

Materials International Space Station Experiment (MISSE): Overview, Accomplishments and Future Needs

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ABSTRACT

Materials and devices used on the exterior of spacecraft in low Earth orbit (LEO) are subjected to environmental threats that can cause degradation in material properties, possibly threatening spacecraft mission success. These threats include: atomic oxygen (AO), ultraviolet and x-ray radiation, charged particle radiation, temperature extremes and thermal cycling, micrometeoroid and debris impacts, and contamination. Space environmental threats vary greatly based on spacecraft materials, thicknesses and stress levels, and the mission environment and duration.

For more than a decade the Materials International Space Station Experiment (MISSE) has enabled the study of the long duration environmental durability of spacecraft materials in the LEO environment. The overall objective of MISSE is to test the stability and durability of materials and devices in the space environment in order to gain valuable knowledge on the performance of materials in space, as well as to enable lifetime predictions of new materials that may be used in future space flight. MISSE is a series of materials flight experiments, which are attached to the exterior of the International Space Station (ISS). Individual experiments were loaded onto suitcase-like trays, called Passive Experiment Containers (PECs). The PECs were transported to the ISS in the Space Shuttle cargo bay and attached to, and removed from, the ISS during extravehicular activities (EVAs). The PECs were retrieved after one or more years of space exposure and returned to Earth enabling post-flight experiment evaluation. MISSE is a multi-organization project with participants from the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD), industry and academia. MISSE has provided a platform for environmental durability studies for thousands of samples and numerous devices, and it has produced many tangible impacts. Ten PECs (and one smaller tray) have been flown, representing MISSE 1 through MISSE 8, yielding long-duration space environmental performance and durability data that enable material validation, processing recertification and space qualification; improved predictions of materials and component lifetimes in space; model verification and development; and correlation factors between space-exposure and ground-facilities enabling more accurate in-space performance predictions based on ground-laboratory testing.

A few of the many experiment results and observations, and their impacts, are provided. Those highlighted include examples on improved understanding of atomic oxygen scattering mechanisms, LEO coating durability results, and polymer erosion yields and their impacts on spacecraft design. The MISSE 2 Atomic Oxygen Scattering Chamber Experiment discovered that the peak flux of scattered AO was determined to be 45° from normal incidence, not the model predicted cosine dependence. In addition, the erosion yield (E_y) of Kapton H for AO scattered off oxidized-Al is 22% of the E_y of direct AO impingement. These results were used to help determine the degradation mechanism of a cesium iodide detector within the Hubble Space Telescope Cosmic Origins Spectrograph Experiment. The MISSE 6 Indium Tin Oxide (ITO) Degradation Experiment measured surface electrical resistance of ram and wake ITO coated samples. The data confirmed that ITO is a stable AO protective coating, and the results validated the durability of ITO conductive coatings for solar arrays for the Atmosphere-Space Transition

Explorer program. The MISSE 2, 6 and 7 Polymer Experiments have provided LEO AO E_y data on over 120 polymer and composites samples. The flight E_y values were found to range from 3.05×10^{-26} cm³/atom for the AO resistant polymer CORIN to 9.14×10^{-26} cm³/atom for polyoxymethylene (POM). In addition, flying the same polymers on different missions has advanced the understanding of the AO E_y dependency on solar exposure for polymers containing fluorine. The MISSE polymer results are highly requested and have impacted spacecraft design for WorldView-2 & -3, the Global Precipitation Measurement-Microwave Imager, and other spacecraft. The flight data has enabled the development of an Atomic Oxygen Erosion Predictive Tool that allows the erosion prediction of new and non-flown polymers. The data has also been used to develop a new NASA Technical Standards Handbook "Spacecraft Polymers Atomic Oxygen Durability Handbook." Many intangible benefits have also been derived from MISSE. For example, over 40 students have collaborated on Glenn's MISSE experiments, which have resulted in >\$80K in student scholarships and awards in national and international science fairs. Students have also given presentations and won poster competition awards at international space conferences.

Because MISSE operations need to change significantly in the post-Shuttle era, from 2011 to 2013, NASA invested in the next generation MISSE concept called MISSE-X. The MISSE-X team surveyed the space community for future external flight experiment demands and needs. Information was gathered on the types of experiment accommodations needed by potential users. Forty-seven responses were received from NASA, DoD, academia and industry principal investigators (PI). The MISSE-X team developed facility requirements and a design concept for the next generation MISSE based on PI needs. Given the high demand for a future MISSE-like capability on ISS, NASA issued a NASA Research Announcement soliciting proposals for either a full commercial business model, or a partial commercial business model, for developing and maintaining an ISS external facility for testing and demonstrating performance, reliability, and durability of spacecraft materials, devices, and subsystems. The MISSE-X facility requirements were used as the basis for needed capabilities listed in the NRA. Some of the capabilities include: accommodation of active and passive experiments, exposure in ram, zenith and wake orientations, environmental monitoring in each exposure direction, and the ability to return experiments to Earth. In addition, the facility needs to be installed and maintained using ISS robotic capability. Future desired experiments include: the study of new materials for use in the space environment, radiation exposure and shielding studies, optical and protective coating durability, device and sensor performance and durability, and LEO degradation and mitigation studies. The accomplishments of MISSE over the past decade, and the projected demand for future needs, indicates the importance of developing a future external facility for the space community to enable the continuation of studies on the durability of materials and devices in the LEO environment.



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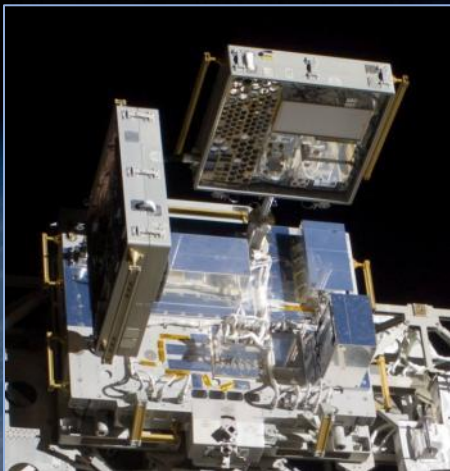
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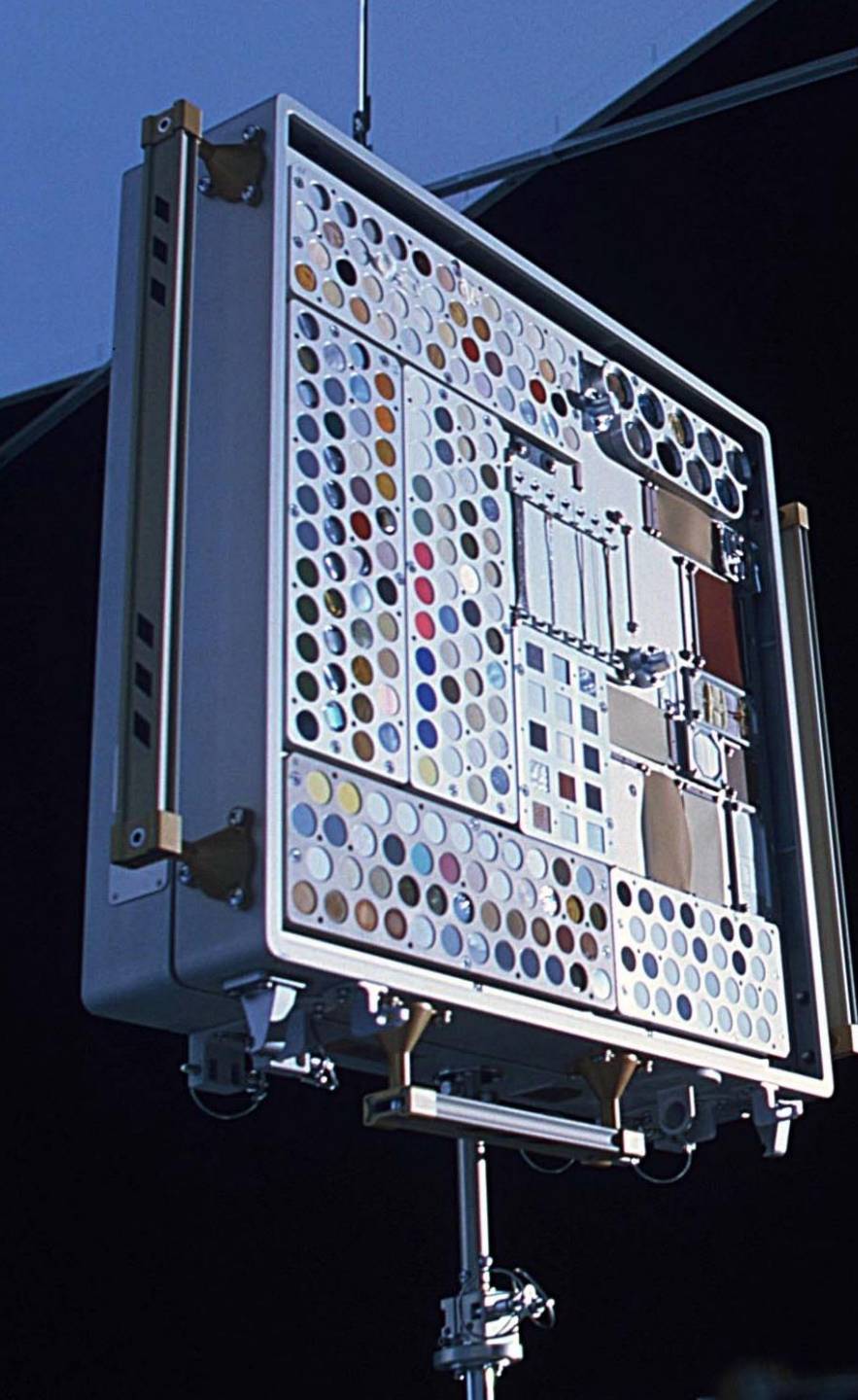
*Discoveries Plenary Presentation at the
3rd Annual International Space Station Research and Development Conference
June 17-19, 2014, Chicago, IL*



MISSE 7A & 7B



April 2010
(STS-131)



*We would like to acknowledge
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Bruce A. Banks,
SAIC at NASA GRC

Shane Juhl, AFRL

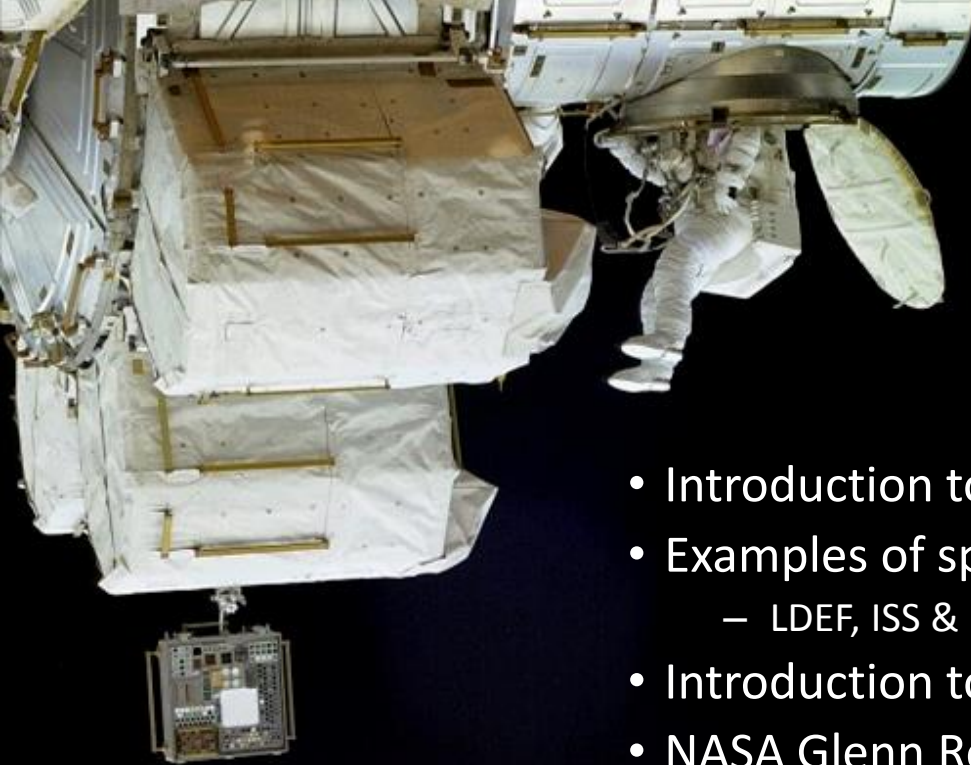
Miria Finckenor, NASA MSFC

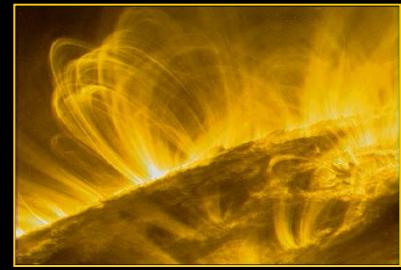
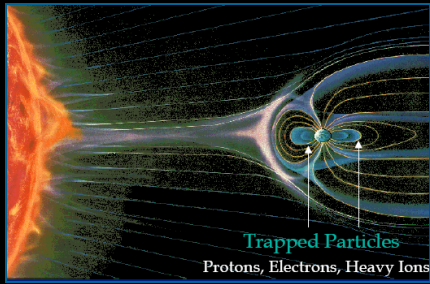
Sharon Miller, NASA GRC

Iwona Palusinski,
The Aerospace Corporation

Outline

- Introduction to the space environment
- Examples of space environment induced damage
 - LDEF, ISS & Hubble Space Telescope (HST)
- Introduction to MISSE
- NASA Glenn Research Center's MISSE experiments
- Experiments & benefits from other MISSE Investigators
 - NASA Marshall Space Flight Center
 - Naval Research Laboratory (NRL)/ US Naval Academy/NASA Glenn Research Center/Space Test Program (STP)
 - Air Force Research Laboratory (AFRL)
 - Boeing
 - The Aerospace Corporation/NRL
- MISSE-X & future needs
- MISSE team recognition



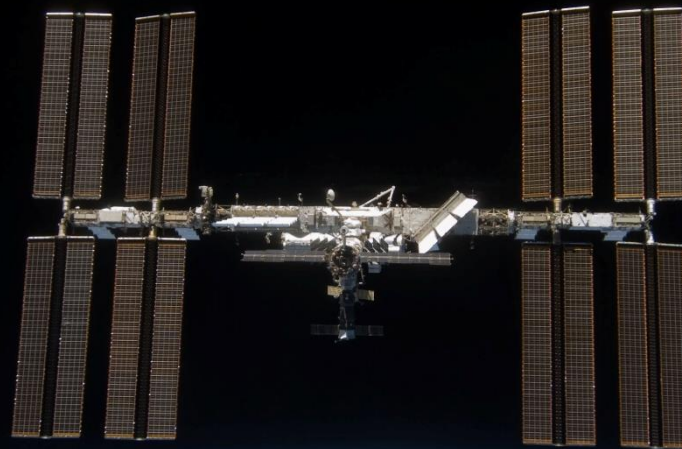


The Space Environment

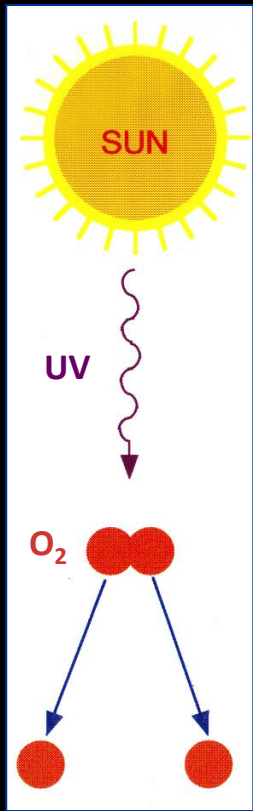
Exterior spacecraft materials are exposed to many space environmental threats that can be damaging to the spacecraft & their operation

In low Earth orbit (LEO) these threats include:

- Solar radiation (ultraviolet (UV), x-rays)
- “Solar wind” particle radiation (electrons, protons)
- Temperature extremes & thermal cycling
- Micrometeoroid & orbital debris (space particles)
- Atomic oxygen (reactive oxygen atoms)



Atomic Oxygen (AO)

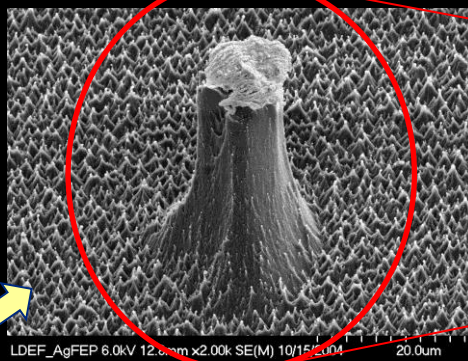
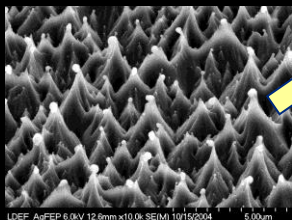


Atomic Oxygen

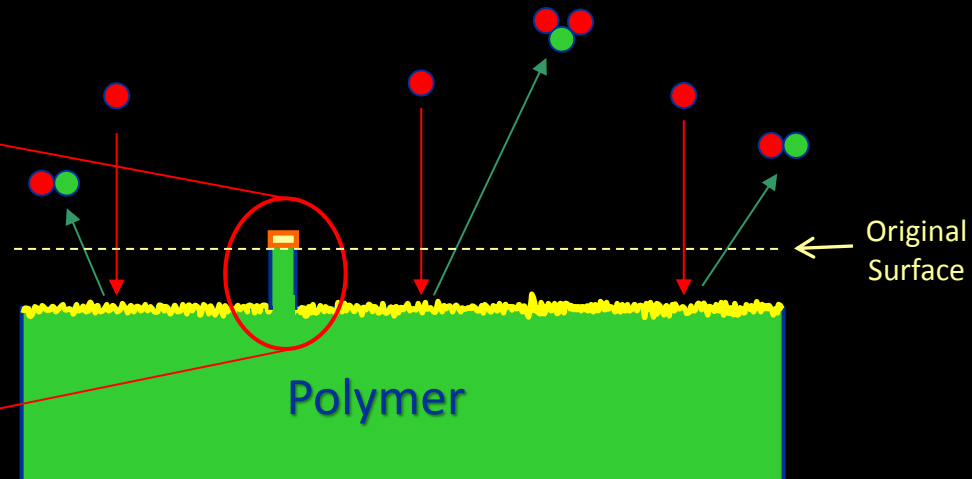
- AO is the predominant species in LEO ($\approx 200\text{-}650\text{ km}$)
- It is formed by photodissociation of molecular oxygen (O_2) by short wavelength energetic UV radiation
- At ram impact velocities (17,000 mph) the average impact energy is 4.5 eV
- AO oxidizes certain spacecraft materials such as polymers, resulting in gas formation - so *the material erodes away...*

\Rightarrow *AO is a serious threat to spacecraft survivability*

Ram AO
erosion causes
"cone" formation



2000X

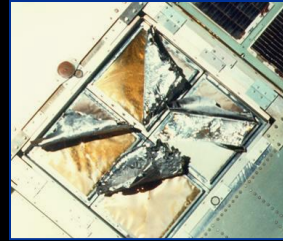




Space Environment Induced Degradation



Radiation induced darkening



Structural degradation

Pre-flight

Post-flight

Long Duration Exposure Facility (LDEF)
5.8 yrs in space

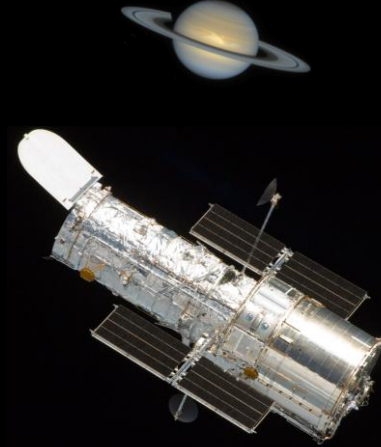
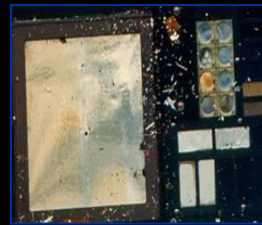


AO erosion of Kapton blanket



Impact site

Debris generation



Hubble Space Telescope (HST)

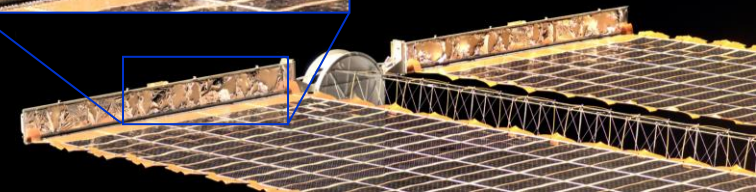


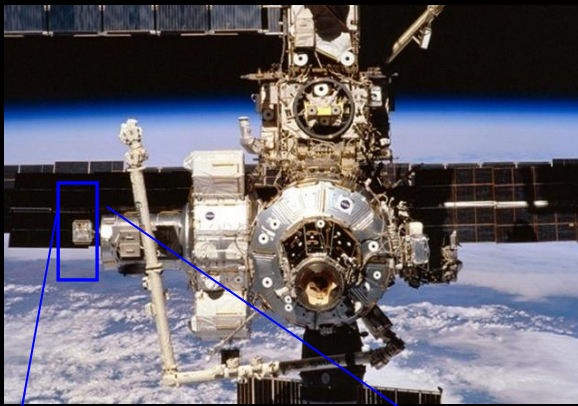
Radiation induced embrittlement & cracking of Teflon insulation (6.8 yrs)



International Space Station (ISS)
2001

AO undercutting erosion of the P6 Port Solar Array Al-Kapton blanket box cover (1 yr)





Materials International Space Station Experiment



MISSE is a series of materials flight experiments consisting of trays called Passive Experiment Containers (PECs), that were exposed to the space environment on the exterior of the International Space Station (ISS). The PECs were positioned in either a *ram/wake orientation* or a *zenith/nadir orientation*.

Objective: To test the stability and durability of materials and devices in the space environment





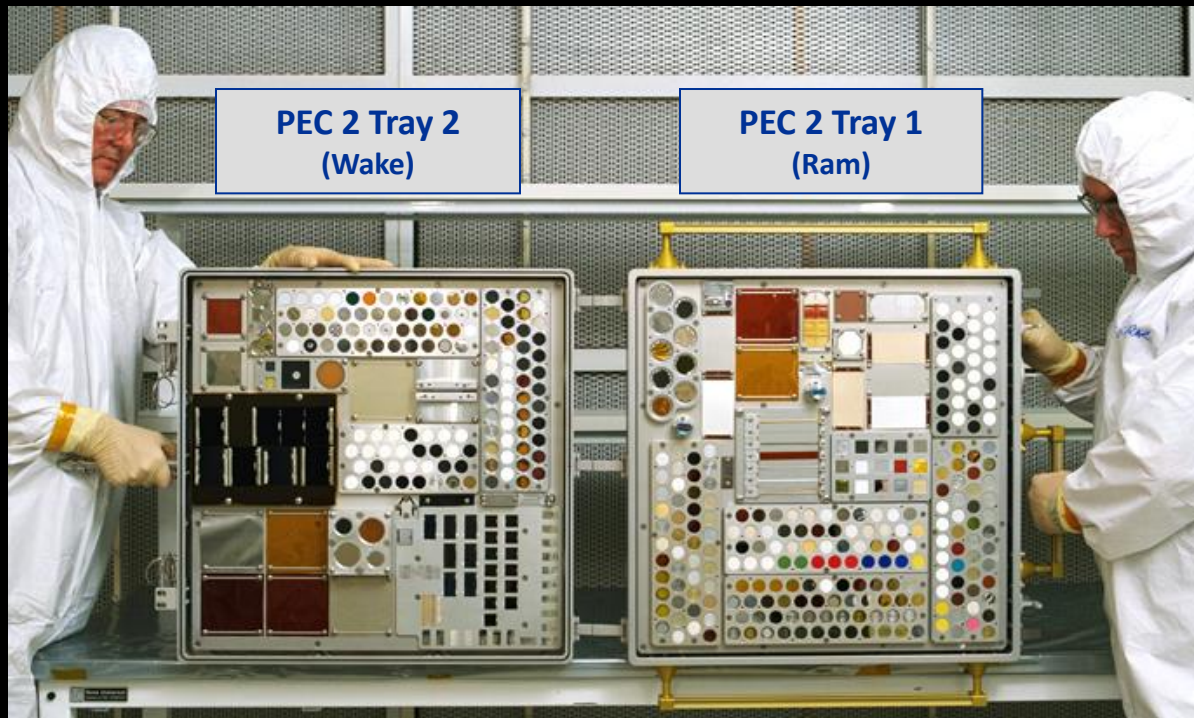
MISSE Overview



MISSE is a multi-organization project with participants from NASA, the Department of Defense (DoD), industry and academia.

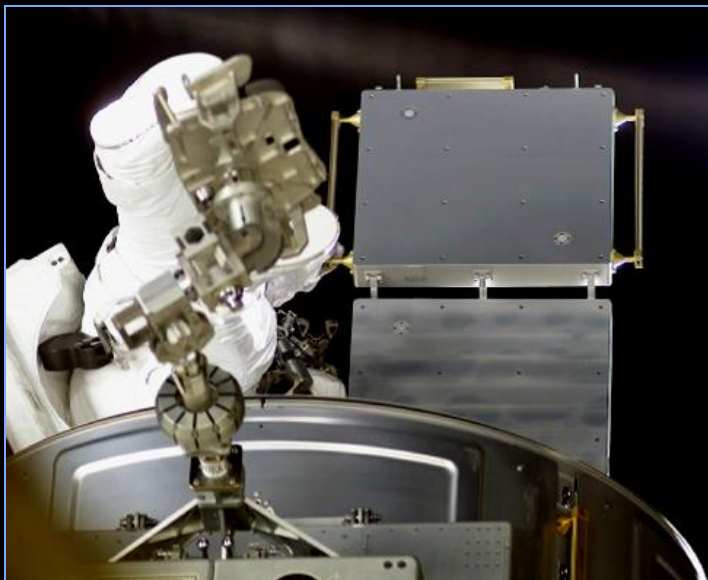
MISSE PEC	Mission PI	Managers*	Sponsors	Major Participants	Experiment Type
1 & 2	Bill Kinard (NASA LaRC)	NASA LaRC, AFRL/ML	NASA & AFRL/ML	NASA LaRC, AFRL/ML, Boeing, MSFC, GRC, TRW, Loral, Lockheed-Martin, Hughes, The Aerospace Corporation, AZ Technology, Rockwell Science Center, ATK Space Systems, PSI, Northrop Grumman, Alion S & T, JPL, GSFC, SRS Tech, Entech	Passive material experiments
3 & 4	Bill Kinard (NASA LaRC)	NASA LaRC, AFRL/ML	AFRL/ML	NASA LaRC, AFRL/ML, Boeing Phantom Works, NASA MSFC, NASA GRC, TRW, Loral, Lockheed-Martin, Hughes, The Aerospace Corporation, AZ Technology, Rockwell Science Center, ATK Space Systems, PSI, Northrop Grumman, Alion S & T, JPL, NASA GSFC, Triton, Wayne State University, GSFC & others	Passive material experiments
5	Rob Walters (NRL)	NRL	NRL	NRL, NASA GRC, US Naval Academy, AFRL/ML, NASA LaRC, Boeing Phantom Works, Spectrolab Incorporated, Entech, Emcore Corporation, NASA MSFC	Active solar cell and passive material experiments; Self-powered with on-board, two-way comms (PCSat2 Amateur Radio system)
6A & 6B	Bill Kinard (NASA LaRC)	NASA LaRC	NASA, AFRL/ML, Boeing, AFOSR	AFRL/ML, AFRL-Edwards, AFOSR, Air Force Academy, The Aerospace Corporation, ATEC, Boeing Phantom Works, Physical Sciences, Sensortex, Plasma Processes, Inc., NRL, Sandia Labs, NASA - LaRC, ARC, GRC, MSFC, Montana Space Grant Consortium, U. of Illinois, U. of Pittsburg, Utah State U., North Dakota State	Active and passive material & device experiments; ISS power & data stored on data loggers to be analyzed post-flight
7A & 7B	Phil Jenkins (NRL)	NRL	NASA & NRL	NRL, NASA GRC, AFRL/ML, Boeing Phantom Works, NASA GSFC, Lockheed Martin, DR Tech, Emcore Photovoltaics, Spectrolab, Microlink, United Solar, Dutch Space, Assurance Technology, Aerospace Corporation, Sandia National Laboratory, NASA LaRC, NASA Ames, NASA MSFC, US Air Force Academy, U. of Arizona	Active and passive material & device experiments; ISS power and communication links (telemetry data to Earth)
8	Phil Jenkins (NRL)	NRL	NASA & NRL	NRL, Lockheed Martin, JAXA, Kyushu Institute of Technology, Aerospace Corporation, Sandia National Laboratory, NASA GRC, AFRL, Boeing Phantom Works, NASA MSFC, Emcore Photovoltaics, Spectrolab, Microlink, United Solar	Active and passive material & device experiments; ISS power and communication links (telemetry data to Earth)

**The DoD Space Test Program (STP) is responsible for integration of all the MISSE PECs with the space shuttle, and for launch and on-orbit operations of the experiments*



MISSE

Experiment
Integration,
Shuttle
launch &
EVA
Attachment



Patrick Forrester
& PEC 2

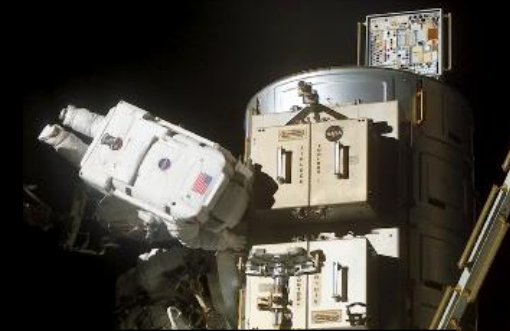
August 16, 2001





MISSE 1-8

Mission Summary



MISSE PEC	Launch Mission	Date Placed Outside ISS	Location on ISS	Tray Orientation	Retrieval Mission	Date Retrieved from Outside of ISS	LEO Exposure Duration (years)
1 & 2	STS-105	8/16/2001	PEC 1: High Pressure Gas Tank (HPGT) PEC 2: Quest Airlock	Ram & Wake	STS-114	7/30/2005	3.95
3 & 4	STS-121	8/3/2006*	PEC 3: HPGT PEC 4: Quest Airlock	Ram & Wake	STS-118	8/18/2007	1.04
5	STS-114	8/3/2005	Aft P6 Trunion Pin Handrail	Zenith & Nadir	STS-115	9/15/2006	1.12
6A & 6B	STS-123	3/22/2008	Columbus Laboratory	Ram & Wake	STS-128	9/1/2009	1.45
7A & 7B	STS-129	11/23/2009	EXPRESS Logistics Carrier 2 (ELC 2) on the S3 Truss	7A: Zenith & Nadir 7B: Ram & Wake	STS-134	5/20/2011	1.49
8 & ORMatE-III R/W	STS-134	8: 5/20/2011 ORMatE-III R/W: 7/12/2011**	EXPRESS Logistics Carrier 2 (ELC 2) on the S3 Truss	8: Zenith & Nadir ORMatE-III R/W: Ram & Wake	SpaceX-3 Dragon	7/9/2013	MISSE 8: 2.14 ORMatE-III: 2.00

* Deployed during Expedition 13

** Deployed during STS-135

ORMatE-III R/W: Optical Reflector Materials Experiment III Ram/Wake



Examples of NASA Glenn Research Center's MISSE Experiments and Benefits



NASA Glenn's MISSE Materials Experiments

MISSE	# Expts	Types of Experiments	Orientation	# Samples	Active/ Passive
1 & 2	7	Gossamer materials & thin film polymers, SiOx-coated Kapton, AO scattering chamber, spacecraft silicones	Ram Wake	80	P
3 & 4	8	Gossamer materials & thin film polymers, SiOx-coated Kapton, AO scattering chamber, spacecraft silicones, EMI shielding	Ram Wake	71	P
5	4*	Thin film polymers (tensile & erosion), silicones	Nadir	105	P
6A & 6B	11	Stressed polymers, thin film polymers, ITO coatings, solar cells, Cermet coatings, thermal control paints, AO scattering chamber, AO pinhole camera, AO fluence monitor	Ram Wake	177	A & P
7A & 7B	10*	Thin film polymers (tensile & erosion), spacesuit fabrics, seals, thermal control paints, AO scattering chamber, AO pinhole camera, AO fluence monitor	Ram Wake Zenith Nadir	155	A & P
8 & ORMatE-III	1	Thin film polymers (tensile & erosion)	Ram Wake Zenith	42	P

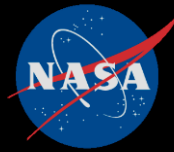
* Does not include the MISSE FTSCE experiments

NASA Glenn has flown 41 experiments with 630 samples



MISSE 2 PEACE Polymers Experiment

Polymers Erosion and Contamination Experiment (PEACE)



Objective:

To determine the atomic oxygen erosion yield (E_y , volume loss per incident oxygen atom) of a wide variety of polymers exposed for an extended period of time to the LEO space environment*



** Common spacecraft materials and materials chosen to explore AO E_y dependence upon chemical composition*

Kim de Groh

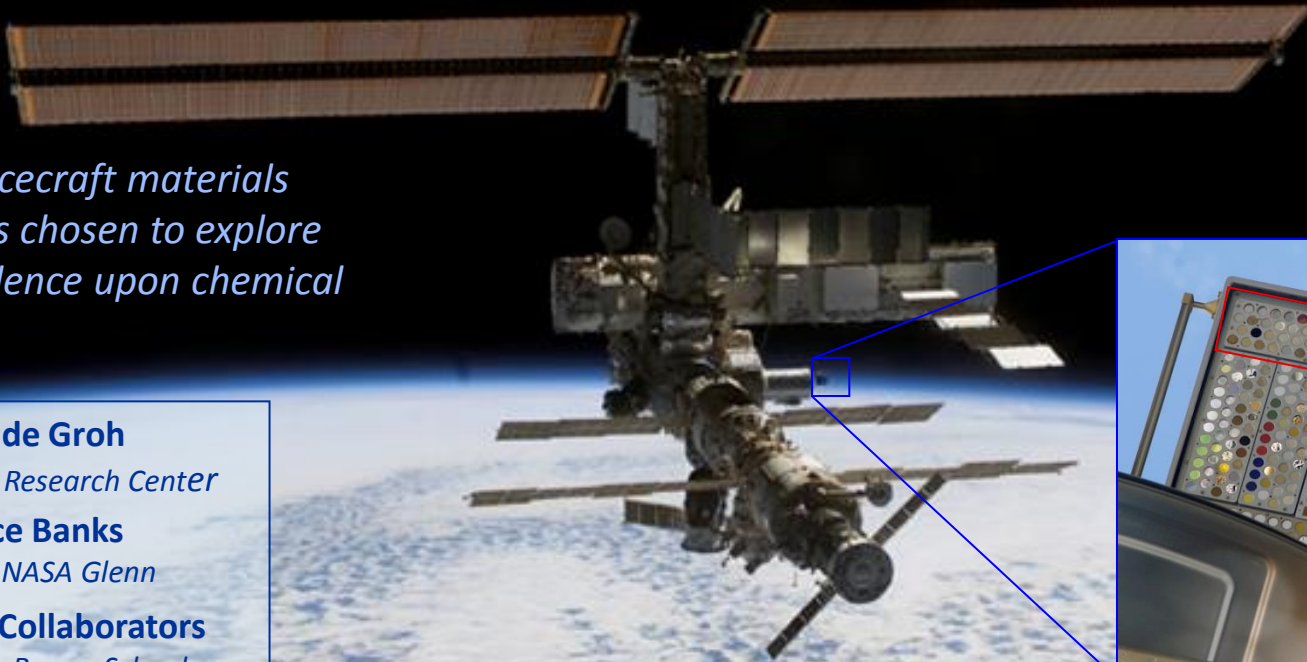
NASA Glenn Research Center

Bruce Banks

SAIC at NASA Glenn

Students Collaborators

Hathaway Brown School



MISSE 2 PEACE Polymers Experiment



Pre-flight



Post-flight

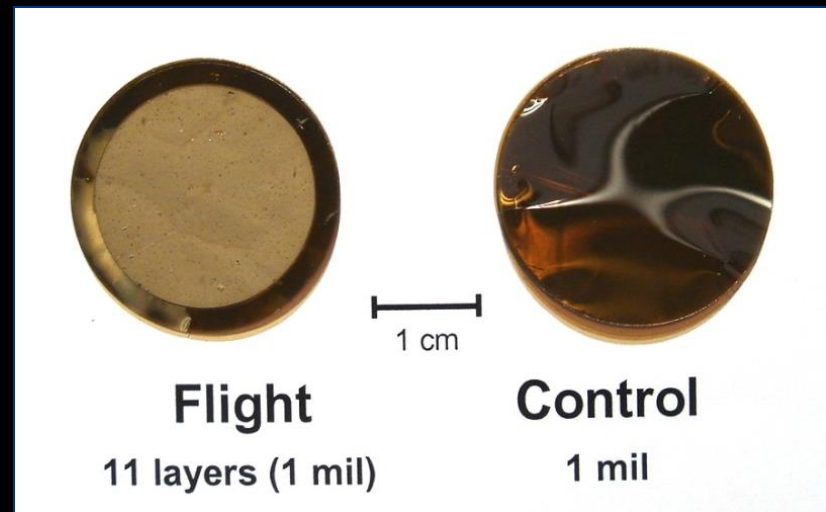
Polyimide (PMDA) Upilex-S

2-E5-32

Post-flight photos



In flight tray



Out of tray

Complete erosion

Partial erosion

No erosion





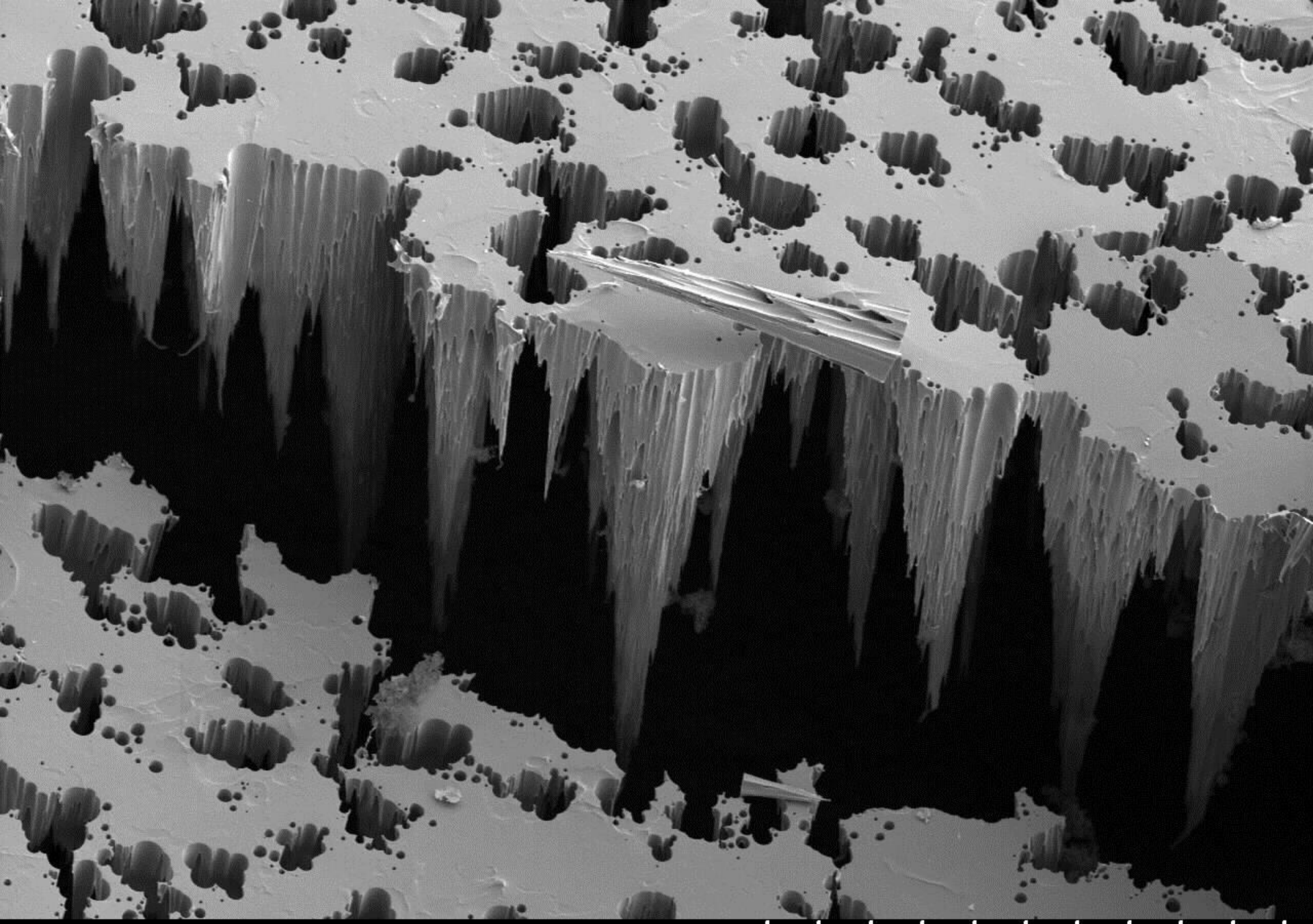
MISSE 2 PEACE Polymers Erosion Yield Data



Polymer	Abbrev.	E_y (cm ³ /atom)	E_y Uncertainty (%)	Polymer	Abbrev.	E_y (cm ³ /atom)	E_y Uncertainty (%)
ABS		1.09E-24	2.7	PEI		> 3.31E-24*	2.6
CA		5.05E-24	2.7	PA 6		3.51E-24	2.7
PPD-T (Kevlar)		6.28E-25	2.6	PA 66		1.80E-24	12.6
PE		> 3.74E-24*	2.6	PI (CP1)		1.91E-24	2.8
PVF (Tedlar)		3.19E-24	2.6	PI (Kapton H)		3.00E-24	2.7
PVF (White Tedlar)		1.01E-25	4.1	PI (Kapton HN)		2.81E-24	2.6
POM (Delrin)		9.14E-24	3.1	PI (Upilex-S)		9.22E-25	3.0
PAN		1.41E-24	3.3	PI (PMR-15)		> 3.02E-24*	2.6
ADC (CR-39)		> 6.80E-24*	2.6	PBI		> 2.21E-24*	2.6
PS		3.74E-24	2.7	PC		4.29E-24	2.7
PMMA		> 5.60E-24*	2.6	PEEK		2.99E-24	4.5
PEO		1.93E-24	2.6	PET (Mylar)		3.01E-24	2.6
PBO (Zylon)		1.36E-24	6.0	CTFE (Kel-f)		8.31E-25	2.6
EP		4.21E-24	2.7	ECTFE (Halar)		1.79E-24	2.6
PP		2.68E-24	2.6	ETFE (Tefzel)		9.61E-25	2.6
PBT		9.11E-25	2.6	FEP		2.00E-25	2.7
PSU		2.94E-24	3.2	PTFE		1.42E-25	2.6
PU		1.56E-24	2.9	PFA		1.73E-25	2.7
PPPA (Nomex)		1.41E-24	2.9	AF		1.98E-25	2.6
PG		4.15E-25	10.7	PVDF (Kynar)		1.29E-24	2.7

* E_y > this value because sample stack was partially, or fully, eroded through

Average error: 3.30%



2-E5-30 2.0kV 30.5mm x1.00k SE(L) 4/7/2009

50.0um



MISSE 2 PEACE Polymers Experiment

Kim K. de Groh, NASA Glenn Research Center



- Objective:

- *To determine the atomic oxygen erosion yield (E_y , volume loss per incident oxygen atom) of a wide variety of polymers exposed for an extended period of time to the LEO space environment*



MISSE 2 PEACE experiment post-flight

- Results:

- LEO AO E_y data of 38 polymers & pyrolytic graphite have been obtained
- Flight data used for determining ground-to-space correlations for AO ashers
- An AO Erosion Predictive Tool was developed using the flight data (B. Banks)

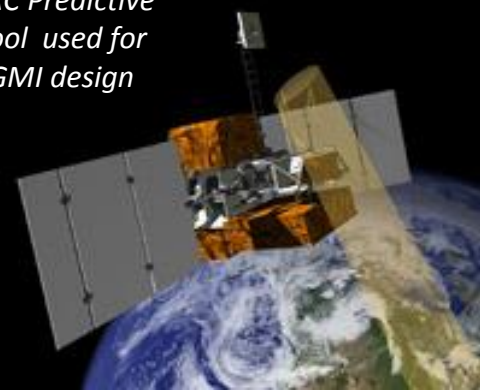


More accurate ground testing

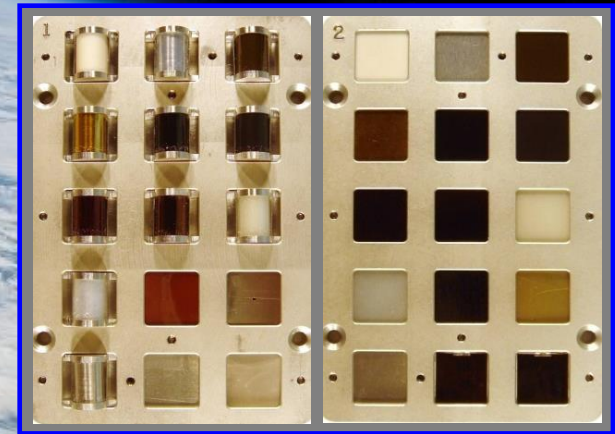
- Benefits:

- *PEACE, or Predictive Tool E_y data has been highly requested (50+ requests) and the data has directly impacted spacecraft materials design, including:*
 - ISS (external debris shielding components)
 - Global Precipitation Measurement-Microwave Imager (GMI)
 - Space Test Program's Standard Interface Vehicle (STP-SIV)
 - Operational Land Imager (OLI)
 - WorldView-2 & Worldview-3
- *Flight data enables more accurate ground-laboratory testing*
- *NASA Technical Standards Handbook "Spacecraft Polymers Atomic Oxygen Durability Handbook" has been written based on the flight data*

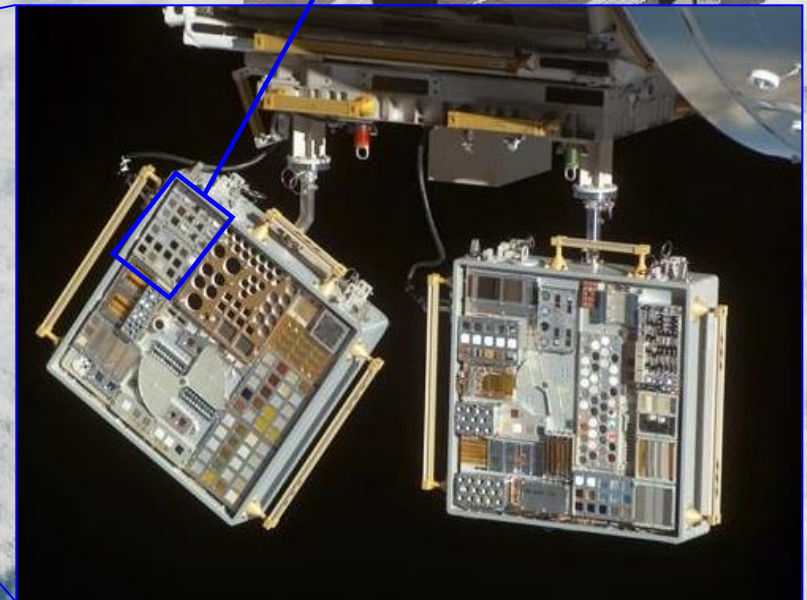
GRC Predictive Tool used for GMI design



Stressed Polymers Experiment

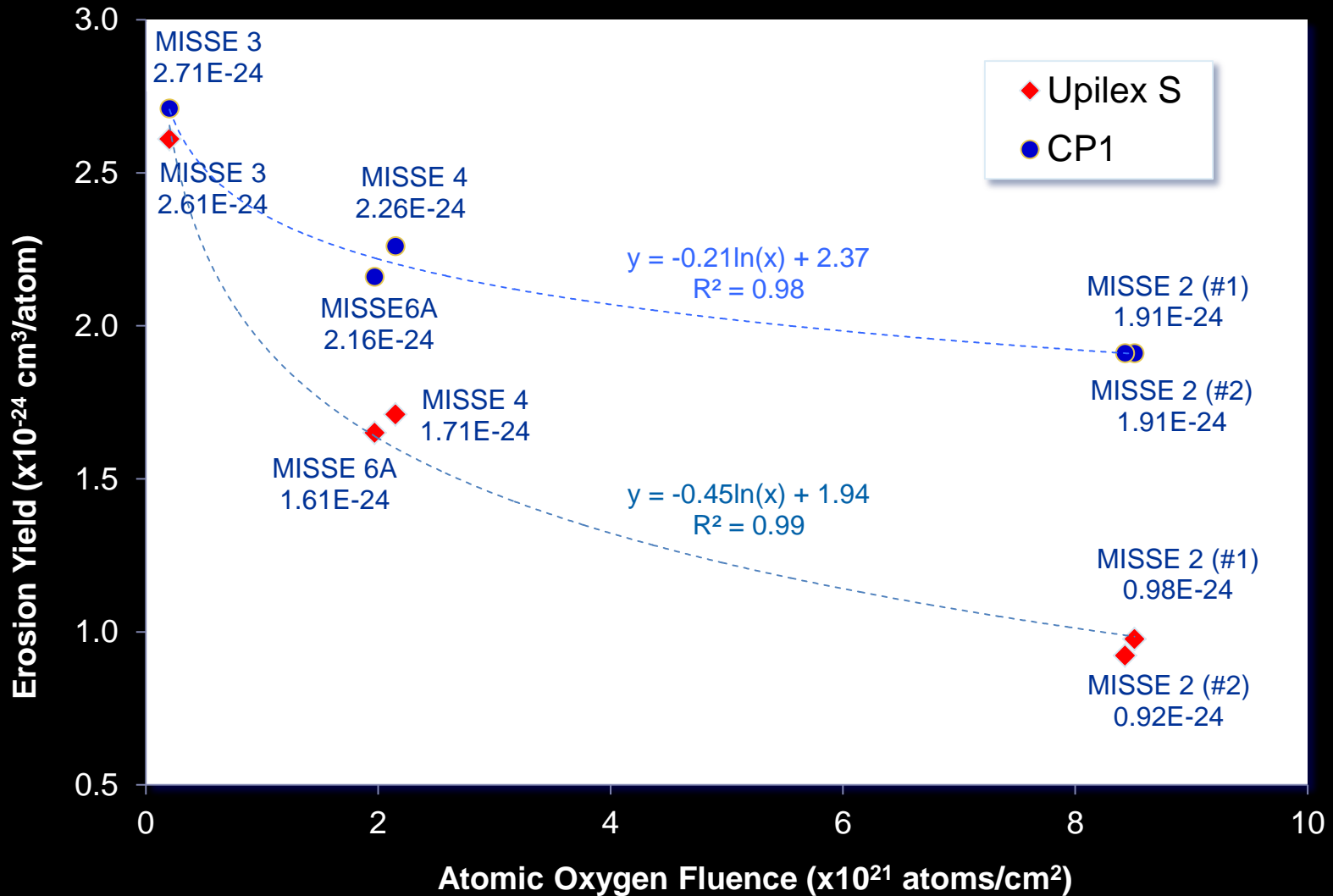


MISSE 6A & 6B
Deployed March 22, 2008
Retrieved Sept. 1, 2009
1.45 years of space exposure



Upilex-S and CP1 (Clear Polyimide)

Erosion Yield Vs. AO Fluence

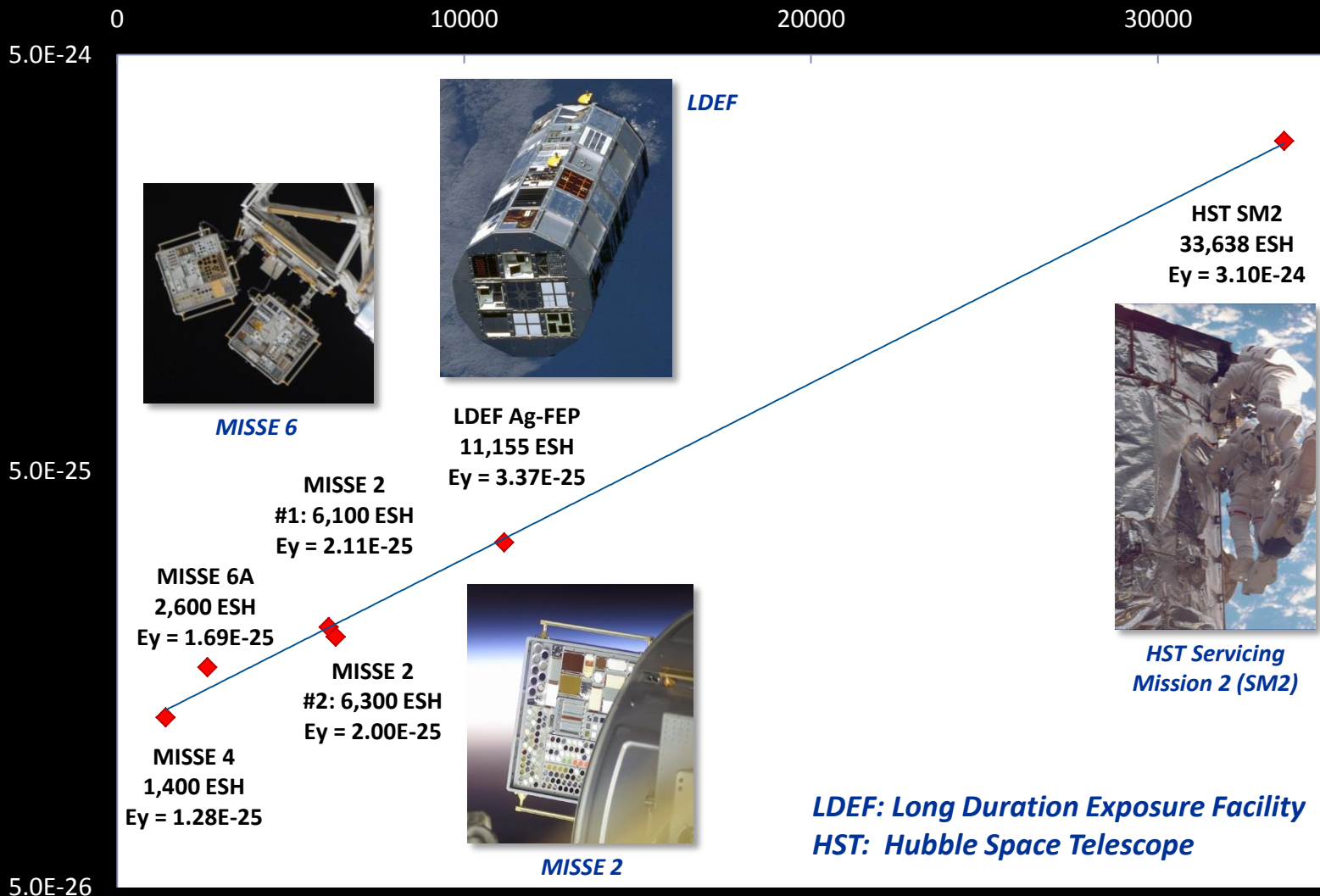


⇒ Flying the same polymer on various MISSE missions provides important information on erosion dependence on environmental exposures.

Teflon Fluorinated Ethylene Propylene (FEP) Erosion Yield Vs. Equivalent Sun Hours (ESH)

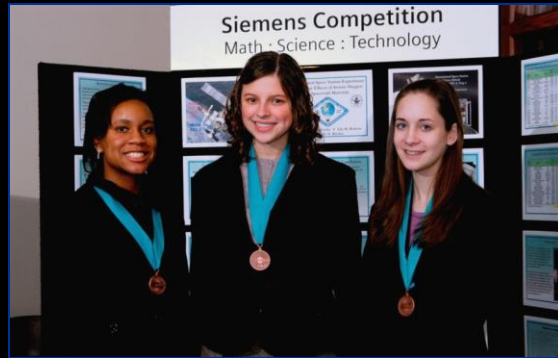
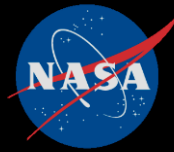
Equivalent Sun Hours (ESH)

Erosion Yield (cm^3/atom)





NASA Glenn Research Center and Hathaway Brown School (HB) Collaborative MISSE Experiments



*PEACE Team
examining Glenn's
MISSE 6 Stressed Polymers
Experiment post-flight*



Student Involvement:

- 3 to 6 students are on the PEACE team at a time
(28 students involved since 1998)
- Students work at Glenn 6 wks full time each summer, plus 1 day per week after school in the school year
- Students research has included:
 - MISSE pre-flight research
 - MISSE 2, 5-8 flight sample fab. & pre-flight characterization
 - MISSE 2, 5, 6 & 7 post-flight characterization

Benefits:

- Glenn gains technical collaboration
- Students gain technical knowledge & confidence
- Students graduate w/ publications & presentation experience
 - Students have given presentations and won poster competition awards at international space conferences
- Scholarships & fellowships (>\$80K from science fair awards)





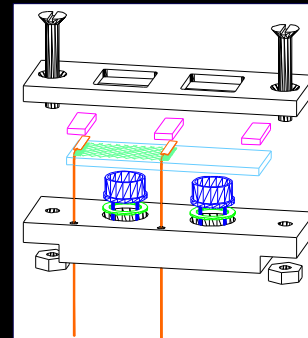
MISSE 6 Indium Tin Oxide (ITO) Degradation Experiment

Bruce A. Banks, SAIC at NASA Glenn Research Center



- MISSE 6 Indium Tin Oxide (ITO) Degradation Experiment:

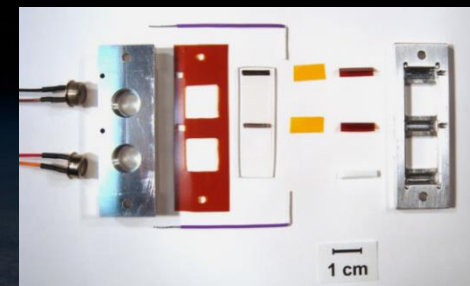
- *Experiment objective:* To investigate the effects of space solar exposure and combined effects with atomic oxygen on the optical and electrical properties of transparent conductive ITO coatings.
- Samples flown in ram and wake directions



Exploded view drawing

- Results:

- The ITO coating reduced the transmittance by ~4 to 6% in comparison to uncoated fused silica windows
- Surface resistance of ram & wake samples was comparable, hence there appears to be little effect of AO on conductivity of ITO



Individual components

- Benefits:

- Results validated AO durability of ITO conductive coatings for solar arrays for the Atmosphere-Space Transition Explorer program
- Data prevented Lockheed Martin Space Systems from making spacecraft design changes that “significantly impacted both cost and schedule for our current and future applications”



Post-flight photo of ram ITO Experiment



MISSE 6 Thermal Control Paints Experiment

Donald A. Jaworske, NASA Glenn Research Center



- MISSE 6 Thermal Control Paints Experiment:

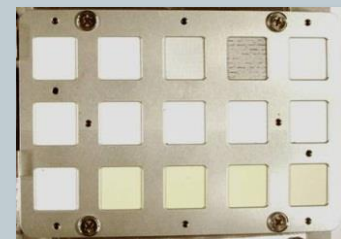
- Next generation white thermal control coatings were developed under NASA SBIR projects with Applied Material Systems Engineering, Inc., including binder, pigment, and plasma spraying developments
- Ground-based testing completed at the Space Combined Effects Primary Test and Research Facility (SCEPTRE)
- MISSE flight data validated on-orbit optical property durability

⇒ *PS-16 used on the Gravity Recovery And Interior Laboratory (GRAIL) carbon-carbon composite radiators*

- Advantages:

- Plasma spray (PS) capable
- Applied to carbon-carbon composites successfully
- Acceptable Beginning-of-Life and End-of-Life optical properties
- Durability to simulated space environment:
 - 1 keV, 10 keV, & 4.5 MeV electrons, and thermal cycling
- Heritage on MISSE 6 with 1.45 yrs of space exposure

Robust Engineered Thermal Control Materials



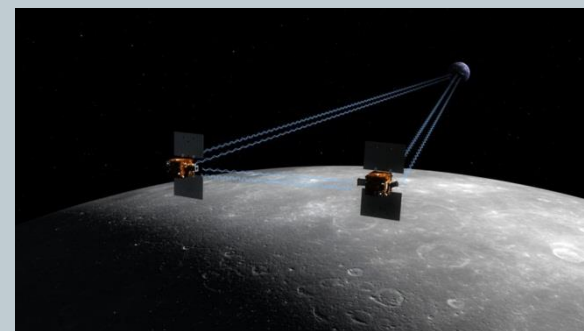
MISSE 6 Thermal Control Paints Experiment
(post-flight)



PS-16 thermal control coating on test radiator



GRAIL radiator with PS-16

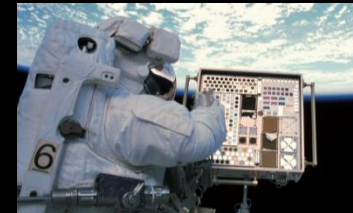


Artists rendition of GRAIL in lunar orbit



MISSE 6 Polymer Film Tensile Experiment (PFTE)

Sharon K. R. Miller, NASA Glenn Research Center



- MISSE 6 Polymer Film Tensile Experiment (PFTE):

- *Experiment objective:* To expose a variety of polymer films to the low Earth orbital environment under both relaxed and tension conditions

- AO Erosion Results:

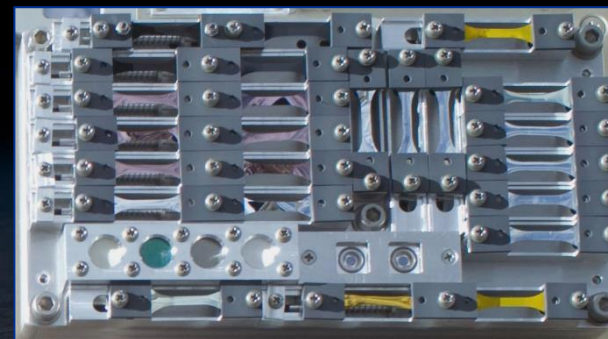
- Data showed that the erosion rate of some polymers increases if the material is under tensile loading which impacts missions flying in LEO with polymers under tensile loading, like solar array blankets

- Benefits:

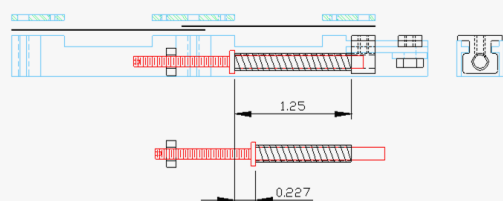
- *Data used to provide information on changes that could be expected for polymers under tension for James Webb Space Telescope enabling better material selection*



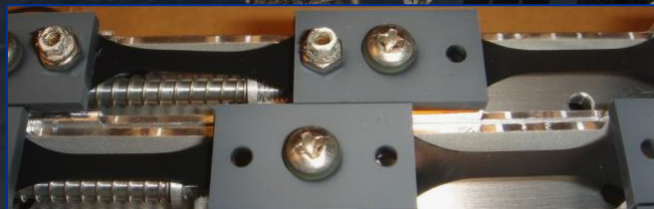
On-orbit photo of MISSE 6 PFTE ram tray



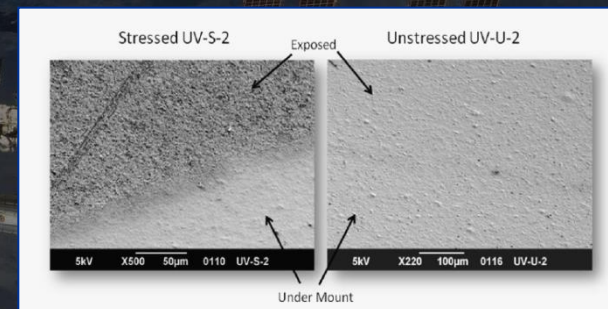
On-orbit photo of MISSE 6 PFTE wake tray



Side view drawing of a stressed sample holder



Stressed (left) and unstressed (right) samples



SEM images of stressed (left) & unstressed (right) Kapton XC



Examples of Experiments and Benefits from Other MISSE Investigators

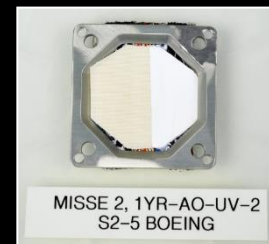




Examples of Benefits from MISSE ISS Sustaining Engineering

Miria Finckenor, NASA Marshall Space Flight Center

- Valuable data on numerous **ISS external materials** including:
 - Trailing Umbilical System (TUS) cable, multi-layer insulation, fasteners, adhesive tapes, passive thermal control, part labeling, windows, seals, conductive coatings, measures for astronaut safety*
- Z93P** white ceramic thermal control coating maintained optical properties over nearly four years in space
 - Confirmed that contamination control measures put in place after Shuttle-Mir program worked to maintain ISS radiators*
- MISSE S13GP/LO** data helped determine if two GPS antennae from ISS needed coating refurbishment. The covers of these units had yellowed some, but MISSE samples exposed to LEO longer had acceptable optical properties.
 - Decision was made to re-fly as is*
- Impact of **perfluorooctanoic acid (PFOA)** removal from Teflon processing (>900 materials approved for use in space applications contain Teflon)
 - No performance differences of PFOA-free beta cloth vs. old beta cloth, used in multi-layer insulation blankets*
 - Flight data mitigates the need to retest all materials (e.g. thermal vacuum stability, environmental durability, toxicity, flammability, etc.) saving significant budget costs*



Post-flight photo of
MISSE 2 TUS sample



TUS Cable on ISS





Examples of Benefits from MISSE Multiple Program Support

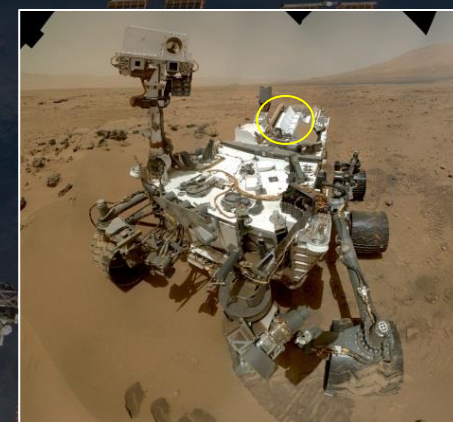
Miria Finckenor, NASA Marshall Space Flight Center



- Astronomical Roentgen Telescope - X-Ray Concentrator (ART-XC) – *optics, contamination effects*
- Lunar Atmosphere and Dust Environment Explorer (LADEE) – *Z93C55, other thermal control coatings*
- Lightning Imaging Sensor (LIS) spare, to fly on ISS in 2016 – *optics, contamination effects*
- Lunar Crater Observation and Sensing Satellite (LCROSS) – *Deft thermal control coating*
- Lunar Reconnaissance Orbiter (LRO) – *white thermal control coatings*
- Orion Multi-Purpose Crew Vehicle (MPCV) – *variety of materials*
- Commercial Crew program – *AZ-400 for radiators*
- James Webb Space Telescope – *coated Kapton E for sunshield*
- Defense Meteorological Satellite Program – *antennae coating*
- Dragon spacecraft – *Z93C55*
- Global Precipitation Measurement mission - *antennae coating*
- GPS-3 – *indium tin oxide and thermal control coatings*
- Hinode (Solar-B) – *CCAg failure analysis*
- Fermi Gamma-ray Space Telescope – *GLAST beta cloth and silverized Teflon*
- Mars Science Laboratory - Curiosity rover – *AZ-2100 thermal control coating*
- Mars Hand Lens Imager (MAHLI) – *fluorescence of thermal control coatings*
- SMDC-ONE - *Alodine, copper, solar cells, sulfuric acid anodized aluminum*
- SLATE-T4 - *Stretched Lens Array materials*
- BUMPER Meteoroid / Space Debris code – *meteoroid/debris survey*
- Data Matrix ID (NASA-STD-6002) – *all of the RSVI, Siemens, and Infosight samples*



AZ Tek AZ-2100 thermal control coating: data from this and other samples led to it being chosen for Curiosity's radiator

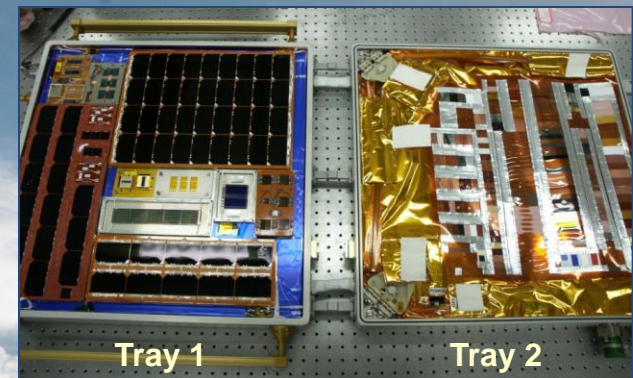
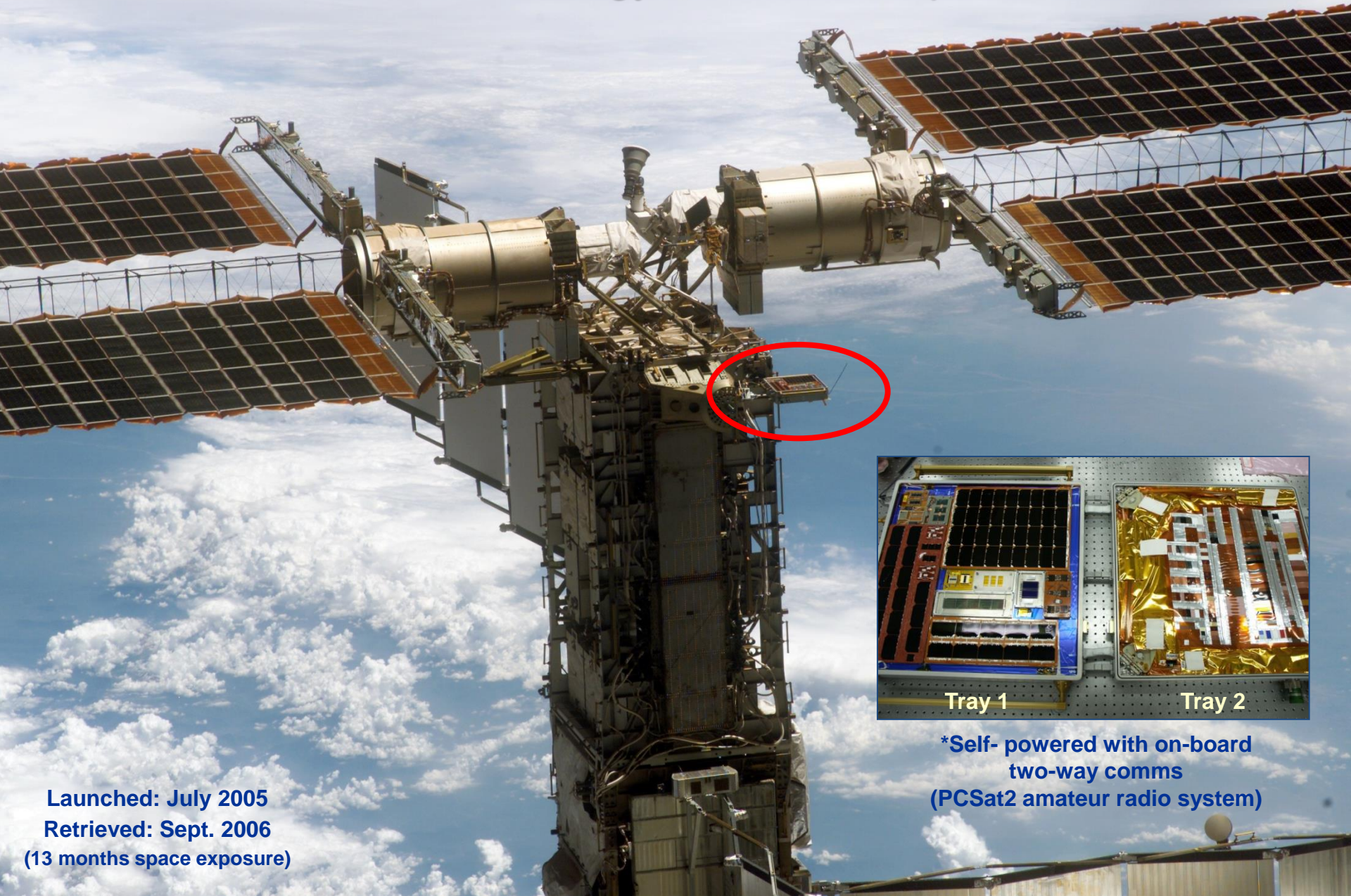


AZ Tek AZ-2100 coating on Curiosity radiator (self image from Mars)



MISSE 5

Forward Technology Solar Cell Experiment



***Self- powered with on-board
two-way comms
(PCSat2 amateur radio system)**

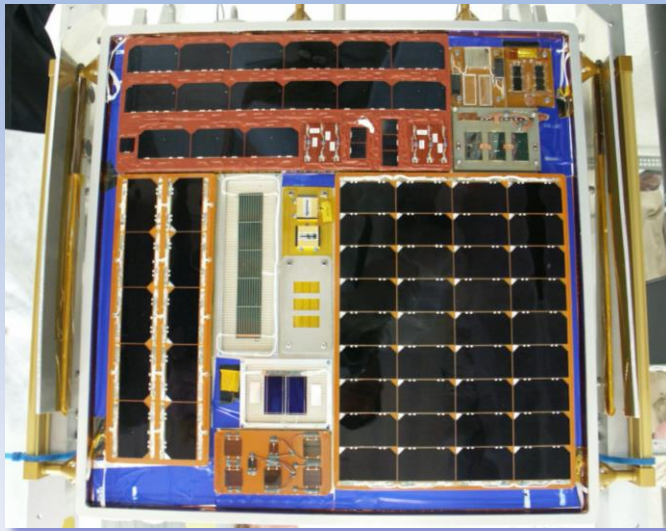
**Launched: July 2005
Retrieved: Sept. 2006
(13 months space exposure)**



FTSCE Overview & Benefits



Experiment Deck Solar Cell Samples



FTSCE Overview:

- MISSE on ISS provides unique, nearly ideal opportunity for rapid space access & sample return
- Experiment goal: rapidly put current and future generation space solar cells on orbit and provide validation data for these technologies
- Exercising solar cell technologies in a true space environment, and characterizing the devices post-flight, allow highest fidelity technology validation
 - The results give confidence in use of the tested solar cell technologies in space
 - Results allow calibration of solar cell samples in a true AM0 illumination environment

Benefits from MISSE 5 DoD flight data:

MISSE 5 provided rapid access to space to produce mission critical solar cell performance data, providing:

- Anomaly resolution data for on-orbit spacecraft
- Real time data - enabling DoD mission hardware to be designed and built
- On-orbit data for ground-test data validation



MISSE 7A & 7B

Active & Passive Experiments

Deployed: Nov. 2009

Retrieved: May 2011

(1.49 years space exposure)

In addition to traditional passive MISSE samples, MISSE 7 expanded the scope to include 20 experiments with real-time command and control, testing new radiation tolerant computer architectures and active monitoring of the space environment.

* ISS power and
communication links
(telemetry data to Earth)

MISSE 8

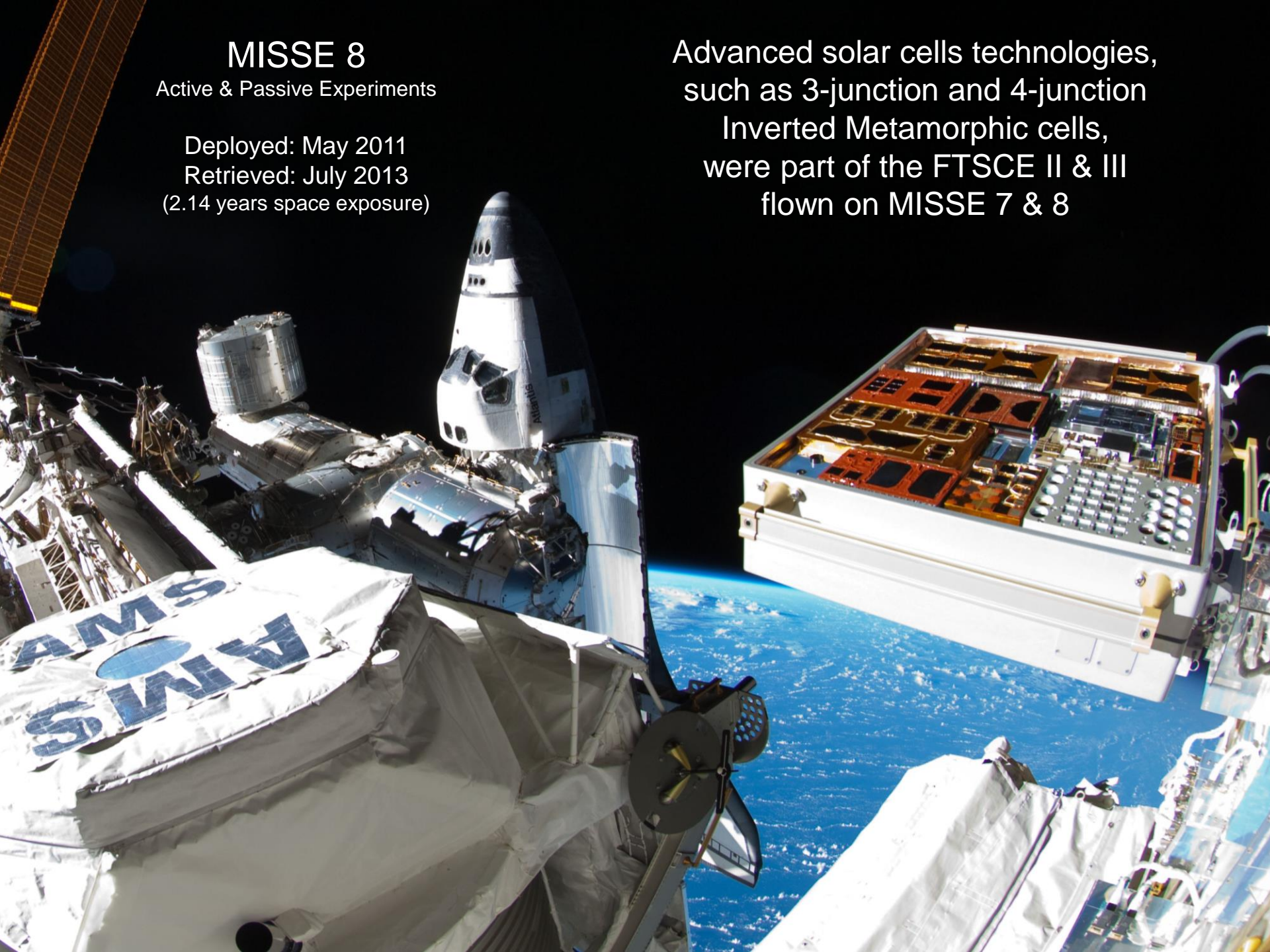
Active & Passive Experiments

Deployed: May 2011

Retrieved: July 2013

(2.14 years space exposure)

Advanced solar cells technologies,
such as 3-junction and 4-junction
Inverted Metamorphic cells,
were part of the FTSCE II & III
flown on MISSE 7 & 8





AFRL MISSE

“To date, AFRL has contributed well over \$15M to MISSE and has seen immeasurable benefits; from new higher power solar cell technology, electromagnetic shielding nano-materials, to fundamental science and the understanding of atomic oxygen erosion; MISSE has been a testing and proving ground for AFRL.”

AFRL Experiments on MISSE 7:

- AFRL had 10 experiments (6 active)
- Over 130 samples
- Real time data streamed from ISS to AFRL ground station

Micro tribometers (friction/wear)

Advanced Solar cell technology

Conductivity measurements

Thermal control coatings

Hypersonic materials

Deployable materials

Thermal protection

Fibers

Electronics

Metamaterials

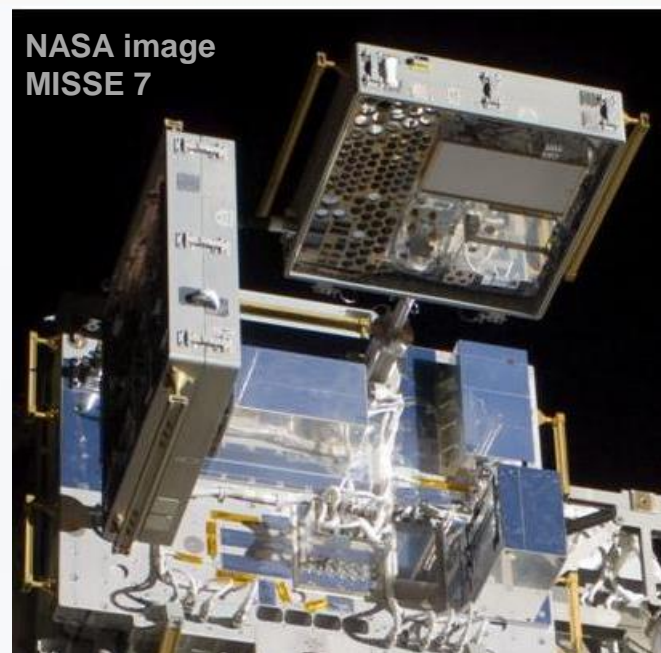
Resin systems

Optical coating

Nanocomposites

Optical reflectors

NASA image
MISSE 7



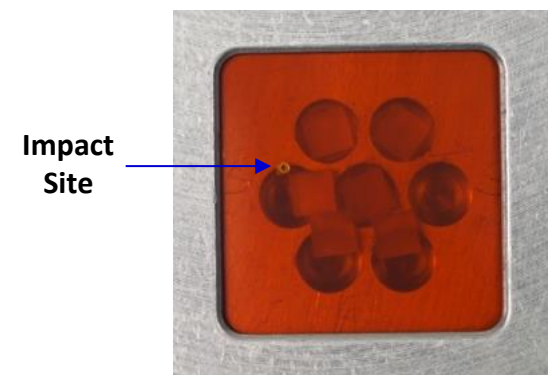
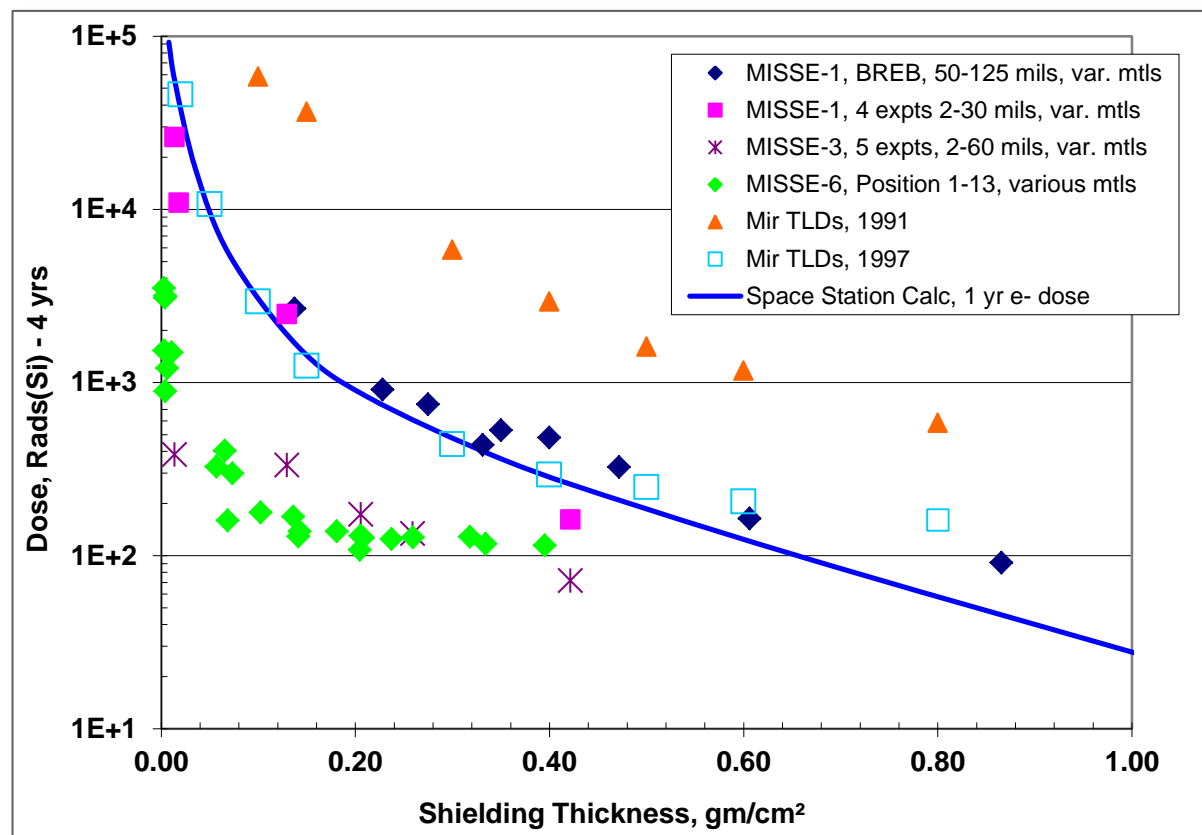
Benefits:

- Material Validation
- Processing Recertification
- Model Verification
- Basic Science

Particulate Radiation Exposure

Gary Pippin, Jerry Wert & Eugene Normand, Boeing

- Boeing and Space Systems/Loral have flown multiple passive radiation detectors
 - Thermoluminescent detectors (TLDs) were flown on MISSEs 1-4, 6*, 7 & 8
 - Individual detectors were shielded by different materials and/or thicknesses
- Boeing measured the output of the TLDs



- Results are in agreement with dose levels detected on Russian expt (Bion 11)
- Calculations of annual dose for ISS in agreement with 4 year measured dose

⇒ *Demonstrates extent of effective shielding by ISS*



Optical Reflector Materials Experiment (ORMatE) Series On Board MISSE

3rd Annual ISS Research and Development Conference
Chicago, IL
June 19, 2014

Iwona A. Palusinski, Ph.D., The Aerospace Corporation
Justin R. Lorentzen, Naval Research Laboratory

ORMatE Series Purpose



- **Two-fold function for ORMatE series**
 - *Provide a space platform to expose new materials to the various space environments*
 - *Generate on-orbit flight performance data to support space qualification of these materials.*
- **Evaluate performance of novel optical coatings and mirror substrate materials**
 - *Separate variables by studying substrates and coating separately as well as together*
- **Provide on-orbit truth data to increase confidence in new materials**
 - *Populate developing databases to track new materials for space applications*
 - *Compare ORMatE data among all MISSE flights, and Long Duration Experiment Facility (LDEF) data*
- **Combine on-orbit data with ground testing to improve fidelity of material modeling**
 - *Enable lifetime performance extrapolation for systems using new materials*



ORMatE Series Supports Space Qualification

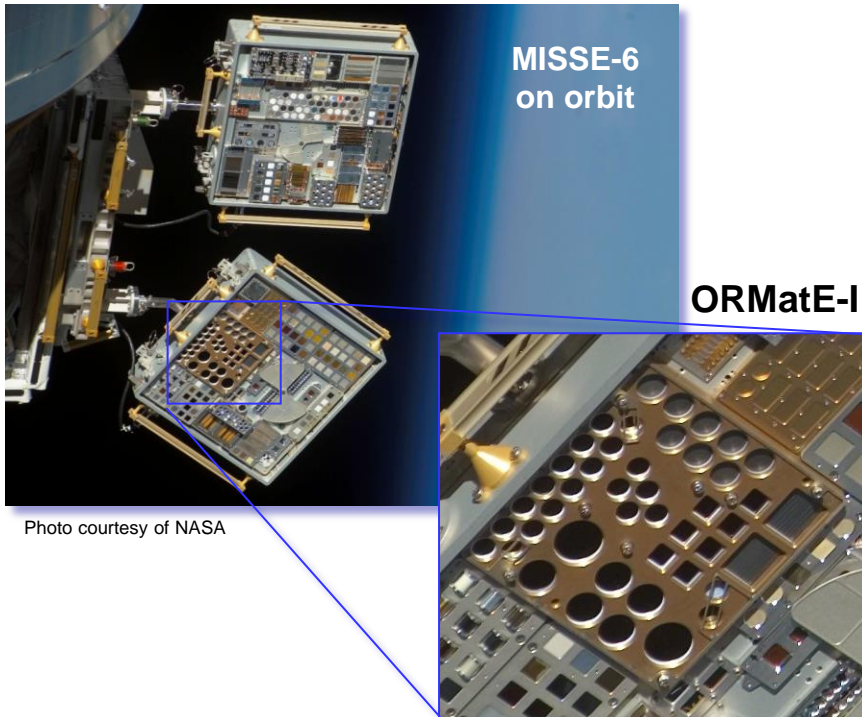


Photo courtesy of NASA



Photo courtesy of NASA

MISSE Flights

- MISSE 6 - ram & wake (ORMatE-I)
- MISSE 7 - ram & wake (ORMatE-II)
- MISSE 8 - ram & wake (ORMatE-III) plus samples in zenith direction

Benefits

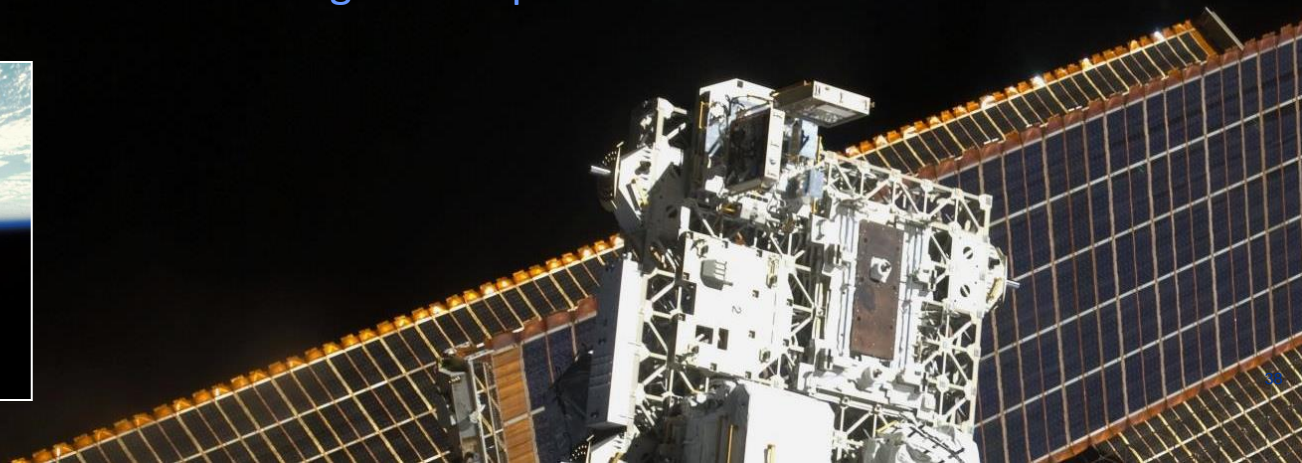
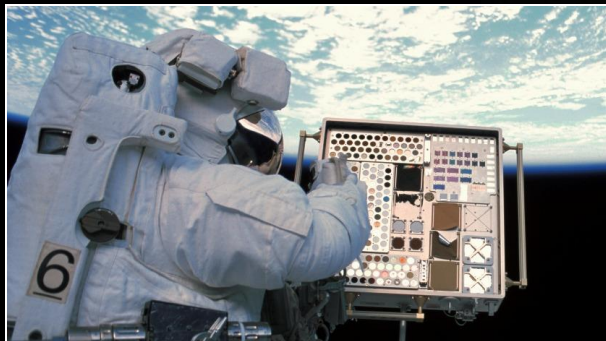
- Reduce risk of incorporating new technology into future satellite systems
- Inexpensive way to evaluate vendor space readiness on small scale
 - *Apply scientific rigor at early stages of development*
- Educate vendors on surviving space environments with emphasis on material processes (quality, packaging, contamination, etc.)
- Use flight data as initial step to space qualification
- Compare on-orbit results to ground-based testing (improve fidelity of material modeling)





MISSE Overview & Benefits

- MISSE is the longest running multi-organization technology development and materials testing project on the ISS
- 1000's samples & devices exposed to the space environment since 2001
- Provides long-duration space environmental performance & durability data:
 - Material selection, validation, processing recertification & space qualification
 - ⇒ *Benefits from MISSE have impacted a wide variety of aerospace programs*
 - Improved predictions of materials, components and devices lifetimes in space
 - Model verification and development (i.e. Glenn AO Erosion Predictive Tool)
 - Determination of correlation factors between space-exposure and ground-facilities:
 - ⇒ *Enabling more accurate in-space performance predictions based on ground testing*
 - NASA Technical Standards Handbook "*Spacecraft Polymers Atomic Oxygen Durability Handbook*"
- However, MISSE operations need to change in the post-Shuttle era





MISSE-X Overview

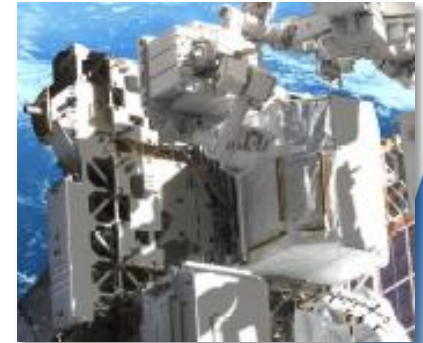


Because MISSE operations need to change significantly in the post-Shuttle era, NASA invested in the next generation MISSE concept called MISSE-X:

- Space Technology Mission Directorate (STMD) Technology Demonstration Missions (TDM) Project, funded from 2011 to 2013

Future MISSE Facility:

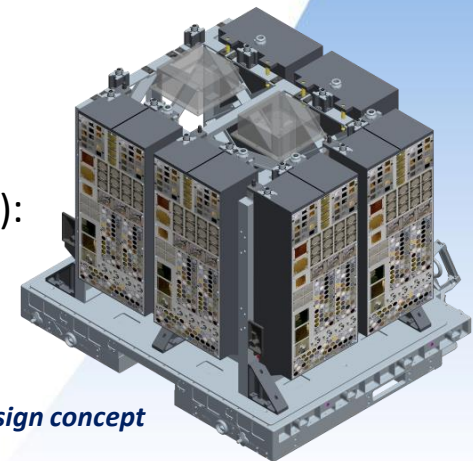
- Needs to host small, modular experiments for testing and demonstrating performance, reliability and durability
- Needs to accommodate aerospace technology customers from industry, government and academia
- Needs to be a *robotically serviceable ISS external facility*



Robotically serviceable

Key Products from the MISSE-X Project:

- Surveyed the space community for future external flight experiment demands & needs
- Developed Facility Requirements (FRs), supported by survey results
- Developed a design concept (passed the System Requirements Review):
 - *Robotic plug & play capability*
 - *Ram, wake, zenith & nadir exposures*
 - *Supports active & passive experiments*
 - *Environmental exposure monitoring*



Design concept



MISSE-X User Base & Continuing Need



	2013 Capabilities RFI Survey		2012 RFI Letters of Interest		2010 Questionnaire*	
Total # Responses	47		25		24	
# of Active	29	62%	16	64%	18	75%
# of Passive	18	38%	5	20%	4	17%
# of Unknown	0	0%	4	16%	2	8%
Affiliations						
NASA	24	51%	12	48%	20	83%
DoD	3	6%	1	4%	3	13%
Academia	9	19%	4	16%	1**	4%
Industry	11	23%	8	32%	N/A	N/A

* The 2010 MISSE-X Questionnaire included NASA & DoD only

** United States Naval Academy

**Prior MISSE utilization (85+ organizations)
& MISSE-X survey responses:
Strong customer base & continuing need
for a future MISSE platform on ISS**

2013 Capabilities RFI Survey:

- **Experiment Categories:**
 - 45% Materials
 - 36% Materials & Devices
 - 13% Sub-systems
- **Requested exposure duration:**
 - 56% ≤1 years
 - 38% 2 years
 - 6% 3 years
- **57% request experiment return**
- **Exposure Orientation**
 - 53% ram
 - 28% zenith
 - 13% wake
 - 6% nadir
- **60% request images after deploy/prior to retrieval**
- **Environmental Sensors priority:**
 - UV, TID, AO & Temperature
- **28V most requested supplied power**
- **Top 5 Capabilities:**
 1. Exposure orientation
 2. Facility provided power
 3. Exposure area
 4. Facility provided communication/telemetry
 5. Experiment return



Path Forward



- **ISS NRA NNJ13ZBG001N "Soliciting Proposals for Exploration Technology Demonstration and National Lab Utilization Enhancements"**
 - *"NASA is soliciting proposals (follow-on activity associated with RFI-LARC-MIS-3) that suggest either a full commercial business model, or a partial commercial business model for developing and maintaining an ISS external facility for testing and demonstrating performance, reliability, and durability of spacecraft materials, devices and subsystems."*
 - **Full commercial model:** proposer would fund the development and ongoing operations of the facility privately, and develop a menu of fee-based services for users of the platform based on market forces.
 - **Partial commercial model:** proposer could suggest some level of government funding to augment private financing, with user fees adjusted accordingly.
- **An ISS external facility will enhance ISS utilization and provide long duration space environmental performance and durability data, and will:**
 - Become a new ISS facility for the life of ISS
 - Accelerate technology insertion through TRL maturation of new space materials and devices
 - Continue the long rich heritage of the MISSE missions in the post-Shuttle era

NRA Website: <http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7b21E0270C-BC1F-EFC4-3D87-30713B5FF373%7d&path=open>



“MISSE Collaboration for Materials Testing on ISS”

- Kim K. de Groh, NASA Glenn Research Center (GRC)
- Miria M. Finckenor, NASA Marshall Space Flight Center (MSFC)
- Dr. Donald A. Jaworske, NASA GRC
- Dr. William H. Kinard (retired), NASA Langley Research Center (LaRC)
- Dr. Robert Mantz, Air Force Office of Scientific Research (AFOSR)
- Dr. Gary Pippin (retired), Boeing
- Michael Stropki, Air Force Research Laboratory (AFRL)
- Dr. Sheila A. Thibeault, NASA LaRC

Additional Major Collaborators

- Bruce A. Banks, SAIC at NASA GRC
- Richard A. Caldwell, Department of Defense Space Test Program
- Johnnie Engelhardt, MEI Technologies, Inc.
- Sandra M. Gibbs, NASA LaRC
- Karen B. Gibson, NASA LaRC
- Dr. John L. Golden (retired), Boeing
- Irby Jones (retired), NASA LaRC
- Shane B. Juhl, AFRL/Materials Laboratory
- Sharon K. R. Miller, NASA GRC
- Dr. Timothy K. Minton, Montana State University
- Lewis “Chip” Moore, NASA MSFC
- Dr. Iwona A. Palusinski, The Aerospace Corporation
- Andrew M. Robb, Boeing
- Edward A. Sechkar, ZIN Technologies, Inc.
- Dr. Alan F. Stewart, Boeing
- Dr. Paul C. Trulove, AFOSR
- Manuel S. Urcia, Boeing
- Dr. Suzanne L. B. Woll, Boeing

Participants listed alphabetically





“MISSE Collaboration for Materials Testing on ISS”

*This award is graciously accepted on behalf of all participants of the MISSE project:
Visionaries, sponsors, managers, designers, integrators, mission and experiment investigators, etc.*

*There have been **100's of participants** over the past 15 years.*

Each participant has made a valuable contribution, and all share in this honor.

Participating Organizations (85+)

- Acuity CiMatrix
- Air Force Office of Scientific Research (AFOSR)
- Air Force Research Laboratory (AFRL) - Edwards Air Force Base
- AFRL - Kirtland Air Force Base
- AFRL/Materials Laboratory (AFRL/ML)
- Alion
- Alphaport
- Applied Material Systems Engineering, Inc. (AMSENG)
- Aerospace Fabrication & Materials
- ASRC Aerospace Corporation
- Assurance Technology
- Astral Tech
- ATC Materials
- ATEC
- ATK
- AZ Technology
- Ball Aerospace
- Boeing
- Cleveland State University
- College of William and Mary
- Composite Optics
- Composites Technology Development, Inc.
- Cornell University
- Cornerstone Research Group
- Department of Defense (DoD) Space Test Program
- DR Technology
- Dutch Space
- Emcore Photovoltaics
- ENTECH, Inc.
- EOSpace
- Hathaway Brown School
- ILC Dover
- Integrity Testing Laboratory
- Japanese Aerospace Exploration Agency (JAXA)
- Jet Propulsion Laboratory
- Johns Hopkins University/Applied Physics Laboratory
- Kyushu Institute of Technology
- L'Garde
- Lockheed Martin Space Systems Company
- Manchester College
- MEI
- MicroLink Corporation
- MIT Lincoln Laboratory
- Montana Space Grant Consortium
- Montana State University
- Muniz Engineering
- MURI Team (Univ. of Pittsburg, Univ. of Notre Dame)
- NASA Ames Research Center
- NASA Glenn Research Center
- NASA Goddard Space Flight Center
- NASA Johnson Space Center
- NASA Langley Research Center
- NASA Marshall Space Flight Center
- NeXolve Corporation
- Northrup/Grumman
- Naval Research Laboratory (NRL)
- Physical Sciences Inc.
- Plasma Processes Inc.
- Rochester Institute of Technology
- Rockwell
- RSVI Symbology Research Center
- SAIC at NASA Glenn Research Center
- Sandia National Laboratories
- SatAC
- Sensortex, Inc.
- Space Systems/Loral
- Teledyne
- The Aerospace Corporation
- Triton Systems
- Tufts University
- UES, Inc.
- Uni-Solar
- United States Air Force Academy
- United States Naval Academy
- United Technologies Research Center
- University of Arizona
- University of Connecticut
- University of Florida
- University of Illinois
- University of North Dakota
- University of Oxford
- Utah State University
- Wayne State University
- Xilinx
- Xinetics
- ZIN Technologies, Inc.

