Mars 2020 Mission Planetary Protection Implementation and Lessons Learned

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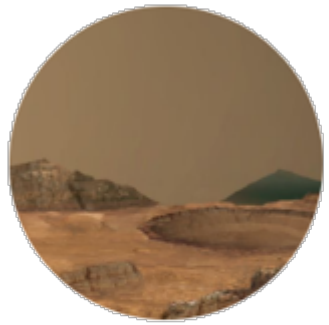
SCIENCE GOAL 1:
Determine Whether
Life Ever Arose on Mars

SCIENCE GOAL 2:
Characterize the
Climate of Mars



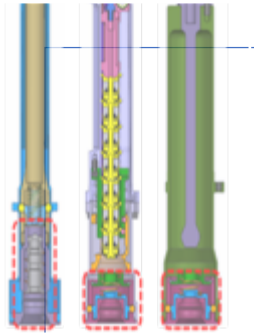
SCIENCE GOAL 3:
Characterize the
Geology of Mars

SCIENCE GOAL 4:
Prepare for Human
Exploration

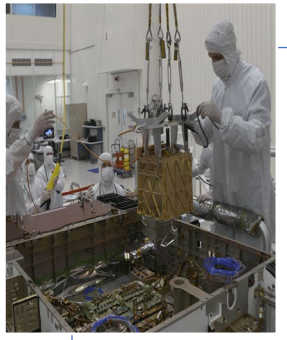
Introduction

- Planetary protection (PP) Implementation for a flagship mission is an extremely complex process, often involving coordination with internal teams, vendors, and external agencies.
- Developing and executing an effective PP implementation plan involves strategizing spacecraft bioassay sampling timing, bioburden accounting, and effective coordination with the build engineers.
- The Mars 2020 spacecraft was kept biologically clean for two purposes:
  - Forward planetary protection - to avoid harmful contamination of Mars, which could confound future searches for life.
  - Returned sample science cleanliness - to limit Earth-based contamination in the samples that the mission will collect for science purposes.
- Sharing M2020 Lessons Learned can help future missions understand potential and realized pitfalls to improve future processes.

Forward PP Implementation Approach

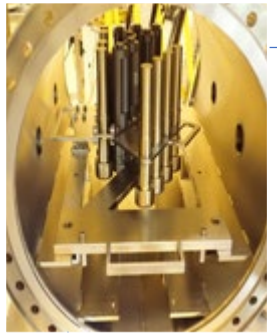


PP Stakeholders involved at the hardware design/change review stage



Cleanroom Assembly

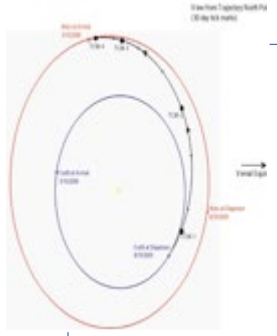
- ISO-8 or better cleanrooms



Microbial Reduction Processes

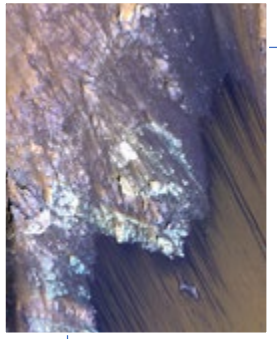
- Heat
- IPA wiping
- Vapor Hydrogen Peroxide

Biological Cleanliness Monitoring throughout hardware assembly and testing



Limiting hardware going to Mars, e.g.

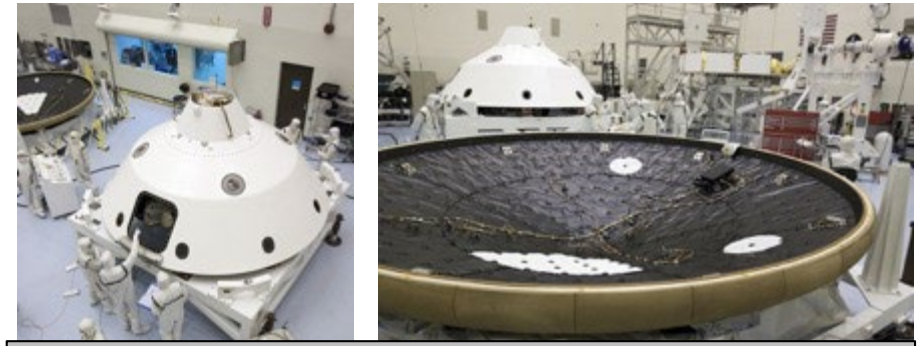
- Trajectory biasing of Launch Vehicle
- Atmospheric burn-up of Cruise Stage



Avoid natural and induced special regions for landing

Aeroshell = Heat shield + Back shell + Parachute

- **Back Shell, Heat Shield Implementation Approach:**
  - Due to impact, all surfaces and embedded organisms are accountable bioburden.
  - The heat shield and back shell honeycomb structure was heat microbially reduced during its fabrication (curing of adhesive) by the maximum allowed 6-log (cure temp min = 177°C for 48 hrs).
  - Coupons: HS Coupon from MSL is being used for Mars 2020 as a witness plate. BS Coupons (4) being manufactured during Mars 2020 build as organic witness plate.
  - Cables, insulation, and seals: Bakeout to achieve at least a 3-log surface reduction.
  - Back shell electable balance masses and separation devices: IPA cleaning
  - **MEDLI2:** All MEDLI2 Heat Shield and Backshell instrumentation underwent a 4-log surface HMR and 3-log bulk HMR with exception of the MISP SLA Plug (backshell) and MISP PICA Plugs, which underwent a 3-log surface HMR and 3-log bulk HMR process. MEADS bioburden was low enough to waive HMR.
  - Bioassay to verify upon last access (at LM for MLI and MEDLI2)



Backshell (left) and Heatshield (right, MSL flight spare).

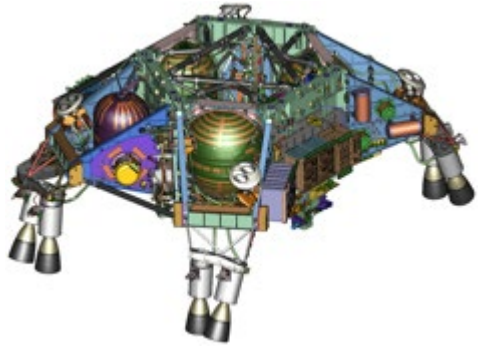
Aeroshell = Heat shield + Back shell + Parachute

- **Parachute Implementation Approach:**
  - During fabrication of the Mars 2020 flight parachute, roll and trim fragments were made available to establish the baseline bioburden.
  - A quilt of parachute materials were delivered to OPP and JPL for direct submersion sampling.
  - JPL PP sampled the parachute directly pre-DHMR
  - The entire system was subjected to a HMR regimen: 125C for 5 hours – 3-log microbial reduction
  - The mortar charge will be separately cleaned (IPA), assayed and subsequently integrated with the Parachute.

Cruise Stage

- CS includes: primary structure, secondary structure, propulsion, solar arrays, guidance navigation and control (GNC), avionics, heat rejection system (HRS)
- **Implementation Approach:**
  - The cruise stage will meet PP requirements for microbial reduction during Mars orbit entry heating

Descent Stage



DS structure

- **Implementation Approach:**
  - Fabrication microbial reduction credits for select boards
  - HMR of cabling
  - IPA wipe and Bioassay to verify that cleanliness levels are within the allocation.

Rover

- **Implementation Approach:**
  - Varies greatly by component, but per the PPIP. Select hardware implementation approaches and status will be highlighted in the upcoming slides.

Mobility

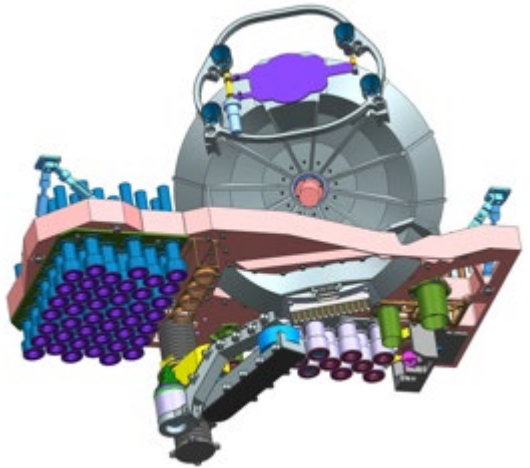
- **Implementation Approach:** IPA wipe of exterior and bioassay prior to last access pre-DHMR, DHMR wheels and bag with clean material until loss of access.

Robotic Arm

- **Implementation Approach:**
- Bioassay actuators and RA at the vendor prior to closeout.
- Arm assembly-level bakeout (110°C, 98 hours). DHMR of flex cabling at 110C for 60 hrs.

Remaining SCS Hardware

- Bit Carousel - doors remained closed after final bakeout / DHMR (141h @ 110˚C)
- Corer - Percussion operations (@ high velocity) not permitted after final corer bakeout / DHMR with flight launch bit
- Dispenser, Volume Probe, Tube (DVT) Assembly - Fluid mechanical particle barriers (FMPB) covers / gloves must remain in place after final combustion cleaning (150˚C, 29 hrs)
- Tube storage assembly - FMPB gloves must remain in place after final combustion cleaning (150˚C, 29 hrs)
- T-0 Purge
  - Tubes precision cleaned and baked at 125±5°C for 89 hrs.
  - 0.2 micron filter built into the exit of the purge cart



T-0 purge line

Hardware designations within the Sampling and Caching System

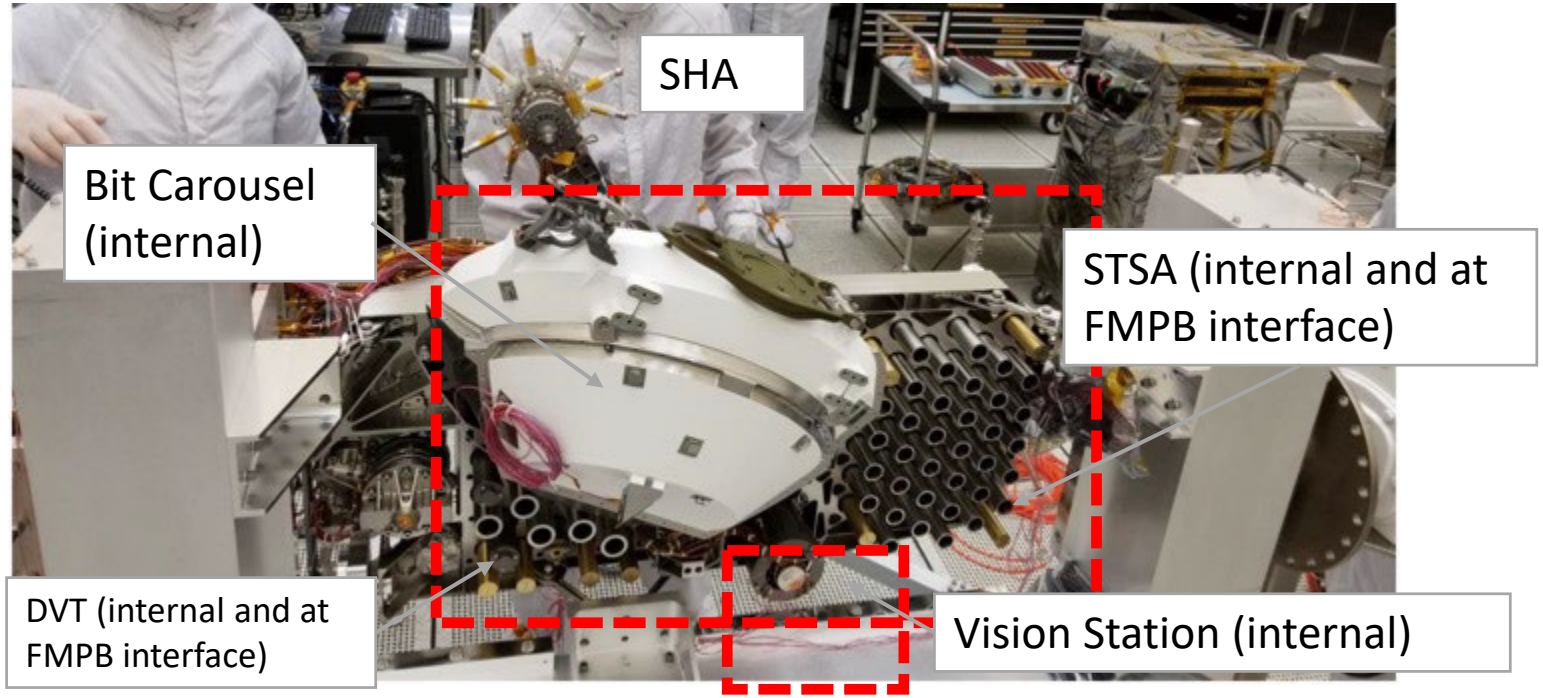
Sample Intimate Hardware (SIH) is defined as any hardware that comes in direct contact with the sample. Specifically, SIH includes the following:

- Sample Tube
- Hermetic Seal Components
- Volume Probe
- Coring, Regolith and Abrading Bit Assemblies

Sample Handling Hardware (SHH) is defined as hardware that comes into close proximity to the sample or in directly contact or close proximity to SIH. Specifically, SHH includes the following:

- Gloves
- Covers
- Sample Tube Storage Assembly (STSA)
- Hermetic Seal Dispenser Assembly
- Volume Probe Housing
- Dispenser Volume Tube (DVT) Assembly
- Bit Carousel
- Vision Assessment Station

PP Sampling Restricted Surfaces



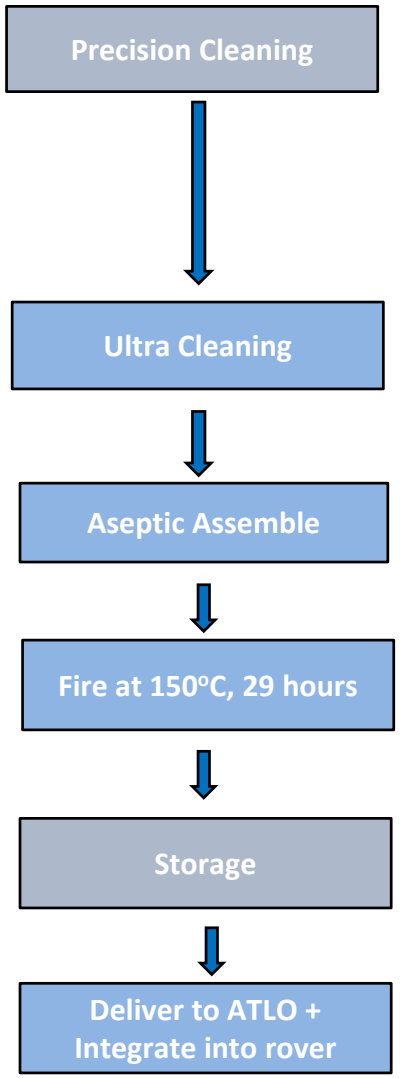
Restricted Surfaces

- Bit Carousel
  - internal parts, PCL100, A/10
  - bits, PCL50, A/10
  - Exterior white paint surface
- Vision Station
  - (Baffle + Illuminator) internal surface, PCL 100, A/10
- Sample Tube Storage Assembly (STSA), PCL50, A/10
- Dispenser Volume Tube (DVT), PCL50, A/10

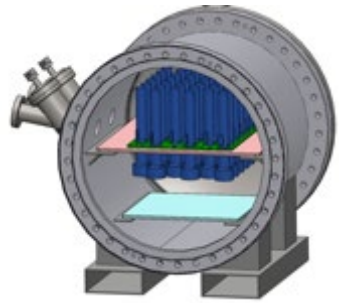
Sampling Approach

- NASA Standard Assay Sampling between precision cleaning & final ultra cleaning steps for PCL 50/PCL100 SIH & SHH
- PP witness coupons used as proxy for bit carousel exterior white paint surface

SIH/SHH PP Implementation Approach



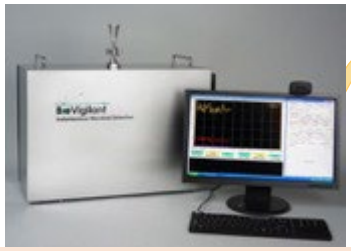
- **Precision cleaning:** Conventional precision cleaning at JPL precision cleaning facility to meet standard hardware cleaning requirement (300 spores/m^2)
- **Baseline analysis:** NSA analysis before Ultra cleaning to determine the hardware microbial contamination level
- **Ultra cleaning:** Ultra sonic cleaning in solvents to achieve 2~3 log microbial contamination reduction
- **Aseptic Assembly:** Hardware assembled in ISO 5 flow bench in ISO 5 cleanroom. Monitor assembly area using BioVigilant (< 1cfu/25cm^2). NSA analysis using proxy SIH/SHH/ witness plate.
- **Combustion Cleaning (STSA&DVT):** Fire at 150°C for 29 hours inside the CASE, 6 log bioburden reduction
- **Hardware Storage and delivery:** SFM Hardware stored in the CASE, hermetically sealed and delivered to ATLO for final integration (swapped in place for AFM). Monitor assembly area using BioVigilant (< 1cfu/25cm^2). NSA analysis using proxy SIH/SHH/ witness plate.



PP Implementation for Aseptic Assembly

Planetary Protection Implementation Procedures for Aseptic Assembly

Environmental Monitoring & Sampling



BioVigilant continuous monitoring of airborne particles (inert & biological)

Facility settling plates

Facility wipe sampling (10 to 15 wipes) on a bi-weekly basis

Active air sampling

PP & Bio-RSCC

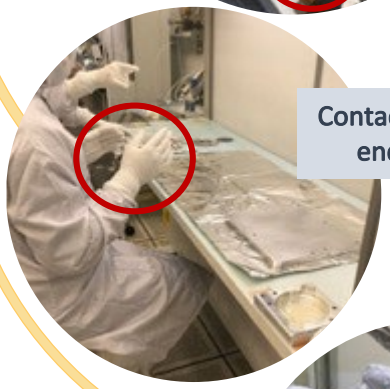
Hardware sampling pre-Ultra Cleaning

SIH & SHH GSE & Tooling

VHP sterilization of tools, 1 hour turn-around time for urgent items

Aseptic Assembly Monitoring & Sampling

Settling plates for ~4hrs increment



Contact plates at the end of activity

Activity monitoring PP support

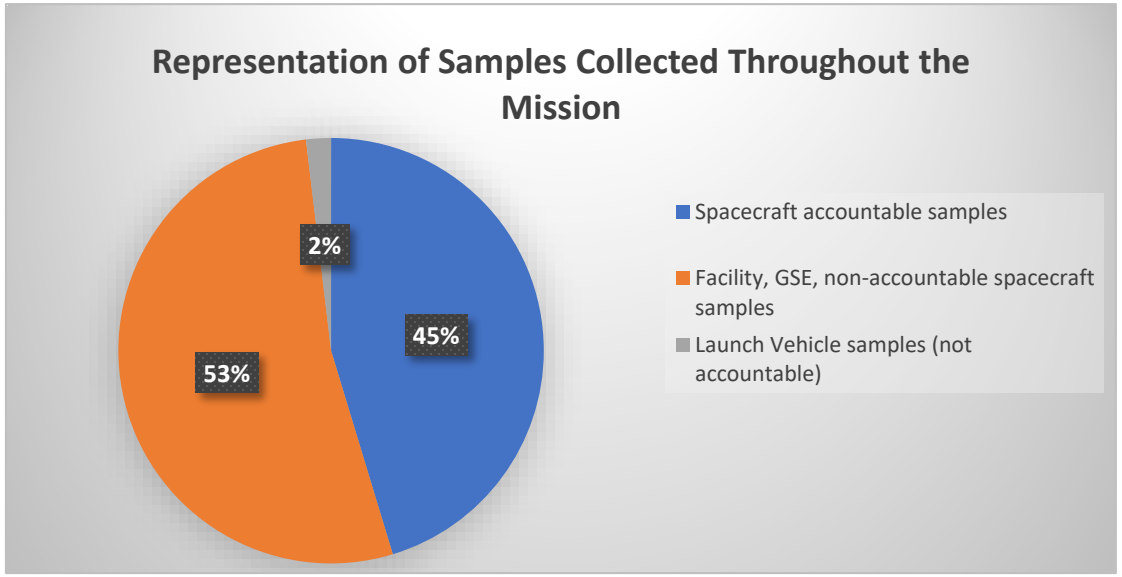
Sample quantities for M2020 versus Heritage Missions

	MER (Both)	MSL	InSight	Mars 2020
Swabs	3,066	3,472	1,983	11,601
Wipes	529	1,283	1,127	2,543

Does not include Genetic Inventory samples: 1122 samples covering 109 m^2

- The large sample quantities for Mars 2020 correspond to:
  - Significant increases in environmental monitoring and flight hardware build in support of SCS assembly.
  - An additional accountable surface area of 354 m^2 on Mars 2020 compared to MSL.

45% (6409 samples) are accountable hardware samples

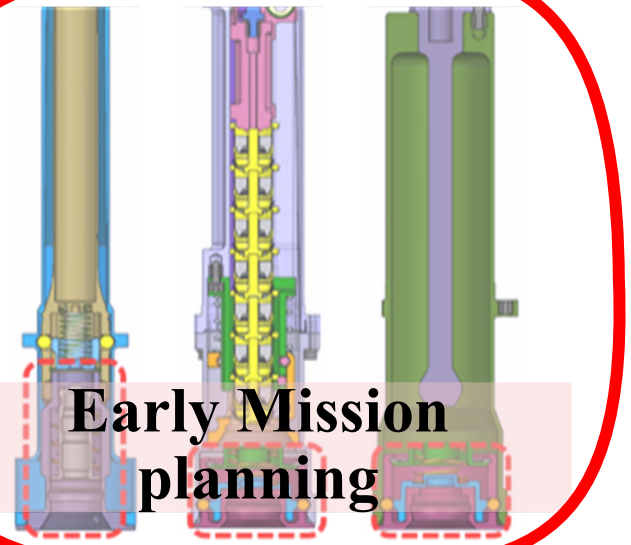


Forward Contamination Compliance Results

Subsystem	Accountable		Total spore burden at launch [spores x 10^4]
	Surface Area [m^2]	Volume [cm^3 x 10^4]	
Rover			
Landed hardware	214.15	4.173	1.47
Impacting Hardware – Planned	0.00		0.00
Descent Stage			
Landed hardware	153.31	-	0.598
Impacting Hardware – Planned	1616.06	132	25.6
Aeroshell			
Landed hardware	592.79	-	1.37
Impacting Hardware – Planned	1206	98	2.9
Other EDL			
Landed hardware	736.9	-	0.411
Impacting Hardware – Planned	-	-	
Cruise Stage			
Landed hardware	-	-	-
Impacting Hardware – Planned	-	-	5
Requirement			<50
Total			37.3
Reserve			12.7

N = 5745 swabs and 674 wipes.

Lessons Learned Categories



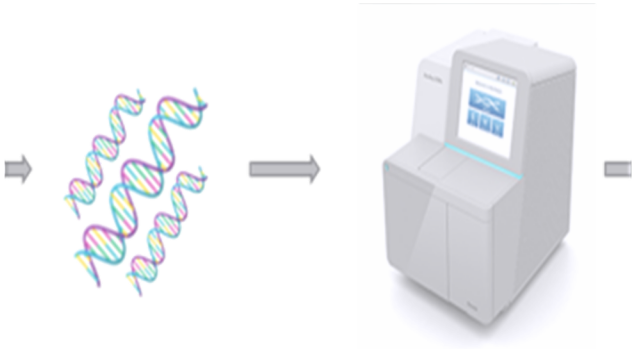
Early Mission planning

Sampling Coordination and Implementation

Aseptic Assembly Facility

Facility

Launch Vehicle

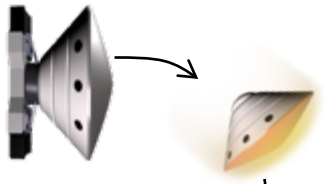


Genetic Inventory

Risk-based approach - Mission Timeline

Earth: ATLO → Launch → Cruise → Mars EDL → Mars Surface: Commissioning → Mars Surface: Operations, Non-Sampling → Mars Surface: Operations, Sampling → Mars Surface: Future Missions

Cruise
- 7 month cruise, vacuum environment
- ACA volume is closed out, preferred flow path via HEPA filters
- Protections in place to protect sensitive hardware from contamination



Entry, Descent, and Landing (EDL)
- Transient event, repressurization
- ACA volume is closed out, preferred flow path via HEPA filters
- Protections in place to protect sensitive hardware from contamination
- Rover exposed to ambient flow at heatshield separation (bit carousel, corer)

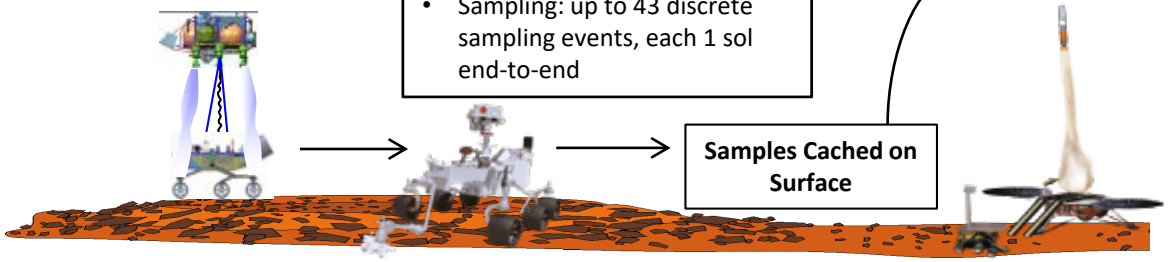
Launch
- Transient event, depressurization
- ACA volume is closed out, preferred flow path via HEPA filters
- Protections in place to protect sensitive hardware from contamination

Commissioning
- ACA is opened up (belly pan dropped, carousel doors opened)
- Drive away from landing site
- Hardware checkouts

Surface Operations
- Non-sampling: tubes, seals, volume probe remain protected when not in use
- Sampling: up to 43 discrete sampling events, each 1 sol end-to-end

Future Missions
- Sealed samples retrieved by future rover, launched from Mars surface, and returned to Earth

Assembly, Test, and Launch Operations (ATLO)
- Precision cleaning & bakeouts
- Special cleaning and handling of sensitive hardware (350C bakeout, storage in clean environment, separate sterile and ATLO flight models)
- Protections in place to protect sensitive hardware from contamination post-cleaning
- T-0 purge of ACA (from final component installation through launch)



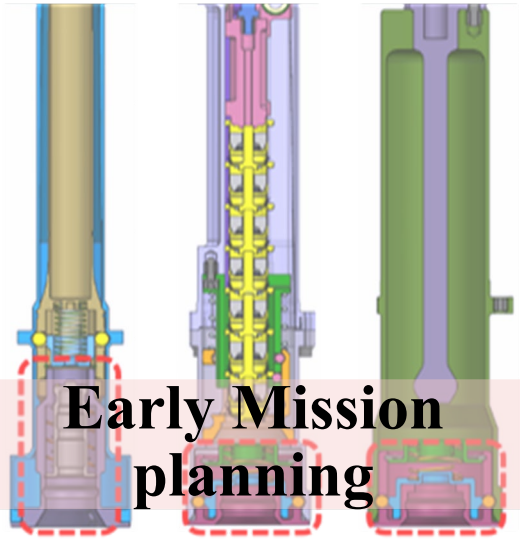
Samples Cached on Surface

Risk-based approach

- The M2020 Project has adopted a contamination knowledge strategy that is designed to interrogate all contamination pathways involved in the sampling process, while at the same time avoiding pathways NOT involved in the sampling process.
  - Strategy is documented in: Mars 2020 Returned Sample Contamination Knowledge Strategy
    - Ken Farley, Ken Williford, Yulia Goreva; 2/9/2018

- The M2020 Project contamination knowledge strategy relies on collecting:
  - Flight witness assemblies
  - Non-flight curated assemblies
  - Biological samples
  - Curated flight material samples
  - Curated samples of flight processing materials
  - Curated environmental witness plates
  - Curated data

Lessons Learned Categories



Early Mission planning

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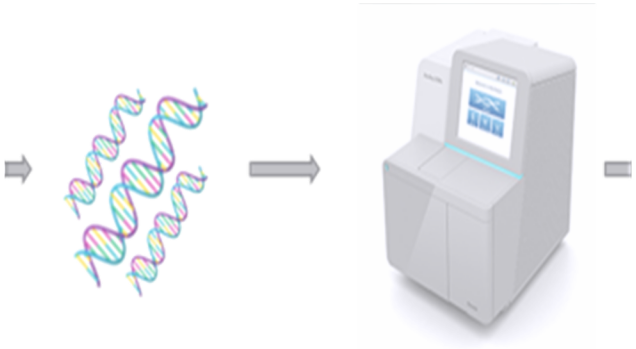

Genetic Inventory

Bioburden Statistical Calculations

- **Background/Scope:** While this sum of the means bioburden assessment methodology was appropriate for assessing the risk for forward contamination, a better statistical approach should be applied that considers the low rates of positive microbial counts.
- **Finding:** Conservatively, 1 spore was added to groupings where zero spores were detected from samples. Adding one raw spore when all zeroes are detected was done prior to converting it into a bioburden density. This “zero-to-one” conversion penalty has a larger impact on a smaller grouping of samples.
- **Recommendation:** Efforts are underway to update the standard statistical approach prescribed to calculating the total bioburden density to include an empirical Bayesian approach (Benardini et al. 2020, Gribok et al. 2021).

The total effective area sampled is given by

$$A_s = \sum_{i=1}^{n_s} a_{s_i} f_{s_i} e_{s_i} + \sum_{j=1}^{n_w} a_{w_j} f_{w_j} e_{w_j} \quad (1)$$

The total number of spores counted is

$$N_{tot} = \sum_{i=1}^{n_s} N_{s_i} + \sum_{j=1}^{n_w} N_{w_j} \quad (2)$$

In the occasion where N_{tot} is equal to zero, i.e., no growth for any of the acquired samples, for conservatism, N_{tot} was changed from zero to one. The bioburden density, B, is given by

$$B = N_{tot}/A_s \quad (3)$$

Count Alert Level Communication

- **Background/Scope**: It is imperative that PP Engineers are equipped with the knowledge to alert the PP Lead as soon as the bioburden counts exceed the limits so that an appropriate mitigation path can be developed.
- **Finding:** A newly developed tool for Mars 2020 PP was created to calculate the "Count Alert Level" or CAL for each sampling event so that all team members would be empowered to raise a flag on high bioburden results.
- **Recommendation:** Implement the CAL philosophy for future missions so that it is clear when the bioburden has been exceeded. This has allowed for rapid communication with CogEs and vendors to mitigate any issues.

Calculator excerpt:

Sample Quantity and Alert Level Calculator

This tool allows PP samplers to calculate the quantity of samples required to achieve 10% and determine raw spore alert levels. Samplers are also able to cross-check an increase the number of samples collected to give a better buffer in alert level. Users must input data in the yellow fields.

Use this before you sample for simple swab or wipe estimates

Wipe (W) or Swab (S) Sampling Event?	Total PP Accountable Surface Area for This Part/Grouping (m^2)	Target Spore Bioburden Density (spores/m^2)	Minimum number of Samples collected to meet 10%	Raw Bioburden Alert Level
S	0.75	53	29.9	1.0

Use this if you have mixed sampling tools or after the sampling event with the as-run collected quantities

How Many Wipes did you take?	How Many Swabs did you take?	Total PP Accountable Surface Area for This Part/Grouping (m^2)	Target Spore Bioburden Density (spores/m^2)	Did you meet your 10% requirement?	Raw Bioburden Alert Level
0	30	20.00	53.33	NO	1.0

THANKS AGAIN TO

Mars 2020 Planetary Protection Team

Jet Propulsion Laboratory
California Institute of Technology

- Past PP Team members throughout the entire mission:
  - Moogega Stricker
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MARS 2020 PERSEVERANCE


THANK YOU!