NEEMO 21: TOOLS, TECHNIQUES, TECHNOLOGIES & TRAINING FOR SCIENCE EXPLORATION.

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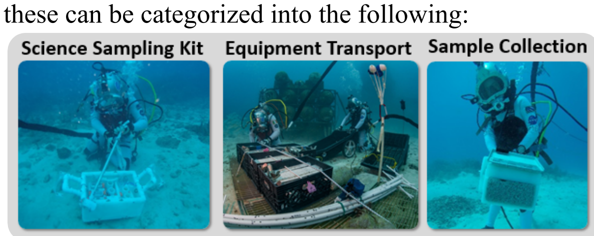
Introduction: The 21[st] mission of the National Aeronautics and Space Administration (NASA) Extreme Environment Mission Operations (NEEMO) was a highly integrated operational field test and evaluation of tools, techniques, technologies, and training for science driven exploration during extravehicular activity (EVA). The mission was conducted in July 2016 from the Aquarius habitat, an underwater laboratory, off the coast of Key Largo in the Florida Keys National Marine Sanctuary. An international crew of eight (comprised of NASA and ESA astronauts, engineers, medical personnel, and habitat technicians) lived and worked in and around Aquarius and its surrounding reef environment for 16 days. The integrated testing (both interior and exterior objectives) conducted from this unique facility continues to support current and future human space exploration endeavors.

Expanding on the scientific and operational evaluations conducted during NEEMO 20 [1], the 21[st] NEEMO mission further incorporated a diverse Science Team comprised of planetary geoscientists from the Astromaterials Research and Exploration Science (ARES/XI) Division from the Johnson Space Center, marine scientists from the Department of Biological Sciences at Florida International University (FIU) Integrative Marine Genomics and Symbiosis (IMaGeS) Lab, and conservationists from the Coral Restoration Foundation [2]. The Science Team worked in close coordination with the long-standing EVA operations, planning, engineering, and research components of NEEMO in all aspects of mission planning, development, and execution.

Objectives: The primary EVA objectives for this operational field test were to analyze the integrated aspects of science, operations, and equipment in a mission-like environment to evaluate 1) EVA concepts of operations in a natural science-rich environment, 2) equipment requirements for conducting science, and 3) operational methods that enable effective and efficient communication between the Science Team and the crew during an EVA, while utilizing a flexible execution methodology [3]. The mission simulated Mars exploration conditions by applying a 15 minute communication latency on all voice and data transmissions. Serving as an appropriate proxy for planetary surface exploration and sampling activities, marine science research was conducted focusing on assessing the photosynthetic capability of corals and their genetic connectivity between deep and shallow reefs [4,5]. Over the course of the mission, > 60 hours of science driven EVA operations were conducted, including 1) the construction and initial science investigation of two long-term coral nurseries, 2) follow-on research and re-sampling of NEEMO 20 targets of interest, 3) further exploration of the surrounding reef environment to identify, document, and sample additional coral species, and 4) stand-alone tool testing to evaluate sampling procedures and on-going geoscience tool development. This abstract briefly summarizes the tools, techniques, technologies, and training conducted during NEEMO 21.

Tools: A number of prototype hardware designs were evaluated for maturation of tools and equipment, these can be categorized into the following:

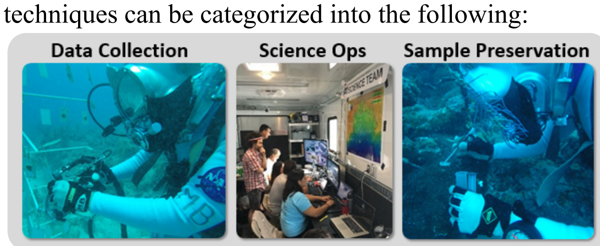


Science Sampling Kit. Evaluated EVA hardware and operations for science sampling in a surface/partial-g environment. This kit includes a variety of end effectors for collecting surface, float, regolith, chip, and core samples [6]. This kit also included an updated sample marker design used for communicating targets of interest during pre-sampling surveys to the Science Team.

Equipment Transport. Evaluated EVA hardware and operations for transporting and stowing tools and samples. The various components included multiple cart/sled configurations for moving equipment between science sites, and a sling bag for organizing small EVA items (sample markers, hand tools, electronics, etc.).

Sample Collection. Evaluated sample collection tools and containers with special emphasis on contamination control.

Techniques: Evaluated exploration concepts of operations and science processes and procedures. These techniques can be categorized into the following:



Data Collection. A portable scientific instrument (a Pulse Amplitude Modulated (PAM) fluorometer) was utilized for marine science research. This allowed evaluation of the utility and impact of in-situ measurements on the science decision making process and overall EVA strategies and methodology.

Science Operations. Figure 1 displays the components, communication methods, and flow used to conduct EVA science operations. NEEMO 21 further developed these techniques and evaluated what functions and capabilities are needed to enable effective operation and actively direct science operations over a long communication latency [7].

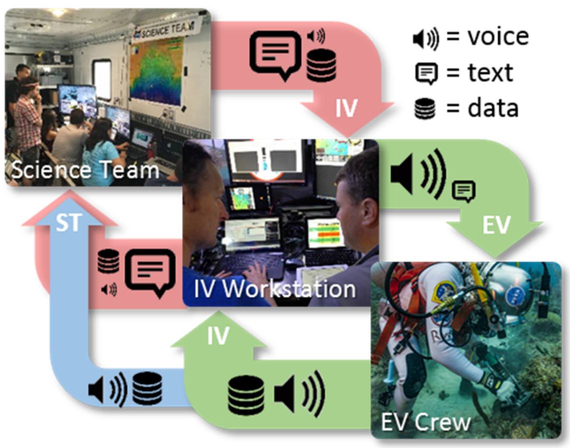


Figure 1: Components, communication methods and flow used to conduct EVA science operations.

Sample Preservation. Along with sampling tools, the processes and procedures for sample collection were evaluated. The collection of biologically relevant marine science samples for subsequent DNA analysis played a key role in the sample preservation techniques.

Technologies: NEEMO 21 assessed numerous technology needs for navigation, communication, and operations to support accomplishment of science objectives.

Navigation. A combination of digital maps, traverse plans, and an active underwater navigation system enabled the crew to locate all science sites and maintain situational awareness.

IV Workstation. Evaluated the support system requirements for the intravehicular (IV) crewmember in order to effectively handle the amount of information and tasking the crewmember inside the habitat must contend with while actively directing the EVA. This IV support system will be key for exploration operations with long communication latencies.

Informatics. NEEMO 21 incorporated a digital cue card system (Figure 2) that enabled the crew to conduct general navigation, execute uploaded traverse plans, identify samples, and guide themselves through procedures. This type of information system permits increasing EVA and crew autonomy.

Figure 2: Home page of the tablet based digital cue card system developed and used during NEEMO 21.

Training: NEEMO missions enabled training and integration across diverse skill sets and teams. Training opportunities included:

Crew Training. Provided crew training and leadership opportunity supported by the astronaut office.

Skill-Set Integration. Facilitated integration, coordination, and educational opportunities from multiple disciplines across numerous organizations.

Team Training. NEEMO continues to provide an excellent opportunity for collaboration and integration within JSC, across NASA centers, alongside our international partners, and with academia, industry, institutions and the military.

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References: [1] Graff *et al.* (2016), *47th LPSC* #2212. [2] Nedimyer et al. (2016), *13th Intl Coral Reef Sym* #29957. [3] Hodges and Schmitt (2011), *GSA*, v. 483 p.17-31. [4] Dougan *et al.* (2016), *13th Intl Coral Reef Sym* #29615. [5] Bonthond *et al.,* in prep. [6] Hood et al. (2016), *47th LPSC* #1249. [7] Chappell *et al.* (2017) *IEEE Aerospace Conference*, submitted #2442.