NASA/ESA MARS SAMPLE RETURN

National Aeronautics and Space Administration

MSR Planetary Protection: Fall 2024 Update

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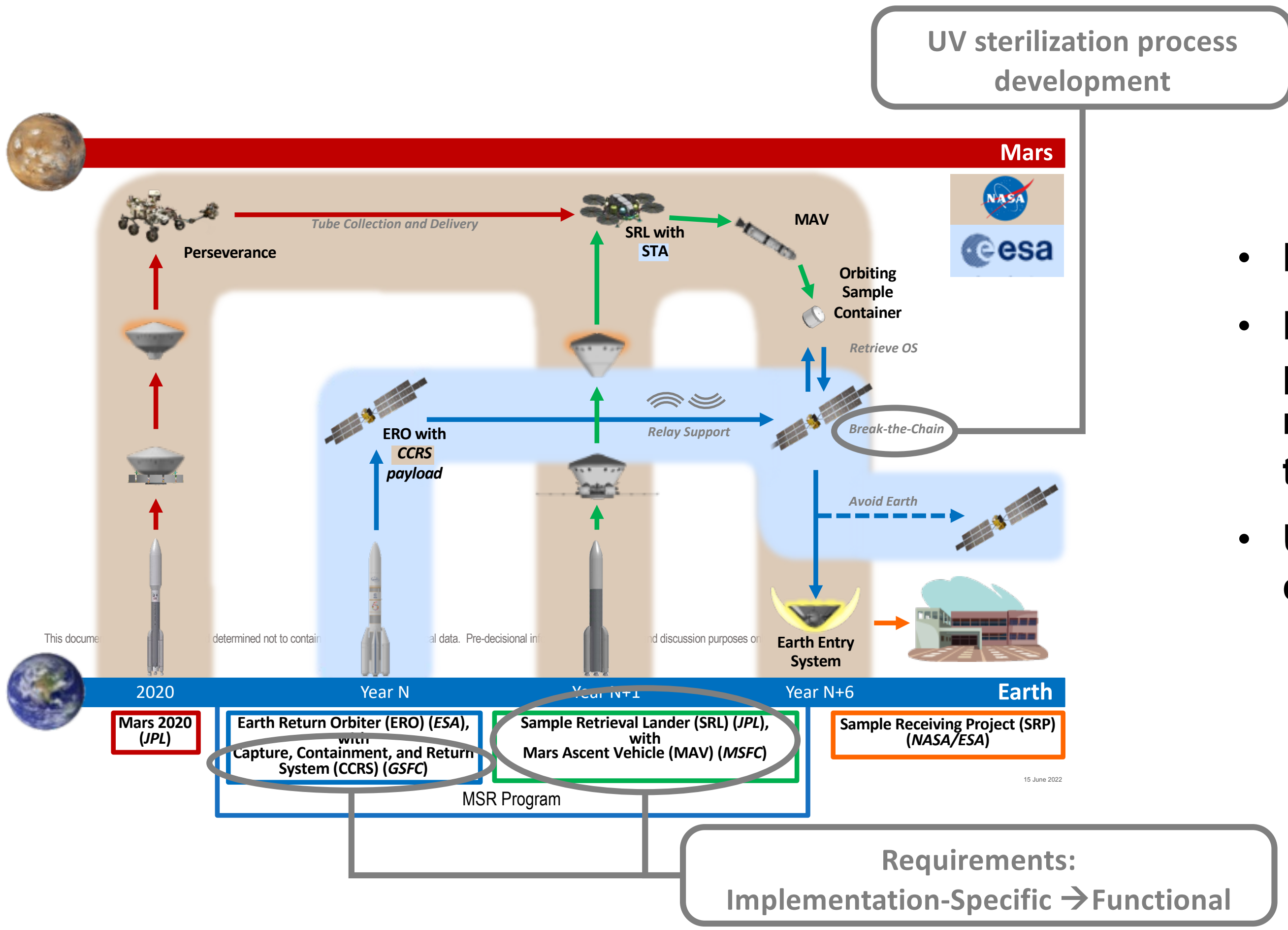
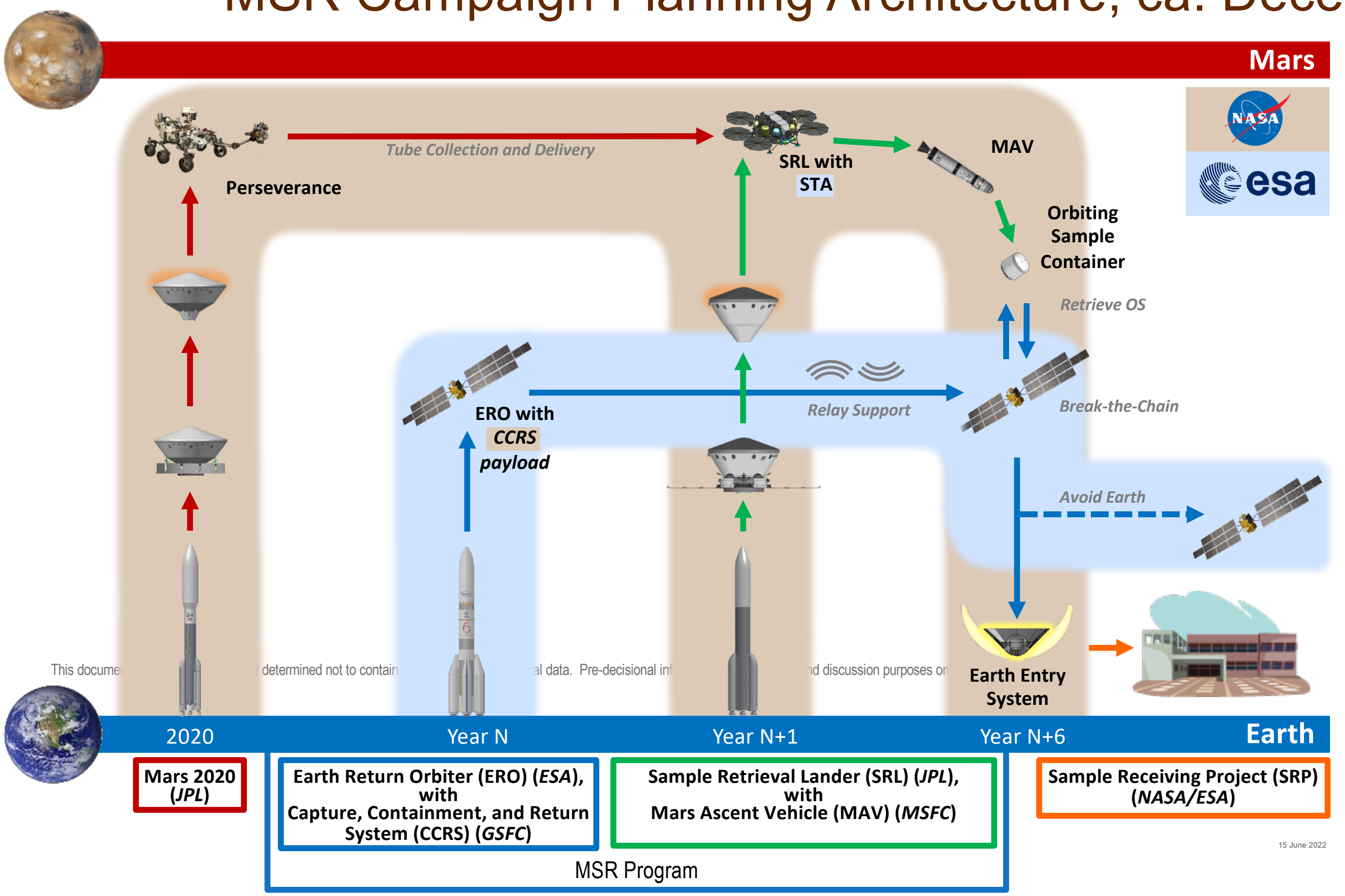
MARS SAMPLE RETURN (FORMULATION/PHASE B)



Outline

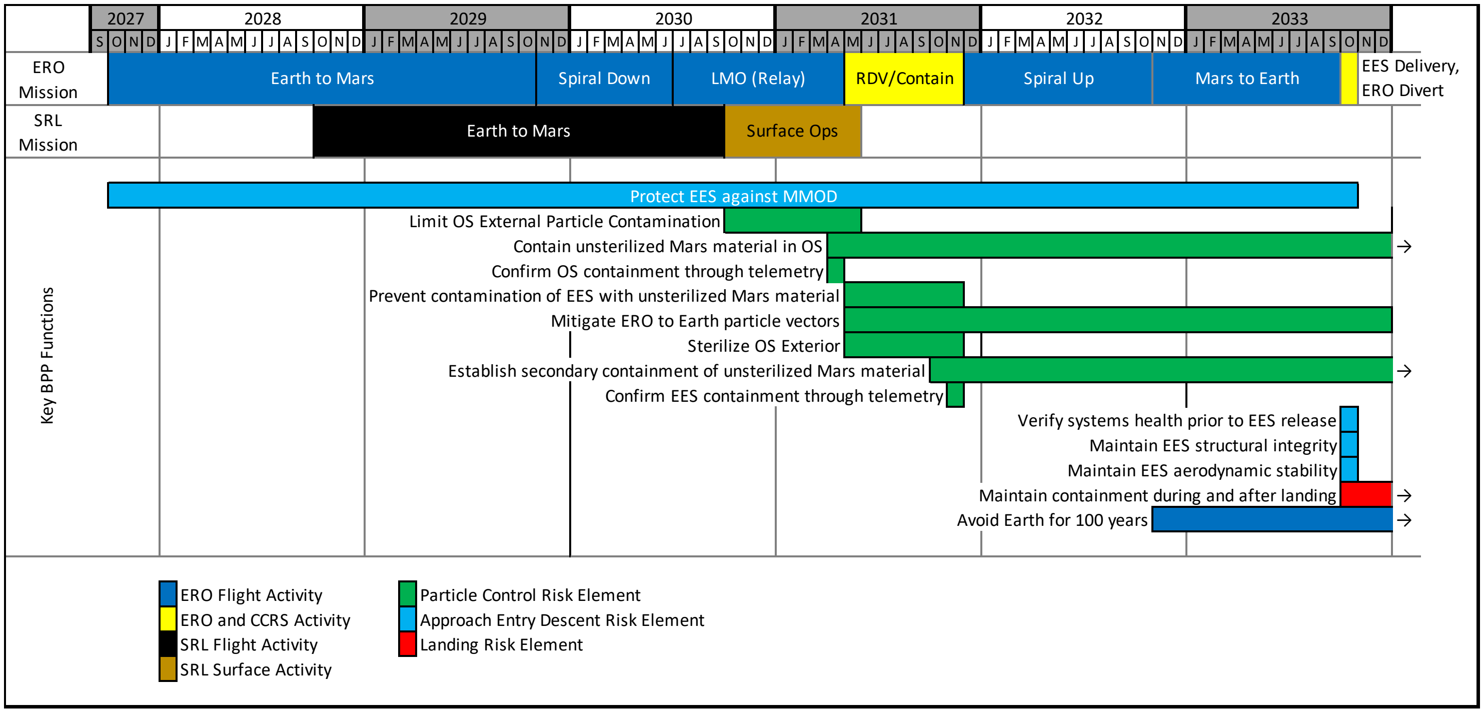
- **Brief Programmatic Update**
- **Backward planetary protection requirements; moving from implementation- to function-focused**
- **UV sterilization process development progress**

MSR Campaign Planning Architecture, ca. December 2023



- MSR Program was reviewed by a NASA Independent Review Board in mid-2023
- Based on the resulting report, NASA elected to pause certain work in late 2023 and evaluate alternative architectures
- NASA is currently evaluating rapid response studies on alternative MSR architectures and elements
- **In the interim, the MSR Program Planetary Protection team is developing architecture-independent backward planetary protection requirements**

Previous Backward Planetary Protection Requirements



Previously, MSR Program-level requirements were implementation-specific – tightly focused on the existing, reference architecture

Function-focused requirements are needed to better serve the range of possible architectures

Proposed MSR Program BPP Functions

Top-level requirements would be focused on five functions

- **Continue** – Implement standard forward planetary protection measures to protect Mars science from Earth biology
- **Control** – Limit Mars dust on flight hardware to minimize cross-contamination downstream and enable sterilization
- **Contain** – Isolate all unsterilized Mars material inside multiple, redundant containers through landing
- **Confirm** – Provide confirmation of planetary protection measures by telemetry prior to committing to Earth return
- **Dispose** – Prevent contaminated flight hardware from reaching Earth's biosphere or the Lunar surface for >100 years

MSR Program is currently converting these functions to requirements with a goal of having top-level engineering guidance in place for the Program architecture when selected

Proposed MSR Program BPP Functions – Detail (1 of 2)

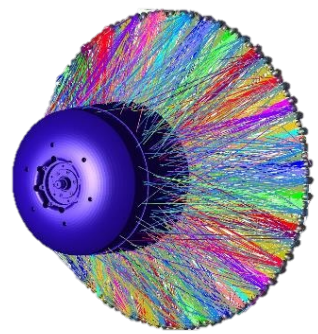
- **Continue** – Implement standard forward planetary protection measures to protect Mars science from Earth biology
    - Previously, forward PP was addressed within each project and not addressed in MSR Program requirements
    - Maintains the status quo with regards to bioburden and/or impact probabilities for all flight elements.
    - Establishes a clear requirement for organizations that do not derive PP requirements from their standard flight project practices
- **Control** – Limit Mars dust on flight hardware to minimize cross-contamination downstream and enable sterilization
    - Provides program-mediated control over the quantity of unsterilized, uncontained material that needs to be mitigated other all flight elements
    - Allows downstream elements to plan to a particular budget; initial proposed value would be the particle load limit required of SRL in the reference architecture

Proposed MSR Program BPP Functions – Detail (2 of 2)

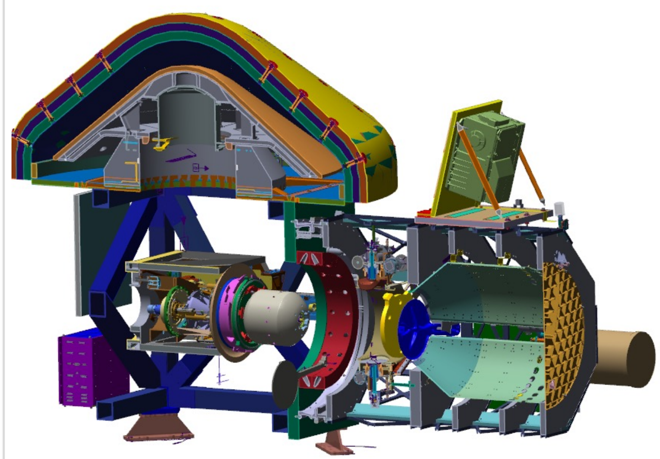
- **Contain** – Isolate all unsterilized Mars material inside multiple, redundant containers through landing
  - Would ensure safety through hand-off to the Sample Receiving Project
  - Resilience in credible, off-nominal scenarios would be included in this requirement
  - Recasts sterilization as an option for specific architectures (including the reference architecture) without mandating a specific approach
- **Confirm** – Provide confirmation of planetary protection measures by telemetry prior to committing to Earth return
  - Clarifies that missions would be required to downlink data from flight activities related to backward PP
- **Dispose** – Prevent contaminated flight hardware from reaching Earth's biosphere or the Lunar surface for >100 years
  - Previously not addressed for NASA elements in the reference architecture
  - Provide a requirement for any future architectures that include NASA flight elements carrying Mars material near Earth

Ultraviolet (UV) Sterilization Update

- In 2023, MSR selected UV sterilization for the reference architecture
- UV sterilization would mitigate any uncontained Mars material on the exterior of the Orbiting Sample container
- Relative to heat, UV sterilization reduced mechanical complexity and mass without risk to sample integrity
- Active UV sterilization as applied by MSR would ensure the OS exterior is sterilized before being placed in a Secondary Containment Vessel (SCV)
- Establishing a passive, or Solar UV, sterilization process would confirm that free-flying particles are mitigated before reaching Earth's biosphere



UV illumination modeling developed to guide preliminary system designs for sterilizing the sample container (in blue) exterior



Side cutaway view of the Capture, Containment and Return System showing the UV Illumination Assembly (white arrow) and orbiting sample container (blue arrow)

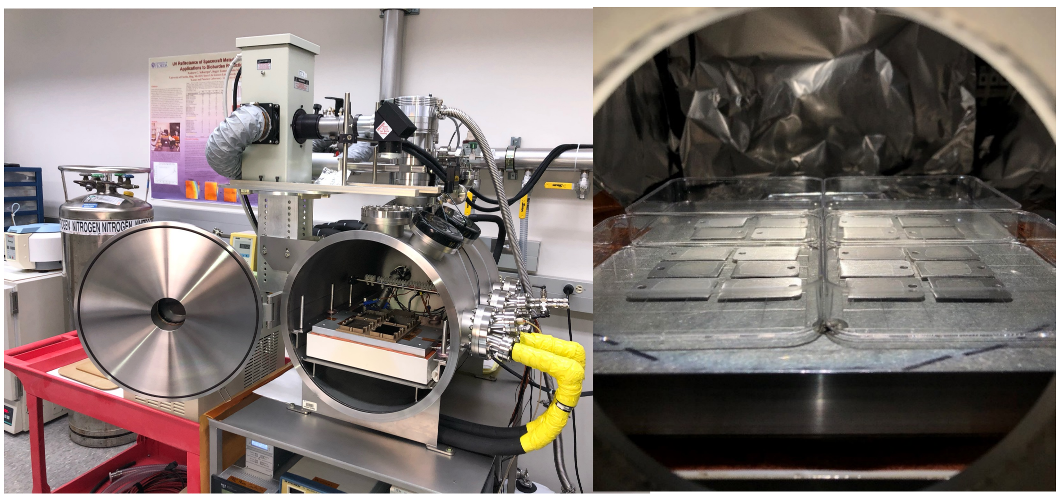
Sterilization Process Definition: Experimental Programs

- Sterilization processes are formally defined by data derived under application-specific conditions
  - Organisms are exposed to varying UV light doses to assess dose-effect correlations and demonstrate robust inactivation of large organism populations (e.g., 10^6 per test)
  - UV exposures would be carried out using light filtered through dust at space vacuum and flight temperatures
- Key process definition considerations
  - Selection of target organisms (a.k.a. bioindicators)
  - Achieving inactivation of 10^6 organisms under application-specific conditions – simulated Solar UV or LED-based, narrow-band UV illumination
- MSR established a three-track program in 2023 to establish the correct conditions for developing and confirming a robust UV sterilization process

Sterilization Process Definition – Solar UV Experiments

Objective: Determine time needed in low-Mars orbit (LMO) conditions to achieve sterilization with solar UV

All experiments were performed by the Schuerger Lab at the University of Florida in the Planetary Atmosphere Chamber, simulating low-Mars orbit (LMO) conditions



Images provided by UF

Experiment 1

Expose UV resistant organisms to 1-sol LMO conditions

Experiment 2

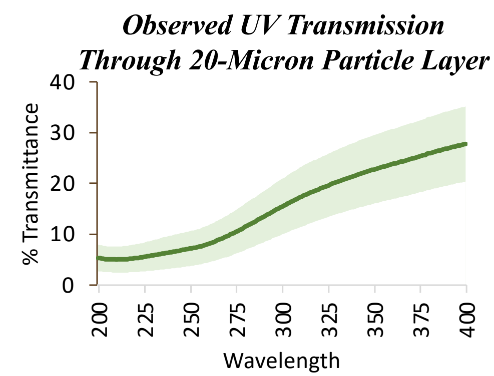
Determine sterilization doses for two most resistant organisms (one bacterial, one fungal)

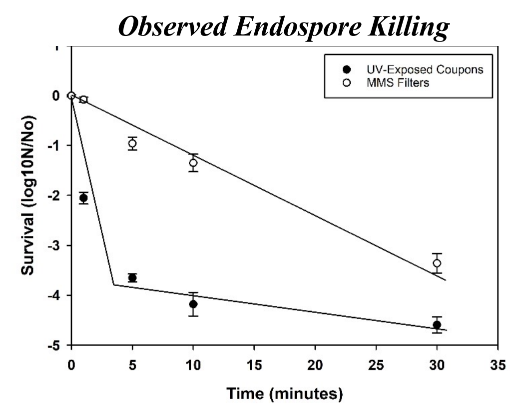
Experiment 3

Determine protective effects of Mars-analog materials

Key Result: Solar UV Demonstrates Predictable Attenuation

- Mars simulant was utilized to build 'filters' equivalent to large, rare windborne particles
  - 20- micron thick layer of Mojave Mars Simulant that blocks ~90% of UVC transmittance
  - Less than 1 in a billion windborne Mars dust particles are ≥20 microns
- UV-tolerant bacterial spores were exposed to simulated solar UV with and without light 'filtration'
- Disinfection of *B. pumilus* SAFR-032 was achieved in ~30 minutes
  - Lethality rate was reduced by 90% as expected
- **Particle sizes relevant to the MSR reference architecture slow but do not inhibit sterilization**
- Data on additional organisms and UV doses will be reported in an upcoming paper by Schuerger et al.

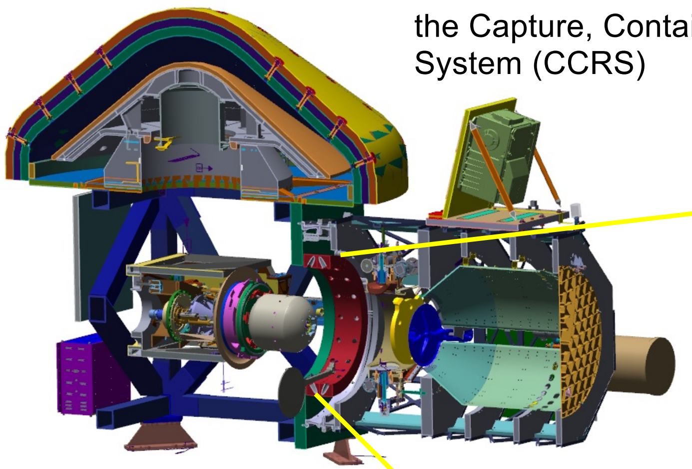


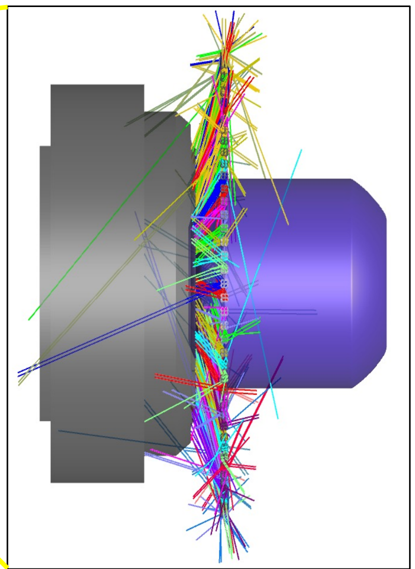


Data: JPL and the Schuerger Lab, Univ. of FL

Sterilization Process Definition – Active UV Experiments

UV Illumination Assembly (UVIA) ring within the Capture, Containment and Return System (CCRS)





A double ring of LEDs would be used to irradiate the OS surface at a flux higher than at the top of Mars' atmosphere and high enough to overcome any shadowing from potential dust or other surface features on the OS.

Images provided by GSFC

Objective 1

Test active UV parameters needed for sterilization with fail-fast experiments

Objective 2

Design UVIA prototype to mimic flight configuration and achieve required flux (done by GSFC)

Objective 3

Design test campaign to define active UV parameters and test sterilization capability of UVIA prototype under spaceflight conditions

Key Result: Initial Active UV Experiments show >6-log reductions

Objective 1 - JPL

Test active UV parameters needed for sterilization with fail-fast experiments at ambient conditions

- Tested proposed UV dose derived from existing studies with UV resistant species
- Illumination: 280nm UV LEDs in ambient temperature and pressure
- Doses from 5 to 20 kJ/m^2 at 10 W/m^2 yielded **no survivors**

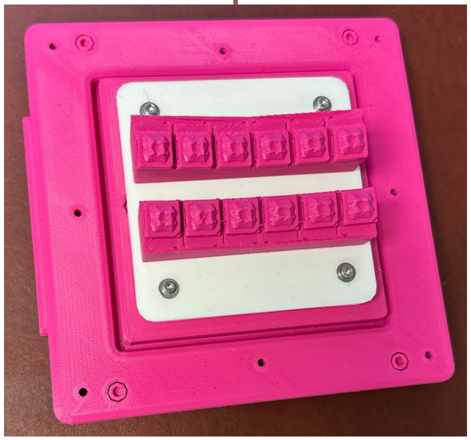
Test Organism	Dose kJ/m^2	n	Starting population	Log Reduction
Bacillus pumilus SAFR-032	20	4	8.00E+06	>6.9
Bacillus pumilus SAFR-032	10	3	8.00E+06	>6.9
Bacillus pumilus SAFR-032	5	3	8.00E+06	>6.9
Aspergillus fumigatus ISSFT-021-30	20	3	8.00E+06	>6.9
Aspergillus fumigatus ISSFT-021-30	10	3	6.50E+07	>7.8
Aspergillus fumigatus ISSFT-021-30	5	3	6.50E+07	>7.8

Sterilization Process Definition – Active UV Experiments

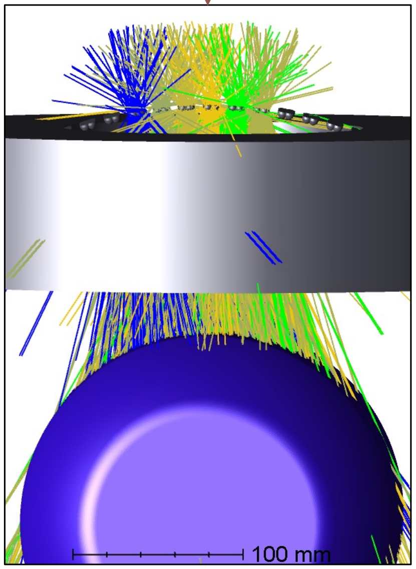
Objective 2 - GSFC

Design UVIA prototype to mimic flight configuration and achieve required flux (done by GSFC)

- Goddard Space Flight Center's UV Illumination Assembly team has designed a unit to provide UV illumination through an environmental chamber window
- The unit would illuminate microbes on coupons inside the chamber and provide a range of test fluxes and doses
- Assembly of the testbed unit is underway



Light engine prototype design allows biological tests with either of two 6-engine LED arrays



Ray tracing of 6 light engines through a quartz glass window
Data to date indicate fluxes >> 375 W/m^2

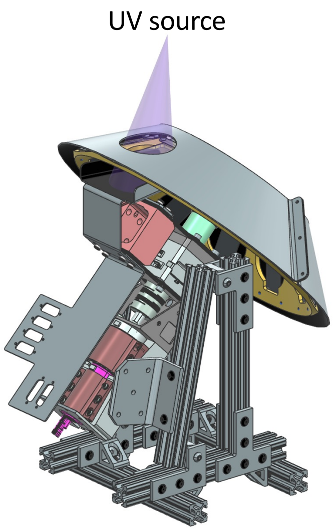
Images provided by GSFC

Sterilization Process Definition – Active UV Experiments

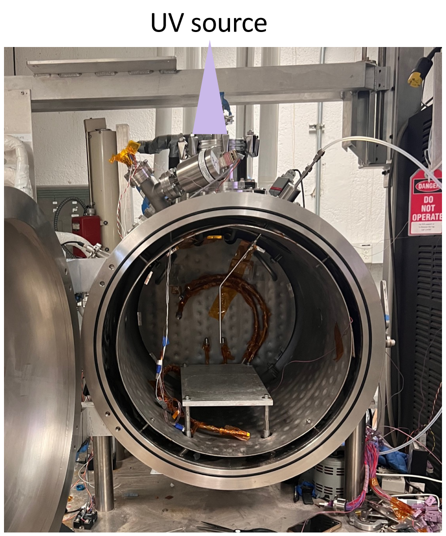
Objective 3 JPL & GSFC

Design test campaign to define active UV parameters and test sterilization capability of UVIA prototype under spaceflight conditions

- Test coupons coated with aerosol-deposited microbes will be placed on a rotating stage to restrict exposure to one sample at a time under the UV illumination unit built by GSFC
- Exposures will simulate pulsed and continuous operation of light engines across a range of fluxes and total doses to simulate flight capabilities
- Current status: stage design and aerosol deposition method development underway



Rotating stage, preliminary design



Environmental test chamber at JPL

Images provided by JPL

Sterilization Process Definition – Active UV Experiments

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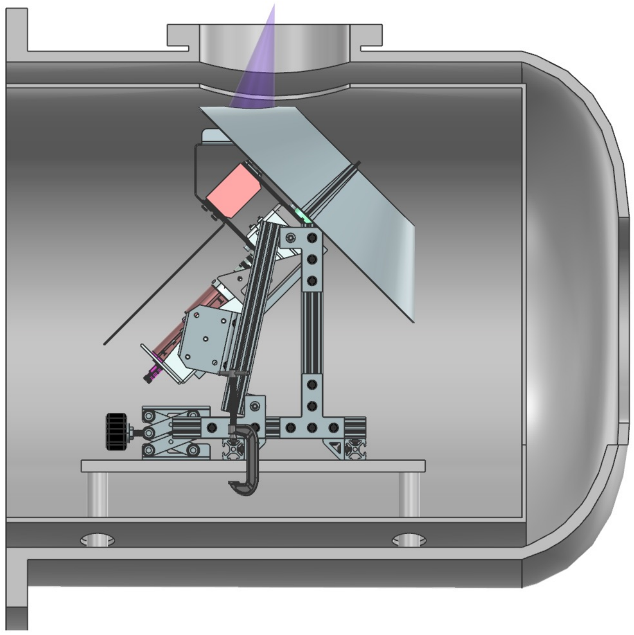

Side cutaway view of the rotating stage (preliminary concept) in an Environmental test chamber at JPL

Images provided by JPL

Summary

- **As selection of a new architecture proceeds, MSR Program Planetary Protection engineering effort continues to progress**
- **Function-focused Program-level planetary protection requirements are in development**
  - Goal is to establish clear, rapid path to lower-level engineering requirements for the future MSR architecture
- **UV sterilization process development continues**
  - Solar UV sterilization has been demonstrated with UV-resistant microbes
  - UV attenuation from particles has been shown to be predictable and compatible with sterilization
  - Process definition work is underway for LED-based Active UV illumination with a target end date of October 2025

Thank you