EXTERNAL CONTAMINATION CONTROL OF ATTACHED PAYLOADS ON THE INTERNATIONAL SPACE STATION

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ABSTRACT

The International Space Station (ISS) is an on-orbit platform for science utilization in low Earth orbit with multiple sites for external payloads with exposure to the natural and induced environments. Contamination is one of the induced environments that can impact performance, mission success and science utilization on the vehicle. This paper describes the external contamination control requirements and integration process for externally mounted payloads on the ISS. The external contamination control requirements are summarized and a description of the integration and verification process is detailed to guide payload developers in the certification process of attached payloads on the vehicle. A description of the required data certification deliverables covers the characterization of contamination sources. Such characterization includes identification, usage and operational data for each class of contamination source. Classes of external contamination sources covered are vacuum exposed materials, sources of leakage, vacuum venting and thrusters. ISS system level analyses are conducted by the ISS Space Environments Team to certify compliance with external contamination control requirements. This paper also addresses the ISS induced contamination environment at attached payload sites, both at the requirements level as well as measurements made on ISS.

1. ATTACHED PAYLOADS ON THE INTERNATIONAL SPACE STATION

Multiple attached payload sites are present on ISS at the port and starboard segments of the U.S. Segment truss, the Japanese Experiment Module, the European Columbus module and on the Russian Segment (Fig. 1).

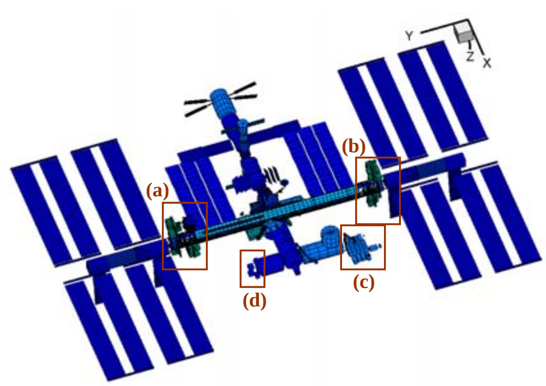

Figure 1. ISS Attached Payload Sites
(a) U.S. Segment Starboard Truss Site
(b) U.S. Segment Port Truss Sites
(c) Japanese Experiment Module Sites
(d) European Columbus Module Sites

Five attached payload sites are present on the truss of the U.S Segment. The Alpha Magnetic Spectrometer 2 (AMS-02) is currently occupying the inboard-zenith site on the starboard side of the truss. An Express Logistics Carrier (ELC) pallet is present at each of the four remaining sites (Fig. 2). Each ELC currently provides accommodations for 2 attached payloads plus a complement of ISS spares known as Orbital Replacement Units (ORUs).

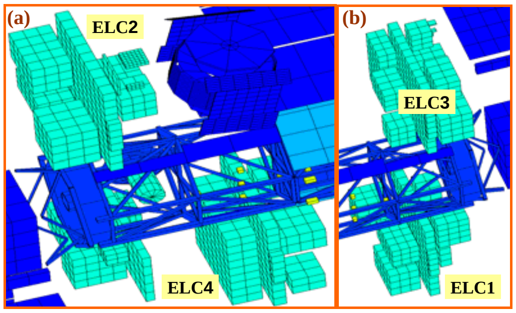

Figure 2. U.S. Segment Truss Payload Sites: (a) Starboard and (b) Port

The external environment is an interface between the vehicle and individual payloads. In addition to the natural environment, attached payloads are exposed to the environment induced by the vehicle (ISS), visiting vehicles (Russian Soyuz and Progress spacecrafts, European Autonomous Transfer Vehicles, Japanese H-II Transfer vehicles, the Dragon and Cygnus commercial cargo spacecrafts, and future commercial crew vehicles), and other attached payloads present on ISS.

Being exposed to the ISS induced environment, attached payloads must be designed to perform within the induced contamination environment. It is critical that contamination-sensitive payload projects have a thorough understanding of the induced environment on the vehicle.

All attached payloads, contamination sensitive or not, also contribute to the induced environment. Hence, attached payloads must be designed for compatibility with contaminant release requirements.

2. REQUIREMENTS

The ISS system-level requirements are contained in the System Specification for the International Space Station (SSP 41000).[1] The system level specification calls on specific sections of the Space Station Contamination Control Requirements, SSP 30426[2] (sections 3.4, 3.5 and 3.6). Of special note, the system level requirements specify an induced contaminant deposition limit equivalent to 130 Å/year on contamination sensitive surfaces from all sources of contamination on the vehicle combined.

The system level contamination requirement must be met for performance (all hardware must perform within the specified system level environment) and for contaminant releases. Hence, the induced contamination contribution from an attached payload, when combined with all other sources of contamination, must not lead to a violation of the system level requirement.

The ELC Payloads Interface Control Document (ICD) specifies the payload interfaces to ISS. The ICD also identifies the applicable ISS requirements that the payload has to meet, the method of verification, the required verification data inputs and delivery dates.

Payloads designed for deployment on the U.S Segment attached payload sites must comply with contamination requirements detailed in SSP 57003, SSP 57003-ELC (if payload will be ELC-based), SSP 57004, SSP 57004-ELC (if payload will be ELC-based) and SSP 57011.[3,4,5,6]

Requirements from SSP 57003, "Attached Payload Interface Requirements Document" Revision F are applicable at the integrated ELC level:

- Section 3.5.1.5.2.A limits a payload site's contribution to surface contamination of another payload site in the form of molecular deposition via materials outgassing and venting to 1E-14 g/cm^2/s, or equivalent to a contaminant deposition thickness of 30 Å/yr.
- Section 3.5.1.5.2.B limits a payload site's contribution to surface contamination of sensitive ISS surfaces in the form of molecular deposition via materials outgassing and venting to 1E-15 g/cm^2/s, or equivalent to a contaminant deposition thickness of 3 Å/yr.
- Section 3.5.1.5.3 limits a payload site's active venting release of particulates to only particulates less than 100 microns in size.
- Section 3.5.1.5.1 limits the molecular column density due to venting, leakage and outgassing of a payload site from exceeding along any unobstructed line of sight a value of 1E+14 molecules/cm^2 for any individual species, when viewed from any other attached payload location.

Requirements from SSP 57003-ELC, "Attached Payload Interface Requirements Document – ELC Cargo Interface Requirements Document" are applied to individual payloads on an ELC:

- Section 3.5.1.5.2.A limits an ELC payload's contribution to surface contamination of another payload in the form of molecular deposition via materials outgassing and venting to 5E-15 g/cm^2/s, or equivalent to a contaminant deposition thickness of 15 Å/yr.

- Section 3.5.1.5.2.B limits an ELC payload's contribution to surface contamination of sensitive ISS surfaces in the form of molecular deposition via materials outgassing and venting to 5E-16 $g/cm^2/s$, or equivalent to a contaminant deposition thickness of 1.5 Å/yr.
- Section 3.5.1.5.3 limits a payload site's active venting release of particulates to only particulates less than 100 microns in size.
- Section 3.5.1.5.1 limits the molecular column density due to venting, leakage and outgassing of a payload site from exceeding along any unobstructed line of sight a value of 1E+14 $molecules/cm^2$ for any individual species, when viewed from any other attached payload location.

SSP 57004, "Attached Payload Hardware Interface Control Document Template", and SSP 57004-ELC, "Attached Payload Interface Control Document – ELC Cargo Interface Control Document Template", includes deadlines and actions a payload developer must support for satisfactory closure of verification requirements.

Analyses are performed to assess compliance with the requirements documented in SSP 57011, Payload Verification Program Plan, and to ensure that the complement of payloads meets ISS interface requirements. The payloads are assessed at the element level as well as the ISS system level.

Requirements governing integration and verification of payloads on the European Columbus Module are specified in the Columbus External Payloads Interface Requirements Document (COL-RIBRE-SPE-0165).[9] These requirements are similar in principle, but differ on payload-to-payload induced contamination sub-allocations since the Columbus exposed facility has a different payload topology than the U.S. ELCs.

Payloads flying on the Japanese Experimental Module Exposed Facility (JEM-EF) are governed by the Exposed Facility/Payload Standard Interface Control Document (JPAH Vol. 3, NASDA-ESPC-2563).[10] The JEM-EF requirements specify compatibility with the ISS system level requirements but do not make specific sub-allocations for payload-to-payload induced contamination level within the JEM-EF. However, JAXA conducts induced contamination analyses to ensure successful integration of payloads within the JEM-EF.

3. METHOD OF VERIFICATION

Verifications of external contamination requirements are conducted via analysis. These analyses are performed by the ISS Space Environments Team since external contamination requirements are verified at the ISS system level in addition to the element level.

The verification analysis addresses payload induced contamination to ISS vehicle systems, visiting vehicles, and payloads at other attached payload sites and within the ELC payload site.

Detailed characterization of contamination sources on the payload and identification of contamination sensitive surfaces critical to verification are a responsibility of the Payload Developer.

4. VERIFICATION DATA DELIVERABLES

Payload developers deliver a characterization of contamination sources on their payloads. Sources of contamination are vacuum exposed materials (all non-metallic materials outside of a pressurized or hermetically sealed environment), vacuum venting (liquids and gases), leakage, thrusters and particulate releases.

4.1 Materials Outgassing

All non-metallic vacuum exposed materials are sources of molecular contamination. That includes all materials outside of a pressurized or hermetically sealed environment. The following data is required for all non-metallic vacuum exposed materials:

- Material identification
- Location of application on payload
- Vacuum exposed surface area
- Nominal operating temperature range
- Outgassing rate data from ASTM E1559[7] testing

Acceptability of a particular material application depends on several factors such as vacuum exposed area, operating temperature, pre-processing (vacuum baking) conditions, location and geometry of the application (line-of-sight to sensitive surfaces).

The on-orbit thermal environment of a material is a critical input to contamination analyses. Condensable outgassing rates increase with the operating temperature of a material and this phenomenon has a typically non-linear fashion. Small increases in operating temperatures can produce significant increases of condensable outgassing rates if new species are released.

The preferred format for the definition of operating temperature data for payload materials is one that specifies the percentage of time spent under 30°C, between 30° and 60°C, and between 60°C and the maximum operating temperature. This type of definition removes excessive conservatism from the analysis when compared to an analysis using only maximum operating temperature data.

Outgassing rate data from ASTM E1559 testing is used in the analysis. Testing for the ISS Program is based on Method B of the ASTM E1559 standard. The minimum test duration is 144-hours. Four Thermally-controlled Quartz Crystal Microbalances (TQCMs) are used for condensable outgassing rate measurements. The TQCMs are held at 80K, -40°C, -10°C and +25°C. The selection of these temperatures was based on the operating temperatures of ISS contamination sensitive surfaces which include active and passive thermal control system radiators, laser retro-reflectors, windows, sensors and science payloads.

4.2 Vacuum Venting and Leakage

Vacuum venting and leakage are sources of molecular contamination and can impact molecular column density. Additionally, liquid venting can produce frozen particulates that can be a source of damage through direct contact or orbital recontact. The following data is required for all sources of vacuum venting and leakage:

- Vent/leakage location
- Direction vector
- Composition and state of effluents (including trace elements)
- Mass flow rate
- Plume definition or characterization of dispersion
- Exit conditions (pressure, temperature, velocity)

4.3 Thrusters

Characterization of the thruster, its performance and exhaust plume are required if thrusters are present. The following is a typical list of required data for chemical thrusters (the characterization data required for electrical or other types of thrusters is not addressed here):

- Location
- Direction vector
- Propellant composition including trace components
- Specific Impulse (Isp)
- Nozzle length
- Nozzle exit radius
- Nozzle area ratio
- Reaction efficiency
- Exhaust composition
- Plume model (gas and liquid phases)

4.4 Particulate Releases

The release of particulates greater than 100 microns in size is strictly limited on ISS. Essentially, sources of particulates must be controlled during manufacturing and cleanliness must be verified through inspections from assembly through all ground processing prior to launch. The following data is required if sources of particulates are present:

- Location
- Direction
- Composition
- Size distribution
- Characterization of dispersion

4.5 Payload Contamination Sensitive Surfaces

Characterization of contamination sensitive surfaces on the payload is also required. This data is used to track induced contamination on the payload from the vehicle (ISS), visiting vehicles and other payloads.

5. VERIFICATION DATA SUBMITTAL DATES

At minimum, two verification input data deliverables are required for ELC payloads. A verification data deliverable is required 24 months prior to launch (L-24 months) with preliminary characterization of contamination sources. An update to the preliminary data delivery is required if significant sources of contamination (or significant changes) are introduced prior to final data delivery. The final verification data submittal is required 7.5 months prior to launch (L-7.5 months).

The preliminary data delivery at L-24 months is used to identify potential issues and allow for corrective action with minimal impacts to cost and schedule of payload development and integration. The same principle applies to updates; analysis results are used to identify potential issues.

The final verification analysis is conducted with the delivery of the final data certification package at L-7.5 months. The final analysis reports supporting verification are issued by L-3 months.

A diagram of the external contamination integration and verification workflow is shown in Fig. 3.

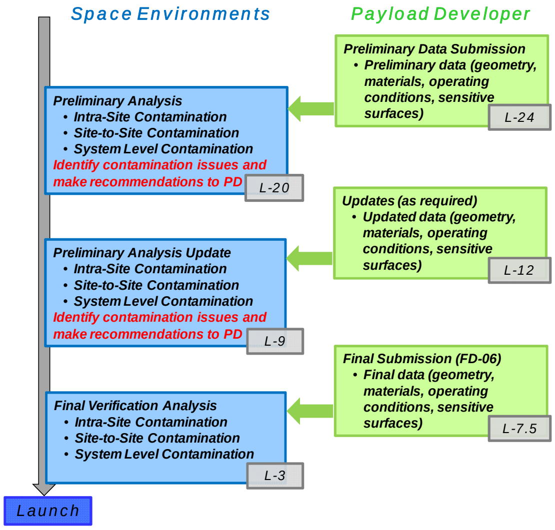

Figure 3. External Contamination Integration and Verification Workflow

6. ISS EXTERNAL CONTAMINATION ENVIRONMENT FOR ATTACHED PAYLOADS

The ISS system level requirement specifies that contaminant deposition will not exceed 130 Å/year on contamination sensitive surfaces. Analyses are performed to integrate all ISS hardware elements and verify that the system level contamination control requirement is maintained for ISS payloads.

Predicted contamination levels at ISS payload sites are lower than the system level specification for select surfaces and many contamination sensitive payloads have relied on predicted levels in operational planning.

Currently the ISS does not have active monitoring of the induced contamination environment on the vehicle. However, contaminant deposition measurements have been made on returned hardware and comparisons to analysis predictions have been made to assess performance against expectations.

6.1 MISSE 2 Contamination Measurements

The Materials International Space Station Experiment (MISSE) program has been deploying materials experiment trays on ISS since 2001. The MISSE trays are exposed to the natural and induced environment on ISS and subsequently retrieved for return and analysis. MISSE 1 and 2 had 4 years of exposure on ISS being first deployed on ISS in August 2001 and retrieved in August 2005. Both were located on the U.S. airlock (Fig. 4).

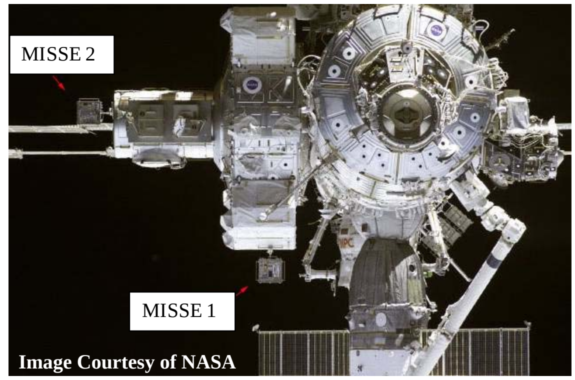

Figure 4. MISSE 1 and 2 on U.S. Airlock

Two MISSE 2 gold mirror samples supplied by NASA MSFC (Mrs. Miria Finckenor) were analyzed by Boeing with X-Ray Photoelectron Spectroscopy (XPS) to determine the composition and thickness of contaminant layer after 4 years of exposure.

Contamination measurements on the ram-facing mirror show a contaminant deposit layer of approximately 50 Å. The elemental composition of the contaminant layer is carbon, oxygen, silicon, and traces of selenium and magnesium. Fig. 5 shows the depth profile of the ram-facing mirror.

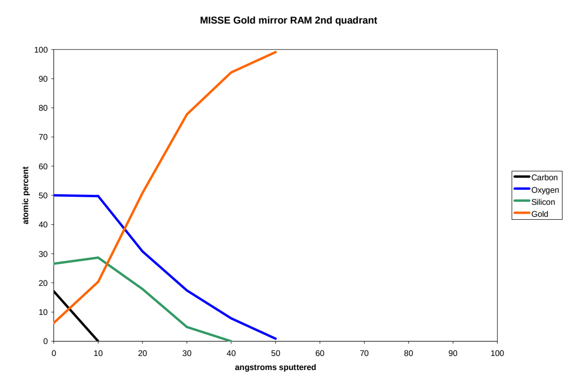

Figure 5. MISSE 2 Ram Facing Mirror XPS Results

The wake-facing mirror was shown to have a contaminant deposit layer of approximately 500 Å. The elemental composition of the contaminant layer is carbon, oxygen, silicon. Fig. 6 shows the depth profile of the wake facing mirror.

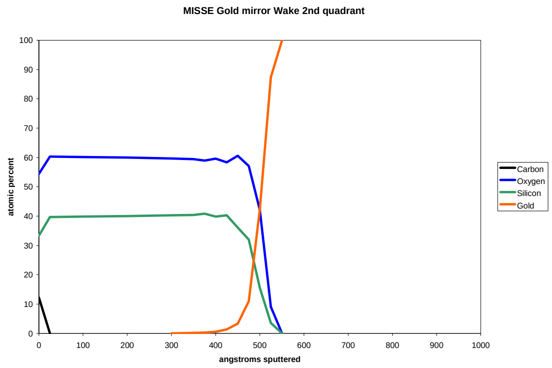

Figure 6. MISSE 2 Wake Facing Mirror XPS Results

MISSE-2 contamination measurements provide a reference for comparison with analysis predictions. It should be noted that the MISSE-1 and 2 locations on the Joint Airlock were not originally planned for external payload deployment on ISS and hence, not tracked and protected as contamination sensitive locations.

A comparison of the MISSE 2 ram and wake-facing samples with analysis predictions showed excellent agreement in contaminant deposition values. Measured values were within a factor of 1.6 of predictions. Predicted (surface averaged) and measured contamination levels on MISSE-2 are summarized in Tab. 1.

Table 1. Comparison of Predicted and Measured Contamination Levels on MISSE-2

MISSE-2	*Predicted Contamination*	*Measured Contamination*
Ram	80 Å	50 Å
Wake	730 Å	500 Å

MISSE-2 was deployed during ISS Stage 7A.1 and retrieved during Stage 11A (Fig. 7). The most significant sources of contamination to MISSE-2 ram facing surfaces were the Space Shuttle, the U.S. Lab, the airlock and the S0 and S1 truss segments. MISSE-2 wake facing surfaces were exposed to a large number of contamination sources. The most significant were Soyuz vehicles docked to the Functional Cargo Block (FGB) and Docking Compartment 1 (DC-1) nadir docking ports, the FGB, the Service Module (SM), the Joint Airlock, Progress vehicles on the DC-1 nadir port and on the SM Aft port, the DC-1 and the Primary Mating Adapter 1 (PMA-1).

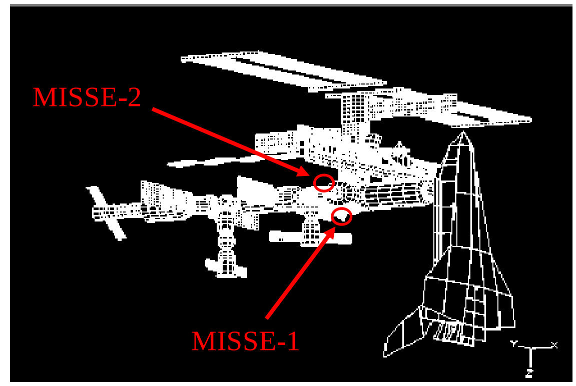

Figure 7. ISS Stage 11A Assembly Configuration

Localized (non surface averaged) predicted levels of contamination on the MISSE-2 trays are shown in Fig. 8.

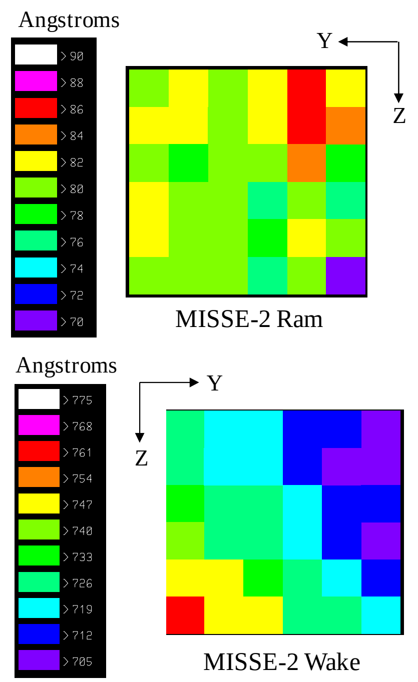

Figure 8. Predicted Contamination on MISSE-2

Additionally, the ram facing measurements are significantly lower (almost one order of magnitude) than the ISS system level specification limit (520 Å for four years of exposure).

Wake facing measurements were close to the 520 Å limit (for 4 years of exposure) and a result of contamination sources on the Russian Segment that were deployed prior to MISSE 2 installation on the U.S. Airlock.

6.2 MPAC&SEED Contamination Measurements

The Micro-Particles Capturer and Space Environment Exposure Device (MPAC&SEED) flown by the Japanese Space Exploration Agency (JAXA) provided another opportunity to compare induced contamination predictions with measurements from flight hardware. The first MPAC&SEED experiment was mounted outside the Russian Service Module (SM) in 2001. The SM/MPAC&SEED consisted of 3 identical units which were exposed for periods ranging from 10 months to almost 4 years. All of the SM/MPAC&SEED units were returned from ISS for ground-based testing including a thorough investigation of deposited contamination. Fig. 9 shows a view of the ram-facing side of the fully deployed experiment. Fig. 10 shows a view of the experiment from the wake-facing side.[11,12]

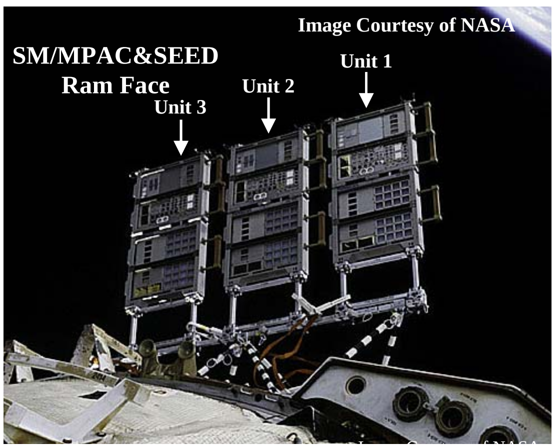

Figure 9. SM/MPAC&SEED On-Orbit, Ram-Facing Side

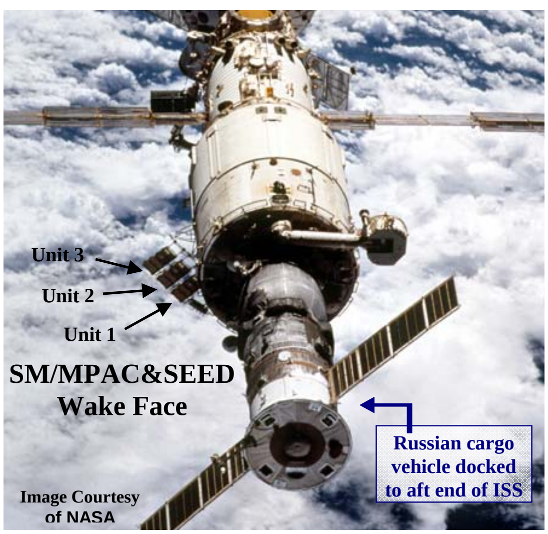

Figure 10. SM/MPAC&SEED On-Orbit, Wake-Facing Side

JAXA used XPS to measure element composition and depth profiles of the contamination layers. Four measurements were taken for each unit – two on the ram side and two on the wake side. Results show silicon to be a significant constituent on the ram side of all 3 units. Silicon was also present on the wake side but generally in lesser quantities. The presence of silicon is highly indicative of material outgassing induced contamination. Oxygen, carbon, nitrogen, sodium, iron, and nickel were also detected. Nitrogen was consistently more prominent on the wake side compared to the ram. The presence of nitrogen and observed droplet features on the wake-facing surfaces strongly indicates thruster plume induced contamination.

The ISS Space Environments Team performed induced contamination analyses for SM/MPAC&SEED to compare predictions with measured contamination levels on the flight hardware. Analysis results consistently showed high levels of material outgassing induced contamination on the ram-facing surfaces. The wake-facing surfaces were predicted to accrue contamination due to a combination of material outgassing and thruster plume impingement from Russian cargo vehicles. These results are qualitatively consistent with visual inspection and XPS measurements of the flight hardware. The calculated depth of contamination on the ram side surfaces is within a factor of 3 of measurements (see Tab. 2).[11,12,13]

Table 2. Comparison of SM/MPAC&SEED Measured and Predicted Contamination

Measured Vs. Predicted Contamination Depth (Å)

Side	Unit 1		Unit 2		Unit 3	
	Measured	Predicted	Measured	Predicted	Measured	Predicted
Ram	300	106 - 135	750	303 - 354	930	459 - 533
Ram	300		750		940	
Wake	55	86 - 103	70	186 - 237	110	317 - 414
Wake	500		100		85	

Predictions may improve with better characterization of outgassing sources. For instance, available data for the Russian Segment elements only included characterization of materials with a relatively large surface area. As a result, it is likely that there are significant outgassing sources that have not been identified. In addition, the on-orbit thermal environment has a considerable effect on outgassing but only limited thermal data was available. Considering, however, the number of outgassing sources on ISS and long duration of the experiment, the predicted results for the ram side represent good agreement with the measured depth of contamination.

Plume contamination can be more difficult to quantify with XPS measurements than outgassing induced contamination as thruster plumes have multiple byproducts and produce droplet features with a non-uniform distribution of contaminants. Although XPS is limited in characterizing depth of plume contamination, the measured and predicted results are of similar scale for the wake-facing surfaces.[11]

7. CONTAMINATION MAPPING ON ISS

As part of ISS payload integration activities, contamination forecast maps are being generated for U.S. attached payload sites to support payload feasibility, topology and placement studies. An example of a contamination forecast map for the two ELCs on the starboard side of the ISS truss is shown in Fig. 11. This forecast map covers HTV-3 mission annualized contamination from all sources of materials outgassing. Similar forecast maps are being generated for future timeframes to support payload manifesting decisions.

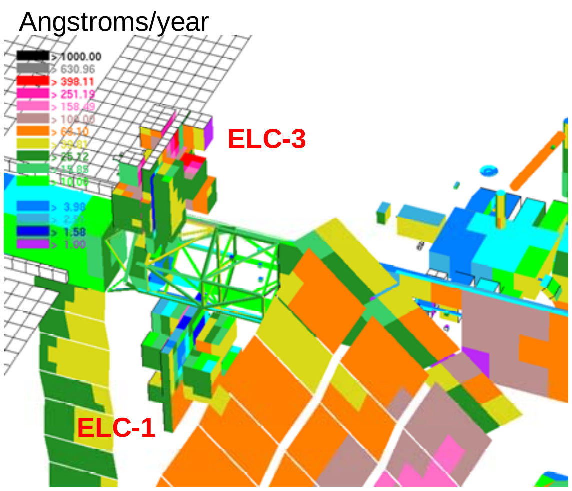

Figure 11. HTV-3 Mission Contamination Forecast Maps for ELC-1 and ELC-3

8. CONCLUSIONS

The International Space Station (ISS) provides a unique platform for multiple science payloads in low Earth orbit. Multiple science payloads introduce complex induced contamination environment interactions that must be accounted for successful integration of the payload complement in operation on ISS.

The ISS itself, with contributions from visiting vehicles and the entire external payload complement, produces and induced contamination environment on each externally mounted payload. These external payloads must be designed to perform within this induced environment.

Since each external payload is also a contributing source of contamination, its contaminant releases must be controlled for compatibility with existing requirements. These requirements protect the ISS and the existing external payload complement from excessive contamination.

Payload developers supply the required data certification deliverables characterizing the sources of contamination on the payload. This characterization includes identification, usage and operational data for each class of contamination source. Classes of external contamination sources covered are vacuum exposed materials, leakage sources, vacuum venting and thrusters and sources of particulates.

ISS system level analyses are conducted by the ISS Space Environments Team to certify compliance with external contamination control requirements. These integration and verification activities ensure success of ISS as a platform for scientific experiments in low earth orbit.

Although the ISS does not have active monitoring of the induced contamination environment on the vehicle, contaminant deposition measurements have been made on returned hardware and comparisons to analysis predictions have been made to assess performance against expectations. One example is measurements made on MISSE 2 gold mirror samples that were returned after 4 years of exposure on the vehicle. These measurements show that contaminant deposition levels were within the system level specification and in excellent agreement with predictions. Contamination measurements on JAXA's SM/MPAC&SEED experiment likewise showed contamination deposition levels that were in excellent agreement with prediction.

As part of ISS payload integration activities, contamination forecast maps are being generated for U.S. attached payload sites to support payload feasibility, topology and placement studies. These activities ensure success of scientific mission objectives of payloads on ISS.

9. ACKNOWLEDGEMENTS

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External Contamination Control of Attached Payloads on the International Space Station

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Introduction

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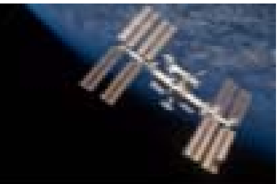
- **The International Space Station (ISS) is a platform for science utilization in low Earth orbit with multiple sites for external payloads**
- **Contamination is one of the induced environments that can impact performance, mission success and science utilization on the vehicle**
- **External contamination control requirements at the system and element level ensure successful integration and verification of external payloads**
- **Payload Developers deliver characterization of contamination sources to support system level analyses and to certify compliance with external contamination control requirements at U.S. payload sites**
- **Measurements of the ISS induced contamination environment show contamination levels meet or exceed system level requirements**

Attached Payloads on ISS

- **Multiple attached payload sites are present on ISS at the port and starboard segments of the U.S. Segment truss, the Japanese Experiment Module, the European Columbus module and on the Russian Segment**
- **Five attached payload sites are present on the truss of the U.S Segment**
- **The Alpha Magnetic Spectrometer 2 (AMS-02) is currently occupying the inboard-zenith site on the starboard side of the truss**
- **An Express Logistics Carrier (ELC) pallet is present at each of the four remaining sites (Fig. 2)**
  - Each ELC currently provides accommodations for 2 attached payloads plus a complement of ISS spares known as Orbital Replacement Units (ORUs).

Attached Payloads on ISS



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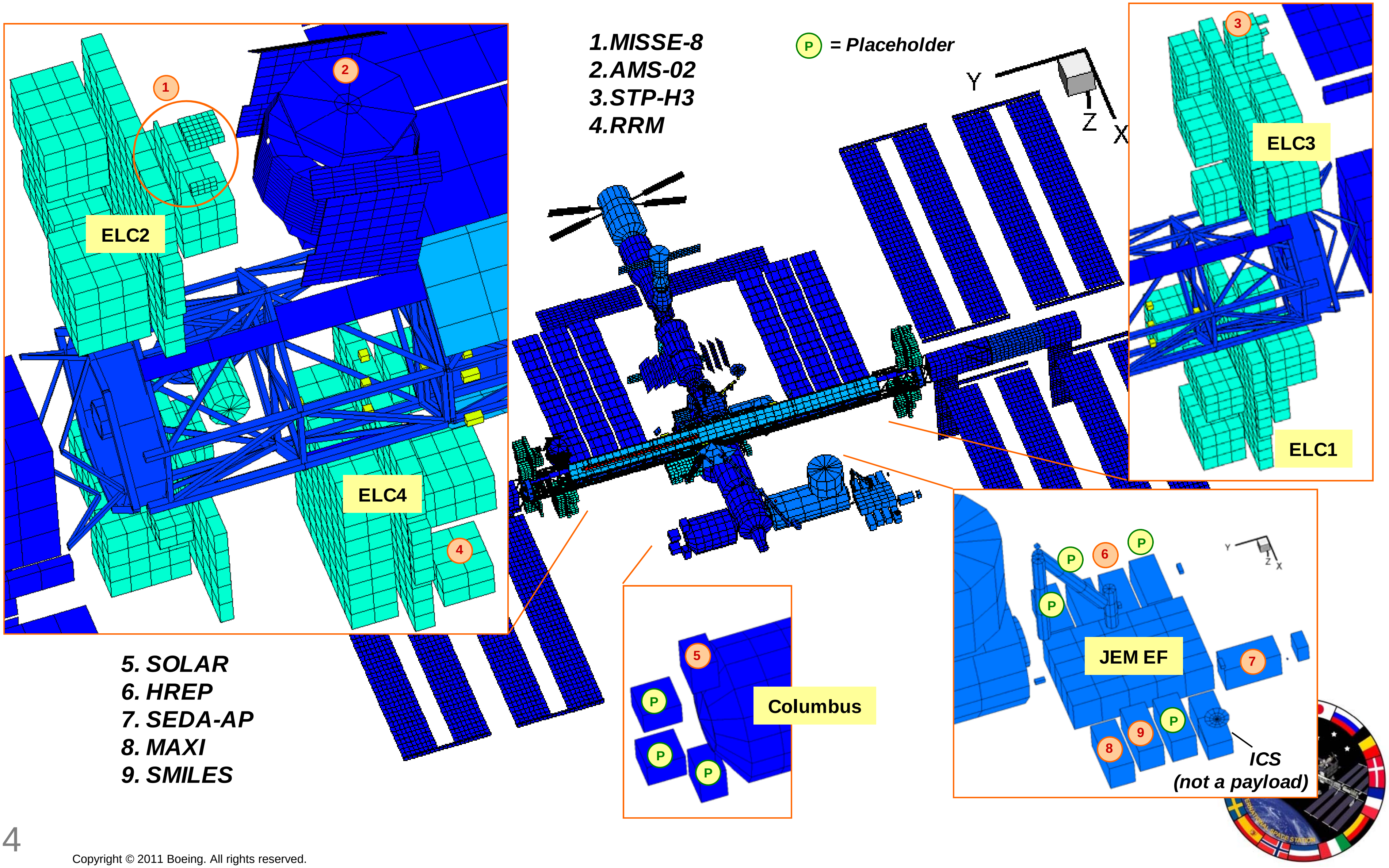

Requirements

- **System level requirements are contained in the System Specification for the International Space Station (SSP 41000)**
  - Calls on specific sections of the Space Station Contamination Control Requirements, SSP 30426: sections 3.4, 3.5 and 3.6
  - Specify an induced contaminant deposition limit equivalent to 130 Å/year on contamination sensitive surfaces from all sources of contamination on the vehicle combined
- **ELC Payloads Interface Control Document (ICD) specifies the payload interfaces to ISS and identifies the method of verification, the required verification data inputs and delivery dates**
- **Payloads designed for deployment on the U.S Segment attached payload sites must comply with contamination requirements detailed in SSP 57003, SSP 57003-ELC (for ELC-based payloads), SSP 57004, SSP 57004-ELC (for ELC based payloads) and SSP 57011**

Attached Payloads Interface Requirements

- **Requirements from SSP 57003, "Attached Payload Interface Requirements Document" are applicable at the integrated ELC level**
  - Section 3.5.1.5.2.A limits a payload site's contribution to surface contamination of another payload site in the form of molecular deposition via materials outgassing and venting to 1E-14 g/cm^2/s [30 Å/year]
  - Section 3.5.1.5.2.B limits a payload site's contribution to surface contamination of sensitive ISS surfaces in the form of molecular deposition via materials outgassing and venting to 1E-15 g/cm^2/s [3 Å/yr]
  - Section 3.5.1.5.3 limits a payload site's active venting release of particulates to only particulates less than 100 microns in size
  - Section 3.5.1.5.1 limits the molecular column density due to venting, leakage and outgassing of a payload site from exceeding along any unobstructed line of sight a value of 1E+14 molecules/cm^2 for any individual species

Attached Payloads Interface Requirements

- **Requirements from SSP 57003-ELC, “Attached Payload Interface Requirements Document” are applicable at the integrated ELC level**
  - Section 3.5.1.5.2.A limits a payload site’s contribution to surface contamination of another payload site in the form of molecular deposition via materials outgassing and venting to 5E-15 g/cm^2/s [15 Å/year]
  - Section 3.5.1.5.2.B limits a payload site’s contribution to surface contamination of sensitive ISS surfaces in the form of molecular deposition via materials outgassing and venting to 5E-16 g/cm^2/s [1.5 Å/yr]
  - Section 3.5.1.5.3 limits a payload site’s active venting release of particulates to only particulates less than 100 microns in size
  - Section 3.5.1.5.1 limits the molecular column density due to venting, leakage and outgassing of a payload site from exceeding along any unobstructed line of sight a value of 1E+14 molecules/cm^2 for any individual species

Attached Payload Interface Requirements

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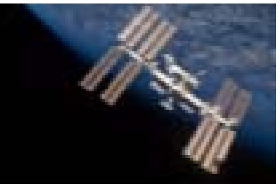
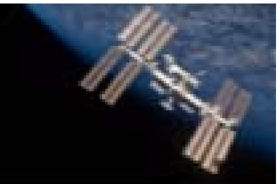
- **SSP 57004, "Attached Payload Hardware Interface Control Document Template", and SSP 57004-ELC, "Attached Payload Interface Control Document – ELC Cargo Interface Control Document Template", includes deadlines and actions a payload developer must support for satisfactory closure of verification requirements**
- **Analyses are performed to assess compliance with the requirements documented in SSP 57011, Payload Verification Program Plan, and to ensure that the complement of payloads meets ISS interface requirements**
- **The payloads are assessed at the element level as well as the ISS system level**

Columbus and JEM-EF Requirements



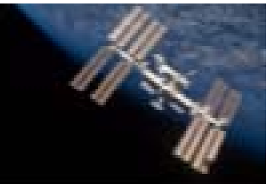
- **Requirements governing integration and verification of payloads on the European Columbus Module are specified in the Columbus External Payloads Interface Requirements Document (COL-RIBRE-SPE-0165)**
  - Similar to U.S. Segment requirements in principle, but differ on payload-to-payload induced contamination sub-allocations since the Columbus exposed facility has a different payload topology than the U.S. ELCs
- **Payloads flying on the Japanese Experimental Module Exposed Facility (JEM-EF) are governed by the Exposed Facility/Payload Standard Interface Control Document (JPAH Vol. 3, NASDA-ESPC-2563)**
  - JEM-EF requirements specify compatibility with the ISS system level requirements but do not make specific sub-allocations for payload-to-payload induced contamination level within the JEM-EF
  - JAXA conducts induced contamination analyses to ensure successful integration of payloads within the JEM-EF

Verification Data Deliverables



- **Payload developers deliver a characterization of contamination sources on their payloads**
  - Vacuum exposed materials (all non-metallic materials outside of a pressurized or hermetically sealed environment)
  - Vacuum venting (liquids and gases)
  - Leakage
  - Thrusters
  - Sources of particulate releases
- **Identification of contamination sensitive surfaces on the payload is also required**
  - This data is used to track induced contamination on the payload from the vehicle (ISS), visiting vehicles and other payloads

Materials Outgassing

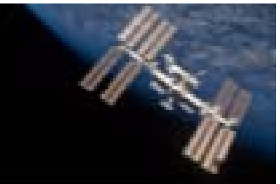


- **Required data for all non-metallic vacuum exposed materials**
  - Material identification
  - Location of application on payload
  - Vacuum exposed surface area
  - Nominal operating temperature range
  - Outgassing rate data from ASTM E1559 testing
- **The preferred format for the definition of operating temperature data for payload materials is one that specifies the percentage of time spent under 30°C, between 30° C and 60°C, and between 60°C and the maximum operating temperature**
  - This type of definition removes excessive conservatism from the analysis when compared to an analysis using only maximum operating temperature data

Outgassing Rate Data

- **Outgassing rate data from ASTM E1559 testing is required to support induced contamination analysis**
- **Testing for the ISS Program is based on Method B of the ASTM E1559 standard**
  - Minimum test duration of 144 hours
  - Four Thermally-controlled Quartz Crystal Microbalances (TQCMs) are used for condensable outgassing rate measurements
    - TQCMs are held at 80K, -40°C, -10°C and +25°C
    - Selection of these temperatures was based on the operating temperatures of ISS contamination sensitive surfaces which include active and passive thermal control system radiators, laser retro-reflectors, windows, sensors and science payloads

Verification Data Submittals



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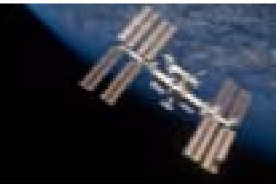
- **Preliminary verification data deliverable is required 24 months prior to launch (L-24 months) with preliminary characterization of contamination sources**
  - The preliminary data delivery at L-24 months is used to identify potential issues and allow for corrective action with minimal impacts to cost and schedule of payload development and integration
- **An update to the preliminary data delivery is required if significant sources of contamination (or significant changes) are introduced prior to final data delivery**
  - The same principle applies to updates; analysis results are used to indentify potential issues
- **Final verification data submittal is required 7.5 months prior to launch (L-7.5 months)**
- **The final analysis reports supporting verification are issued by L-3 months**

Integration and Verification Workflow



Space Environments

Preliminary Analysis (L-20)
- Intra-Site Contamination
- Site-to-Site Contamination
- System Level Contamination

Identify contamination issues and make recommendations to PD

Preliminary Analysis Update (L-9)
- Intra-Site Contamination
- Site-to-Site Contamination
- System Level Contamination

Identify contamination issues and make recommendations to PD

Final Verification Analysis (L-3)
- Intra-Site Contamination
- Site-to-Site Contamination
- System Level Contamination

Launch

Payload Developer

Preliminary Data Submission (L-24)
- Preliminary data (geometry, materials, operating conditions, sensitive surfaces)

Updates (as required) (L-12)
- Updated data (geometry, materials, operating conditions, sensitive surfaces)

Final Submission (FD-06) (L-7.5)
- Final data (geometry, materials, operating conditions, sensitive surfaces)

ISS Contamination Environment

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- **System level requirement specifies a contaminant deposition limit of 130 Å/year on contamination sensitive surfaces**
  - Analyses are performed to integrate all ISS hardware elements and verify that the system level contamination control requirement is maintained for ISS payloads
- **Predicted contamination levels at ISS payload sites are lower than the system level specification for select surfaces**
  - Several contamination sensitive payloads have relied on predicted levels in operational planning
- **Contaminant deposition measurements have been made on returned hardware and comparisons to analysis predictions have been made to assess performance against expectations**
- **Active monitoring of the induced contamination environment on ISS is not yet available**

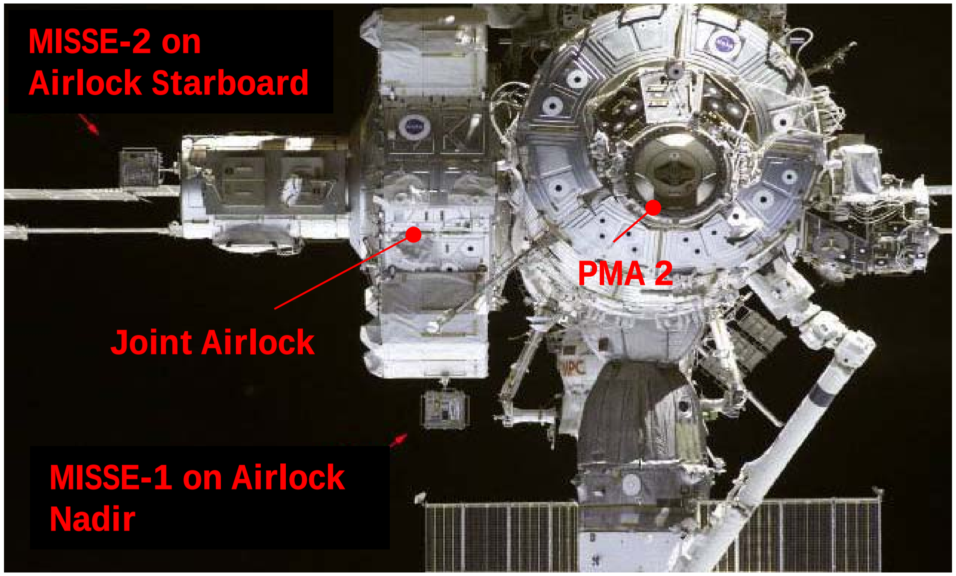
Summary of Mir Observations

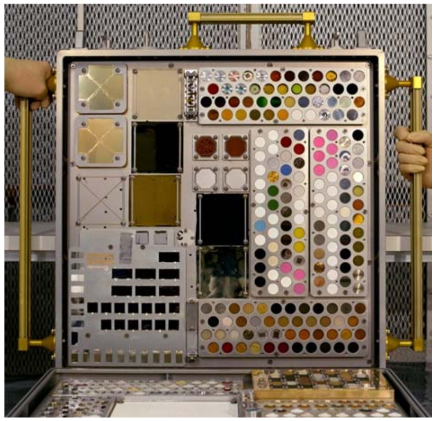
Mir External Contamination Observations

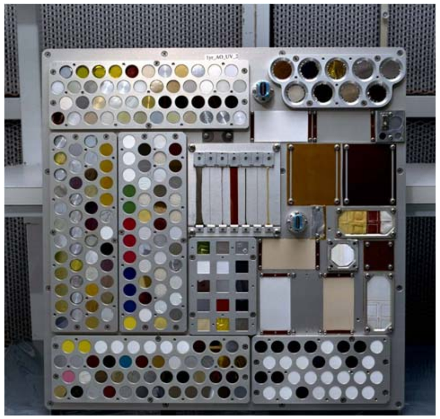
Comes-Aragatz (CNES)	350 - 780 Å	in 13 months
Camera Bracket (NASA)	12,000 Å	in 4 months
ICA QCM 1 (ESA)	13,000 Å	in 3 months
ICA QCM 2 (ESA)	14,500 Å	in 3 months
ICA QCM 3 (ESA)	4,500 Å	in 3 months
Trek Blanket (NASA)	> 20,000 Å	in 4.2 years
Astra-II (RSC-Energia)	5,000 Å	in 13 months

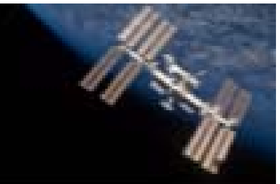
Predictions & Correlations with Measurements: MISSE

- **Returned materials samples from MISSE flight experiment confirmed low levels of induced contamination from U.S. Segment hardware**









Predictions & Correlations with Measurements: MISSE

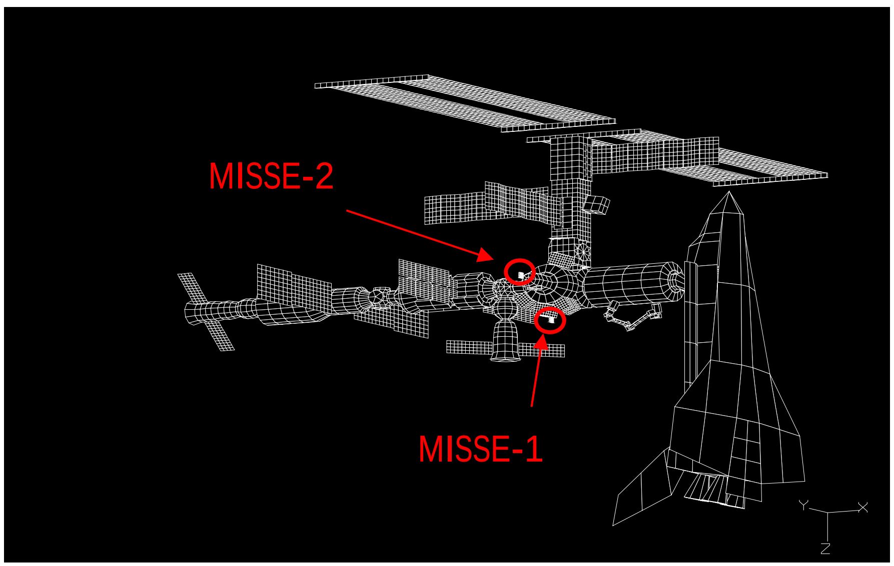
- **ISS induced contamination levels on MISSE were measured on ram and wake facing MISSE gold mirrors (WR 200802140)**
  - Measured wake facing mirror contamination was less than 500 Å
  - Measured ram facing mirror was less than 50 Å
- **Excellent agreement between predicted and measured contamination results for the 4.0-year flight**

Experiment	Side	Predicted	Measured
MISSE 2	ram	80 Å	50 Å
	wake	730 Å	500 Å

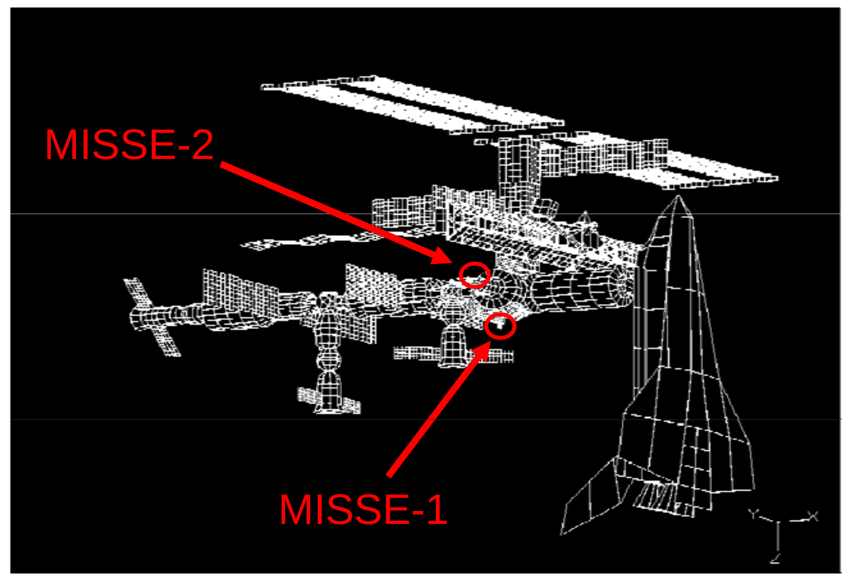
  - – Dominant contamination source for ram surfaces is Orbiter
  - – Dominant sources for wake surfaces are FGB and docked Soyuz vehicles

MISSE-1 and 2 Background

- **Deployed on Aug. 16, 2001 (on mission 7A.1)**
- **Retrieved on Aug. 3, 2005 (on LF1, after 11A)**
- **Exposure duration of 4.0 years**

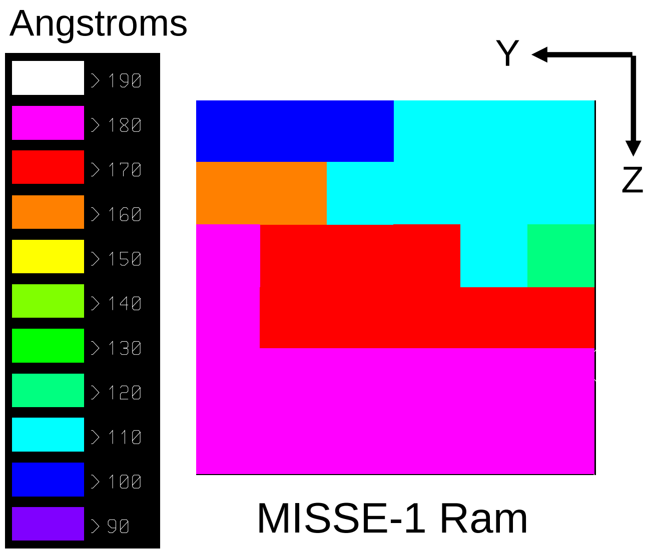


7A.1

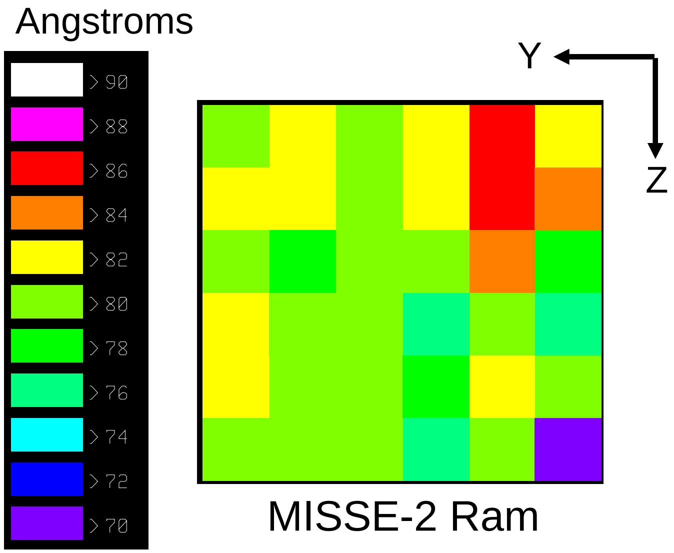


11A

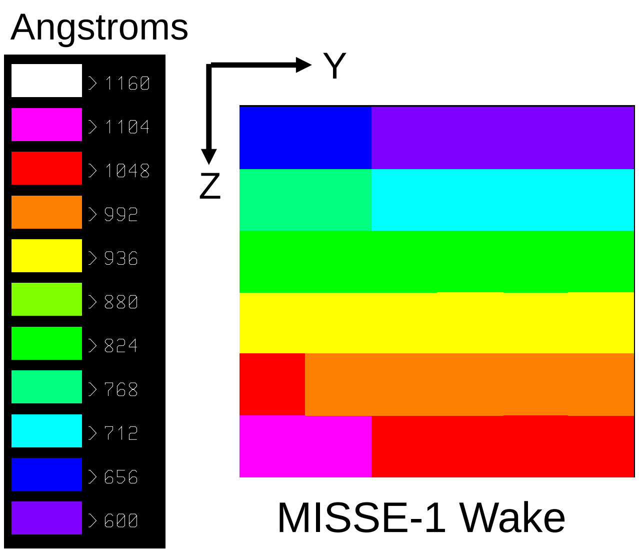
Contamination Results



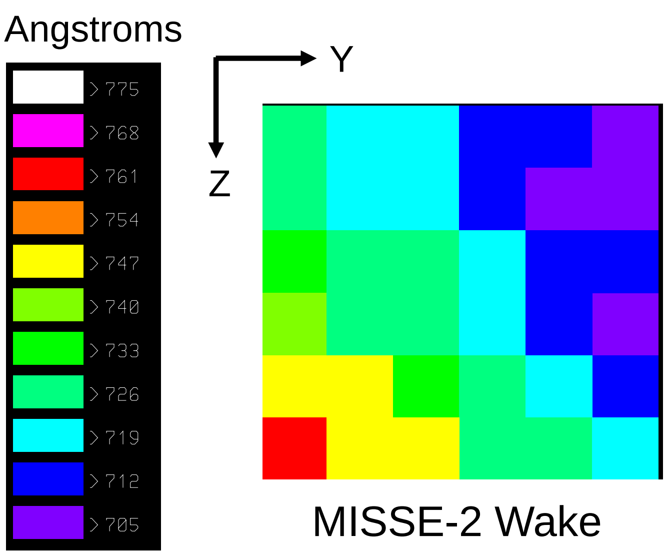
MISSE-1 Ram



MISSE-2 Ram

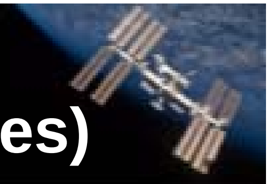


MISSE-1 Wake



MISSE-2 Wake

Ram Surface Contamination (Weighted Averages)



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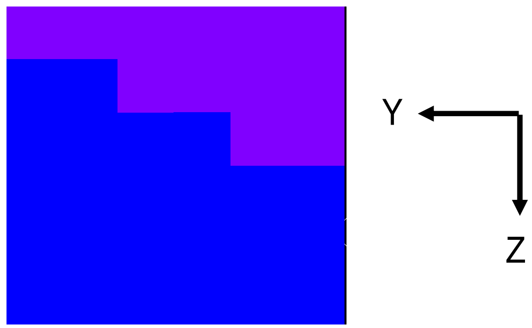
Source	MISSE-1 (Å)	MISSE-2 (Å)
Orbiter on PMA2 Fwd	141.5	49.7
U.S. Lab (Destiny)	8.6	5.2
Joint Airlock	6.3	3.1
S0	0.0	19.1
S1	0.2	2.6
...	...	...
Total	*157.4*	*81.3*

Each source not shown contributed less than 1.0 Å to each MISSE tray.

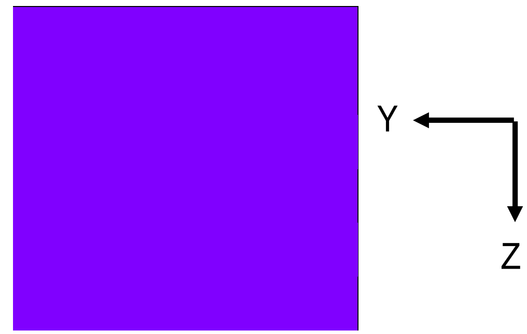
Wake Surface Contamination (Weighted Averages)

Source	MISSE-1 (Å)	MISSE-2 (Å)
Soyuz on FGB Nadir	386.1	91.6
FGB	320.1	554.3
Soyuz on DC-1 Nadir	89.7	56.8
SM	73.5	11.6
Joint Airlock	8.7	0.9
Progress on DC-1 Nadir	7.5	8.4
Progress on SM Aft	3.2	0.5
DC-1	1.1	0.7
PMA-1	0.0	1.7
...	...	...
Total	*889.9*	*727.1*

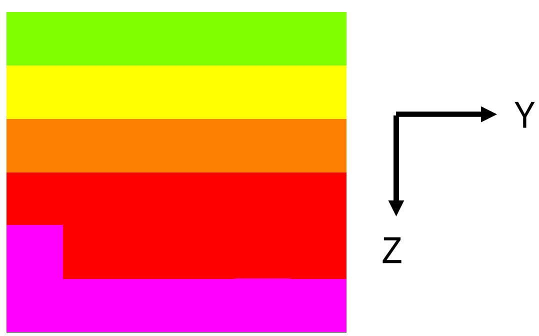
Results (Single Scale)



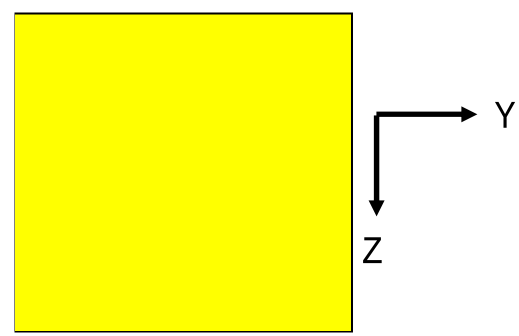
MISSE-1 Ram



MISSE-2 Ram



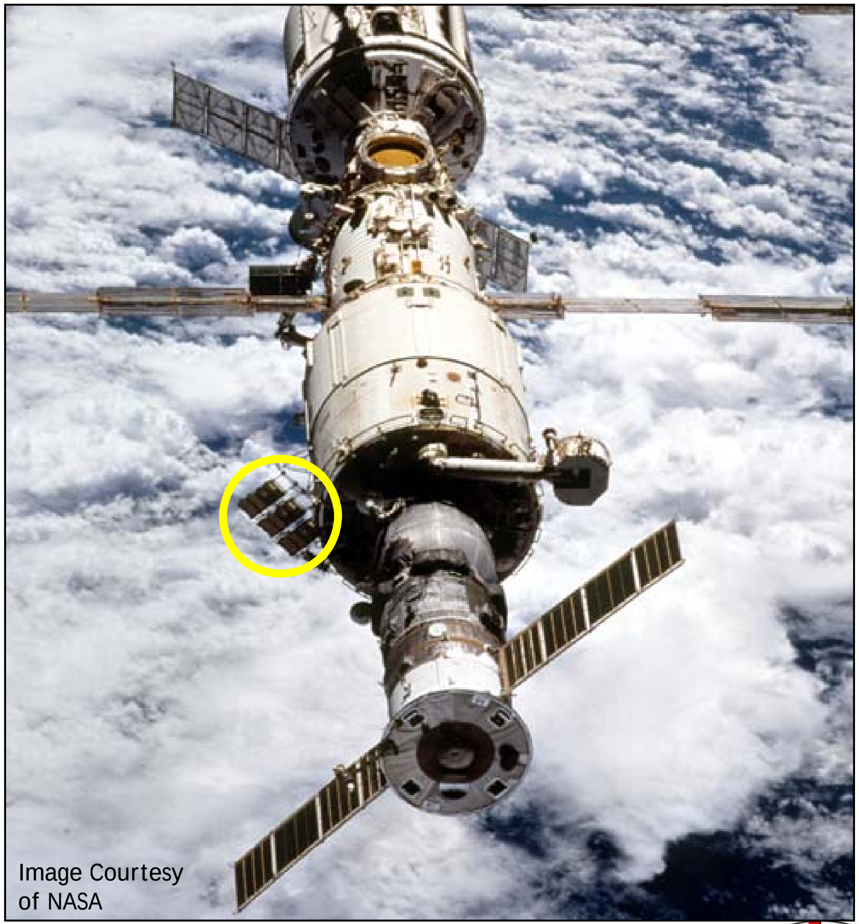
MISSE-1 Wake



MISSE-2 Wake

Predictions & Correlations with Measurements: MPAC&SEED

Micro PArticle Capturer and Space Environment Exposure Device deployed on the Service Module port-nadir side
(View from International Space Station Aft end)



Background – SM/MPAC&SEED

- **Three identical SM/MPAC&SEED units.**
- **Samples on the ram and wake facing surfaces.**
  - MPAC – experiment to capture micrometeoroids and space debris particles.
  - SEED - exposure experiment to characterize degradation of materials in LEO.

Image Courtesy of JAXA

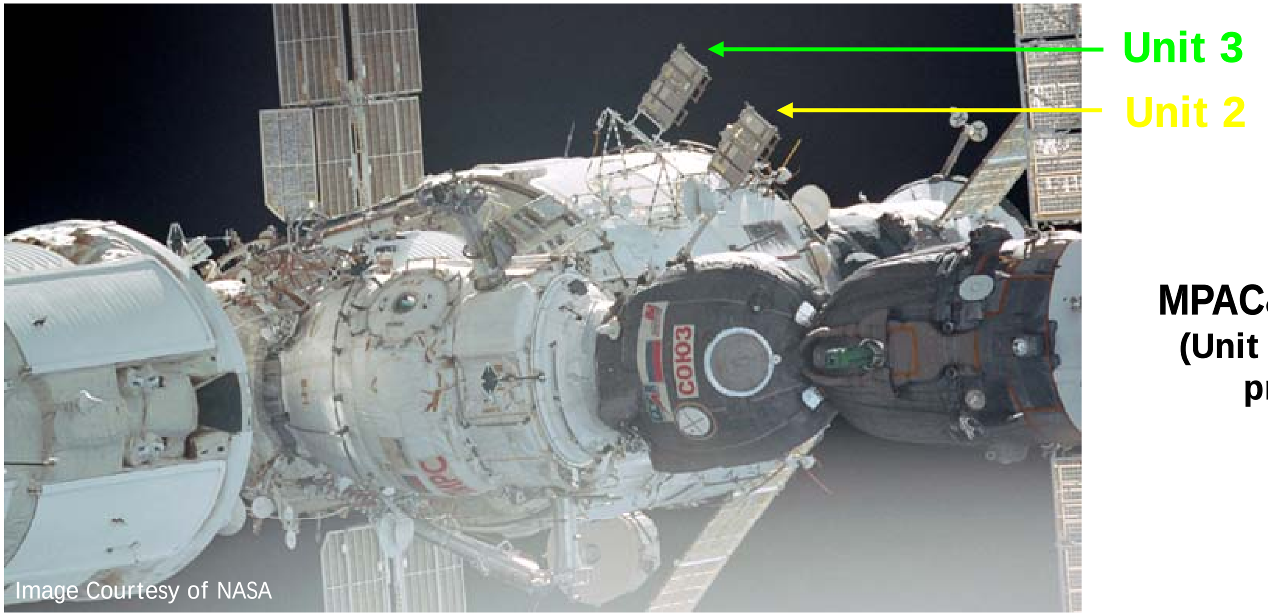
A single MPAC&SEED Unit (Ram-Facing Surface)

References:

Neish, et. Al. *Microparticle Capture on the International Space Station Using Aerogel and Polyimide Foam*; Proceedings of the 9th International Symposium on Materials in a Space Environment, ESA SP-540, Noordwijk, The Netherlands, 16-20 June 2003.

Background – SM/MPAC&SEED

- **All 3 units deployed on October 15, 2001**
  - First unit retrieved on August 26, 2002 - *315 Days*
  - Second unit retrieved on February 26, 2004 - *865 Days*
  - Third unit retrieved on August 18, 2006 - *1403 Days*



MPAC&SEED with Unit 1 Removed
(Unit 2 was relocated into the position previously occupied by Unit 1)

SM/MPAC&SEED Contamination Observations

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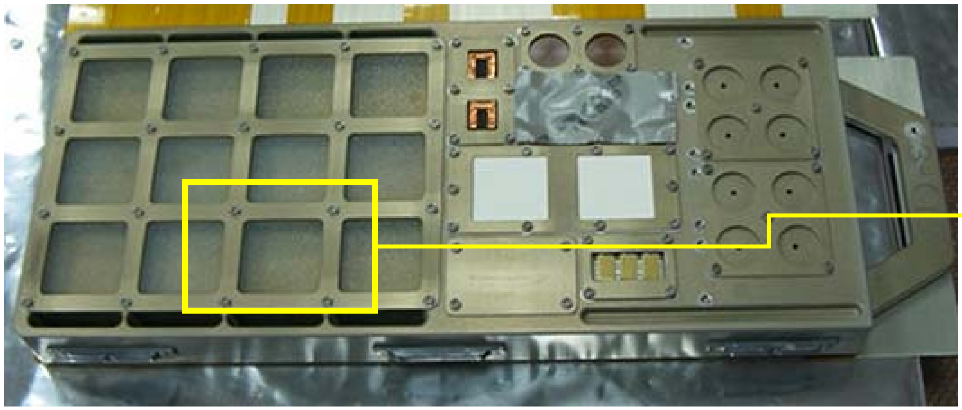


Image Courtesy of JAXA

Wake face

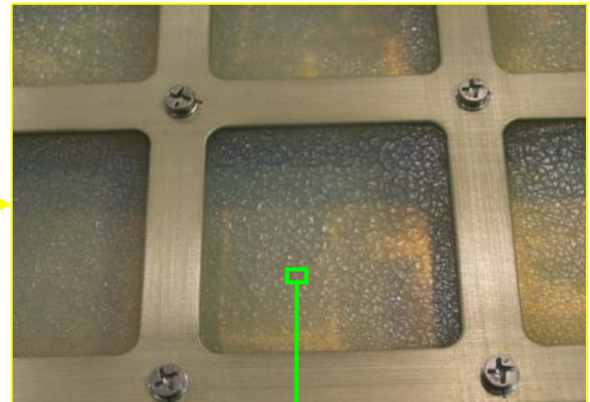


Image Courtesy of JAXA

Aerogel Sample

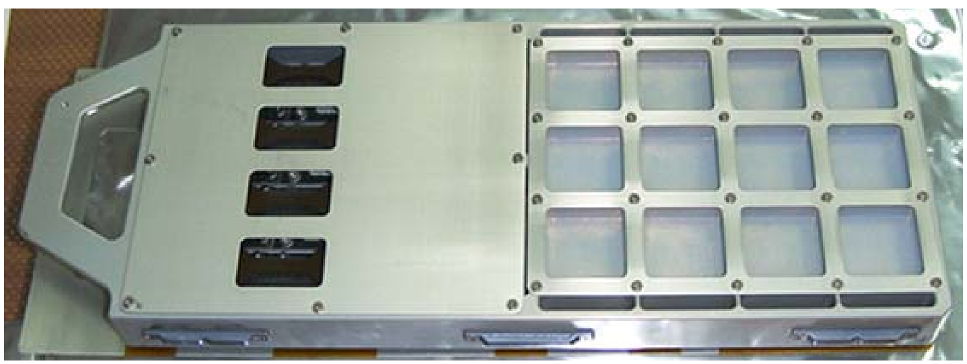


Image Courtesy of JAXA

Ram face

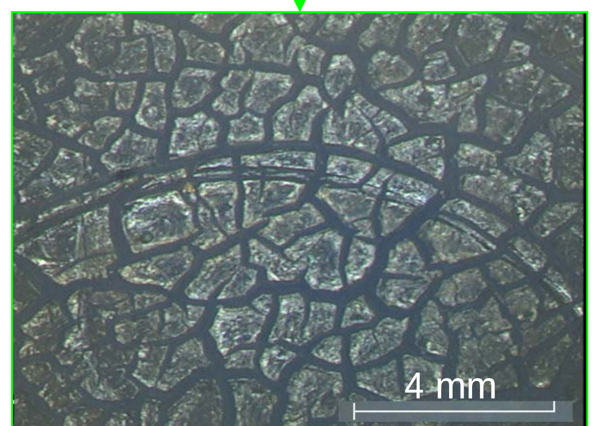


Image Courtesy of JAXA

Reference: Neish, Michael; Imagawa, Kichiro; Inoue, Toshihiko; Ishizawa, Junichiro; Kitazawa, Yukihito; Yamaura, Yukiko; Murakami, Atsushi; Ochi, Yoshiyuki. *Microparticle Capture on the International Space Station Using Aerogel and Polyimide Foam*.

SM/MPAC&SEED
XPS Measurements

- **X-ray Photoelectron Spectroscopy (XPS) used to measure element composition and depth profiles.**
  - Element composition:
    - Silicon major constituent on ram side. Also present on wake side in lesser quantities.
    - Other constituents: oxygen, carbon, nitrogen, sodium, iron, and nickel.
  - Approximate Contamination Depth based on XPS Measurements:

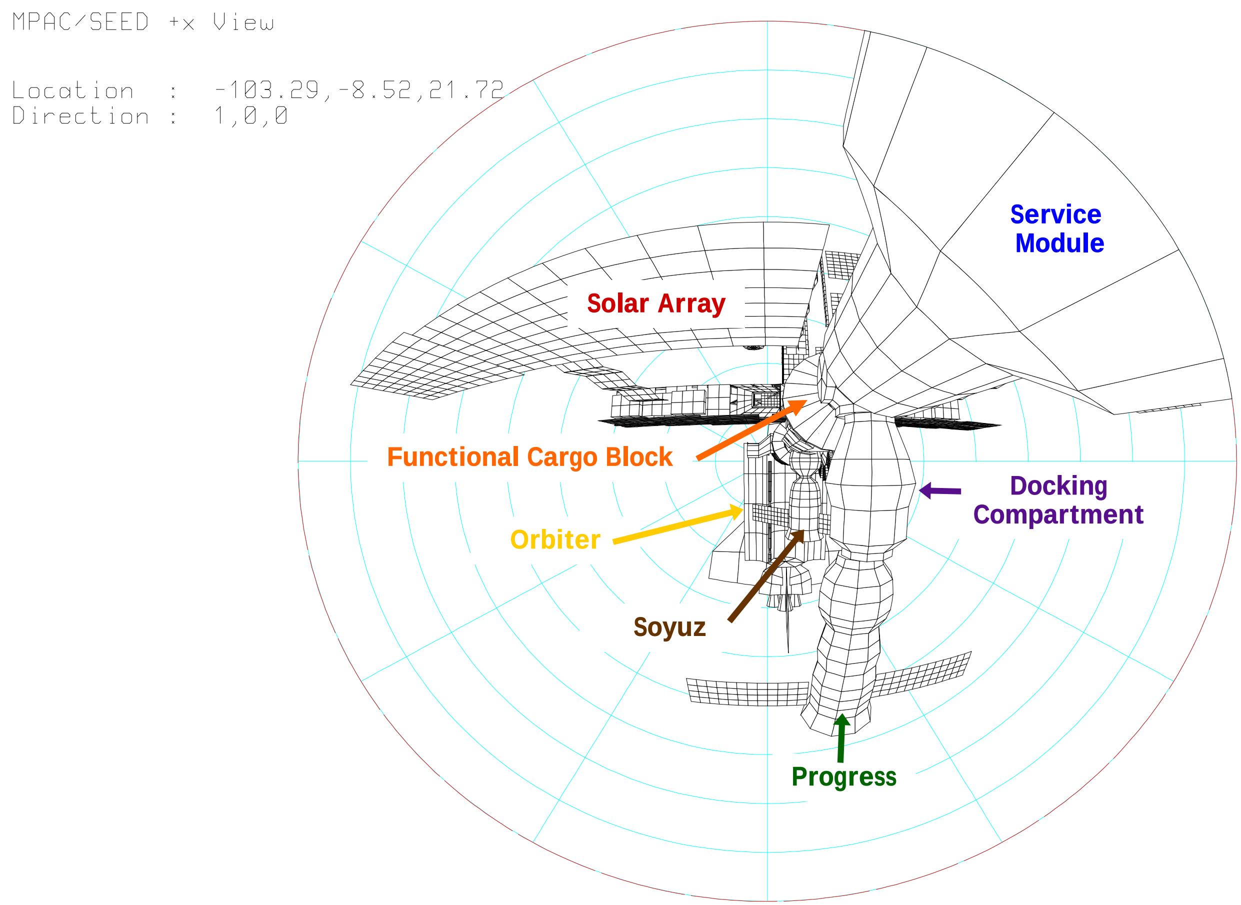
Measured Contamination Depth - Angstroms (Å)

Side	*Unit 1*	*Unit 2*	*Unit 3*
Ram (1)	300	750	930
Ram (2)	300	750	940
Wake (1)	55	100	110
Wake (2)	500	70	85

Reference: Baba, Naoko; Imagawa, Kichiro; Neish, Michael; and Inoue, Toshihiko. *External Contamination Control for JAXA Spacecraft*. ISTS 2004-h-06. Copyright 2004 by the Japan Society for Aeronautical and Space Sciences and ISTS.

Contamination Sources
Material Outgassing

- **Hemispherical View from SM/MPAC&SEED Ram Side:**



Contamination Sources
Material Outgassing

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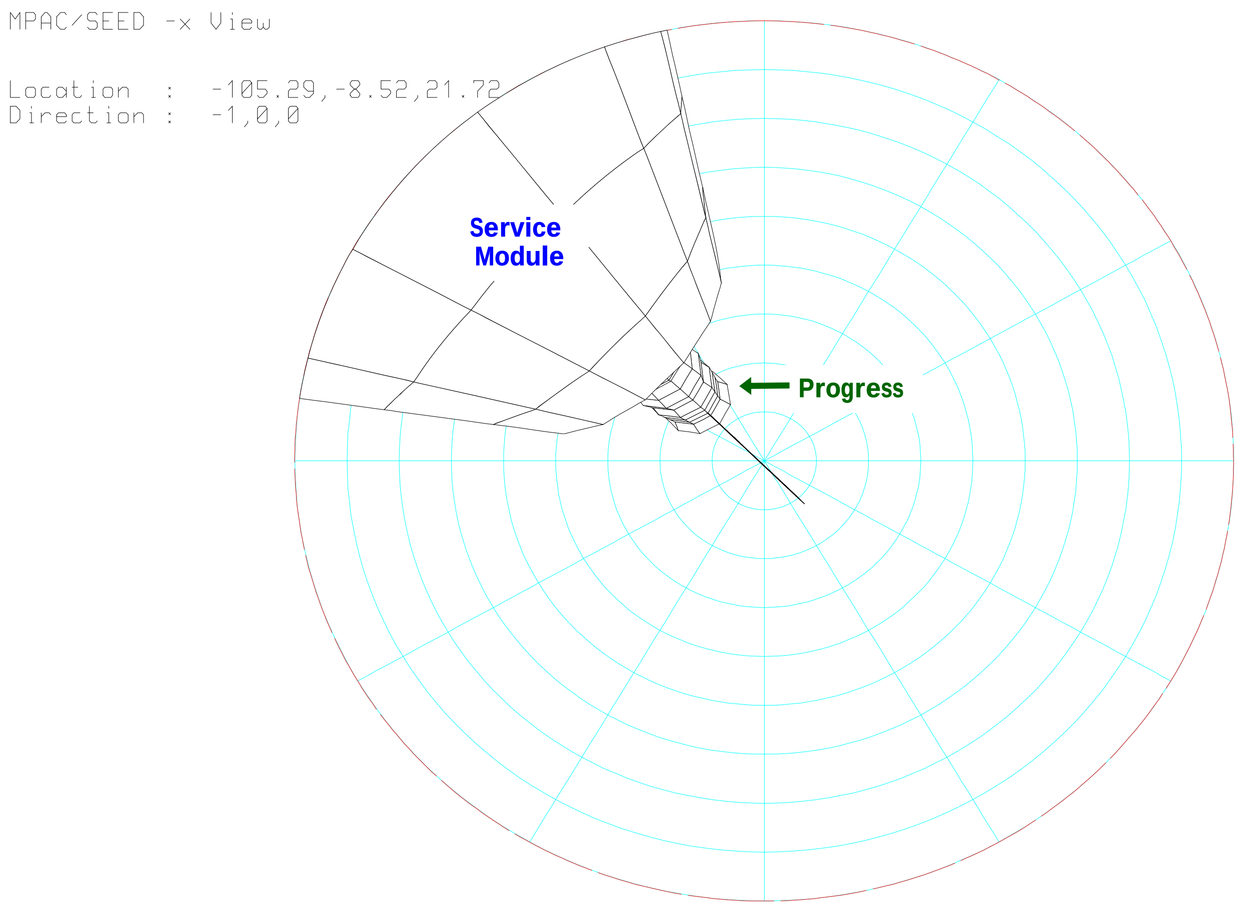
- **Hemispherical View from SM/MPAC&SEED Wake Side:**



Contamination Sources
Thruster Plume

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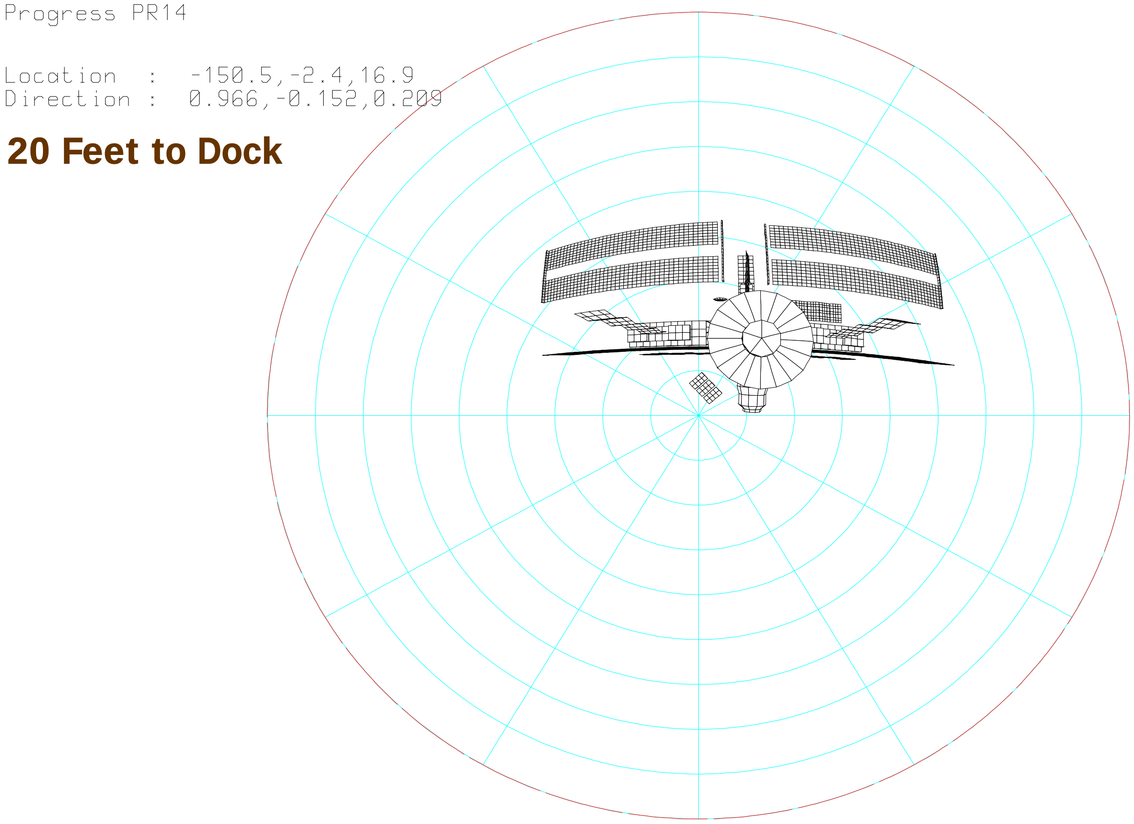
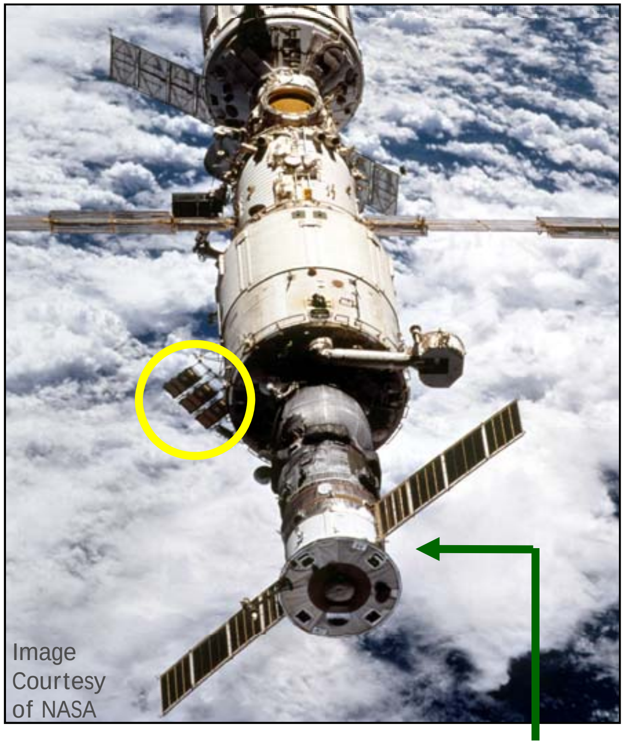
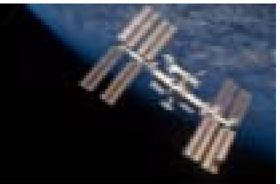
- **Hemispherical View to SM/MPAC&SEED wake side from Progress braking engines:**





Analysis Results

Example – SM/MPAC&SEED Unit 1 Ram Side (315 Days)



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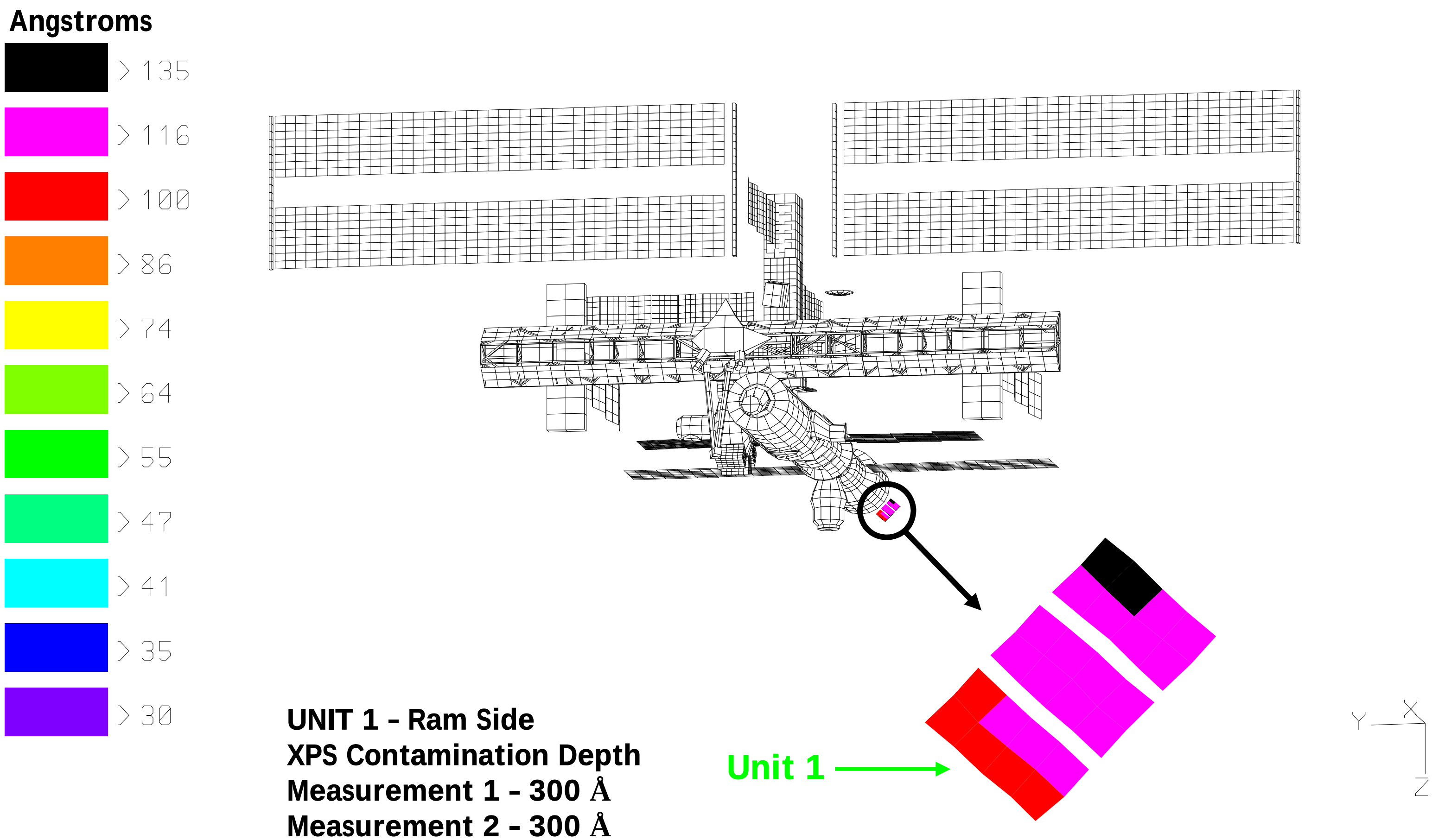
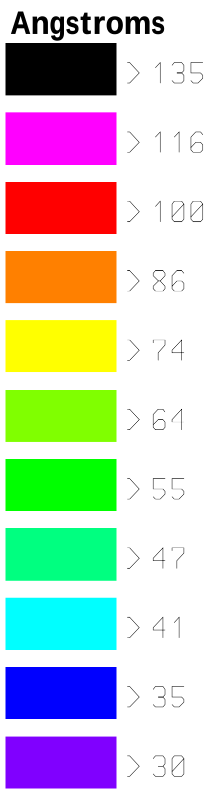
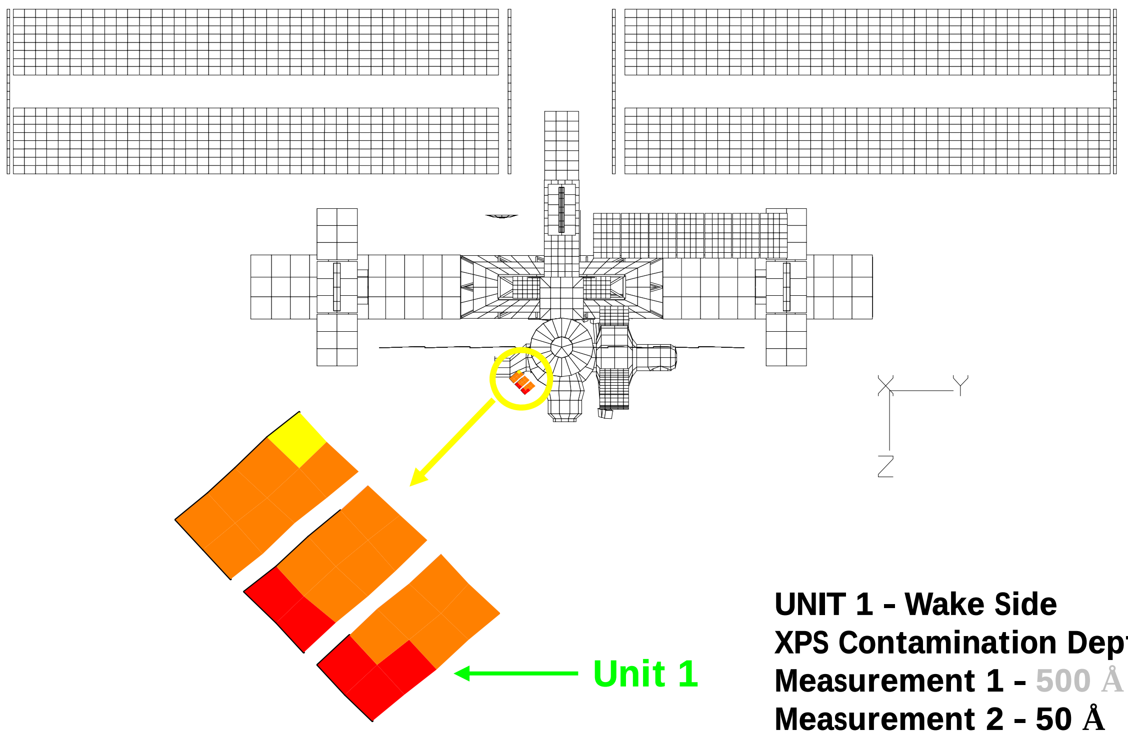


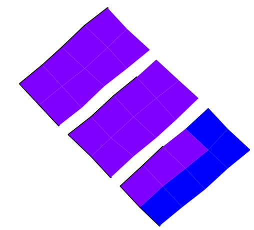
Analysis Results
Example – SM/MPAC&SEED Unit 1 Wake Side (315 Days)



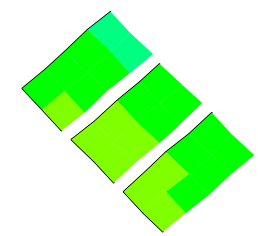


UNIT 1 - Wake Side
XPS Contamination Depth
Measurement 1 - 500 Å
Measurement 2 - 50 Å

Contribution from Material Outgassing



Contribution from Thruster Plumes



Analysis Summary
SM/MPAC&SEED

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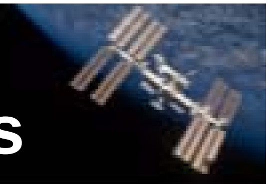
- **Results for Ram Side:**
  - Material outgassing induced contamination predicted and measured.
- **Results for Wake Side:**
  - Contamination predicted from combination of materials outgassing and thruster plume impingement.
- **Calculated depth of contamination within a factor of 2-3 of measured contamination.**

Measured Vs. Predicted Contamination Depth (Å)

Side	*Unit 1*		*Unit 2*		*Unit 3*	
	Measured	*Predicted*	*Measured*	*Predicted*	*Measured*	*Predicted*
Ram	300	106 - 135	750	303 - 354	930	459 - 533
Ram	300		750		940	
Wake	55	86 - 103	100	186 - 237	110	317 - 414
Wake	500		70		85	

Reference: C. Steagall, K. Smith, A. Huang, C. Soares, and R. Mikatarian. *Induced Contamination Predictions for JAXA's Micro-Particles Capturer and Space Environment Exposure Devices*, Proceedings of the International Symposium on the SM/MPAC&SEED Experiment, Tsukuba, Japan, 18 April 2008.

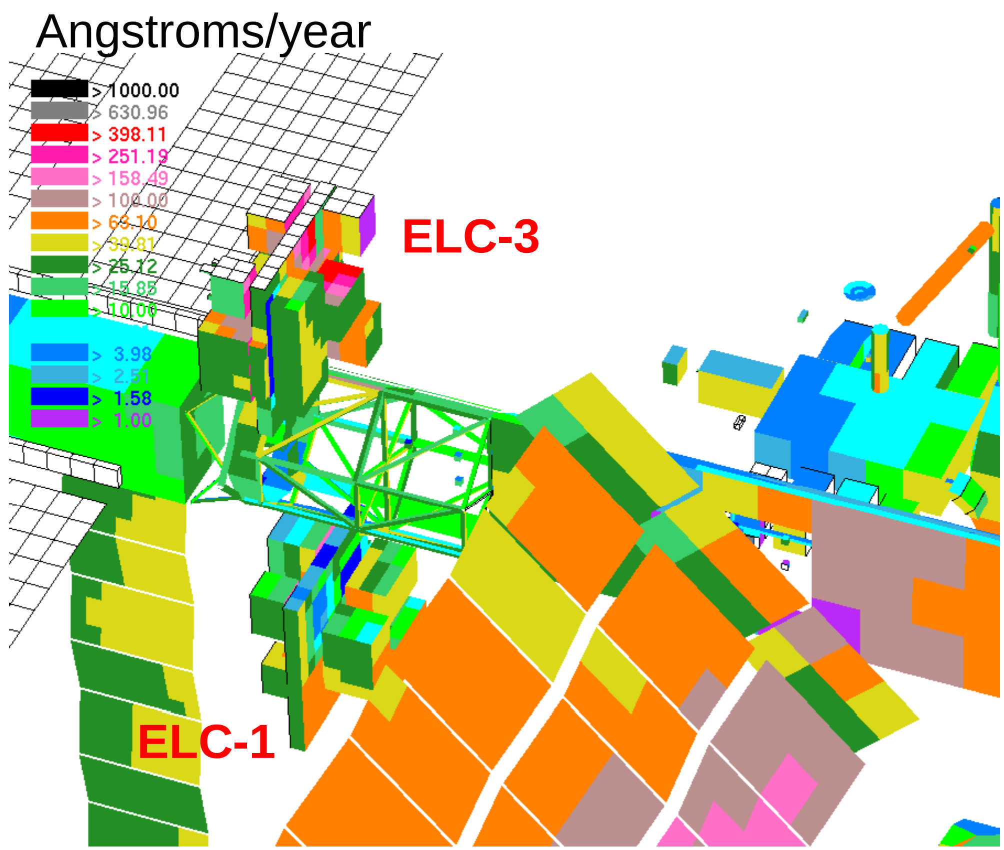
SM/MPAC&SEED Measurements Vs. Predictions



- **Results are qualitatively consistent with XPS measurements.**
  - On ram side, predictions and measurements dominated by a silicon-based contaminant.
  - Lesser degree of silicon-based contaminant predicted and measured on wake side.
  - Droplet features and presence of Nitrogen on wake side are indicative of thruster plume induced contamination.
- **Predicted results for Ram Side show good agreement with XPS measurements.**
  - Possible improvements for material outgassing calculation:
    - Better characterization of the outgassing sources.
    - Additional consideration for on-orbit thermal environment.
- **XPS measurements have limitations in regard to quantifying plume contamination.**
  - Thruster plumes have multiple byproducts.
  - Dominated by the liquid phase, producing droplet features and a non-uniform contamination layer.

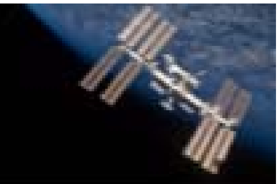
Contamination Mapping

- **Contamination forecast maps are being generated for U.S. attached payload sites to support payload feasibility, topology and placement studies**



HTV-3 Mission Annualized Contamination from Outgassing

Conclusions



- **Multiple science payloads introduce complex induced contamination environment interactions that must be accounted for successful integration of the payload complement in operation on ISS**
- **External payloads must be designed to perform within the ISS induced environment which includes contributions from visiting vehicles and its payload complement**
- **Since each external payload is also a contributing source of contamination, its contaminant releases must be controlled for compatibility with existing requirements**
  - These requirements protect the ISS and the existing external payload complement from excessive contamination
- **Payload developers supply the required data certification deliverables characterizing the sources of contamination on the payload**

Conclusions (concluded)

- **Characterization includes identification, usage and operational data for each class of contamination source (vacuum exposed materials, leakage sources, vacuum venting, thrusters and sources of particulates)**
- **ISS system level analyses are conducted to certify compliance with external contamination control requirements**
- **Contaminant deposition measurements have been made on returned hardware and comparisons to analysis predictions have been made to assess performance against expectations**
- **Measurements made on MISSE 2 gold mirror samples show that contaminant deposition levels were within the system level specification and in excellent agreement with predictions**
- **Measurements made on SM/MPAC&SEED likewise show that contaminant deposition levels are in excellent agreement with predictions**

Backup

Ram Views from MISSE-1

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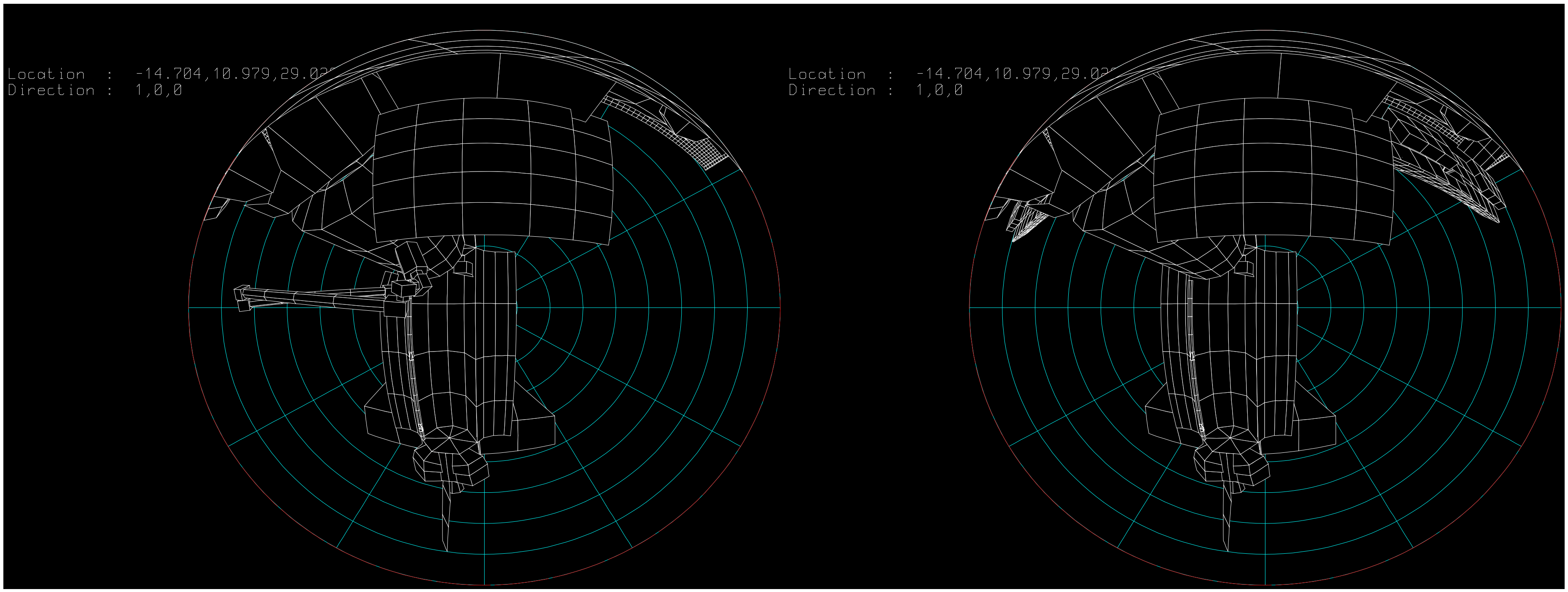

Wake Views from MISSE-1

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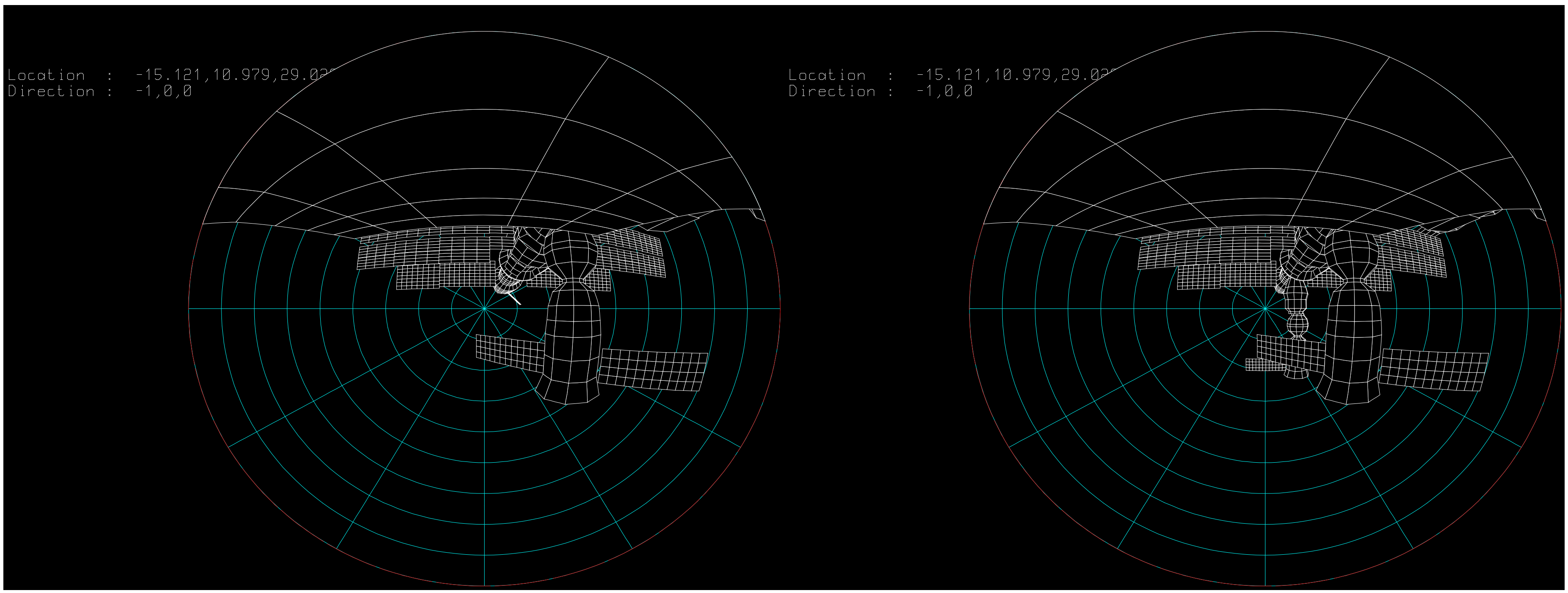

Ram Views from MISSE-2

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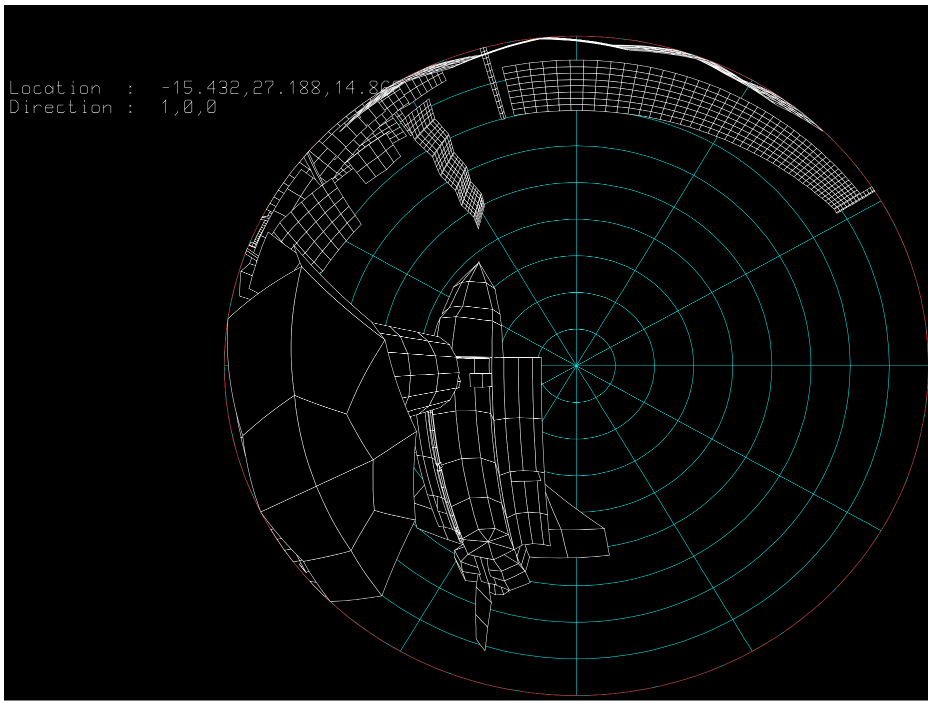
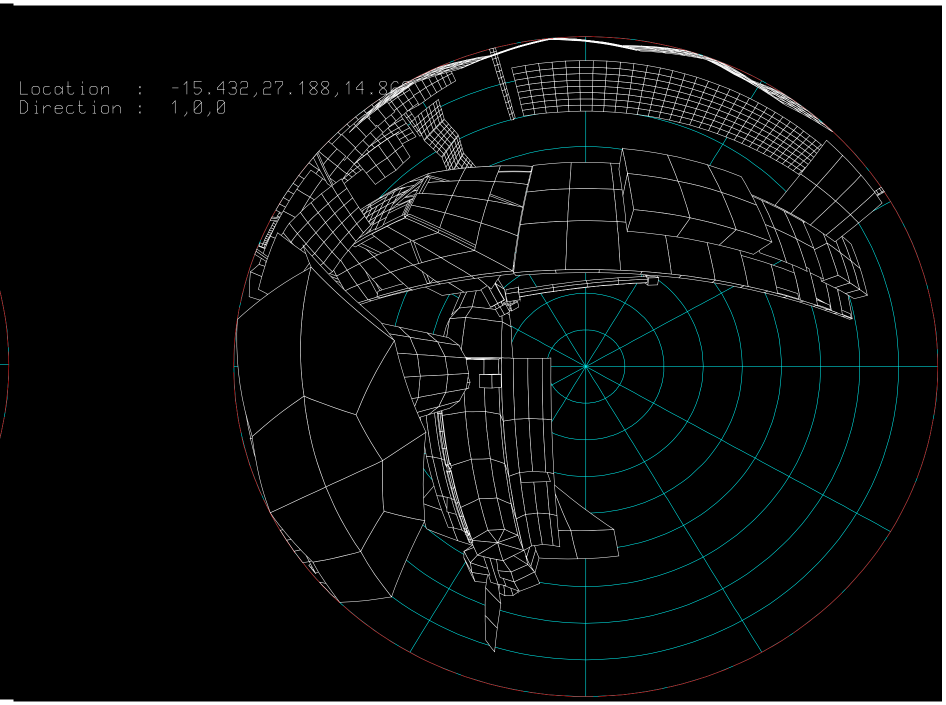


11A



Wake Views from MISSE-2

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