



## NASA SBIR 2021 Phase I Solicitation

### S4.05 Contamination Control and Planetary Protection

Lead Center: JPL

Scope Title:

CC and PP Implementation and Verification

#### Scope Description:

The planetary protection (PP) and contamination control (CC) subtopic focuses on mission-enabling and capability-driven technologies to improve NASA's ability to prevent forward and backward contamination. Forward contamination is the transfer of viable organisms from Earth to another body. Backward contamination is the transfer of material posing a biological threat back to Earth's biosphere. NASA is seeking innovative technologies or applications of technologies to facilitate meeting portions of forward and backward contamination requirements to include:

- Improvements to spacecraft cleaning and sterilization that remain compatible with spacecraft materials and assemblies.
- Prevention of recontamination and cross contamination throughout the spacecraft lifecycle.
- Improvements to detection and verification of organic compounds and biologicals on spacecraft, to include microbial detection and assessments for viable organism and deoxyribonucleic-acid- (DNA-) based verification technologies to encompass sampling devices, sample processing, and sample analysis pipelines.
- Active in situ recontamination/decontamination approaches (e.g., in situ heating of sample containers to drive off volatiles prior to sample collection) and in situ/in-flight sterilization approaches (e.g., UV or plasma) for surfaces.
- Enabling end-to-end sample return functions to assure containment and pristine preservation of materials gathered on NASA missions.

For CC efforts, understanding contaminants and preventing contamination supports the preservation of sample science integrity and ensures spacecraft function nominally. NASA is seeking analytical and physics-based modeling technologies and techniques to quantify and validate submicron particulate contamination, low-energy surface material coatings to prevent contamination, and modeling and analysis of particles to ensure hardware and instrumentation meet organic contamination requirements.

Examples of outcomes:

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- End-to-end microbial reduction/sterilization technology for larger spacecraft subsystems.
  - Microbial reduction/sterilization technology for spacecraft components.
  - Ground-based biological contamination/recontamination mitigation system that can withstand spacecraft assembly and testing operations.
  - In-flight spacecraft component-to-component cross-contamination mitigation system.
  - Viable organism and/or DNA sample collection devices, sample processing (e.g., low biomass extraction), and sample analysis (e.g., bioinformatic pipelines for low biomass).
  - Real-time, rapid device for detection and monitoring of viable organism contamination on low-biomass surfaces or in cleanroom air.
  - Bioburden spacecraft cleanliness monitors for assessing surface cleanliness throughout flight and surface operations during missions.
  - DNA-based system to elucidate abundance, diversity, and planetary protection relevant functionality of microbes present on spacecraft surfaces.
  - An applied molecular identification technology to tag/label biological contamination on outbound spacecraft.
  - Low surface area energy coatings.
  - Molecular adsorbers (“getters”).
  - Experimental technologies for measurement of outgassing rates lower than  $1.0 \times 10^{-15}$  g/cm<sup>2</sup>/s with mass spectrometry, under flight conditions (low and high operating temperatures) and with combined exposure to natural environment (e.g., high-energy radiation, ultraviolet radiation, atomic oxygen exposure).
  - Physics-based technologies for particulate transport modeling and analysis for continuum, rarefied, and molecular flow environments, with electrostatic, vibro-acoustic, particle detachment and attachment capabilities.
  - Modeling and analysis technologies for view-factor computation technologies for complex geometries with articulation (e.g., rotating solar arrays, articulating robotic arms).

**Expected TRL or TRL Range at completion of the Project:** 2 to 6

**Primary Technology Taxonomy:**

Level 1: TX 07 Exploration Destination Systems

Level 2: TX 07.3 Mission Operations and Safety

**Desired Deliverables of Phase I and Phase II:**

- Research
- Analysis
- Prototype
- Hardware
- Software

**Desired Deliverables Description:**

Phase I deliverable: proof-of-concept study for the approach to include data validation and modeling.

Phase II: detailed analysis and prototype for testing.

Areas to consider for deliverables are, technologies, approaches, techniques, models, and/or prototypes, including accompanying data validation reports and modeling code demonstrating how the product will enable spacecraft compliance with PP and CC requirements.

**State of the Art and Critical Gaps:**

PP state of the art leverages the technologies resulting from the 1960s to 1970s Viking spacecraft assembly and test era. The predominant means to control biological contamination on spacecraft surfaces is using some

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combination of heat microbial reduction processing and solvent cleaning (e.g., isopropyl alcohol cleaning). Notably, vapor hydrogen peroxide is a NASA-approved process, but the variability of the hydrogen peroxide concentration, delivery mechanism, and material compatibility concerns still tends to be a hurdle to infuse it on a flight mission with complex hardware and multiple materials for a given component. Upon microbial reduction, the hardware then is protected in a cleanroom environment (ISO 8 or better) using protective coverings when hardware is not being assembled or tested. Biological cleanliness is then verified through the NASA standard assay, which is a culture-based method. Rapid cleanliness assessments can be performed, but are not currently accepted as a verification methodology, to inform engineering staff about biological cleanliness during critical hardware assembly or tests that include the total adenosine triphosphate (tATP) and limulus amoebocyte lysate (LAL) assays. Terminal sterilization has been conducted with recontamination prevention for in-flight biobarriers employed for the entire spacecraft (Viking) or a spacecraft subsystem (Phoenix spacecraft arm). In addition to the hardware developed approaches for compliance, environmental assessments are implemented to understand recontamination potential for cleanroom surfaces and air. Although the NASA standard assay is performed on the cleanroom surfaces, DNA-based methodologies have been adopted to include 16S and 18S ribosomal-ribonucleic-acid- (rRNA-) targeted sequencing, while metagenomic approaches are currently undergoing development. Thus, the critical PP gaps include the assessment of DNA from low-biomass surfaces (<0.1 ng/ $\mu$ L DNA, using current technologies, from 1 to 5 m<sup>2</sup> of surface), sampling devices that are suitable for low biomass and compounds (e.g., viable organisms, DNA) but also compliant with cleanroom and electrostatic discharge limits, quantification of the widest spectrum of viable organisms, enhanced microbial reduction/sterilization modalities that are compatible with flight materials, and a ground- and flight-based recontamination systems.

CC requirements and practices are also evolving rapidly as mission science objectives targeting detection of organics and life are driving stricter requirements and improved characterization of flight-system- and science-instrument-induced contamination. State-of-the-art CC includes:

- Testing and measurement of outgassing rates down to  $3.0 \times 10^{15}$  g/cm<sup>2</sup>/s with mass spectrometry, under flight conditions (low and high operating temperatures) and with combined exposure to natural environment (high-energy radiation, ultraviolet radiation, atomic oxygen exposure).
- Particulate transport modeling and analysis for continuum, rarefied, and molecular flow environments with electrostatic, vibro-acoustic, particle detachment and attachment capabilities.
- Modeling and analysis of molecular return flux using direct simulation Monte Carlo (DSMC) and the Bhatnagar–Gross–Krook (BGK) formulations.

#### **Relevance / Science Traceability:**

Protection requirements has emerged in recent years with increased interest in investigating bodies with the potential for life detection such as Europa, Enceladus, Mars, etc. and the potential for sample return from such bodies. The development of such technologies would enable missions to be able to be responsive to PP requirements as they would be able to assess viable organisms and establish microbial reduction technologies to achieve acceptable microbial bioburden levels for sensitive life detection instruments to prevent inadvertent “false positives,” to ensure compliance sample return planetary protection and science requirements, and to provide a means to comply with probabilistic-based planetary protection requirements for biologically sensitive missions (e.g., outer planets and sample return).

#### **References:**

Planetary Protection, <https://planetaryprotection.nasa.gov/>

Handbook for the Microbial Examination of Space

Hardware, [https://explorers.larc.nasa.gov/2019APSMEX/SMEX/pdf\\_files/NASA-HDBK-6022b.pdf](https://explorers.larc.nasa.gov/2019APSMEX/SMEX/pdf_files/NASA-HDBK-6022b.pdf)

