LONG TERM ENVIRONMENTAL MONITORING: NECESSARY STRATEGY AND INTEGRATED TECHNOLOGIES TO ENSURE SUCCESSFUL SCIENCE, RESOURCE UTILIZATION AND PLANETARY PROTECTION DURING HUMAN EXPLORATION.

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Introduction: Within the next several decades humans are likely to be exploring planetary surfaces beyond low Earth orbit. A number of scenarios exist within human exploration architectures for both NASA and other space agencies that are relevant to the International Space Exploration Coordination Group (ISECG) [1]. NASA's human exploration focus is currently the Journey to Mars, with plans including repeat visits by human crews, a single location of habitation involving long duration stays, and a range of human exploration via traverses with pressurized rovers on the order of ~ 100 km from the primary habitat (currently called the Exploration Zone, or EZ) [2]. Even if the grand vision of the Journey to Mars is not fully realized, the likelihood of humans operating on the surface of planetary bodies to achieve scientific goals is high. Such an endeavor involving *in situ* human operations, especially on the surface of a planet with the possibility of past or extant life, will require an unprecedented collaborative effort between NASA's science, *in situ* resource utilization (ISRU) and planetary protection communities, the goals of which are sometimes seemingly contradictory.

Successfully enabling human-conducted science and resource utilization while maintaining planetary protection protocols will require new strategies and technologies. To fully address this topic requires discussion of policy and international agreements. *Here we discuss an element to this topic, long term environmental monitoring, which we consider to be a necessary approach to responsible human exploration of the Solar System*.

Rationale: Human exploration *in situ* on the Martian surface will enable unique scientific opportunities [3]. Humans will likely utilize local materials such as water to produce resources. However, the presence of water establishes Special Regions on the surface or sub-surface that could harbor extant or past life, requiring protection from human contamination. A human presence will alter the local Mars environment, as demonstrated by the Apollo Cold Cathode Gauge Experiment that showed elevated gas concentrations (2 order of magnitude) during the lunar daytime associated with human surface operations [4]. Current ISS testing includes characterization of gas and microbe leakage both from the ISS and from astronaut's space suits during EVA [5]. Thus, fully characterizing the pristine Mars environment prior to humans is a baseline requirement to which measurements can be compared after the human presence is established. Long term monitoring that begins prior to human operations will enable the most accurate understanding of the atmosphere, the surface mineralogy and geochemistry coupled with that atmosphere, and ultimately the response of the local environment to the human operations.

Strategy: The mineralogy and geochemical character of the exploration zone (EZ) tells part of the story about the habitability potential of the Martian environment for human explorers and possibly other accompanying Earth life. Physical aspects to the Martian environment that are also important— diurnal variation in ground and air temperature, cosmic radiation, solar irradiance, wind velocity and variability, atmospheric pressure cycles, surface stability with respect to hardness, slope, porosity, permeability, magnetic character and electrostatic charging are examples.

Any approach for human exploration must also include a comprehensive plan for monitoring both chemical and physical environmental dynamics as humans invariably alter the exploration zone, even if the goal is to alter that environment only minimally. We propose a long term interrogation of proposed landing sites from the perspective of the ease with which the integrated set of environmental monitoring measurements can be deployed in semi-permanent array at intervals around the exploration zone, with outward looking observation posts that extend the data set to include data relevant to human safety and environmental preservation at larger spatial scales. This requires the development of integrated instrument packages that are inclusive of needs from science, ISRU, and planetary protection.

Monitoring stations must be deployable robotically, well in advance of the human operations. The style of human-robot interactions is an ongoing topic of discussion, including operations by crew members in Mars orbit that can take advantage of low-latency operations [6, 7]. It should be stated that the goal of this strategy is to develop a robust monitoring package that can be replicated and deployed throughout the EZ and across multiple potential or actual EZs. Here, the goal is to recognize what level of detail is “good enough” for long term monitoring and focus funding on the development of numerous packages as opposed to a single instrument or instrument suite. Ideally, monitoring stations would not require physical interaction with humans but would monitor changes throughout the EZ as human operations commence. Furthermore, the ability to augment this effort by adding stations would enable a response to environmental changes. Distributed sensor networks can be piggybacked onto communication relay nodes that also enable global positioning, meeting three requirements for minimizing the risks associated with a sustained human presence at Mars.

Technologies: Because of existing datasets from Mars Science Laboratory’s Rover Environmental Monitoring Station (REMS) [8] and what will have been acquired by ESA’s ExoMars [9] and MEDA on NASA’s Mars 2020 [10] missions (as well as potential TBD precursors), we have a good idea of the range of measurements that are relevant to the characterization of environmental dynamics. Ground and air temperature, relative humidity, atmospheric pressure, and variation of ionizing radiation are key measurements to make at a frequency of at least a few minutes per hour. Dust characterization and atmospheric loading and the presence and heading of dust devils are also important, as is monitoring the approach of dust storms. An upward looking observatory for tracking tau and other astronomical observations would also be important for understanding relationships between the dynamical elements of the environment. Monitoring surface sample chemistry and mineralogy as related to changes in the atmosphere (phase changes) will be critical and should be done in such a way as to enable routine evaluations of the toxicity of materials in the surface soils.

The physical response of the local geology to human operations must also be understood. ISRU processing could potentially redistribute significant surface mass as ice is converted to liquid or gas and transported to other locations. Offloading surface mass on Earth can create a seismic response, thereby requiring monitoring of seismicity. Futhermore, processing of frozen volatiles can create surface runoff or subsurface migration of liquids, which could lead to surface instability. Both cases could pose unforeseen hazards to human habitats, especially if seismicity is powerful enough to damage structures or initiate mass movements. Furthermore, liquid and gas release and migration should be monitored to assess plume migration and related surface/atmospheric chemistry variability.

Conclusions & Other Considerations: Long term environmental monitoring of any planetary surface on which humans plan to operate should be a requirement of responsible human exploration [see also 11]. A challenge to this strategy is that this type of technology development can fall between funding programs, potentially leading to inadequate support or neglecting important concerns. It is critical that the science, ISRU and planetary protection communities continue interacting as has recently been initiated through numerous workshops inside and outside of NASA.

To support human survival, the Mars system should be considered in much the same way that the Department of the Interior and U.S. Geological Survey consider geologic frameworks as they relate to responsible land-use strategy for the United States of America. Resources must be responsibly used and proper protections put in place to ensure that harmful pollutants and human impacts do not impede the achievement of the science goals that motivated humans to go to Mars in the first place. It is possible that a changing environment could necessitate changing boundaries in special or protected regions. Hazard assessments might also change in real time. This will include new approaches to mapping and interrogation of the subsurface to ensure that Mars is not made less habitable upon the arrival of humans. Instruments exist to address these issues now or could be modified from existing hardware, and the Earth serves as a case study for properly conducting this approach elsewhere. Global communication and positioning will be key enabling infrastructure to ensure astronaut safety and mission success.

References:

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