NEEMO 20: SCIENCE TRAINING, OPERATIONS, AND TOOL DEVELOPMENT.

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Introduction: The 20th mission of the National Aeronautics and Space Administration (NASA) Extreme Environment Mission Operations (NEEMO) was a highly integrated evaluation of operational protocols and tools designed to enable future exploration beyond low-Earth orbit [1]. NEEMO 20 was conducted from the Aquarius habitat off the coast of Key Largo, FL in July 2015. The habitat and its surroundings provide a convincing analog for space exploration. A crew of six (comprised of astronauts, engineers, and habitat technicians) lived and worked in and around the unique underwater laboratory over a mission duration of 14-days.

Incorporated into NEEMO 20 was a diverse Science Team (ST) comprised of geoscientists from the Astromaterials Research and Exploration Science (ARES/XI) Division from the Johnson Space Center (JSC), as well as marine scientists from the Department of Biological Sciences at Florida International University (FIU). This team trained the crew on the science to be conducted, defined sampling techniques and operational procedures, and planned and coordinated the science focused Extra Vehicular Activities (EVAs). The primary science objectives of NEEMO 20 was to study planetary sampling techniques and tools in partial gravity environments under realistic mission communication time delays and operational pressures. To facilitate these objectives two types of science sites were employed 1) geoscience sites with available rocks and regolith for testing sampling procedures and tools and, 2) marine science sites dedicated to specific research focused on assessing the photosynthetic capability of corals and their genetic connectivity between deep and shallow reefs. These marine sites and associated research objectives included deployment of handheld instrumentation, context descriptions, imaging, and sampling; thus acted as a suitable proxy for planetary surface exploration activities.

This abstract briefly summarizes the scientific training, scientific operations, and tool development conducted during NEEMO 20 with an emphasis on the primary lessons learned.

Science Training: Prior to the start of the mission the crew was instructed on the proper scientific procedures and protocols for both the geology and marine science sites. This training was accomplished in two ways 1) through crew briefings that covered the science objectives, sample collection procedures, and instrument techniques, and 2) through the use of quick reference cue cards. These science-focused cue cards were available as guides during EVAs. Adapted from previous analog testing, the geoscience cue cards used a graphical methodology to display the procedures for sample descriptions and collection (Figure 1).

Science Training Lessons Learned

- Maximizing science-focused training is crucial, especially for non-scientist crew members. Further incorporation and refinement of science-focused training into mission planning is essential.
- Crew understanding of the scientific intent, objectives, instrumentation, and procedures is increasingly important as they become more autonomous (given the increased communication latencies as we explore beyond low-Earth and the resulting delayed communication with the ST).
- The graphical methodology of displaying procedures for sample descriptions and collection was identified by the crew as a useful guide and effective quick reference (Figure 1).
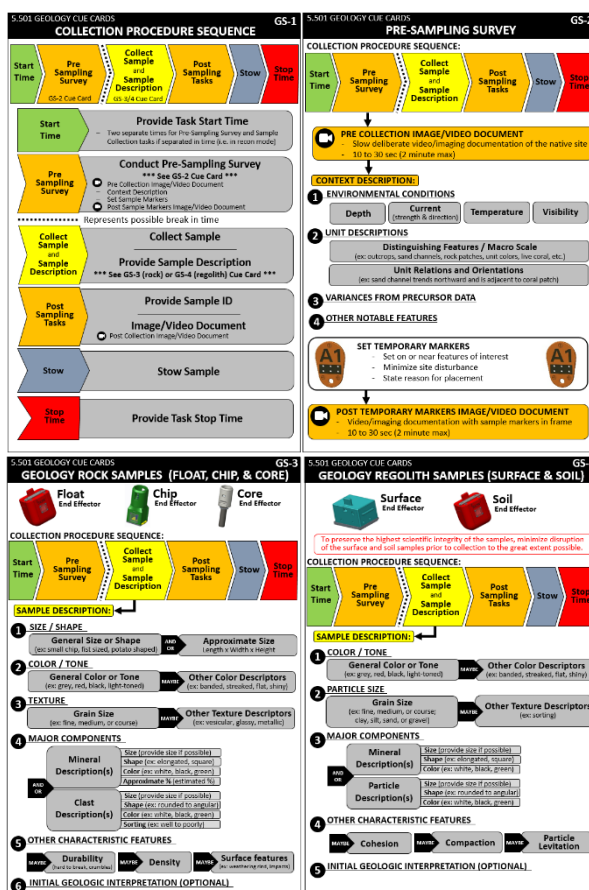

Figure 1: Collection procedures and geoscience cue cards

Science Operations: Precursor imagery of the science sites was collected prior to the mission. Using this data the ST annotated areas of interest and identified possible samples for collection or instrument deployment locations (Figure 2). During an EVA, as additional imagery and data became available, the ST would relay further information to a crew member supporting the EVA from a dedicated workstation within the Aquarius habitat (known as the Intravehicular (IV) position). During NEEMO 20 communication delay between the crew, Mission Control Center (MCC), and ST was varied to study effects of communication latencies and mitigation strategies [2].

Science Operations Lessons Learned

- The geology and the marine science tasks were realistic enough to effectively test and evaluate a number of planetary operational concepts. The extensive scientific input incorporated into NEEMO 20 dramatically increased the overall level of realism to the mission.
- Time-delayed feedback from the ST to the crew, derived from information collected during an EVA, is seen as significantly enhancing to the mission from both the crew and ST perspective. Hybrid approaches that incorporate aspects of crew autonomy based solely on precursor information and pre-planning should be further tested (with the appropriate detailed crew training that is required).
- The ST needs to be further incorporated into MCC during science-focused EVAs to better facilitate integration and communication.
- During science-focused EVAs the IV crew member has a tremendous workload. Operational improvements should be implemented to improve the overall IV workload and workstation.
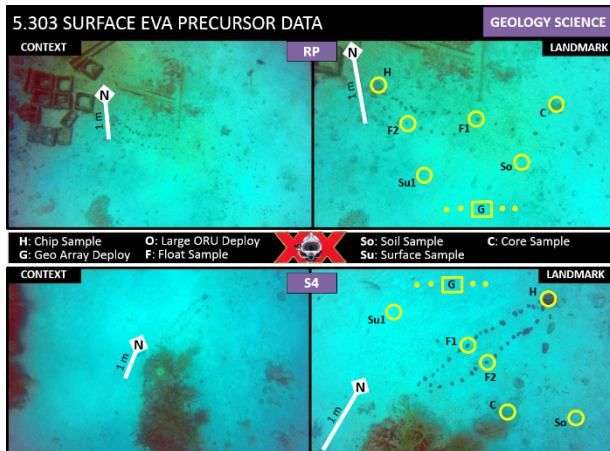

Figure 2: Precursor imagery with annotated science targets

Tool Development: NEEMO 20 incorporated an integrated geology sampling kit [3]. The kit consisted of a briefcase that housed end effectors used for sample collection. Multiple types of end effectors allowed the crew to capture float, soil, surface, core, and chip samples using one of two common drivers (one manual and one powered). In an initial step to address the contamination requirements put forth by the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM), the end effectors were single-use and each doubled as a sample container (Figure 3). This system simulated a design and operational approach to enable pristine sample collection and minimize contamination between sample sites.

Tool Development Lessons Learned

- The integrated sampling system concept proved feasible for EVA collection and stowage of a variety of rock and regolith samples.
- The size and mass of the kit is large compared to the actual samples obtained. Further work is required to minimize the size and mass of sampling tools and end effectors, while maximizing returned samples.
- Further work is needed on methods and tool modifications to keep the crew from contaminating areas as they collect samples.
- A thorough list of detailed tool improvements was documented and should be incorporated in future prototypes and analog missions.
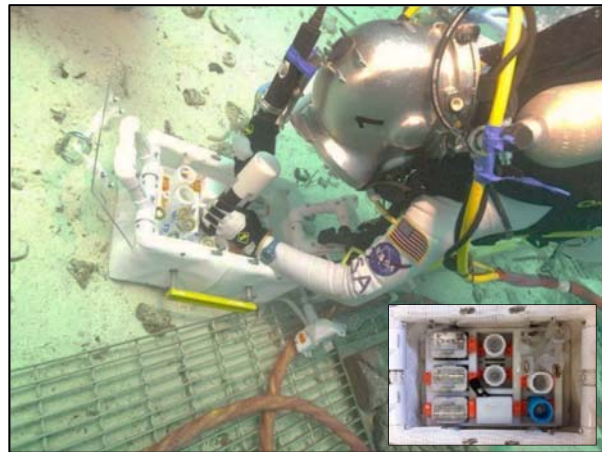
Figure 3: Crew member interfacing with the integrated geology sampling kit using the power driver; inset displays detailed view of the tool kit and various end effectors (3 float/soil, 2 core, 2 chip, & 1 surface)

References: [1] Todd *et al.* (2015) NEEMO 20 Post-Mission Report and Preliminary Findings. [2] Chappell *et al.* (2016) *IEEE Aerospace Conference*, #2394. [3] Hood *et al.* (2016) this volume.