Evaluation of SPE and GCR Radiation Effects in Inflatable, Space Suit and Composite Habitat Materials Project

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Primary TA:

Start TRL: N/A

End TRL: N/A

Goal / Gap

Indicate the goal being addressed. Provide a brief statement about the capability need / knowledge gap, including a brief review of state of the art / knowledge in this area.

The radiation resistance of polymeric and composite materials to space radiation is currently based on irradiating materials with ^{60}Co γ-radiation to the equivalent total ionizing dose (TID) expected during mission. This is an approximation since γ-radiation is not truly representative of the particle species; namely, Solar Particle Event (SPE) protons and Galactic Cosmic Ray (GCR) nucleons, encountered in space. In general, the SPE and GCR particle energies are much higher than ^{60}Co γ-ray photons, and since the particles have mass, there is a displacement effect due to nuclear collisions between the particle species and the target material. This effort specifically bridges the gap between estimated service lifetimes based on decades old ^{60}Co γ-radiation data, and newer assessments of what the service lifetimes actually are based on irradiation with particle species that are more representative of the space radiation environment.

Approach / Innovation

Identify one or more key technical challenges and provide a brief overview of the technical approach / research plan including one or more key objective(s), milestone(s), or deliverable(s) for this year. Describe how this is different from or complimentary of other efforts in industry, academia, or government. Briefly state the next step(s) anticipated after this year's work.

Innovative spacecraft structures, such as inflatable activity modules and multifunctional composite habitats are being advanced in order to make spacecraft lighter, safer, and more versatile. For example, metallic foams are being considered as the Micrometeoroid and Orbital Debris (MMOD) arresting layer in multifunctional composite habitats, and self-healing gels are being considered for use in inflatable habitats. Also, ultra-high strength fabrics are being considered for space suits developed for the Martian surface mission. The safety margins and function of these materials are highly dependent on the radiation resistance of one or several materials in a given design. For example, the overall function of inflatable habitats can depend heavily on the strength retention of the restraint material, the permeability of the bladder material, or on changes in the rheology of self-healing gels after radiation exposure. The overall function of composite habitats can depend heavily on the integrity of the adhesive bondline between the facesheet and underlying honeycomb or metallic foam core. In space suits, performance can be driven changes in the strength of the outer high-strength rip-stop, or in the permeability of coated fabric inner layers.

This effort addresses these concerns by irradiating materials deemed critical to the performance of inflatable habitats, composite habitats, and space suits. The total ionizing mission doses for these materials are calculated using the latest version of the High charge (Z) and Energy TRaNsport) (HZETRN) computer

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code. In 2015 and 2016, HZETRN calculations were completed for two Z-series Extravehicular Mobility Unit (EMU) space suit designs, and three inflatable habitat designs: 1) Bigelow, 2) NanoSonic STTR T12.03-9881 cold temperature flexible material, and 3) ILC Dover Armor Flex material. In 2017, HZETRN calculations will be extended to current state-of-the-art composite and inflatable habitat designs. After HZETRN TID calculations are made, composite and inflatable habitat materials will be irradiated at doses representing a 50-year space radiation exposure in the Summer of 2017 at the Brookhaven National Laboratory NASA Space Radiation Laboratory (BNL NSRL) (proposal deadline: November 2016). Aside from transport code modeling and irradiations, the bulk of the fiscal year 2017 effort will focus on completing testing on the backlog of materials irradiated in 2015 and 2016. Over 600 test specimens have been irradiated in 2015 and 2016 and results to date indicate measureable property changes and varying degrees of material degradation following irradiation. Planned testing will be accomplished at the NASA JSC White Sands Test Facility (WSTF) (mechanical, thermal, and hypervelocity tests; FTIR spectroscopy; sol-gel extractions), the NASA Johnson Space center (JSC) (permeation, cold flex, mechanical property, and thermomechanical tests), Honeywell (high denier Spectra® fiber tests), and, depending on funding, at NanoSonic (-45, 23, 90 °C tensile tests, cryo-puncture tests, and rheometry). Last, and in addition to two NASA Investigative Reports (due October 2016 and September 2017), and peer-reviewed scientific publications in the open literature (by September 2017), findings of this 3-year effort will be integrated into new NASA standard protocol for certifying nonmetallic materials for space radiation environments based on NASA-HDBK-6015 (due September 2017). There is no known complementary work going on with NASA at this point; however, synergies will be explored with other NASA groups to minimize beam use costs.

Results / Knowledge Gained

Briefly describe the outcome and knowledge gained (this includes lessons learned). Insert or append any images or charts that add context to the results. Identify any funded follow on work.

Radiation-induced property modification has been observed for inflatable habitat NanoSonic bladder material developed under STTR T12.03-9881 (tensile strength increases as high as 205% were observed, see Table 1), inflatable habitat Armorflex® bladder material (low molar mass weight loss component increases as high as several percent as measured by thermogravimetric analysis were noted, see Figure 1), and inflatable habitat Kevlar® MMOD arresting layer (degraded ballistic performance, see Figure 2). NanoSonic self-healing gel performance unaffected. Inflatable bladder permeation tests (K. Shariff), space suit tests (B. Peters), and composite habitat material tests (D. Litteken) are still being conducted. Also, tensile test methods are being refined for high strength polymer fabrics (Spectra® and Vectran®). Test method refinement includes collaboration with Honeywell (ASTM D5035 tensile grab tests on Spectra® 375 denier fabric), and collaboration between JSC and WSTF test experts (ASTM D6775 breaking strength on Vectran® tape). In summary, this effort provides risk reduction data to ensure the safety and reliability of new materials and designs in their intended space radiation environments. In the case of little or no physical or mechanical property change, the use of new materials technologies for manned interplanetary flight to reduce vehicle mass and improve safety and performance are accelerated. In the case of measurable or significant physical or mechanical property changes, engineering control and or design and material changes will implemented to increase safety margins.

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Table 1. Tensile Data for NanoSonic controls (Pre-Irradiation) and SPE and GCR Irradiated Low Air Permeable Polymer Infused Spectra® Bladder Material

Temperature (°C)	Spectra® Unirradiated		Spectra® Post-irradiated Run 1A mixed 1-GeV 709 cGy			Spectra® Post-irradiated Run 11A10300 cGy protons		
	Tensile Stress at Max Load (MPa)	Elongation at Break (%)	Tensile Stress at Max Load (MPa)	Elongation at Break (%)	Increase in Tensile Strength (%)	Tensile Stress at Max Load (MPa)	Elongation at Break (%)	Increase in Tensile Strength (%)
RT	104.2	12.0	242.2	7.0	**132%**	317.9	8.0	**205%**
90	57.4	10.0	107.3	9.7	**87%**	71.9	13.0	**25%**
-45	366.9	11.0	708.8	15.7	**93%**	567.8	12.8	**55%**

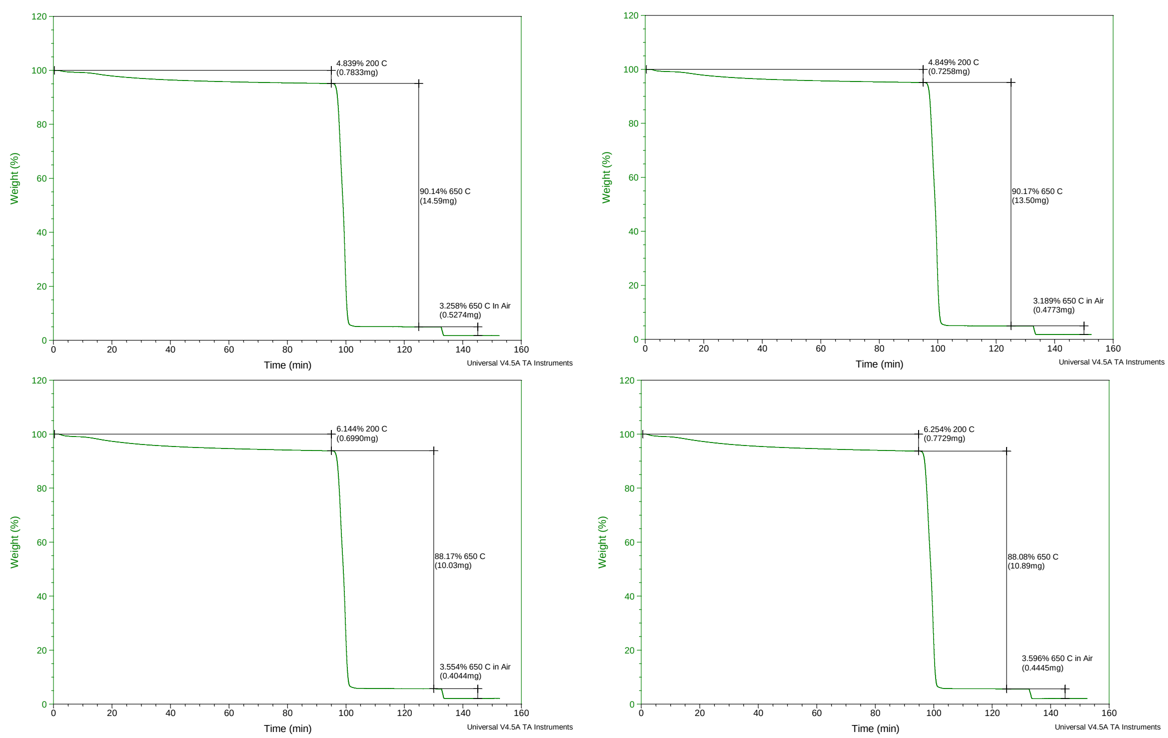

Figure 1. Duplicate analysis showing consistent, small increases in the low and high molar mass weight loss component of ILC Dover Armorflex® bladder material for an unirradiated control, (top), and after irradiation with 103 Gy 20-30 MeV protons (bottom) simulating a 50-year worst case exposure to solar particle event radiation.

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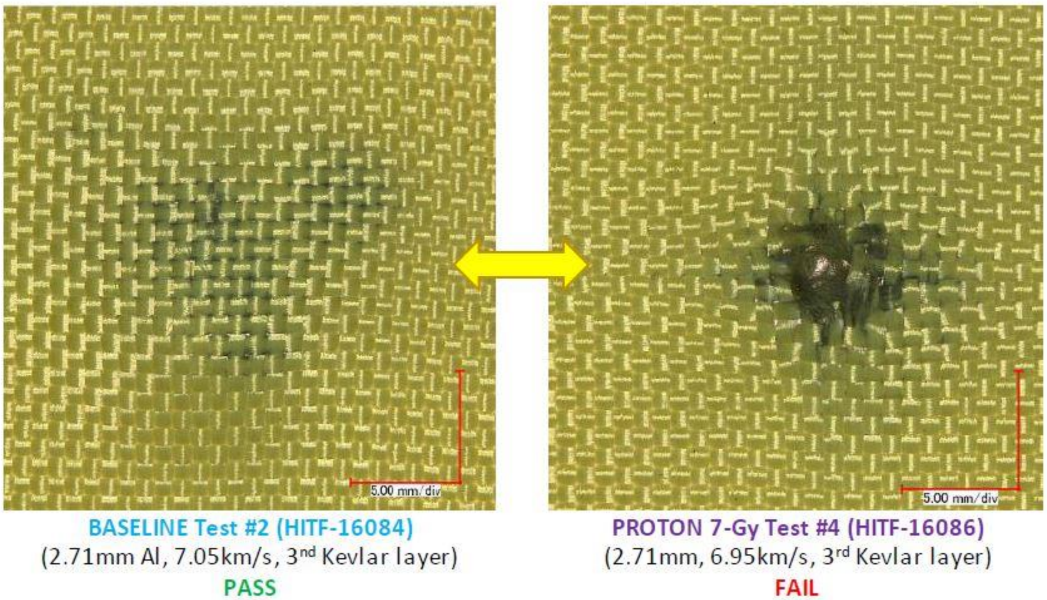

Figure 2. Comparison of the hypervelocity impact damage in the 3rd (final) Kevlar® layer for an unirradiated control stack (left) and a 1-GeV proton irradiated test stack (right).
NOTE: 2.71-mm aluminum projectile fired at approximately 7 km/s.

Reports / Proposals

List any publications, new technology reports, pending patents, subsequent proposals, follow-on / spin-off work ***selected*** *by another program, etc. that resulted from this activity.*

Title of Item	Type: Publication, NTR, Pending Patent, Solicitation Title, Program Sponsorship, or Other	Status: Confirmed or Submitted	Brief Description
Inflatable Structures Air Bladder Material Cold Flexure Evaluation, Litteken & Shariff,	Material Testing Preliminary Project Report, August, 2015	Submitted	The objective of this report was to evaluate the performance of candidate bladder materials before and after cold temperature flexure, based on permeability and tensile strength. Baseline data (cold flex, tensile, permeation) are presented on unirradiated candidate materials using consensus procedures.
Ultra Low Air and H2 Permeability Cryogenic Bladder Materials for Inflatable Habitats, Lalli & Bowers	Phase 2 STTR Proposal # T12.03-9881, July 19, 2016	Submitted, While the Phase 1 study was awarded, the Phase 2 was not.	Phase I STTR program results are presented, showing the effect of radiation on NanoSonic's multifunctional low air permeable, cryogenically flexible, self-healing bladder for space inflatables, with a rheologically recoverable self-sealing polymer gel. This class of low Tg polymers

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			maintained its self-sealing capacity after 50-year simulated solar particle event (SPE) and galactic cosmic ray (GCR) radiation under a dose of 10,300 cGy with 24.3 MeV protons, and 709 cGy 1 GeV proton, Fe, and proton/Fe. Initial results suggest that the tensile strength of the bladder composite increases upon SPE and GCR exposure when tested at -45°C, 23 °C, and 90 °C.
Ionizing Radiation Effects on Flexible Multi-Shock Micrometeoroid and Orbital Debris Shields, Lear, Christiansen, Valle, Davis	Technical data: Test Series 1, Ver. 7, 27 July. 2016	Submitted	This test series was conducted under the terms of the Memorandum of Understanding (MOU) for 0.17-caliber research tests and shows that exposure of Nextel and Kevlar fabrics to more severe ionizing radiation in space could potentially reduce the flexible multi-shock (FMS) shield ballistic performance and increase risk of shield failure.
Space Radiation Effects on Inflatable Habitat and Space Suit Materials on Inflatable Habitat and Space Suit Materials, Waller, et al.	NASA Investigative Report	Draft due 10/31/16	Comprehensive NASA IR on HZETRN modeling results, BNL NSRL beam characteristics and irradiations, post-irradiation test evaluations on inflatable habitat, composite habitat, and space suit materials-of-construction.
Smart Rheologically Recoverable Self-Healing and Radiation Shielding Bladder Material, Lalli, Valle	SPIE conference paper for the 'Behavior and Mechanics of Multifunctional Materials and Composites XI' topic area	Planned for March 2017	http://spie.org/SS/conferencedetails/multifunctional-materials-composites

Technology Maturation Opportunities (Optional)

Beyond any follow-on / spin-off work or proposals identified above, suggest the next step STMD could help support to mature the technology. Consider what form the next activity might take: further research and development, commercial or academic involvement, orbital / suborbital flight testing, etc.

Recommended STMD Next Steps	**Type** further research and development, commercial or academic involvement, orbital / suborbital flight testing, etc.	Description

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Depending on fiscal year 2017 findings, recommend interaction with NASA's Human Exploration and Operation (HEO) Advanced Exploration Systems (AES) division for FY18 follow-on work	Future research and development on: 1. physical aging + radiation effects 2. secondary radiation effects on materials 3. shielding of cabin/ astronauts 4. reformulation of polymeric and composite materials to improve radiation resistance	Collaboration with small businesses, academia, possibly resulting in new STTR or SBIR proposals.

Material test methods, infrastructure, and industry contacts have become well defined over the course of this effort. This provides a new capability for integrated material radiation modeling and testing that will provide a direct benefit for spacecraft, especially those operating beyond the relative safety of Earth's magnetosphere. A number of new inflatable, composite and space suit materials and designs were have and are being investigated by the team; and newer materials and design are anticipated in fiscal year 2017. All considered, this assembled multidisciplinary team is in an excellent position to accommodate follow-on work that is likely to result.

Resources

List value of collaboration in $

Collaborator	Type (NASA, academia, etc.)	Est. Value of Resources (FTE, Hours, or $$)	Overview
Dr. Steven Koontz	*NASA-JSC-ES*	included	*overall guidance for space radiation effects on materials*
Dr. Kristina Rojdev	*NASA-JSC-ES*	0.10 FTE	*HZETRN transport code modeling*
Gerard Valle, Khadijah Shariff	*NASA-JSC-ES*	0.15 FTE	*Beam Principle Investigator, inflatable materials*
Charles Nichols, Mark McClure	*NASA-JSC-WSTF-RF*	0.25 FTE	*overall project management, proposal, and contracting support*
Amy Ross, Ben Peters	*NASA-JSC-ES*	included	*Space Suit Engineer, SHERLOC deep UV fluorescence*

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Doug Litteken	*NASA-JSC-ES*	included, plus $5K for materials procurement	*Composite Core Competency Lead, fabrication of habitable composite specimens, thermal and thermomechanical testing*
Dana Lear	*NASA-JSC-ES*	included	*Hypervelocity impact testing*
Nathaniel Greene	*NASA-JSC-ES*	included	*ISS COPV Systems Manager*
Jennifer Lalli	*NanoSonic*	Seek additional funding	*President, NanoSonic*
Dr. Adam Rusek	*NSRL PI, Brookhaven National Laboratory NASA Space Radiation Laboratory (BNL NSRL)*	Included in beam time proposal due November 2016	*NSRL PI, Brookhaven National Laboratory NASA Space Radiation Laboratory (BNL NSRL), simulated SPE (^{1}H) and GCR (^{1}H, ^{56}Fe) irradiations*