

## Space Environment Factors Affecting the Performance of International Space Station Materials: The First Two Years of Flight Operations

Steven L. Koontz<sup>(1)\*</sup>, Michael Peldey<sup>(1)</sup>, Ronald R. Mikatarian<sup>(2)</sup>, John Golden<sup>(2)</sup>, Paul Boeder<sup>(2)</sup>, John Kern<sup>(3)</sup>, Hagop Barsamian<sup>(2)</sup>, Brian Mayeaux<sup>(1)</sup>, John Alred<sup>(2)</sup>, Carlos Soares<sup>(2)</sup>, Eric Christiansen<sup>(4)</sup>, Todd Schneider<sup>(5)</sup>, Dave Edwards<sup>(5)</sup>

### Abstract

In this paper, the natural and induced space environment factors affecting materials performance on ISS are described in some detail. The emphasis will be on ISS flight experience and the more significant design and development issues of the last two years. The intent is to identify and document the set of space environment factors, affecting materials, that are producing the largest impacts on the ISS flight hardware verification and acceptance process and on ISS flight operations.

Orbital inclination ( $51.6^\circ$ ) and altitude (nominal 350 km to 400 km altitude) determine the set of natural environment factors affecting the functional life of materials and subsystems on ISS. ISS operates in the F2 region of Earth's ionosphere in well-defined fluxes of atomic oxygen, other ionospheric plasma species, and solar UV, VUV, and x-ray radiation, as well as galactic cosmic rays, trapped radiation, and solar cosmic rays (1,2). The high latitude orbital environment also exposes external surfaces to significantly less well-defined or predictable fluxes of higher energy trapped electrons and auroral electrons (3,4). The micrometeoroid and orbital debris environment is an important determinant of spacecraft design and operations in any orbital inclination.

Environment factors induced by ISS flight operations include ram-wake effects, magnetic induction voltages arising from flight through Earth's magnetic field, hypergolic thruster plume impingement from proximity operations of visiting vehicles, materials outgassing, venting and dumping of fluids, ISS thruster operations, as well as specific electrical power system interactions with the ionospheric plasma (5-7). ISS must fly in a very limited number of approved flight attitudes leading to location specific environmental exposures and extreme local thermal environments (8). ISS is a large vehicle and produces a deep wake structure from which both ionospheric plasma and neutrals (atomic oxygen) are largely excluded (9-11). At high latitude, the ISS wake may produce a spacecraft charging environment similar to that experienced by the DMSP and Freja satellites (800 to 100 km altitude polar orbits), especially during geo-magnetic disturbances (12-14). ISS is also subject to magnetic induction voltages ( $\mathbf{V} \times \mathbf{B} \cdot \mathbf{L}$ ) on conducting structure, a result of high velocity flight through Earth's magnetic field. The magnitude of the magnetic induction voltage varies with location on ISS, as well as the relative orientation of the vehicle velocity vector and planetary magnetic field vector, leading to maximum induction voltages at high latitude (15).

The space environment factors, natural and induced, that have had the largest impact on pre-launch ISS flight hardware verification and flight operations during the first two years of ISS flight operations are listed below and grouped according to the physical and chemical processes driving their interaction with ISS materials.

#### I. Ionosphere, geomagnetic field, magnetosphere interactions

- 1) Spacecraft charging driven by the photovoltaic electrical power system
- 2) Spacecraft charging at high latitudes driven by auroral electrons
- 3) Spacecraft charging via  $\mathbf{V} \times \mathbf{B} \cdot \mathbf{L}$  magnetic induction voltages at high latitudes

#### II. Molecular deposition on external surfaces

- 1) Materials outgassing and contamination from nonmetallic materials
- 2) Hypergolic engine plume impingement contamination effects
- 3) Propellant purges
- 4) Water venting

#### III. Ionizing radiation effects

- 1) Radiation damage to external materials from high energy electrons
- 2) Radiation effects on microelectronics from solar and galactic cosmic rays
- 3) Crew dose limits and shielding augmentation issues

#### IV. Ballistic impact of small particles

- 1) Low to medium velocity particle impact effects from: a) engine plumes, b) condensate and waste water dumps
- 2) MM/OD impact on ISS view ports

Spacecraft charging interactions (item I above) may lead to the application of electrostatic fields across dielectrics that can lead to breakdown and arcing. Degradation of some thermal control coatings, electrical system noise, and shock hazards to EVA crew may result (2,11). PV array driven ISS charging has been shown by measurement to be less severe than predicted before flight (5,7). Auroral charging, a highly material property dependent process (13,14) has not yet been observed. Historical data for the DMSP and Freja satellites suggest that auroral charging may be observed infrequently, when the ISS orbit carries the vehicle to extreme magnetic latitudes (15,16). Predictive models of magnetic induction voltages for ISS have been developed and verified with flight data (17). The ISS program has established a process for the evaluation and management of spacecraft charging (18). In-flight characterization of ISS charging and the ambient ionospheric flight environment with dedicated flight instrumentation is the key component of the ISS charging management process.

The ISS external contamination environment is controlled primarily during the design and development stage by rigorous control of materials utilization, and placement of vents and purges. Several worst-case assumptions are built into the materials control and requirements verification process so that real ISS molecular contamination deposition rates during quiescent periods should be much better than expectations. Gross external contamination and general materials stability performance are tracked in-flight by optical imaging of the exterior surfaces of ISS with a variety of imaging methods and tools. Photography of ISS view ports and window surfaces from the interior of ISS is also a valuable monitoring tool that has revealed some as yet unexplained contamination events

which may possibly be attributed to leaving view ports and windows unprotected during thruster firings.

The ISS electrical power system and avionics suite (including commercial-off-the-shelf or COTS components) are performing well ahead of expectation with respect to the single event effects and total dose effects produced by the ionizing radiation environment in LEO. No correlation between solar proton events (radiation storms) identified by the NOAA GOES satellites, or ISS radiation monitoring instruments, and any electronic anomaly on ISS has been identified during the first two years of flight. Similarly, no GCR effects, as revealed by a geomagnetic latitude dependence of electronic failures, have been identified; however, events that may be produced by high rigidity GCR particles are the subject of an ongoing investigation.

Solar array performance degradation, largely the result of energetic electron dose (19), is well within design limits. Energetic electron dose is also the principal threat to the durability of Teflon<sup>R</sup> based materials on the exterior of ISS. Large uncertainties in AE-8 predictions of electron dose predictions, combined with uncertainties in the synergistic contributions of mechanical stress, thermal cycling, and atomic oxygen to the energetic electron induced degradation of Teflon<sup>R</sup> (20) lead to corresponding uncertainty degradation rates. Teflon<sup>R</sup> is an excellent insulator, which complicates accelerated ground based testing of energetic electron degradation effects as a result of target electrostatic charging in high dose rate electron beams. On orbit, dose rates are much lower, permitting continuous discharge of exposed Teflon<sup>R</sup> materials by dielectric relaxation processes (given enough time, even the best insulator can conduct some current), producing a dose-depty profile that is difficult to reproduce in ground based accelerated testing.

Complying with NASA headquarters directives aimed at reducing ionizing radiation dose to ISS expedition crews to As Low As Reasonably Achievable (ALARA) levels has raised a number interesting questions in the area of nuclear and radiation chemistry of materials (21-23). Design of augmented radiation shielding for ISS and verification of shielding effectiveness is complicated by the limited accuracy of existing theoretical models of cosmic ray reaction and transport in spacecraft materials (22). The difficulty of accurately characterizing the complex ionizing radiation field inside the spacecraft introduces additional uncertainty. Materials selection criteria for ISS crew shielding augmentation will be presented, as well as a summary and review of the available flight and laboratory data on shielding effectiveness.

Ballistic particle impacts are already visible on some ISS view ports. Both hypervelocity MM/OD events and pitting from much lower velocity engine plume impacts are visible on some service module view ports, similar to the observations made on the corresponding locations on the Mir station (24). Operational controls of particle impact degradation of critical materials are based on operational protection of sensitive surfaces during proximity operations by visiting spacecraft or during ISS venting or purging operations. PV arrays are positioned edge-on to the direction of plume flow. View ports and windows should be covered, and cameras pointed away from the particle source.

Low to medium velocity particles only affect the optical performance of view ports, windows, and PV array glass cover slips. MM/OD strikes can create significant loss of mechanical properties in window and view port materials raising crew safety issues.

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\* Author to whom correspondence should be addressed.

ES4/Dr. Steve Koontz, ISS Environments Manager  
NASA Johnson Space Center  
Houston, Texas, 77058  
Phone:(281)-483-8860 & Fax: (281)-244-1301  
e-mail: [steven.l.koontz1@jsc.nasa.gov](mailto:steven.l.koontz1@jsc.nasa.gov)

- (1) Structural Engineering Division  
Mail code ES4  
NASA Johnson Space Center  
Houston, Texas 77058
- (2) Specialty Engineering  
Boeing Space Station  
Houston, Texas 77058
- (3) Dynacs Engineering Co. Inc.  
1110 NASA Rd. 1  
Houston, Texas 77058
- (4) Solar System Exploration Division  
Mail Code SX2  
NASA Johnson Space Center  
Houston, Texas 77058
- (5) NASA Marshall Space Flight Center  
Engineering Physics  
Mail Stop ED31  
Huntsville, Alabama 35812