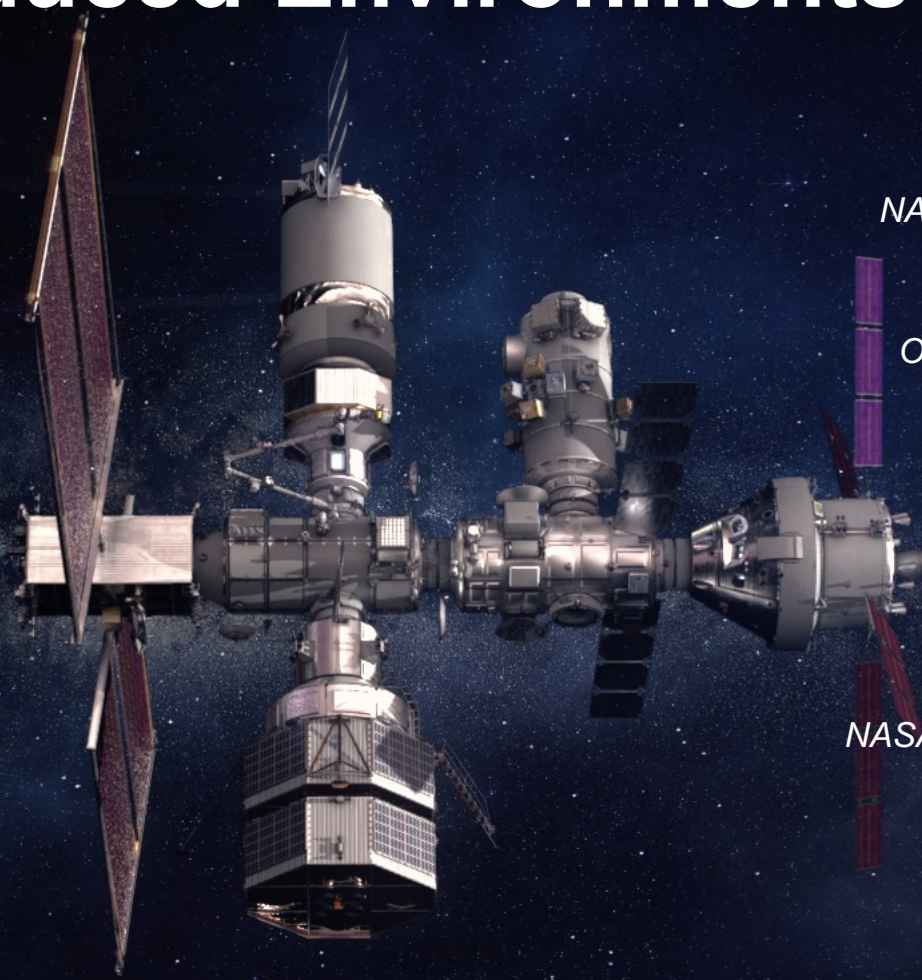


# Gateway Induced Environments Overview



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**2023 CCMPP**

**Contamination, Coatings, Materials,  
and Planetary Protection Workshop**

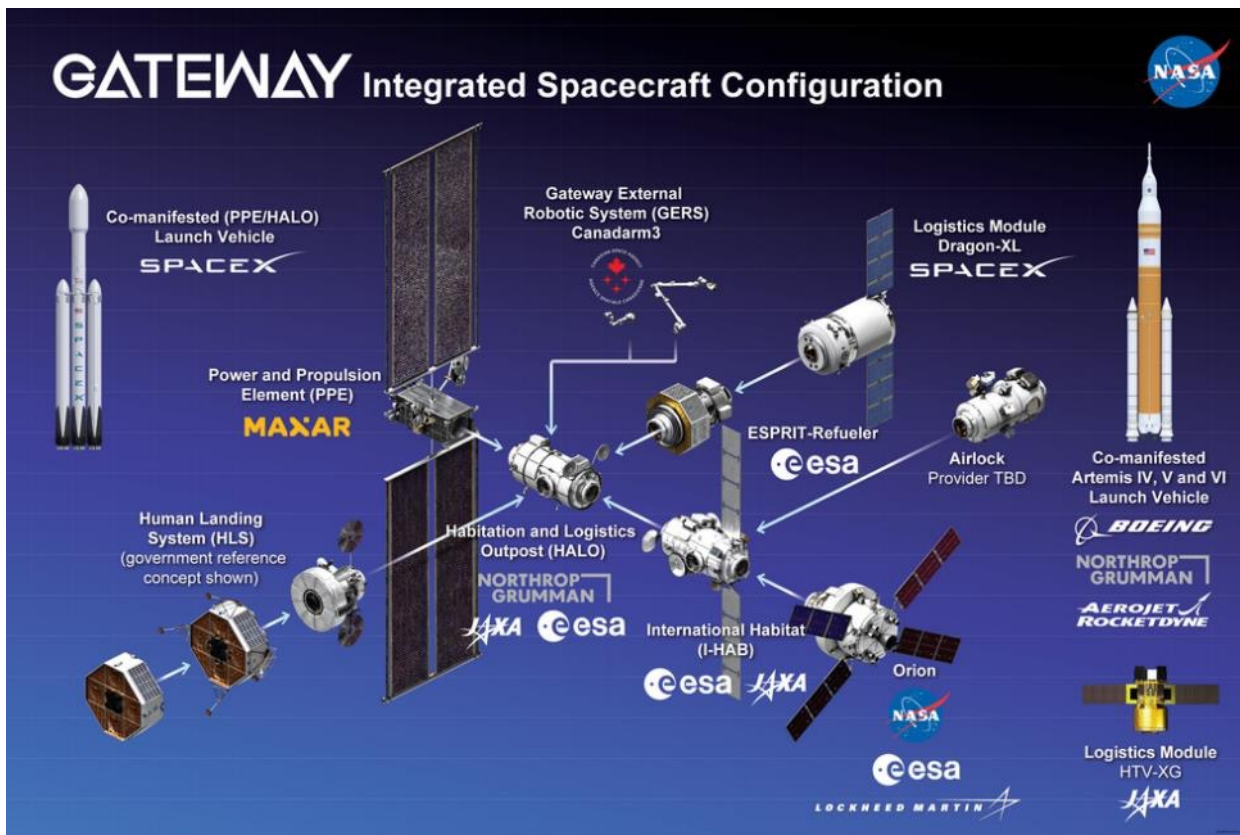
*NASA Goddard Space Flight Center*

*Sept. 12-14, 2023*

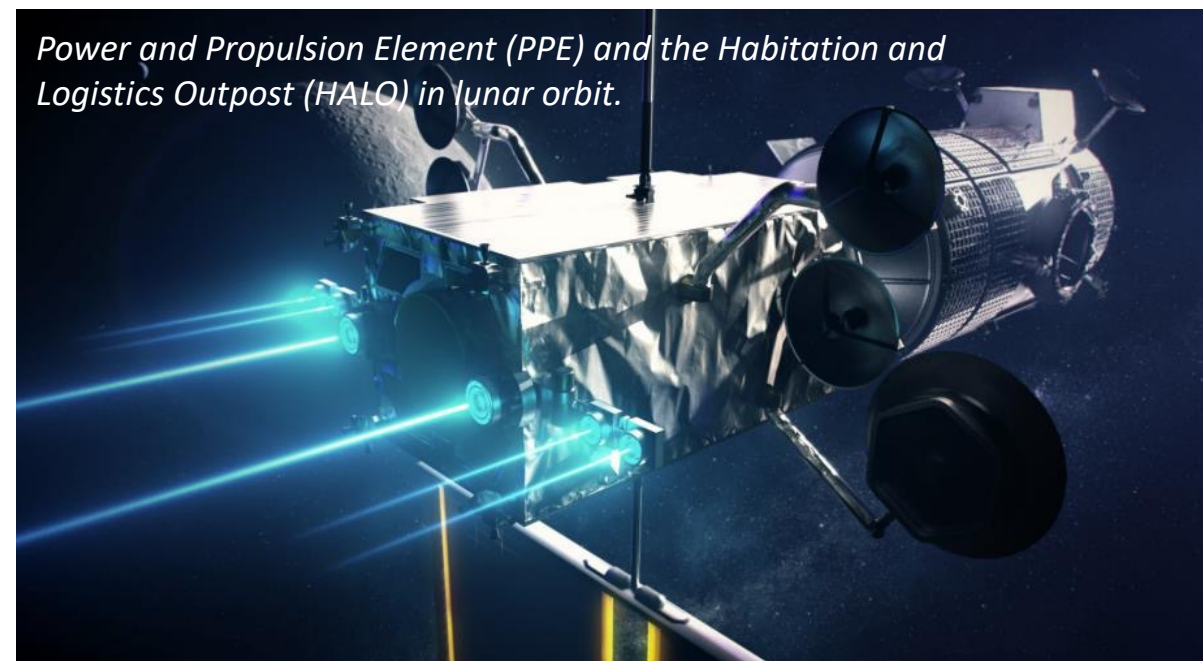


**Publicly Available - NASA NF-1676 20230011722**





- 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.



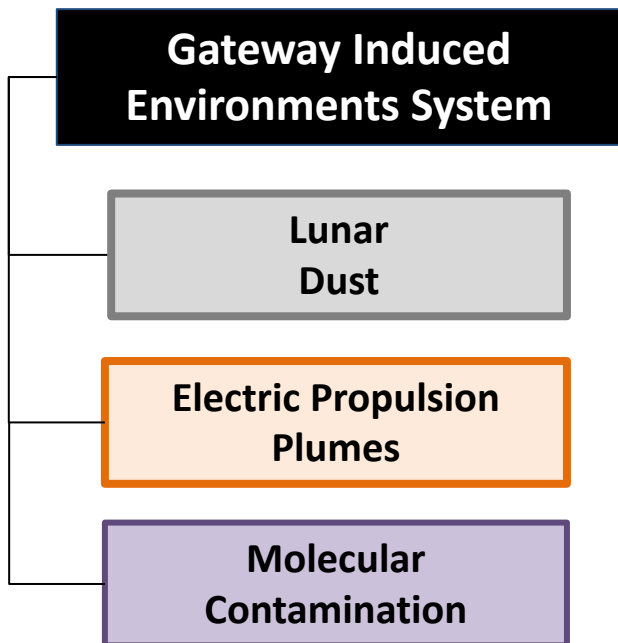
- **Over its assembly and lifetime, Gateway will be exposed to a variety of induced environments, including:**
  - Lunar dust transport (from the Human Lander System, HLS)
  - Chemical and electric thruster plumes
  - Materials outgassing
  - Vacuum vents
- **Gateway elements and visiting vehicles will 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.**

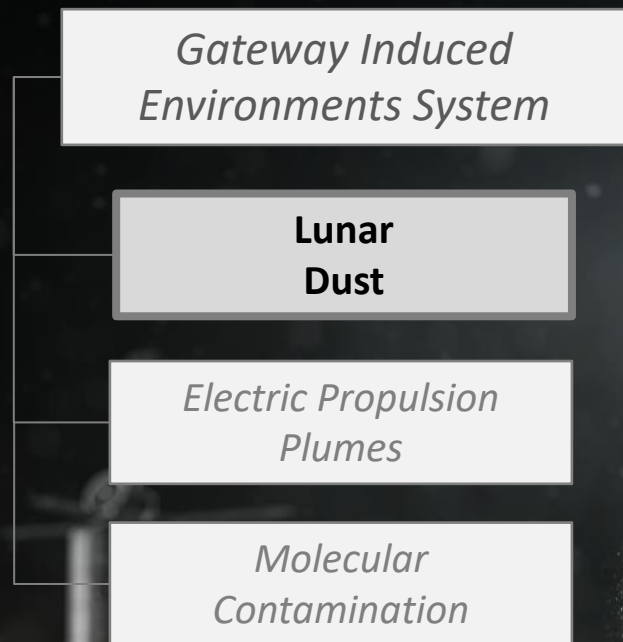


# Gateway Induced Environments System



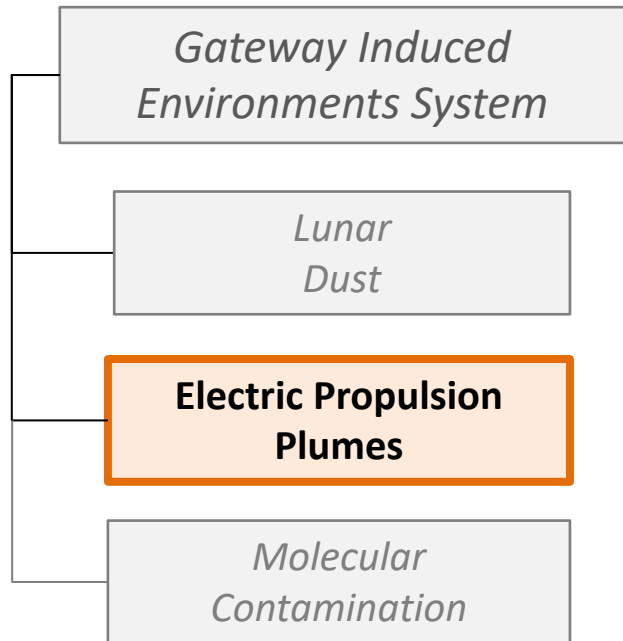
GP 10057 'Gateway Space Induced Environments Requirements'	
<p><b>Induced Environments Limits</b> <i>Verified by Gateway analysis</i></p>	<p>Defines Gateway induced environments limits that Gateway will be managed to:</p> <ul style="list-style-type: none"> <li>• Specifies <b><u>lunar dust contamination</u></b> due to transfer from of a returning Lunar Surface excursion vehicle.</li> <li>• Specifies <b><u>sputter erosion limit of 100Å/year</u></b> due to electric propulsion thrusters plume impingement on Gateway sensitive surfaces.</li> <li>• Specifies a <b><u>molecular contamination limit of 250 Å/year</u></b> on contamination sensitive surfaces from all sources (Note: Includes corresponding element-level allocations.)</li> <li>• Limits <b><u>venting</u></b> of substances that contaminate or degrade external surfaces.</li> </ul>
<p><b>Vehicle Performance (Design to's)</b> <i>Verified by hardware owners (e.g. hardware impact assessments / mitigations)</i></p>	<p>Defines the on-orbit induced environments that Gateway elements, visiting vehicles, payloads, etc. must operate in (e.g. hardware impact assessments / mitigations):</p> <ul style="list-style-type: none"> <li>• Lunar dust contamination</li> <li>• Electric propulsion induced sputtering and plasma.</li> <li>• Molecular contamination limit of 250 Å/year.</li> </ul>



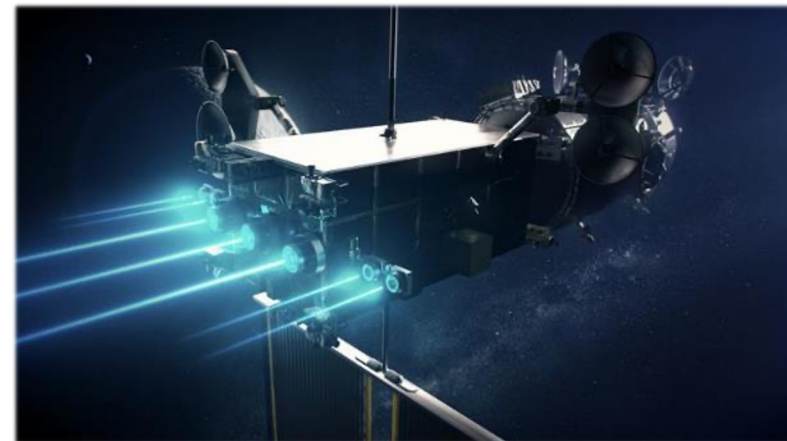


- The return of lunar surface vehicles, samples, and suits contaminated by lunar dust to Gateway can have serious impact on the environment, equipment/systems, and crew health.
- Gateway Induced Environments is working to address:
  - Characterization of external dust transport due to lunar return vehicle
  - 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”

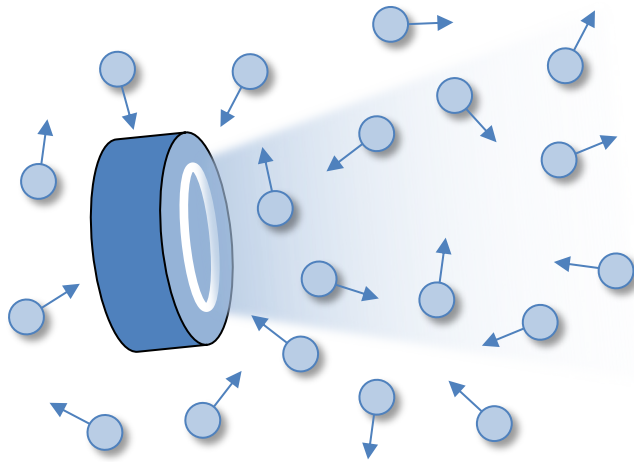


- **Electric thrusters on Gateway’s Power Propulsion Element (PPE) provide primary thrust for lunar transit, most orbit maintenance, and orbit transfer operations.**
- **Induced environments resulting from Electric Propulsion (EP) plumes include:**
  - **Sputter erosion:** ions impacting s/c surfaces 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

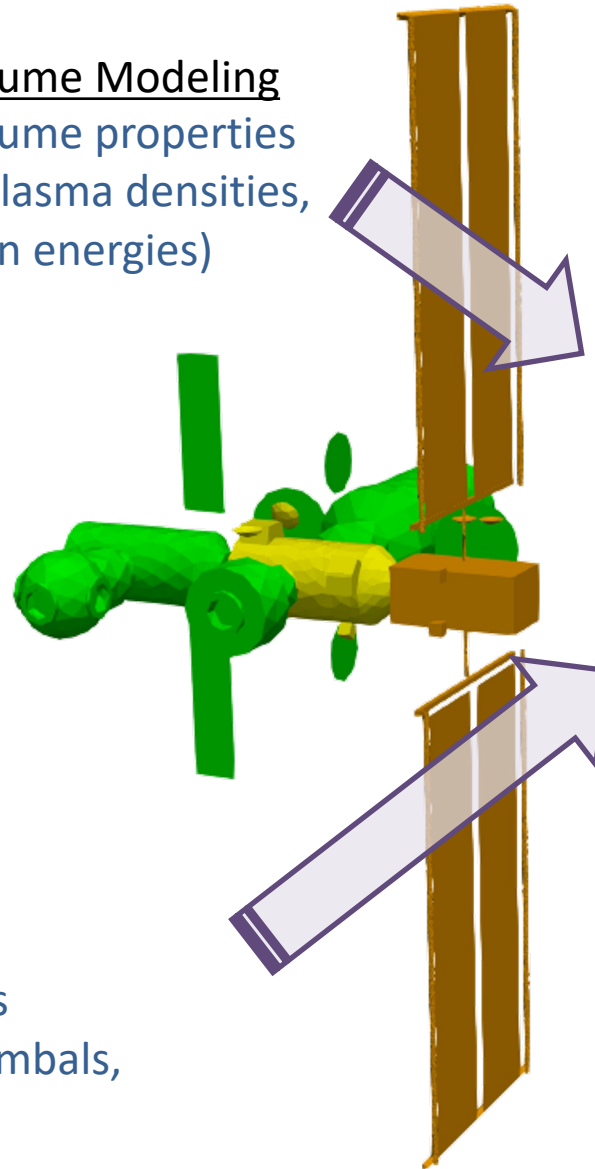


**EP Plume induced environments at Gateway are characterized by the Ion Propulsion System Team at Glenn Research Center (GRC)**

Thruster information  
Design information  
Test data



Plume Modeling  
Plume properties  
(plasma densities,  
ion energies)



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

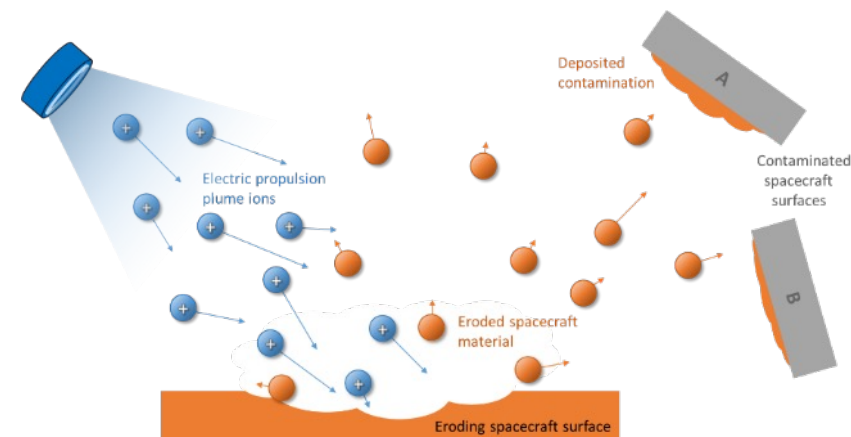
Interactions modeling  
Sputter erosion / redeposition  
Plasma/electrical interactions  
(e.g. s/c charging, solar array current collection)

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

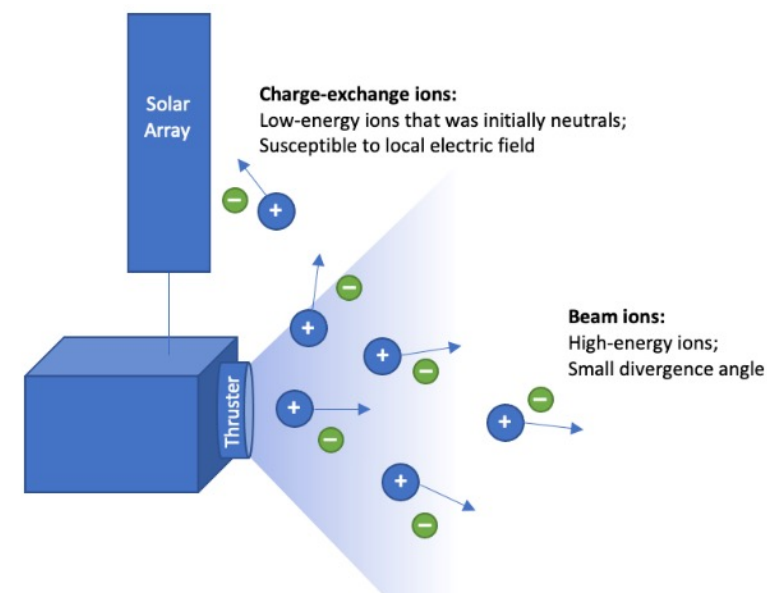
Outputs  
Erosion rates  
Deposition rates

- **EP Plume-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  $100\text{\AA}/\text{year}$ .)
  - 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 ( $\sim -100\text{V}$ ).
- **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.**

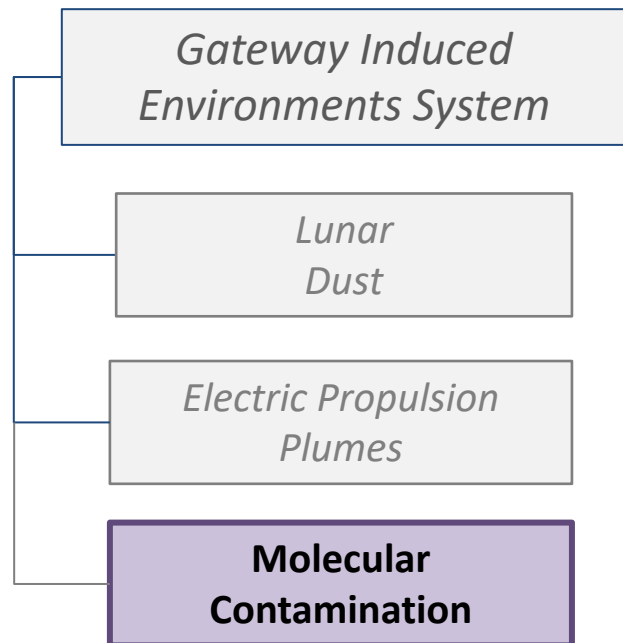
## EP Plume Induced Erosion / Redeposition Visualization



## EP Plume Induced Plasma Visualization







- **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.**



# Approach (Molecular Contamination)



## Thruster information

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



## Plume modeling

Bipropellant  
Plume Model

**Transport Modeling**  
View factor calculations  
Transport routines

## Vent modeling

Point source (gas)  
Multi-phase flows

## Vent information

Vent Design  
information  
Composition



## Vacuum-Exposed Materials

Identification / usage  
Operating temperatures

## ASTM E1559

Outgassing rate  
test data

Materials  
processing  
(If Necessary)



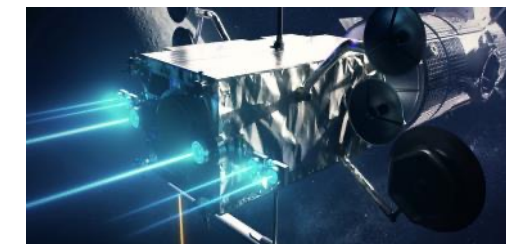
## Outputs

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

## Products

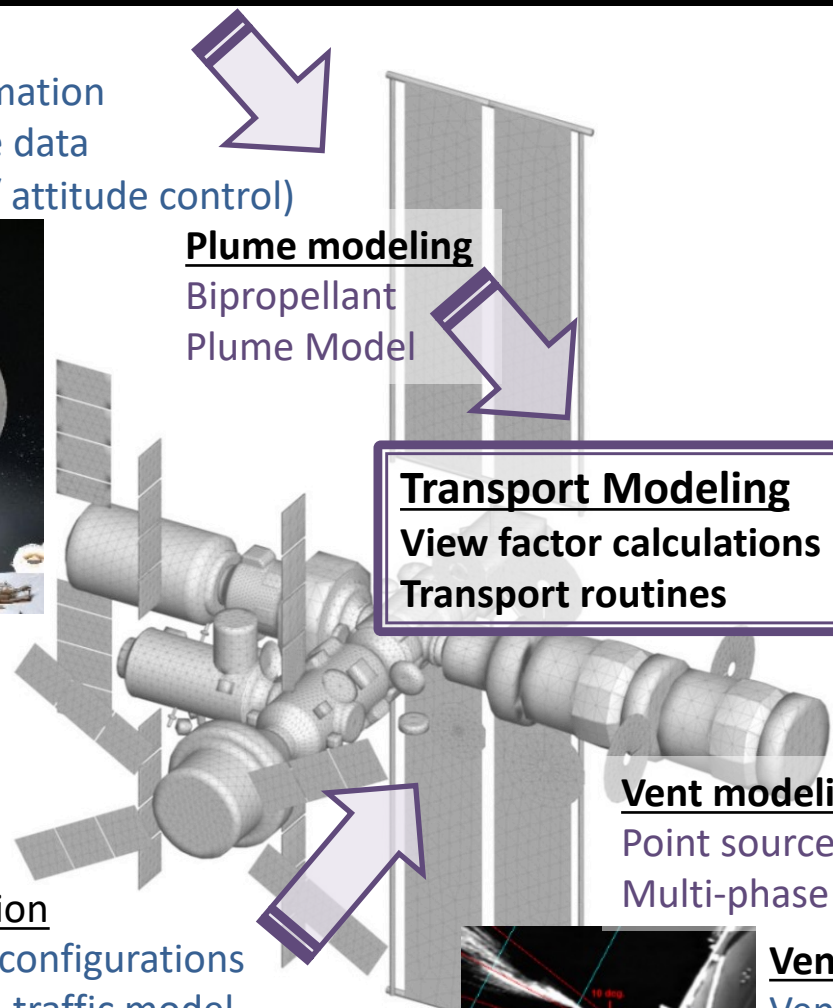
GP 10057 verification  
Operational constraints  
(TBD)

Redeposited sputter material  
from ion thrusters



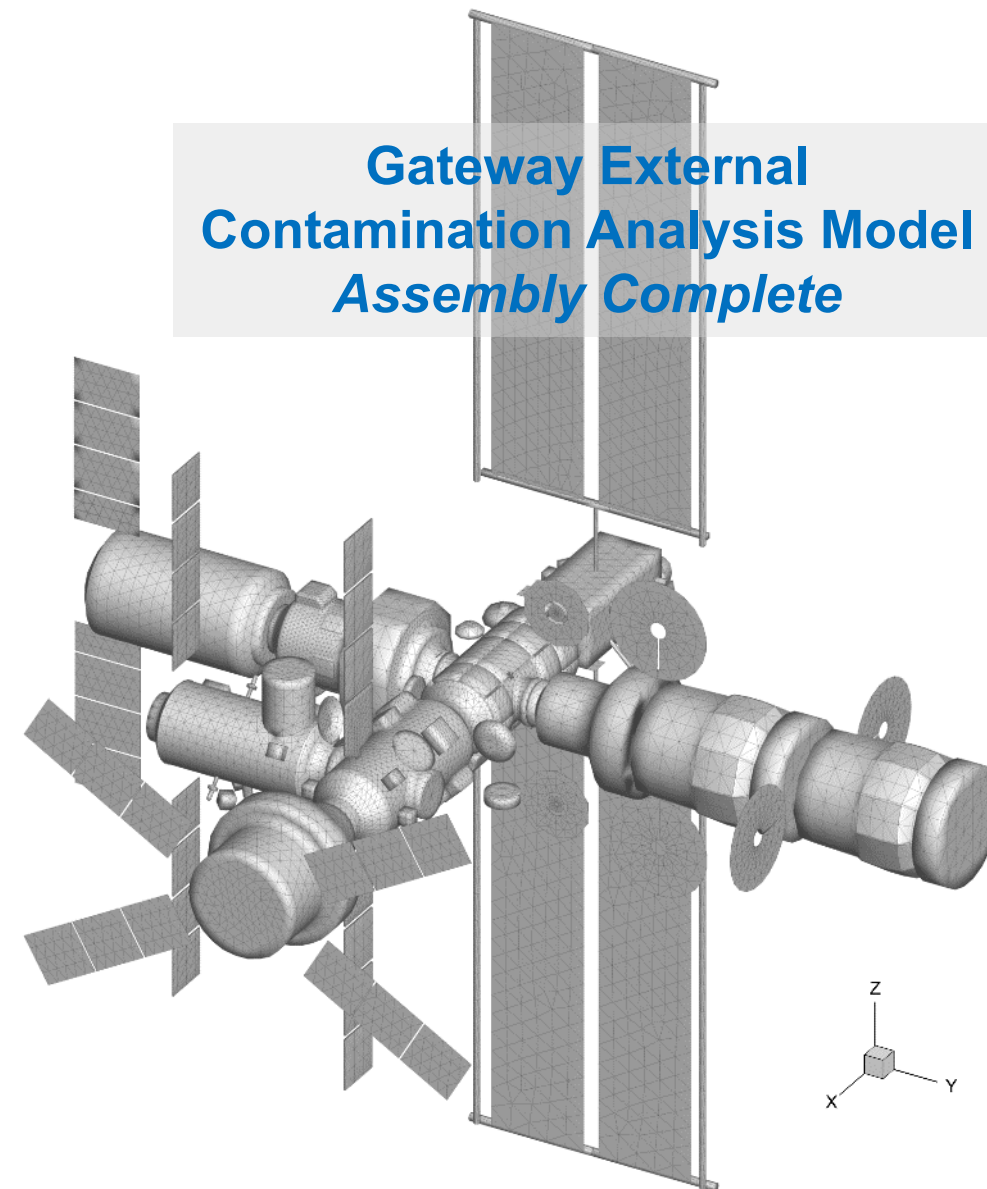
## Spacecraft Information

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



- **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**



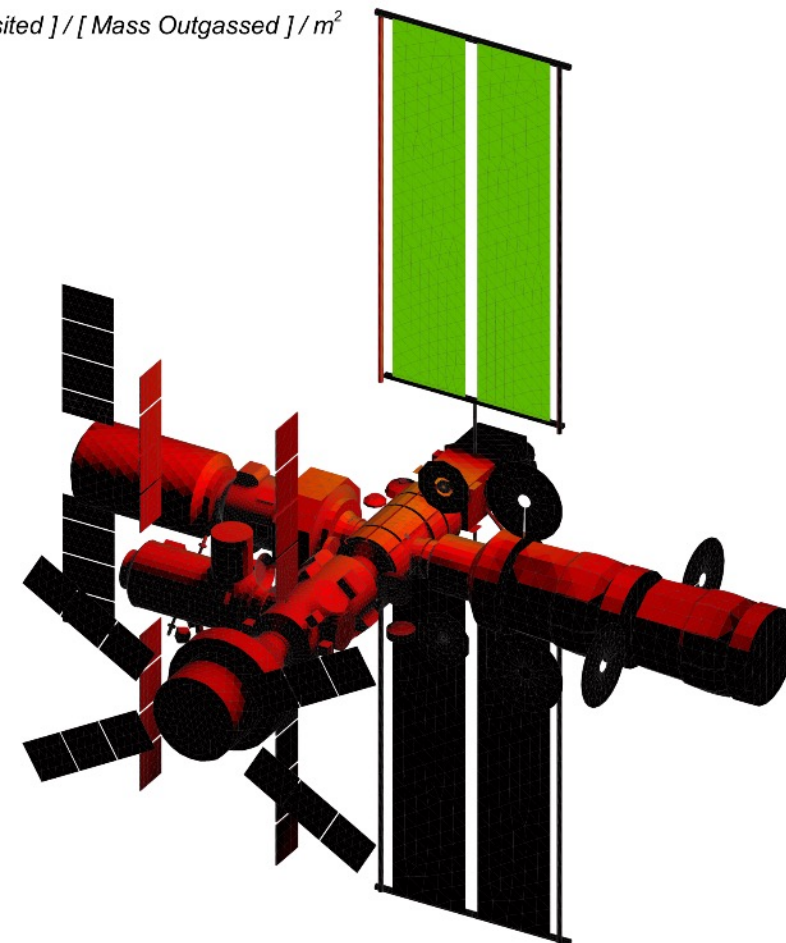
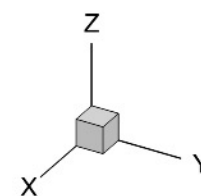
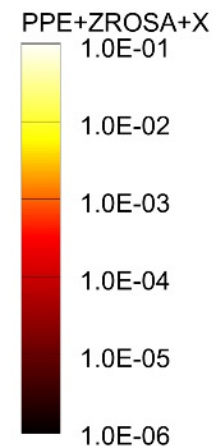


- **Gateway utilizes a predictive model developed by JPL which allows manipulation/scaling of analysis inputs for early look assessments.**
  - Incorporates a Gateway view factor matrix to compute molecular transport for outgassing source / receiver combinations.
  - Provides materials outgassing deposition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

## Example System Assessment (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)*

Units of  $[ \text{Mass Deposited} ] / [ \text{Mass Outgassed} ] / \text{m}^2$

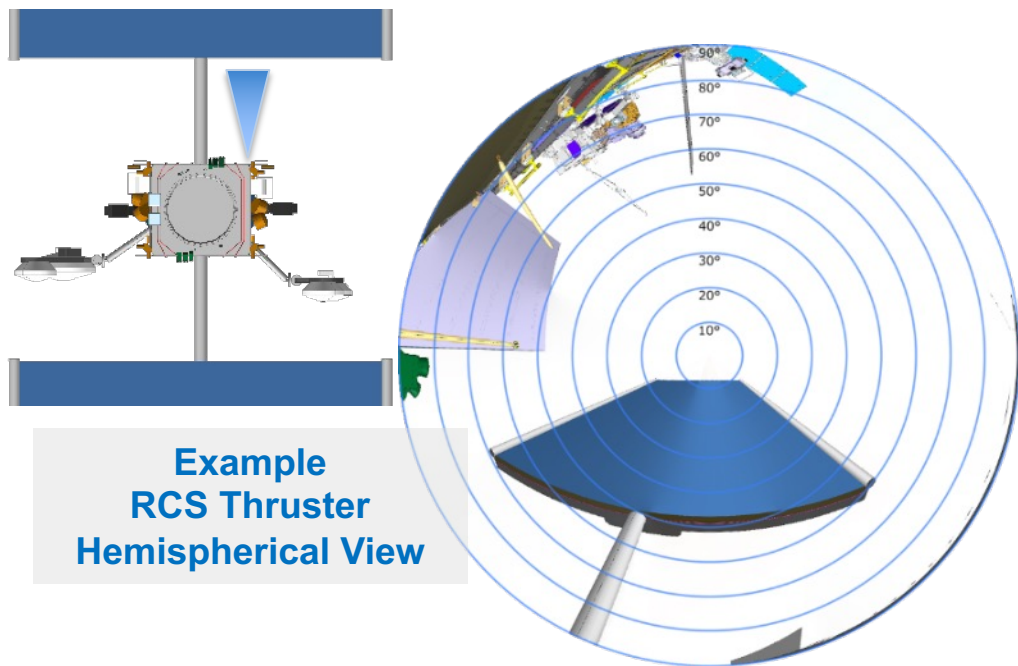


### Example View Factor Visualization

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

- **Gateway will be exposed to multiple chemical thruster plumes:**

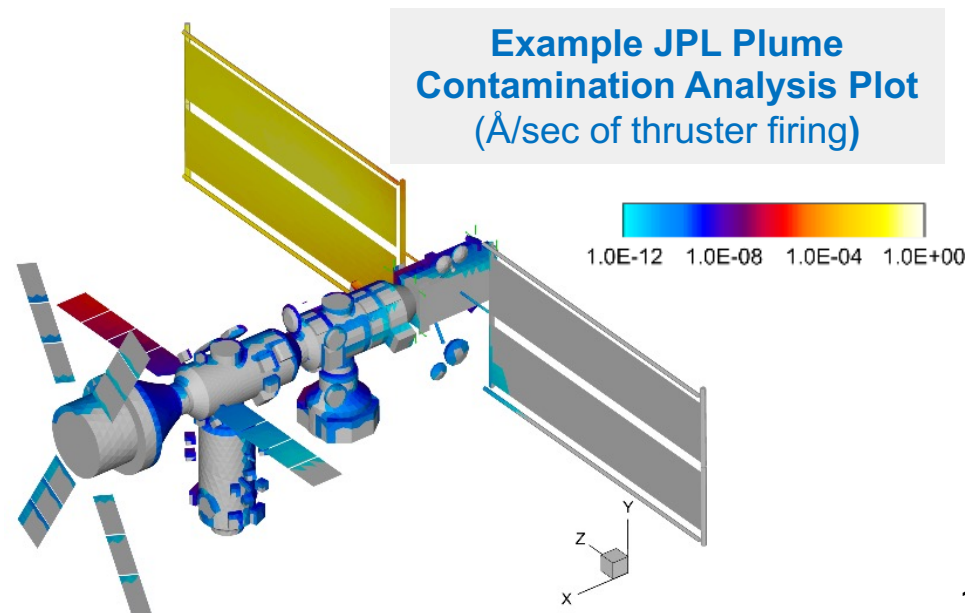
- Reaction Control System (RCS) Thrusters
- Visiting vehicle thrusters (e.g. Artemis mission elements)



**Example RCS Thruster Hemispherical View**

- **Gateway collaborated with the JPL on a simplified thruster plume contamination model for conducting parametric assessments for select Gateway thrusters.**

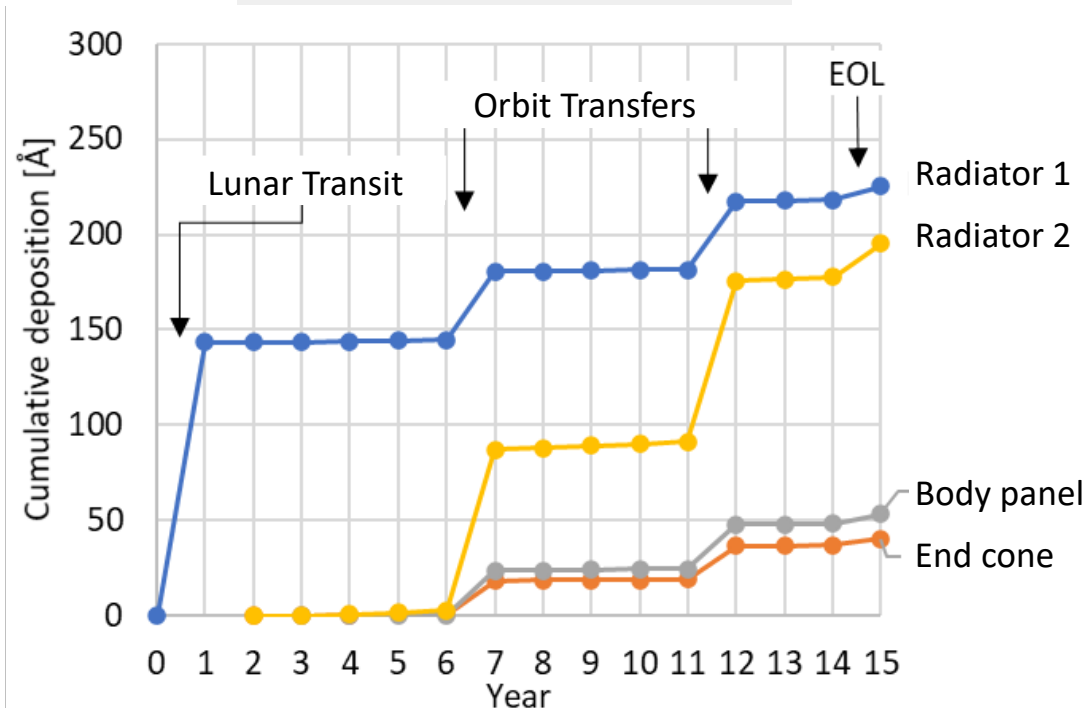
- Contamination is calculated using the heritage ISS bipropellant plume contamination model.
- Analysis data provided in tabular format (separated by thruster / receiver surface) to allow manipulation/scaling of thruster on-time assumptions for analysis scenarios of interest.
- **Estimated annualized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



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

- 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)

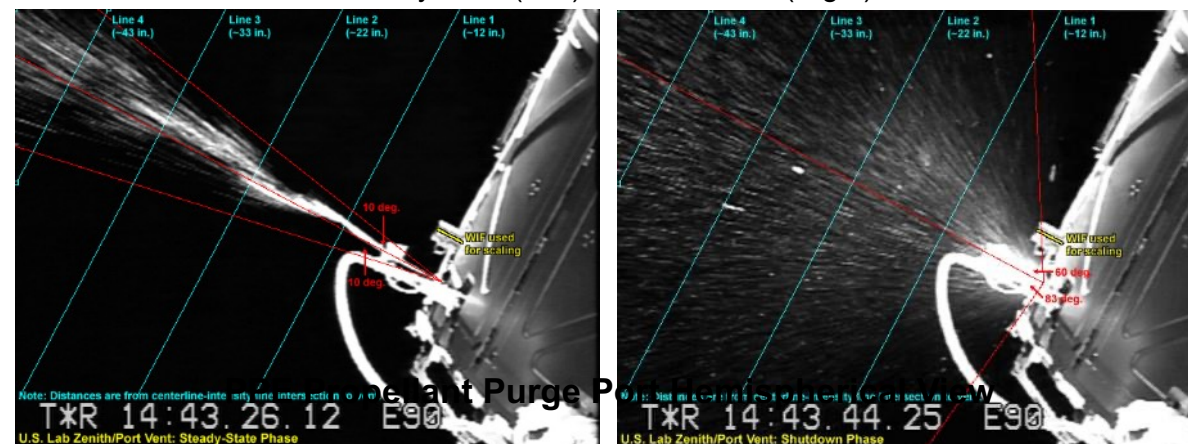


EP thrusters will be used heavily during transit of the first co-manifested elements to the Gateway orbit. EP plume contamination may be more significant during this lunar transit phase. GRC provides EP plume analysis data for lunar transit to affected hardware owners.

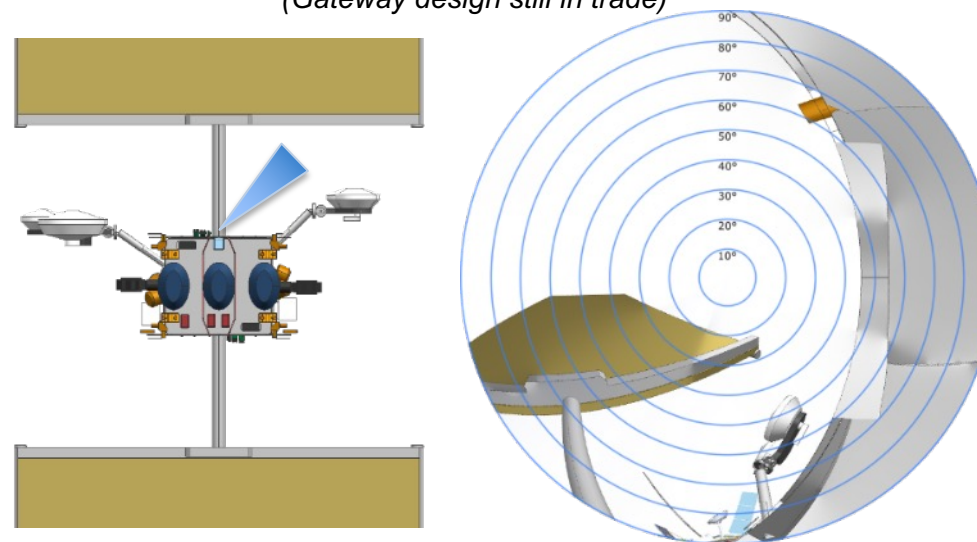


- **Vacuum vents not expected to be a significant contamination source at Gateway (controlled via requirements).**
  - Most Gateway vents are inert gases, water vapor, etc.
  - **Neglected in this example system assessment.**
- **Substances of concern requiring integrated analysis:**
  - Liquids (which 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)





# 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

  > 250 Å/Year (System Limit)

	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
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

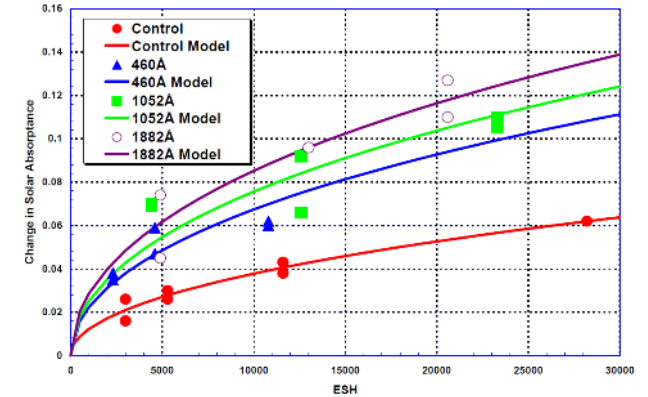
## • Summary:

- 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.

## 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.



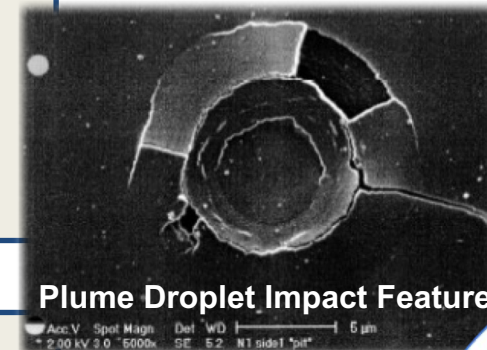
**Absorptivity Change Due to Contamination**

## Placement/orientation assessments

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

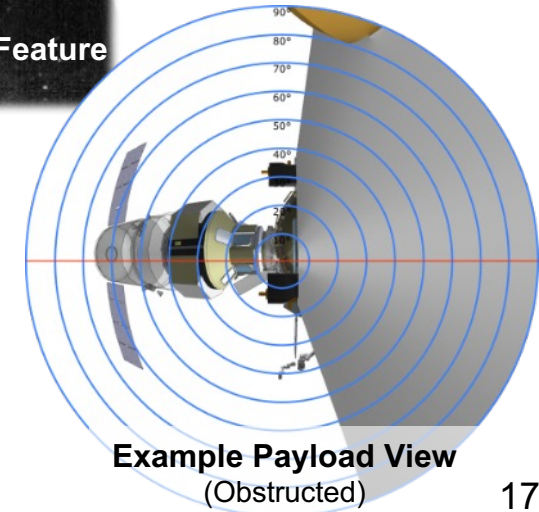
## Special studies / candidate future activities:

- 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.



**Plume Droplet Impact Feature**

Image courtesy of NASA



**Example Payload View (Obstructed)**

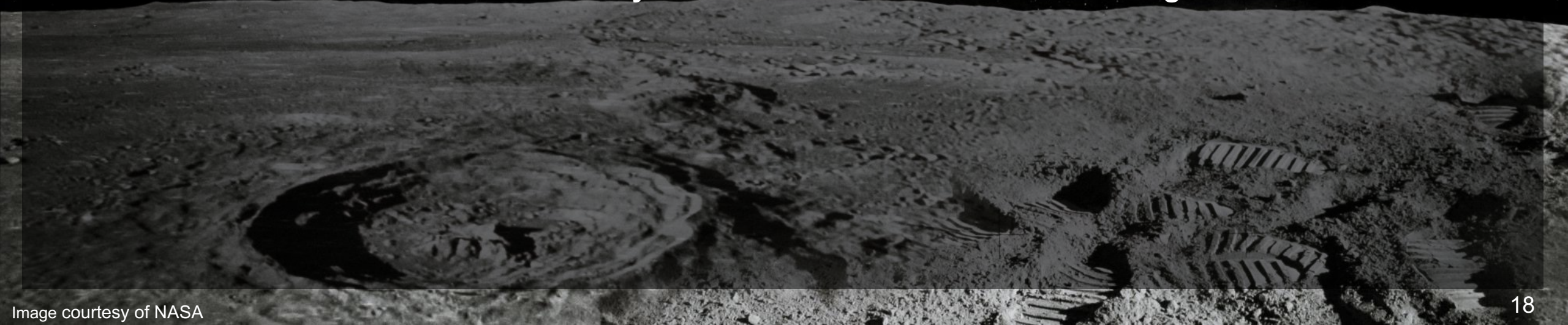




# Concluding Remarks



- **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.**







Thank you!



- 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](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 15<sup>th</sup> 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](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 Conference, 2001.
- 13) Zinecker, et al., "Solar Absorptivity Degradation of Spacecraft Materials due to UV and Charged Particles in the Gateway Environment." Proceedings of the 15<sup>th</sup> 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 15<sup>th</sup> International Symposium on Materials in the Space Environment, Leiden, The Netherlands, 18-23 Sept. 2022.





## Gateway Induced Environments Overview

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John T. Yim<sup>e</sup>, John M. Alred<sup>f</sup>, John R. Anderson<sup>f</sup>, William A. Hoey<sup>f</sup>, Carlos E. Soares<sup>f</sup>,  
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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.