CONDUCTING SCIENCE-DRIVEN EXTRAVEHICULAR ACTIVITIES DURING PLANETARY SURFACE EXPLORATION – THE NEEMO (NASA EXTREME ENVIRONMENT MISSION OPERATIONS) 22 MISSION.

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Introduction: Analog tests, or high fidelity multidisciplinary mission simulations, are a crucial part of preparing for the next generation of planetary surface exploration. The NEEMO (NASA Extreme Environment Mission Operations) program is one such analog. NEEMO utilizes The Aquarius habitat, the world's only undersea research facility, located six miles off the coast of the Florida Keys. Since the early 2000s, NASA, in coordination with international, academic, military, and industry partners, has been running a series of NEEMO analog missions, studying the exploration of the Moon, Mars, and small bodies. The missions have been geared toward developing science operations procedures, closing EVA (Extravehicular Activity) operations and technical knowledge and capability gaps, and exploring ISS (International Space Station) and Orion-related IV (Intravehicular Activity) habitat objectives. Recent NEEMO missions have incorporated high-fidelity marine science objectives whose sampling and instrument deployment techniques closely mimic those we expect to be used in future planetary surface exploration.

Here, we detail the efforts of the NEEMO 22 mission in exploring architectures for the exploration of the Moon and Mars. NEEMO 22 took place from June 18-27, 2017 at the Aquarius Reef Base. The ten-day mission included an international crew of astronauts and scientists and operated under a lunar time delay for the first half of the mission (1.7-seconds one-way) and a representative Mars time delay for the second half of the mission (10-minutes one-way). Each EVA consisted of two EV crew conducting science outside and one IV crewmember supporting them inside the habitat.

Integrated EVA and Science Operations: The backbone of the EVA strategy during NEEMO 22 was the highly integrated EVA and Science Operations structure. Not only were the EVA and Science objectives for the mission developed in tandem, but the two groups integrated throughout the mission to conduct all EVA operations. The ultimate goal was to investigate the concept of operations for executing EVA excursion plans with a unique structure between the EV crew, their supporting IV crewmember, the Science Team (ST) and the Mission Control Center team (MCC) (Figure 1). Prior analog missions, along with spaceflight missions, identified the importance of an IV crewmember in EVA operations, who serves as a communication hub between the EV crew and any supporting personnel on 'Earth' (on the ST and/or in MCC). All video and audio communications from each of the two EV crew is visible by both the IV crew and by specialists on 'Earth'. When MCC or the ST wanted to communicate with the EV crew, they did so through the IV crewmember by standard radio voice transmissions and/or text. Text communications proved effective in both NEEMO 22 time latencies.

This operational strategy also enabled the testing of flexible execution of planned traverses, a core objective of NEEMO 22. After the ST designed each day's traverse, the crew would execute them, adapting real-time (with input from the IV and from the ST when the communications delay allowed) based on their in situ observations and any in situ instrument data.

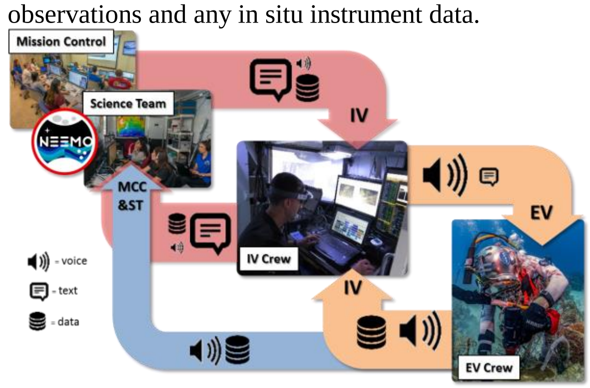

Figure 1: NEEMO 22 Integrated EVA and Science Operations Communication Structure.

In Situ Instrumentation: The Apollo lunar surface missions were characterized by sample collection and curation and the deployment of basic science experiments, but never has a human explorer collected and reacted to in situ instrument data beyond low-Earth orbit. Future planetary exploration will likely include higher resolution technology that is capable of providing astronauts with real-time geochemical and geophysical data that they can use both for sample high-grading and for redefining traverse plans. It is critical for the community to start now both in designing technology that can be deployed by a spacesuited astronaut as well as the operational architecture that can support this flexible traverse execution to allow room for updates to the initial plan based on in situ data. Additionally, many of the currently available portable instruments are time-intensive for the crew, meaning that future EVA traverses will have to carefully account for not just sample collection and documentation time, but also for instrument deployment and subsequent data assimilation time. NEEMO 21 and 22 examined the architecture under which this will take place, and moved to close the knowledge gap of how portable instruments will be used on future exploration missions. All instruments deployed in NEEMO both accomplish marine science objectives as well as closely resemble a relevant planetary surface tool. For example, the Pulse Amplitude Modulation Fluorometer deployed on NEEMO 21 provides marine scientists with a quick look at the photosynthetic state of a coral colony and its deployment technique closely mimics that of the handheld x-ray fluorescence spectrometer, which has been deployed in several analog tests and could be included on future exploration missions [1].

EVA Tools: The last several NEEMO missions have included high-fidelity EVA Tools for EVA science with high relevance to planetary surface operations concepts. A cutting edge breakaway core bit technology, developed by Honeybee Robotics, was integrated with an underwater drill to test new sampling and curation techniques. Additionally, NEEMO 22 tested the Modular Equipment Transport System (METS), a concept for manually transporting EVA tools, equipment, and samples on traverses [2]. The METS included a cart for transporting larger tools, pioneering equipment, sampling technology and collected samples, and in situ instruments in a series of Modules, each designed for a specific EVA task. EV crews also wore smaller tools in Modules mounted to their wrists and thighs, giving them constant access to the most used tools without having to return to the larger and harder to maneuver cart. The METS concept is discussed in detail by Walker et al. (this meeting).

EVA Support System and IV Workstation (IV W/S): As discussed above, the IV crew is critical for the success of science-driven EVAs. As the IV crew is responsible for viewing, integrating, and managing so many datasets (audio and text communications with support teams and with the EV crew, recording scientific data as it's collected, keeping track of spacesuit and spacecraft data, managing the timeline, etc.), a capable and highly-functioning Support System and W/S must be developed to support this important position. The last several NEEMO missions have continued to develop the IV W/S, and NEEMO 22 updates included the addition of software to track EV suit data and EVA consumables, a Hololens to explore ways to include augmented reality into the W/S, a complex configuration of computer monitors, projectors, and iPads to evaluate how to use space effectively (as real estate in future habitats is sure to be limited), and the addition of EVA task and timeline tracking systems to enable the IV crew to monitor EVA progress [3]. Modifications were also made to the supporting scientific documentation software, enabling the IV crew to keep track of all samples and data collecting, offloading the EV crew and keeping the ST updated real-time.

EVA Informatics: Though the IV crew is tasked with helping direct EVA science tasks, there is still a need for the EV crew to be able to easily access plans, procedures, sampling support data, and troubleshooting information. The issues facing an EV crew working in an underwater environment are in many ways comparable to a spacesuit-clad crewmember (e.g. no current touch screen capabilities, helmet obscuring field of view, etc.). To address the needed informatics capability in this challenging analog environment, we have developed a set of Digital Cue Cards loaded on an iPad in an iDive underwater housing that enable NEEMO crews to test the use of a single electronic device platform for viewing traverse plans, accessing navigation aides, identifying correct specimens to sample, following sampling and instrument procedures, and accessing troubleshooting procedures. The Digital Cue Cards were updated daily by the ST based on the evolving in-situ information and mission plans, and the new file was pushed to the crew's iPad before each day's EVA. These Cue Cards proved very beneficial in maximizing the efficiency of EVA Science Operations, and will continue to be developed for future missions, with the possibility of developing these Cue Cards for incorporation into a heads-up display capability in the future.

Future Work: The NEEMO testing platform is incredibly valuable in testing a wide variety of EVA and associated IVA technologies, operational architectures, and scientific concepts. Important lessons learned are a direct result of the combined efforts of a diverse team of planetary scientists, EVA operators and engineers, mission managers, marine scientists, and tools engineers. The ability to annually iterate on developing operations concepts has enabled us to produce valuable insights on what future exploration of the Moon, Mars, and small bodies will look like, and future NEEMO missions will continue to advance the current state of knowledge on enabling planetary surface exploration.

References: [1] Young K. E. et al. (2016) *Applied Geochemistry*, *72*, 77-87. [2] Walker M. et al. (2018) *49th LPSC*, this meeting. [3] Miller M. et al. (2018) *49th LPSC*, this meeting.