Mars 2018

Planetary Protection and Sample Integrity
Focused Technology Development

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Outline

• Introduction
• MSR Planetary Protection Requirement (Draft)
• Technology Gap for Mars 2018
• PP&SI Focused Technology Plan
Earth

Mars

Break the chain

Assure containment

SRF

Earth

Mars 2018

MSR-L

MSR-O

Time progression

Protect Earth (Inbound Phase)

"Back Contamination"

Category V. $10^{-6}$ (TBC) chance of one single 0.1 micron (TBD) size un-sterilized Martian particle being released to earth environment

Protect Sample

Terrestrial TOC contamination limit <50 ppb in sample. Microbial contamination limit (TBD)

Protect Mars (Outbound Phase)

"Forward Contamination"

Category IVb

IVb

MAV

EEV

Planetary Protection Requirement Categories

Ying Lin (Nov, 2011)
Probability of launch vehicle H/W impact <10^{-4}

<300,000 spores* on exposed surfaces of landed H/W; <0.03 spores*/m^2 on sample handling sub-system surfaces; recontamination prevention measure throughout the mission; additional spore limits for planned-impacting H/W

Probability of containment of one 200 nm (TBD) particle not assured <10^{-6} (TBD)

*spore definition per NPR 8020.12D

Round trip blanks/controls

50 ppb TOC in sample; 1 ng/cm^2 TOC on sample (TBD)

10^{-2} (TBD) probability of sample contamination by viable Earth organism

TBD Level of Earth-source organic molecules

TBD Level of Earth-source inorganic contaminants

NASA Planetary Protection Requirements

Sample Containment (Protect Earth)

Contamination of Mars (Protect Mars)

Returned Sample Contamination (Protect Sample)

Returned Sample Contamination

MSR Science Requirements

Draft requirement guideline by Planetary Protection Officer for MSR, taken as goal for technology development.
Mars 2018 new PP requirements and needs

- Sample handling hardware remain sterile until the sampling activity is completed (Not in Category IVc or IVa)
- Total 50 ng/g TOC contamination in sample. (MSL CC requirements only restrict the organic contamination transfer from hardware surfaces)
- Microbial contamination limit in sample (TBD)
- 1 ng/cm² TOC (TBD) Sample contacting hardware cleanliness and recontamination prevention measures required throughout the mission operation. (MSL CC requirement is 100 ng/cm² without recontamination prevention requirements)
- Sample integrity through containment, sealing and reduce any contamination risk during sample storage on Mars
- Round-trip blanks/controls are required (MSL optional)
- NASA PPO approval before launch (MSL, project approval for organic contamination)

Technology and capability gaps in the areas of contamination risk assessment, cleaning, sterilization, validation, and containment.
PP and SI Technology Plan Development Process

- Draft PP Requirements
- Science CC Requirements
  - not available yet

- Current SOA Technology Capability Survey
- PP & SI focused technology plan
- Mars 2018 PP & SI Implementation Strategy
- Past and Future Relevant Missions
- Material, Technology Heritage
- MSL Contamination Control Technology Heritage
I. **Contamination risk assessment**
- Quantitative contamination burden assessment of hardware
- Contamination (biological and organic) transport measurement and modeling
- Risk assessment of sample contamination

II. **Surface sterilization and precision cleaning**
- CO$_2$ cleaning, laser, plasma
- Cleaning validation (microbes, molecules, particles)
- SHEC cleaning

III. **Re-contamination prevention**
- Clean assembly
- Contamination barrier
- Organic sensor, getter

IV. **Sample containment, sealing, sample integrity**
- Material selection, compatibility to Martian samples
- Sealing method and materials
- Sample integrity
Area I: Contamination Risk Assessment

Description:
System Engineering approach to establish quantitatively the pathway of contamination transport from spacecraft hardware and environment to samples
- Quantitative organic and microbial contamination burden assessment of hardware
- Contamination (biological and organic) transport measurement
- Transport modeling, Integrated tool development
- Risk assessment of sample contamination

Objectives:
- Enable the Mars 2018 project to develop reliable implementation approaches including a set of flow-down requirements on outgassing material usage limits, hardware surface cleanliness levels, and hardware containment needs.
- Enable the project to demonstrate that it meets the PP sample organic and microbial contamination requirements
Hydrophobic Microbes

Hydrophilic

Molecular polarity

Amino acids
Amines or Amides
DNA
Hydroxyl containing compounds

Hydrophilic (water soluble)

Hydrophobic (Solvent removal)

Microbes (physical removal)

TOC

(Proportion is for illustration only)

Amino Acid analysis
HPLC (1 ng/cm²)
CE (pptr)

Water (80)

Carbonyl containing compounds
Benzene
Aromatic hydrocarbons
Non-aromatic hydrocarbon

Hexane (1.88)
DCM (9.1)
Acetone (21)
IPA (18)

GC (ppb, 1ng/cm²)

Total Organic Carbon Composition Chart

Ying Lin (Nov, 2011)
There are at least three pathways by which contaminants can be transported into samples:

- Direct contact – microbial and molecular contaminants are transferred from the hardware surfaces to samples by direct contact.
- Particle transport – microbes and molecular contaminant-containing particles are dislodged from spacecraft hardware surfaces by wind or by mechanical forces and are then carried by wind to the sampling ground or into the sample tube.
- VOC transport – outgassed volatile organic compounds from nonmetallic parts will diffuse or be carried by wind to condense on the sampling ground, sample contacting hardware, and samples.
Assumptions:
• Far field model under unidirectional wind of 7 m/s steady
• Rover moves 1 km away in the direction of the wind 48 hours after landing
• Another 24 hours at the sampling site
• Initial total spores on the rover is $3 \times 10^5$ and the corresponding VEM $3 \times 10^8$

Key points illustrated:
• The simple BOTE estimate illustrates that the risk of sample contamination is not low.
• It also shows that understanding accurately the particles dislodgement and the Martian weather conditions are critical to the overall contamination risk.
Sample Handling, Encapsulation, and Containerization (SHEC) Description

SHEC Subsystem
(enclosed)

Sample carousel

Sample measurement/sealing station

Bit carousel

Bit chambers

Insertion bellow, seal

Plugs (green)

Sample tubes (yellow)
Capsules when filled

Sample canister (blue)

Spare tubes (yellow)

Linear actuator, tube gripper

2-DOF handling arm

Bit (blue)
Note: Most paths where lubricant can flow have been sealed using Felt or Parker Teflon Seals. There is one path that is not sealed (other than utilizing a labyrinth approach) however the sample tube should never come in contact, can explain further as necessary.
### Calculator of Probability of Roundtrip Viable Earth Microbe (VEM) in Sample from Mars

#### Times of Day Wind Events

<table>
<thead>
<tr>
<th>Manual Day Wind Times</th>
</tr>
</thead>
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#### Speeds of Day Wind Events

<table>
<thead>
<tr>
<th>Manual Day Wind Speeds</th>
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#### Load Settings from a Row in a Spreadsheet

#### Parameter Values – User Can Change by Clicking on Them (See Next Slide)

#### Selection Among Sterilization Options

- **Sterilization**
  - NONE
  - HS = 0.1
  - DHMR = 0.0001
  - H2O2 = 0.001
  - UV = 0.0001
  - Other = 0.01

- **Cleaning**
  - NONE
  - IPA
  - UPW

- **Filters**
  - NONE
  - In Use

- **Load Settings**
  - from a row in a spreadsheet

#### Interactive and Integrated Tool
Main areas include physical process understanding, model development and validation, and an end-to-end model integration.

1. Wind-induced particle dislodgement
2. Vibration-induced dislodgement
3. Direct coring tool contamination
4. Contamination inside the SHEC
5. Martian wind information
6. Special weather conditions
7. Far field transport models
8. Near field transport
9. Organic vapor transport
10. Quantify organic molecules-particle association
11. Spore-particle association
12. The ratio of VEM to spores
13. Particle size distribution
14. End to end model integration and analysis
Contamination Burden Assessment

• Develop strategies to quantitatively assess the total organic carbon (TOC) burden of spacecraft hardware.
• Quantitatively assess the total microbial burden of spacecraft hardware.

Contamination Transport Measurements

Objectives: Generate critical and realistic physical parameters that are necessary to develop a comprehensive end-to-end microbial and organic contamination transport model.

Approach: by conducting experiments in testbeds including the Mars Wind Tunnel with drill, SHEC, and rover analogue, critical relevant interaction phenomena pertaining to particle and organic removal, transport will be measured.

Contaminant Transport Integrated Interactive Model Development

Objectives:
• Determine contaminant transport during surface operations in the Martian atmosphere to quantify spacecraft cleanliness requirements for surrounding area and samples.
• Develop an integrated interactive tool for assessing prognosis of meeting PP requirement.
Description:
Develop precision cleaning technologies to achieve surface organic cleanliness and microbial sterilization. It also has potential for in situ cleaning applications
   – CO₂ jet cleaning, Laser/plasma cleaning
   – Cleaning validation (microbes, molecules, particles)
   – SHEC cleaning

Objectives:
Enable the Mars 2018 project to successfully implement planetary protection (category IVb and sample contamination requirements) and mission science requirements
**CO₂ Jet Cleaning**

**Objectives:**
- Develop a cleaning method that will remove sub-micron particles by varying parameters such as CO₂ crystal size, speed of delivery onto surfaces
- Validate cleaning efficiency
- Develop a TRL 6 touch-up cleaning device
- Evaluate the possibility for in situ clean sampling applications on Mars

**Cleaning Validation**

**Objectives:**
- Validate surface cleaning methods
- Design and build optical detection system for surface particle analysis
- Calibrate and measure detection sensitivity
- Distinguish contaminant types
Ultra-cleaning technologies are needed to achieve surface sterility and be organics clean; methods needed for all relevant material surface and geometry; cleaned parts must be protected from recontamination (use of glovebox or sealed bags free of contamination)

Clean assembly, touch-up surface cleaning, contamination barriers are required. Must actively monitor contamination transfer within the glovebox or barriers

Surface cleaning to sterility is needed after each assembly step and re-work

Cleaning validation (trace organics and submicron particles) methods are needed for verification

Clean assembly, touch-up surface cleaning (e.g. with hand-held CO2/plasma jet), contamination barriers are required
A Possible PP Implementation Approach (Con’t)

Cruise Stage
Environment: Temp TBD, Hard Vacuum
Duration: 6 months
Cont. Source: N/A

Martian Re-Entry
Environment: Temp TBD, Hard Vac, Re-Entry Vibe
Duration: 15 minutes
Contamination: FOD due to vibe

Martian Roving
Environment: Temp TBD, Pressure 10torr
Duration: TBD years
Cont. Source: N/A

Procedures must be taken to avoid sampling area contamination from rest of (dirtier) lander or rover. Transport models (vapor, particle, contact) for Martian environments are needed for contamination risk analysis.
A Possible PP Implementation Approach (Con’t)

**B**

Insert clean sample tube in bit assy and remove Bit from SHEC

- **Environment:** Temp TBD, Pressure 10torr
- **Duration:** ~10 minutes
- **Cont. Source:** N/A

Core Sample Directly Into Sample Tube

- **Environment:** Temp TBD, Pressure 10torr
- **Duration:** ~2 hours
- **Cont. Source:** Cross-cont. from previous samples

Place Bit Assy into SHEC and remove sample Tube from Bit

- **Environment:** Temp TBD, Pressure 10torr
- **Duration:** ~10 hours
- **Cont. Source:** Cross-cont. from previous samples

Cap and Seal Sample Tube and Place in Sample Canister

- **Environment:** Temp TBD, Pressure 10torr
- **Duration:** ~1 hour
- **Cont. Source:** Cross-cont. from previous samples

Place sample canister on Martian Surface and await Fetch Rover

- **Environment:** Temp TBD, Pressure 10torr
- **Duration:** ~5 years
- **Cont. Source:** Atmospheric Dust, failed seal

**Reqs:**

1. No live microbes
2. 50 ppb TOC

Modeling tools, experimental data are needed for requirements flow-down (e.g. limits on offgassing, outgassing rates, non-metallic materials used: amounts and locations, hardware surface cleanliness requirements)

Sample integrity, material compatibility
Description:
Strategies for preventing re-contamination between hardware components.
- Clean assembly
- Contamination barriers
- Organic sensor, getter

Objectives:
- Prevent contamination transport between hardware components (molecular and particulates)
- Protect cleaned sample contacting hardware from re-contamination during ground handling and sample acquisition on Mars
  - PP requirements (*MSR Campaign, Caching Mission, and MAV Mission, July 2011*):
    - Surface molecular cleanliness of < 1-10 ng/cm² (TBD)
    - Surface microbial cleanliness < 0.03 spores/m²
    - No particles > 200 nm in diameter (TBD)
- Prevent contamination of Martian sample from terrestrial contaminants carried by spacecraft
  - PP Requirement: < 50 ng/g of terrestrial organics transferred to Martian sample
  - Microbial contamination probability limit < 10⁻³ VEM (TBD)
Implementation Strategies

• Clean assembly techniques (mini-environments)
  – Vacuum enclosure required for 1 ng/cm² cleanliness level
• Develop contamination barriers
  – Encapsulation on Earth and Mars
• Molecular sensors for monitoring of contaminants
• Develop custom filters and molecular getters
• Fly controls/blanks to monitor contamination health

**Cross-Contamination Prevention Technologies**

**Objectives:**

• Develop strategies to prevent re-contamination of hardware components
  • Clean assembly
  • Contamination barriers
  • Molecular sensors, getters
Description:
Establish and test candidate material capabilities to samples by working with the caching and science teams to fulfill sample integrity science requirements for Mars 2018
- Material selection, compatibility to Martian samples, sample integrity
- Sealing method and materials

Sample Containment, Sealing, and Sample Integrity

Objectives:
- Define and deliver standard procedures for evaluating and recommending compatible materials.
- Evaluate sample/container interaction through chemical, mechanical, and physical compatibility tests using Martian analogue soils
- Assess material integrity against environmental factors
- Investigate materials and sealing techniques within constraints of the Martian environment
- Deliver a material lifetime prediction based on an Arrhenius–based model fit of the data
Summary

• Mars 2018 is a Cat V and IVb mission with corresponding PP requirements
• MSR PP requirements are sufficiently different from all previous Mars missions that new technology and capabilities are needed.
• Technology gaps for Mars 2018 have been identified and an investment portfolio developed
• Mars Focused Technology program will invest in four critical areas:
  - Contamination risk assessment
  - Surface sterilization and precision cleaning
  - Cross contamination prevention
  - Sample containment, sealing, sample integrity