Overview of International Space Station Orbital Environments Exposure Flight Experiments

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ABSTRACT

This paper presents an overview of International Space Station (ISS) on-orbit environments exposure flight experiments. International teams are flying, or preparing to fly, externally mounted materials exposure trays and sensor packages. The samples in these trays are exposed to a combination of induced molecular contamination, ultraviolet radiation, atomic oxygen, ionizing radiation, micrometeoroids and orbital debris. Exposed materials samples are analyzed upon return. Typical analyses performed on these samples include optical property measurements, X-ray photo spectroscopy (XPS) depth profiles, scanning electron microscope (SEM) surface morphology and materials properties measurements. The objective of these studies is to characterize the long-term effects of the natural and induced environments on spacecraft materials. Ongoing flight experiments include the U.S. Materials International Space Station Experiment (MISSE) program, the Japanese Micro-Particles Capturer and Space Environment Exposure Device (SM/MPAC&SEED) experiment, the Russian SKK and Kromka experiments from RSC-Energia, and the Komplast flight experiment. Flight experiments being prepared for flight, or in development stage, include the Japanese Space Environment Data Acquisition Attached Payload (SEDA-AP), the Russian BKDO monitoring package from RSC-Energia, and the European Materials Exposure and Degradation Experiment (MEDET). Results from these ISS flight experiments will be crucial to extending the performance and life of long-duration space systems such as Space Station, Space Transportation System, and other missions for Moon and Mars exploration.

Keywords: contamination, International Space Station, flight experiment, materials, orbital environments

1. INTRODUCTION

This paper presents an overview of several externally mounted materials exposure trays that international teams are flying or preparing to fly on the International Space Station (ISS). One of the purposes of these trays is to expose a variety of materials samples to the natural and induced on-orbit environments. The samples on these trays are exposed to the combined effects of induced molecular contamination, ultraviolet (UV) radiation, atomic oxygen (AO), ionizing radiation (IR), and micrometeoroids/orbital debris (MM/OD).

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Materials samples are analyzed upon return. Typical analyses performed on these samples include optical property measurements (absorptivity, emissivity, transmissivity and reflectivity), X-ray Photoelectron Spectroscopy (XPS) depth profiles, Scanning Electron Microscopy (SEM) surface morphology and measurements of materials properties. The objective of these studies is to characterize the long-term effects of the natural and induced environments on spacecraft materials.

2. U.S. MISSE FLIGHT EXPERIMENT (NASA/USAF/BOEING)

The purpose of the Materials International Space Station Experiment (MISSE)[1] is to characterize the performance of new materials when subjected to the effects of the space environment. MISSE is a joint NASA/USAF/Boeing flight experiment. The MISSE Project Office is located at the NASA Langley Research Center.

MISSE was previously flown on the Mir space station (STS-76/STS-86). MISSE units are deployed by the crew during extravehicular activity (EVA) and attached to exterior handrails with a clamp/pointer assembly. A MISSE unit consists of a Passive Experiment Container (PEC) in which two passive experiment trays are mounted. The MISSE deployed assembly and experiment specimens are passive and have no power, data, thermal or maintenance requirements.

MISSE 1 and MISSE 2 were mounted on the U.S. Airlock (locations shown in Figure 1) in August 2001 during the STS-105 mission. MISSE 1 and MISSE 2 each have over 400 candidate spacecraft materials, which have been exposed to the ISS on-orbit environment for approximately three years.

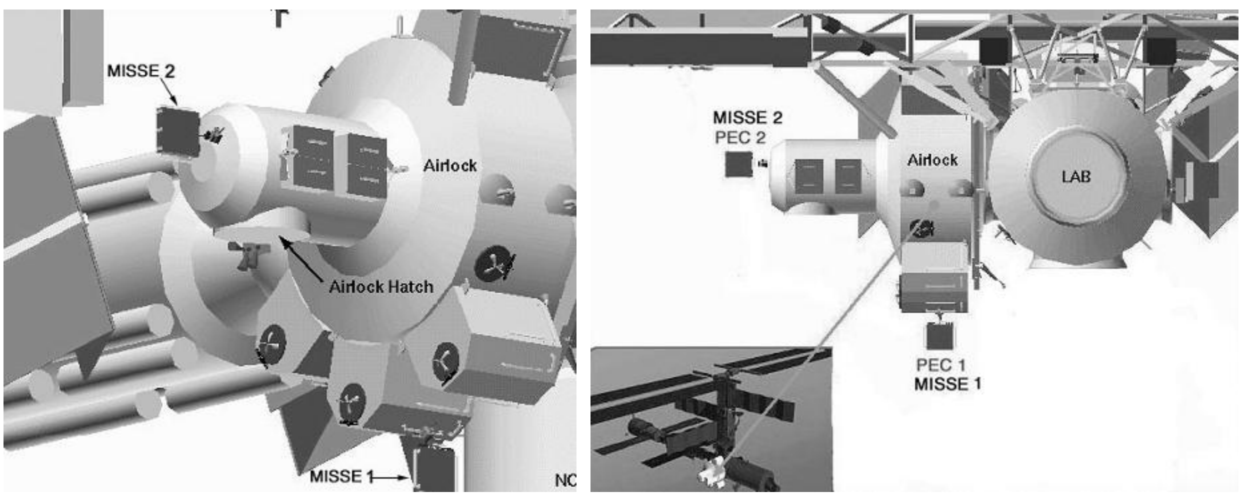

Figure 1: MISSE 1 and MISSE 2 locations on ISS

The orientation of the MISSE trays on ISS determines the level of exposure to ultraviolet radiation and atomic oxygen the various materials samples receive. The orientations of the MISSE trays on ISS targeted separating the sample exposures into (1) those seeing both atomic oxygen and UV or (2) those seeing only UV. However, since the current ISS flight attitude alternates between XVV (ISS X-axis towards Velocity Vector) and XPOP (ISS X-axis Perpendicular to Orbital Plane), both MISSE trays are receiving exposure to UV and AO.

Figure 2 shows MISSE 1 prior to flight on STS-105. Samples on MISSE 1 include polymers, thermal control coatings, mirror materials, optical coatings and materials, composites, solar cell materials, inflatable materials, metals, radiation shielding materials and glass fabrics.

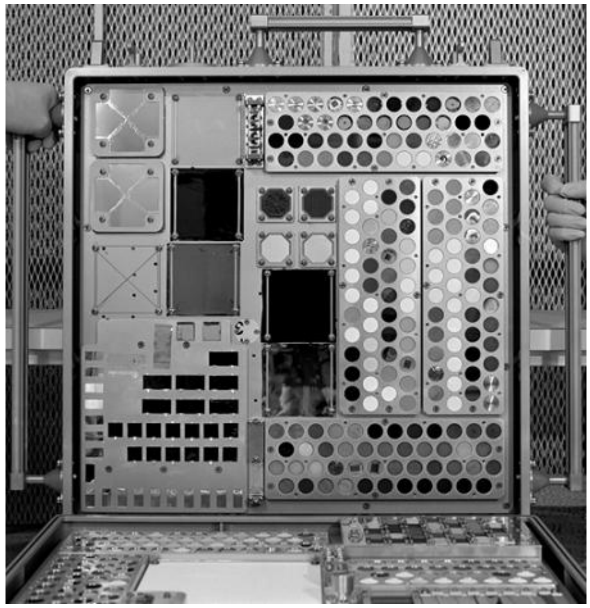

Figure 2: MISSE 1 prior to flight on STS-105

MISSE 1 and MISSE 2 are currently planned for retrieval on the STS-114 mission. MISSE 3 and MISSE 4 will replace MISSE 1 and MISSE 2 as they are retrieved. MISSE 5 will follow on a subsequent mission and it will be installed on the ISS truss (a different location from the previous four experiments).

MISSE has been monitored through on-orbit imaging during ISS and Orbiter missions. Figure 3 shows an EVA photo of the MISSE 2 deployment on STS-105. Figures 4 and 5 show Expedition 6 photos of MISSE 1.

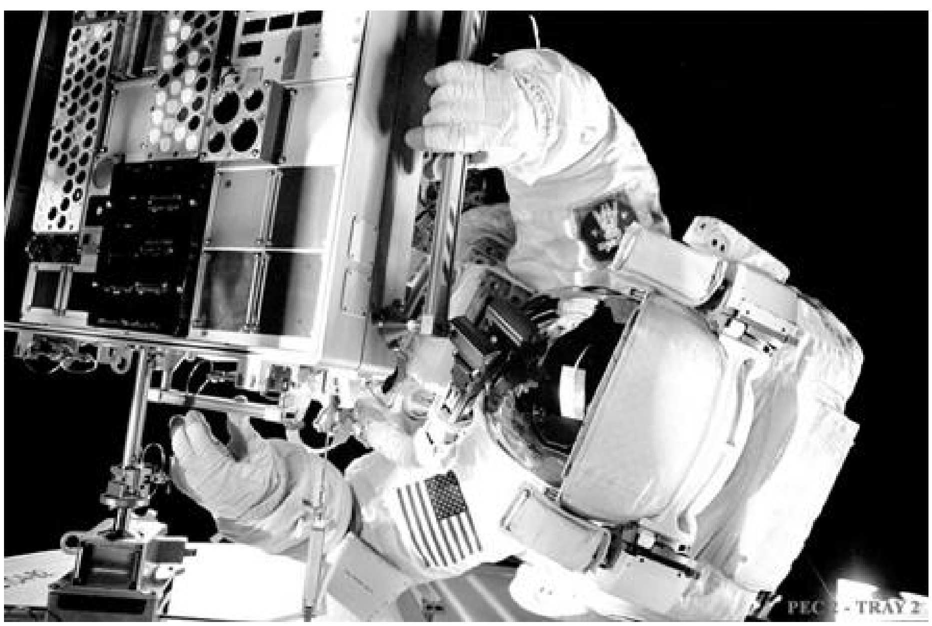

Figure 3: MISSE 2 deployment (PEC 2 Tray 2)

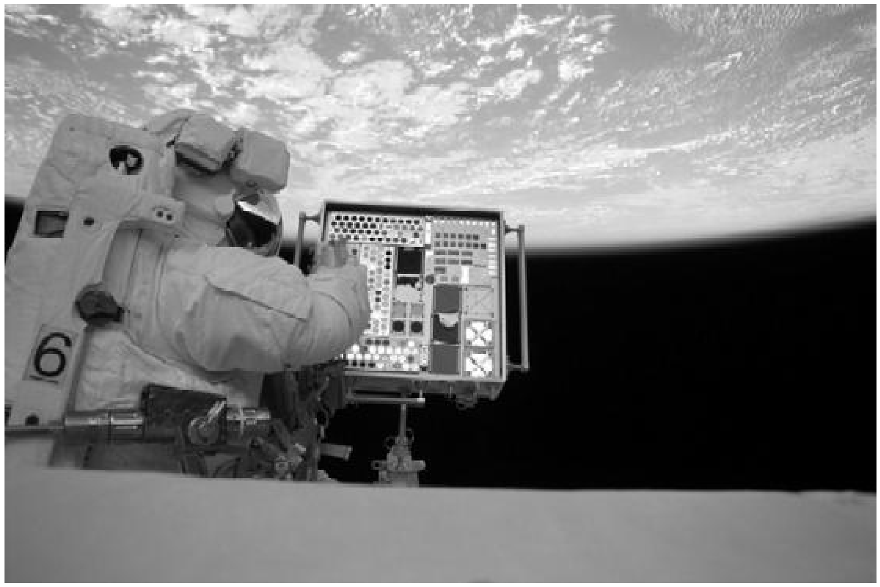

Figure 4: MISSE 1 (PEC1 Tray 1) Photo from ISS Expedition 6

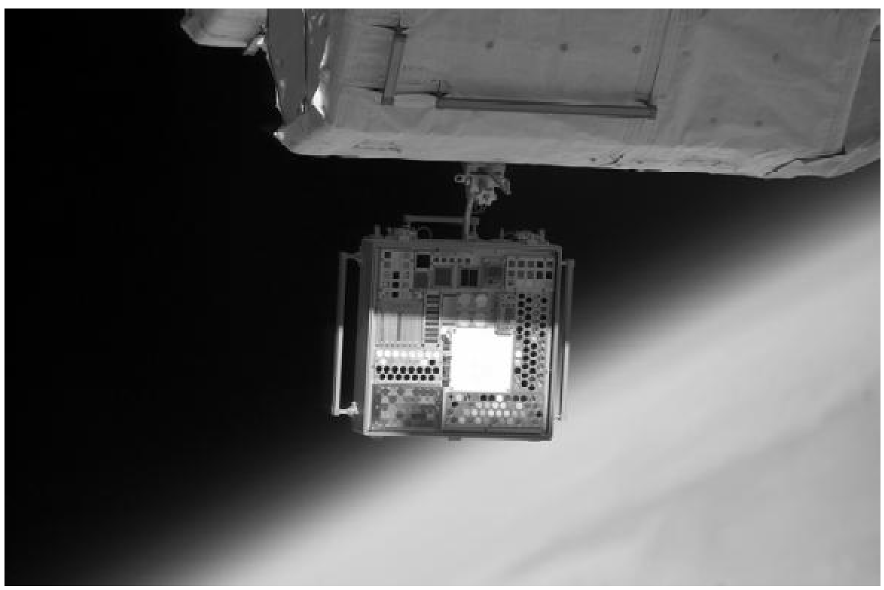

Figure 5: MISSE 1 (PEC1 Tray 2) photo from ISS Expedition 6

3. JAXA SM/MPAC&SEED FLIGHT EXPERIMENT

The Japanese Aerospace Exploration Agency (JAXA) is also currently flying experiments to characterize the effects of on-orbit environments exposure. The JAXA flight experiment consists of three sets of identical passive experiment trays: the Micro-Particles Capturer (MPAC) and the Space Environment Exposure Device (SEED).[2] Since MPAC&SEED trays were deployed on the Service Module (SM), the experiment was designated SM/MPAC&SEED. Figure 6 shows the SM/MPAC&SEED configuration and Figure 7 shows both sides of an MPAC&SEED tray.

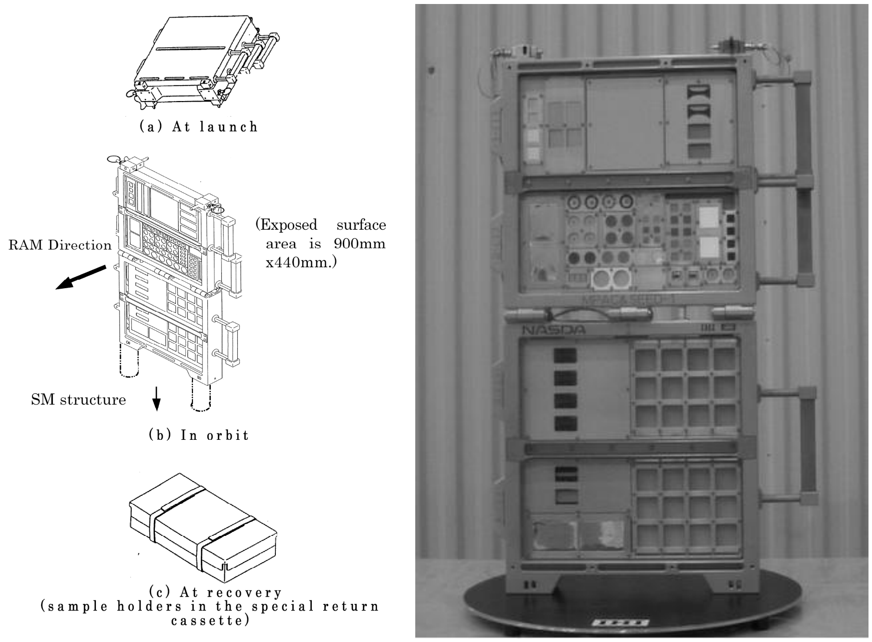

Figure 6: SM/MPAC&SEED configuration

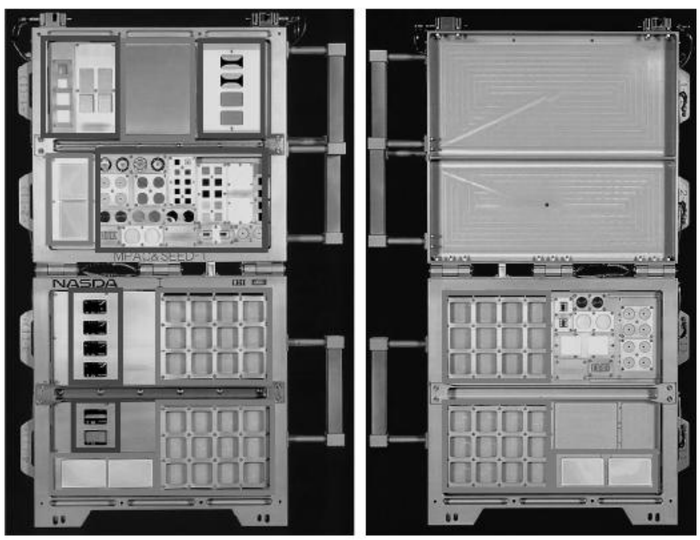

Figure 7: SM/MPAC&SEED ram (left) and wake (right) sides
(SEED outlined in red, MPAC outlined in green)

MPAC is a passive device designed to capture micro-particles, such as micrometeoroids or orbital debris, and consists of an aluminum plate, polyimide foam, and silica aerogel. MPAC's post-flight measurements include MM/OD particle composition, impact energy and velocity.[3, 4]

SEED is a passive device for material exposure experiments. Its purpose is to characterize the effects of exposure of JAXA materials to the ISS orbital environments: ionizing radiation, atomic oxygen, ultraviolet radiation and induced molecular contamination. SEED exposed specimens consist of polymers, paints, adhesives, bearings, and composites. Selected monitoring materials mounted on SEED determine the doses of AO, UV, and IR received during flight. SEED monitoring materials are polyimides (Kapton-H and Vespel) and carbon for AO and polyurethane for UV. Ionizing radiation is monitored with dosimeters, both passive (thermoluminescence, TLD, and polymer-alanine, PLA, dosimeters) as well as active (radiation sensing field effect transistor, RadFET).

SM/MPAC&SEED was launched on board a Progress M-45 vehicle in August 2001, and installed on the outside of the SM in October 2001 by astronauts performing EVA. Figures 8 and 9 show the experiment after deployment on the SM. MPAC&SEED 1 was retrieved in August 2002 after 315 days of on-orbit exposure. MPAC&SEED 2 was retrieved in February 2004 after 865 days of exposure. Both experiments are undergoing post-flight analysis at the JAXA Tsukuba Space Center. MPAC&SEED 3 is scheduled for retrieval in October 2005, after completion of four years of on-orbit exposure.

Figure 8: SM/MPAC&SEED deployed on the Service Module (STS108-304-008)

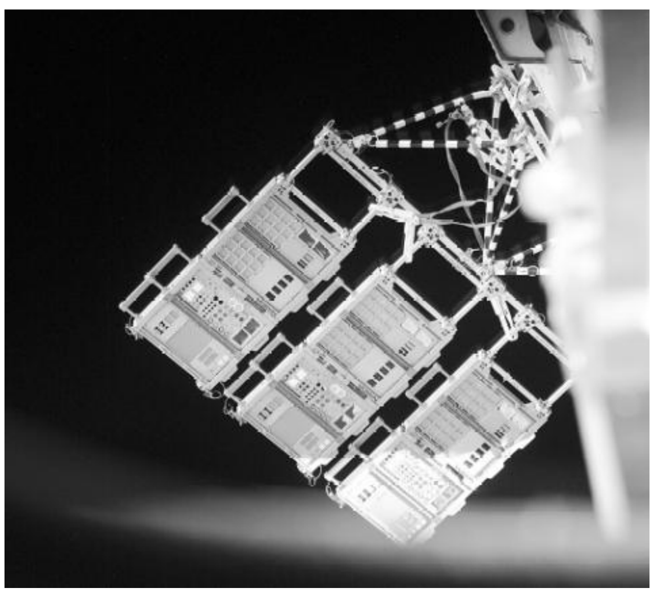

Figure 9: Close-up of SM/MPAC&SEED deployed on the Service Module
(Expedition 3 photo ISS003E6729)

For comparison, JAXA has simulated the estimated on-orbit exposure using ground-based reference experiments. Specimens were exposed to single AO, UV, and electron beams (EB, to simulate cosmic rays and irradiation) using JAXA's space-effects test facilities. These ground reference experiments are used to correlate the degradation mechanisms observed on MPAC&SEED materials when exposed to the Low Earth Orbit (LEO) environment.

MPAC&SEED will continue once the Japanese Experiment Module (JEM) is deployed on ISS. The next experiment will fly as part of the Space Environment Data Acquisition (SEDA) attached payload on the JEM Exposed Facility (JEM-EF).

4. JAXA SEDA-AP AND JEM/MPAC&SEED FLIGHT EXPERIMENT

JAXA is developing the Space Environment Data Acquisition Attached Payload (SEDA-AP) flight experiment, an attached payload for the JEM-EF. The SEDA launch is scheduled for 2006. SEDA-AP carries an MPAC&SEED package along with a neutron detector and other space environment sensors. Figure 10 shows the JEM/MPAC&SEED on the SEDA-AP.

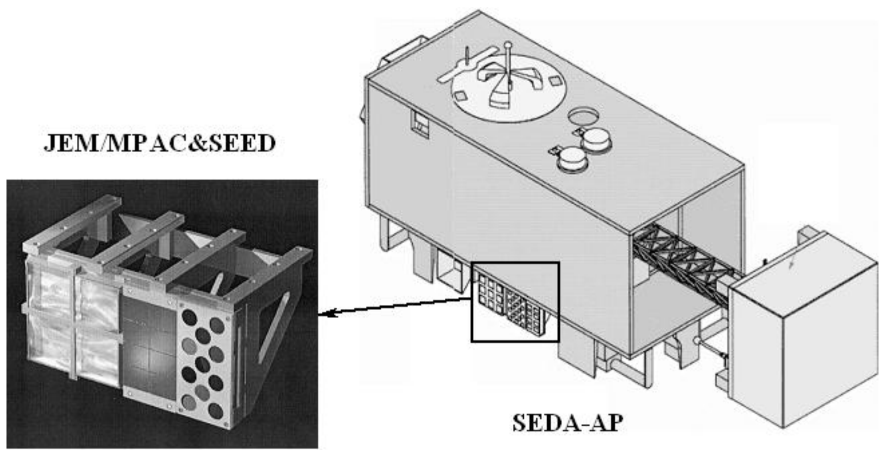

Figure 10: JEM/MPAC&SEED on SEDA-AP

SEDA-AP is composed of a Neutron Monitor (NEM), Heavy Ion Telescope/Plasma Monitor (HIT/PLAM), Standard Dose Monitor (SDOM), Atomic Oxygen Monitor (AOM), Electronic Device Evaluation Equipment (EDEE), and Micro-Particles Capturer & Space Environment Exposure Device (JEM/MPAC&SEED). The NEM sensor extends about 1 m from the structural body and measures neutrons.

SEDA-AP sensors will make measurements of the space environment (neutrons, high-energy light particles, heavy ions, cosmic dust, atomic oxygen, plasma, etc.) and environmental effects on materials and electronic devices to investigate the interaction with and from the space environment at JEM-EF. The data acquired by this mission will support space equipment design, space-related scientific research, International Space Station operation, and space weather forecasting.

5. RUSSIAN SKK FLIGHT EXPERIMENT (RSC-ENERGIA)

The SKK (Russian acronym for removable cassette containers) trays were developed to characterize the effects of exposure to the on-orbit environments (natural and induced) on materials samples. They are deployed in a "briefcase" type configuration and installed via EVA, typically clamped to a Russian handrail, and then opened to expose materials samples. SKK trays are passive experiments. Typical SKK materials samples are thermo-optic coatings (such as silicate-based thermal control paints), paints, anodic coatings, composite materials, coated and uncoated polymer films (polyimides, fluorocarbons, polyethylenes, etc.), and multi-layer insulation materials (such as Russian TCOH glass fabrics).

SKK trays were flown extensively on the Salyut and Mir space stations. Fifteen SKK trays were flown from 1970 through the year 2000, with exposure periods ranging from 1 to 4.5 years with over 600 materials samples tested. Measurements included optical properties (solar absorptance, emittance, transmissivity and reflectivity), mass, maximum and minimum temperatures, physical and mechanical properties, and morphology of the samples. Results were instrumental in materials selection for the ISS Russian Segment.

Three SKK trays were deployed on ISS in January 2002. Two trays, SKK Nº1-SM and SKK Nº2-SM, were installed on the Service Module. Figure 11 shows SKK Nº1-SM on the Nadir/Starboard side of the SM Propulsion Section and SKK Nº2-SM on the aft-end of the module. The third SKK tray, SKK Nº1-DC was installed on the Docking Compartment 1 (DC1) and is shown in Figure 12.

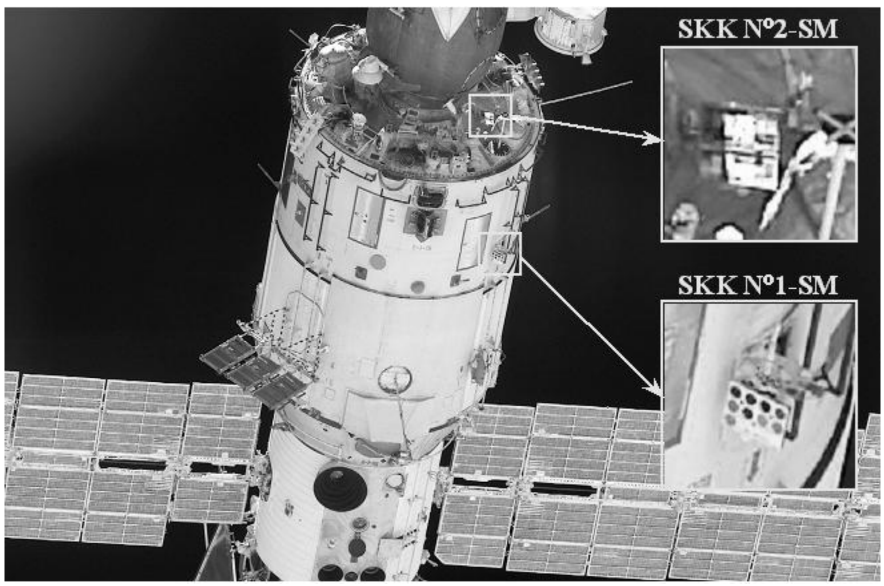

Figure 11: Two SKK trays (SKK Nº1-SM and SKK Nº2-SM) deployed on the ISS Service Module (S111E05668)

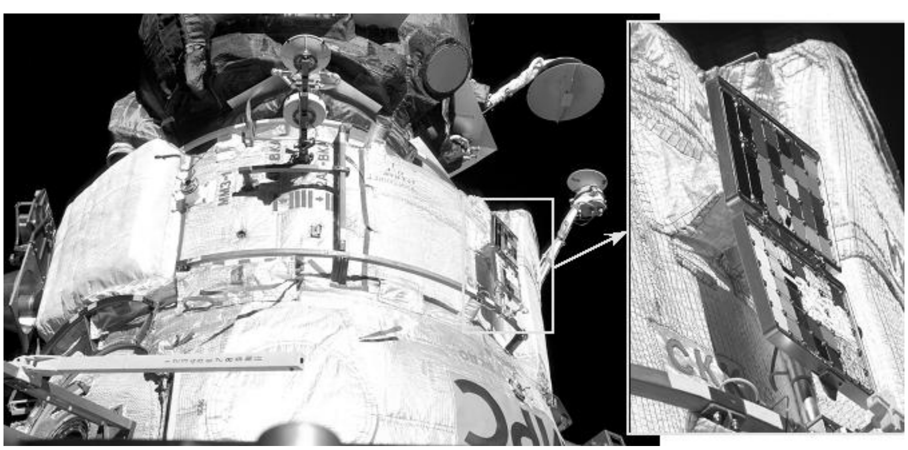

Figure 12: SKK Nº1-DC tray deployed on the ISS Docking Compartment 1
(Expedition 7 photos ISS007E10657 and ISS007E10650)

Two SKK trays (SKK Nº1-SM and SKK Nº1-DC) were retrieved and replaced with new ones in February 2004. SKK Nº2-SM will be replaced during a future EVA. Upon return, the samples undergo analyses to determine space environments effects under ISS flight conditions. Analysis results will support development of new materials and coatings for long-term space applications.

6. RUSSIAN KROMKA 1 FLIGHT EXPERIMENT (RSC-ENERGIA/KELDYSH)

The objectives of the Russian Kromka 1[5] flight experiment are to characterize bipropellant thruster induced contamination onto spacecraft material samples with exposure to the on-orbit environment and to verify the characteristics of RSC-Energia's gasdynamic limiting devices (designated by the Russian acronym GZU). Kromka 1 trays are mounted on Service Module handrails with proximity to SM attitude control thrusters on the ISS. GZU units have been installed on the SM attitude control thrusters (roll, pitch and yaw) to limit the angular spread of droplets in the plumes.

Two Kromka 1 trays, numbered 1-0 and 1-1, have already been deployed and retrieved. Kromka 1-0 was installed in October 2001 (next to the SM port yaw thrusters as shown in Figure 13) and retrieved in January 2002. Kromka 1-1 was installed in January 2002 and replaced with Kromka 1-2 in August 2002. Figure 14 shows Kromka 1-1 mounted on a handrail next to the SM Nadir roll/pitch thrusters. Kromka 1-2 is still on orbit, awaiting retrieval.

Results from Kromka 1-0 and Kromka 1-1 were published by Naumov, et al,[5] and by Gerasimov, et al.[6] The results include measurements on contaminant composition, optical property degradation of materials samples, as well as observations on AO bleaching of Kromka specimens.

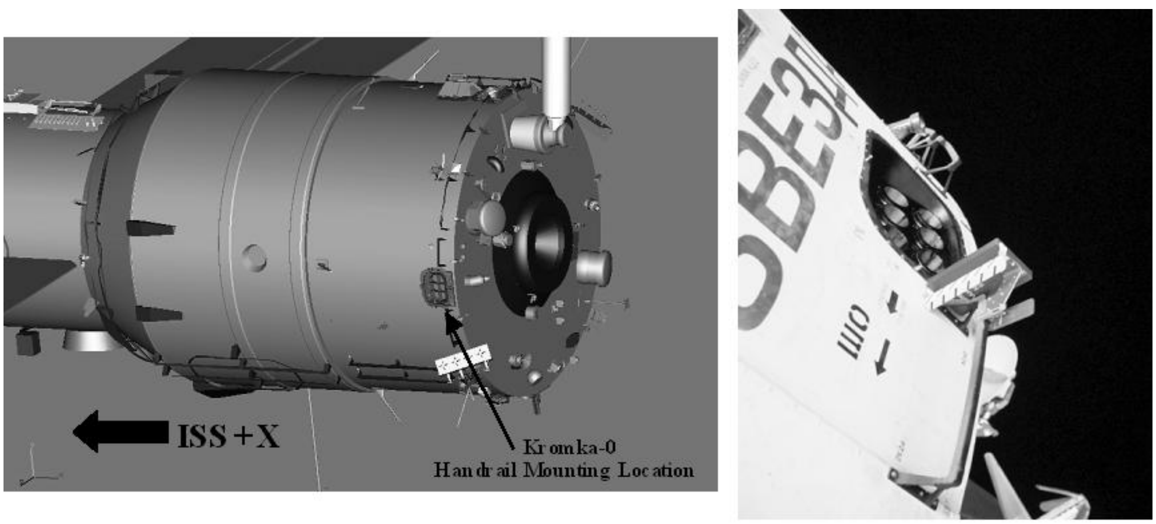

Figure 13: Kromka 1-0 mounted on SM handrail next to SM port yaw thrusters (EVA3 photo on the right)

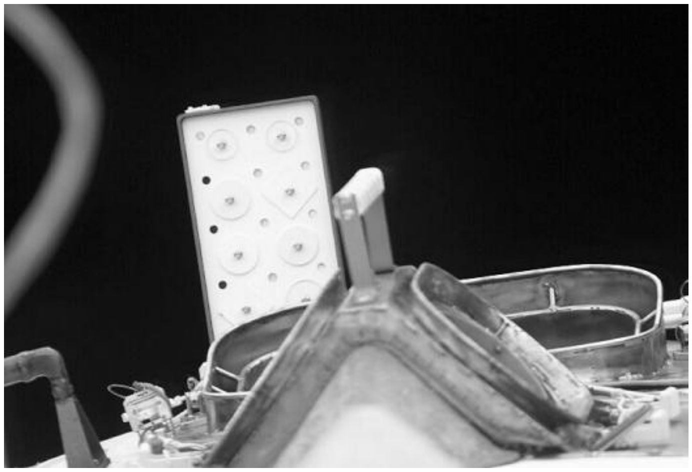

Figure 14: Kromka 1-1 mounted on SM handrail next to SM Nadir roll/pitch thrusters (Expedition 4 photo ISS004E6902)

7. RUSSIAN BKDO FLIGHT EXPERIMENT (RSC-ENERGIA)

BKDO stands for Contamination Monitoring Block (Russian acronym) and is designed to measure molecular deposition in the ISS environment. BKDO consists of a non-pressurized container, covered with multi-layer insulation and attached to a revolving boom on the ISS Docking Compartment 1 (DC1). The orientation of the BKDO package can be altered during operation for measurements in different directions.

BKDO employs two Quartz Crystal Microbalances (QCMs) facing opposite directions. The QCMs will measure molecular deposition (operating range from $5 \cdot 10^{-9}$ to $1.25 \cdot 10^{-4}$ g/cm^2), recording one measurement per second. The BKDO QCMs are not thermally controlled, but include temperature sensors for thermal monitoring. The estimated operating temperature for these QCMs is from 5° to 30° C.

BKDO was launched on Progress flight 14 in May 2004 and installed during an EVA in July 2004. The QCMs will initially be oriented parallel to the DC1 longitudinal axis, as shown in Figure 15.

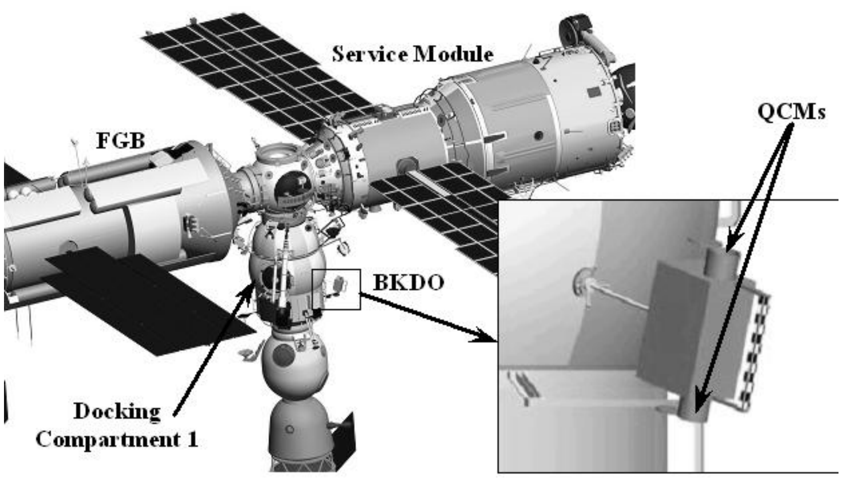

Figure 15: BKDO mounted on ISS DC 1 (close-up showing QCM orientations)

8. KOMPLAST FLIGHT EXPERIMENT

Komplast exposure trays were mounted on the ISS Functional Cargo Block (FGB) prior to launch in November 1998. The FGB was built by the Khrunichev State Research and Production Space Center under Boeing contract for the ISS. These Komplast trays are awaiting return after six years of exposure to the on-orbit environment. Komplast trays are outfitted with materials exposure samples as well as sensors.

The Komplast flight experiment has several objectives: to verify the performance of structural materials after long-term exposure to actual operational conditions, to determine the effects of space environments exposure on the characteristics of sample materials, to provide data on space environment effects on the behavior of defects in structural materials (such as crack development), and to provide additional data on the degradation of selected materials under long-term exposure to space environments.

Komplast trays were previously flown on the Kvant 2 module of the Mir space station. Their design is similar to the RSC-Energia SKK trays. However, Komplast trays also employ monitoring sensors in addition to materials samples. Figure 16 shows the photo of an FGB Komplast tray prior to installation.

Figure 16: Closeout photo of a Komplast tray prior to mounting on the FGB

Komplast sensors collect space environment data that is periodically downlinked to Earth. Measurements from temperature and UV monitoring sensors are periodically downlinked to Earth. Ionizing radiation and micrometeoroid sensors are also installed but require the return of the experiment for analysis. Materials exposure samples on Komplast include polymers, composites, adhesives, anodized coatings and multi-layer insulation materials.

Nine Komplast trays are currently installed on the FGB: two trays are located on the FGB Pressurized Adapter, four on the Instrument Compartment and three on the conical aft-end. Figure 17 shows Komplast trays on the aft end of the FGB.

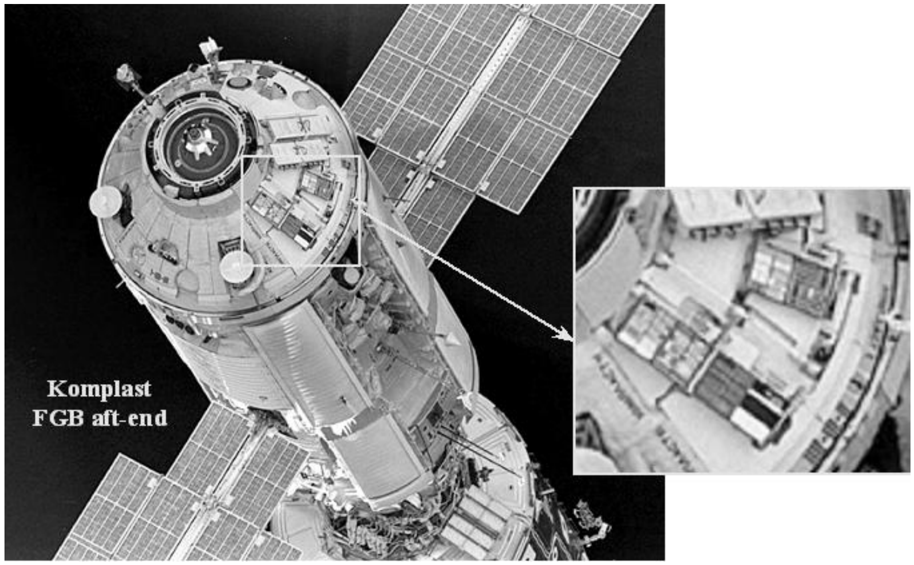

Figure 17: Komplast trays on the aft end of the FGB (Flight 2A, STS 88-369002)

9. ESA EUTEF/MEDET FLIGHT EXPERIMENT

The Materials Exposure and Degradation Experiment (MEDET) is one of the payload modules integrated on the European Technology Exposure Facility (EuTEF). MEDET is part of the European Space Agency's (ESA) early utilization program. EuTEF is currently assigned to the starboard/zenith payload site of the European Columbus module. The European Technology Exposure Facility (EuTEF) is a facility to provide accommodation and resources to a complement of scientific payloads. EuTEF's estimated minimum operational time is three years. MEDET has a projected lifetime of 18 months, with a possible 18 month extention. Figure 18 shows the EuTEF configuration and the placement of MEDET on EuTEF.

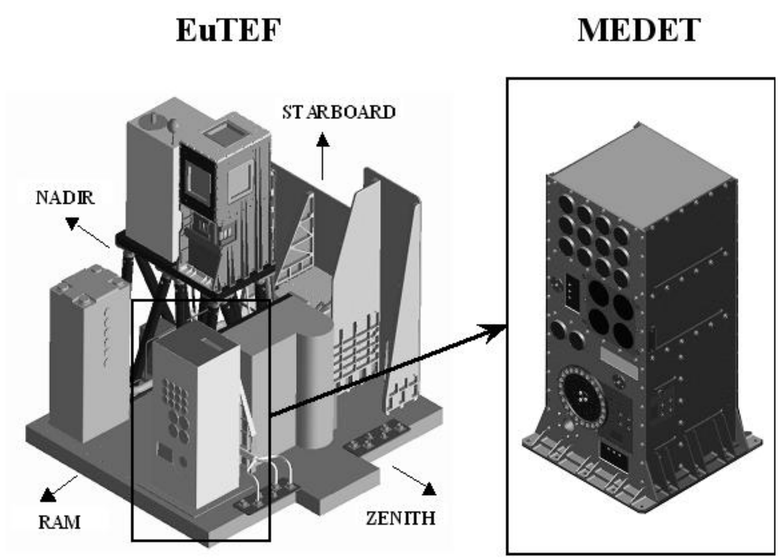

Figure 18: MEDET placement on the EuTEF

The purpose of MEDET is to actively monitor material degradation dynamics in LEO, and to characterize the Space Station natural and induced environment. After flight operations are complete, MEDET will be returned to Earth for analysis of its material samples. Figure 19 shows a mock-up model of MEDET on EuTEF on the end-cone of the Columbus module, and the configuration of MEDET experiments.

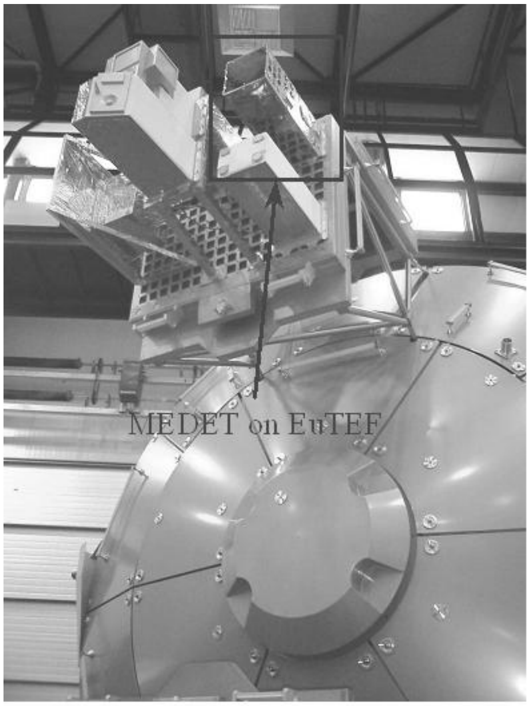

Figure 19: MEDET on EuTEF (left) and configuration of MEDET experiments (right)

MEDET will employ a complement of sensors and materials samples:

- 14 micro-calorimeters to measure thermo-optical properties of materials (anodized materials, coatings and thermal control films)
- SODAD, an active micro-particle impact detector based on a capacitor discharge technique
- Aerogel to capture micro-particles in an intact state and return to earth for analysis
- STORM, a suite of sensors to monitor UV, X-ray and AO flux. (STORM sensors are exposed on ram and zenith faces)
- Pressure gauge (cold cathode type gauge to measure local pressure)
- Two groups of 3 QCMs used to measure atomic oxygen and contamination flux
- Spectrometer for measurements of spectral transmission of optical windows. Materials samples are mounted on a sample wheel. Samples include a variety of optical materials and coatings

10. CONCLUSION

ISS offers a platform for long duration flight experiments, and several international teams are utilizing ISS to conduct space environment exposure experiments. These ISS experiments are collecting data on the long-term effects of natural and induced space environments on spacecraft materials including induced molecular contamination, plume induced contamination, exposure to ultraviolet radiation, atomic oxygen, ionizing radiation, and micrometeoroids/orbital debris. Upon return, exposed samples are analyzed with a variety of measurements including optical properties, surface morphology, molecular contamination layer profile and mechanical properties. These results are compared to predictions from models and laboratory test chamber experiments.

Results from these ISS flight experiments will be crucial to extending the performance and life of long-duration space systems such as Space Station, Space Transportation System, and other missions for Moon and Mars exploration.

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