MARS SOIL-BASED RESOURCE PROCESSING AND PLANETARY PROTECTION. G. B. Sanders[1] and R. P. Mueller[2], [1]NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX, gerald.b.sanders@nasa.gov, [2]NASA Kennedy Space Center, FL, rob.mueller@nasa.gov

Introduction: The ability to extract and process resources at the site of exploration into products and services, commonly referred to as *In Situ* Resource Utilization (ISRU), can have significant benefits for robotic and human exploration missions. In particular, the ability to use *in situ* resources to make propellants, fuel cell reactants, and life support consumables has been shown in studies to significantly reduce mission mass, cost, and risk, while enhancing or enabling missions not possible without the incorporation of ISRU. In December 2007, NASA completed the Mars Human Design Reference Architecture (DRA) 5.0 study [1]. For the first time in a large scale Mars architecture study, water from Mars soil was considered as a potential resource. At the time of the study, knowledge of water resources (their form, concentration, and distribution) was extremely limited. Also, due to lack of understanding of how to apply planetary protection rules and requirements to ISRU soil-based excavation and processing, an extremely conservative approach was incorporated where only the top several centimeters of ultraviolet (UV) radiated soil could be processed (assumed to be 3% water by mass). While results of the Mars DRA 5.0 study showed that combining atmosphere processing to make oxygen and methane with soil processing to extract water provided the lowest mission mass, atmosphere processing to convert carbon dioxide (CO_2) into oxygen was baselined for the mission since it was the lowest power and risk option [2]. With increased knowledge and further clarification of Mars planetary protection rules, and the recent release of the Mars Exploration Program Analysis Group (MEPAG) report on “Special Regions and the Human Exploration of Mars” [3], it is time to reexamine potential water resources on Mars, options for soil processing to extract water, and the implications with respect to planetary protection and Special Regions on Mars.

Potential Water Resources for ISRU: The concentration, form, depth, and distribution of water resources on Mars varies greatly as a function of latitude and geological features. At the equatorial region (between 30°S and 30°N), areas of enhanced water from Mars Odyssey neutron analysis are usually interpreted as being due to hydrated minerals. These minerals can contain water at extremely low concentrations <2% to as much as 13% by mass. At the mid latitudes (30° to 60°) subsurface ice/permafrost may exist in the top 5 meters and fresh impacts have exposed ice excavated from 0.3-2.0 meters in depth. At higher latitudes, ice exists at higher concentrations and closer to the surface, but are seasonally covered with CO_2 ice in the winter. Soil excavated by the Phoenix lander descent and landing rocket plume and the robotic excavator arm showed dirty near-pure ice near the surface. Two other forms/location of water on Mars have been postulated but not yet proven; subterranean aquifers and briny water in Recurring Slope Lineae (RSL). Since both of these potential forms of water are considered Special Regions, they have been excluded for consideration as resources for ISRU extraction operations. Both hydrated minerals and icy soils are considered viable resources for ISRU extraction operations.

Excavation and Soil Processing Techniques for Water Extraction: Two general approaches to extract water from Martian soil have been considered: remove the water *in situ* from the soil, and excavate and transfer the soil to a heating chamber that can be enclosed so that water released can be removed and collected.

To remove the water in situ, the surface of the soil to be processed needs to be covered with a collection dome and the soil heated directly. Two concepts have been proposed to heat the soil directly; 1) via solar heating through a greenhouse-like transparent dome and 2) via microwave energy. Once the soil is heated, water is released in the form of vapor and is collected in a cold trap. Due to the low heating rate from solar energy, the rate at which water is evolved will be low. Also, because of the significant potential for the water vapor to recondense in the soil or other locations than the cold trap, no significant work has been performed to advance this method of water extraction. Experimental work has been performed using microwaves to extract water from ice in lunar regolith simulants that shows promise [4]. Because microwave energy can be concentrated, the collection dome can be much smaller. To promote the evolution of water, it has also been proposed to drill holes into the soil before heating to provide a path for water vapor migration to the cold trap. While this approach for *in situ* water extraction will be much more efficient than solar heating, there is still the potential for water vapor condensation back into the soil at the border between heated and non-heated soil thereby reducing extraction efficiency.

To excavate Mars soil for subsequent processing, the technique chosen will have to consider the soil and form of water present (hydration vs icy) and the compactness/hardness of the soil. For hydrated soils or soils with low concentrations of ice, traditional excavation methods such as the lift-haul-dump or bucketwheel/bucketdrum concept may be favored. As ice concentration increases, along with material hardness, vibratory blades or augers to break up and move the material may be required. Once the material has been excavated, it can then be transferred to a heating chamber. Three heating methods have been considered for soil processing; 1) electrical heaters/conduction, 2) fluidization/convection, and 3) microwave heating. Significant work has been performed over the last 10 years on the first two heating methods for hydrogen reduction of lunar regolith, lunar ice prospecting, and Mars soil drying [5]. To remove all the water from hydrated soils typically requires the soil to be heated to above 600°C. However, based on data from the Sample Analysis on Mars (SAM) instrument on the Curiosity rover, a heating limit of <450°C may be desired to mitigate the production of HCl and H_2S contaminates released as carbonates and perchlorates in the soil breakdown as temperature increases [6]. A significant fraction of the water (~80%) is released below 450°C. Laboratory tests suggest heating times of 30 to 60 minutes may be required. For removal of water from icy soils, the heating temperature is expected to be <300°C. An interesting concept that combined using an auger to excavate material and an enclosure cap to heat the soil while still on the auger blades was designed and built by Honeybee Robotics, called the Mobile In Situ Moon/Mars Water Extractor (MISME). The MISME concept demonstrated that significant amounts of water could be obtained from icy soils with minimal hardware and energy [7]. Once the soil is processed, it will be removed from the heating chamber and dumped back on the ground; either immediately or delivered to a designated site.

Soil-based ISRU and Planetary Protection: Any soil-based ISRU process on Mars needs to ensure that i) there is no Forward Contamination from the hardware utilized, and ii) no Special Region is created based on the excavation and processing of soil containing water. To ensure no forward contamination occurs, the ISRU excavation and soil processing hardware will be sterilized to Viking mission standards before launch. This is not considered to be a significant design issue for the soil heating chamber since sustained operating temperatures of up to 450°C are expected. COSPAR defines Special Regions as ''a region within which terrestrial organisms are likely to replicate'' and states that ''any region which is interpreted to have a high potential for the existence of extant Martian life forms is also defined as a Special Region'' [8]. It is therefore important for ISRU process not to allow water in Martian soil to remain in a liquid state for an extended period of time. The duration of this time is TBD and will need to be agreed upon with the Planetary Protection community. Therefore, soil processed to extract water may be required to be cooled below the freezing point before discarding back to the surface. Processing durations may also be imposed on methods associated with in situ heating of the Mars soil as well.

Conclusion: The processing of the soil on Mars to extract water for subsequent use in making propellants, fuel cell reactants, and life support consumables is enabling for future human exploration of Mars. The processing of Martian soil to extract the water present raises both Forward Contamination and creation of Special Region issues that will need to be addressed before operations can begin. At this time, it is believed that the currently proposed Mars soil-based ISRU concepts will be able to mitigate both of these planetary protection concerns.

References:

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