Organic and Inorganic Contamination Control Approaches for Return Sample Investigation on Mars 2020

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Abstract—**The Mars 2020 Rover mission will have the capability to collect and cache samples for potential Mars sample return. Specifically, the sample caching system (SCS) is designed for coring Mars samples and acquiring regolith samples as well as handling, sealing and caching on Mars. As the potential first Martian samples that could be returned to Earth, assuring low levels of terrestrial contamination is of the utmost concern. In developing the SCS, the project prioritizes limiting sample contamination in organic, inorganic and biological areas. The focus of this paper is on the strategies being implemented to limit terrestrial organic and inorganic contamination in the samples.**

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1. INTRODUCTION

While many aspects of the Mars 2020 Rover mission are different from MSL, perhaps the most challenging and notable is the addition of the Sampling and Caching Subsystem (SCS) which will be capable of acquiring core and regolith samples for potential Mars sample return. Because of the requirement to support return sample science investigations (RSS), more stringent contamination requirements have been placed on Mars 2020 than any previous NASA mission. Specifically, the three key and driving Mars 2020 contamination requirements for organic, inorganic and biological contamination are as follows:

1.Organic Contamination. "The Mars 2020 landed system must be capable of encapsulating samples for return such that the returned sample meets the organic cleanliness standards." This includes keeping "Tier 1" compounds below 1 ppb in the sample. The Tier 1 compounds are specific organic compounds of astrobiological significance (e.g. DNA), and keeping total organic carbon (TOC) below 10 ppb.

2. Inorganic Contamination. Inorganic requirements on the acquired samples includes 33 specific elements and mandates that, depending on the element present, their concentration be no greater than 0.1% or 1% of their average concentration measured previously in classes of Martian meteorites known as shergotty nakhla chassigny (SNC) and are shown in Table 1.

*3. Biological Contamination. "*The Mars 2020 landed system must be capable of encapsulating samples for return such that each sample in the returned sample set has less than one viable Earth-sourced organism."

While meeting any one of these three driving requirements would requirement new solutions, the combination of all three presents a new challenge in terms of designing the sampling hardware owing to the varied nature of contamination in each case. Moreover, some techniques employed previously for controlling vectors in the hardware for one kind of contamination could have adverse effects for other contamination requirements. For example, a deployable bag was used on Viking to create a biological barrier [1]. Although Viking cleaned its instruments to sub-monolayer levels (the sample path hardware was cleaned to 1 nanogram/cm^2) [2], they did not have a requirement to consider the organic contamination contribution from the bag itself which will outgas over the course of its journey to Mars. Hence, if the same bagging technique were employed for the SCS, the concentration of outgassing products from the bag would render SCS well above the requirement levels. Thus, a novel approach must be taken to ensure that the system meets the requirements of all three areas of

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Table 1: Inorganic Contamination Requirements for Mars 2020 samples

Species Name	Target % of SNC	g/g
Sulfur	1	1.10E-05
Phosphorus	1	2.20E-05
Chlorine	1	6.30E-07
Bromine	1	4.00E-09
Lithium	1	2.10E-08
Boron	1	1.00E-08
Scandium	1	3.90E-07
Mangenese	1	3.70E-05
Cobalt	1	5.80E-07
Nickel	1	2.70E-06
Zinc	1	6.30E-07
Rubidium	0.1	3.40E-10
Strontium	0.1	3.30E-08
Yttrium	1	1.40E-07
Zirconium	1	2.10E-07
Niobium	1	2.50E-09
Caesium	1	1.50E-10
Lanthanium	1	3.00E-09
Cerium	1	1.10E-08
Samarium	1	9.70E-09
Europium	1	4.50E-09
Gadolinium	1	1.80E-08
Ytterbium	1	1.20E-08
Lutetium	0.1	1.80E-10
Hafnium	0.1	9.10E-10
Tungsten	0.1	4.10E-11
Rhenium	0.1	1.70E-11
Osmium	0.1	1.10E-10
Lead	0.1	2.00E-10
Thorium	0.1	2.40E-11
Uranium	0.1	7.00E-12

concern. Here we focus however, on approaches for inorganic and organic contamination only, keeping in mind that they must work in concert with those for biological contamination requirements as well. Since SCS hardware will have intimate contact with the sample, unique contamination strategies are employed to mitigate against all three contamination vectors while allowing SCS to maintain a mechanical functionality for performing sample acquisition and caching. Here we describe approaches for the mitigation of organic and inorganic contamination.

2. SAMPLING AND CACHING SUBSYSTEM (SCS)

An overview of SCS is shown in figure 1. Specifically, SCS includes the Adaptive Caching Assembly (ACA), Rover robotic arm and the Turret. The turret includes the coring drill used to obtain the sample.

The ACA (see Figures 2-3) houses most of the sample intimate hardware including the following components:

- Sample tubes –sample collection and storage
- Seals – for hermetic sealing of samples in tubes
- Volume probe – assessing the amount of sample acquired
- Vision assessment station –assessing the amount of sample acquired and recording any anomalies
- Tube warming station – removing molecular organic contamination from the tube prior to sampling (if required – open trade)
- Sample Handling Assembly (SHA) – for manipulating sample tubes
- Drill bits – for acquiring samples
- Drill bit carousel – houses the drill bits and allows for insertion of tubes and extraction of drill bit + tube by the turret-mounted coring drill.

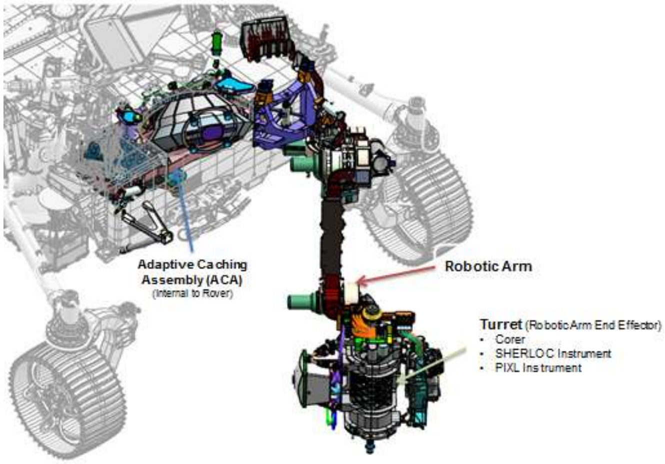


Figure 1: Overview of the Sampling and Caching Subsystem.

The components of SCS work together to create a sampling chain where sample tubes are transferred from protective sheaths within the ACA to sampling bits installed in the drill external to the rover chassis. The tubes are removed from the tube storage assembly by the SHA, warmed at the tube warming station, and inserted into bits contained with the bit carousel through the carousel's inner door. Once the tube is secured within the selected bit, the bit is positioned at the bit carousel outer door opening where it is picked up by the robotic arm/turret-mounted drill to perform sample acquisition on the surface of Mars. Once sample acquisition is completed, the robotic arm re-docks the turret with the bit carousel. The drill and inserts the bit containing the filled sample tube back into the carousel where it is positioned at the carousel inner door for access with the SHA. The SHA moves the filled sample tube through volume measurement, hermetic seal pick up, and sealing, with images taken with the vision assessment station between each step. The sample handling operation culminates with the replacement of the filled and sealed tube back into the tube storage assembly where it remains until it is placed onto the Martian surface. Because this sampling chain has multiple inorganic and organic contamination vectors which could contaminate the samples, this system is carefully architected to include multiple features described below to take advantage of the

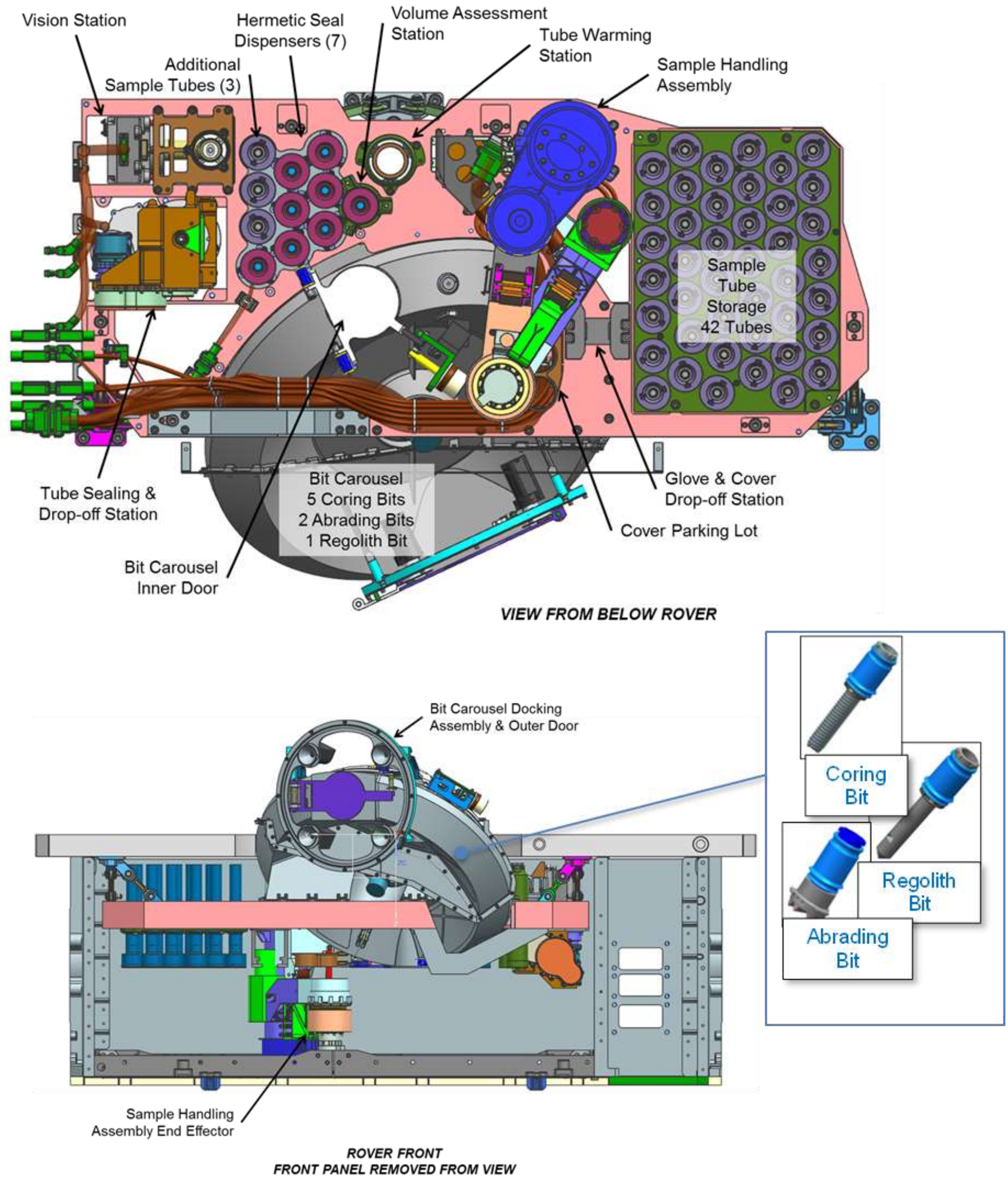


Figure 2: An overview (top and side) of the adaptive caching assembly

Martian environment to reduce the contamination burden.

3. CONTAMINATION CONTROL APPROACHES

The project has established a set of cleanliness zones on the rover. Cleanliness requirements in each zone are set based on assessment of the potential contamination risk from hardware in that zone to the inside of a sealed returned tube.

- The sample collection tubes and associated hardware (seals) are in the cleanest zone. This hardware is subject to precision cleaning and then a 350°C combustion cleaning in atmosphere to achieve sterility and near elimination of organic carbon. Fluid Mechanical Particle Barriers (FMPB) are used to protect the tubes from recontamination after cleaning (Fig. 3). The FMPBs participate in the 350°C cleaning and are therefore already in place and protect the hardware immediately following cleaning.

- Drill bits and hardware that contacts the drill bits are in the second cleanest zone since some of the contamination on the drill bits could probabilistically transfer to the sample tube. This hardware is first pre-cleaned and then follows processes (e.g. dry heat microbial reduction) to reduce the viable organism and molecular organic contamination below pre-cleaning levels.

- Detailed Phase B/C contamination transport analysis shows that for most of the rest of the Mars 2020 hardware, the cleanliness levels achieved on MSL to prevent forward contamination of Mars are sufficient to avoid significant likelihood of contamination of the returned sample. Where more stringent cleanliness levels are required, additional requirements are placed on specific hardware elements.

3.1 Organic Molecular Contamination

As described above, the general approach is to clean and maintain cleanliness in the hardware that is in intimate contact with the sample. Initially, the sample intimate hardware is located within the ACA and therefore a unique combination of techniques is employed to prevent organic contamination from reaching the sample. The sample intimate hardware includes: sample tubes, seals, drill bits, and the volume probe.

3.1.1 Inert Surface Materials

Since the tubes are the most sample intimate hardware, Mars 2020 will include low energy surface coatings on their interior to prevent organic molecular contamination.

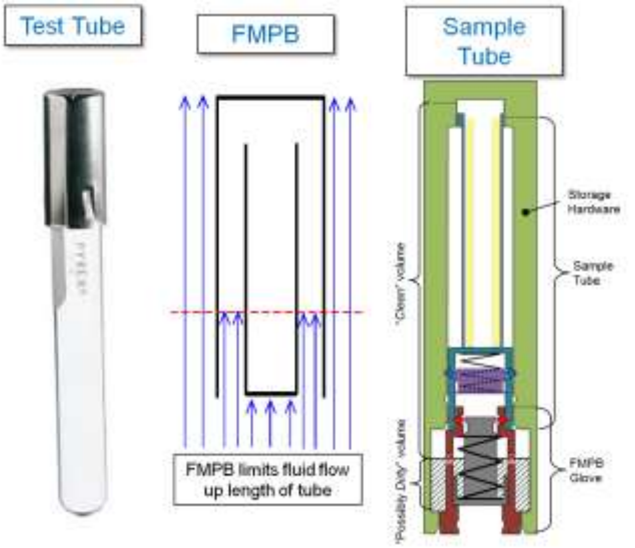


Figure 3: A fluid mechanical particle barrier (FMPB) for a laboratory test tube (left) which limits the particle flow to the interior of the tube (flow direction shown by upward arrows). The storage and FMPB design of the sample tubes on Mars 2020 are shown on the right for comparison. The small clearances between the storage hardware and sample tube create the FMPB which protects the tube from particulate contamination as well as limits the diffusion of molecular contamination.•

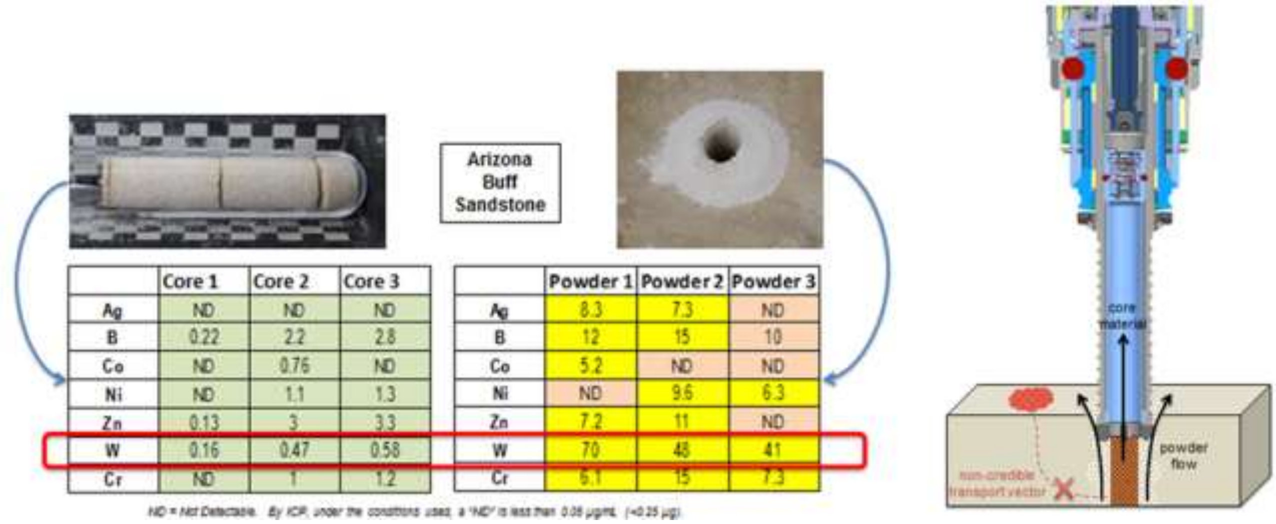
Specifically previous studies on gold have shown that chemisorption does not occur on the surface for a wide range of molecular weights (~150-500amu) due to the full d-shell of Au atom [3]. Moreover, the sticking coefficient of organic molecules on surfaces like Au are predictable and dependent on the chain length of the organic moieties [3]. Similarly, TiN is also inert and inhibits chemisorption of organic molecules to its surface. Hence, TiN is coated on the surfaces of sample tubes and seals to prevent recontamination after cleaning. Furthermore, organic molecules adsorbed to these surfaces can be removed at much lower temperatures (~100°C) and cleaned down to ~1 ng/cm^2 levels necessary to meet the Mars 2020 organic contamination requirements (Anderson 2016).

3.1.2 Molecular Absorbers

Molecular absorbing materials are also being considered for mitigation against organic contamination. Previous investigations have shown both MAC and Tenax materials to be capable of readily adsorbing organic molecules in vacuum as well as 7 Torr CO_2 environments [4, 5]. During cruise to Mars, these materials will be relevant in capturing outgassed contamination from ACA components. This would prevent molecular contamination from reaching the sample intimate hardware.

3.1.3 Hardware and Materials Design

One key approach for contamination control on Mars 2020 is through the design of the ACA. The hardware is not only designed to manipulate tubes, seals, and the samples but



	Core 1	Core 2	Core 3
Ag	ND	ND	ND
B	0.22	2.2	2.8
Co	ND	0.76	ND
Ni	ND	1.1	1.3
Zn	0.13	3	3.3
W	0.16	0.47	0.58
Cr	ND	1	1.2

	Powder 1	Powder 2	Powder 3
Ag	8.3	7.3	ND
B	12	15	10
Co	5.2	ND	ND
Ni	ND	9.6	6.3
Zn	7.2	11	ND
W	70	48	41
Cr	6.1	15	7.3

ND = Not Detectable. By ICP, under the conditions used, a "ND" is less than 0.05 µg/mL (<0.25 µg)

Figure 4: Example data set from inorganic drilling test show 2 orders of magnitude more inorganic contamination in the surrounding powder than in the sample. The design of the drill bit forces powder away from the sample and thus protects against inorganic contaminants.

also to inhibit contamination. For example, fluid mechanical particle barriers (FMPBs) are in place for all tubes and seal stacks to prevent diffusion of organics and particulate contamination (Fig. 3).

However, while the FMPB provides some protection against molecular contamination, it cannot guarantee against the molecular diffusion of organic contamination from within the ACA. Mars has a 7 Torr CO_2 atmosphere which allows for greater outgassing (larger mean free path of diffusion) of organic contaminants when compared to Earth's atmosphere. Therefore, a deployable venting area (i.e. the panel below the ACA) is designed into the ACA to remove outgassing products during surface operations on Mars. This opening is also required to allow full range of motion for the SHA. The panel will be deployed after entry, descent and landing (EDL) but prior to sample collection on the Mars surface.

The selection of materials is also important for the organic cleanliness of ACA hardware. Specifically, tube, seal and drill bit materials are carefully selected to ensure they can be combustion cleaned at high temperatures (350°C) in order to achieve a cleanliness level of <1 ng/cm^2. These parts will be fired as subassemblies such that they can be stored in a clean environment until final installation into the rover.

The assembly flow of this hardware is also designed to ensure minimal recontamination by allowing late integration at the launch facility. This late integration is accomplished through surrogate hardware which is "swapped" with flight hardware at last access. This allows flight hardware to remain in a sealed container after combustion cleaning in order to maintain the required cleanliness.

3.2 Inorganic Contamination

Inorganic contamination constraints on the Mars 2020 samples present a particular challenge to materials selection. While some materials are appealing from an organic and/or biological contamination standpoint, they may pose a threat to the inorganic requirements on the sample. Therefore, the approach for inorganic requirements involved careful selection of materials and repeated testing to ensure their compliance with the requirements. Interestingly, the drill bit design appears to reduce inorganic contamination by forcing the contaminants to flow outward/away from the sample (figure 4).

It is assumed that the largest contamination vector for inorganic contamination is by mechanical transfer through the drilling/coring process. The surfaces of the tube and drill bit assembly come into direct contact with the sample during sample acquisition (through rotary percussive motion) and therefore must be relatively "free" of the inorganic elements of concern. However, most metal alloys contain trace amounts of metals, many of which are on the inorganic requirements list. Testing of the hardware mechanical transfer of inorganic contaminants during sample acquisition shows that most of the inorganic contaminants remain in the surrounding powder and not in the sample. An example of the resulting data is shown in figure 4 where trace metals within the alloys of the hardware were used to track contamination transferred to the sample and powder. Resulting rock cores and surrounding powder were analyzed using inductively coupled plasma atomic emission spectroscopy (ICP-OES) and hardware coupons were analyzed by glow discharge mass spectrometry (GD-MS).

3.3 Particulate Contamination

Depending on their nature, particulates also pose a threat to organic, inorganic or biological contamination. Therefore,

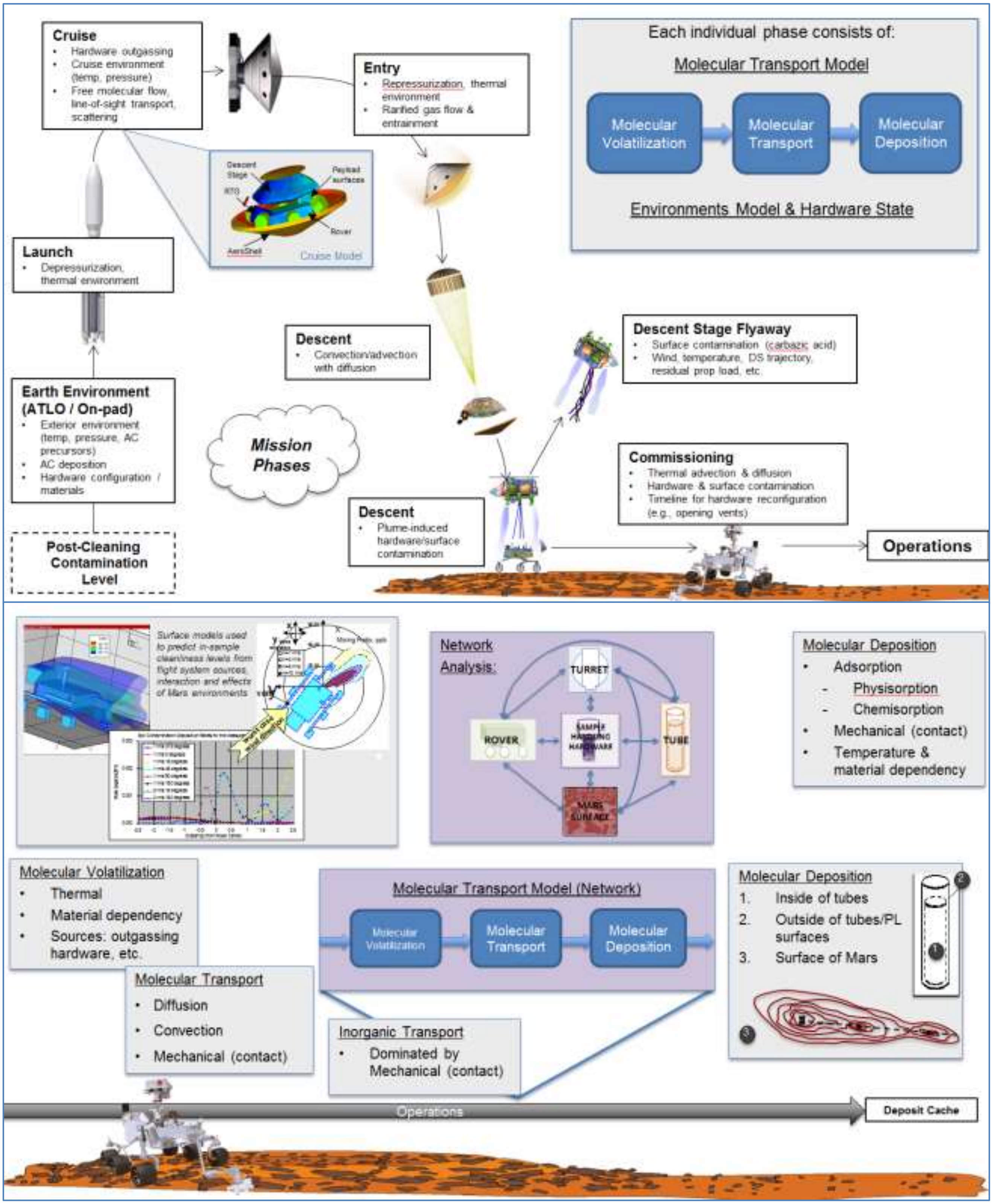


Figure 5: Illustration of end-to-end modelling approach for organic contamination. This model is informed by previous MSL outgassing test data as well as new outgassing/desorption/adsorption test data designed to track the diffusion of molecular organic contamination to the sample from hardware assembly to surface operations on Mars.

particle contamination is tracked closely on Mars 2020. As stated above, the FMPB provides protection for sample tubes and seals against particulate contamination. This design is also employed for other sample intimate hardware including seals and the volume probe.

Making use of the environment, Mars 2020 will leverage “EDL cleaning” to remove particulate contamination prior to surface operations. Specifically, the rover will be exposed to wind velocities up to 146 m/s during EDL [6]. Since the mean speed of nominal winds on the surface of Mars is ~ 5 m/s (based on Viking Lander 2 measurements [1]) particulates that are not removed during EDL cleaning will not likely be removed while on the surface of Mars. Off-nominal wind events, such as dust devils, can also occur on Mars but most are of comparable speeds to the nominal wind speeds. Dust storms typically do not exceed 40 m/s. In some extreme cases, dust devils can reach up to 75 m/s (rotational + translational speeds) but their probability of occurrence and of striking the rover is extremely low. Nevertheless, for all wind scenarios (nominal and extreme), EDL flow speeds to which most of the rover will be exposed are expected to be much higher.

Unlike static landers, Mars rovers can traverse away from contamination deposited during both landing and early operations. Thus, Mars 2020 also leverages the ability to maneuver away from the initial “contamination” area where particulates may come to rest from EDL cleaning.

3.4 Transport Modelling (Particulate and Molecular)

In the case of Mars Science Laboratory Rover mission, end-to-end testing of the entry, descent and landing (EDL) approach was not possible. Nevertheless, it was tracked through test-informed analysis and modelling of the end-to-end EDL approach. A similar logic is taken for the Mars 2020 contamination control where, though end to end testing is not feasible, each phase of the end-to-end contamination budget is tracked and modelled with analysis and testing. This approach provides an understanding of the overall contamination budget for the sample and is taken for both particulate as well as molecular contamination tracking.

Two models (particulate and molecular, Fig 5) are used to track and verify end to end contamination of the sampling chain. The molecular transport model is used to track surface cleanliness levels based on data from outgassing tests on the hardware and desorption tests on relevant surfaces. It takes into account absorption of molecular contamination of the Rover surfaces. Combining the derived relevant diffusion coefficients with surface cleanliness level data, this model tracks molecular organic contamination from the assembly of subsystems, through ATLO, cruise, EDL and sampling stages.

A similar modelling approach is used for the end-to-end particulate contamination analysis. Extensive reviews of work on particle adhesion and resuspension, performed over the last two decades [7], has allowed us to develop and validate a model that allows us to track particles from assembly to surface operations on Mars. The model also makes use of CFD simulations as well as testing of particles under simulated wind and force conditions (mimicking the launch vibrational and EDL load forces on the FMPB configurations employed in the ACA). The results of these tests and simulations are fed into the model to create the verification and validation of the approaches described above.

4. CONCLUSIONS

Keeping flight hardware clean from the organic, inorganic or biological contamination levels mandated for the Mars 2020 mission would pose a challenge for any one of these contamination areas. Meeting the requirements for all three types of contamination has yet to be accomplished by any previous mission. While the challenges are great, unique strategies have already shown great promise for the mission. Like EDL on MSL, an end-to-end test of the entire system to ensure cleanliness of the sample is not possible. Instead, Mars 2020 will leverage an end-to-end modelling approach similar to that used for EDL on MSL

Tracking contamination is accomplished through multiple analyses and tests combined with a general model of the end-to-end vectors. Novel techniques are employed for designing a system which provides mitigation for organic and inorganic contamination as well as works in concert with biological contamination requirements. While the Mars 2020 Rover presents new challenges for functional capabilities, perhaps more challenging is the design of an integrated system that would meet the requirements of organic, inorganic and biological contamination without any compatibility issues. Using the strategies listed above as well as continuing to design hardware for contamination control will provide a robust and unique system for the first Mars sample caching mission, and, potentially, for sample return.

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Biography

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Keith Rosette is a graduate of Virginia Tech where he earned a B.S. in Aerospace Engineering in 1991 and an M.S. in Mechanical Engineering in 1994. He has developed and delivered hardware in support of numerous programs involving both human and robotic space exploration, from Hubble Space Telescope Servicing at Goddard Space Flight Center to the Mars Science Laboratory Curiosity Rover at JPL. He has served in roles from mechanical design engineer to spacecraft lead system engineer. Keith currently serves as the Product Delivery Manager responsible for the design, fabrication, test, and delivery of the Sampling and Caching Subsystem for the Mars 2020 Rover.