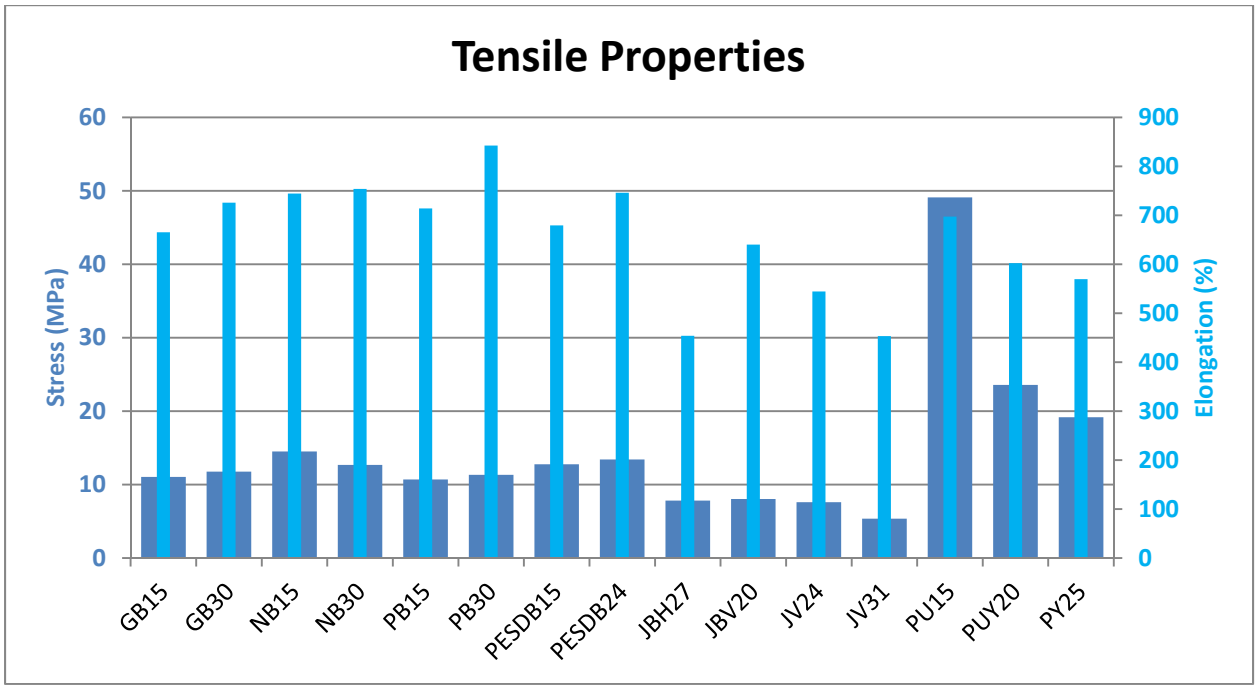

Figure 8. Tensile properties of gloves tested in this study.

Table 5. Tensile properties of the gloves tested in this study.

	GB15 Ave.	GB30 Ave.	NB15 Ave.	NB30 Ave.	PB15 Ave.	PB30 Ave.	PESDB15 Ave.	PESDB24 Ave.
Stress (Mpa)	11	12	15	13	11	11	13	13
% Elong	666	726	745	754	714	843	680	746
Load (lbf)	16	27	23	31	15	27	14	19
Thickness (in)	0.020	0.029	0.021	0.034	0.019	0.032	0.015	0.020

	JBH27 Ave.	JBV20 Ave.	JV24 Ave.	JV31 Ave.	PU15 Ave.	PUY20 Ave.	PY25 Ave.
Stress (MPa)	7.8	8.0	7.6	5.4	49	24	19
% Elong	454	640	545	453	697	603	570
Load (lbf)	16	10	14	15	55	37	30
Thickness (in)	0.045	0.017	0.025	0.039	0.015	0.022	0.021

Puncture Resistance

All of the gloves exceed the minimum puncture resistance of 100 lbf/in required for electrical gloves[5]. The SRS specification does not explicitly require puncture testing, so these data are for information and comparison purposes only. The gloves can be ranked from highest to lowest puncture resistance: polyurethane, polyurethane-Hypalon®, Hypalon®, Butyl and Viton®, Butyl-Hypalon® and finally Butyl-Viton®, as shown in Figure 9.

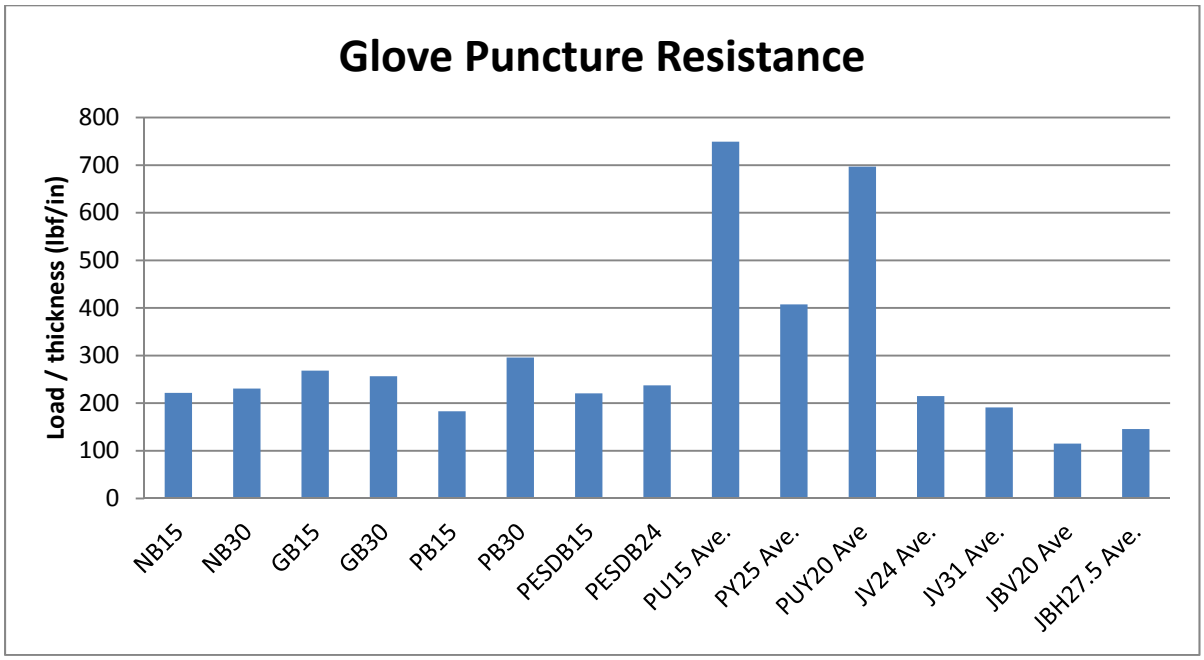

Figure 9. Puncture resistance of the gloves evaluated in this study.

Dynamic Mechanical Analysis

Dynamic Mechanical Analysis (DMA) was also conducted on the samples. The materials were generally well behaved with storage moduli and loss moduli decreasing with increasing temperatures, with the exception of North Butyl. North Butyl exhibited an increase in the loss modulus between 50 and 75°C, the temperature range over which a discontinuity in the permeation as a function of reciprocal temperature was observed. The details are available in Ref. 6. The glass transition (T_g) temperature for each of the polymers was also determined. The T_g, Storage moduli, and tan δ are presented in Table 6. These data indicate that T_g for Butyl rubber is about -60°C; the other gloves have significantly higher T_gs at -30°C for polyurethane and approximately -16°C for Hypalon® and Viton®. The composite glove of polyurethane-Hypalon® has a T_g that is intermediate between polyurethane and Hypalon®, while Viton®-Hypalon® has a more complex T_g that exhibits a total of three transitions. The additional transition may be due to an interaction between the Viton® and Hypalon®. The glass transition temperatures for gloves with single transitions are presented graphically in Figure 10. All of the T_gs are well below room temperature, so no adverse effects are predicted for them during operations.

Table 6. Average measured Tg, Storage Modulus, and Tan δ for all the samples.

	~Approx T_g (°C)	Actual T_g (°C)	Storage Modulus at T_g (Mpa)	Tan δ at T_g
G15	-60.8	-68.6	4201	0.137
G30	-60.6	-68.7	4397	0.133
N15	-60.7	-68.4	3795	0.140
N30	-60.2	-68.1	4306	0.130
P15	-60.6	-68.4	2794	0.137
P30	-60.4	-68.7	4288	0.132
P15ESDB	-60.6	-68.4	3739	0.136
P24ESDB	-59.6	-69.4	3566	0.136
P25Y	-16.2	-25.1	1489	0.067
P15U	-30.6	-39.2	1852	0.068
P20UY	-24.1	-35.3	1935	0.055
J24V	-17.0	-24.5	2738	0.089
J31V	-16.5	-24.4	2749	0.100

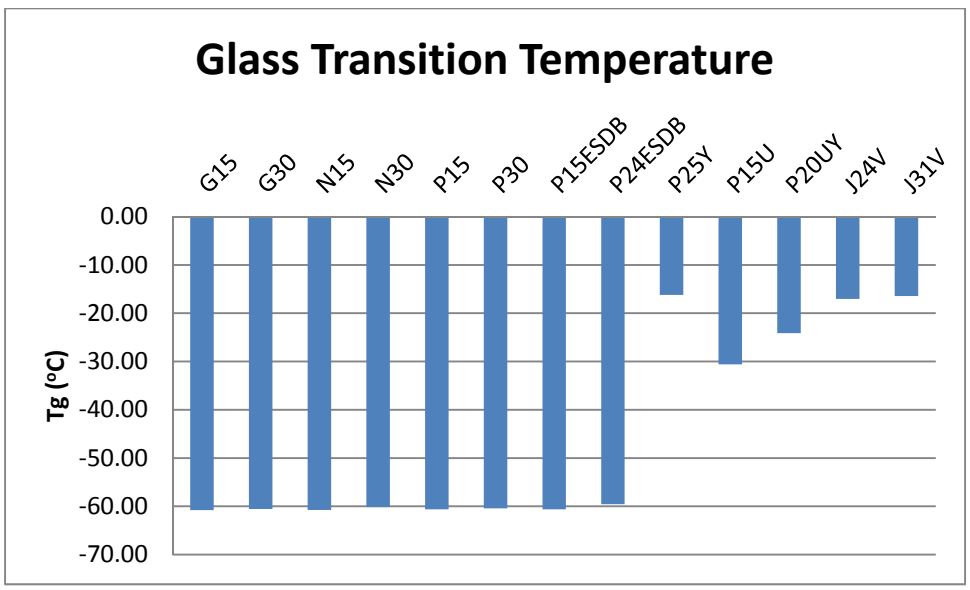

Figure 10. Glass transition temperatures for the gloves tested in this study that exhibited single T_g.

Summary and Conclusions

Butyl Rubber samples from gloves supplied have a permeability of between 5 and 11 barrers at room temperature.

The Viton® rubber gloves exhibit the lowest permeability for both air and hydrogen.

Thicker butyl gloves reduce the amount of tritium released from glove boxes.

All of the gloves exhibit some off-gassing of an unknown compound, and additional testing with appropriate analytical test apparatus is recommended.

All of the gloves meet or exceed the 100 lbf/in requirement stated in ASTM D120 for electrical gloves. The Butyl gloves exhibit puncture resistance in excess of 200 lbf/in and the Polyurethane gloves exhibit the highest puncture resistance with a value of nearly 750 lbf /in. Jung Butyl Viton® glove failed in a two stage manner with the lowest puncture resistance.

The Piercan Polyurethane gloves were the strongest material tested. They exhibited the highest tensile strength, well over minimum tensile elongation, and the highest load to failure. They were also one of the thinnest gloves tested which may offer improved tactile response.

The glass transition temperature, T_g, of the materials used in gloves of interest for SRS Tritium Facility glovebox use was determined. The T_g of all the butyl gloves was consistent and about -60°C. The composite gloves exhibited three different behaviors: the Polyurethane-Hypalon® had a T_g that was intermediate between Polyurethane and Hypalon®; the butyl-Viton® glove exhibited two distinct T_gs, at approximately the same values as the component constituents; while the butyl-Hypalon® composite material exhibited three distinct T_gs; one that was at approximately each of the constituent materials and a final one that was about 2°C.

All of the T_gs are well below room temperature and so brittle behavior is not expected for any of the glove materials in Tritium Facility operating conditions. Even the highest measured T_g, of 2°C for the Jung Butyl-Hypalon®, is well below room temperature.

The North butyl exhibits an increase in the loss modulus at temperatures between 50 and 75°C. The reason for this increase was not evaluated; however, the temperature range that this deviation was observed in is consistent with the observed change in the plot of log permeation rate as a function of reciprocal temperature.

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