**HIGH-YIELD DIHYDROGEN-MONOXIDE RETRIEVAL AND TERRAIN IDENTIFICATION ON NEW WORLDS III (HYDRATION III).**

G. Lordos[1,2], P. Manandhar[2], R. de Filippi[2], E. Bui[2], P. Patel[2], T. Sevigny[2], S. Yang[2], M. Féasson, P. do Vale Pereira[2], O. de Weck[2] and J. A. Hoffman[2]. [1]Corresponding author: glordos@mit.edu, [2] https://spaceresources.mit.edu, Massachusetts Institute of Technology, 77 Mass.Av, 33-409, Cambridge, MA 02139

**Executive Summary:** In-situ water will be vital for sustained operations on the Moon and Mars. MIT's HYDRATION III is an Earth-conditions proof of concept for a semi-autonomous water ice mining system for Mars, using mechanical drilling and downhole radiative heating to melt and pump water from a subsurface ice reserve covered by a shallow (0.5m) regolith layer. It also serves as a prospecting system to digitally identify and classify layers of underlying regolith on the Moon, using drilling telemetry from multiple independent sensors. In September 2021, HYDRATION III demonstrated fully hands-off operations over 12 hours at a NASA-sponsored competitive setting and produced 4.3L/hr of water (peak) and 2.0L/hr (average).

**Motivation:** NASA is returning to the Moon with the Artemis project, this time to stay and to develop technologies for the exploration of Mars. Sustainably staying on the Moon and Mars requires technology development to utilize water that is bound up in subsurface ice. In response, several alternative architectures for water ISRU are under development.

**Comparison to Current State of the Art:** One water mining design well-suited to thick ice sheets, used in Antarctica today, is the Rodwell, where hot water is circulated under feedback control to sustain a self-deepening, simple and reliable water well. One version of this for Mars is RedWater [1]. However, Rodwells in general have some energy losses into the ice. HYDRATION III is a dry-hole variant of the Rodwell, which, like Honeybee's PVEx [2], is based on down-hole radiative heating with immediate extraction of cold water instead of recirculation of hot water.

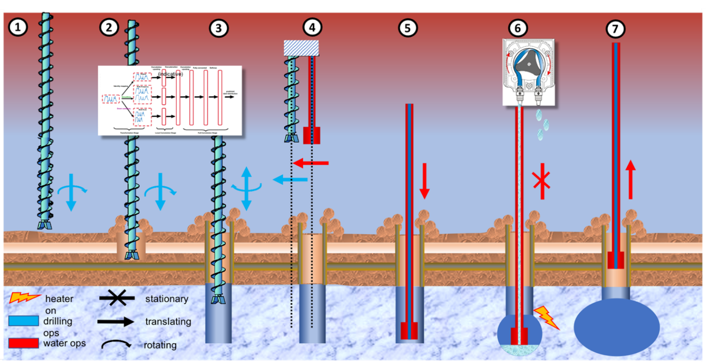


*Fig. 1: HYDRATION III Concept of Operations (1) Positioning (2) Overburden drilling (3) Casing borehole with mud (4) Translating (5) Lowering heater & water inlet (6) Ice melting & water pumping (7) Remove heater*

**Experiment Concept:** As shown in Fig. 1 above, the remotely-controlled HYDRATION III system drills a self-casing borehole through the simulated overburden layers and into the simulated ice sheet. It then retracts the drill bit, translates by a fixed distance and lowers a cylindrical 700W radiative heater into the ice sheet with a regenerative filter and intake to melt and collect the water. In addition, during steps 2 and 3, high-resolution data is collected by several sensors including power, weight on bit, accelerometer and torque on lead screw. The time-stamped sensor data stream is designed to be fed into a pre-trained neural net to automate the remote identification of the overburden layers, yielding a "digital core". However, the current version of HYDRATION relies on manual interpretation of the data stream, as more training data would be required to implement the neural net.

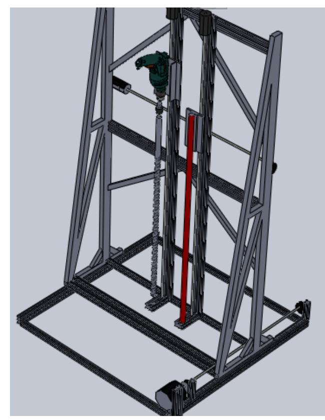

*Figure 2: HYDRATION III System CAD, showing the Z1 drilling axis and the Z2 water production axis supported on the structure. For clarity, electrical panel is not shown.*

**System Description:** Fig. 2 has our CAD and Fig. 3 shows HYDRATION III mounted on our ice box test station. The key subsystems labeled in Fig. 3 are: (a) Y-axis servo motor and lead screw (b) e-panel mounted using anti-vibration dampers (c) 75VDC power supply for servos (d) servo control hub & PDU (e) RaspberryPi 4 computers running our custom 'Mission Control' client/server software (f) 5V PSU for computers (g) power meter (h) 24V PSU for pump and control boards (i) triac controller for drill and heater setpoint control (j) 8A rotary hammer drill motor (k) Z1 and Z2 axis servos, 5.8Nm peak / 1.2Nm cont and lead screws, with in-line S-shape load cells (l) 1"x42" carbide-tipped concrete drill bit (m) 700W heater, water pickup and regenerative filter stack and (n) peristaltic water pump. System limits include SWaP = 1.9m$^3$, 58.35kg, 1KW, drilling force <150N, maximum vertical speed of 0.05m s$^{-1}$ and maximum drilling speed of 900RPM.

**Experiment Results:** Over 12 hours of competitive head-to-head testing at the 2021 RASC-AL Moon to Mars Ice & Prospecting Challenge taking place at Hampton, VA from 23-25 September 2021, HYDRATION III produced a total of 24.335L of water, almost matching the total water production by all ~30 teams in the first 3 years of the Challenge (2017 – 2019). In addition, this was accomplished entirely in 'hands-off' mode. The results validated HYDRATION III's 'hands-off' remote operation and remote contingency recovery capabilities embodied in our real-time, in-house developed 'Mission Control' software. We also validated a peak water production rate of 4.3 L/hr and an average water production rate of 2 L/hr, with turbidity of 136NTU on day 1 (471NTU on day 2).

**Discussion and Conclusion:** With an Equivalent System Mass of ~210kg (given its ~1KW power budget), HYDRATION III demonstrated that it could produce its own mass in water every ~5 days from reserves of subsurface ice covered by shallow (~0.5m) regolith. The system performance is owed to both engineering design and extensive integrated testing. Compared to the classic Rodwell design, the constant collection of cold water reduces heat losses into the ice; a secondary benefit is that it cools the boom assembly above the heater cartridge, helping to maintain the frozen neck of the ice cavity which supports the overburden and the hole wall. Future work includes remote operation demonstration tests in collaboration with the ASCLEPIOS II Mars analog mission and collection of more drilling data to train a neural net.

**Acknowledgments:** the authors wish to thank the organizers, National Institute of Aerospace; the sponsors MassRobotics, Massachusetts Space Grant, NASA Langley Research Center and Honeybee Robotics, and the competition judges from Honeybee, NASA LaRC, NASA JSC, Aerospace Corp. and SpaceX. The authors are also grateful to the members of the MIT HYDRA [3] and HYDRATION [4], [5] teams for their work on predecessor rigs and last but not least our many undergraduate colleagues at EPFL in Switzerland. We stand on the shoulders of giants!

**References:** selected references are shown below.

[1] Z. D. Mank, K. A. Zacny, et al. RedWater: A Rodwell System to Extract Water from Martian Ice Deposits, Earth and Space 2021 : Space Exploration, Utilization, Engineering, and Construction in Extreme Environments. 2021.

[2] Zacny, K., Robotics, H., Indyk, S., Luczek, K., Paz, A., & LEAG, J. (2015). Planetary Volatiles Extractor (PVEx) for In Situ Resource Utilization (ISRU). Earth and Space, 378.

[3] Lordos, G., Arzuaga, I., et al., "HYDRA: High Yield Dihydrogen-monoxide Retrieval Assembly Final Report", RASC-AL Special Edition Mars Ice Challenge Forum, Hampton, VA, May 2018

[4] Adams, A., Alowayed, M., de Filippi, R., Takahashi, R., Vanderhout, A., "HYDRATION: High Yield Dihydrogen-monoxide Retrieval And Terrain Identification On New worlds", RASC-AL Special Edition Mars Ice Challenge, Hampton, VA, May 2019

[5] Lordos, G., Vanderhout, A., Adams, A., Alowayed, M., de Filippi, R., Hoffman, J., de Weck, O., Takahashi, R., "HYDRATION: Mining Water Ice on the Moon and Mars Using Downhole Radiative Heating", 17th Biennial International Conference on Engineering, Science, Construction in Challenging Environments / Earth and Space 2021, April 2021

*Figure 3: HYDRATION III mounted on simulated Mars surface test station loaded with ice and overburden. (Letter labels are described in "System Description")*