47th International Conference on Environmental Systems
16-20 July 2017, Charleston, South Carolina
ICES-2017-61

Ultraviolet Testing of Space Suit Materials for Mars

Kristine Larson[1] and Dr. Marc Fries[2]
National Aeronautics and Space Administration's Johnson Space Center, Houston, Texas, 77062

Human missions to Mars may require radical changes in the approach to extra-vehicular (EVA) suit design. A major challenge is the balance of building a suit robust enough to complete multiple EVAs under intense ultraviolet (UV) light exposure without losing mechanical strength or compromising the suit's mobility. To study how the materials degrade on Mars in-situ, the Jet Propulsion Laboratory (JPL) invited the Advanced Space Suit team at NASA's Johnson Space Center (JSC) to place space suit materials on the Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC) instrument's calibration target of the Mars 2020 rover. In order to select materials for the rover and understand the effects from Mars equivalent UV exposure, JSC conducted ground testing on both current and new space suit materials when exposed to 2500 hours of Mars mission equivalent UV. To complete this testing, JSC partnered with NASA's Marshall Space Flight Center to utilize their UV vacuum chambers. Materials tested were Orthofabric, polycarbonate, Teflon, Dacron, Vectran, spectra, bladder, nGimat coated Teflon, and nGimat coated Orthofabric. All samples were measured for mass, tensile strength, and chemical composition before and after radiation. Mass loss was insignificant (less than 0.5%) among the materials. Most materials loss tensile strength after radiation and became more brittle with a loss of elongation. Changes in chemical composition were seen in all radiated materials through Spectral Analysis. Results from this testing helped select the materials that will fly on the Mars 2020 rover. In addition, JSC can use this data to create a correlation to the chemical changes after radiation—which is what the rover will send back while on Mars—to the mechanical changes, such as tensile strength.

Acronyms

UV	=	Ultraviolet
NASA	=	National Aeronautics and Space Administration
MSFC	=	Marshall Space Flight
JSC	=	Johnson Space Center
DUV	=	Deep Ultraviolet
JPL	=	Jet Propulsion Laboratory
SHERLOC	=	Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals
EMU	=	Extravehicular Mobility Unit
EVA	=	Extravehicular Activity
TMG	=	Thermal Micrometeoroid Garment
psi	=	Pounds per Square Inch

I. Introduction

HUMAN missions to Mars may require radical changes in the approach to extra-vehicular (EVA) suit design. A major challenge is the balance of building a suit robust enough to complete multiple EVAs under intense UV light exposure without losing mechanical strength or compromising the suit's mobility. To study how the materials degrade on Mars in-situ, JPL invited the Advanced Space Suit team at JSC to place space suit materials on the Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC)

---

[1] Advanced Space Suit Engineer, Space Suit & Crew Survival Systems Branch, and 2101 NASA Parkway, Houston, TX 77058.
[2] Space Scientist, Astromaterials Research and Exploration Science Directorate, and 2101 NASA Parkway, Houston, TX 77058.

instrument's calibration target of the Mars 2020 rover. In order to select materials for the rover and understand the effects from Mars equivalent UV exposure, JSC conducted ground testing on both current and new space suit materials when exposed to 2500 hours of Mars mission equivalent UV. From this testing, they were able to down select to six materials to be used for the Mars rover. In addition, they can start to create a ground model of how space suit materials degrade post-radiation. The final goal is to create a relationship between what the chemical compositions readings are when received from the SHERLOC instrument and the mechanical strength.

II. Test Overview

As stated previously, one of the purposes of this test is to down select a prioritized list of space suit materials to test on the Mars 2020 rover. In addition, this test was to prove that the SHERLOC instrument would receive valuable data from the space suit materials after being radiated. SHERLOC uses Deep UV (DUV) Raman and Fluorescence spectra to collect chemical analysis of the materials. It needed to be shown through testing that the space suit materials would show changes with the SHERLOC after being radiated with Mars equivalent UV light to prove that this future experiment on the rover was worth completing.

A. Test Article Selection

Space suit materials from the bladder through the last layer of the Thermal Micrometeoroid Garment (TMG) define the capability of the suit; thus, identifying candidate materials early in the design life cycle is a critical milestone for all future suit development. Not developing the materials compatible with the Mars radiation environment could create an unsustainable logistics need or severely limit the amount of EVAs that could be conducted on any mission due to fabrics losing their mass and mechanical strength, or even change chemistry. Understanding current suit materials behavior on Mars will bound the problem by determining what today's state of the art can provide.

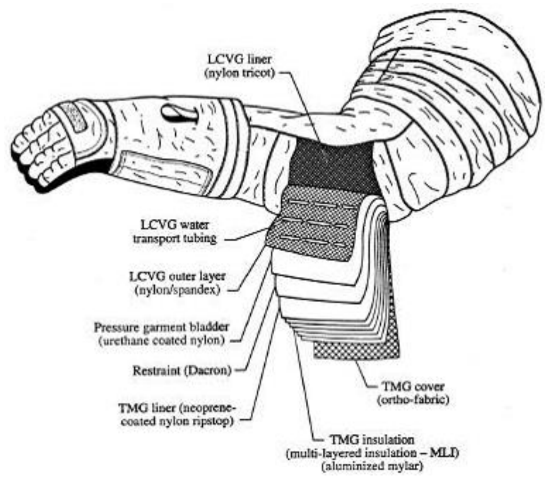

Figure 1 Space Suit Material Lay-up. *Soft good material lay-up for the Extravehicular Mobility Unit (EMU) currently used on the International Space Station.[1]*

The most important materials to select are the ones on the outside of the suit, since they will see the highest amount of UV Radiation and dust while on Mars. For the EMU, those materials are Orthofabric, Teflon, polysulfone (EMU Visor Material), and boot sole silicone. For advanced space suits, such as the Z-2 space suit prototype, they are nGimat coated Orthofabric, nGimat coated Teflon, Makralon Polycarbonate (Z-2 Helmet Material), and boot sole rubber by Wolverine. The nGimat coating is a dust resistant, omniphobic coating that is being considered for advanced materials on the space suit. Due to budget and time constraints to complete this test series, polysulfone, boot sole silicone, and the boot sole rubber was eliminated from the testing list.

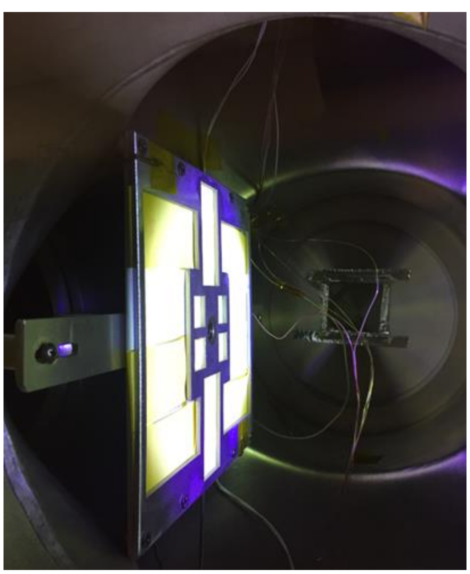

Figure 2 Set-up of UV Chamber. *View of the inside of the UV Chamber with a material set mounted.*

Others soft good materials considered for testing were the main restraint and structure materials of the EMU space suit. As seen in Figure 1, Dacron and Bladder material are two of those materials. In addition, Spectra and Vectran are also used for restraint. The main reason these materials were considered for evaluation for the Mars 2020 rover is for the testing that can be done right after the Mars Rover lands. This will tell real-time how the materials have degraded on the journey to Mars due to higher radiation sources such as Galactic Cosmic Radiation (GCR) and Solar Particle Events (SPE) radiation. These materials won't be exposed to the intense UV radiation that the outer space suit materials will be throughout a Mars mission, but if they are included on the calibration target for the reason of studying their higher energy radiation degradation received on the trip to Mars, then there is a need to characterize them as well. In addition, future outer layer soft goods materials, if developed and utilized in a future mission, may have similar characteristics as these materials, and therefore, predictions can be made for how they will degrade on the surface of Mars. In addition, it will help to further prove the ground model testing that can be done on soft good materials to certify them for a Mars surface mission.

The final list of nine materials that were tested for this study are the following:

- Orthofabric
- nGimat coated Orthofabric
- Teflon fabric
- nGimat coated Teflon fabric
- Polycarbonate
- Vectran fabric
- Dacron fabric
- EMU Bladder cloth
- Spectra weave

B. Test Set-up

The first selection for the test set-up was where to complete the UV radiation testing in the time and budget allocated to the project. For these factors, MSFC was selected to complete radiation testing in two of their UV Radiation Vacuum chambers. The lamps used were 1 kW mercury-xenon lamps that accentuated UV output. One UV lamp had a 7 inch spot size, and the other a 9 inch spot size. The set-up of their UV vacuum chamber can be seen in Figure 2. A radiation time of 2500 hours of Mars equivalent UV was selected for a reference mission of 500 day surface stay on Mars with a 10 hour EVA every other day. To radiate each of the materials for this length required approximately 23 days of continuous exposure in a chamber. This was determined by the intensity of each lamp. In addition, the lamps radiation level was between 230-500 nanometers. In comparison, the most damaging rays of Mars UV radiation that the soft good materials will receive is between 200-400 nanometers.

Testing locations were also chosen for pre/post measurements of mechanical strength and chemical composition. Mass measurements and tensile testing occurred at JSC in the Advanced Material Lab by Joseph Settles and Katelyn Melone. Chemical composition was gathered through DUV Raman Spectra and Fluorescence Analysis at JPL by Ivria Doloboff. This chemical analysis was chosen to be completed at JPL because it is a table-top version of the SHERLOC instrument.

Finally, ASTM standards had to be selected for the tensile testing for mechanical strength. For the all the soft good materials except the spectra weave, ASTM D5035-11 was used. This is tensile testing using a strip method of 6”x1” strips of fabrics being tensile tested. In previous tests, the spectra weave had used this standard. However, the results were very inconsistent due to spectra’s material strength. Therefore, the spectra weave was tested according to ASTM D6775-13 for more consistent results. The polycarbonate material was tested according to ASTM D638-14 as a type I dog-bone sample.

III. Results

All nine materials were radiated with 2500 hours of Mars equivalent UV as planned. The following table shows the number of tensile and spectral test samples each material had. Materials with less than five tensile test samples post-radiation or less than three spectral test samples was due to the limitations of the spot size of the UV lamp and the amount of time allowed for testing. Those limitations made us have to eliminate some of the material being tested. The following sections describe all the changes that were observed from the materials pre- and post- radiation testing.

Table 1 Amount of Materials

Material	Pre-Radiation Tensile Sample Quantity	Post-Radiation Tensile Sample Quantity	Pre-Radiation Spectral Sample Quantity	Post-Radiation Spectral Sample Quantity
Orthofabric	5	5	3	3
nGimat coated Orthofabric	5	4	3	2
Teflon fabric	5	5	3	3
nGimat coated Teflon fabric	5	4	3	2
Polycarbonate	5	3	3	2

Vectran fabric	5	5	3	3
Dacron fabric	5	5	3	3

C. Physical Changes

One of the first changes to be noticed between the pre- and post- radiation of all the materials is a yellowing discoloration that can be seen below in Figure 3. This discoloration is caused by the UV rays breaking down the chemical bonds in the materials. Some materials were more affected than others. An interesting material that was affected and could have operational impacts going forward was polycarbonate. This is the planned helmet pressure bubble material and the UV radiation caused the material to yellow and transparency was degraded which can be seen in Figure 4. Further study will need to be completed about the concern of this discoloration of the polycarbonate, but it may warrant for UV protective coatings being placed on the bubble or spares to be sent for change out on the surface during a future Mars mission. Another material, Dacron, was one of the materials most affected by this color change. Again, that can be seen in Figure 3.

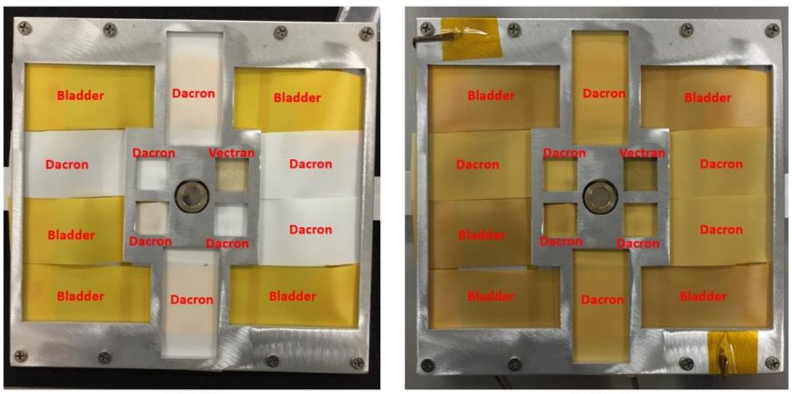

Figure 3 Pre/Post Radiation of Polycarbonate after Tensile Testing. *Discoloration was seen for all the materials tested. Dacron, seen above, was one of the materials most effected.*

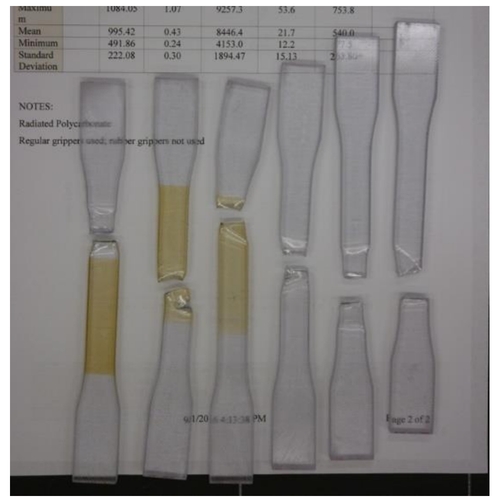

Figure 4 Pre/Post Radiation of Polycarbonate. *Left three post-radiation samples are yellowed compared to the pre-radiation on the right.*

D. Mass loss

Mass was another characteristic measured pre- and post- radiation to see if there was a significant change caused by the radiation. However, mass loss was insignificant (less than .5%) among all the materials. See the Figure 5 below for the results of the mass loss comparison.

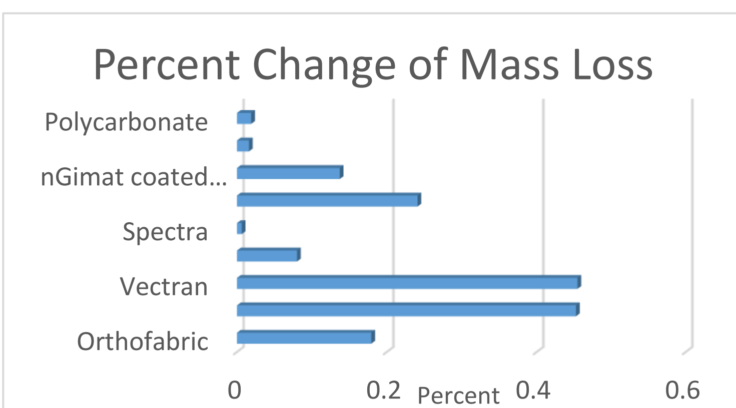

Figure 5 Graph of Mass Loss. *Graph showing the material comparisons of mass loss post-radiation.*

E. Material Strength

Material strength is a crucial characteristic for soft good materials used to fabricate a pressurized space suit. Under current planetary space suit architectures, the suit needs to operate at a pressure of 4.3 pounds per square inch (psi) to keep a crew member alive and working effectively. The operating pressure may even be as high as 8.3 psi to eliminate the time required for pre-breathe operations such as how they currently operate EVAs with the EMU on the International Space Station. This study was one of the first of its kind to be completed to understand how Mars equivalent UV will degrade the soft goods material strength and chemical composition to understand how the materials are affected. Because the information received from SHERLOC in-situ on Mars is only the chemical composition, it is essential to understand how those chemical changes relate to material strength loss here on the ground. This will directly feed into which materials should be chosen for a Mars space suit material construction. It is important to note this pilot study only included one data point of material strength and chemical composition at 2500 hours, and more testing will need to be completed.

Tensile testing was chosen as the method of evaluating material strength. As stated before in the part "B. Test Set-up", this testing was completed in JSC's Advanced Material lab using three different ASTM standard to accommodate the different materials.

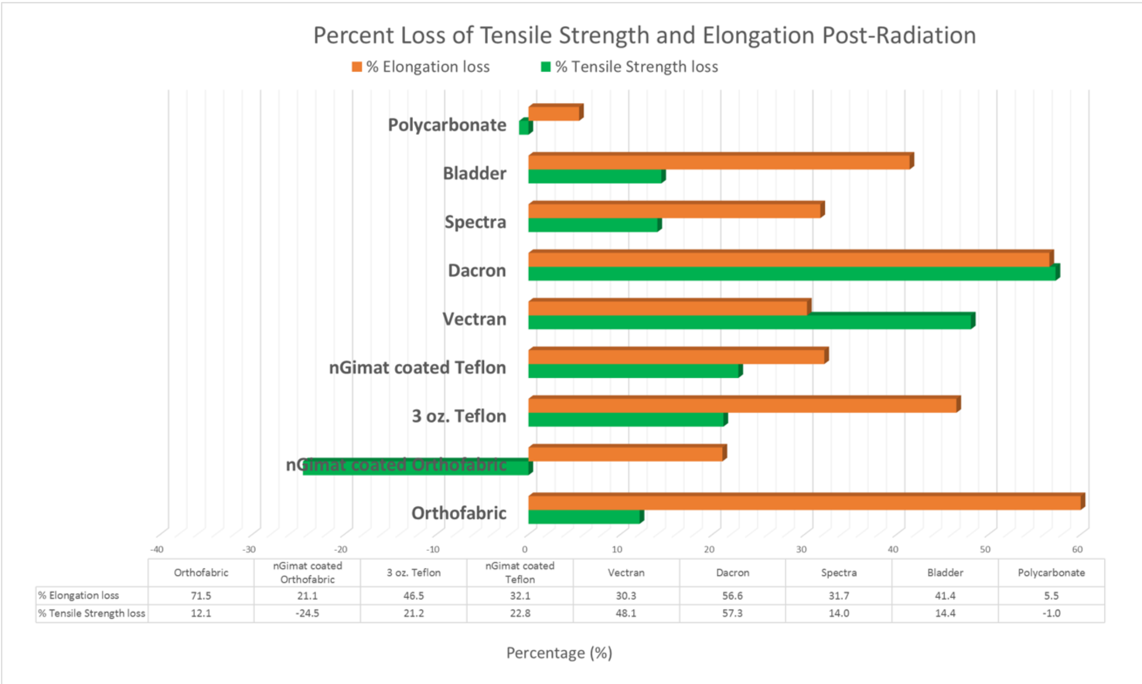

Figure 6 Percent Loss of Tensile Strength and Elongation Post-Radiation. *Graph of the comparison of tensile strength and elongation pre- and post- radiation.*

The average of the tensile testing results are shown in Figure 6. Dacron and Vectran were the most affected, losing 58.7% and 48.1% of tensile strength. In this experiment all the materials, except the nGimat coated Orthofabric lost tensile strength due to the UV radiation. It is not known why the nGimat coated Orthofabric "gained" strength. The standard deviations for the materials when tensile tested—especially those post-radiation—were high. Three factors have been identified as potential causes to the variability in the tensile testing. First, the soft good textiles were not conditioned prior to tensile testing. Lab conditions such as temperature and humidity have a known affect to tensile test results, especially affecting soft good textiles. A future method to reduce this standard deviation is to condition the materials according to ASTM D1776 for textiles and ASTM D618-13 for plastics. The second factor is the tested post-radiated materials were shipped to Marshall for radiation exposure and then shipped back to JSC for testing. The pristine materials were just pulled out of storage directly before tensile testing was completed. This may have affected the tensile test results of the materials, and potentially this difference could have been magnified because of no conditioning being completed. It might reduce future variability if the tensile testing is completed at Marshall for both pre- and post- radiated materials to reduce time the materials spend in shipping and processing. The last factor is the small quantity of samples. Because of the limited time the team had to complete the pilot study only five of each material were radiated then tested. Textiles are known to have more variability in tensile test results. It will reduce future variability if the quantity of sample size of each material is increased.

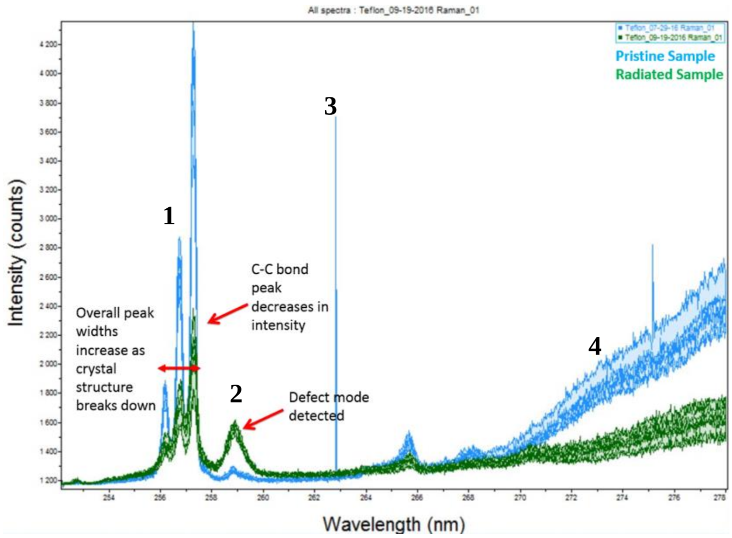

Figure 7 DUV Raman Spectra for Teflon. *Spectral wavelengths show the Teflon's chemical composition pre- and post- radiation. See text for explanation of the numbered items.*

F. Elongation

A study of percent elongation loss can be seen above in Figure 6. This was to understand if the material became brittle after being radiated. It was interesting to see that non-coated Orthofabric became much more brittle than the nGimat coated Orthofabric. However, because of the variability in the nGimat Orthofabric tensile test results this result will need to be further investigated before validated. If this result is constantly seen in further testing, it would be an additional reason to coat the Orthofabric to maintain the fabric's flexibility.

G. Chemical Composition

All of the materials radiated saw changes to their chemical composition. An example of this can be seen in Figure 7, which is the DUV Raman spectra from Teflon. The blue shows the pristine sample and the green is the radiated sample. As seen in the figure, the bond peaks start to increase width as the crystal structure breaks down. This causes defect modes—peaks in the spectra not seen previously—to be detected. For this Raman spectrum, the trio of peaks labeled "1" arise from vibrations of C-C and C-F bonds. Note that the peak intensities drop significantly for the irradiated samples (green spectra), indicating loss or shielding of the Teflon molecular structure. The peak width has increased (not visible here), indicating breakdown of the Teflon crystalline structure. Also important is the appearance of an unattributed defect mode (labeled "2"), a broad feature arising from deviations from the nominal Teflon chemical structure. The feature labeled "3" is an artifact. Aside from the Raman features, it is evident that the native fluorescent background at the high-wavelength end of the spectrum has diminished during irradiation, resulting in a lower intensity. All of the Raman and fluorescence features can be measured and used as empirical means of measuring chemical changes in the space suit materials upon irradiation.

The success of this analysis shows that a correlation between changes in the spectral analysis can be related to a certain material strength through tensile testing. It is the goal of the SHERLOC space suit material experiment that this data of spectral analysis can be compared to the ground results at close to equivalent radiation levels to validate this ground testing method of using a UV vacuum chamber to mimic Mars surface radiation.

IV. Conclusions

This study of space suit materials evaluated the physical, material strength, elongation, and chemical changes caused by UV radiation by 2500 hours of Martian equivalent UV. It successfully showed that correlations can be drawn between changes seen in tensile strength to changes seen in chemical composition. This validates the space suit material experiment that will take place on the Mars 2020 rover. From the findings of this study, the six materials were chosen that will fly on that experiment. They are Orthofabric, Teflon, nGimat coated Teflon, Dacron, Vectran, and Polycarbonate. All six of these material also pass the off-gas requirements for the Mars 2020 rover from tests completed at Marshall and Goddard Space Flight Centers.

V. Forward Work

The next step is to create a Mars-like chamber to complete more UV radiation testing in. In this chamber, we will strive to maintain a Mars equivalent temperature, pressure, and atmosphere. By making a Mars chamber, it is our hope that the results will be closer to those that are seen in-situ on Mars. The team at JSC and MSFC received funding in November 2016 to start this work through the NASA Innovation Kick-Starter fund (NIKS).

After the Mars-like chamber has been created and validated, the testing will start to create a ground model of each material selected. The Mars 2020 rover has an expected life of 1 Martian year, which equals about 12,000 hours of UV exposure. Because the rover does not have a scheduled interval for when it will look at its calibration target, we need to have ground-based data throughout its lifetime to correlate what the chemical changes mean to material strength to see if the ground-based model matches the in-situ data. How that can be accomplished is by pulling materials at intervals through the radiation testing, and complete the material strength and chemical composition analysis. The rover's results can then be used to evaluate the effectiveness of our ground testing, and create a standard in which to test any material—especially soft goods used for space suits and habitats—in future Mars missions.

Acknowledgments

This project was funded through NASA's Johnson Space Center Innovation Charge Account (ICA). It provided the team with $10,000 and 3 months to complete the work required to complete this pilot study.

We had many contributors from other NASA Centers helping us complete the work. Marshall Space Flight Center's Jason Vaughn and Brandon Phillips completed the UV radiation testing. Joseph Settles and Katelyn Melone at Johnson Space Center completed the mass measurements and tensile testing. At Jet Propulsion Laboratory, Ivria Doloboff completed the DUV Raman and fluorescence spectral analysis.

References

[1]Wilson et al., "Shuttle Space Suit: Fabric/LCVG Model Validation," NASA 20040065987, 2003.

[2]Mihály, J., Sterkel, S., Ortner, H.M., Kocsis, L., Hajba, L., Furdyga, É. and Mink, J., 2006. FTIR and FT-Raman spectroscopic study on polymer based high pressure digestion vessels. Croatica chemica acta, 79(3), pp.497-501.