

**OVERVIEW OF SPACE ENVIRONMENT EFFECTS ON  
MATERIALS AND GRC'S TEST CAPABILITIES**

Bruce A. Banks and Sharon K.R. Miller  
National Aeronautics and Space Administration  
Glenn Research Center  
Cleveland, Ohio



**NASA Glenn Research Center**

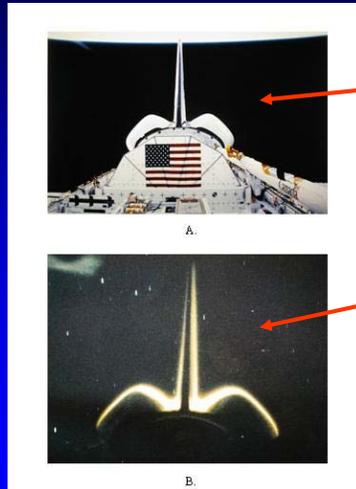
---

**Overview of Space Environment Effects  
on Materials and GRC's Test Capabilities**

Bruce A. Banks  
Sharon K. R. Miller  
Electro-Physics Branch  
Presented at the Seals Workshop, Nov. 9, 2005



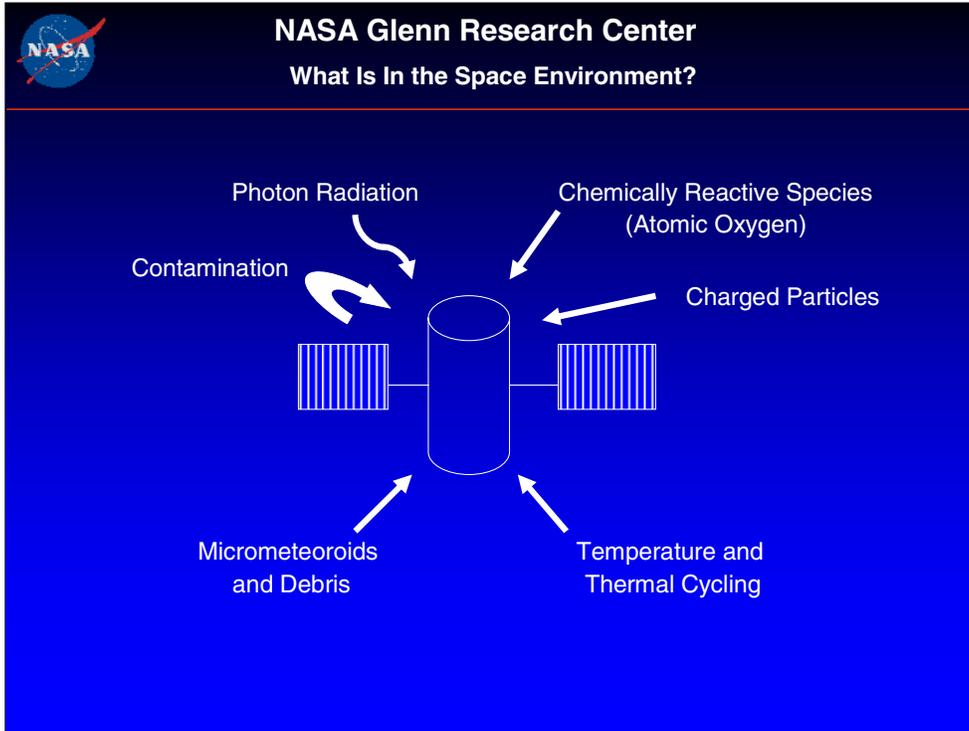
## NASA Glenn Research Center Evidence of Environmental Reactions



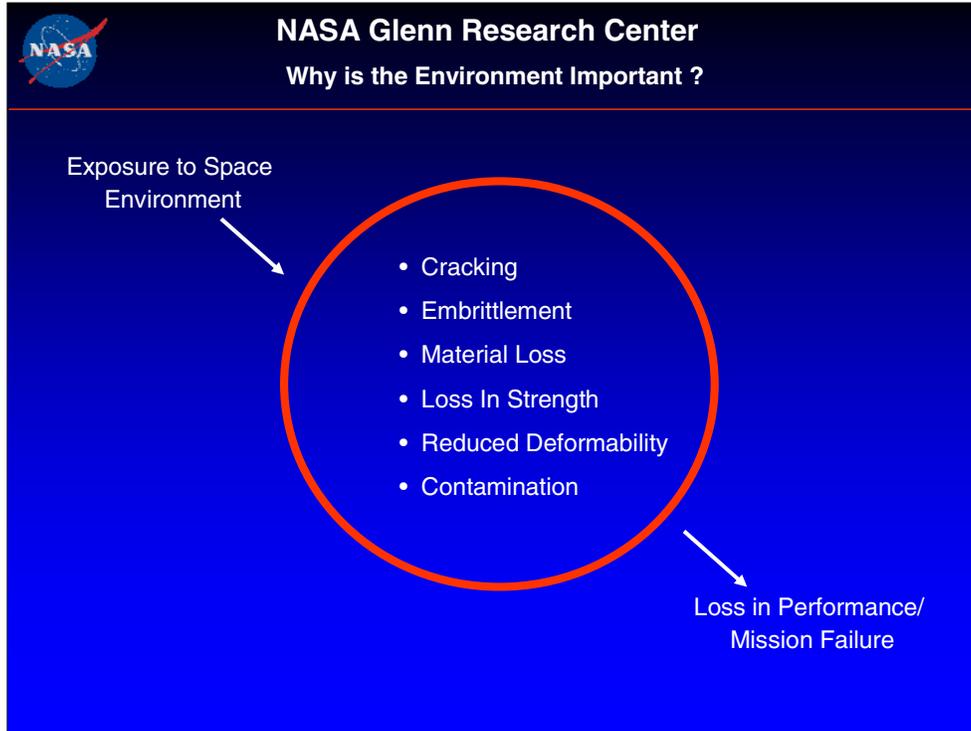
Daytime Photo of Shuttle Bay

Time Exposure of Shuttle Bay  
at Night

Evidence of the interaction of the space environment with spacecraft surfaces can be seen from this time exposure image of the shuttle bay at night. The glow around the tail section is caused by the impact of atomic oxygen and other low Earth orbit (LEO) environment species on the shuttle surface creating short lived excited species that emit visible radiation.



The space environment contains chemically reactive species such as atomic oxygen, photon radiation, charged particles, and micrometeoroids. It also contains man made or self generated debris and contamination. The thermal flux from the sun and traveling of spacecraft into areas of planetary shadow create heating and thermal cycling which also affects spacecraft performance. What environmental constituent is of concern for a particular mission is highly dependent on where the spacecraft will fly and the desired mission life.



Why is the space environment important for seals? Exposure to the space environment over time can lead to cracking and embrittlement of polymer and silicone seals, loss of seal material, reduction in the strength of the material, and increased hardness which lowers the deformability. Ejecta from micrometeoroid and debris impacts depositing on seals can provide places where leaks can occur. In addition, the seals themselves can produce contamination which can deposit on sensitive optics or thermal control surfaces if the seal material contains too high of a level of condensable volatile components. All of these can lead to loss in performance and ultimately failure of the mission.

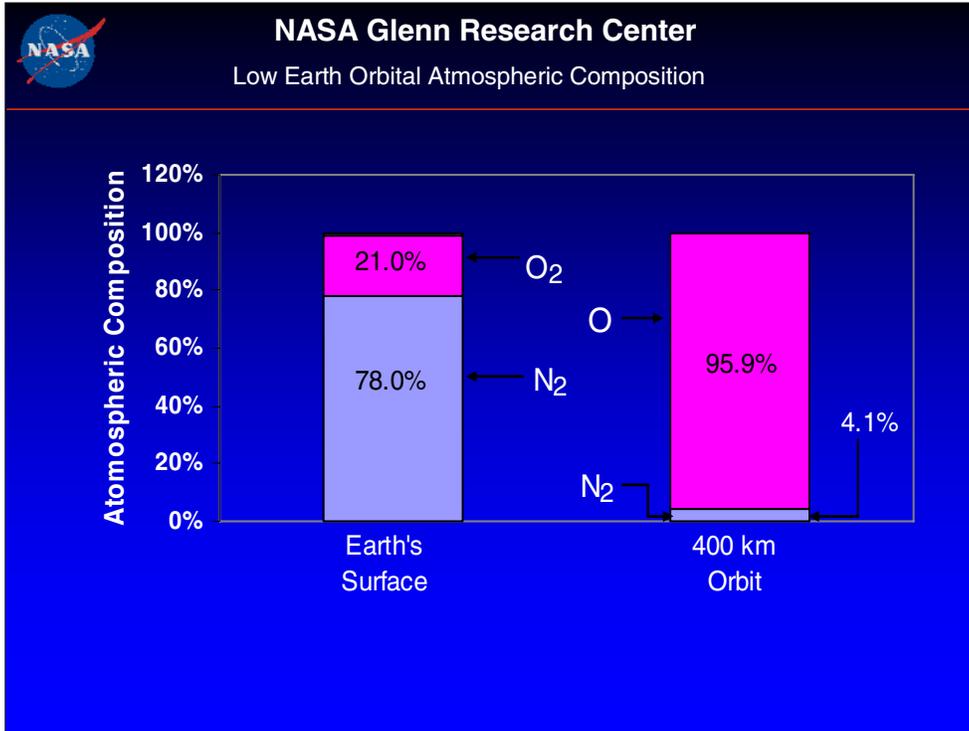


## NASA Glenn Research Center

### Environments Discussed

- Atomic Oxygen
- Vacuum Ultraviolet (VUV) Radiation and Near UV Radiation
- Particulate Radiation (electrons, protons & ions )
- Temperature
- Contamination
- Micrometeoroids and Debris

This presentation focuses on the main environments that are experienced in Earth orbit, although many of these are applicable to other planetary and transitional environments as well. In some cases, the environments can combine to produce synergistic effects that produce damage to materials beyond that seen in either environment alone. This has been observed for particulate radiation in combination with solar heating.

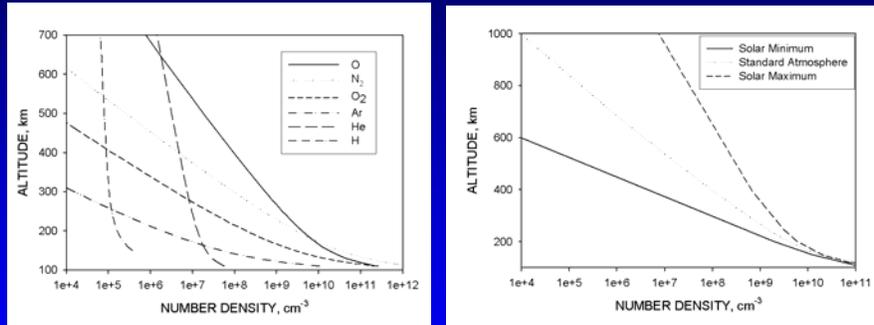


At the surface of the earth, the primary constituent of the atmosphere is molecular nitrogen, as the altitude increases, the amount of nitrogen decreases and atomic oxygen becomes the predominant component of the atmosphere.



# NASA Glenn Research Center Atomic Oxygen

## Atomic Oxygen Concentrations in Low Earth Orbit (LEO)

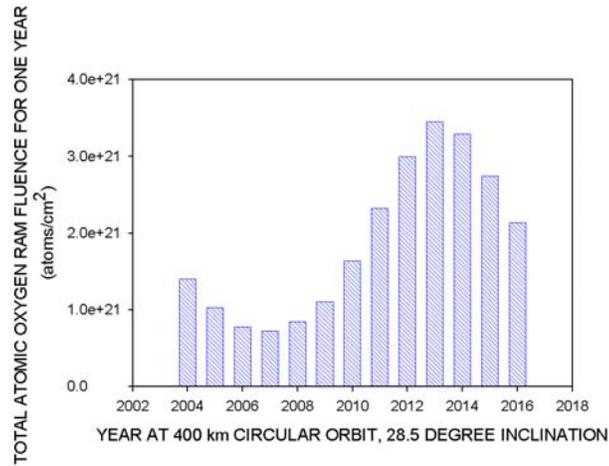


The altitudes at which atomic oxygen are dominant are between 180 and 650 km. The amount of atomic oxygen present is highly dependent on solar activity and is highest during periods of elevated sun spot activity.



## NASA Glenn Research Center Atomic Oxygen

Atomic Oxygen Arrival Per Year at 400 km Altitude, 28° Inclination

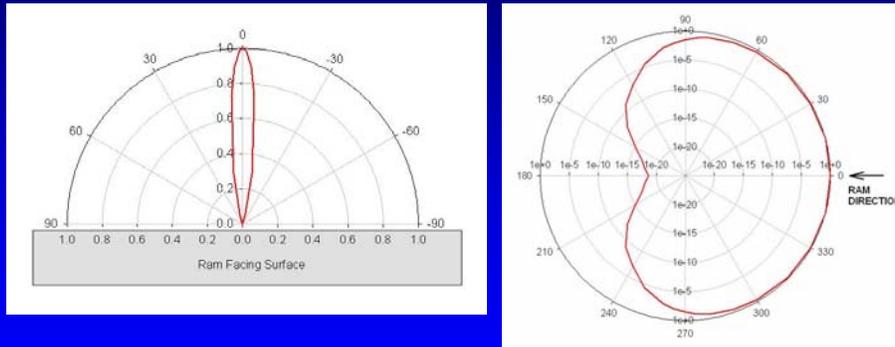


Solar activity varies over an 11 year cycle. Atomic oxygen concentrations arriving at spacecraft surfaces also follow this 11 year cycle.



## NASA Glenn Research Center Atomic Oxygen

### Directionality of Arrival

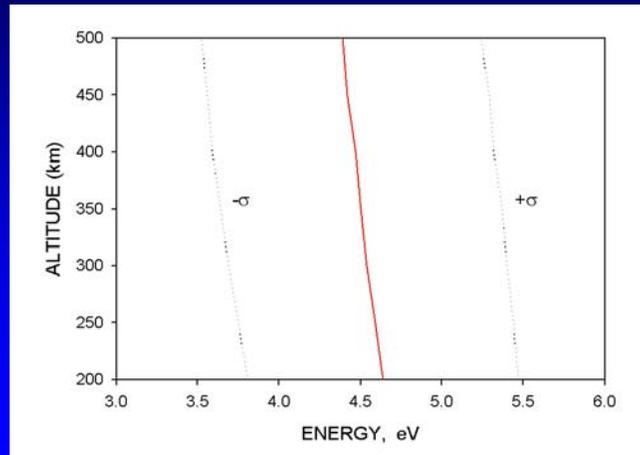


As a spacecraft orbits the Earth at velocities on the order of 7.7 km/sec, it runs into the atomic oxygen (“ram” atomic oxygen). If the spacecraft is in an orbit that has zero inclination, then the average angle of attack is perpendicular to surfaces whose surface normal points in the direction of travel. Most spacecraft have orbits which are inclined with respect to the Earth’s equatorial plane. This causes the average angle of attack of the atomic oxygen to sinusoidally vary around the orbit as a result of the vectorial addition of the orbital spacecraft velocity vectors. In addition, atomic oxygen atoms have thermal velocities associated with their Maxwell-Boltzman distribution (which can be as high as 1000K) actually allowing some atomic oxygen atoms to catch up with the trailing surfaces of the spacecraft producing a small arrival flux which is orders of magnitude lower than the ram flux. The figure on the left shows the arrival of atomic oxygen with respect to the ram arrival for a ram facing surface as a function of angle for a spacecraft orbiting at 400 km altitude with a 28.5 degree angle of inclination. The figure on the right is for the same altitude and inclination, but shows the flux as a function of angle around the spacecraft. This will vary with altitude and angle of inclination.



## NASA Glenn Research Center Atomic Oxygen

Energy Distribution vs Altitude

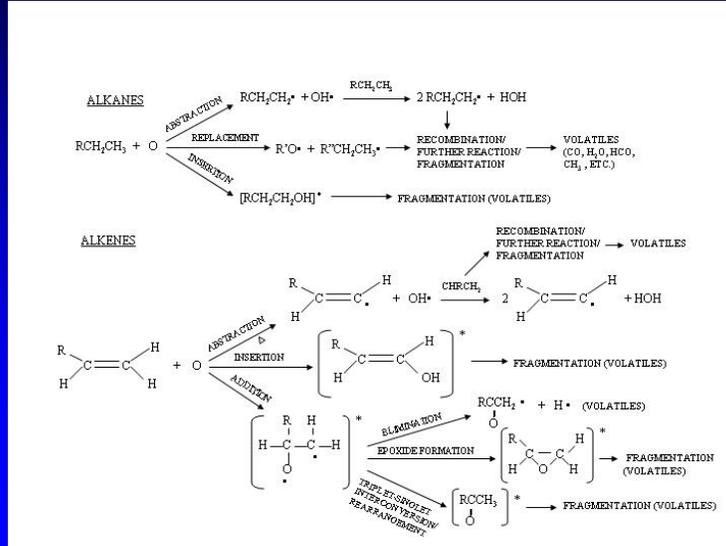


The impact energy of the arriving atomic oxygen in LEO is dependent upon the orbital spacecraft velocity vector, the Earth's atmospheric co-rotation velocity vector, and the thermal velocity vector. This results in an energy distribution that varies as a function of altitude at a fixed inclination and thermosphere temperature. The plot above is for 28.5 degree inclination and 1000K thermosphere.



# NASA Glenn Research Center Atomic Oxygen

## Atomic Oxygen Reaction Pathways



These energies combined with the reactivity of the atomic oxygen allow the breaking of most organic polymer bonds and the subsequent formation of volatile species by a variety of pathways.



## NASA Glenn Research Center

### Atomic Oxygen

Materials International Space Station Experiment  
After 4 Years in Low Earth Orbit

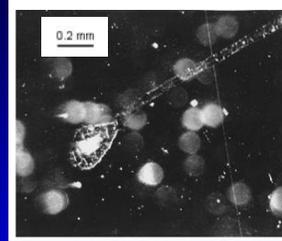
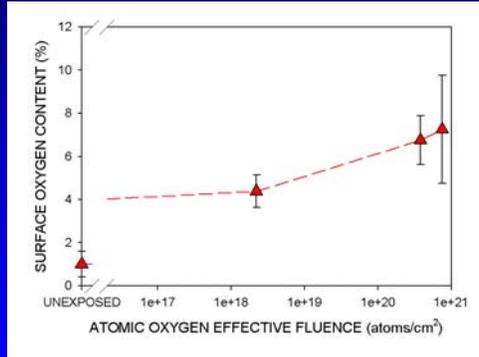


The loss of material through reaction with atomic oxygen has been the focus of several flight experiments. This is an example of an experiment tray that was recently retrieved after flying four years on the International Space Station in an attempt to better understand the reactions that occur and enable quantification of material durability in LEO for future missions.

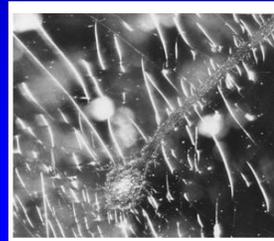


## NASA Glenn Research Center Atomic Oxygen

Exposure Results in Increased Oxidation  
of the Surface



Unexposed DC93-500

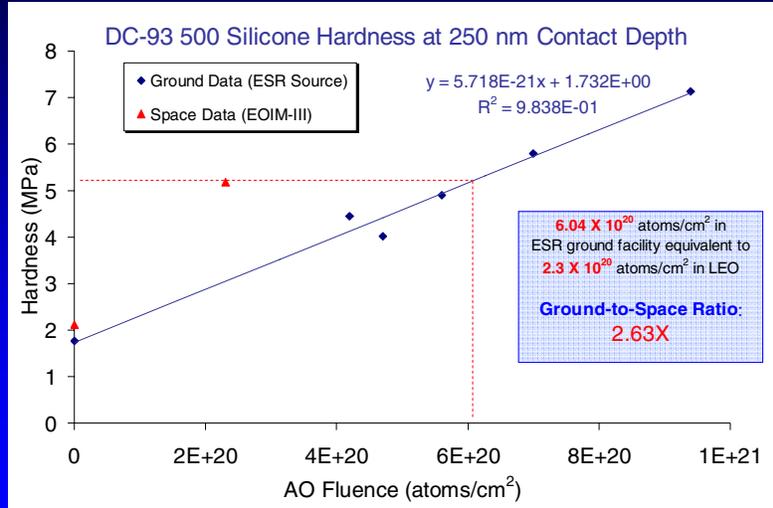


DC93-500 Exposed to 2.3e20 atoms/cm<sup>2</sup>

Surfaces of polymers exposed to atomic oxygen develop an increase in oxygen content as shown in the figure on the left. Oxidation of surfaces of silicones such as that shown on the right causes removal of methyl groups and gradual conversion of the surface to silica. This frequently results in shrinkage and crack formation in the exposed silicones as they are transformed from the lower modulus silicone into higher modulus silica. This cracking can continue through branch cracking as the cracks open up and expose more silicone to oxidation.



## NASA Glenn Research Center Atomic Oxygen

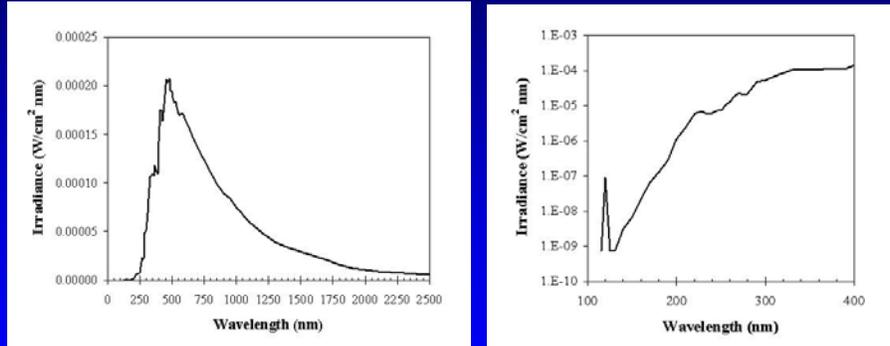


The hardness of silicones also increases as the conversion from silicone to silica takes place with increasing atomic oxygen arrival. The plot above shows this trend and how the surface hardness measured from space exposed samples can be used to estimate the equivalent dose that would be needed in a ground based exposure facility to achieve the same level of damage.



## NASA Glenn Research Center Ultraviolet Radiation

### Air Mass Zero Solar Spectrum



Photon radiation is defined by the Air Mass Zero solar spectrum, which is the irradiance that is measured as a function of wavelength at one astronomical unit from the sun as shown in the figure on the left. The greatest damage is produced by the ultraviolet radiation portion of the spectrum which is shown in the right figure. Ultraviolet radiation can further be subdivided into vacuum ultraviolet radiation (VUV) (100-200 nm) and near UV (NUV) radiation (200-400 nm). The VUV radiation produces surface damage while the NUV radiation can penetrate more deeply.



## NASA Glenn Research Center Ultraviolet Radiation

- Photochemical Reactions Can Lead To:
  - Loss in Mechanical Properties
    - Tensile Strength
    - Elongation to Failure
  - Increase in Optical Absorption
- Longer Wavelength Radiation Produces Deeper Damage
- Effects Can be Synergistic With Temperature

Photochemical reactions consist predominantly of chain scissioning in polymers and formation of absorbing color centers. Both can lead to loss in performance through reduced mechanical properties or overheating which can both result in mission failure. These effects can also be accelerated by exposure to ultraviolet radiation in combination with temperature elevation.



## NASA Glenn Research Center Particulate Radiation and Temperature

Combined Electron and Proton Radiation with On-Orbit Thermal Cycling  
Led to Hubble Space Telescope FEP Blanket Failure

Cracking After  
6.8 Years on Orbit

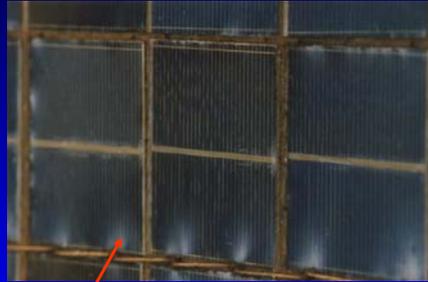


Synergistic effects can also be observed for polymers exposed to electron and proton radiation at elevated temperature. This combined exposure produces more severe damage than either environment alone. This type of exposure is believed to have caused the cracking and tearing of the FEP Teflon thermal blanket cover on the Hubble Space Telescope after 6.8 years on orbit.

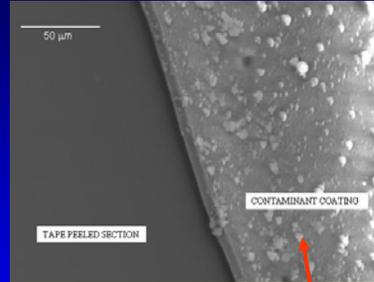


## NASA Glenn Research Center Contamination

### Silicone Contamination on MIR Solar Array After 10 Years in LEO



Oxidized Silicone  
Contamination on Front  
Side of MIR Array



Contaminant Coating on  
Front of Array



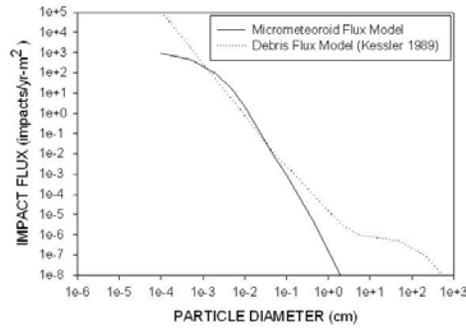
Tape Peeled Segment  
On Back of Array Showing  
Contaminant Removal

Silicone seals and other silicone containing materials should be used with caution in the space environment. The silicone fragments that are volatilized in the vacuum of space can land and be fixed on other surfaces by ultraviolet radiation or oxidation by atomic oxygen. In an atomic oxygen environment the layers can build forming a thick contaminant like that observed on the MIR solar array as shown in the top left and right images. The contaminant layer here was produced as a result of volatilized and fixed silicone fragments from the silicone adhesive bonding the array together. The contaminant on the front of the array stayed fairly clear and was thick (up to 4.6 microns thick). If the deposition of silicone fragments, however, is accompanied by hydrocarbon deposition, a much more optically absorbing coating can result. The contamination on the back side of the MIR solar array was more tan in appearance for this reason as shown in the lower figure. The diamond pattern on the back of the cell is caused by contaminant being deposited where there was a fabric net stretched across the back. Areas where the net covered were protected from atomic oxygen attack which prevented the conversion of silicone to silica. The contaminant could be removed by tape peeling for thickness measurement which on the back side was about 1.24 microns thick. To reduce the occurrence of this, low outgassing materials with low volatile condensable materials are needed. Testing for compliance can be done using ASTM E-595. Not all materials listed as being “space qualified” do meet this requirement. Some silicone seals failed the outgassing test due to an incomplete cure, but were sold as “space qualified”.

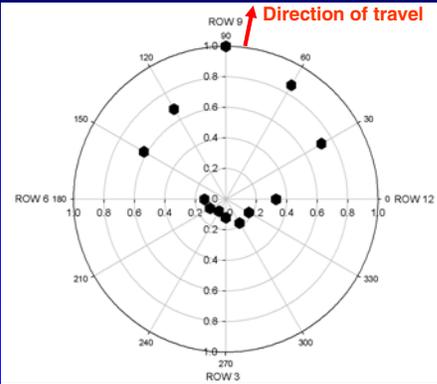


## NASA Glenn Research Center Micrometeoroids and Debris

Modeling of Flux vs Size of Particle



Impact Distribution on LDEF

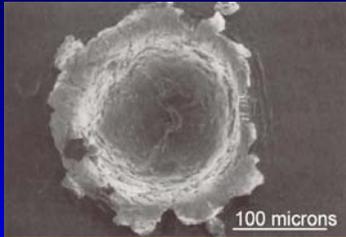


Micrometeoroids are of extraterrestrial origin and will have a flux which is reasonably constant with time with an average velocity near 20 km/sec. Orbital debris is of man-made origin and has an average velocity of 8.7 km/sec. Because of the man-made origin and atmospheric drag, orbital debris flux is highly dependent upon the world's spacecraft launch frequency and occurrences of orbital breakups. Size distribution models for both are contained in the figure on the left. The figure on the right contains a polar plot of the combined micrometeoroid and debris impacts on the LDEF satellite (a space environment reaction exposure free flyer) which was in orbit 69 months. It illustrates the nonuniformity of impacts around a spacecraft with a fixed orientation relative to the ram velocity direction.

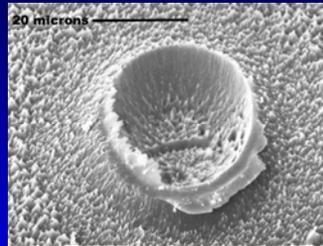


## NASA Glenn Research Center Micrometeoroids and Debris

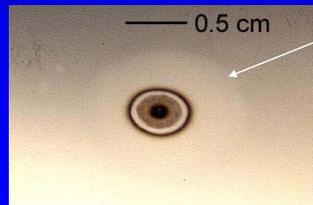
Crater Volumes = 10x That of the Impacting Particle  
Ejecta can compromise seal surface



Impact Crater in Aluminum



Impact Crater in FEP Teflon



Impact in Layered FEP, Silver and Z306 Black Paint

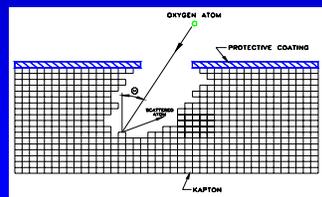
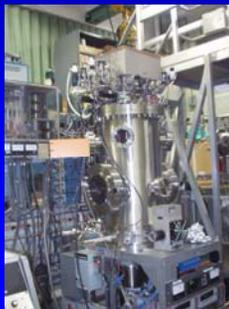
The impact of micrometeoroid or orbital debris particles with spacecraft materials is sufficiently energetic to cause vaporization of the impacting particle as well as produce an impact crater of volume 10x that of the impacting particle. Impacts shown on the top left and right were in bulk materials (aluminum on the left and atomic oxygen textured FEP Teflon on the right). Laminated materials can experience delamination of a significant area around the impact site as shown in the lower figure. The likelihood of large impacts on seal surfaces which will affect their performance, however, is much lower than the potential for seal problems caused by sputter ejecta from impacts landing on the seal surface.



## NASA Glenn Research Center

### Determining Durability

Electro-Physics Branch Uses a Combination of Flight Testing,  
Ground Exposure Testing and Modeling to Determine Material Durability



Contact: Bruce Banks (216) 433-2308  
bruce.a.banks@nasa.gov

The Electro-Physics Branch at NASA Glenn Research Center has been involved with evaluating the durability of materials and understanding environment interactions for over 20 years. A combination of flight experiments (upper left figure), ground based exposure facilities, and environmental modeling provide a well rounded approach to material durability evaluation and prediction for future missions. Ground based testing includes atomic oxygen exposure facilities (large and small area thermal facilities and directed atomic oxygen with and without VUV radiation (upper right figure)), VUV and NUV exposure facility (lower left figure), and thermal cycling facility with and without UV radiation.

A lunar dust exposure facility is also being brought on-line. Material reactions in these facilities is compared to that observed in space. The lower right figure shows a sample output from a Monte Carlo model developed to predict the extent of reaction of scattered atomic oxygen entering a coating defect or a recessed portion of a spacecraft.

Further information about the environment, and testing can be obtained at <http://www.grc.nasa.gov/www/epbranch/ephome.htm> or contacting Bruce Banks, Chief of the Electro-Physics Branch at [bruce.a.banks@nasa.gov](mailto:bruce.a.banks@nasa.gov), (216)-433-2308