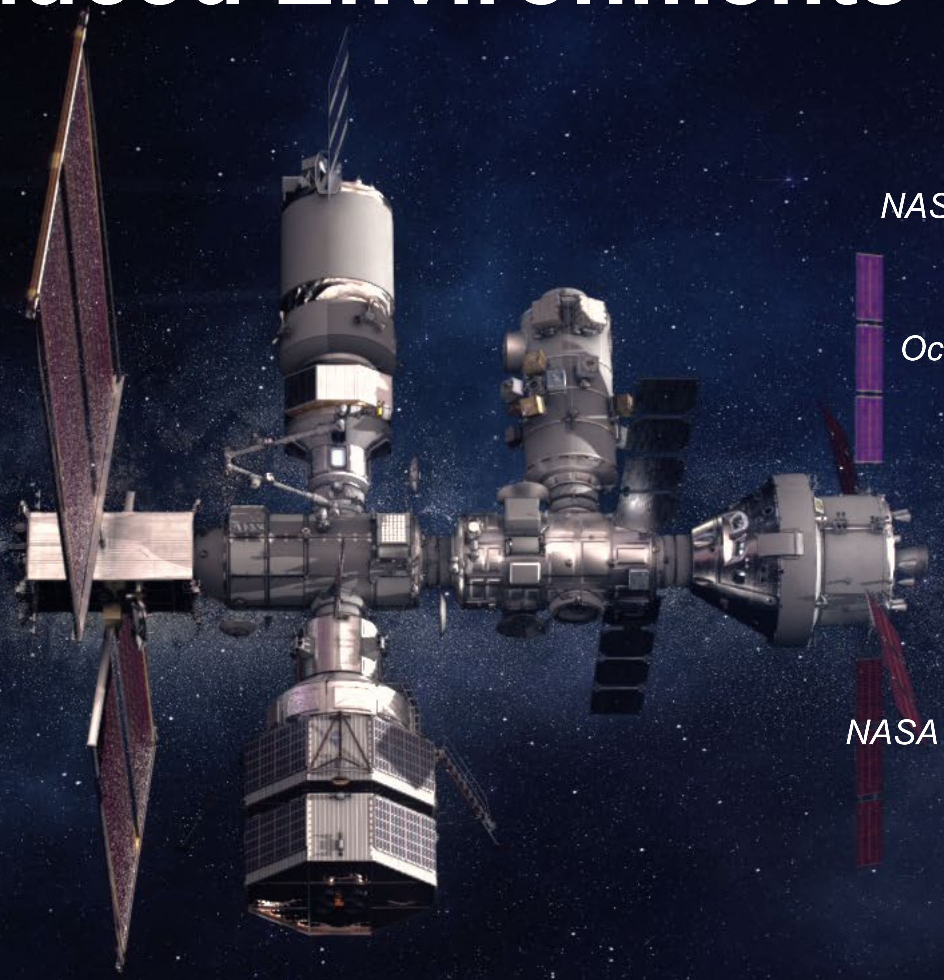
Gateway Induced Environments Overview



Courtney A. Steagall
NASA Johnson Space Center, Houston, TX, USA,
courtney.a.steagall@nasa.gov

Crystal A. Quiroz
Oceaneering, JETS Contract, Houston, TX, USA

Gary L. Brown
Barrios Technology, Houston, TX, USA

Ronald G. Lee, Jr
Booz Allen Hamilton, Houston, TX, USA

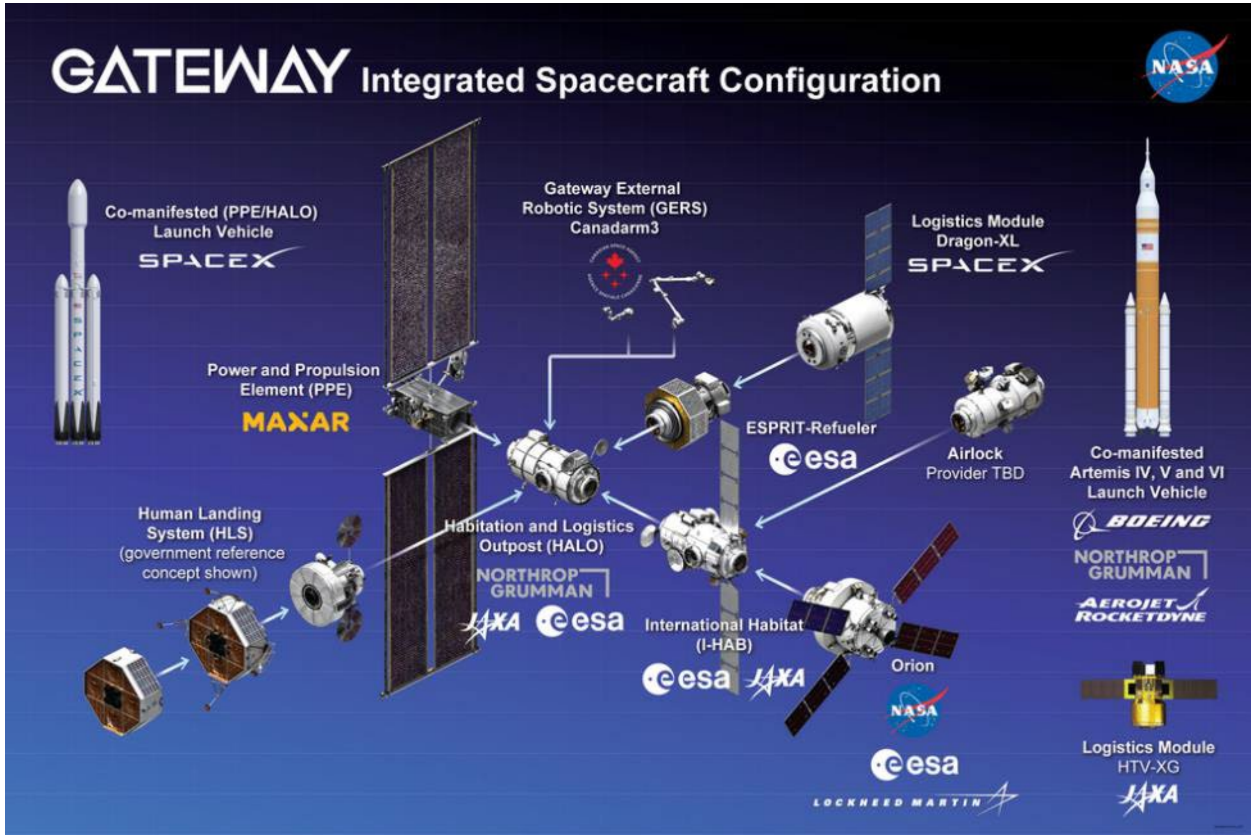
Maria Choi
John T. Yim
NASA Glenn Research Center, Cleveland, OH, USA

John M. Alred
John R. Anderson
William A. Hoey
Maxwell G. Martin
Gregory S. Shallcross
Carlos E. Soares
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

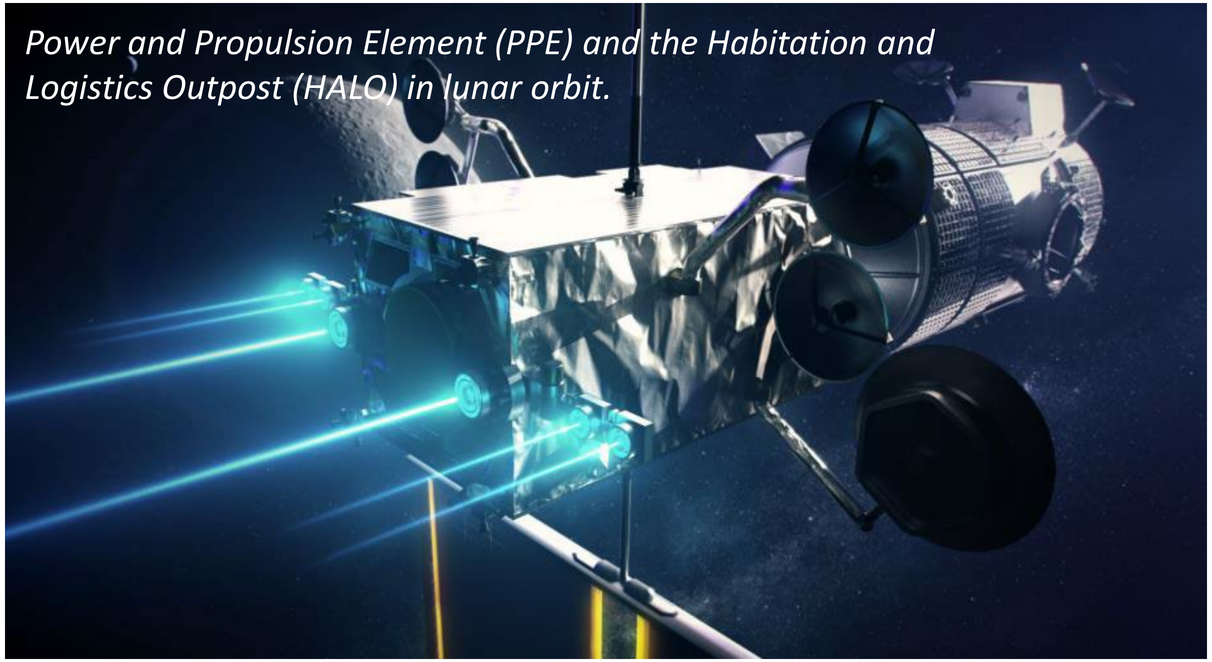
2023 **CCMPP**
Contamination, Coatings, Materials, and Planetary Protection Workshop
NASA Goddard Space Flight Center
Sept. 12-14, 2023

Publicly Available - NASA NF-1676 #20230011722

Introduction – Gateway



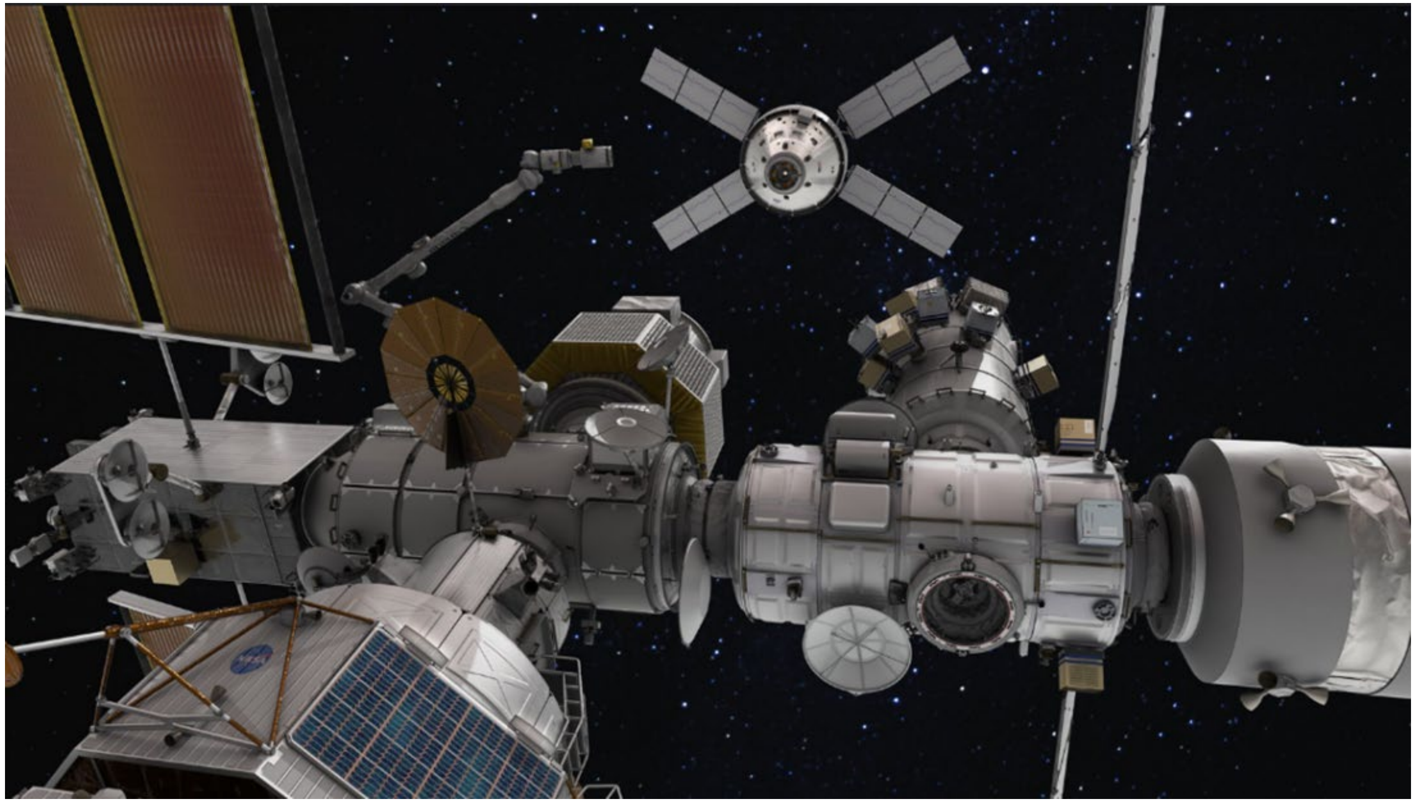
- **Gateway will be a long duration space station orbiting the Moon in support of NASA's Artemis campaign.**
- **The first two elements of Gateway will launch together (co-manifested) on a commercial vehicle no earlier than Nov. 2025.**



Images courtesy of NASA

Introduction – Gateway Induced Environments

- **Over its assembly and lifetime, Gateway will be exposed to a variety of induced environments, including:**
  - Lunar dust transport (from the Human Lander System, HLS)
  - Chemical and electric thruster plumes
  - Materials outgassing
  - Vacuum vents
- **Gateway elements and visiting vehicles will also contribute to these induced environments.**
- **Induced environments can impact vehicle performance, utilization, and mission success.**



The Gateway Induced Environments Team has developed induced environments requirements and methodologies to support successful Gateway system integration.

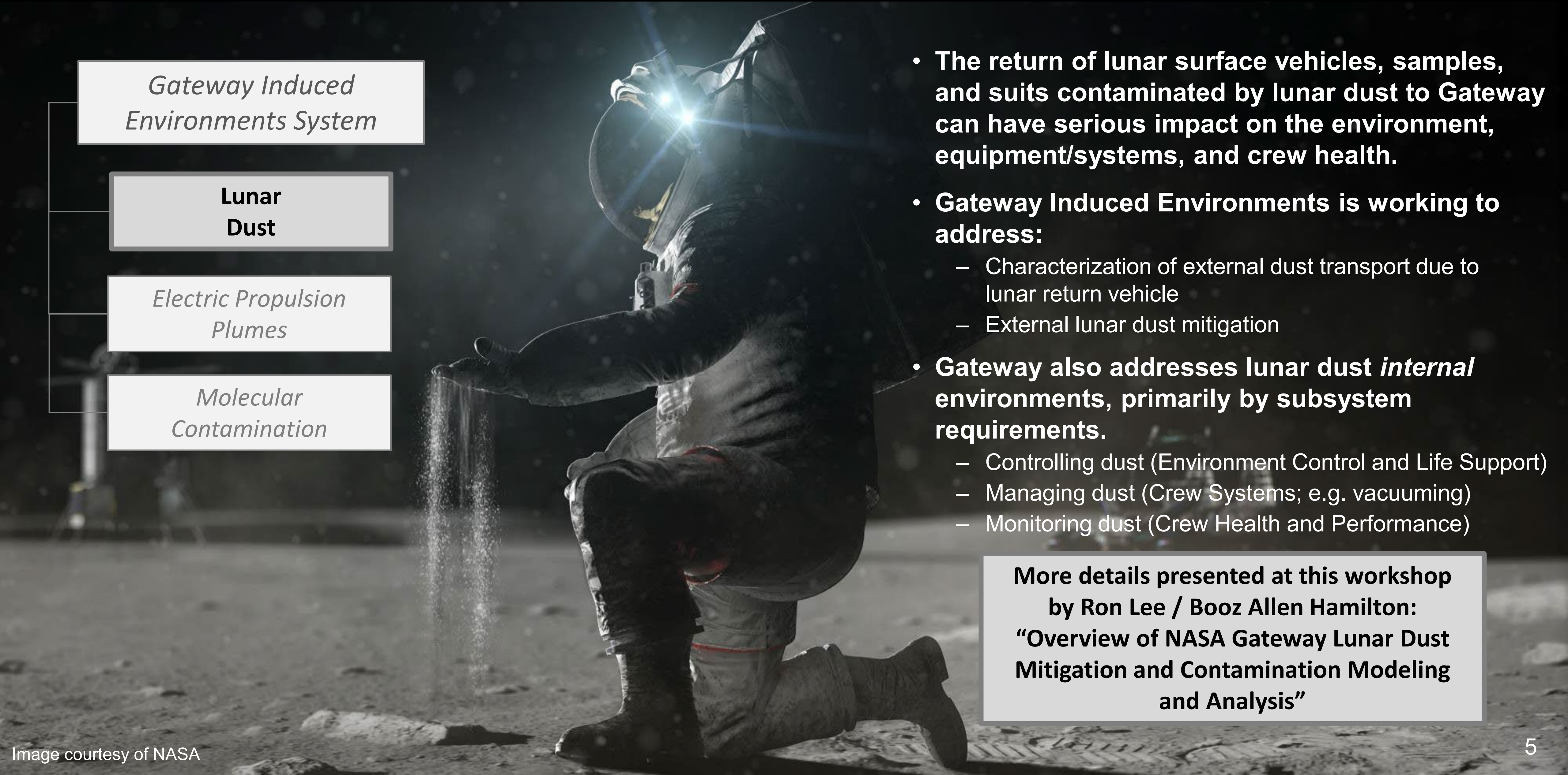
Image courtesy of NASA

Gateway Induced Environments System

- **Gateway Induced Environments System**
  - **Lunar Dust**
  - **Electric Propulsion Plumes**
  - **Molecular Contamination**

GP 10057 ‘Gateway Space Induced Environments Requirements’	
Induced Environments Limits *Verified by Gateway analysis*	Defines Gateway induced environments limits that Gateway will be managed to: • Specifies **lunar dust contamination** due to transfer from of a returning Lunar Surface excursion vehicle. • Specifies **sputter erosion limit of 100Å/year** due to electric propulsion thrusters plume impingement on Gateway sensitive surfaces. • Specifies a **molecular contamination limit of 250 Å/year** on contamination sensitive surfaces from all sources (Note: Includes corresponding element-level allocations.) • Limits **venting** of substances that contaminate or degrade external surfaces.
Vehicle Performance (Design to’s) *Verified by hardware owners (e.g. hardware impact assessments / mitigations)*	Defines the on-orbit induced environments that Gateway elements, visiting vehicles, payloads, etc. must operate in (e.g. hardware impact assessments / mitigations): • Lunar dust contamination • Electric propulsion induced sputtering and plasma. • Molecular contamination limit of 250 Å/year.

Spotlight on Lunar Dust



Gateway Induced Environments System

- **Lunar Dust**
- *Electric Propulsion Plumes*
- *Molecular Contamination*

- **The return of lunar surface vehicles, samples, and suits contaminated by lunar dust to Gateway can have serious impact on the environment, equipment/systems, and crew health.**
- **Gateway Induced Environments is working to address:**
  - Characterization of external dust transport due to lunar return vehicle
  - External lunar dust mitigation
- **Gateway also addresses lunar dust *internal* environments, primarily by subsystem requirements.**
  - Controlling dust (Environment Control and Life Support)
  - Managing dust (Crew Systems; e.g. vacuuming)
  - Monitoring dust (Crew Health and Performance)

More details presented at this workshop by Ron Lee / Booz Allen Hamilton: "Overview of NASA Gateway Lunar Dust Mitigation and Contamination Modeling and Analysis"

Image courtesy of NASA

Spotlight on Electric Propulsion

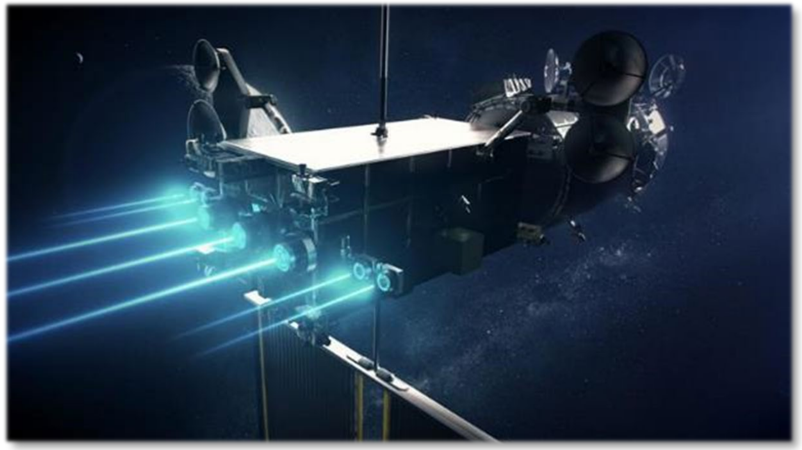
Gateway Induced Environments System

Lunar Dust

Electric Propulsion Plumes

Molecular Contamination

- **Electric thrusters on Gateway's Power Propulsion Element (PPE) provide primary thrust for lunar transit, most orbit maintenance, and orbit transfer operations.**
- **Induced environments resulting from Electric Propulsion (EP) plumes include:**
  - **Sputter erosion**: ions impacting s/c surfaces may sputter material off and result in loss of material over time
  - **Sputter redeposition**: sputter eroded s/c material may transport to other s/c surfaces with line-of-sight and deposit as a contaminant
  - **Electrical**: the EP plumes are a relatively cold and quasi-neutral plasma that can interact electrically with s/c surfaces



EP Plume induced environments at Gateway are characterized by the Ion Propulsion System Team at Glenn Research Center (GRC)

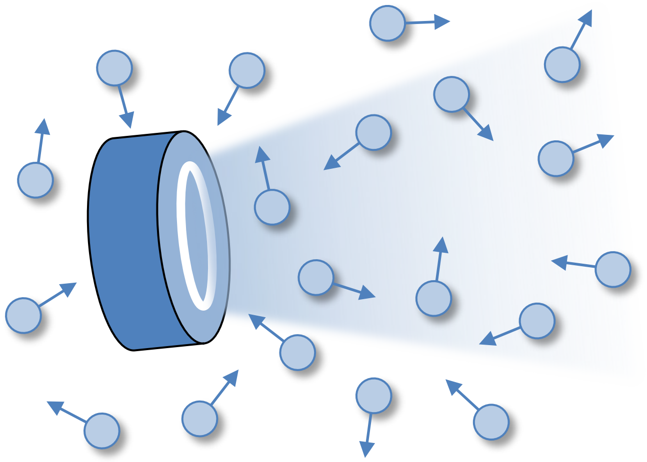
Image courtesy of NASA

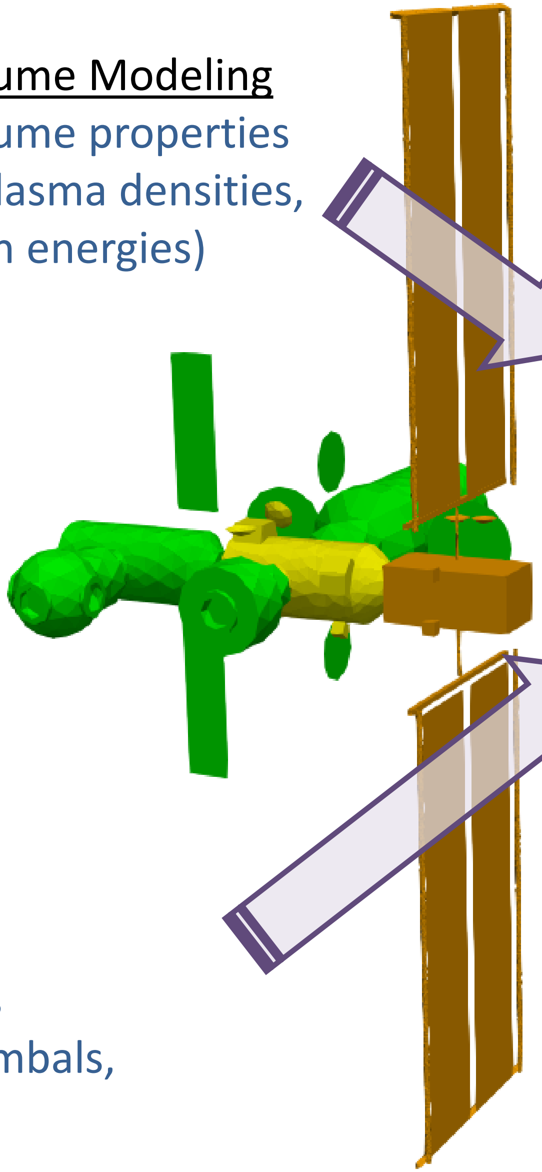
Approach (EP Plumes)

Plume Modeling
Plume properties
(plasma densities,
ion energies)

Supplemental information
Material properties (e.g. sputter yields)
Impact limits (e.g. deposition limits)

Thruster information
Design information
Test data





Interactions modeling
Sputter erosion / redeposition
Plasma/electrical interactions
(e.g. s/c charging, solar array current collection)

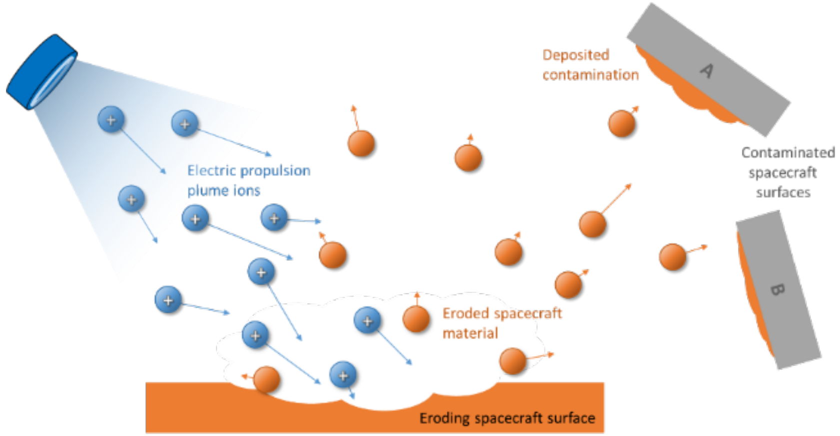
Spacecraft information
Geometries, configs, materials
Conops including thrusters, gimbals,
arrays, antennas

Outputs
Erosion rates
Deposition rates

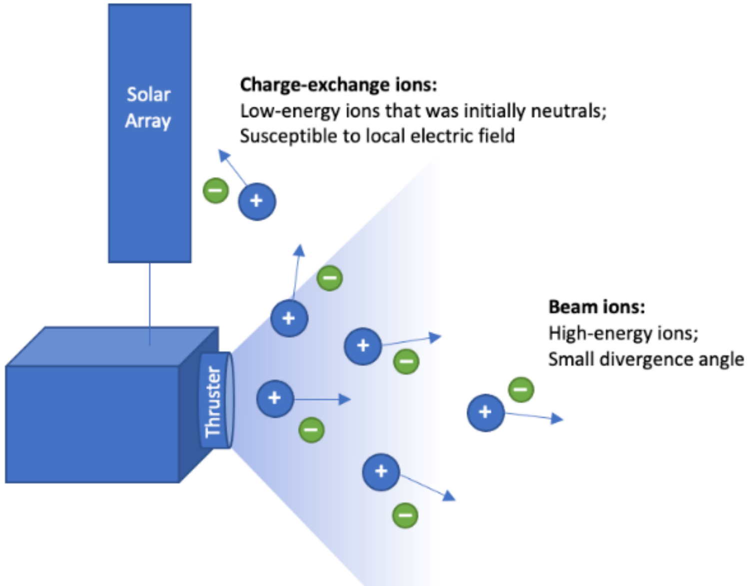
EP Plume System Analyses

- **EP Plume-Induced Sputter Erosion and Redeposition Contamination**
  - Sputter erosion from EP plume impingement is expected to be negligible for most of Gateway during nominal operations (i.e., well below the specified limit of 100Å/year.)
  - Contamination from redeposition of sputter eroded material incorporated in the Gateway system level external contamination analysis.
- **EP Plume-Induced Plasma Environment**
  - When the EP thrusters are firing, the EP-induced plasma is expected to be the dominant environment over natural environments (except for shadowed locations).
  - The spacecraft charging due to the EP plume will be up to the solar array voltage (~ -100V).
- **EP plume analyses are updated as part of the Gateway integrated analysis cycles and shared with Gateway partners/ hardware owners to support hardware impact assessments.**

EP Plume Induced Erosion / Redeposition Visualization



EP Plume Induced Plasma Visualization



Spotlight on Molecular Contamination

- *Gateway Induced Environments System*
  - *Lunar Dust*
  - *Electric Propulsion Plumes*
  - **Molecular Contamination**

- **The Gateway induced molecular contamination environment includes contributions from Gateway elements, visiting vehicles, and external payloads.**
  - Molecular contamination sources include:
    - Materials outgassing
    - Thruster plume-induced contamination
    - Redeposit of sputtered material (due to ion thrusters)
    - Vacuum vent releases
  - Materials outgassing is expected to be the dominant molecular contamination source during quiescent periods.
  - Localized deposition possible during non-quiescent periods (e.g., thruster operations, vents/purges, visiting vehicle proximity operations).
- **Contamination-sensitive surfaces include solar arrays, thermal control surfaces, optical sensors, windows, and science instruments.**

Jet Propulsion Laboratory
California Institute of Technology

The Gateway Induced Environments Team is collaborating with the JPL Contamination Control Engineering Team on early look Gateway external contamination assessments.

Approach (Molecular Contamination)

Thruster information
Thruster design information
Thruster performance data
Firing data (prox ops / attitude control)

Plume modeling
Bipropellant
Plume Model

Vacuum-Exposed Materials
Identification / usage
Operating temperatures

ASTM E1559
Outgassing rate
test data

Materials
processing
(If Necessary)

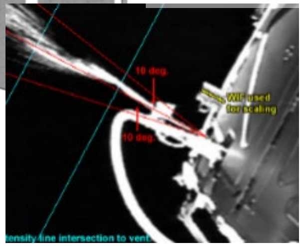
Transport Modeling
View factor calculations
Transport routines

Outputs
Element- & System-level deposition (source-to-receiver)

Products
GP 10057 verification
Operational constraints (TBD)

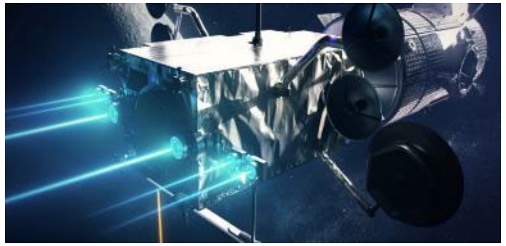
Vent modeling
Point source (gas)
Multi-phase flows

Spacecraft Information
Gateway geometry, configurations
Assembly sequence, traffic model
Contamination-sensitive surfaces
Conops including thrusters, vents, array & radiator articulation



Vent information
Vent Design information
Composition

Redeposited sputter material
from ion thrusters



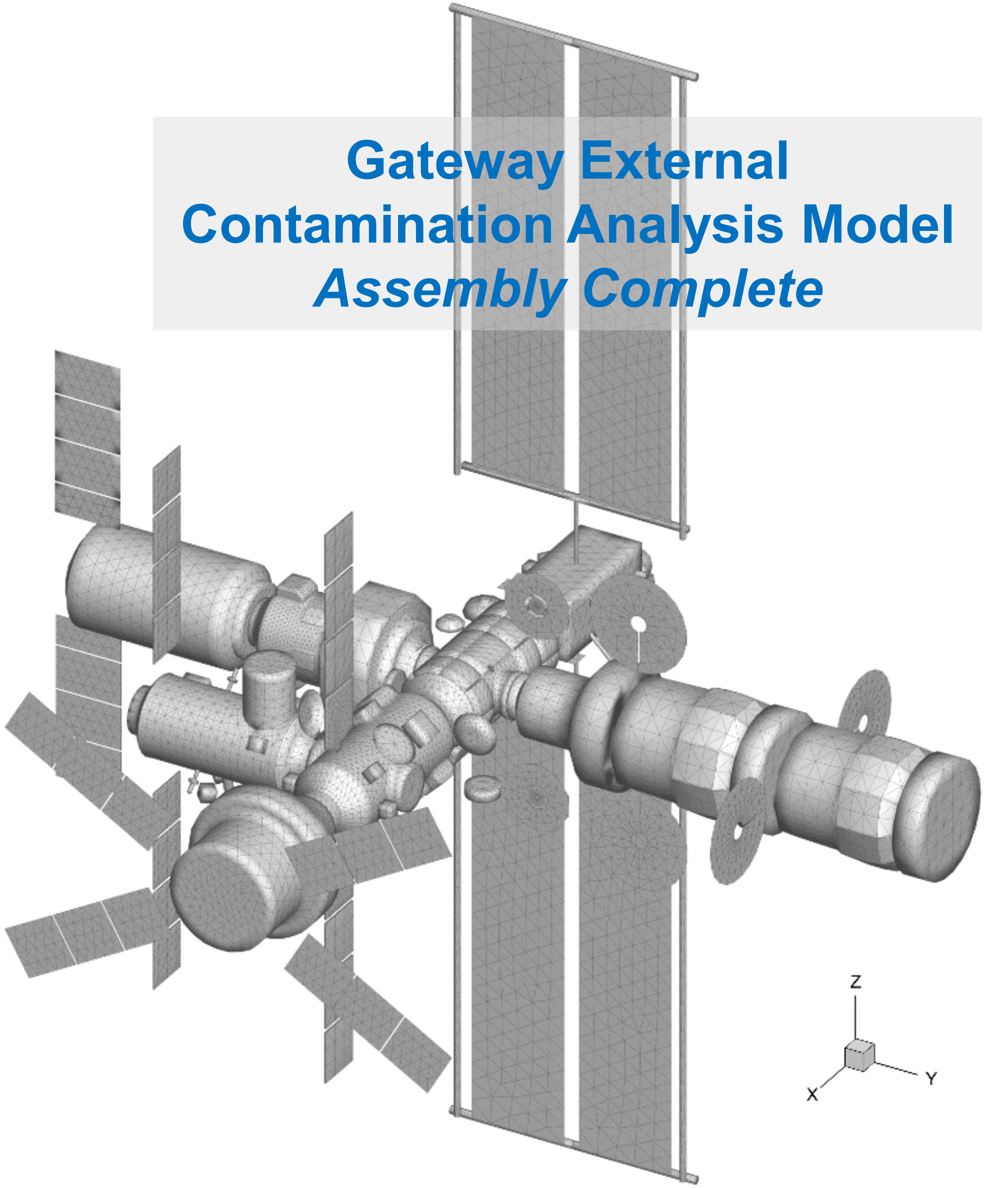
Images Courtesy of NASA

Example System Level Contamination Assessment

- **Early look Gateway integrated external contamination assessments needed to:**
  - Inform Gateway system-level and element-level requirements (and associated data requirements).
  - Conduct system studies to identify integration issues / risks.
  - Formulate long-term strategy for addressing external contamination tools/process/verification.
- **This example assessment represents a summation of all induced contamination sources, including**
  - Materials Outgassing
  - Chemical Thruster Plume-Induced Contamination
  - Redeposited Sputter Material (due to ion thrusters)
  - Vacuum venting
- **Results considered against the system level molecular contamination limit of 250 Å/year on contamination sensitive surfaces.**

Contamination-sensitive (receiver) surfaces:
Radiators Solar Arrays
Windows Payload Sites

Gateway External Contamination Analysis Model *Assembly Complete*

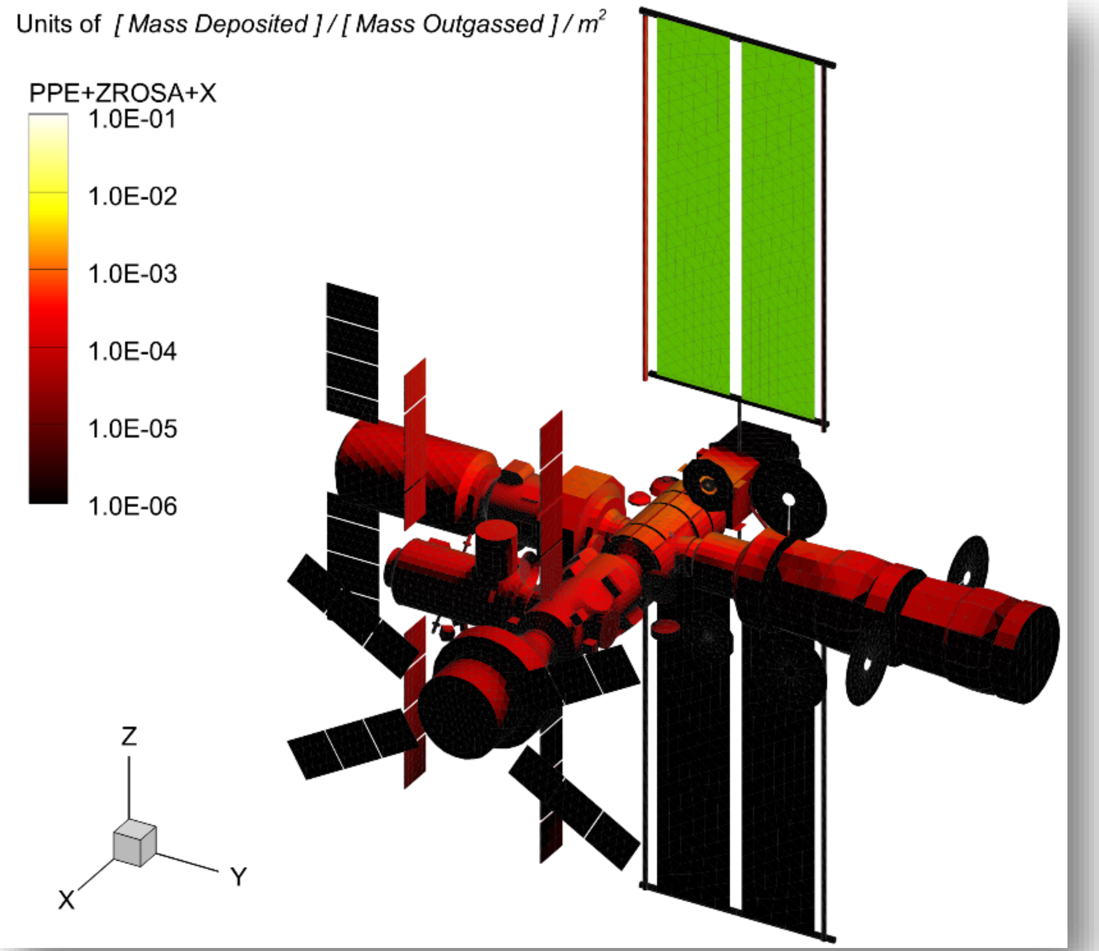


Materials Outgassing

- **Gateway utilizes a predictive model developed by JPL which allows manipulation/scaling of analysis inputs for early look assessments.**
  - Incorporates a Gateway view factor matrix to compute molecular transport for outgassing source / receiver combinations.
  - Provides materials outgassing deposition results based on outgassing rate assumptions and durations.
  - Enables system trade studies and evolving assessments as analysis inputs are better defined (materials, temperatures, etc.)

<u>**Example System Assessment**</u> (Assembly Complete):

- 177 source groups × 164 receiver groups
  = 29,028 view factor coefficients
- Outgassing rate source terms based on similarity to other spacecraft and ASTM E1559 outgassing rate test data
  (time-phased arrival of elements and outgassing rate decay included)
- Direct flux outgassing only
  (i.e. first line-of-sight from source to receiver)

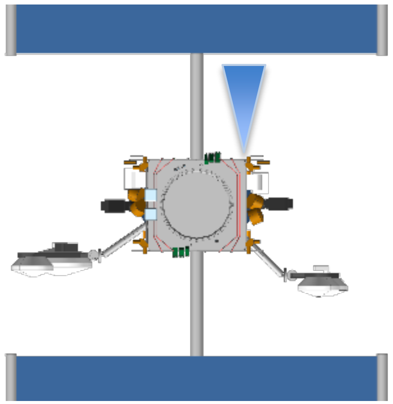


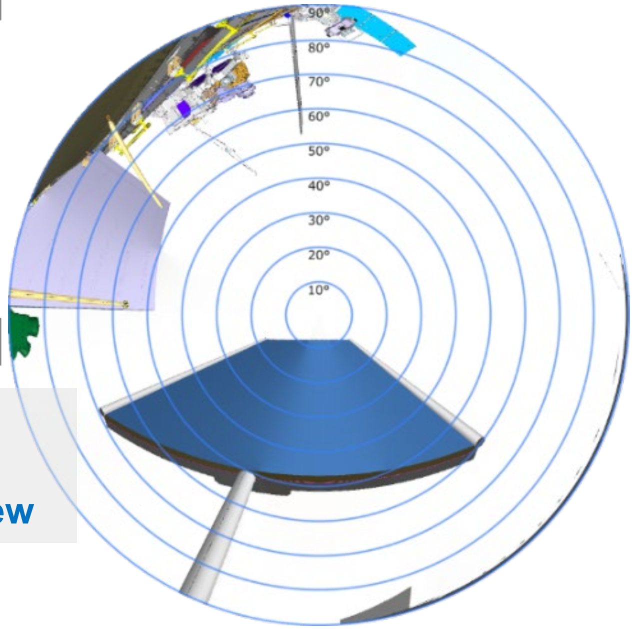
Example View Factor Visualization
This direct flux transport visualization shows the fraction of total mass outgassed from the source group (in **green**) that arrives at each receiver facet.

Thruster Plume-Induced Contamination

- **Gateway will be exposed to multiple chemical thruster plumes:**
  - Reaction Control System (RCS) Thrusters
  - Visiting vehicle thrusters (e.g. Artemis mission elements)

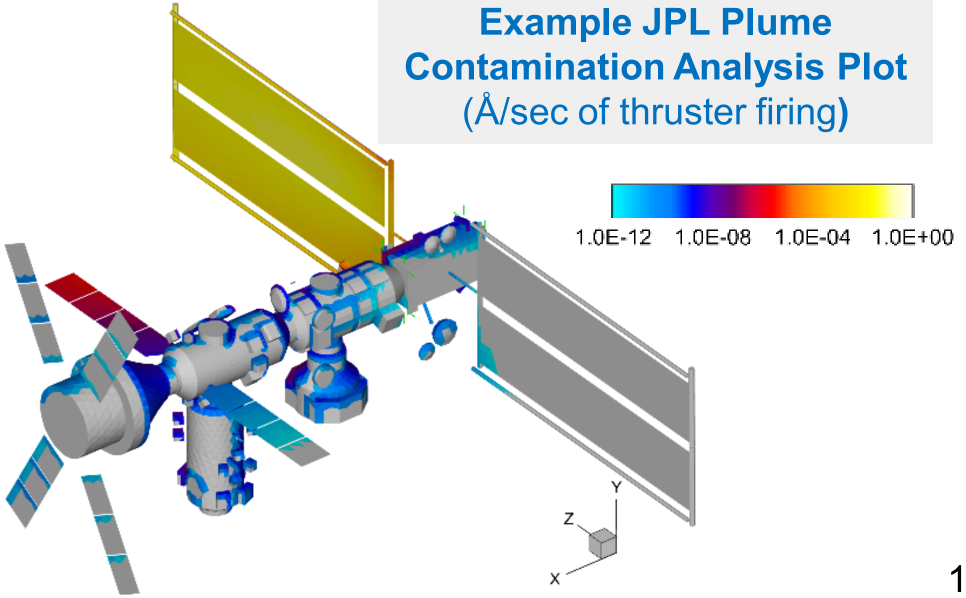
- **Gateway collaborated with the JPL on a simplified thruster plume contamination model for conducting parametric assessments for select Gateway thrusters.**
  - Contamination is calculated using the heritage ISS bipropellant plume contamination model.
  - Analysis data provided in tabular format (separated by thruster / receiver surface) to allow manipulation/scaling of thruster on-time assumptions for analysis scenarios of interest.
  - **Estimated annualized thruster on-time used for example system assessment.**





Example RCS Thruster Hemispherical View

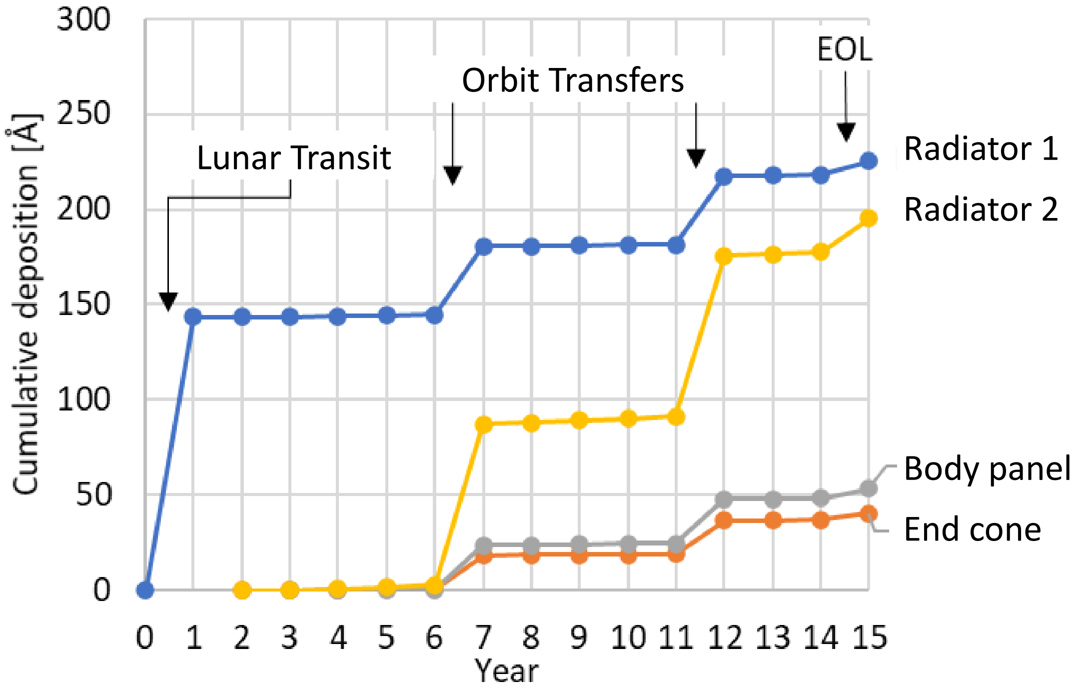
Example JPL Plume Contamination Analysis Plot (Å/sec of thruster firing)



Redeposited Sputter Material

- **Sputter erosion from EP plume impingement and redeposit of EP sputtered material is modeled/analyzed by NASA GRC / Gateway Ion Propulsion Team.**
- **GRC provides estimates of redeposited sputtered material on Gateway contamination-sensitive surfaces for incorporation into the system contamination analysis.**
  - Analysis shows insignificant levels of contamination during nominal operations / orbital maintenance.
  - Some EP plume induced contamination is expected if cis-lunar orbit transfers are performed. However, orbit-transfers are expected to be infrequent and are not included in this example assessment.

Example GRC EP Plume Redeposition Analysis
(Å)



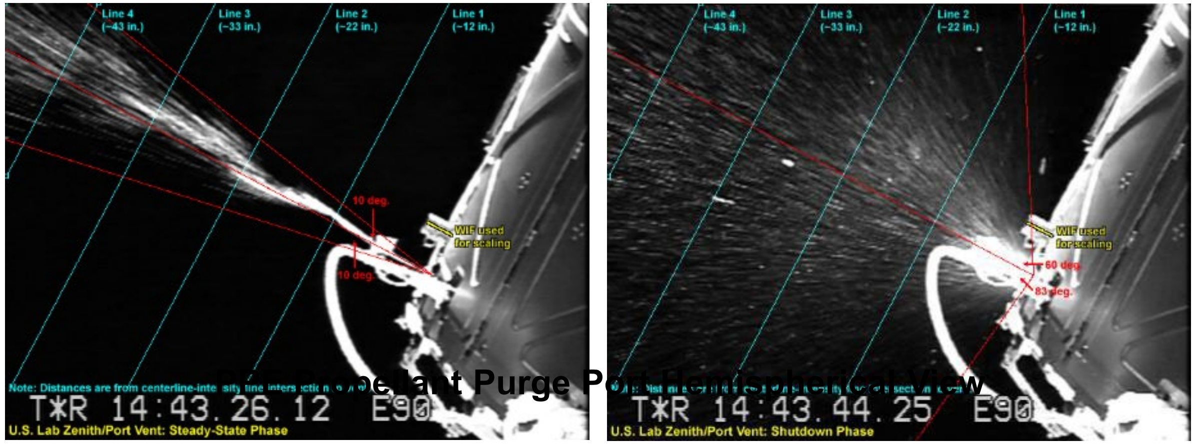
EP thrusters will be used heavily during transit of the first co-manifested elements to the Gateway orbit. EP plume contamination may be more significant during this lunar transit phase. GRC provides EP plume analysis data for lunar transit to affected hardware owners.

Vacuum Venting

- **Vacuum vents not expected to be a significant contamination source at Gateway (controlled via requirements).**
  - Most Gateway vents are inert gases, water vapor, etc.
  - **Neglected in this example system assessment.**
- **Substances of concern requiring integrated analysis:**
  - Liquids (which can cause impact damage to sensitive surfaces via direct or orbital recontact).
  - Chemically reactive substances (e.g. fuels/oxidizer, corrosives).
  - Substances that can condense at Gateway surface temperatures, resulting in a permanent deposit.
- **Induced Environments is tracking several items for continued evaluation including:**
  - Orion wastewater venting (primarily a transit concern; Orion will limit wastewater venting at Gateway)
  - Propellant purging (associated with refueling operations).
  - Payload waste gas venting.

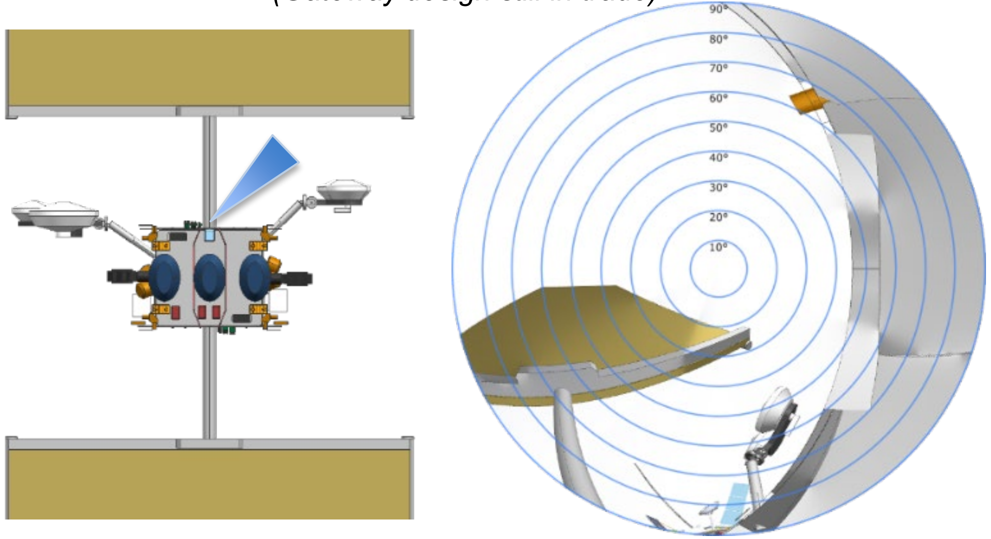
ISS U.S. Lab Condensate Vent

Steady-state (Left) and Shutdown (Right)



Hypothetical Propellant Purge Hemispherical View

(Gateway design still in trade)



Images courtesy of NASA

Example System Level Contamination Results

Gateway System Level Deposition (Å/Year)

	Receiver Surface	Outgassing	Thruster Plumes	Sputter Redeposit	Grand Total
Radiators	PPE+ZRad	94	0	0	94
	PPE-ZRad	95	0	0	95
	HALOMainRad	164	0	0	165
	HALOHLCSRad	157	0	0	157
	IHAB+Zrad	200	0	0	200
	IHAB-Zrad	202	0	0	202
	ERM-ZRad	26	0	0	26
	ERM+ZRad	26	0	0	26
	ERM-XRad	113	3	1	117
	ALM+Zrad	260	0	0	260
	ALM-Zrad	254	0	0	255
Solar Arrays	PPE+ZROSA+X	187	21	0	207
	PPE+ZROSA-X	22	14	0	36
	PPE-ZROSA+X	187	23	0	209
	PPE-ZROSA-X	22	16	0	38

	Receiver Surface	Outgassing	Thruster Plumes	Sputter Redeposit	Grand Total
Windows	ERM+Xwindow	77	0	0	77
	ERM-Z+XWindow	49	0	0	49
	ERM-Z-XWindow	43	0	0	44
	ERM-Xwindow	73	0	1	74
	ERM+Z-XWindow	42	0	0	43
	ERM+Z+XWindow	48	0	0	48
Payload Sites	PPE+YSORI+Y	209	0	1	209
	PPE-YSORI-Y	95	0	1	95
	HALOSORI+Z	118	0	2	119
	IHAB+YSORI+Y	166	0	0	166
	IHAB+Y+ZSORI+Y+Z	112	0	0	112
	IHAB-YSORI-Y	77	0	0	77
	IHAB-Y-ZSORI-Y-Z	66	0	0	66
	ALM-X+YSORI-X	139	0	0	139
	ALM-X-YSORI-X	31	0	0	31
	ALM+X+ZSORI+Z	98	0	0	98
	ALM+X-ZSORI+X	1385	0	0	1385

(Highlighted) **> 250 Å/Year** (System Limit)

- **Summary:**
  - Material outgassing is the overwhelming dominant molecular contamination source.
  - Assessment shows localized exceedances → focus areas for more detailed modeling/analysis.
  - Results give support to Gateway external contamination requirements/allocations as appropriate and achievable.
  - **Gateway hardware providers should evaluate to the Gateway on-orbit external contamination environment of 250 Å /year** - not accounting for margin in system analysis (given analysis uncertainty and design immaturity).

These results reflect an 'early look' system study aimed to give indication of contamination drivers based on view factors and lots of assumptions. Determining actual deposition levels is future work for Gateway integration / verification.

Other External Contamination Activities

Induced contamination impact on hardware performance

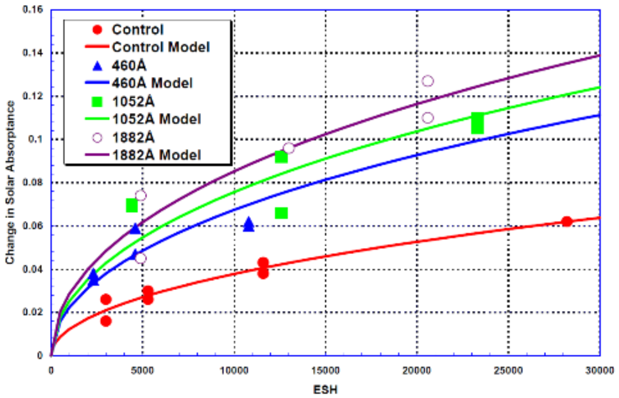
- Optical property degradation / optics testing coordination.
- Molecular contamination and thermal analysis interdependencies.
- Bipropellant thruster plume testing; thruster plume-induced erosion.

Placement/orientation assessments

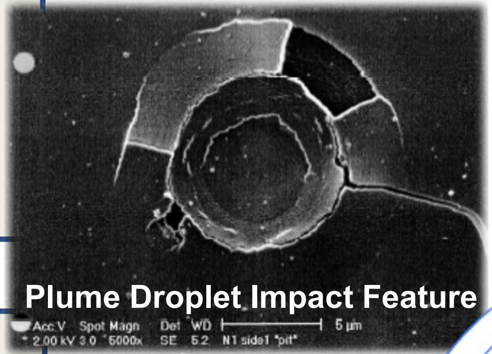
- Payload sensor placement / orientation to minimize contamination effects.
- Vacuum vent nozzle orientations.
- MLI configuration / preferential vent paths to mitigate outgassing impacts.

Special studies / candidate future activities:

- Ionized contamination return flux assessment.
- Ionizing radiation effects on materials outgassing.
- Cargo integration / contamination during transit to Gateway
- Investigate on-orbit active contamination monitoring (e.g. TQCMS).
- Investigate outgassing rate testing / process improvements.

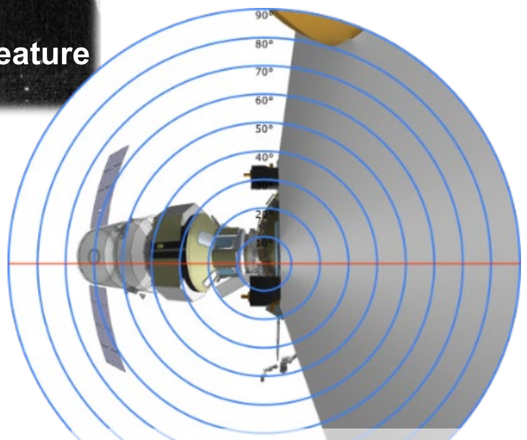


Absorptivity Change Due to Contamination



Plume Droplet Impact Feature

Image courtesy of NASA



Example Payload View
(Obstructed)

Concluding Remarks

- The Gateway Induced Environments Team is a multidisciplinary organization working to address lunar dust, electric propulsion thruster plumes, and molecular contamination topics.
- Significant progress has been made in establishing requirements and methodologies for managing induced environments to appropriate and achievable system limits.
- However, significant forward work remains to develop and validate models, respond to design and configuration changes, and finalize integration / verification workflow with numerous hardware providers and partners.
- Early and close coordination with hardware owners on Gateway induced environments requirements and data deliveries is essential for early issue resolution and successful integration.

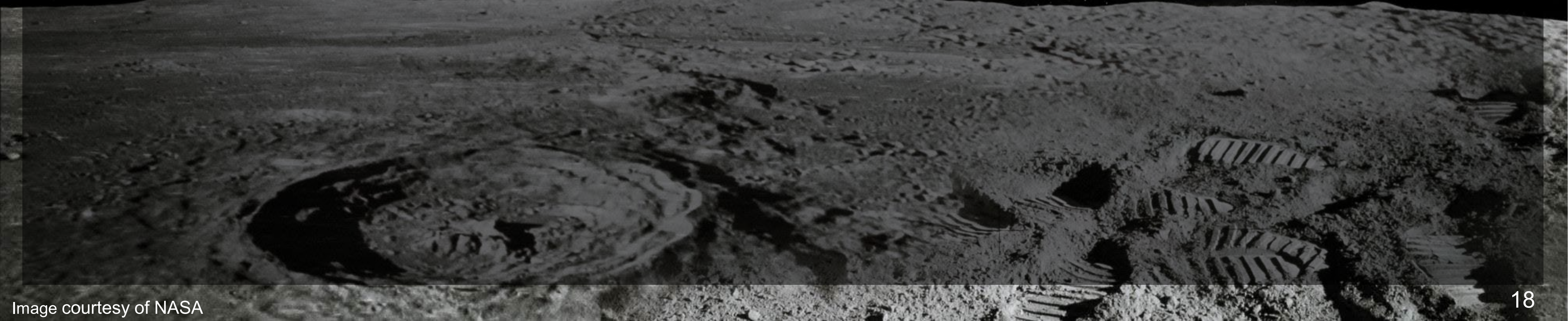


Image courtesy of NASA

Thank you!

Image courtesy of NASA

References

1) Gateway Overview. https://www.nasa.gov/gateway/overview
2) NASA's Lunar Exploration Program Overview, September 2020. https://www.nasa.gov/sites/default/files/atoms/files/artemis_plan-20200921.pdf
3) NASA GP 10057, "Gateway Space Induced Environments Requirements."
4) R.G. Lee, E.S. Worthy, E.M. Willis, G.L. Brown, F. Cipriani, and D.C. Barker, Development of a Comprehensive Physics-Based Model for Study of NASA Gateway Lunar Dust Contamination, IAC-22-D5.3.9, 73rd International Astronautical Congress, Paris, France, 18-22 September 2022.
5) ASTM E1559, "Standard Test Method for Contamination Outgassing Characteristics of Spacecraft Materials."
6) Hoey, W. A., et al., "A Predictive Model of Lunar Gateway Molecular Contamination," Proceedings of the 15th International Symposium on Materials in the Space Environment, Leiden, The Netherlands, 18-23 Sept. 2022.
7) A. Huang, G. Kastanas, L. Kramer, C. Soares, and R. Mikatarian, "Materials Outgassing Rate Decay in Vacuum at Isothermal Conditions", SPIE Proceedings Volume 9952, Systems Contamination: Prediction, Control, and Performance, 27 September 2016.
8) C. Soares, R. Mikatarian, and H. Barsamian, "International Space Station Bipropellant Plume Contamination Model", Proceedings of the 8th AIAA/ASMT Joint Thermophysics and Heat Transfer Conference, AIAA 2002-3016, St. Louis, Missouri, 24-27 June 2002.
9) C. Soares, R. Olsen, C. Steagall, W. Schmidl, B. Myers, R. Mikatarian, S. Koontz, and E. Worthy, "Improvements in Modelling Thruster Plume Erosion Damage to Spacecraft Surfaces", Proceedings of the 13th International Symposium on Materials in a Space Environment, Pau, France, 22-26 June 2015.
10) JSC Image Science and Analysis Group, "SDTO 16004-A: Characterization of U.S. Non-Propulsive Condensate Water Vents." https://isal-web1.jsc.nasa.gov/Content/folder587/sdto_video.htm
11) Schmidl, W.D., et al., "Characterization of On-Orbit U.S. Lab Condensate Vacuum Venting", International Astronomical Federation Conference, IAF-02-T.P.06, International Astronomical Federation, Paris, 2002.
12) Alred, J. W., and Soares, C. E., " Solar Absorptivity as a Function of Spacecraft External Contamination," 33rd SAMPE Technical Conférence, 2001.
13) Zinecker, et al., "Solar Absorptivity Degradation of Spacecraft Materials due to UV and Charged Particles in the Gateway Environment." Proceedings of the 15th International Symposium on Materials in the Space Environment, Leiden, The Netherlands, 18-23 Sept. 2022.
14) C. Soares and R. Mikatarian, "Thruster Plume Induced Contamination Measurements from the PIC and SPIFEX Flight Experiments," SPIE 4774-20 International Symposium on Optical Science and Technology, Seattle, July 2002.
15) Anderson, J. R., et al., "Assessment of Contamination Ionization Due to Interaction with the Natural Environment for Gateway," IEEE Aerospace Conference, Big Sky, MT, 4-11 Mar 2023.
16) Alred, J. M., et al. "Development of Multispecies Model for Comprehensive Characterization of Outgassing Molecular Constituents." Proceedings of the 15th International Symposium on Materials in the Space Environment, Leiden, The Netherlands, 18-23 Sept. 2022.

Abstract

Gateway Induced Environments Overview

Courtney A. Steagall[a*], Crystal A. Quiroz[b], Gary L. Brown[c], Ronald G. Lee, Jr[d], Maria Choi[e], John T. Yim[e], John M. Alred[f], John R. Anderson[f], William A. Hoey[f], Carlos E. Soares[f], Maxwell G. Martin[f], Gregory S. Shallcross[f]

[a] *NASA, Johnson Space Center, Houston, TX, USA,* courtney.a.steagall@nasa.gov
[b] *Oceaneering, JETS Contract, Houston, TX, USA*
[c] *Barrios Technology, Houston, TX, USA*
[d] *Booz Allen Hamilton, Houston, TX, USA*
[e] *NASA, Glenn Research Center, Cleveland, OH, USA*
[f] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*
* Corresponding Author

Gateway will be a long duration space station orbiting the Moon in support of NASA's Artemis campaign. Over its lifetime, Gateway will be exposed to a variety of induced environments, including materials outgassing, chemical and electric thruster plumes, vacuum vents, and lunar dust transport (from the Human Lander System, HLS). Induced Environments can impact vehicle performance and mission success. The multidisciplinary Gateway Induced Environments Team has developed requirements and methodologies to address the complex challenge of integrating multiple elements and visiting vehicles while maintaining the Gateway induced environments within prescribed limits. The Gateway Induced Environments requirements are summarized along with the integration / verification process and preliminary system analysis results.