USING OPERATIONAL FIELD TESTS TO PREPARE FOR SURFACE SCIENCE OPERATIONS. K. E. Young[1], T. G. Graff[2,3], D. Coan[3,4], T. J. Lindsey[3,4], M. Reagan[3], W. Todd[3,5], A. Naids[3], M. Walker[3], M. Miller[2,3], C. Pittman[2,3], E. B. Rampe[3], N. Mary[3,4], and K. Zacny[6], [1]NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD, 20771 (corresponding author email: Kelsey.E.Young@nasa.gov); [2]Jacobs at NASA JSC, 2101 NASA Pkwy, Houston, TX, 77058; [3]NASA Johnson Space Center, 2101 NASA Pkwy, Houston, TX, 77058; [4]The Aerospace Corporation at NASA JSC, 2101 NASA Pkwy, Houston, TX, 77058; [5]Booz Allen Hamilton at NASA JSC, 2101 NASA Pkwy, Houston, TX, 77058; [6]Honeybee Robotics, 2408 Lincoln Ave, Altadena, CA, 91001

Introduction: As NASA prepares to send astronauts to the lunar surface with the Artemis program, the lunar science and operations community is also readying itself for conducting crewed science operations. Though we have experience in lunar surface operations from the six Apollo missions that operated on the Moon, the last several decades of technological advancements offer a myriad of new ways to prepare for future lunar surface exploration. One way to develop the technology and operational concepts for future crewed exploration is in high-fidelity analog environments, or sites that mimic the conditions that will be encountered during future exploration. This abstract will highlight several areas of ongoing development in two different underwater analog environments.

NASA Extreme Environment Mission Operations (NEEMO): NEEMO missions are conducted using the Aquarius Reef Base (ARB), an underwater habitat located several miles from Tavernier, FL, in ~60ft of water. ARB is managed by Florida International University (FIU), and NASA has conducted 23 NEEMO missions using the habitat in the last two decades. Each NEEMO mission has a crew of six people; four astronauts, engineers, and/or scientists supplied by NASA and international, academic, and industry partners and two habitat technicians supplied by FIU. NEEMO missions are well-suited to mimic missions on both the International Space Station (ISS) and at exploration destinations, including the Moon. During NEEMO missions, the ARB habitat simulates the ISS, the Gateway lunar orbiting station, or a lunar or martian surface habitat or lander while crewmembers conduct extravehicular activities (EVAs) outside of the habitat on the ocean floor. The NEEMO platform enables the development of technology and operational concepts in a high-fidelity operational analog.

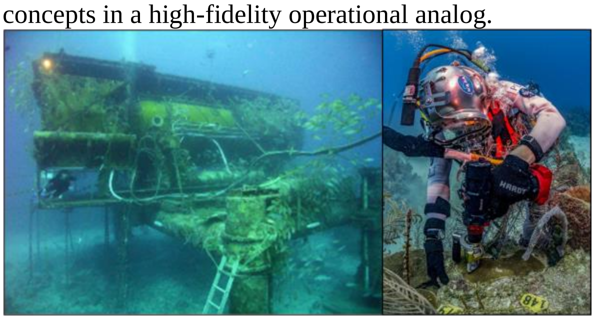

Figure 1 (above): NEEMO missions are operated out of the ARB (left). Aquanauts (NEEMO crewmembers) conduct simulated EVAs (right) to test technologies and procedures for future planetary exploration.

NEEMO as an Analog: ARB sits in the Carpenter Basin and is surrounded by marine life, including abundant coral and sponge species. Exploring and sampling these species is analogous to lunar and martian exploration as the processes and techniques used to explore this unknown environment are similar to how astronauts will explore other planetary surfaces.

NEEMO Technology Testing: The NEEMO platform is able to investigate and develop a number of lunar-relevant exploration technologies. For example, through a partnership with Honeybee Robotics, we were able to develop a core sample acquisition system (Fig. 1, right) that could be used in future lunar exploration. We also have iterated on the Modular Equipment Transport System (METS) over the last several NEEMO missions, which is a wheeled system to transport hardware and samples while on EVA.

In addition to sampling and transport hardware, we have tested a series of informatics capabilities, or platforms to enable real-time and efficient access to procedures, data, and navigation during EVA operations. These informatics capabilities include a heads-up display system, in partnership with the Navy, as well as digital cue cards and an intravehicular (IV) workstation to allow IV crew inside the habitat to support their EV counterparts.

NEEMO Operational Concept Testing: NEEMO is one of the longest standing platforms with which to test operational concepts for lunar and future martian exploration. With the EV and IV crew operating in an extreme environment on a realistic mission timeline, supported by flight control teams on 'Earth' (including ISS CapComs) in a simulated mission control, we can drive out lessons learned on how we will operate on the lunar surface. Recent NEEMO missions have completed 8-9 EVAs, geared primarily to integrated operations with high-fidelity science objectives and EVA tools. The recent NEEMO 23 mission conducted from June 10-19, 2019 included lunar-relevant communications blockages as well as a comparison between a ground IV versus a crew IV from the habitat directing the EVA operations. NEEMO 23 also evaluated techniques to allow for a flexible execution of a pre-determined traverse place.

NXT (Neoteric eXploration Technologies): NXT represents a second underwater analog activity, geared toward testing one- and two-person submersibles as an analog for lunar surface EVA excursions and rover operations. By using an underwater Exosuit Atmospheric Diving System (ADS) and Dual Deepworker (DDW) 2-person submersible (Figure 2), both 1-atmosphere dive systems developed and maintained by Nuytco Research Ltd., we simulated traversing the lunar surface with a two-person rover and crewmember on EVA. We conducted the NXT Feasibility Mission in August 2019 on Catalina Island, CA, at the USC Wrigley Institute for Environmental Studies. Eight pilots completed a series of excursions in both the Exosuit and the DDW in Fisherman's Cove, Harbor Reef, and at Bird Rock. In addition to the underwater evaluations, the NXT crew also completed geology and science operations training and evaluations on the surface within a local terrestrial geology area. This geologic training was critical for the NXT 'Surf and Turf' model, whereby pilots needed an understanding of what to expect geologically for their future traverses in the Exosuit and DDW in the unknown exploration area. Catalina Island was an excellent place for this work due to is complex geology. While the rocks themselves were not analogous to lunar materials, the diversity of materials at the site provided an excellent opportunity to describe and document a variety of geologic materials.

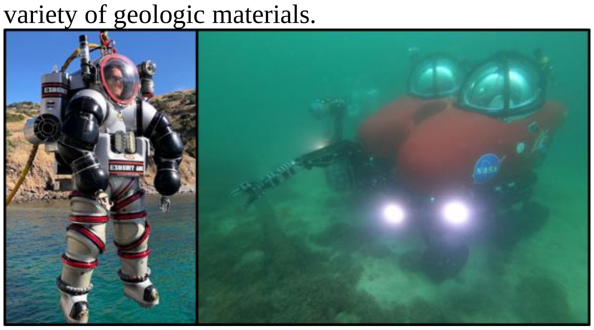

Figure 2 (above): The Exosuit (left) and Dual Deepworker submersible (right). NXT uses these assets to develop technologies and concepts of operation for future crewed lunar surface exploration.

NXT Technology Testing: The NXT platform enables the testing of multiple technologies relevant for future lunar surface exploration. For example, during the 2019 mission, we tested informatics-relevant heads-up display (HUD) capabilities using Lumus DK-52 glasses, which can project procedures, data, and tracking information real-time during operations. By implementing this HUD capability in this operational analog, while completing exploration traverses and engineering tasks in an unknown environment, we evaluated the utility of this type of technology for future analogous lunar traverses. End operator and subject matter expert input is critical in these evaluations, so development within the mission and post-mission feedback was critical in developing lessons learned.

NXT Operational Concept Testing: In addition to testing technologies that are of interest for future lunar exploration, the NXT environment enables us to drive out lessons learned in operational concepts for completing scientifically-motivated exploration in an unknown environment. For example, the Exosuit and the DDW can evaluate how a suited crewmember and a rover can interact to maximize efficiency and science productivity. Additionally, by linking up pilots in the Exosuit and the DDW to not only each other but also to a science backroom staffed with both Mission Control personnel and science expertise, we are able to evaluate how best to accomplish science objectives on a traverse through an unknown terrain. Driving out these lessons learned in an environment that is operationally complex at an analog site that resembles the lunar surface (in that it is an inhospitable environment as well as one with compelling science questions that need to be answered) is critical, and NXT resembles a valuable platform for the development of Artemis-relevant operational concepts.

Conclusions and Moving Forward: As NASA moves closer to putting boots on the lunar surface, analog testing is critical to drive out technology, procedures, and concepts of operation for completing scientifically-motivated EVAs on another planetary body. Underwater analog testing, such as NEEMO and NXT, provide valuable platforms with which to advance in these critical areas due to several factors. Putting crewmembers in an extreme environment with relevant proxy science, in a realistic mission timeline, supported by operators, scientists, and engineers in Mission Control not only drives out lessons learned critical to success in upcoming missions but also creates an environment for the entire operations team to start to train and prepare for the future. Future testing should directly address gaps and risks identified by the Science and EVA communities and should feed forward into tools, technique, technology, and training requirements.

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