Material EASE

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TESTING IN THE SPACE ENVIRONMENT

The previous article asked (and hopefully answered) the question, "What are the technical challenges of operating military systems in the space environment, and how do materials enable many of these missions to succeed?" Subsequently, this article poses the next logical question, "How do we know that our material, component, assembly, or system will work in space?" Like applications in any other service environment (e.g. land, sea, or air), the only way to validate material and design choices prior to fielding is to test them. For space systems, this is easier said than done. The vacuum, microgravity, thermal, and radiation effects of space are extremely difficult to reproduce on the surface of the earth; thus only a handful of facilities exist which can reproduce some of these conditions.

This article explores some of the conditions of space environments that systems are designed to operate in; and how their materials and components are tested, both at earthbound facilities, and in space. We are sure you will find this an informative companion piece to the previous article. - Editor

THE SPACE ENVIRONMENT

Space is an unforgiving environment – one of harshest known to mankind. Yet, space is far less understood than other service environments in which DOD systems operate. It has been known to limit the useful life of satellites, with 20 to 25% of all mission failures being attributed to the effects of the space environment.[1] Since access to space is so costly, materials and components must function throughout the life of a mission without repair or replacement. Yet, overdesign is not an option, as the cost of launch (driven by payload weight and volume) severely limits the redundancy and size of components. Adding to these challenges, future spacecraft will be designed to last longer, their functionality will become ever more complex, and their power requirements will continue to increase.

The natural space environment (often referred to as space weather) depends heavily on the satellite orbit, the time of year, and the solar activity. The environment is largely determined by the type of orbit. Low-Earth-Orbits (LEO) provide maximum sensor resolution for weather and reconnaissance missions. Satellites and spacecraft in LEO are subjected to atomic oxygen and can experience greater thermal cycling than in other orbits. Moving farther away from Earth, satellites in geosynchronous orbits (GEO) around the equator have the same angular velocity as the earth, thus GEO satellites remain over a fixed point on the Earth. Many communication and weather satellites are parked in GEO. Mid-Earth Orbits (MEO) are between LEO and GEO. Systems in MEO are subjected to the trapped radiation in the Van Allen Belts. A polar orbit is a special LEO to MEO orbit where the satellite travels over the poles. Since the Earth turns underneath the satellite, it can cover the entire globe in a short time period. Polar orbiting satellites typically experience higher radiation environments. A sun-synchronous orbit is a special polar orbit where the satellite passes over the same part of the Earth at roughly the same local time each day (for more information, please refer to the '*Orbits*' section of the article, '*Materials and the Final Frontier*' in this issue). This can make communication and various forms of data collection convenient.

Space weather causes a range of problems to materials on spacecraft. Thermal/vacuum effects, atomic oxygen, micrometeorites, ultraviolet radiation, and electron and proton radiation can all adversely impact space materials. The following sections describe these environmental factors and the materials problems they create.

THERMAL/VACUUM EFFECTS

The atmospheric density at an altitude of 300 km (Space Shuttle orbit) is ten orders of magnitude less than at sea level. Most organic materials will outgas under these vacuum conditions. The majority of metallic and ceramic materials do not outgas unless they have a high vapor pressure, like cadmium or zinc. Organic outgassing products include moisture and volatile organic compounds. Moisture sources include both desorption of moisture trapped inside the organic material and loss of water vapor adsorbed on the surface. For structural components, outgassing can lead to changes in the dimensional stability for stiffness-critical components such as optical benches. The more serious issue is that the outgassing products can condense and contaminate critical surfaces such as radiometers, solar cells, and sensors. Cold systems (<100°K), like infrared detectors, are especially prone to condensing contamination.[2] Microgravity can compound the effects of contamination products by keeping the contaminants near the satellite.

In addition, the vacuum environment eliminates convective cooling as a form of heat transfer. Structures can only be cooled if the heat is con-

ducted to a point where it can be radiated to space. At lower earth orbits, moving in and out of the earth's shadow occurs frequently. For a 550 km circular orbit, the satellite would experience 15 eclipses each day. Under such circumstances, a number of special materials would be required to provide thermal management for the satellite. Thermal management typically accounts for roughly 5% of the mass of a satellite.[1] See our article on *Thermal Control Coatings* and *Space Environmental Testing* for more details on thermal management.

Atomic Oxygen

Atomic oxygen is produced in the upper atmosphere when ultraviolet radiation (UV) from the sun is absorbed by oxygen molecules (O_2) and causes them to dissociate into negatively charged ions. Atomic oxygen is prevalent in orbits between 100 and 650 kilometers. The atmospheric density at these altitudes depends highly on both orbit and solar activity. While the density is small, the ionic flux encountered is high given the spacecraft's velocity of orbit. At Space Shuttle orbits of 250 km to 300 km, a density of 10^9 atoms/cm^3 yields a flux of 8 x 10^{14} atoms/cm^{2}s. The high velocity of orbit also gives atomic oxygen roughly 5 electron volts (eV) impact energy per ion.[2] The carbon bonds of many organic materials are susceptible to impact energies of this magnitude. As an example, the polyimide film Kapton (a material used extensively for thermal blankets on spacecraft) shows erosion rates of 150 mils (milli-inches) per year in a 200 km orbit. Additionally, a few metallic materials (such as silver) exhibit degradation/erosion in atomic oxygen. Some metals that form protective oxide films are susceptible to degradation, since low gas pressures can inhibit the formation of adherent oxide films. Atomic oxygen can also excite some materials to emit radiation. The glow around the Space Shuttle is attributed to this phenomenon.

Particle Impact

Spacecraft must also contend with impact of particles either from space debris or dust. Most of the space debris is found in low earth orbits from 350 km to 2000 km. The debris largely consists of materials ejected from spacecraft during launch and deorbit, including alumina from solid rocket motor propellants, aluminum, and oxides from thermal control coatings (zinc and titanium oxides). All told, it is estimated that there is over 3,000,000 kg of space debris. The United States Strategic Command currently tracks over 8,000 objects in space that are over a centimeter in size - but there are an estimated 1,000 kg of particles under this limit.[3] Relative impact velocities depend upon the satellite orbit but are on the order of 10 km/s. Particles as small as 0.1 mm cause erosion on most materials and particles greater than 1 mm cause significant damage.[1]

Micrometeoroids and interplanetary dust also can damage spacecraft. Most micrometeoroids are a result of comet ejection. These particles typically have velocities relative to the earth from between 10 to 70 km/s. They are at least 0.2 microns in diameter since smaller particles are swept away by the solar wind.[4]

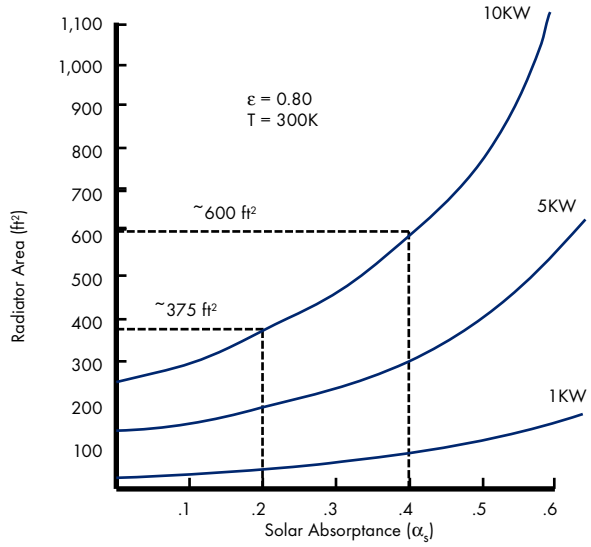

Figure 1. Radiator Size vs. End-of-Life Solar Absorptance.

Space Radiation

Radiation can wreak havoc on materials, causing either permanent or transient changes in their physical and electrical properties. Radiation comes in electromagnetic and particle forms. Nearly 99% of the solar electromagnetic radiation at one astronomical unit (distance from the earth to the sun) has a wavelength between 0.3 and 11 µm. In fact, visible light accounts for 41% of the total electromagnetic energy emitted from the sun. Together, both the ultraviolet and infrared spectrums account for most of the remaining energy. X-Rays, extreme ultraviolet, and radio wavelengths account for less than 0.1% of the solar energy. Solar electromagnetic radiation changes with solar activity and season (the distance between the earth and the sun changes, as the earth's orbital path is slightly elliptical).[5] Reflected radiation (albedo) from both the earth and the moon contribute to the total irradiance. The albedo is important to low earth orbits and varies with clouds and terrain.

Ultraviolet Radiation: Ultraviolet radiation (UV) is particularly damaging to some materials. Most UV radiation is absorbed by the Earth's ozone layer. However, in space, high intensity UV radiation can sever organic chemical bonds. In addition, UV can lead to discolorations in polymeric materials and ceramics (e.g. glasses), which change the solar absorptivity of materials. Changes to a material's performance, such as the absorptance of white thermal control coatings must be accounted for in the design process, since the rate of heat transfer will change proportionately. As Figure 1 shows, changing the solar absorptance from 0.2 to 0.4 over the life of a satellite dramatically increases the needed radiator area from 375 ft^2 to 600 ft^2 for a 10 KW satellite. Note, the emissivity (ε) of the white coating does not change much during the satellite life and it is shown as a constant 0.80. Designers must account for end-of-life properties by overdesigning components such as radiators. However, increased

area translates to extra weight. It is important to note that as the trend to higher power satellites continues, accounting for the degradation of thermal control paints will become increasingly critical during their design phase.

Charged Particle Radiation: The sun also emits a continuous stream of energetic charged particles. These electrons and protons (and some heavier ions) are called the "solar wind". On average these particles travel at over 400 km/s with a density of 5 particles per cubic centimeter. During solar flares the charged particles are accelerated. In addition, particles emitted by other stars pass through our solar system. Charged particles from a solar flare are referred to as solar cosmic radiation while particles from other stars are known as galactic cosmic radiation. Electrons and protons found in cosmic radiation typically have much higher energy levels than those found in the solar wind.

The earth's magnetic field traps charged particles in radiation belts known as the *Van Allen Belts*. The Van Allen Belts consists of two concentric donut-shaped belts that surround the Earth. Because of the effect of the solar wind on the magnetic field, both belts are asymmetrically shaped. On the Earth's sun-facing side, its magnetic field is compressed from the solar wind, while the field is expanded on the other side. The magnetic fields have funnel shaped cusps over the poles that allow penetrating radiation to reach much lower altitudes. In the inner Van Allen belt, the maximum proton density is found at about 5,000 km above the Earth's surface. This belt contains mostly high energy protons produced by cosmic ray collisions with the Earth's upper atmosphere. The particles in this belt are highly energetic, and with prolonged exposure they can damage materials. The outer belt's maximum proton density occurs at 16,000 to 20,000 km. This belt contains low to medium energy electrons and protons mostly generated from the influx of particles during geomagnetic storms, which occur after solar flares. These particles are deflected by the Earth's magnetic field, but are captured on the night side of the planet. Particle densities can increase by a factor of 10 to 1000 in less than an hour.[6]

Effect of Energetic Particles: Charged particles can damage an impacted material by a combination of ionization and atomic displacements. These effects can lead in turn to chemical reactions and changes in the local morphology. Electrons slow by generating a continuous ionized path in materials. Protons are heavily ionizing and produce higher ionization near the end of the particle path. The size of damage depends upon total flux, intensity of radiation, and the angle of impingement. The interaction of these particles with organic materials can lead to outgassing, shrinkage, cracking, pitting, embrittlement and discoloration. Energetic particle radiation also influences the absorptivity of materials. As seen with UV radiation, the solar absorptance of thermal control coatings show an increase over time. For example, when simulating the Galileo mission, the solar absorptance of Zinc OrthoTitanate (ZOT), a thermal control coating, increased from 0.13 to 0.42.[7] Charged particle radiation also can lead to "darkening" of optical materials.

Satellite electrical charging (the buildup of static electricity on the satellite surface) is one of the most common anomalies caused by radiation. Charging occurs when a satellite moves through charged particles (called "wake charging"). Charging can also occur through direct particle bombardment or through a photoelectric effect, with some materials subjected to electromagnetic solar radiation. When the breakdown voltage of a material is exceeded, an electrostatic charge will ultimately result in a discharge or arc; which can severely damage materials, cause spurious circuit switching, or result in false sensor readings. Materials especially prone to damage include electronic materials, thermal coatings, and solar cell materials.[5]

The high-energy protons from either cosmic radiation or the inner Van Allen Belt can completely penetrate a satellite. As they pass through, they can ionize particles deep inside the system. A single proton can deposit enough charge to cause a circuit switch, spurious command, or memory change. These incidents are labeled "single event upsets". With a push towards lower voltage commercial-off-the-shelf microelectronics, it is actually easier to cause electrical upsets than with older satellites. Additionally, the lessening of the perceived nuclear threat has reduced the level of nuclear hardening of satellites. While intended to protect systems from the radiation of a nuclear explosion, this type of hardening also helped to protect satellites from the radiation naturally present in the space environment.[5]

Many satellites use electro-optical sensors to maintain their orientation in space. These sensors reference the direction of certain stars to achieve precise pointing accuracy. When a high energy proton impacts a sensor material, a flash of light is produced and misinterpreted as a star. The computer will then try to find the star in its star catalogue. At this point the satellite could become disoriented, creating the possibility that communications antennas, sensors, solar panels all could fail to orient themselves properly, thus impacting the mission. In extreme cases, the satellite could even be lost if the batteries were to drain from a lack of solar power. For this reason, nearly all satellites have a sun sensor. While not providing the navigational accuracy of a star sensor; a sun sensor can help the satellite recover its orientation following an upset.[5]

SPACE COMBINED EFFECTS PRIMARY TEST RESEARCH EQUIPMENT (SCEPTRE)

The extreme conditions present in the space environment and the high cost associated with placing space systems in orbit require that spacecraft be thoroughly tested prior to deployment. Every spacecraft program must address the effect of the space environment on their hardware. Additionally, all new materials must be space flight qualified prior to use. Ground-based testing offers the flexibility to study multiple materials in the appropriate environmental conditions, without the extreme cost and limited availability of space flight testing. New materials can be subjected to an initial screening, with a rapid turnaround of test results. Additionally, ground-based testing allows for multiple sample exposures of a material to gain statistical confidence in its life cycle performance. Even small modifications in current state-of-the-art materials, such as changing a raw material supplier or imposing a material processing change, requires satellite manufacturers to initiate a re-qualification program to assure that the new version of the same material performs at least as well as the previous one. Ground-based testing is appropriate for these re-qualifications.

The space environment is difficult to simulate and no facilities exist that can test all of its aspects. On January 31 1958, Explorer I (the first US satellite) discovered charged particle radiation in space using a Geiger

counter package designed by Dr. James Van Allen. This discovery led to the acknowledgment that environmental conditions in space were much harsher than originally thought. Later in 1958, the predecessor to the Air Force Research Laboratory's Materials and Manufacturing Directorate (AFRL/ML) opened a facility to examine some of the environmental conditions found in space, including the combined effects of vacuum and UV. Over the years, its capabilities have increased to include the effects of electron bombardment. Today, it is known as the Space Combined Effects Primary Test and Research Equipment (SCEPTRE) facility. SCEPTRE is the only Air Force-owned facility designed specifically for testing and qualification of spacecraft materials by exposing them to a simulated space radiation environment (Figure 2).

SCEPTRE is designed primarily to simulate the conditions of MEO to GEO with variable temperature, accelerated UV, near visible UV, and electron exposures; all simultaneously in a vacuum environment. SCEPTRE does not simulate the proton environment, nor the extremely high energy particles associated with cosmic radiation or the inner Van Allen Belt. With an eight-inch target area, SCEPTRE can expose 19 one-inch diameter samples and four reference samples per test. During exposure, SCEPTRE measures specimen spectral reflectance, solar absorptance, temperature, electron flux, gross outgassing, and the spectral irradiance of the UV source. After exposure, SCEPTRE can measure the thermal emittance. Additional pre- and post-test measurements can be made in a state-of-the-art optical measurements facility. These optical facilities measure reflectance, absorptance (emittance), transmittance, and scattering as functions of wavelength (0.25 to 15 mm), incidence angle (0 to 89°), polarization, and temperature (-65°F to +450°F).

Flight test data confirms that SCEPTRE simulates a variety of orbital environments and accurately reproduces the rate and extent to which a material will degrade in the actual space environment. The Air Force thermal control coating development program is predicated on performing in-house space environmental testing and validation. To date, SCEPTRE is responsible for greatly advancing the development of thermal control materials and coatings. In addition, SCEPTRE has recently expanded its testing to a wide variety of materials including polymeric films, optical thin films, and threat protection materials. The facility is also used in charging studies, thin film space stability studies, and degradation mechanics studies.

The University of Dayton Research Institute (UDRI) is currently responsible for the operation of the SCEPTRE facility. Under a 1999 Cooperative Research and Development Agreement, UDRI performs material degradation testing on a fee-for-service basis for both government and non-government sponsors.

SPACE FLIGHT TESTING

Despite advancements in ground-based testing, flight experiments are necessary to verify ground-based simulation and analytical modeling efforts. Additionally, flight testing helps validate new materials technology and demonstrates their performance in components. The Materials and Manufacturing Directorate has a rich history of space flight testing despite the often limited availability of such tests. Some of the past experiments include: Spacecraft Charging at High Altitude (SCATHA), Skylab, Long Duration Exposure Facility (LDEF), and the Materials on the International Space Station Experiment (MISSE).

Figure 2. The SCEPTRE Chamber.

Several examples of lessons learned from prominent flight experiments that AFRL/ML has participated in follow. The objective of these experiments was to gain understanding of the changes in the properties before and after exposure to the space environment. This knowledge helped improve predictions based on laboratory experiments and subsequently influenced the design of future flight experiments.

Skylab

Skylab was America's first space station. It was launched on 14 May 1973 by a Saturn V rocket and placed in a low earth orbit (415 km). Three separate astronaut crews occupied the facility for a total of 171 days, 13 hours. The last manned flight returned on 8 February 1974. During this time, Skylab completed 3900 orbits during a period of low solar activity. On July 11, 1979, Skylab returned to Earth and scattered its debris from the Southeastern Indian Ocean across a sparsely populated section of Western Australia.

The Skylab Thermal Control Coatings and Polymeric Films Experiment[8, 9] consisted of three duplicate sets of 36 thermal control coating samples and eight different polymeric film specimens. The thermal control trays were mounted perpendicular to the incident light from the sun for maximum solar exposure. The polymeric films were located 39 degrees off axis to the solar vector. The first set of specimens was retrieved after 35 days/550 hours of solar exposure and the second set after 74 days/1150 hours of solar exposure. A third set of samples was retrieved after 131 days/2040 hours of exposure. All samples were badly contaminated during launch. Post flight analysis of the thermal control coatings indicated that measured changes in specimen thermo-optical properties were due to a combination of excessive contamination and solar degradation. The results from this experiment were used in the design of the Long Duration Exposure Facility M0003-5 Thermal Control Materials Experiment and offered a direct comparison for many on the materials between the two flight experiments.

Long Duration Exposure Facility (LDEF)

The Long Duration Exposure Facility was launched into LEO (410 km orbit) from the Space Shuttle Orbiter Challenger in April 1984 and

retrieved by the Columbia in January 1990. LDEF contained 57 experiments from the Air Force, Navy, NASA, European Space Agency, academia, and industry. LDEF contained over 10,000 materials specimens subjected to 32,422 Earth orbits. The 5.8-year flight greatly enhanced the potential value of most LDEF materials, compared to that of the original 1-year flight plan. Most of the exposed surface of LDEF consisted of chromic anodized aluminum and silver Teflon thermal blankets.

Upon retrieval, particulate debris was observed trailing LDEF. This debris mostly consisted of vapor-deposited aluminum backing from failed thermal-control blankets on the leading edge of the spacecraft. In general, organic materials such as Mylar, Kapton, paint binders, and bare composites were severely eroded. The degradation of these materials was expected since they received prolonged exposure to atomic oxygen. Coated composite materials survived and generally maintained their mechanical properties.

AFRL/ML and the Aerospace Corporation conducted the M0003 experiment on LDEF which consisted of coatings, thermal paints, polymers, glasses, composites, semiconductors, and detectors that provided data on environmental parameters. Most of the materials selected were from various development programs in the 1978 to 1982 time frame. Materials from previous space flight experiments, including Skylab, were included to provide data correlation. The materials were exposed in four separate locations on the vehicle. The first set was exposed on the leading edge of the satellite. The second set was exposed on the trailing edge of the vehicle. The third and fourth sets were exposed in environmental exposure control canisters located 30 degrees off normal to the leading and trailing edges.

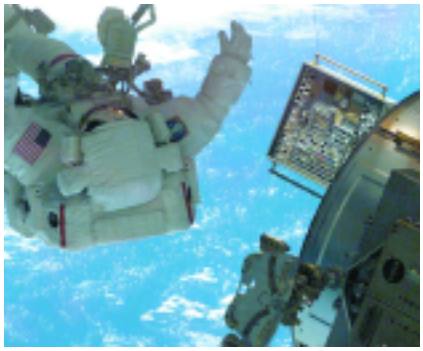

Figure 3. MISSE Integrated on the International Space Station.

The leading edge tray showed atomic oxygen damaged some materials, especially to two silver front surface mirrors, which were destroyed. There was extensive damage to the polymeric film strips. Composite material samples remained intact, but they were bleached or discolored. Silver Teflon covers remained intact; however, they had changed from silver to milky white, where components were located beneath them; and to a gold color where there were no components. The trailing edge showed that contamination discolored many of the specimens. Again, the polymeric film strips were damaged. The thermal control materials were discolored from both contamination and radiation.

Materials on International Space Station Experiment (MISSE)

The first of four Materials International Space Station Experiments (MISSE-1) was attached to the International Space Station (ISS, 350 km orbit) on 10 August 2001. MISSE is a cooperative experiment involving Boeing Phantom Works, AFRL/ML, NASA's Langley Research Center, NASA's Marshall Space Flight Center, and NASA's Glenn Research Center. AFRL/ML coordinated the project between the participating agencies and aerospace companies. In addition, AFRL/ML funded the integration of the passive experimental carrier "suitcases" that carry and hold the materials test samples. The AFRL/ML-led "Space Systems Support and Affordability Effort" (S3AE) consortium, comprised of major spacecraft manufacturers, shared in the experiment. Over 450 candidate spacecraft materials on MISSE-1 (1,700 samples) are currently being exposed to the space environment during solar maximum conditions (Figure 3). Some of the materials classes represented include: bulk polymers, composites, thermal control coatings, gossamer films, inflatable materials, optical materials including mirror materials, and thermal protection materials.

In addition to helping coordinate activities under MISSE, Mr. Edward Stutz from AFRL/ML's Sensor Materials Branch (AFRL/MLPS) designed an experiment to evaluate various emerging semiconductor materials on the space station. The experimental matrix focused on one emerging class of high performance semiconductors, which may have inherent radiation tolerance. Known as "Wide Bandgap Semiconductors" due to their inherent electronic properties, these materials have already led to the demonstration of exceptionally high power density devices, as well as exceptional low noise amplifiers (LNAs) which are critical for space electronics.

The MISSE Semiconductor Materials Evaluation Experiment incorporated a broad spectrum of wide bandgap materials, including gallium nitride (GaN), silicon carbide (SiC) and zinc oxide (ZnO). Mr. Stutz coordinated this activity with a complimentary program sponsored by AFRL's Sensors Directorate (AFRL/SN). AFRL/SN delivered GaN High Electron Mobility Transistors (HEMTs), as well as basic epitaxial materials structures that were included in the MISSE experiment. The devices used are the result of a joint collaboration between Cree, Inc (Durham, NC) and AFRL/SN under a Dual Use Science and Technology program. The program focused on the development of wide bandgap semiconductors for microwave technology applications which are capable of operating under extreme conditions, such as a crowded or hostile electromagnetic spectrum; as well as under limited environmental controls due to constraints of mass, volume, or prime power.

All materials and devices flying on the MISSE payload were extensively characterized by structural, optical, and electronic measurement techniques prior to inclusion on the mission. Upon return, the materials and devices will undergo further testing. The test results will be analyzed to provide an assessment of the impact of the actual space environment on performance. Results of this work will be instrumental in guiding the future development of semiconductor materials and devices for space applications.

SUMMARY

Exploiting space requires a thorough understanding of the space environment's effects on materials. The criticality of new materials to Air Force space missions dictate that all materials be qualified before use. The Air Force Research Laboratory's Materials and Manufacturing Directorate has an extensive 45-plus year history of studying the fundamental interactions of the space environment's effect on materials, and to qualify new materials for use in space. Using its unique ground-

based facility, SCEPTRE, AFRL/ML can approximate the MEO and GEO environments, and thus measure changes in optical properties resulting from exposure to these conditions. In addition, AFRL/ML continues to aggressively pursue space flight testing opportunities to strengthen the understanding of this complex environment.

For more information on SCEPTRE, please contact Dr. Elizabeth Berman, elizabeth.berman@wpafb.af.mil, or Mr. Clifford Cerbus, clifford.cerbus@wpafb.af.mil. For additional information on MISSE's wideband gap semiconductor experiments, please contact Ms. Laura Rea, Laura.Rea@wpafb.af.mil.

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Mr. Jeffrey D. Guthrie has been a senior materials engineer for AMPTIAC since 1998. Prior to joining AMPTIAC, he served as a liaison between the Air Force Philips Laboratory (now AFRL/VS and AFRL/DE) and the Materials Directorate. Mr. Guthrie also spent six years working on Carbon-Carbon Composites for space applications for the Structural Materials Branch (AFRL/MLBC). Mr. Guthrie holds BS and MS degrees in Metallurgical Engineering from Montana College of Mineral Science and Technology.

Mr. Clifford Cerbus is a research physicist with the University of Dayton Research Institute (UDRI). For the past 16-years, he has managed and operated the United States Air Force Research Laboratory's space simulation chamber known as the SCEPTRE Facility. He has also participated in spaceflight experiments including the Long Duration Exposure Facility (LDEF) and the Materials on the International Space Station Experiment (MISSE). Mr. Cerbus received his BS in Physics and Mathematics from Xavier University and his MS in Mathematics from the University of Dayton.

Dr. Elizabeth S. Berman is a senior materials research engineer and the space materials direction leader in the Nonstructural Materials Branch within the Materials and Manufacturing Directorate (AFRL/MLBT) at Wright-Patterson AFB, OH. She is in charge of developing both thermal control coatings and tribological materials for space. She is the government lead for the only Air Force owned facility capable of simulating the space environment for testing of space materials. She also is the AFRL/ML Program Manager for the AFRL MISSE (Materials on the International Space Station Experiment). Dr. Berman holds a BS in Chemical Engineering from the University of Minnesota, an MS in Chemical Engineering from Purdue University, and a PhD in Polymer Science from Pennsylvania State University.

Ms. Laura Rea has served as a program manager for compound semiconductor materials development for the Air Force Research Laboratory for over fifteen years. Her responsibilities as Technology Advisor for the AFRL Sensor Materials Branch include oversight of an electronic and optical materials portfolio with an annual budget of over $20M per year. In 1998, she was selected to serve a one-year assignment as a member of the staff at the Office of the Secretary of Defense, supporting the Director of Defense Research and Engineering, at the Pentagon.