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External Contamination Integration of Visiting Vehicles on the International Space Station

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Introduction

- The International Space Station (ISS) external contamination environment includes contributions from ISS elements, visiting vehicles, and external payloads.
- External contamination can impact performance, mission success, and science utilization.

Visiting vehicles induce multiple types of molecular contamination on ISS, such as materials outgassing and thruster plume-induced contamination.

Visiting Vehicles Contamination Examples

Images Courtesy of NASA

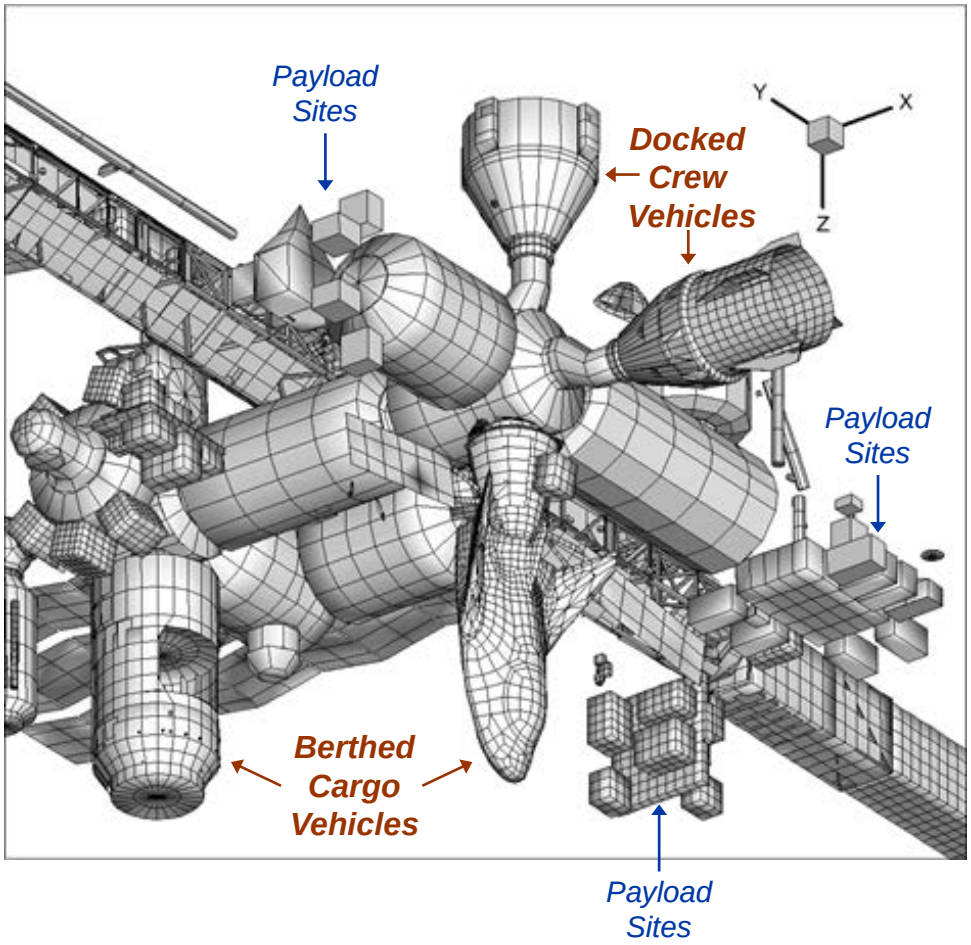
Visiting Vehicles at ISS

- **ISS is currently visited by commercial cargo vehicles and international partner spacecraft.**
- **Several commercial crew and cargo vehicles are in development.**

ISS Program emphasis has shifted from assembly to science utilization

→ Critical to maintain ISS contamination control requirements

U.S. Segment Docking and Berthing Ports



Visiting Vehicle Contamination Concerns

- Materials outgassing
- Thruster plume induced contamination
- Thruster plume induced erosion/pitting
- Vacuum venting/leakage
- Particulates
- Induced contamination to unpressurized cargo
- Visiting vehicle contamination sensitive surfaces

The Space Environments Team of the ISS Program Office has developed visiting vehicle requirements and methodologies to address the increasingly complex challenge of integrating multiple visiting vehicles while maintaining overall ISS contamination control requirements.

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
  - Specifies an induced contaminant deposition limit equivalent to **130 Å/year** on contamination sensitive surfaces from all sources of contamination on the vehicle combined
- **The ISS to Commercial Orbital Transportation Services (COTS) Interface Requirements Document (IRD) identifies the applicable ISS requirements that commercial visiting vehicles must meet and the methods of verification (SSP 50808).**

Visiting vehicle external contamination requirements developed for compatibility with system level requirements.

Visiting Vehicle Interface Requirements
(SSP 50808 ISS to COTS IRD)

Section	Description
Cleanliness 3.3.1.3.6.B	Cleanliness requirement for exterior surfaces to be maintained during ground processing.
External Contamination *Design Environment* 3.3.9.2	The on-orbit quiescent and non-quiescent contamination environments that the visiting vehicle must operate in.
Contamination of the ISS *Contamination Releases* 3.3.10.2.A/B/C/D	A. Limits **cargo vehicle materials outgassing**-induced contamination to **2.5 Å/mission**. B. Limits **thruster plume**-induced contamination to **2 Å/mission** (i.e., for proximity operations) C. Prohibits **venting**/release of chemically reactive substances that can degrade/damage ISS. D. Limits **crew vehicle materials outgassing**-induced contamination to **15 Å/mission**.
Venting 3.3.10.3	Prohibits venting/release of liquid water/waste (water vapor is permitted).

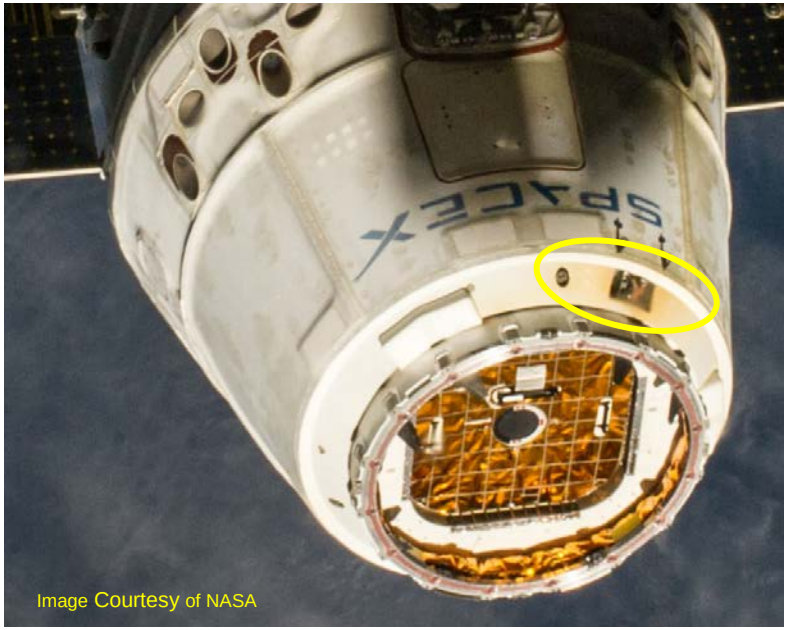
Verification Data Deliverables

- **Verification analyses address visiting vehicle-induced contamination to ISS systems, payloads, and other visiting vehicles.**
  - Visiting vehicle and ISS system level external contamination analyses are performed by ISS Space Environments Team.
- **Visiting vehicle providers are responsible for detailed characterization of visiting vehicle contamination sources:**
  - Vacuum exposed materials (all non-metallic materials outside of a pressurized or hermetically sealed environment)
  - Thruster plumes
  - Vacuum venting (liquids and gases)
  - Sources of particulate releases

Verification Data Deliverables

Materials Outgassing

- **Required data for <u>all</u> non-metallic vacuum exposed materials (including materials in interstitial volumes):**
  - Material identification
  - Location of application on vehicle
  - Vacuum exposed surface area
  - Nominal operating temperature data
  - Outgassing rate data from ASTM E1559 testing



- **On-orbit operating temperature data is a critical input, since outgassing rates can increase significantly with temperature.**
  - Material time-at-temperature data is required to reduce conservatism (i.e., compared to using only maximum operating temperature data).
  - Thermal data corresponding to discrete solar beta cases may be required for TPS / external materials that receive direct illumination.

Verification Data Deliverables

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 (i.e., operating temperatures of ISS contamination sensitive surfaces)
- **Test samples should be configured as flight-like as possible and prepared/processed to flight specification.**

ASTM E595 Total Mass Loss and Collected Volatile Condensable Materials data does not characterize condensable outgassing rates and is not accepted in place of ASTM E1559 test data.

Verification Data Deliverables

Thruster Plumes

- **Required thruster parameters for chemical thrusters:**
  - Location and orientation
  - Propellant mass flow rate
  - Thrust
  - Specific Impulse (I_{sp})
  - Thruster performance test data (i.e., I_{sp} vs. pulse width).
  - Characterization of catalyst ejecta (i.e., for monopropellant thrusters).
- **A database of thruster firing histories for visiting vehicle approach and departure proximity operations with ISS is also required (i.e., timelines of simulated thruster firings).**

Thruster plume contamination occurs in the liquid phase (i.e., unburned/partially burned propellant) in the plume, primarily during start-up and shut-down.

Verification Data Deliverables

Vacuum Venting and Particulates

- **Vacuum venting is a source of molecular contamination and can impact the ISS molecular column density environment. Required inputs:**
  - Vent location / orientation / geometry
  - Composition (including trace elements)
  - Mass flow rate
  - Operational frequency and duration
  - Exit conditions (pressure, temperature, velocity)
- **If a visiting vehicle will release particulates or other sources of contamination (e.g., pyrotechnics), characterization data is required (e.g., composition, plume/particle dispersion models).**

Visiting vehicle propellant purges/liquid venting is prohibited as this can produce frozen particulates that can be a source of damage through direct contact or orbital recontact.

Integration and Verification Workflow

Kick-off
- Technical Interchange Meetings
- Requirements and Data/ Verification Plans
- Parametric Studies

Vehicle Developer

Preliminary Data Delivery
L-24 months
- Materials data
- Thruster data
- Vent / particulate data

Interim Updates
- Design changes / data refinements
- ASTM E1559 test coordination
- Thruster test coordination
- Analysis updates

Space Environments

Preliminary Analyses
- Preliminary analyses
- Identify contamination issues and make recommendations

Vehicle Developer

Final Data Delivery
L-6 months
- Finalized Input Data
- ASTM E1559 Testing Complete

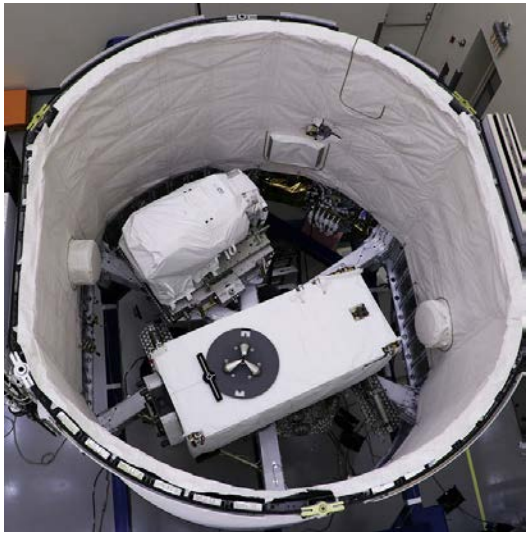
Space Environments

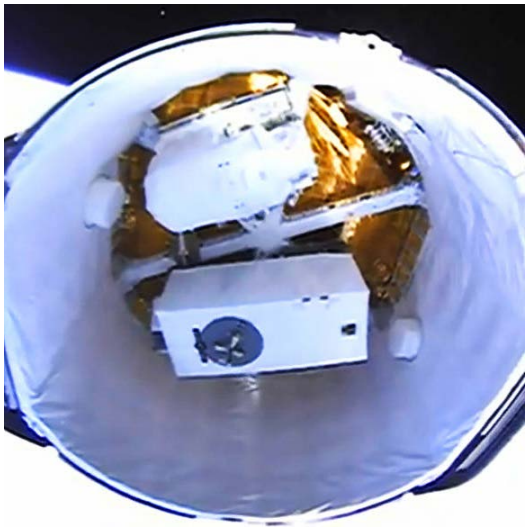
Final Verification Analyses
- Visiting Vehicle Contamination
- ISS System Level Contamination

Launch!

Unpressurized Cargo Integration

- **The Space Environments Team performs unpressurized cargo contamination integration analyses to characterize the contamination environment of payloads/cargo while in transit:**
  - Materials outgassing
  - Visiting vehicle / upper stage thruster plumes
  - Particulates due to pyrotechnics/fairing separation/stage separation
  - Visiting vehicle / upper stage venting/leaking





Images Courtesy of NASA

Unpressurized Cargo Integration

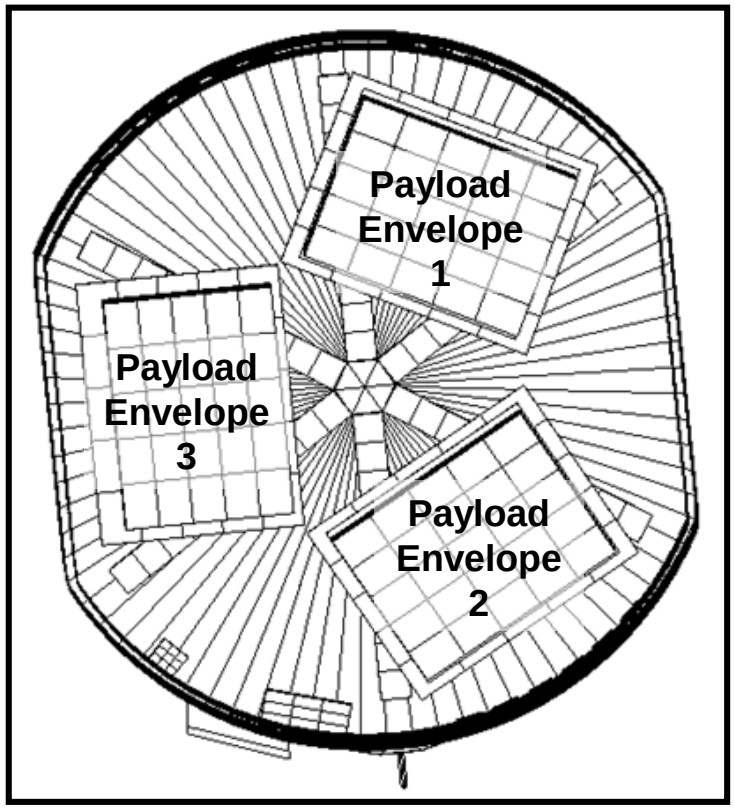
Generic and Flight Specific Materials Outgassing Analyses

Generic Analysis

Generic payload envelopes

Vehicle-induced contamination only

Readily available

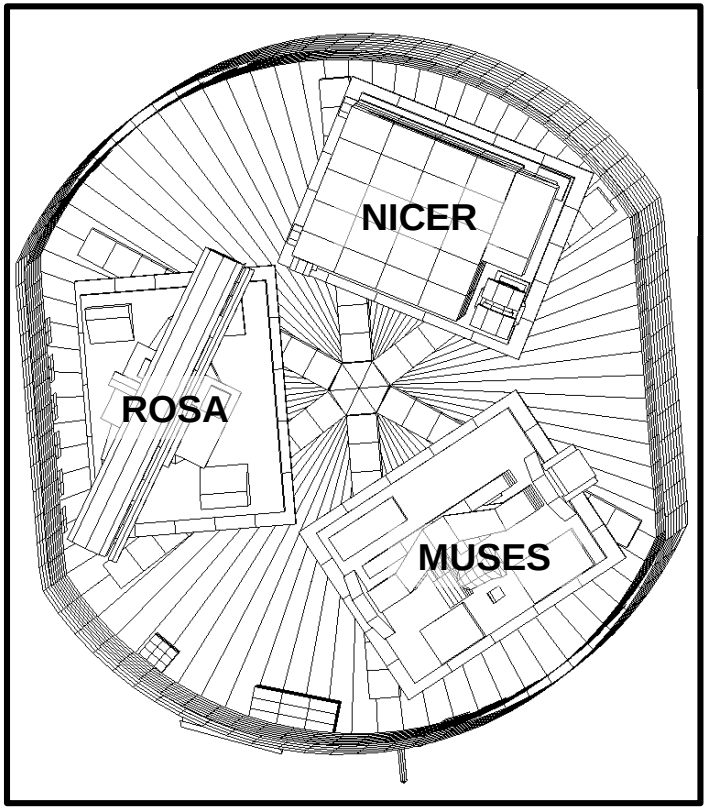


Flight-Specific Analysis

Actual payload configurations

Includes payload-to-payload contamination

Available ~6 months prior to launch



Unpressurized Cargo Integration
Requirements

- **The ISS Program Cargo Transport IRD (SSP 50833) identifies the requirements that COTS vehicle providers must meet for cargo transportation to and from the ISS.**
  - Ground processing / cleanliness
  - Visiting vehicle induced contamination during transit to ISS (i.e., prior to payload installation)
- **Visiting vehicle-induced contamination prior to payload deployment is <u>not</u> included in the 130 Å/year ISS system level limit.**

If a payload is highly sensitive to molecular or particulate contamination, protective measures may be warranted (e.g. temporary covers).

Performance Vs. Expectation

Returned Flight Hardware

- **Space Environments has shown good agreement between contaminant deposition measurements made on returned hardware and analysis predictions.**

MISSE Flight Experiment

Returned after 4 year mission

Exposed to Space Shuttle and Russian vehicles

Excellent agreement between predicted and measured contamination (within factor of ~1.6).

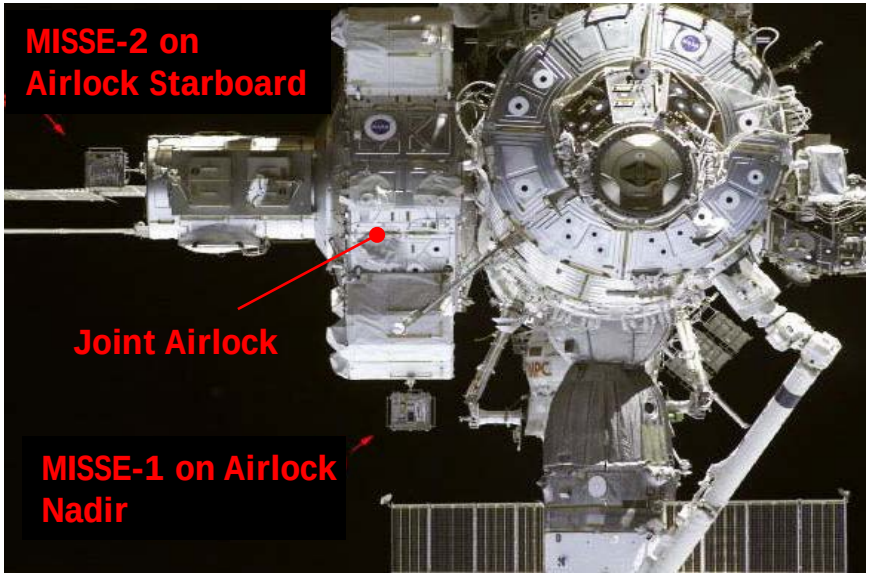


Image Courtesy of NASA

MPAC-SEED Flight Experiment

Incremental tray return (1, 2.5, and 4 years)

Exposed to Space Shuttle and Russian vehicles

Very good agreement between predicted and measured contamination (within factor of 2-3).

Image Courtesy of NASA

Performance Vs. Expectation

On-orbit Imagery

- **Space Environments has also used on-orbit imagery of contamination to corroborate visiting vehicle contamination analysis predictions**

Discoloration of the Node 2 nadir common berthing mechanism

(Composite Image)

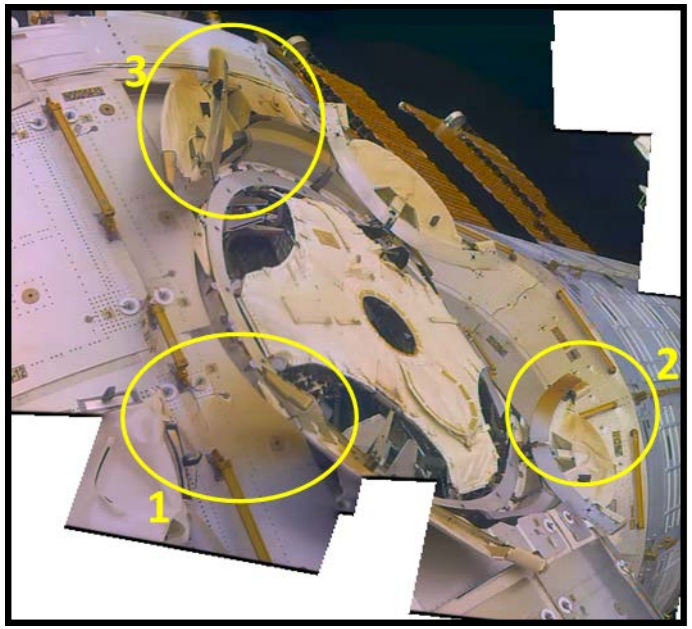
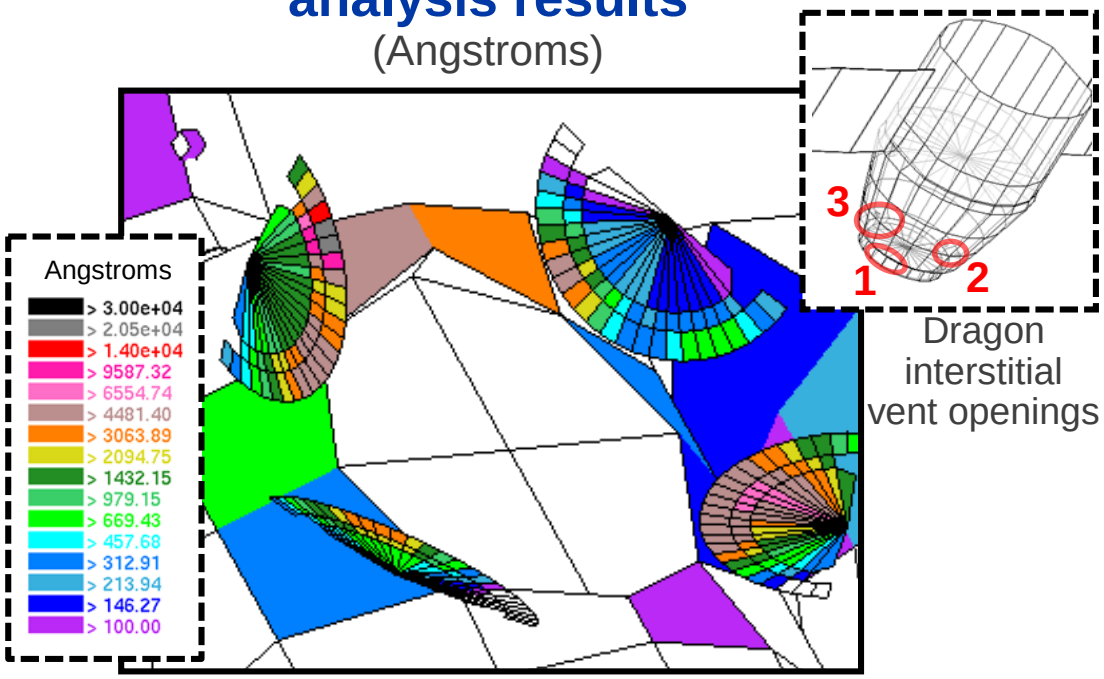


Image Courtesy of the NASA
Image Science and Analysis Group

Dragon materials outgassing analysis results

(Angstroms)



Performance Vs. Expectation

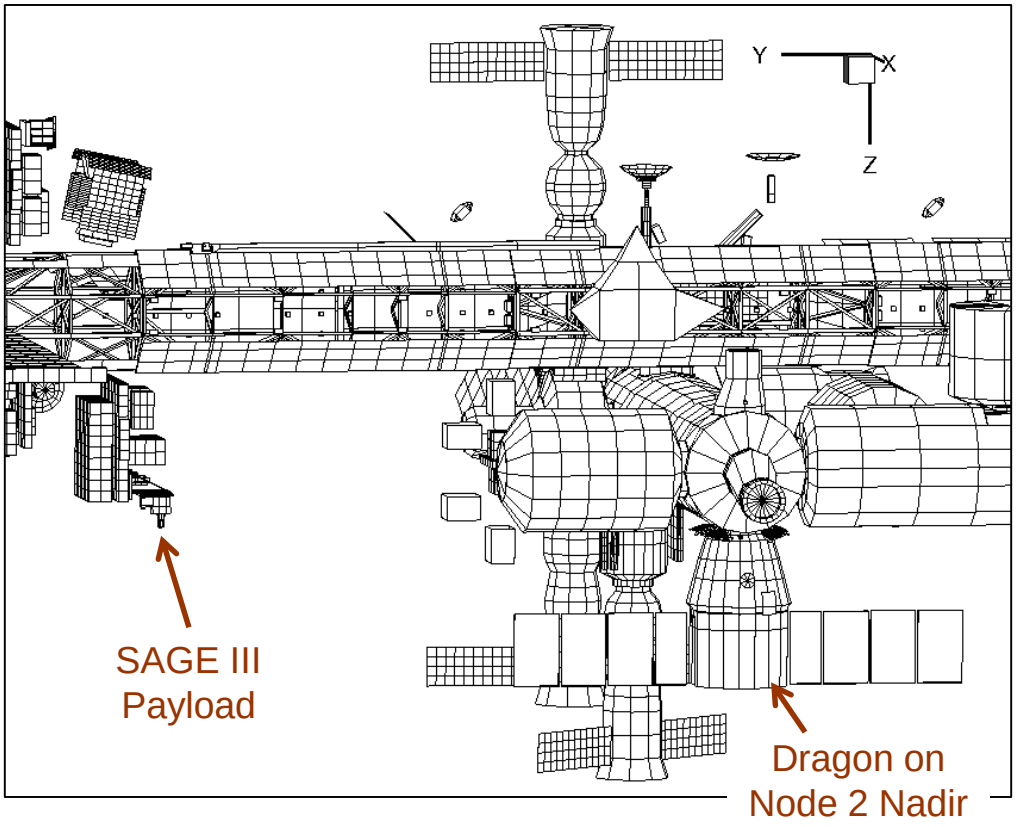
SAGE III Contamination Measurements

- **ISS now has active contamination monitoring, following the arrival of the Stratospheric Aerosol and Gas Experiment III (SAGE III) in Feb. 2017.**
  Note: SAGE III is a NASA Langely payload that measures scattering of solar radiation in the Earth's atmosphere (i.e., limb scattering) to determine the amounts of its components.
- **SAGE III houses eight Thermoelectric Quartz Crystal Microbalances (TQCMs) as part of a contamination monitoring package. Initial observations:**
  - The majority of ISS permanent modules and visiting vehicles are having minimal contributions to contamination.
  - However, the SAGE III TQCMs have consistently measured higher than expected contamination levels while the Dragon cargo vehicle is present at ISS.

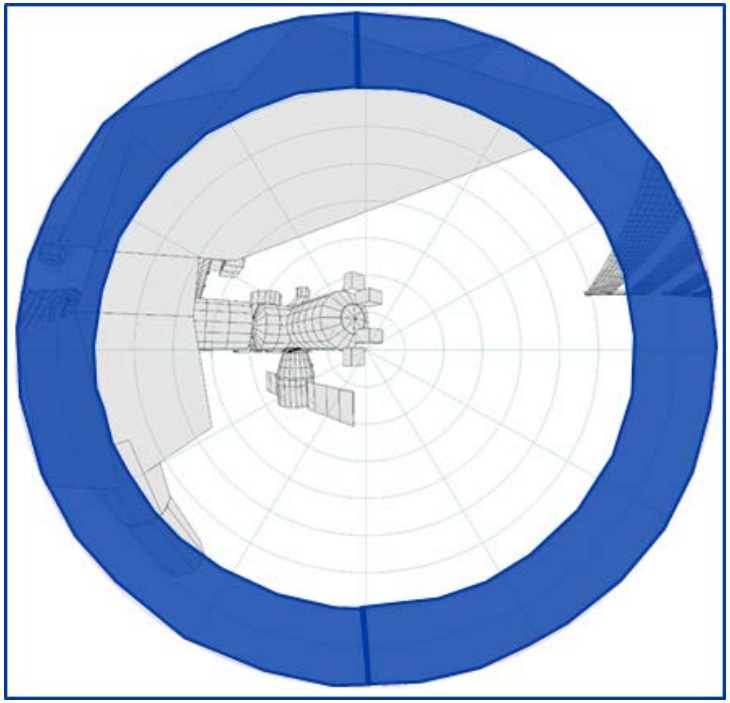
The SAGE III TQCM data indicates that there is a Dragon material outgassing source that needs to be identified and evaluated for impacts to ISS payload sites and hardware.

Performance Vs. Expectation

ISS Geometric Model with SAGE III and Dragon



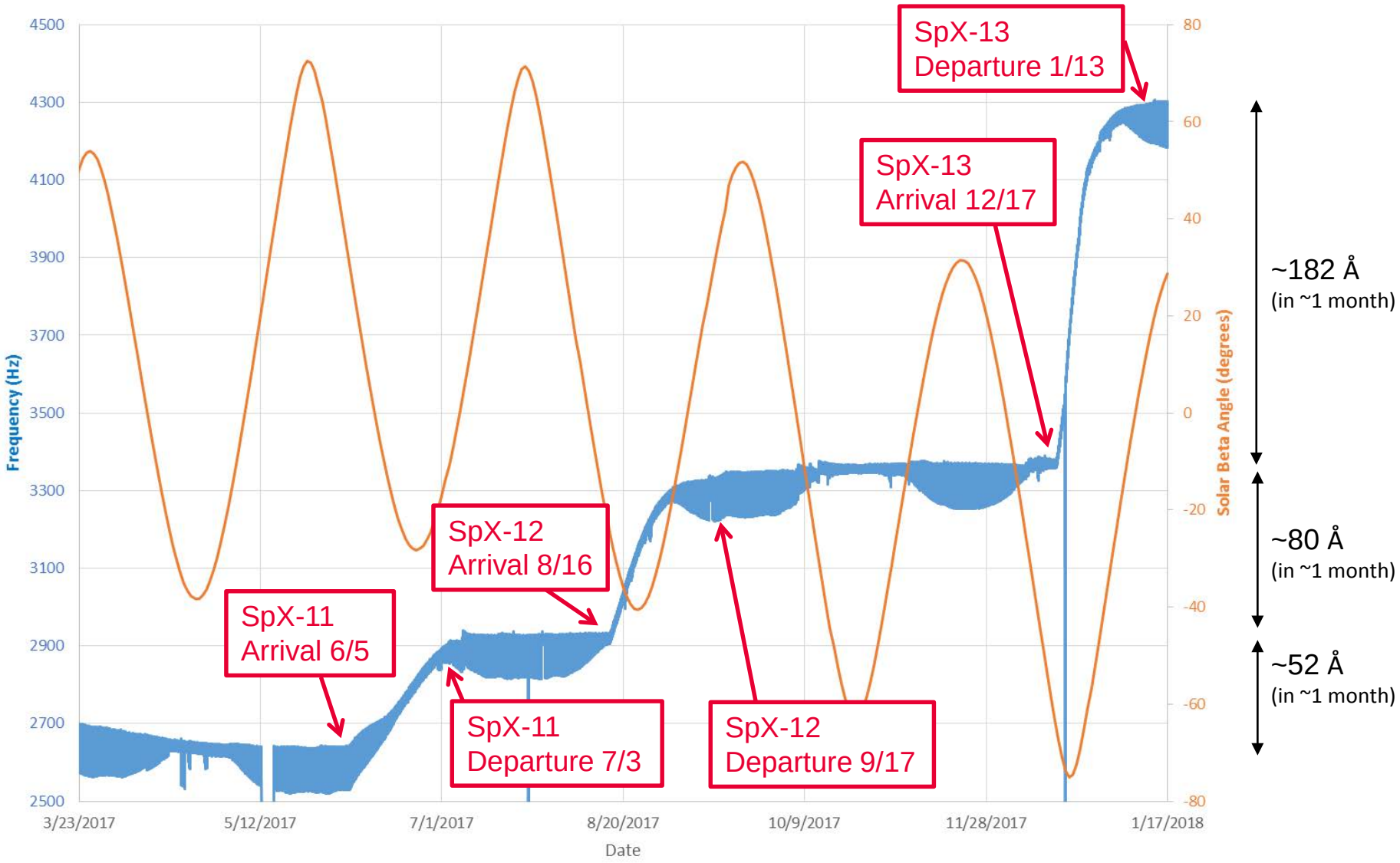
Dragon in SAGE III TQCM
Field-of-View



The Space Environments Team has been tasked to review and interpret the TQCM data and develop an understanding of the cause of the high contamination levels being detected

Performance Vs. Expectation

Example SAGE III TQCM Frequency Data



Performance Vs. Expectation

Solar Beta Dependency

- **There are 2 factors tied to solar beta that could affect material outgassing rates:**
  1. **Material heating / operating temperature**
     Space Environments has assessed via a parametric study that increasing material operating temperatures could account for the observed deposition.
  2. **Ultraviolet (UV) Illumination**
     Ground testing and satellite data have shown that UV illumination can impact material optical properties and contaminant layers.

Space Environments is implementing a resolution plan to address the possibility of elevated Dragon material operating temperatures and/or UV illumination affecting deposition.

Performance Vs. Expectation

Empirical Assessment of Dragon Contamination

- **In parallel with the on-going investigation, Space Environments has developed an empirical Dragon contamination model based on the SAGE III TQCM measurements.**
- **Empirical model used to assess Dragon materials outgassing induced contamination to ISS hardware and payload sites.**
  - Assessment showed that only 7 of the 56 USOS hardware and active payload sites sensitive to induced contamination could experience exceedances of the system level requirement (130 Å/year).
  - The empirical data can be used for hardware impact assessments, payload placement studies, and other system integration activities until the contamination source(s) and corrective actions are ultimately identified.

This investigation highlights the importance of well-characterized vacuum-exposed materials and operating temperature data for visiting vehicles.

Conclusions

- **The Space Environments Team has developed visiting vehicle requirements and methodologies to address the increasingly complex challenge of integrating multiple visiting vehicles while maintaining ISS contamination control requirements.**
  - Visiting vehicle providers supply contamination characterization data (e.g., vacuum exposed materials, thruster plumes, vacuum venting, particulates).
  - The Space Environments Team performs integrated analyses, addressing visiting vehicle induced contamination to ISS and unpressurized cargo.
- **On-orbit measurements have confirmed the visiting vehicle analysis and integration approach.**
  - However, Space Environments is actively investigating higher-than-expected contamination levels observed while the Dragon cargo vehicle is present at ISS.

Early and close coordination with visiting vehicle providers on external contamination requirements and data deliveries is essential for early identification of potential issues and successful integration with ISS.

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