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

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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
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)

- AO is the predominant species in LEO (≈200-650 km)
- It is formed by photodissociation of molecular oxygen (O₂) 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...

⇒ AO is a serious threat to spacecraft survivability
Space Environment Induced Degradation

Long Duration Exposure Facility (LDEF)
5.8 yrs in space

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

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

Hubble Space Telescope (HST)

Debris generation

Impact site

Pre-flight

Structural degradation

Post-flight

AO erosion of Kapton blanket

International Space Station (ISS) 2001

Radiation induced darkening

Pre-flight

Post-flight

AO erosion of Kapton blanket

Debris generation

Impact site
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.

<table>
<thead>
<tr>
<th>MISSE PEC</th>
<th>Mission PI</th>
<th>Managers*</th>
<th>Sponsors</th>
<th>Major Participants</th>
<th>Experiment Type</th>
</tr>
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<tbody>
<tr>
<td>5</td>
<td>Rob Walters (NRL)</td>
<td>NRL</td>
<td>NRL</td>
<td>NRL, NASA GRC, US Naval Academy, AFRL/ML, NASA LaRC, Boeing Phantom Works, Spectrolab Incorporated, Entech, Emcore Corporation, NASA MSFC</td>
<td>Active solar cell and passive material experiments; Self-powered with on-board, two-way comms (PCSat2 Amateur Radio system)</td>
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<tr>
<td>8</td>
<td>Phil Jenkins (NRL)</td>
<td>NRL</td>
<td>NASA &amp; NRL</td>
<td>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</td>
<td>Active and passive material &amp; device experiments; ISS power and communication links (telemetry data to Earth)</td>
</tr>
</tbody>
</table>

*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*
PEC 2 Tray 1 (Ram)
PEC 2 Tray 2 (Wake)

Patrick Forrester
& PEC 2
August 16, 2001

MISSE
Experiment Integration,
Shuttle launch & EVA
Attachment
# MISSE 1-8 Mission Summary

<table>
<thead>
<tr>
<th>MISSE PEC</th>
<th>Launch Mission</th>
<th>Date Placed Outside ISS</th>
<th>Location on ISS</th>
<th>Tray Orientation</th>
<th>Retrieval Mission</th>
<th>Date Retrieved from Outside of ISS</th>
<th>LEO Exposure Duration (years)</th>
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</thead>
<tbody>
<tr>
<td>1 &amp; 2</td>
<td>STS-105</td>
<td>8/16/2001</td>
<td>PEC 1: High Pressure Gas Tank (HPGT) PEC 2: Quest Airlock</td>
<td>Ram &amp; Wake</td>
<td>STS-114</td>
<td>7/30/2005</td>
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<tr>
<td>6A &amp; 6B</td>
<td>STS-123</td>
<td>3/22/2008</td>
<td>Columbus Laboratory</td>
<td>Ram &amp; Wake</td>
<td>STS-128</td>
<td>9/1/2009</td>
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</tr>
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</table>

* 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

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

* Does not include the MISSE FTSCE experiments

NASA Glenn has flown 41 experiments with 630 samples
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

Complete erosion
Partial erosion
No erosion

Flight
11 layers (1 mil)
Control
1 mil

Out of tray

1 cm
### MISSE 2 PEACE Polymers Erosion Yield Data

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Abbrev.</th>
<th>$E_y$ (cm$^3$/atom)</th>
<th>$E_y$ Uncertainty (%)</th>
<th>Polymer Abbrev.</th>
<th>$E_y$ (cm$^3$/atom)</th>
<th>$E_y$ Uncertainty (%)</th>
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<tr>
<td>ABS</td>
<td></td>
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<td>2.7</td>
<td>PEI</td>
<td>&gt; 3.31E-24*</td>
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<td>CA</td>
<td></td>
<td>5.05E-24</td>
<td>2.7</td>
<td>PA 6</td>
<td>3.51E-24</td>
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<tr>
<td>PPD-T (Kevlar)</td>
<td></td>
<td>6.28E-25</td>
<td>2.6</td>
<td>PA 66</td>
<td>1.80E-24</td>
<td>12.6</td>
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<td>PE</td>
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<td>PI (CP1)</td>
<td>1.91E-24</td>
<td>2.8</td>
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<tr>
<td>PVF (Tedlar)</td>
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<td>3.19E-24</td>
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<td>PI (Kapton H)</td>
<td>3.00E-24</td>
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<tr>
<td>PVF (White Tedlar)</td>
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<td>4.1</td>
<td>PI (Kapton HN)</td>
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<td>POM (Delrin)</td>
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<td>9.14E-24</td>
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<td>PI (Upilex-S)</td>
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<td>PAN</td>
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<td>PI (PMR-15)</td>
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<td>ADC (CR-39)</td>
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<td>PBI</td>
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<td>PC</td>
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<td>PBO (Zylon)</td>
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<td>2.6</td>
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<tr>
<td>PG</td>
<td></td>
<td>4.15E-25</td>
<td>10.7</td>
<td>PVDF (Kynar)</td>
<td>1.29E-24</td>
<td>2.7</td>
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</table>

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

**Average error: 3.30%**
**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.

**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).

**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.
Upilex-S and CP1 (Clear Polyimide)
Erosion Yield Vs. AO Fluence

\[ y = -0.45\ln(x) + 1.94 \quad R^2 = 0.99 \]

\[ y = -0.21\ln(x) + 2.37 \quad R^2 = 0.98 \]

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)

**MISSE 2**
- #1: 6,100 ESH
  - Ey = 2.11E-25

**MISSE 6**
- 2,600 ESH
  - Ey = 1.69E-25
- #1: 6,100 ESH
  - Ey = 2.11E-25

**MISSE 4**
- 1,400 ESH
  - Ey = 1.28E-25

**HST SM2**
- 33,638 ESH
  - Ey = 3.10E-24

**LDEF**
- 11,155 ESH
  - Ey = 3.37E-25

**LDEF Ag-FEP**
- 6,300 ESH
  - Ey = 2.00E-25

**HST Servicing Mission 2 (SM2)**

**LDEF: Long Duration Exposure Facility**

**HST: Hubble Space Telescope**

Erosion Yield (cm$^3$/atom) vs. Equivalent Sun Hours (ESH)
NASA Glenn Research Center and Hathaway Brown School (HB) Collaborative MISSE Experiments

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

- 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

- 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”
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
MISSE 6 Polymer Film Tensile Experiment (PFTE)

Sharon K. R. Miller, NASA Glenn Research Center

- **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*

Side view drawing of a stressed sample holder

Stressed (left) and unstressed (right) samples

On-orbit photo of MISSE 6 PFTE wake tray

On-orbit photo of MISSE 6 PFTE ram tray

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

*Missee 5
Forward Technology Solar Cell Experiment

Tray 1
Tray 2

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

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
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.
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
“To date, AFRL has contributed well over $15M to MISSE and has seen immeasurable benefits; from new higher power solar cell technology, electromagnetic shielding nanomaterials, 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**

**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

*MISSE 6 data from LaRC
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

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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

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

• However, MISSE operations need to change in the post-Shuttle era
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*

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*
# MISSE-X User Base & Continuing Need

## 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

## Prior MISSE utilization (85+ organizations) & MISSE-X survey responses:

**Strong customer base & continuing need for a future MISSE platform on ISS**

<table>
<thead>
<tr>
<th>2013 Capabilities RFI Survey</th>
<th>2012 RFI Letters of Interest</th>
<th>2010 Questionnaire*</th>
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</thead>
<tbody>
<tr>
<td>Total # Responses</td>
<td>47</td>
<td>25</td>
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<tr>
<td># of Active</td>
<td>29</td>
<td>16</td>
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<tr>
<td></td>
<td>62%</td>
<td>64%</td>
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<tr>
<td># of Passive</td>
<td>18</td>
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<td>38%</td>
<td>20%</td>
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<tr>
<td># of Unknown</td>
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<td>16%</td>
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<td><strong>Affiliations</strong></td>
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<td>NASA</td>
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<td>Academia</td>
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<td>4</td>
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<tr>
<td>Industry</td>
<td>11</td>
<td>8</td>
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<tr>
<td></td>
<td>23%</td>
<td>32%</td>
</tr>
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</table>

* The 2010 MISSE-X Questionnaire included NASA & DoD only
** United States Naval Academy
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 Pittsburgh, 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
- Xenetics
- ZIN Technologies, Inc.
Back-Up Slides
## Evolution of MISSE Capabilities

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Passive Experiment Containers (PECs) (ram/wake)</td>
<td>1 PEC (zenith/nadir)</td>
<td>2 PECs (ram/wake)</td>
<td>2 PECs (ram/wake, zenith/nadir)</td>
<td>1 PEC (zenith/nadir) 1 ORMatE (ram/wake)</td>
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<td></td>
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<tr>
<td>Active / Passive Experiments</td>
<td>5 / 95 %</td>
<td>50 / 50 %</td>
<td>70 / 30 %</td>
<td>60 / 40 %</td>
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<tr>
<td>Installation onto ISS</td>
<td>EVA only</td>
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<tr>
<td>Power</td>
<td>Battery</td>
<td>ISS</td>
<td></td>
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<tr>
<td>Communications</td>
<td>&lt;5 data loggers (retrieval required)</td>
<td>Amateur radio (near real time)</td>
<td>40-50 data loggers (retrieval required)</td>
<td>1553 data bus (ISS DL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platform Command &amp; Control</td>
<td>None</td>
<td>Selected experiments received uplink commands</td>
<td></td>
<td></td>
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<tr>
<td>Environment Monitoring</td>
<td>Temperature, UV, contamination (on some tray surfaces)</td>
<td>Limited</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Photography</td>
<td>Limited, non-scheduled photographs taken by crew</td>
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<td></td>
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</tr>
<tr>
<td>Data Acquisition Unit (DAU)</td>
<td>None</td>
<td>Individual experiment PI developed interfaces</td>
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<tr>
<td>Experiment Retrieval Method</td>
<td>EVA - All experiments returned at end of life (PECs)</td>
<td></td>
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</tbody>
</table>
⇒ Flying the same polymer on various MISSE missions provides important information on erosion dependence on mission exposures.
MISSE 6B W6 Tray
Kapton H LEO Erosion Yield (Ey)

W6-10
Kapton H 0.5 mil (10 layers + 2-5 mil)
No spacers
Ey = 3.08 x 10^{-24} \text{cm}^3/\text{atom}

W6-9
Kapton H 0.5 mil (10 layers + 1-5 mil)
With 0.014" thick Al spacers
Ey = 3.25 x 10^{-24} \text{cm}^3/\text{atom}

*Increased Ey likely due to trapping of AO between layers

AO F = 1.90 \times 10^{21} \text{atoms/cm}^2
Solar = 2,600 ESH
MISSE 2 Atomic Oxygen (AO) Scattering Chamber Experiment

Bruce A. Banks, SAIC at NASA Glenn Research Center

- MISSE 2 Atomic Oxygen (AO) Scattering Chamber Experiment:
  - *Experiment objective:* To measure the atomic oxygen (AO) erosion characteristics of scattered AO including angular distribution and scattered AO erosion yield.

- Results:
  - The peak flux of scattered AO was determined to be 45° from normal incidence, not the model predicted cosine dependence.
  - The erosion yield \((E_y)\) of Kapton H for AO scattered off oxidized-Al is \(6.54 \times 10^{-25} \text{ cm}^3/\text{atom}\); 0.218 the \(E_y\) of direct AO impingement.

- Benefits:
  - *Results used to help understand degradation of the Hubble Space Telescope Cosmic Origins Spectrograph Experiment*
  - *Results provided understanding of AO damage in telescope cavities for classified programs*

---

**Angular distribution of scattered atomic oxygen erosion rate relative to incident (arrow) atomic oxygen erosion rate**

**SEM image of a salt-protected butte on the inside surface of the flight aperture lid**

**Post-flight photograph of component parts**

**Post-flight photograph of scattering chamber**

**Section view drawing**