Textiles for Extreme Surface Environments and High Oxygen Atmospheres

A spacesuit is essentially a one-person fully equipped spacecraft. It is complex and consists of more than 100 components. One of the primary purposes of the spacesuit is to protect the astronaut from the dangers in space outside the spacecraft. Therefore, it is more than a set of clothes. The current spacesuit used for the International Space Station (ISS) is known as the Extravehicular Mobility Unit (EMU). The EMU was designed for spacewalks on the Space Shuttle and was enhanced for use on the ISS. Extravehicular mobility means the astronaut can move around in space outside the space vehicle.

The astronauts use the spacesuit only when they are performing a spacewalk. When astronauts are inside the space vehicle, they wear regular clothes. When the astronauts prepare to perform a spacewalk, they remove their regular clothes and put on two-piece thermal underwear known as the “thermal comfort undergarment (TCU).” The TCU is only used by the astronauts while they are in the spacesuit. After a spacewalk, the astronaut gets out of the spacesuit and takes off the TCU. The TCU is not part of this solicitation.

NASA has been working on a new spacesuit called the Exploration Extravehicular Mobility Unit (xEMU). The objective of the xEMU is to protect the astronauts from the harsh environment of space. This xEMU is designed for lunar surface exploration and operations in extreme environments. It incorporates more advanced technologies than the current EMU. The xEMU is designed to be the next-generation spacesuit to benefit several space programs, namely the International Space Station, Human Landing System (HLS), Artemis, Gateway, and Orion.

This STTR subtopic covers two different applications of textile technology. First, it addresses the primary need to develop new textiles for the xEMU Environmental Protection Garment (EPG). Second, it addresses the need for crew clothing when the astronauts are not inside their spacesuits.

The EPG is the outer component of the xEMU. The EPG is considered the first line of defense when an astronaut is performing a spacewalk. The function of the EPG is to protect the astronaut from extreme surface environments and flammability in oxygen-rich atmosphere. NASA is looking for innovative materials for the entire EPG. Likewise, NASA is looking for innovative textiles for crew clothing. Crew clothing is not part of the EPG and is never worn inside the spacesuit. Crew clothing includes t-shirts, pants, and sleepwear.

Both the EPG and the crew clothing shall be addressed in the proposal. Also, due to the complexity of the EPG and the urgency for its development for the Artemis program, priority shall be given to the development of the
EPG. Additionally, the Technical Readiness Level (TRL) for the EPG is expected to be the highest level possible at the end of Phase II.

**Part A: Development of the EPG**

The requirements of the EPG are given below and followed by a description of the extreme surface environments and oxygen-rich atmosphere:

**Requirements**

The EPG is a multilayered component consisting of fabrics and thin films. Each layer of this component contributes to the protection of the xEMU from the extreme lunar environment while enabling xEMU functionality of its three subsystems: the Pressure Garment System (PGS), the Portable Life Support System (PLSS), and the informatics system. The EPG is the spacesuit’s first line of defense. It must be designed to have properties to perform in the harsh surface environment of the south pole of the Moon.

The desired properties and requirements of the EPG for the extreme environment of the lunar surface are:

1. Thermal:

   The EPG shall have an average:

   - Ratio of solar absorptivity to infrared emissivity ($\alpha/\varepsilon$) of 0.21
   - Solar absorption of 0.18

2. Physical:

   The EPG solution may consist of many layers. Although the offeror shall address the entire EPG, the offeror shall place a priority on the outermost layer. The outermost layer shall be designed in a manner to limit dust accumulation and penetration. It shall have properties such that the regolith particles of microns and submicrons sizes cannot penetrate the EPG. In addition, the external surface of the outermost layer shall have low energy and a nanotexture that prevents entrapment of most regolith particles. The outermost layer may be a composite structure.

Opportunities for mass reduction for the entire EPG shall be investigated. The reference for mass reduction is the International Space Station (ISS) EMU. Using the current fabric layers, the entire ISS EMU EPG weighs approximately 16 lb. The ISS EMU has a total density of approximately 31 oz/yd2.

The composition of the EMU EPG includes:

- Orthofabric with density 14.25 + 0.75 oz/yd2
- Aluminized Mylar with density 1.12 oz/yd2 maximum per layer with a total of 7 layers
- Neoprene-coated nylon with density 9.0 oz/yd2 maximum

3. Mechanical with respect to mobility:

   The EPG shall not significantly affect mobility of the suit. The EPG fabrics must be flexible with both low
bending and low torsional stiffness to withstand exposure to the extreme temperatures of 260 °F (127 °C) to -292 °F (-180 °C). The outermost layer is directly exposed to these temperatures. The other layers of the xEMU are not subject to these extreme temperatures. The combination of the EPG layers shall not hinder the joint mobility of the xEMU. The EPG fabrics shall not outgas at vacuum.

Extreme Surface Environments

The description of the extreme environments is as follows:

1. Thermal

The environment temperatures will be the temperature on the outside of the suit. The internal layers of the EPG are higher because of the suit heat leak provided by the astronaut, which warms the surrounding area.

- Extreme heat (260 °F, 127 °C)
- Extreme cold (-292 °F, -180 °C)

2. Regolith Terrain

The lunar regolith is a blanket of abrasive dust and unconsolidated, loose, heterogeneous, superficial deposits covering solid rock. The EPG fabrics must have sufficient resistance to abrasion and tear to last for multiple uses.

In the south pole region of the Moon, the regolith is:

- Highly abrasive

The EPG durability in the dust environment is a key requirement. The spacesuit must operate during prolonged exposure and operation in the dusty regolith environment. Because of bending, kneeling, and falling on the lunar surface, the EPG will be in constant contact with the abrasive regolith.

- Electrostatic and Triboelectrostatic Charging

The electrostatic and triboelectrostatic properties of the lunar dust particles are so averse to the outer layer of the EPG that they promote abrasion and wear necessitating the development of new EPG outer fabrics. The electrostatic charges are produced by the photoemission of electrons due to vacuum ultraviolet (VUV) sunlight irradiation. The regolith becomes slightly positively charged. In the shadow, these charges reverse. In addition, the triboelectrostatic charges are created by the friction of fabrics on the regolith. In both cases, there is a risk that these charged particles can be carried inside and contaminate the lunar lander.

3. Radiation and Plasma

The Moon does not have an atmosphere. Therefore, it receives unattenuated galactic and solar radiation. This solar radiation does not cause radioactivity. The annual Galactic Cosmic Rays dose in milli-Sieverts (mSv) on the Moon is 380 mSv (solar minimum) and 110 mSv (solar maximum). The annual cosmic ionizing cosmic radiation on Earth is 2.4 mSv. The EPG layers and particularly the outer layer fabric must be durable over hundreds of hours of VUV radiation exposure without a reduction in functionality.
Plasma is a concern due to the charged environment that may be in contact with the spacesuit. The plasma is explained in a PowerPoint document from Timothy J. Stubbs et al., “Characterizing the Near-Lunar Plasma Environment,” Workshop on Science Associated with the Lunar Exploration Architecture, Tempe, AZ, February 26-March 2, 2007 (https://www.lpi.usra.edu/meetings/LEA/whitepapers/Stubbs_charging_NAC_whitepaper_v01.pdf).

Oxygen-Rich Atmosphere

The EPG must satisfy flammability requirements. The EPG outer layer shall not support combustion in the lunar lander's atmosphere. It is currently determined that atmosphere of the lunar lander in HLS will contain 34% ±2% oxygen at a pressure of 8.2 psia (56.5 kPa). This oxygen concentration may even be higher. Hence, all materials directly exposed to the lunar lander atmosphere are required to be flame retardant.

Past program technologies do not meet the requirements for the HLS and Artemis programs and their sustaining missions. Beta fabric, the glass fiber fabric used in the Apollo spacesuit, addressed only the high flammability risk in the Apollo Lunar Module (LM) atmosphere of 100% oxygen at 4.8 psi (33 kPa). The three extravehicular activities (EVAs) in the last Apollo mission, with an average combined duration of 22 hours, resulted in damage to the outer layer of the Apollo spacesuits, and the suits could not have endured more EVAs. The glass fiber developed for NASA was the first-ever textile microfiber (3.8 µm fiber diameter) that would not burn in a 100% oxygen atmosphere, but it did not have the mechanical properties to withstand abrasion from the lunar regolith.

Part B: Development of Crew Clothing Fabrics

The criteria for the development of new crew clothing fabrics are based on the HLS program requirement of flame retardance in 36% oxygen at 8.2 psia and the need to have clothes to wear when the astronauts are not exploring the surface of the Moon. The new fabric items must be flame retardant inside the lunar lander.

Requirements

1. Flame Retardance

Options for developing flame-retardant clothing include inherently flame-retardant textile fibers and durable flame-retardant treatments. These options are described below:

- Inherently flame-retardant textile fibers:

The 1.5 denier polybenzimidazole (PBI) fiber is the only inherently flame-retardant fiber commercially available to make yarns for apparel fabrics.

While there are several polymers that meet the flame retardant threshold of 36% oxygen at 14.7 psia, few have been used to produce textile fibers. Among those that are currently spun into fibers like polyimide, the fibers are mostly used to make yarns and fabrics for industrial applications.

Most existing textile fibers that do not support combustion in 36% oxygen-rich atmosphere have linear densities too high to produce yarns and fabrics that are comfortable for next-to-the-skin apparel fabrics. In other words, the diameter of these fibers is usually too large, and consequently, the fibers bending and torsional properties are not adequate to produce yarns suitable for knitted garments.

- Durable flame-retardant treatments:
A durable flame-retardant treatment is a treatment that can withstand wear abrasion and 50 laundry cycles. A durable flame-retardant treatment may be applied to fibers, yarns, or fabric considered for crew clothing.

2. Comfort

Comfort is a function of yarn hairiness, which promotes softness and warmth. Greater hairiness promotes flammability. Flame-retardant treatments reduce hairiness and the accompanying comfort. This competition between comfort from hairiness and the reduction of hairiness due to flame-retardant treatment would seem to favor the use of an inherently flame-retardant fiber over a flame-retardant treatment.

A potential solution is a fabric with a flame-retardance outward-facing side, while the inward-facing side next to the skin may be more comfortable with the consequence of reduced flame retardance. This solution may be achieved by methods of fabric construction including woven, knitted, laminated, and nonwoven fabrics.

3. Volatile Emissions

The fabrics shall be free of volatile materials that can be toxic to humans. Also, the fabrics shall not adversely affect the Environmental Control and Life Support System of the lunar lander.

4. Lint Reduction

The fabrics shall produce a minimal amount of lint.

5. Odor Control

The fabrics shall not produce malodor.

6. Resistance to the lunar Regolith

The crew clothing fabrics shall be resistant to wear from the abrasive lunar regolith particles to last for the length of the Artemis mission.

While mentioned previously as not part of this solicitation, the TCU can be a source of regolith contamination. The astronaut takes the TCU off after getting out of the spacesuit. If contaminated with regolith particles, the TCU can contribute to the contamination of materials inside the lunar lander. In addition, regolith dust can enter the lander from an airlock or directly from outside depending on the design of the lander. Because of this exposure, textiles for the crew clothing must be either inherently flame retardant or have flame-retardant finishes. These textiles must not be at risk of losing their flame retardance due to the abrasive nature of the regolith.

Expected TRL or TRL Range at completion of the Project:

2 to 6

Primary Technology Taxonomy:
Level 1: TX 06 Human Health, Life Support, and Habitation Systems
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

Phase I: Phase I offerors are expected to deliver written reports (Interim and Final) containing a plan or strategy that explains in detail their approach for solving the problems of the EPG and the crew clothing. Reports shall include rationale for approach, research, proof of concept, analysis, and any strategy leading to one or more prototypes.

Phase II: Phase II deliverables shall include prototypes or finished goods. The prototypes or finished goods shall be delivered to NASA Johnson Space Center with a Material Inspection and Receiving Report OMB No. 0704-0248. Photographs of the delivered prototypes or finished goods shall accompany the DD250 form. Deliverables shall also include complete documentation such as technical data sheets with detailed description and composition of the material or product, with testing methods and testing data, design sketches or drawings, and full information on material and/or chemical sourcing. The Phase II deliverables shall also include a final report documenting all work accomplished for the Phase II effort and shall not duplicate the Phase II proposal.

Examples of the deliverables for the EPG and crew clothing may include:

- EPG: prototype textiles with coating, lamination, thin film, other new technology, composite structure, or fabrics integrated in a spacesuit.
- Crew clothing: novel fibers, yarns, and fabrics for everyday garment prototypes (e.g. T-shirt, pants, and sleepwear).

The proposers shall clearly state the Technology Readiness Level (TRL) levels at which they start their research and at which they expect to be at the end of Phase I and Phase II. For the EPG, the TRL level is expected to be the highest level possible at the end of Phase II. Reference for the TRL definitions are at the following link: [https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf](https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf).

State of the Art and Critical Gaps:

The gap is the lack of available commercial-off-the-shelf (COTS) textiles that satisfy spacesuit and crew clothing mitigation requirements for extreme surface environments and fire safety in a 36% oxygen atmosphere.

The second gap is the lack of knowledge of the effects of lunar dust on textile products with respect to their useful life in EVA applications. Extent of wear and tear and levels of contamination and retention of the dust in the textile structure are not known.

Relevance / Science Traceability:

This scope is included under the Space Technology Mission Directorate (STMD). The xEMU project is under the Human Exploration and Operations Mission Directorate (HEOMD).

This work will benefit several space programs, namely the ISS, Human Landing System (HLS), Artemis, Gateway, and Orion. Near term, the work on the EPG will directly benefit the xEMU project.
The textiles developed could be useful for other soft goods applications.

References

1. “NASA’s Plan for Sustained Lunar Exploration and Development” (a_sustained_lunar_presence_nspc_report4220final.pdf (nasa.gov)).
11. Lunar Reconnaissance Orbiter Camera (LROC :: QuickMap (asu.edu)).