NEEMO 23 EVA & Science Operations Summary of Results

EVA-EXP-0071

EVA Exploration Working Group

September 17, 2019

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Agenda

- Exploration EVA & Science Operations
- NEEMO 23 Mission Overview & Goals
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  - ESAT & EVA Team
  - Enabling EVA Science Operations for Lunar Surface Missions
  - Development & Integration Themes Focused on at NEEMO 23
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- EVA & Science Objectives and Results
  - Exploration EVA Objectives Tied to Knowledge & Capability Gaps
  - ARES Proxy Planetary Science Objectives
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  - EVA Tools & Equipment
  - EVA Concepts of Operations
- Summary of NEEMO 23 and Relevance to Artemis 2024
- Recommendations for Future Integrated EVA Testing at NEEMO
- Recommendations for Potential NEEMO 24 Mission
- Questions & Answers
- Backup Materials and Additional Information

EVA & Science Objectives per the Mission Objective Request (MOR) for NEEMO 23

"The primary objectives for the EVA Office & ARES/Science Division during NEEMO 23 are to develop informatics capabilities for the xEVA System (including xEMU), evaluate tools and equipment for operating on natural bodies, and examine concepts of operations for planetary missions. The major objectives and components for evaluation on this mission include 1) an augmented vision heads-up display; 2) integrated informatics to allow the crew to operate more effectively; 3) a support system that enables Intravehicular (IV) crewmembers to efficiently manage large amounts of data while directing an EVA; 4) an equipment transportation system for planetary operations, including wheeled and spacesuit-mounted capabilities; 5) tools for core sample acquisition; 6) integrated EVA and science operations during a lunar mission that includes signal outages/blockages; and 7) equipment and techniques for rescuing an incapacitated EVA crewmember."

"The results of the NEEMO mission will inform updates to the Exploration EVA System Concepts of Operations document (EVA-EXP-0042), facilitate closure of EVA capability gaps, and address Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) and Formulation Assessment and Support Team (FAST) findings for EVA collection of science samples. Take-aways from the mission will provide data for hardware design maturation to assist in road-to-flight, especially for the EVA science sample collection and storage tools, and assess xEVA system needs for all Exploration destinations."

NEEMO 23 Mission Overview & Goals

Overview
- 9-day saturation mission from Aquarius underwater habitat
- Exploration EVA, ARES, Gateway, and ISS related objectives
- External partner marine science and neuroscience
- Numerous participating organizations across NASA, JSC, and ESA
- External partnerships with DoD (Navy), Research Institutions, Universities, and Industry

Key Dates
- Full JSC Crew Training Week: May 13-17, 2019
- ARB Crew Training Week: June 3-8, 2019
- Engineering Saturation Run: June 10-13, 2019
- **NEEMO 23 Mission: June 13-21, 2019**

NEEMO XXIII

Crew Members
- **Samantha Cristoforetti** (Astronaut, CDR)
  European Space Agency (ESA), ISS Expedition 42/43
- **Jessica Watkins** (Astronaut Candidate)
  NASA
- **Shirley Pomponi** (Marine Scientist)
  Florida Atlantic University
  Harbor Branch Oceanographic Institute
- **Csilla Ari D'Agostino** (Neuroscientist)
  University of South Florida
- **Mark "Otter" Hulsbeck** (Habitat Technician)
  Florida International University
- **Tom Horn** (Habitat Technician)
  Florida International University
- **Adam Naids** (EVA Tools Engineer)
  NASA, Backup Crewmember

Mission Management Team (MMT – EISD/READy)
- XI / Trevor Graff
  Astromaterials Research & Exploration Sciences (ARES) | Integration Lead
- XI / Kelsey Young
  Astromaterials Research & Exploration Sciences (ARES) | Science Lead
- XM / Marc Reagan
  Exploration Mission Planning Office (EMPO) | Mission Director & IVA Lead
- XM / Bill Todd
  Exploration Mission Planning Office (EMPO) | Project Lead
- XX / David Coan
  Extravehicular Activity Office (EVA) | EVA Lead

NEEMO 23 ESAT & EVA TEAM

Engineering Saturation (ESAT) Crew & Core Team [SEATEST V]

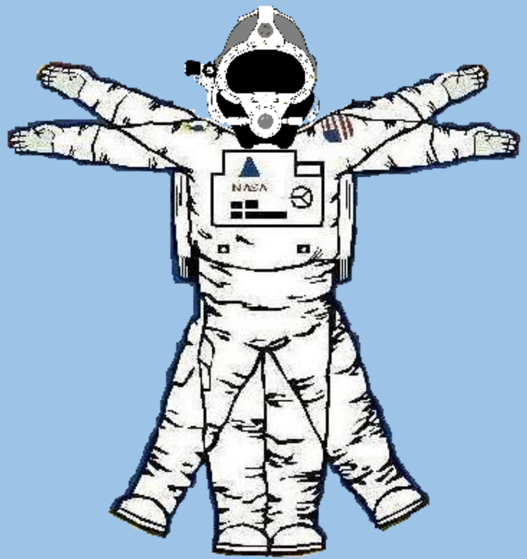
- 4-day saturation test with experienced NASA aquanauts to configure equipment and run initial evaluations of objectives with subject matter experts
- First Aquarius saturation mission since Hurricane Irma
- ESAT Crew
  - **David Coan**
    Aquanaut | NASA EVA Office | EVA SME
  - **Trevor Graff**
    Aquanaut | NASA ARES | Science SME
  - **Tom Horn**
    Aquanaut | Florida International University | Habitat Technician
  - **Mark "Otter" Hulsbeck**
    Aquanaut | Florida International University | Habitat Technician
  - **Marc Reagan**
    Aquanaut | NASA EMPO
  - **Bill Todd**
    Aquanaut | NASA EMPO
- Core Topside Team
  - **Adam Naids**
    Acting EVA Lead | NASA EVA Tools
  - **Kelsey Young**
    Acting Mission Director | NASA ARES

EVA & Science Operations

- David Coan (XX)
  EVA Lead, EVA PI, MCC Ops, Dive Team Lead, Working Diver
- Trevor Graff (XI)
  Integration Lead, ST Ops, Dive Lead, Working Diver
- Kelsey Young (XI)
  Science Lead, Working Diver, ST Ops

EVA Tools & Equipment

- Adam Naids (EC7)
  EVA Tools Lead, Working Diver, MCC Ops
- Mary Walker (EC7)
  EVA Tools, Working Diver Prospect, MCC Ops



IV Workstation & EVA Support System

- Cameron Pittman (XI)
  EVA Support System & IV Workstation, MCC Ops
- Matthew Miller (XI)
  EVA Support System & IV Workstation

MCC Ops Support for EVA

- Jordan Lindsey (XX)
  MCC Ops
- Natalie Mary (XX)
  MCC Ops

EVA Partners & Collaborators (POCs)

- Herve Stevenin
  ESA, LESA
- Paul McMurtrie
  U.S. Navy, Diving Equipment RDT&E Program Manager
- Dennis Gallagher
  U.S. Navy, DAVD Project Manager
- Tomas Gonzalez-Torres
  Iowa State University, Suit Mounted Tools Harness
- James Stoffel
  UND, EVA Repair of 3D Printed Hab

Plus a whole host of science partners from ARES, FAU, and FIU

From the Mission Days 5-6 Status Report

Extravehicular Activity Office (EVA/XX)

The Extravehicular Activity Office is charged with responsibility to serve as the EVA program management authority within NASA. The EVA Exploration Group within the office focuses on developing the Exploration EVA (xEVA) System for a wide range of destinations being considered by NASA, identifying and closing gaps in knowledge and capabilities, and defining future concepts of operations for EVA. An EVA Exploration Engineering & Operations Specialist is filling the critical roles of NEEMO Mission Management Team (MMT) member, EVA Lead, working diver, and EVA equipment expert, along with assisting the Mission Director. The EVA Lead has responsibility for all mission objectives and tasks conducted during EVA excursion operations, including integrating an executable EVA timeline with traceability back to EVA gaps and relevant objectives.

Evaluation of the Augmented Vision Device

The primary goal for the EVA Office during NEEMO 23 is to develop informatics capabilities for the xEVA System, evaluate tools and equipment for operating on natural bodies, and examine concepts of operations for planetary missions. The major objectives and components for evaluation on this mission include 1) an augmented vision heads-up display; 2) integrated informatics to allow the crew to operate more effectively; 3) a support system that enables Intravehicular (IV) crewmembers to efficiently manage large amounts of data while directing an EVA; 4) an equipment transportation system for planetary operations, including wheeled and spacesuit-mounted capabilities; 5) tools for core sample acquisition; and 6) integrating EVA and science operations during a lunar mission that includes signal outages.

Astromaterials / Science Operations

Scientists from the Astromaterials Research and Exploration Science (ARES/XI) Division at JSC are leading the integrated science operations of NEEMO 23. This organization helped prepare the Apollo astronauts for lunar science operations, and continues today providing scientific support and curation facilities for human and robotic planetary exploration. Key science aspects incorporated and evaluated during this year's NEEMO mission include the investigation of an integrated science support team during scientifically-driven EVA, sampling procedures, sampling tools, operational techniques, contamination mitigation strategies, storage and transport of science equipment and samples, traverse planning, handheld instrumentation, and integrated human-robotic operations. NEEMO 23 science tasks include marine science research as an analog for planetary surface geologic and scientific research. The Science Team will investigate and fill the roles of two NEEMO 23 Science Team Co-Leads, two working divers, a SciCom operating from a Science Backroom, a Science Documentarian, and a Science Officer, or Liaison, to the primary MCC. The flight-like environment in NEEMO is vital in testing this science support team structure as exploring the relationship between a separate science control center and the traditional MCC necessitates a full mission team.

The NEEMO 23 Science Team, ensuring realistic lunar proxy science objectives to the mission

Development & Integration Themes (4-T's) Focused on at NEEMO 23

TOOLS

EVA Tools & Systems
- **Handheld Tools for Building & Repair**
- **Handheld Tools for Science**
- **Power Tools**
- **Tool Transport & Stowage Systems**
- Mobility & Compatibility Requirements
- **Crew Rescue Systems**

Instrumentation
- **In-Situ Analytical Instruments**
- Instrument Packages & Payloads

Sample Collection
- **Sample Acquisition & Handling**
- Contamination Mitigation
- **Transportation & Stowage**

TECHNIQUES

Exploration Operations
- **Procedure Development**
- **Communication Methods & Protocols**
- **Data Visualization & Management**
- **Timeline Tracking & Scheduling**

EVA Operations
- **EVA Concepts of Operations**
- **Advanced EVA Capabilities**

Science Operations
- **Traverse Planning**
- **Science Decision Making Protocols**
- **Sample Acquisition & Documentation**

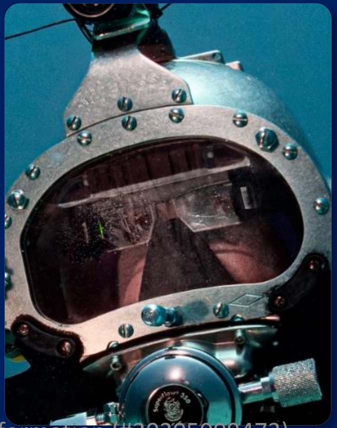
Robotic Operations
- Autonomous vs Crew Controlled
- Human-Robotic Interfaces

TECHNOLOGIES

Emerging Technologies
- **Informatics** & Intelligent Systems
- Virtual/Hybrid Reality Environments
- Medical & Human Performance
- **EVA Support Systems & IV Workstation**
- Advanced Spacesuit Developments

Technology Collaborations
- Commercial Connections
- University & Institute Collaborations
- **Other Government Agencies Links**
- **International Partnerships**

Innovations Incubator
- **Rapid Testing & Development**
- Idea Generation & Gap Recognition



TRAINING

Cross-Disciplinary Training
- **Involvement of Multiple Disciplines**
- **Sharing Between Diverse Skill Sets**
- Extensive Expertise & Experiences

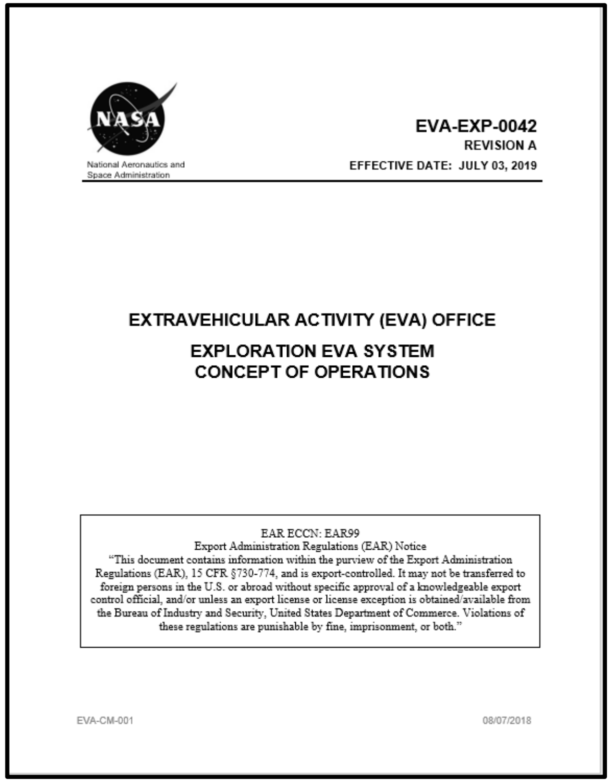
Training Opportunities
- **Exploration Training**
- **Science Training**
- EVA & Space Suit Training
- **Tool & System Training**
- **Student Opportunities**

Astronaut Crew Training
- **Expeditionary Opportunities**
- **Leadership Opportunities**
- **Mission Realistic Environments**

EVA-Specific Goals for Integrated Operational Testing such as NEEMO 23

The primary goal for EVA is to inform the ***Exploration EVA System Concept of Operations*** by exploring the combination of **Operations** and **Engineering** with **Science** for Exploration destinations in a mission-like environment

- Advance the future of the Exploration EVA System and operations
- Understand EVA capability needs and concepts of operations for a wide range of Exploration destinations being considered by NASA
- Assess the system and architectural interactions between Operations, Engineering, and Science
- Determine and document closures to gaps in EVA capabilities and knowledge
- Develop and document concepts of operations for EVA at the Exploration destinations (**EVA-EXP-0042**)
- Realize the needs of EVA equipment and enable the development of concepts for design maturation on the road-to-flight
- Evaluate initial concepts for Artemis



National Aeronautics and Space Administration

EVA-EXP-0042
REVISION A
EFFECTIVE DATE: JULY 03, 2019

EXTRAVEHICULAR ACTIVITY (EVA) OFFICE

EXPLORATION EVA SYSTEM
CONCEPT OF OPERATIONS

EAR ECCN: EAR99
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EVA-CM-001 08/07/2018

Relevancy for Science-Driven EVA Operations

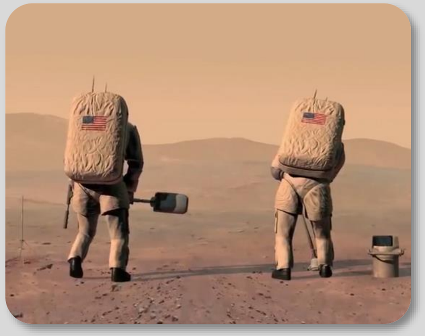
Astromaterials Research & Exploration Science (ARES)

- NEEMO EVA science activities included deployment of handheld instrumentation, context descriptions, imaging, and sampling
- The marine science activities and associated research objectives serve as an appropriate proxy for planetary surface exploration activities

- **Integration, coordination, and education from diverse disciplines and organizations**

Astromaterials

Curation

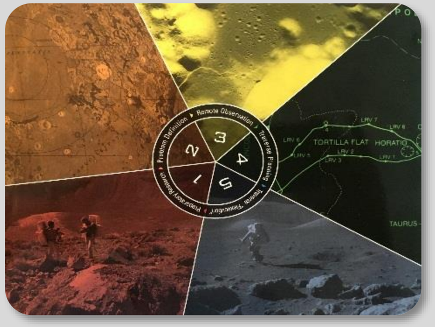


- Sampling Procedures
- Sampling Techniques
- Collection Tools
- Contamination
- Storage & Transport

Research

- Remote Sensing
- In-situ Instrumentation
- High-grading Samples
- Context Descriptions
- Documentation

Exploration



- Science Operations
- Traverse Planning
- Operational Flexibility
- Human-Robot Ops
- Crew Science Training

EVA & Science Objectives and Results

EVA Informatics

EVA Tools & Equipment

EVA Concepts of Operations

ARES Planetary Science Objectives

Exploration EVA Objectives Tied to Knowledge & Capability Gaps

The primary goal for EVA is to inform the ***Exploration EVA System Concept of Operations*** by exploring the combination of **Operations** and **Engineering** with **Science** for Exploration destinations in a mission-like environment

Primary EVA Objectives

		EVA Objectives	EVA Knowledge/Capability Gaps
Informatics		✘ ➢ **Navy Diver Augmented Vision Display (DAVD)** ***"EVA Augmented Vision Heads-Up Display"*** ✘ ▪ **Spacesuit HUD concept development for NASA** ✓ ▪ **Operational assessment of DAVD for NAVSEA** ✘ ➢ **Surface navigation for EVA** ✓ ➢ **EVA Support System and IV Workstation** ✓ ➢ **EVA digital cue cards**	➢ **EVA Suit Heads-Up Display** ➢ **Mixed / Augmented Reality Capability** ➢ **EVA Graphical Display** ➢ **EVA Short Range Navigation** ➢ **IV Support System for EVA Operations**
Tools & Equipment		✓ ➢ **Core Sample Acquisition System** *(Honeybee Robotics)* ✓ ➢ **Modular Equipment Transportation System (METS)** ▪ Wheeled Equipment Transport (WET) ▪ Suit-mounted Equipment Carrying System (SECS) ✓ ➢ **Pioneering construction** ✓ ➢ **ESA's Lunar Evacuation System Assembly (LESA 2.0)**	➢ **Tools for Science Sampling on a Surface EVA** ▪ **Subsurface samples (core)** ➢ **Tool Carrier Device** ➢ **Tool Attachment/Harness for Surface EVA** ➢ **Surface EVA Incapacitated Crewmember Rescue**
Concepts of Operations		✓ ➢ **Integrated EVA operations with science tasks** ▪ Lunar-focused with signal blockages ▪ Comparison of crew IV vs ground IV ✘ ➢ **Integrating informatics during EVA** ▪ Use of advanced informatics concepts during EVA ✓ ➢ **Flexible Execution Methodology (Flexecution)**	➢ **Integrated EVA Flight Control Methodology** ➢ **Tools for Interacting with EVA Over a Comm Latency (Blockage)** ➢ **Flexible Execution Methodology for EVA Science Operations in Undefined Environments**

In Situ Instrumentation Deployment

- ✓ Coral In Situ Metabolism (CISME) experiment deployment techniques and time constraints are analogous to high priority geologic instruments (XRF, XRD, LIBS, etc.)
- ✗ N23 Science Operations objectives focus on feasibility of EVA deployment of in situ tools real-time and efficacy of 1 vs 2 person operations
- ✓ Define areas through crew feedback that can be streamlined in support of future space applications involving non-destructive sample analysis

Opportunistic Sampling

- Sponge spawning and fertilization only if observed on EVA
- Specialized crew training and subsequent EVA 'flexecution'

Geological Sampling

- ✓ Determine the feasibility for novel sampling science operations techniques including (1) scouting, (2) “sterile” sample collection, and (3) real-time sample preservation by the NEEMO crew.
- ✗ Assess multiple sampling techniques including pneumatic coring and chiseling to efficiently collect high volume (~30) of individual samples while simultaneously minimizing contamination risk.
- ✗ Assess workload of crew sampling with 1 vs 2 crewmembers

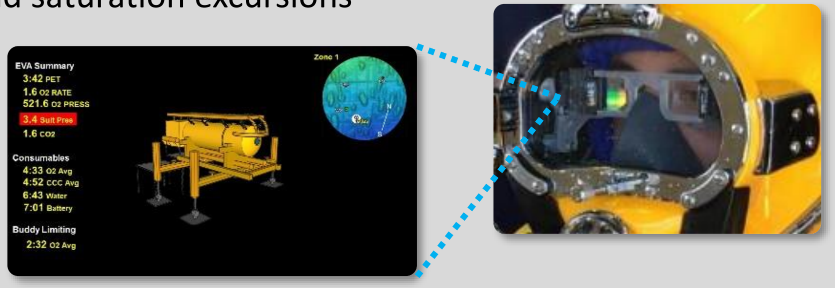
Targeted Geologic and Biomolecular Small-Volume Sampling - The “Stinger”

- ✓ Demonstrate the feasibility of collection of a diversity of targets using a new small volume sampler—the “Stinger"
- Enables collection of high-resolution samples without damaging fragile structures
- ✓ Collect and preserve samples *in situ*

U.S. NAVY DIVER AUGMENTED VISION DISPLAY (DAVD)




- ➢ Evaluate a potential concept for an EVA Augmented Vision Heads-Up Display that allows for real-time data update, augmented cue input, procedure viewing, and task direction capability, which is relevant for spacesuit (xEMU) development
  - "…this would be invaluable for EVA." – Shuttle/ISS 7-EVA experienced astronaut
- ➢ Assess the concept of using an area scanning system (side-scan sonar) for EVA crewmember self-navigation, and IV and MCC situational awareness
- ➢ Utilize the DAVD system during topside dives and saturation excursions
- ➢ Testing plan
  - Topside test dives (EVA & ARES)
  - Saturation test dives (EVA & ARES)
  - Saturation mission evals (NEEMO crew)
  - TBD follow-on testing in the NBL



IV SUPPORT SYSTEM FOR EVA


- ➢ Evolve and evaluate a Support System that utilizes a digital timeline execution and life support system management tool to support the IV crewmember during an EVA
- ➢ Examine use of OpenMCT and Playbook
- ➢ Incorporate DAVD
- ➢ Continue looking into developing an efficient IV workstation

EVA DIGITAL CUE CARDS



- ➢ Refine and evaluate digital cue cards to capture data on what information set is ideal to enable additional EVA crew autonomy

DAVD as an EVA Augmented Vision Heads-Up Display @ NEEMO

Objective

- Evaluate DAVD as a potential capability concept for an EVA Augmented Vision Heads-Up Display – allowing for real-time data update, augmented cue input, procedure viewing, task direction capability, and navigation – for spacesuit (xEMU) development

Implementation

- Utilized Navy-provided DAVD mounted inside a NASA-provided KM37 dive helmet
- Sent real-time data to the EVA crewmember from the IV workstation via DAVD for task direction

Mission Summary

- Evaluated during ESAT by an EVA SME, however system shut down during evaluation, likely due to water intrusion into cable connection on helmet
- Attempted evaluation during mission by an astronaut, however system shut down again, and was not recovered before splash-up

Crew Debrief Comments

- A HUD would be very useful and effective for the xEMU

EVA Results (Key Take-Aways)

- Initial evaluation showed promise for having multiple types of data displayed to an EVA crewmember
- Usable data displayed during eval included EVA status and consumables, cue cards, and video

Recommendations

- Update xEVA con ops to provide extended details on utilizing HUD-type data during lunar surface operations
- Feed forward into technology development of the xEMU xINFO subsystem
- Evaluate upgraded DAVD in the NBL and then again at NEEMO 24
- Add EVA gap for an xEVA suit heads-up display type of capability and associated cognitive loading

Lunar 2024 Relevance

- xEVA Suit not likely to have a HUD for 2024
- Subsequent missions will benefit from the deployment of an informatics system that displays EVA/suit data, procedures, and allows for near real-time information from the IV and Science Team

Area Scanning SONAR for Navigation @ NEEMO

Objective

- Evaluate an area scanning system for EVA crew self-navigation
- Evaluate an area scanning system for IV and MCC tracking of EVA crew location
- Demonstrate 3D area scanning for situational awareness and EVA crew self-navigation

Implementation

- Utilized Navy-provided Kongsberg MS1000 sector scan sonar
- Utilized TrackLink system from Shark Marine
- Utilized Navy-provided CODA Echoscope C-500 3D sonar

Mission Summary

- Sonar evaluated during ESAT, but largely not used by crew during the mission
- TrackLink set up for the mission, but largely not used by the crew due to reliability challenges
- Crew left physical tags at the science location samples were taken

Crew Debrief Comments

- Didn’t really use TrackLink for EVA navigation or tracking of the EVA crew

EVA Results (Key Take-Aways)

- Initial evaluation showed promise of utilizing an area scanning system for IV and MCC situational awareness of EV crew
- Initial evaluation demonstrated potential of EVA self-navigation with area scanning system data displayed to an EVA crewmember via a HUD

Recommendations

- Update xEVA con ops to provide extended details on utilizing an area scanning system for EVA navigation and SA during lunar surface operations
- Feed forward into technology development of the xEMU xINFO subsystem
- Evaluate both the Kongsberg MS1000 sector sonar and CODA Echoscope C-500 3D sonar at NEEMO 24
- Add EVA gap for navigation on a planetary surface

Lunar 2024 Relevance

- Subsequent missions will benefit from the deployment of an area scanning system for IV and MCC situational awareness of EVA crew, and for EVA self-navigation on a planetary surface

EVA SUPPORT SYSTEM & IV WORKSTATION

Objectives

- Evaluate what kind of tools (support system) the IV crewmember will need in order to effectively handle the large amount of information and tasking that they must contend with while actively directing an EVA
- Examine potential EVA task/timeline tracking systems (Playbook), along with tracking of EVA suit data and consumables
- Assess hardware/software needs for a workstation, including ways to minimize what's required for operations to reduce space and launch mass

Implementation

- Open MCT for consolidating input data, visualizing telemetry
- Life support system tracking tool with simulated spacesuit data
- Playbook Tactical EVA Execution Feature
- Programmable keypad (El Gato Stream Deck)

Mission Summary

- Configured IV workstation in hab with physical keypad with hotkeys for accessing predefined IV workstation software configurations
- Observed crew using the predefined software setup to effectively manage information during EVAs

Crew Debrief Comments

- Effective for EVA task/timeline tracking
- Easy to set up, liked the hot key
- Liked the live science task and sample tracking
- Allowed IV to effectively track EV suit data and consumables

EVA Results (Key Take-Aways)

- Predefined software and window layouts can strongly enable IV operator effectiveness by minimizing the overhead workload of initializing and maintaining an IV workstation
- Easily accessible hotkeys for accessing default layouts significantly improve the likelihood that IV operators can access IV workstation functionality
- Integrating IV workstation software design/selection into the EVA planning process significantly improves IV operator effectiveness

Recommendations

- Continue developing IV workstation layout and functionality through analog xEVA missions
- Add EVA gap for an EVA support system & IV workstation

Lunar 2024 Relevance

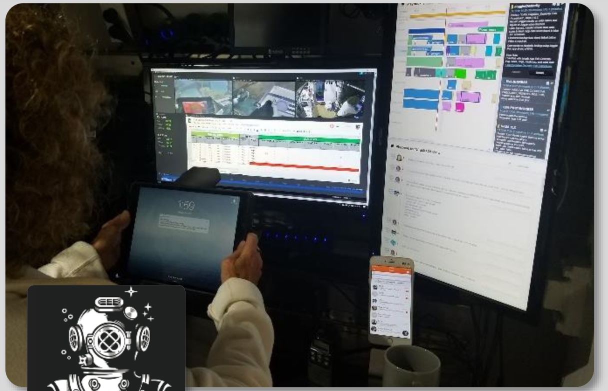
- Lunar 2024 and subsequent missions will benefit from the deployment of a workstation that displays EVA/suit data, procedures, and allows for real-time information to be sent from the IV to the EV crew

Evolution of EVA Support System for IV Operator

NEEMO 20

NEEMO 21

NEEMO 22



NEEMO 23

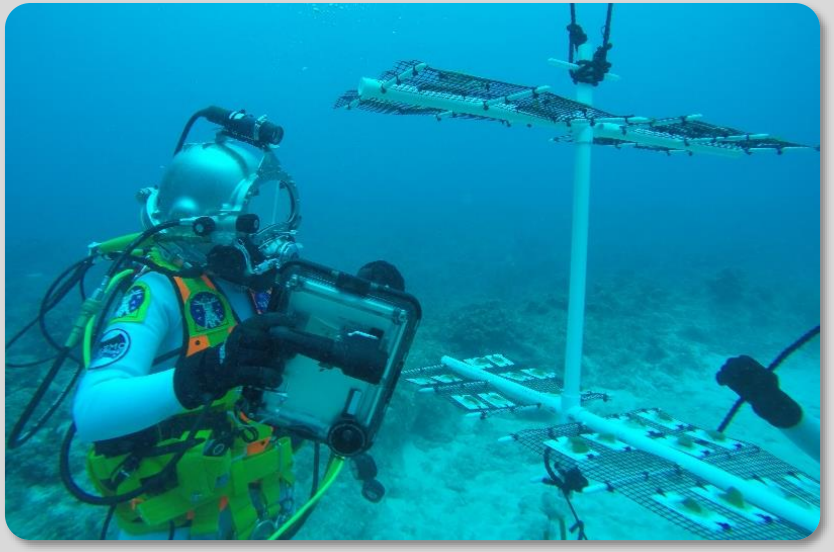
EVA Digital Cue Cards

Objective

- Evaluate digital cue cards for EVA crew that allow crew to operate more effectively and autonomously while offloading IV tasking

Implementation

- Utilize an iPad in an iDive underwater housing to demonstrate the potential for a single device for cue cards/procedures, images/video, instrument control, etc.
- All EVA-accessed and required information will be put into a digital cue card set that's loaded on the iPad



Mission Summary

- Crew utilized the cue card set to view the overview traverse and procedures during the EVAs

Crew Debrief Comments

- Having IV read steps was more effective
- Used cue cards extensively at IV workstation and before EVA to prep
- Used by EVA for METS setup on first day (then knew what to do)
- More illustrations and less words
- Flow chart layout would be useful

EVA Results (Key Take-Aways)

- Most useful for IV to read from and get quick reference information to crew

Recommendations

- Continue to work cue card development from a cloud based source for faster reaction time for IV support
- Avoid over populating the cue card with words
- Add EVA gap for xEVA suit digital display

Lunar 2024 Relevance

- xEVA Suit informatics system will likely not have digital cue card capability, subsequent missions will benefit from the capability of the EVA crew to view images and procedures
- Evaluation of the tools and techniques at NEEMO and other analogs directly lead to development of the proper equipment for planetary surface EVA operations

MOR Objectives Completion Status for xEVA Informatics

#1: Diver Augmented Vision Display (DAVD) [EVA AVHUD]		
Completed	**Partially Completed**	**Not Completed**
	Evaluate the DAVD system during topside dives and saturation excursions by NASA SME/stakeholders and astronaut crewmembers	Evaluate DAVD as a potential capability concept for an EVA Augmented Vision Heads-Up Display – allowing for real-time data update, augmented cue input, procedure viewing, task direction capability, and navigation – for spacesuit (xEMU) development
		Assess the concept of using an area scanning system (side-scan sonar) for EVA crewmember self-navigation, and IV and MCC situational awareness

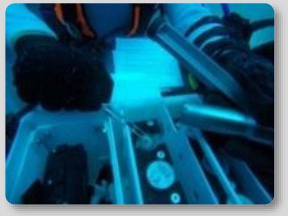
#2: EVA Navigation and Crew Tracking [Navy Sonar]		
Completed	**Partially Completed**	**Not Completed**
	Evaluate an area scanning system for IV and MCC tracking of EVA crew location	Evaluate an area scanning system for EVA crew self-navigation

Technology Prototype: HUD Helmet with DPP and Tether to main workstation		
Completed	**Partially Completed**	**Not Completed**
Demonstrate real-time images from Sector Scan – live feed		Demonstrate real-time images from Echoscope 4G C500 SURFACE – close to 1st person perspective imaging but not mapping
Demonstrate Images and drawing pop-ups on HUD Display		Demonstrate On-Screen navigation direction
Demonstrate TEXT messaging communication with Diver		

#3: EVA Support System and IV Workstation		
Completed	**Partially Completed**	**Not Completed**
Evaluate what kind of tools (support system) the IV crewmember will need in order to effectively handle the large amount of information and tasking that they must contend with while actively directing an EVA	Incorporate DAVD into the workstation	
Assess hardware needs for a workstation, including ways to minimize what's required for operations to reduce space and launch mass		
Evolve and evaluate a Support System that utilizes a digital timeline execution and life support system management tool to support the IV crewmember during an EVA		
Examine potential EVA task/timeline tracking systems (Playbook), along with tracking of EVA suit data and consumables		
Examine use of OpenMCT to display data		
Continue looking into developing an efficient IV workstation		

#4: EVA Digital Cue Cards		
Completed	**Partially Completed**	**Not Completed**
Refine and evaluate digital cue cards to capture data on what information set is ideal to enable additional EVA crew autonomy		

CORE SAMPLE AQUISITION

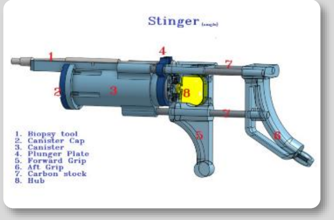


- Evaluate EVA tools and hardware for end-to-end science core sample acquisition
- Iterate core bit technology developed by Honeybee Robotics
- Evaluate curation system capabilities
- Look for ways to compensate for the limited down-force that crew is able to put into a sampling operation due to lower gravity levels
- Answer what efficiencies are gained/lost with having 2 crew work together to sample compared to 1 crewmember separately.

MODULAR EQUIPMENT TRANSPORTATION SYSTEM (METS)

- Evolve and test the Modular Equipment Transport System (METS), a concept for manually transporting & stowing equipment and samples on exploration traverses
- Examine improvements to the Wheeled Equipment Transport (WET; i.e. cart)
- Refine the Suit-Mounted Equipment Carrying System (SECSy) to more effectively transport smaller tools

ASTROBIOLOGY SAMPLE AQUISITION



- IHMC and Harbor Branch Oceanographic Institute objective to evaluate sampling tool
- Include in EVA ops con to evaluate tools and techniques for collecting astrobiology samples during an EVA

ESA EAC EQUIPMENT

- Integrate and evaluate Lunar Evacuation System Assembly (LESA 2.0), ESA's next version of their crew rescue concept
- Integrate and evaluate various ESA geological sampling tools, including scoops and sample markers

EVA Science Sample Acquisition Tools

Objective

- Evaluate EVA hardware and operations for subsurface (core) and regolith science sampling in a surface/partial-g environment
- Determine the feasibility for novel sampling science operations techniques including (1) scouting, (2) "sterile" sample collection, and (3) real-time sample preservation by the NEEMO crew
- Gap addressed: EVA-GAP-45 "Tools for Science Sampling on Surface EVAs"

Implementation

- Apply a breakaway core bit technology developed by Honeybee Robotics with an underwater battery powered drill to acquire core samples
- Use small tools, such as forceps, to stow samples for curation

Mission Summary

- The rotary percussive handheld drill coupled with the Honeybee core bit worked well to retrieve sponge samples

Crew Debrief Comments

- Didn't feel like they had to put in a lot of force when using the rotary percussive drill

EVA Results (Key Take-Aways)

- A rotary percussive power tool alleviates some of the issues with being able to apply the input force needed to acquire a core sample

Recommendations

- Pursue an EVA multiuse rotary percussive handheld power tool for use on planetary surfaces

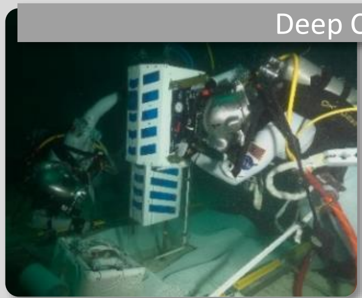
Lunar 2024 Relevance

- The Honeybee breakoff core technology can and should be utilized for taking core samples of rock on the moon
- A rotary percussive handheld power tool will enable core sample acquisition for 2024 and subsequent lunar surface missions
- Evaluation of the tools and techniques at NEEMO and other analogs directly lead to development of the proper equipment for planetary surface EVA operations

Core Sample Acquisition Tool Evolution

SEATEST 2

Deep Core Drill



NEEMO 18

NEEMO 19

NEEMO 20

NEEMO 21

NEEMO 22

NEEMO 23

Astrobiology Sample Collection

Objective

- Demonstrate the feasibility of collection of a diversity of targets using a new small volume sampler— the "Stinger"

Implementation

- Utilized the Stinger developed by IHMC and FAU

Mission Summary

- Stinger was successfully utilized for taking multiple small volume sponge samples

Crew Debrief Comments

- Mechanism worked
- Got good info for improvement
- Preservation worked well

EVA Results (Key Take-Aways)

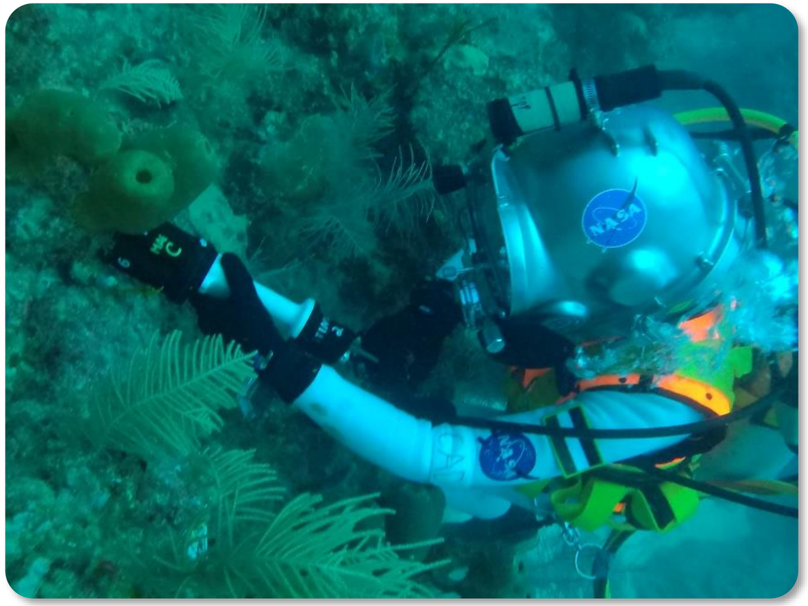
- A tool that enables acquisition of multiple small samples may benefit any mission in terms of providing a lower mass solution for a science tool

Recommendations

- Develop and evolve small sample of devices that would help reduce overall system mass

Lunar 2024 Relevance

- Mission may benefit from a small volume core sample acquisition tool in order to return a larger number of smaller samples
- Evaluation of the tools and techniques at NEEMO and other analogs directly lead to development of the proper equipment for planetary surface EVA operations



ESA Geological Sampling Tools & Equipment Transportation

Objective

- Integrate and evaluate various ESA EAC geological sampling tools, including scoops and sample markers
- Gap addressed: EVA-GAP-45 “Tools for Science Sampling on Surface EVAs”

Implementation

- ESA NEST (Nearby Equipment Support Trolley)

Mission Summary

- Astronauts tested the geological sampling tools and NEST during task-specific evaluations

Crew Debrief Comments

- Add capability for opening the grabber on the jaws for easier dumping of samples into bags
- Likely not worth having a window – know you picked it up because it’s no longer there, and challenging to do any big picture observations through a window
- Hook is good for contingency, but not as a nominal use
- Have markers connected to each other for easier handling of one larger item

EVA Results (Key Take-Aways)

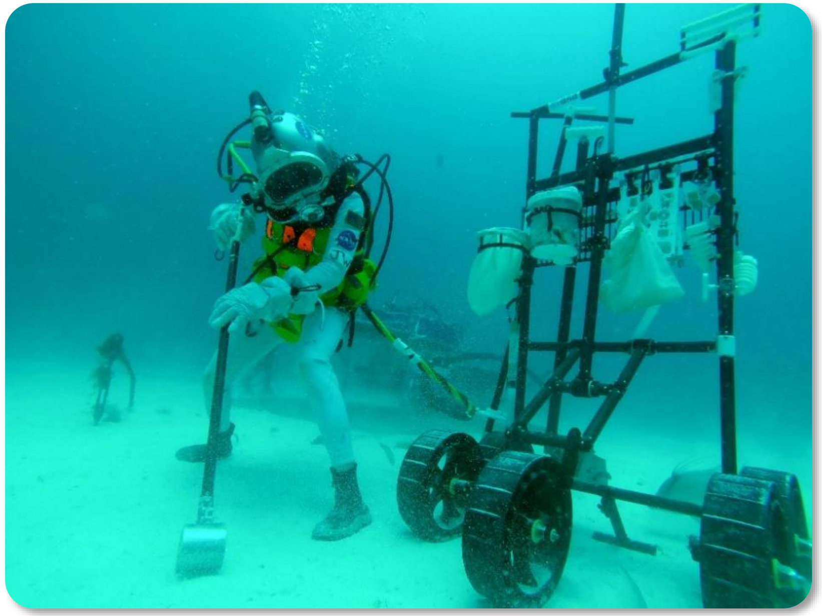
- The sampling tools, based on Apollo heritage equipment, work well for acquiring science samples
- The tools transport device (NEST) demonstrated that an intelligently designed system will allow for multiple tools to be moved on a planetary surface in an efficient manner

Recommendations

- Continue evolving EVA equipment transport systems to find the most compact and low mass possible that still serves the mission science goals

Lunar 2024 Relevance

- All planetary surface missions, beginning with the first Aretmis mission in 2024, will need an effective equipment transport system
- Results from these evaluations at NEEMO will directly feed into design decisions for the Artemis Lunar Tool carrier



Modular Equipment Transport System (METS)

Objective

- Evaluate Modular Equipment Transport System (METS) for manually transporting/stowing tools and samples on exploration traverses
  - Evaluate the Wheeled Equipment Transport (WET) for transport of large equipment in a mobile carrier
  - Evaluate the Suit-mounted Equipment Carrying System (SECS) for transport of small tools on an EVA spacesuit
- Gap addressed: EVA-GAP-43 "Tool Transport on Surface EVAs"

Implementation

- The Modular Equipment Transport System (METS) is a method for transporting equipment from one location to another, grouping hardware into Modules for the appropriate planned activities
  - WET – configurable wheeled carrier, with attachments for modules and science instruments
  - SECS – a forearm stowage device and thigh module attached to the suit after egress

Mission Summary

- The METS worked as designed to provide a method for transporting the equipment necessary to complete the EVA and Science objectives.

Crew Debrief Comments

- Wheeled Equipment Transport
  - A small deployable workstation/foldable table would be helpful that could be set up away from the METS
- Suit-mounted Equipment Carrying System
  - Make deployment quicker
  - Add a Swiss army knife type device
  - SABRE was actually nice, everything was accessible and quick

EVA Results (Key Take-Aways)

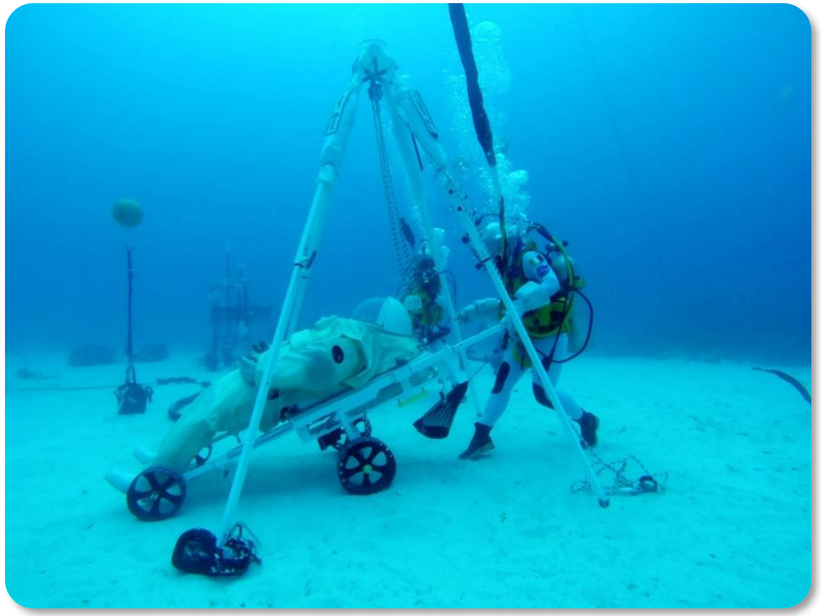
- Having equipment grouped intelligently into modules can be useful when there is a lot of equipment, but it is also constraining and requires accounting for every piece of equipment

Recommendations

- Develop the lunar surface tools set with the modular concept that will allow for use over multiple missions and for multiple tasks

Lunar 2024 Relevance

- The results from these evaluations at NEEMO will directly feed into design decisions for the Artemis Lunar Tool carrier



Objective

- Evaluate a new EVA incapacitated crewmember rescue concept developed by ESA at the European Astronaut Centre
- Gap addressed: EVA-GAP-46 "Incapacitated Crewmember Operations"

Implementation

- Utilized the new concept Lunar Evacuation Systems Assembly (LESA)
- LESA allows an incapacitated crewmember to be lifted up and secured to a Moon EVA Litter for transport back to a habitat/rover

Mission Summary

- LESA was used to successfully demonstrate rescue of an EVA incapacitated crewmember

Crew Debrief Comments

- The more it's self-deployable the better
- Could be a single use device
- Possibly combine with NEST (or some other tool carrier)

EVA Results (Key Take-Aways)

- A rescue device will be critical for all planetary surface missions
- LESA demonstrated a critical capability, but the challenge now will be to make the system smaller
- Combining rescue capability with other equipment (such as tool transport) will be a critical efficiency

Recommendations

- Continue developing and testing an EVA rescue system
- Combine the rescue capability with other nominal use equipment (such as tool transport system)

Lunar 2024 Relevance

- All planetary surface missions, starting with 2024, will need some sort of device to assist an EVA crewmember in rescuing an incapacitated suited crewmember and getting that crewmember back to a safe haven
- Evaluation of the techniques at NEEMO and other analogs directly lead to development of the proper tools and equipment for planetary surface EVA operations

#5: Core Sample Acquisition System		
Completed	**Partially Completed**	**Not Completed**
Evaluate EVA hardware and operations for subsurface (core) and regolith science sampling in a surface/partial-g environment	Evaluate EVA tools and hardware for end-to-end science core sample acquisition	Answer what efficiencies are gained/lost with having 2 crew work together to sample compared to 1 crewmember separately.
Look for ways to compensate for the limited down-force that crew is able to put into a sampling operation due to lower gravity levels	Iterate core bit technology developed by Honeybee Robotics	Evaluate curation system capabilities

#6: Modular Equipment Transportation System (METS)		
Completed	**Partially Completed**	**Not Completed**
Evolve and evaluate the Modular Equipment Transport System (METS), a concept for manually transporting & stowing equipment and samples on exploration traverses		
Examine improvements to the Wheeled Equipment Transport (WET; i.e. cart) for transport of large equipment in a mobile carrier		
Refine and evaluate the Suit-Mounted Equipment Carrying System (SECS) to more effectively transport smaller tools on an EVA spacesuit		

MOR Objectives Completion Status for xEVA Tools & Equipment

#7: Lunar Evacuation System Assembly (LESA)		
Completed	Partially Completed	Not Completed
Evaluate a new EVA incapacitated crewmember rescue concept developed by ESA at the European Astronaut Centre		

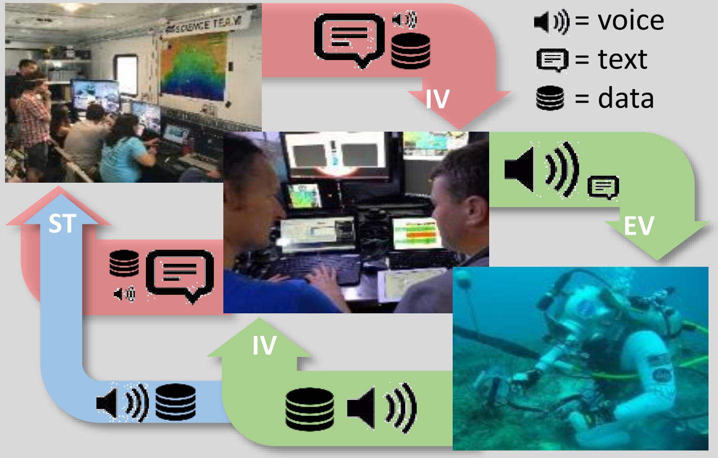
#8: ESA Geology Sampling Tools		
Completed	Partially Completed	Not Completed
Integrate and evaluate various ESA EAC geological sampling tools, including scoops and sample markers		

#13: Science Sampling Tools		
Completed	Partially Completed	Not Completed
Evaluate small volume sampler (Stinger)		
Evaluate CISME for characterizing local area (corals and other organisms)		

#17: Suit Mounted Tool Harness [Iowa State University]		
Completed	Partially Completed	Not Completed
Evaluate a new suit mounted tool harness for carrying small tools on an EVA spacesuit		

EVA CONCEPTS OF OPERATIONS @ NEEMO 23

INTEGRATED EVA SCIENCE OPS



- Evaluate Exploration EVA operations that predominately include science tasks
- Assess lunar-focused science-driven EVA operations with an MCC-based ST providing direction
- Examine con ops with interaction between the MCC ST & the crew over lunar (real-time) comm and with signal outages (scheduled LOS and terrain shadows)
- Assess con ops with MCC/ST generating data (graphics) real-time and sending to IV, and IV sending that data to EV crew's HUD
- Compare a crew IV vs ground IV for science operations

FLEXECUTION DURING EVA

- Appraise a flexecution methodology while utilizing a Science Team and authentic proxy science
- Assess capability for real-time alteration of science-driven EVA timeline

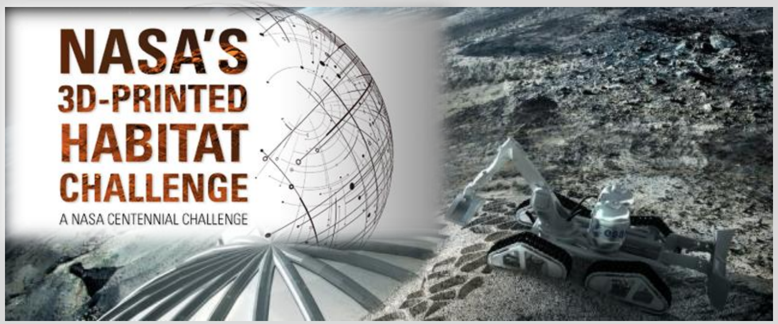
EVA OPS W/ SCIENCE INSTRUMENTS

- Evaluate scenarios for operating on the lunar surface utilizing science instruments and tools

INTEGRATING INFORMATICS FOR EVA

- Evaluate use of advanced informatics concepts during an EVA
- Assess utilizing an area scanning system with data sent to EVA crew for self-navigation

PIONEERING



- Investigate the feasibility of a Critical Contingency EVA Habitat Tile Remove & Replace of a 3D-Printed ISRU Lunar Habitat

Objective

- Analyze integrated EVA science operations to determine what functions/capabilities are needed to enable a Mission Control Center (MCC) and integrated Science Team to effectively operate and actively direct EVA operations with science tasks over a lunar signal (comm & data) latency and blockage
- Evaluate flexible execution methodology and decision making protocols for science tasks during EVA operations

Implementation

- An onshore MCC Flight Control Team (FCT) that includes a Mission Director, EVA Officer, CAPCOM, and other system/subject matter experts
- An onshore Science Team that includes a Science Lead, subject matter experts, and Science Communicator (SCICOM)
- Mission (flight) rules volume and mission priorities, heightened mission tempo and pressure with additional flight control rigor, spacesuit telemetry, FCT GO/NO GO calls, and IVA task/experiment timeline

Mission Summary

- This mission was designed perfectly to assess this objective and is the only testing environment at this time that allows for the evaluation of this objective.

Crew Debrief Comments

- Used combination of voice and mission log
- Voice is better for time sensitive
- Mission Log was helpful for lists
- Mission log was helpful for comm split – SCICOM on science and CAPCOM on pioneering
- Mission log was helpful to keep track of what crew completed during LOS

EVA Results (Key Take-Aways)

- Working in this new paradigm will require a shift in how EVA operations are managed in MCC
- There is still a lot of work to do to figure out the proper roles and responsibilities and communication protocol

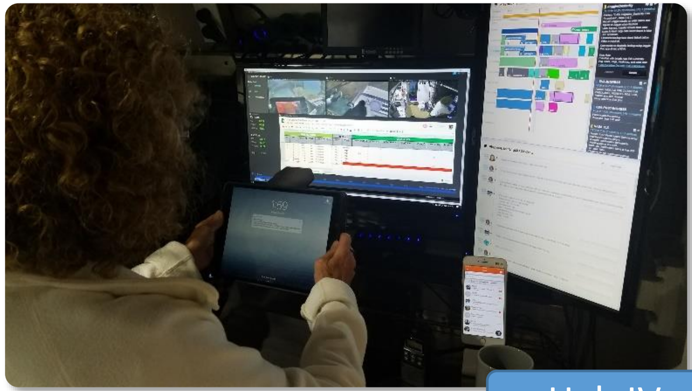
Recommendations

- Continue evaluating the mission control structure for science-driven EVAs at NEEMO and bring the FOD community into the loop
- Utilize the FOD wiki platform to test the capability of Just In Time Training (JITT) to improve efficiency during upcoming EVA operations
- Add EVA gaps for Integrated EVA Flight Control Methodology and for Flexible Execution Methodology for EVA Science Operations in Undefined Environments

Lunar 2024 Relevance

- All planetary surface missions, beginning with Artemis's 2024 flight, will require a paradigm shift from the current flight control method
- Incorporating a Science Team into the Flight Control Team will be critical for successful science return
- Concepts being evaluated for integrating a Science Team with the MCC team at NEEMO will directly benefit the 2024 mission and all flights beyond

Mission Control



Hab IV

Science Team

Objective

- Evaluation scenarios for operating on the lunar surface utilizing science instruments and tools
- Evaluate CISME for characterizing local area (corals and other organisms)
- Gap addressed: EVA-GAP-137 "In-Situ Tools"

Implementation

- Coral In Situ Metabolism (CISME) experiment deployment techniques and time constraints are analogous to high priority geologic instruments (XRF, XRD, LIBS, etc.)

Mission Summary

- Complications with the CISME units led to delay of the ops until well into the mission
- Crew successfully deployed and used the CISME instruments to analyze sponges in the local area

Crew Debrief Comments

- Helped to have a 2nd person as an extra set of hands
- Efficient on MD08 when both working on separate CISME simultaneously
- By day 15, would be more proficient at doing it separately
- Trouble shooting was helped by having a 2nd person
- CISME was a good analog for portable field instruments, though maybe a bit larger, good in terms of flexibility

EVA Results (Key Take-Aways)

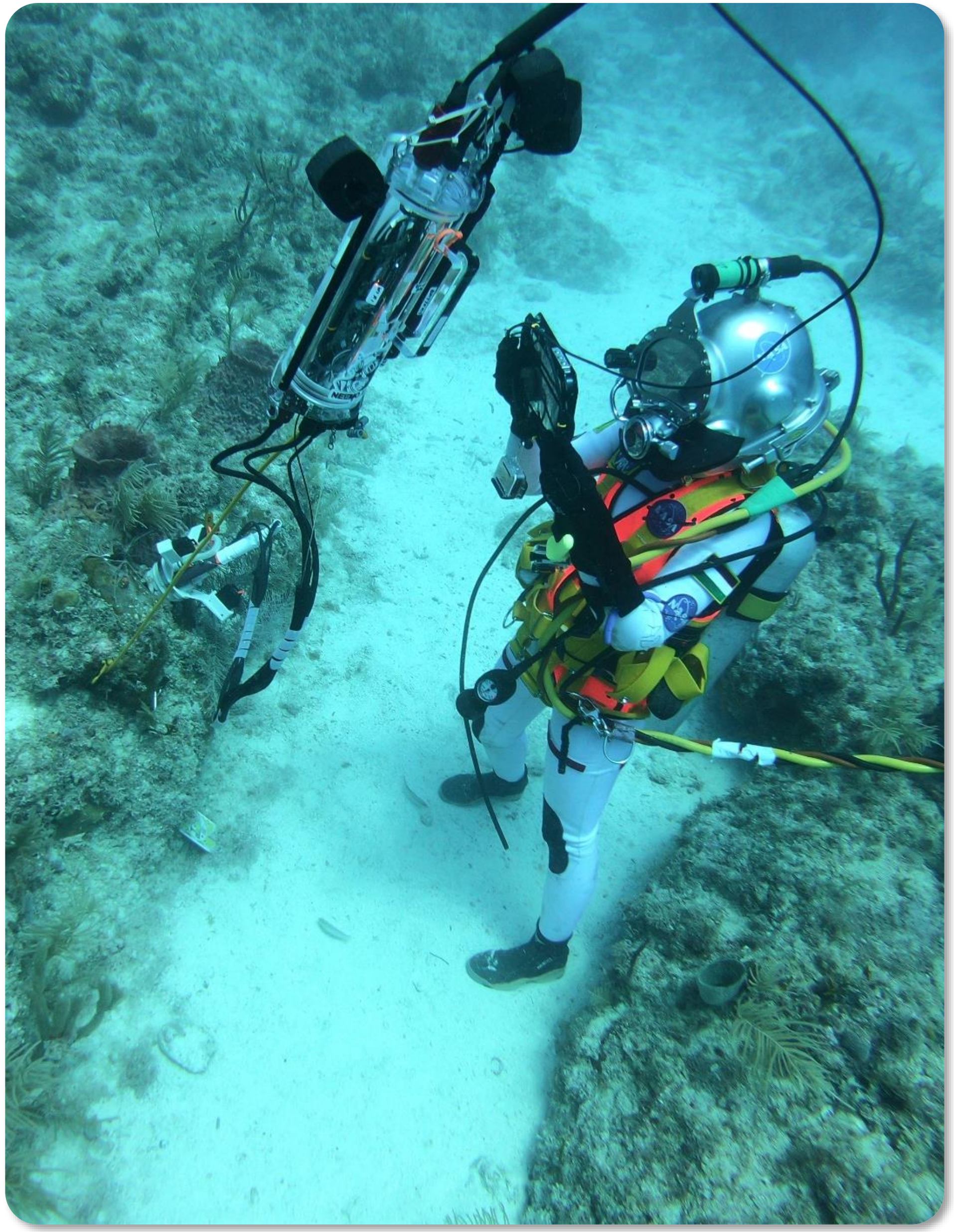
- Handheld science instruments for planetary missions should be easily operable my a single EVA crewmember

Recommendations

- Look for geology relevant tools that will provide for a higher simulation quality

Lunar 2024 Relevance

- The Artemis 2024 mission may include science instruments that will be deployed during surface EVA operations
- Evaluation of the techniques at NEEMO and other analogs directly lead to development of the proper tools and equipment for planetary surface EVA operations



Pioneering Tasks on Planetary Surface

Objective

- Evaluate pioneering/construction tasks on a planetary mission

Implementation

- Build a new coral nursery tree structure on the bow end of the hab
- Rebuild the Mercury Nursery
- Utilize the "EVA 3DP-HAB Repair" initiative as a feasibility study to evaluate the potential associated tools, methods, and concept of operations required for a Critical Contingency Extravehicular Activity (CCE) Repair of a 3D-Printed In-Situ Resource Utilization (ISRU) Lunar and Martian Habitat

Mission Summary

- Crew successfully installed the coral card arms on both the Bow and Mercury coral tree nurseries
- Crew completed a tile repair on the lunar 3D-printed sample

Crew Debrief Comments

- None directed at pioneering tasks

EVA Results (Key Take-Aways)

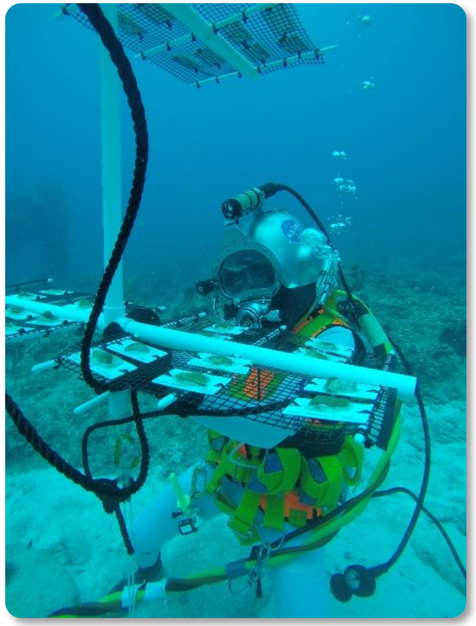
- Transport of all of the necessary parts for pioneering tasks may be challenging on a planetary surface

Recommendations

- Expand evaluations of various pioneering tasks at NEEMO and other analogs in order to drive out the detailed challenges with conducting engineering tasks in partial-gravity on a planetary surface

Lunar 2024 Relevance

- The Artemis 2024 mission and all planetary surface missions beyond will likely involved a multitude of different types of pioneering/engineering tasks
- Pioneering tasks will be critical for long term infrastructure development on the moon
- Evaluations at NEEMO and other analogs will be critical for effectively designing the tools and equipment needed for pioneering tasks



MOR OBJECTIVES COMPLETION STATUS FOR xEVA CONCEPT OF OPERATIONS

#9: Integrated Mission Control Operations for Exploration		
Completed	**Partially Completed**	**Not Completed**
Analyze integrated EVA science operations to determine what functions/capabilities are needed to enable a Mission Control Center (MCC) and integrated Science Team to effectively operate and actively direct EVA operations with science tasks over a lunar signal (comm & data) latency and blockage	Assess lunar-focused science-driven EVA operations with an MCC-based Science Team (ST) providing direction	Assess con ops with MCC/ST generating data (graphics) real-time and sending to IV, and IV sending that data to EV crew's HUD
Evaluate flexible execution methodology and decision making protocols for science tasks during EVA operations		Compare a crew IV (in hab) vs ground IV for science operations
Evaluate Exploration EVA operations that predominately include science tasks		
Examine con ops with interaction between the MCC ST & the crew over • Lunar comm latency • Signal outages (scheduled LOS)		

#10: Integrating informatics during EVA		
Completed	**Partially Completed**	**Not Completed**
	IV/MCC tracking of EVA crew	Evaluate use of advanced informatics concepts during an EVA
		Assess utilizing an area scanning system with data sent to EVA crew for self-navigation

MOR Objectives Completion Status for xEVA Concept of Operations

#11: Flexible Execution Methodology (Flexecution)		
Completed	**Partially Completed**	**Not Completed**
Appraise a flexecution methodology while utilizing a Science Team and authentic proxy science		

#12: Exploration science		
Completed	**Partially Completed**	**Not Completed**
Identify, image, and measure corals with CISME in order to characterize the area	Sponge samples (30-40) to map Gulf – area around hab is a gap in their data	Identify, sample, and image a precursor sample with multiplex Stinger
Assess real-time feedback from a ST		Test precursor sample DNA inside the habitat
		Follow-up sample on a later EVA based on DNA results

#14: Science instruments		
Completed	**Partially Completed**	**Not Completed**
Evaluation scenarios for operating on the lunar surface utilizing science instruments and tools		Assess strategies for gaining efficiencies

#15: Coral Restoration (Nursery Pioneering): Coral Nurseries rebuild		
Completed	**Partially Completed**	**Not Completed**
Build a new hab-mounted coral nursery tree		
Rebuild the Mercury (shallow) nursery		

Extravehicular Activity and Science Operations, from Sea to Space

Summary of NEEMO 23

- **Provided initial look at a HUD system in a dive helmet for xEVA informatics capability development**
- **Navy received good feedback for improving and hardening the DAVD system for production and deployment to fleet divers**
- **Allowed for crew evaluation of EVA science sampling tools and transportation systems**
- **Assessed a concept for rescuing an incapacitated crewmember on lunar surface missions**
- **Evaluated aspects of integrated flight operations for a lunar surface mission that incorporates direct input from a Science Team**

Relevance to the Artemis Lunar 2024 mission

- **Evaluated initial surface EVA concepts of operations for Artemis**
- **Assessed system and architectural interactions for EVA science operations in a natural surface environment**
- **Informed updates to the lunar surface section of EVA-EXP-0042, the *Exploration EVA System Concept of Operations* document that describes the operations required for the 2024 mission**
- **Enabled design maturation of EVA equipment that will be utilized on lunar surface missions**
- **Evaluation of the tools, techniques, and technologies at NEEMO (and other analogs) will directly lead to development of the proper methods and equipment for planetary surface EVA operations**

Recommendations for Testing at NEEMO

- Execute a smaller-scale efficient mission that's focused on the tools, techniques, and technologies needed for EVA and Science Operations on the Artemis Lunar 2024 mission and beyond
    - Focus on science-driven EVA concepts of operations development for a planetary surface, including science sample acquisition
    - Target NASA-relevant objectives with less (or no) external PI objectives
    - Conduct true end-to-end EVA operations, with full deploy and stow of equipment and samples
    - Evaluate the current EVA lunar tools suite
- Evaluate the improved DAVD system as an xEVA HUD concept
- Evaluate the communication and decision making protocols for incorporating near real-time feedback and direction from a Science Team
    - Incorporate FOD for MCC operations and development of flight control techniques
- Incorporate HHP evaluations being done for Exploration EVA
- Perform initial checks of equipment, tasks, and possibly even train crew in the NBL before the mission
    - Utilize the 2+ hour of tightly controlled tests at the NBL to directly lead into end-to-end NEEMO missions that mimic Artemis missions

Outline of Potential NEEMO 24 Mission Plan

- **NBL: Testing of initial concepts and equipment**
  - **Properly dial-in lunar weigh outs, using lunar-like boots and a PLSS volume**
  - **Utilize for EVA tool testing, initial procedure development, initial training, etc.**
  - **Conduct HUD testing and initial equipment verification**
- **ESAT: Testing of equipment for mission and initial SME evaluations of concepts**
  - **Conduct an ESAT run with SMEs well in advance of the mission in order to allow for time to modify equipment and develop procedures**
  - **Establish and verify comm link from EVA crew to MCC/ST**
  - **Set up sampling tool test area and tasks, and conduct initial evaluations**
  - **Verify functionality of DAVD, and conduct initial evaluations**
  - **Finalize and verify EVA procedures**
- **NEEMO 24 mission outline:**
  - **Run a ~7-day mission that mimics the current plan for the Artemis 2024 mission**
  - **Execute mission evaluations of tests initially performed in the NBL**
  - **Crew the mission with 1-3 SMEs and 1-2 astronauts that understand the NASA needs for EVA & Science during surface ops**
  - **Minimize IVA experiments to allow for the proper planning and prep tempo of daily EVAs on the lunar surface**
  - **Use the habitat as a lander to evaluate tasks such as egress and descent to the surface via a ladder**

Thank you!

Questions?

- Additional Objectives & Results Info
- EVA Science Operations
- Minimum Requirements for Success Completion Status
- Review of NEEMO as an Analog for EVA
- Overview of a NEEMO EVA
- Engineering Saturation Run (ESAT)
- Support Dive Operations & Dive Safety
- Other EVA-Related Information
- History of NEEMO Crew

Additional Objectives & Results Info

EVA Informatics

EVA Tools & Equipment

EVA Concepts of Operations

Mission Overview

NEEMO 23 will test a combination of Exploration EVA and ISS/Orion related objectives. On the EVA side, there will be a highly integrated EVA Operations and Science Team comprised of members with expertise in EVA strategic planning and architecture integration, astromaterials and science operations, marine science, and coral restoration. Specifically we will be conducting Lunar-relevant EVAs. Authentic marine science will be conducted, under the guidance of Florida Atlantic University-Harbor Branch, as a proxy for the planetary science concepts and strategies we envision for future human surface operations. Once again, we will be teaming up with the Coral Restoration Foundation (CRF) and Florida International University (FIU) to help set up and monitor deep long-term coral nurseries at Aquarius Reef Base, which supports on-going research and restoration efforts. A system for rescuing an incapacitated crewmember on the lunar surface which is sponsored by ESA will also be evaluated. On the ISS/Orion side are a number of objectives supporting use of a scanning electron microscope, Counter Measures equipment, autonomous reality (AR) procedure execution, evaluation of concepts and technologies to improve efficiency and reduce the footprint of an IV workstation, a technology for very precise tracking of people and devices onboard a habitat, and studies related to physiological response to oxidative stress. In addition to numerous participating organizations across NASA JSC, collaborators include

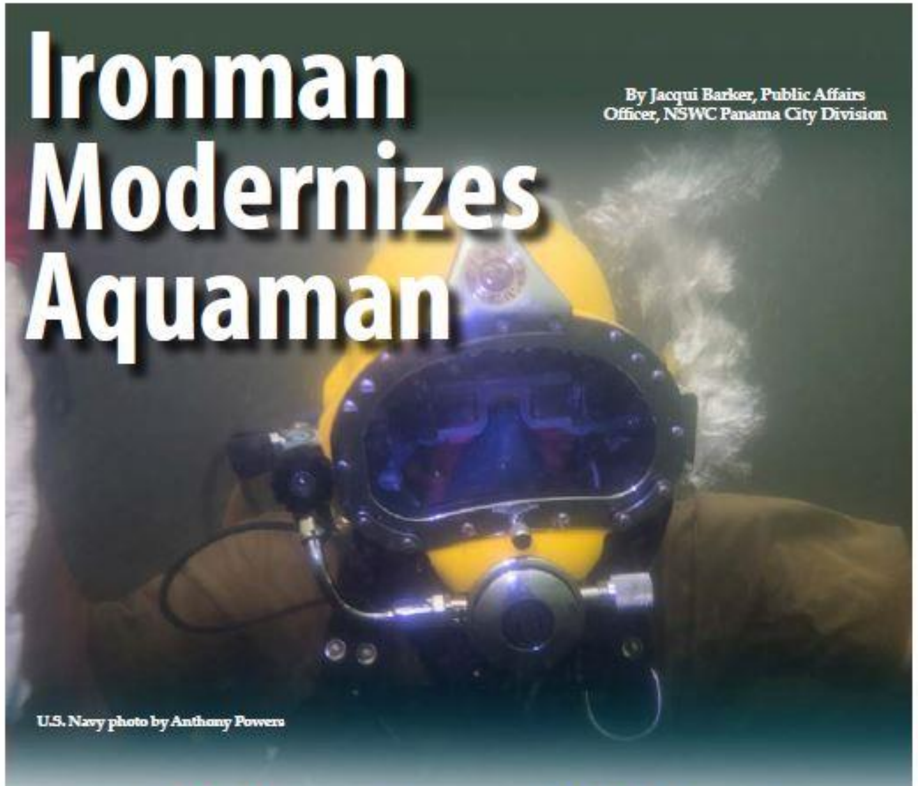
- NASA ARC, KSC, GSFC, and JPL;
- International Partner Agencies: ESA
- Research Institutions: Institute for Human and Machine Cognition, Coral Restoration Foundation;
- Department of Defense: Naval Sea Systems Command (NAVSEA), Office of Naval Research, Naval Experimental Dive Unit, Panama City;
- Universities: Florida International University (FIU), University of South Florida (USF), Florida Atlantic University (FAU)
- Industry Partners: Draper, AllTraq, Aexa Aerospace, Honeybee Robotics, Shark Marine
- Non-Profit Partners: Coral Restoration Foundation

An EVA Augmented Vision Heads-Up Display (AVHUD) would allow for real-time data update (pushed by MCC and/or hab IV), augmented cue input, procedure viewing, enhanced task direction, and self-navigation capability. This type of system would enable Exploration mission concepts of operations baselined by the EVA Office (ref. EVA-EXP-0042, Exploration EVA System Concept of Operations), especially those on natural planetary surfaces. An EVA AVHUD is also relevant for current spacesuit (xEMU) development efforts and the xINFO system. The U.S. Navy's Divers Augmented Vision Display (DAVD), developed by Naval Sea Systems Command (NAVSEA) and Naval Surface Warfare Center (NSWC) Panama City, will be tested as an AVHUD concept. It utilizes binocular lenses that allow for viewing a multitude of data types, incorporates real-time instrumentation feed (e.g., sonar), and allows for augmented reality input in a heads-up display. The DAVD system uses a sector and 3D sonar real-time feed to allow for diver self-navigation.

Evaluation of the DAVD system during the mission will double as an operational assessment on the performance of the DAVD prototype for the U.S. Navy. This provides a unique opportunity in the design process, and will be part of developing the system for their fleet divers. NAVSEA will also benefit from the mission by obtaining data for additional goals, including operational utilization of the Kongsberg MS-1000, operation of the CODA Echoscope C-500, and development of 3D underwater models and maps.

Ironman Modernizes Aquaman

By Jacqui Barker, Public Affairs Officer, NSWC Panama City Division



U.S. Navy photo by Anthony Powers

DAVD Proves Successful HVL Event, Surpasses Phase II Testing

PANAMA CITY, Florida - Ironman is one step closer to modernizing Aquaman, at least for the U.S. Navy's Fleet.

Naval Surface Warfare Center Panama City Division's Diver Augmented Vision Display (DAVD) project team successfully surpassed all expectations at the first in-water testing Oct. 10-13, 2017.

Sponsored by Naval Sea Systems Command Supervisor, Diving and Salvage (NAVSEA 00C), Panama City's project team was elated to see how well the DAVD prototype performed in the intended environment.

The DAVD is a binocular head-up display (HUD) that is mounted inside the Kirby Morgan 37 (KM-37) dive helmet and the MK-20 Full Face Mask (MK-20 FFM). The prototype uses commercial see-through lenses and custom 3D printed frame systems for the helmet and facemask versions.

Dive supervisors relay high-resolution visual mission data to the HUD via an Ethernet cable married to the diver's primary umbilical. Divers can clearly view text messages, video, photographs, instructions, and augmented reality images even in murky, zero visibility conditions. They can also see their real-time location during the dive mission via scanning sonar imagery, just like a virtual reality video game.

> "The break-through head-up display technology can be used for other types of work conducted in low or zero visibility conditions… even in outer space."
>
> *- Dennis Gallagher, DAVD Project Manager*

"We learned a lot about how the system can be used effectively by our divers conducting real missions. Overall, our test objectives were met, and now were are focused on Phase III development," said DAVD Project Manager Dennis Gallagher.

DAVD is one of NSWC Panama City's most recent rapid prototyping and high-velocity learning initiatives. Total concept to test time has been less than two years.

"This is my first life-cycle project," said DAVD mechanical engineer Allie Pilcher. "It feels really good to see our team come so far so fast and for all the right reasons."

The DAVD project and tests were made possible by innovation and collaborative efforts between NSWC PCD and local commands. NSWC PCD welcomed Fleet divers and commanding officers from the Naval Experimental Diving Unit, Naval Diving and Salvage Training Center, and the Center for Explosive Ordnance and Diving to participate in the tests.

"DAVD has multiple applications - military diving, public safety/first responders, science diving, as well as for commercial use," said Gallagher. "The break-through head-up display technology can be used for other types of work conducted in low or zero visibility conditions…even in outer space."

Outer space?

Representatives from the National Aeronautics And Space Administration's (NASA's) Johnson Space Center were on hand to observe the DAVD tests, and are in discussions with NSWC PCD to explore a possible collaborative development for the next-generation Extra Vehicular Activity (EVA) space suit's informatics head-up display capability.

Ironman and Aquaman.
Aquanauts and Astronauts.

The saga continues…

NSWC PCD Commanding Officer Capt. Aaron Peters, USN, dives the DAVD system October 12, 2017.

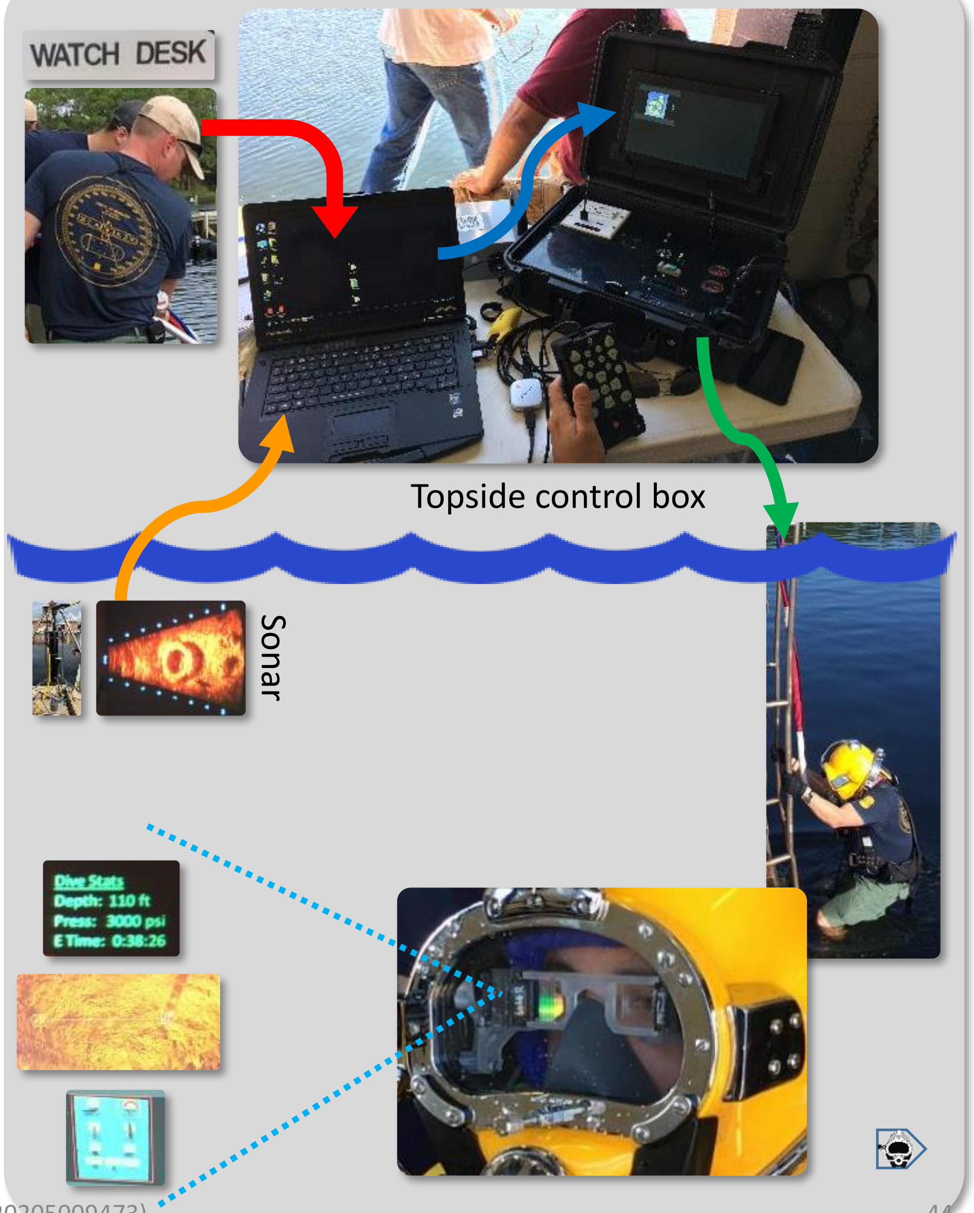
U.S. Navy photos by Ronnie Newsome

U.S. Navy Divers Augmented Vision Display (DAVD)


KM37


MK20 FFM

- Sponsored by Naval Sea Systems Command Supervisor, Diving and Salvage (NAVSEA 00C), and developed by the Naval Surface Warfare Center Panama City Division
- The DAVD system
  - Binocular heads-up display (HUD) mounted inside a Kirby Morgan 37 (KM37) dive helmet and a MK-20 Full Face Mask (MK20 FFM)
  - Prototype uses commercial lenses (Lumus) and custom 3D printed frame/mounting systems
- DAVD capabilities
  - Allows a topside dive supervisor to relay visual mission data to the HUD via an Ethernet cable
  - Divers can view text messages, video, photographs, instructions, and augmented reality images
  - Divers can also utilize real-time sector scanning sonar imagery for navigation
  - Allows for operations even in murky, zero visibility conditions
- During diver testing, DAVD operated as advertised, with Navy divers able to utilize it for navigation, identification of objects, and for receiving task instructions real-time

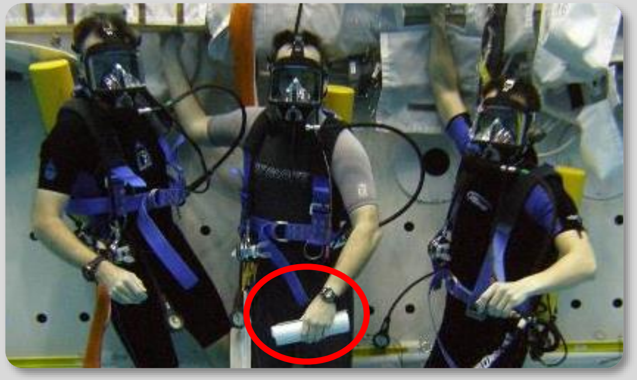


NASA Exploration EVA Spacesuit and Operations

- An EVA Augmented Vision Heads-Up Display (HUD) would allow for real-time data update, augmented cue input, procedure viewing, enhanced task direction, and self-navigation capability
  - Enables Exploration mission concepts of operations baselined by the EVA Office, especially those on natural planetary surfaces
  - Relevant for current spacesuit (xEMU) development efforts and the xINFO system
- DAVD system abilities translate into capabilities needed by NASA for the Exploration EVA Suit and planetary operations

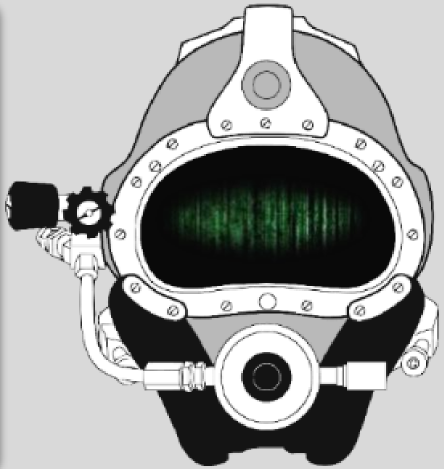
Enhanced ISS EVA Training

Utilize MK20 FFM version of DAVD to view procedures and graphics sent by Test Conductor

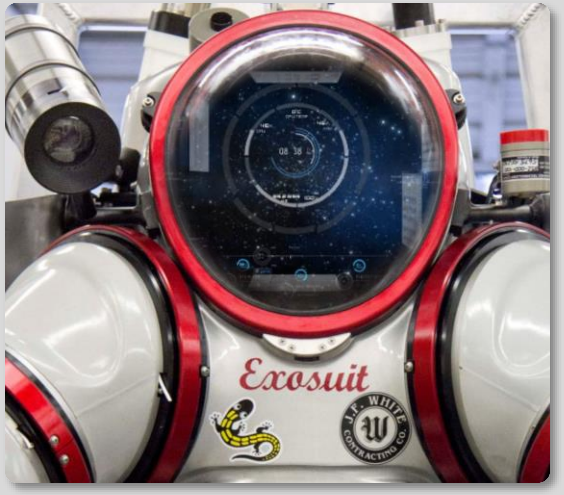


Potential Spacesuit (xEMU) Development

DAVD Mounted Lenses



DAVD Projection System



DAVD System in Suit

xEMU HUD

DAVD Equipment: Diver-worn, Control Box, and Sonar

- DAVD Generation 1 Prototype
  - Lens mounted into KM37 Diver-worn canister for data
- 300’ data umbilical from canister (on diver) to control box (inside hab)

- Control box that takes data from laptop and pushed into lenses
- Display for IV to see what diver sees
- Box will be inside the hab and connected to the IV workstation

- Kongsberg MS1000 Sonar
  - Sonar head on stand
- Interface box (connects to laptop)
- Handheld controller for directing sonar
- 300’ cable from sonar head to interface box (in hab)

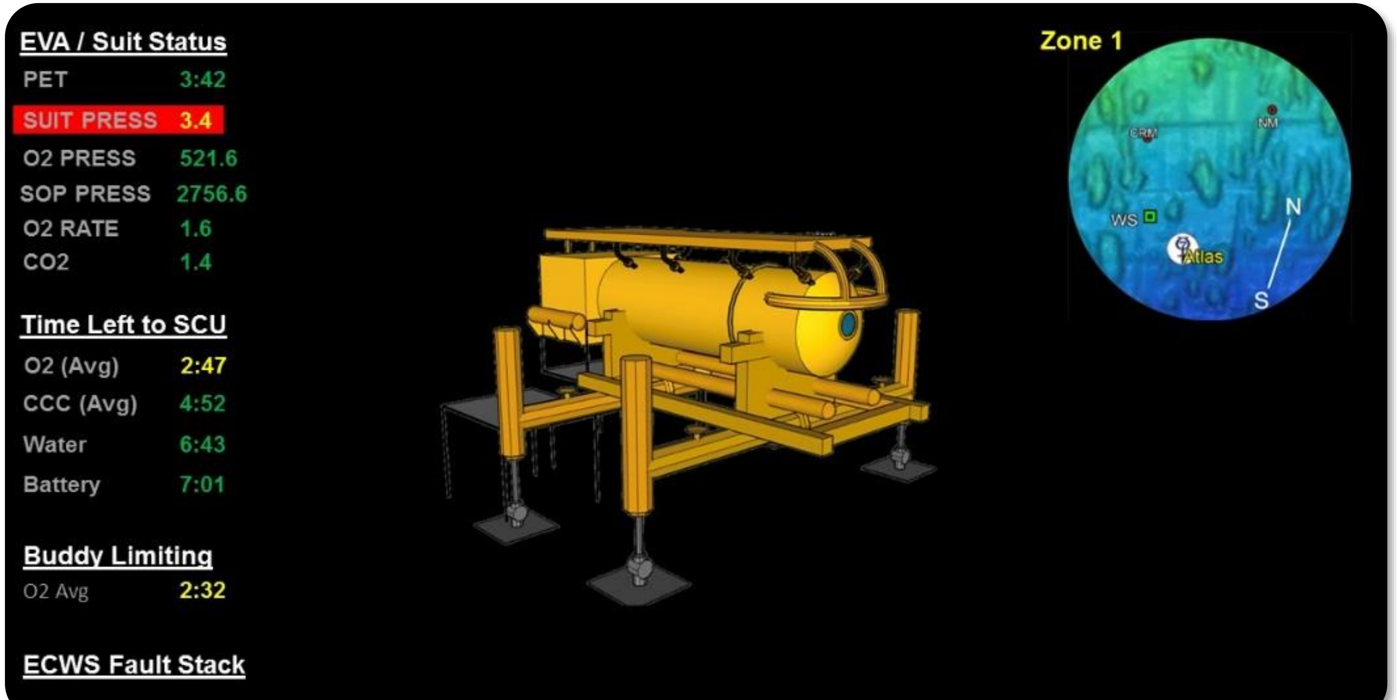
DAVD as an EVA Augmented Vision Heads-Up Display @ NEEMO

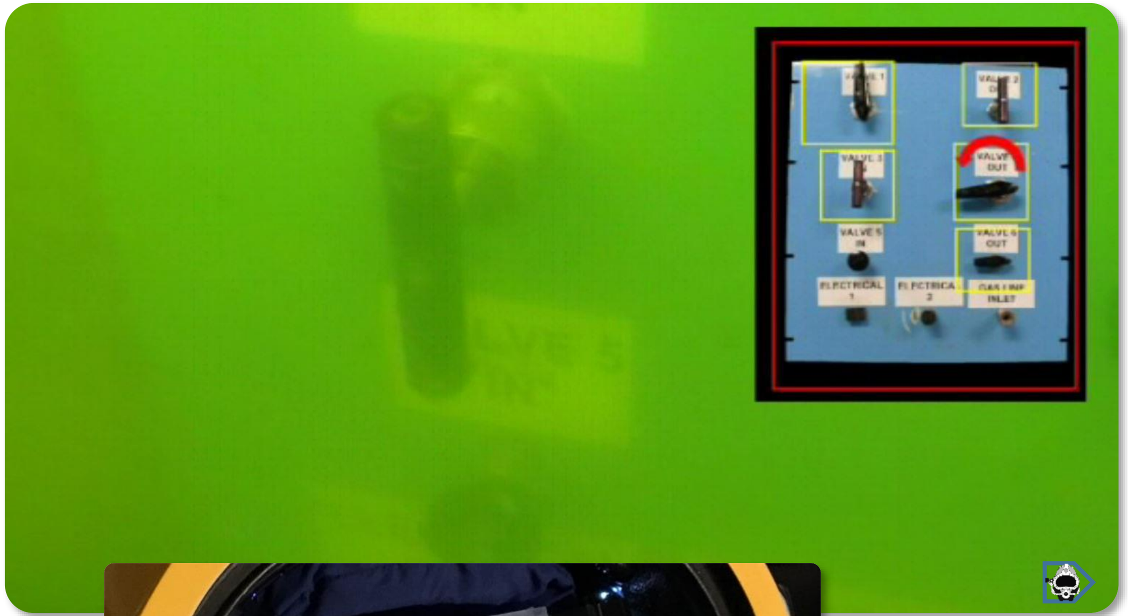
Objective

- Evaluate DAVD as a potential capability concept for an EVA Augmented Vision Heads-Up Display – allowing for real-time data update, augmented cue input, procedure viewing, task direction capability, and navigation – for spacesuit (xEMU) development

Implementation

- Utilize DAVD mounted inside a KM37 dive helmet
- Send real-time data to the EVA crewmember from the IV workstation via DAVD for task direction



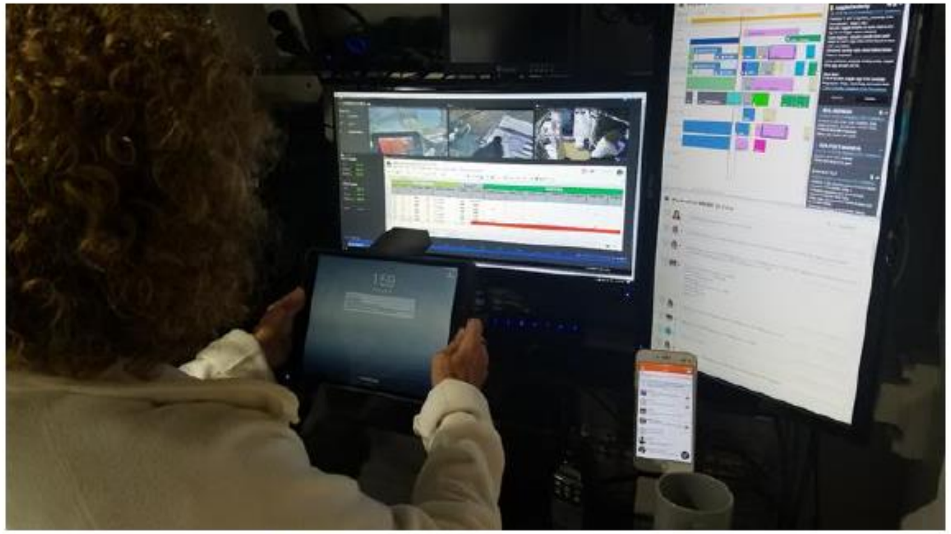


IV Workstation Per the Mission Objective Request for NEEMO 23

The EVA Support System & IV Workstation will utilize a combination of Marvin, Open MCT (Mission Control Technologies), and Playbook. Marvin is an open-source digital timeline execution and life support system management tool designed to support Intravehicular Activity during EVA. It provides synthesized timeline status information in the form of timeline margin which adjusts throughout the execution of the EVA (e.g. how much time beyond the completion of planned timeline tasks can the life support system currently provide), and displays simulated EMU telemetry data. Open MCT is "a next-generation mission control framework for visualization of data on desktop and mobile devices", and it "is being used by NASA for data analysis of spacecraft missions, as well as planning and operation of experimental rover systems". Playbook is a crew planning and timeline tool being developed for use on ISS and future missions.

IV Workstation

The EVA Office will evaluate the role that an intravehicular (IV) support system can play during EVA. The IV workstation and decision support system will utilize existing NASA software, including Playbook and Open MCT, both developed by NASA Ames Research Center. Playbook will support timeline management (both during and outside of EVA), MCC to IV text communication, and EVA informatics management. Open MCT is a general-purpose visualization and layout engine that will be utilized to visualize telemetry, emplace science data entry within the IV workstation, and manage live video feed windows. Lastly, a physical, programmable keypad called an El Gato Stream Deck will be trialed as a workspace configuration tool. Physical keys on the Stream Deck will automatically launch and arrange workstation windows to standardize workspace configurations. The associated IV workstation focuses on examining ways to minimize the amount of equipment and manual effort required for operations, hence reducing space and launch mass needed, while also supporting IV crew member productivity. Lessons learned from using this on NEEMO will feed forward into Gateway requirements.



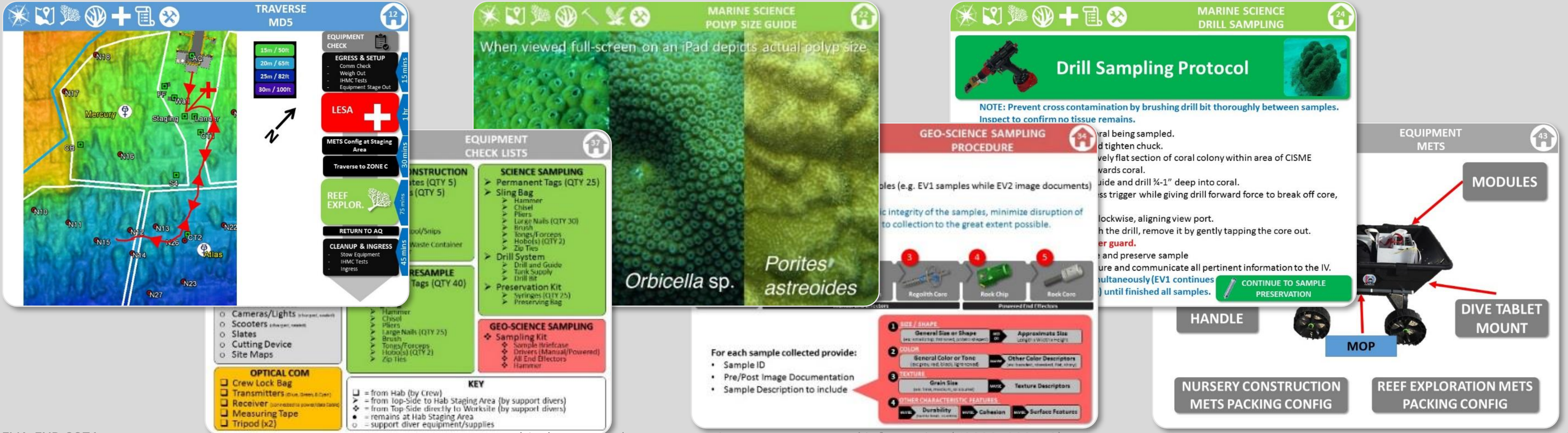
IV Workstation supporting an EVA

Objective

- Evaluate digital cue cards for EVA crew that allow crew to operate more effectively and autonomously while offloading IV tasking

Implementation

- Utilize an iPad in an iDive underwater housing to demonstrate the potential for a single device for cue cards/procedures, images/video, instrument control, etc.
- All EVA-accessed and required information will be put into a digital cue card set that's loaded on the iPad



- What capabilities of an “EVA Augmented Vision Heads-Up Display” (EVA AVHUD) allow for effective and efficient EVA operations at Exploration destinations?
  - Does an EVA AVHUD allow for pertinent real-time data updates, augmented cue input, procedure viewing, and enhanced tasking direction?
  - Does an EVA AVHUD allow for effective self-navigation capability, especially on a natural planetary surface?
  - What aspects and capabilities of an EVA AVHUD are relevant for the xEVA System, including current spacesuit (xEMU) development efforts and the xINFO system?
- What functions/capabilities are needed in an EVA Support System and corresponding IV Workstation that allow an IV to effectively control EVA operations with input from MCC/ST over a signal (comm) latency and/or blockage/outage?
  - How effective was the EVA task/timeline tracking using Marvin/OpenMCT and/or Playbook? What improvements are desired, warranted, or required?
  - How efficient was the science task and sample tracking? What improvements are desired, warranted, or required?
  - Was the IV and MCC able to track the real-time location of the EV crew? What improvements are desired, warranted, or required?
  - Did the support system allow the IV to effectively track EV suit data and consumables? What improvements are desired, warranted, or required?
  - What equipment is needed for an effective workstation?
- Do EVA Digital Cue Cards allow crewmembers to execute more efficient EVA operations? What improvements are desired, warranted, or required?

Other key integrated EVA and science aspects incorporated and evaluated during this NEEMO mission include detailed sampling procedures, effective sampling tools and techniques for biological sampling in a challenging environment, contamination mitigation strategies, storage and transportation of equipment and samples (via the Modular Equipment Transportation System), various traverse planning methods, utilization of hand-held instrumentation, and methods and techniques for operational flexibility.

The use of in situ instrumentation will be evaluated during the NEEMO mission through the use of the CISME instrument (Coral In-Situ Metabolism Experiment). The CISME instrument requires crew time to set up the instrument and then there is a 20 minute instrument integration time where the crew will be hands-off the instrument. After 20 minutes, the crew will return to tear down and move the instrument to a new location. The NEEMO mission will include the use of two CISME instruments so the crew can work more efficiently through their workflow. There will be 1+ EVA where the crew collects only CISME data and then returns to the CISME work area on a subsequent EVA to sample. There will be 1+ EVA where the crew alternates between collecting CISME data and sampling at their discretion. The NEEMO team will thus be able to evaluate workflow efficiencies of using both in situ instrumentation and traditional sampling strategies.

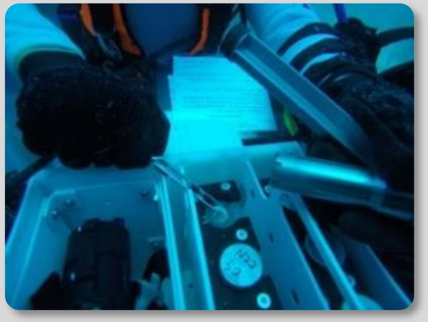
EVA Sample Acquisition Tools

Objective

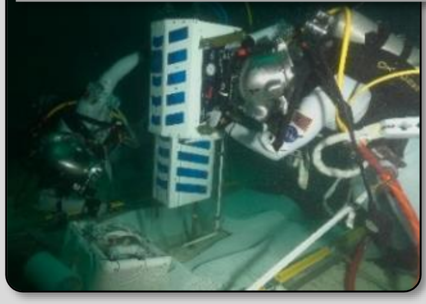
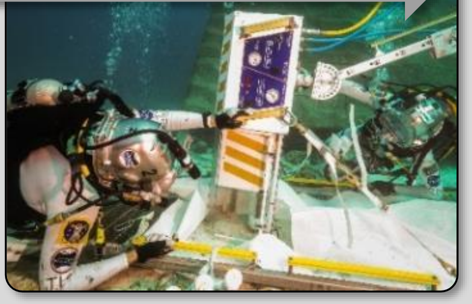
- Evaluate EVA hardware and operations for subsurface (core) and regolith science sampling in a surface/partial-g environment

Implementation

- Apply a breakaway core bit technology developed by Honeybee Robotics with an underwater battery powered drill to acquire core samples
- Use small tools, such as forceps, to stow samples for curation


Core Sample Acquisition Tool Evolution

Deep Core Drill

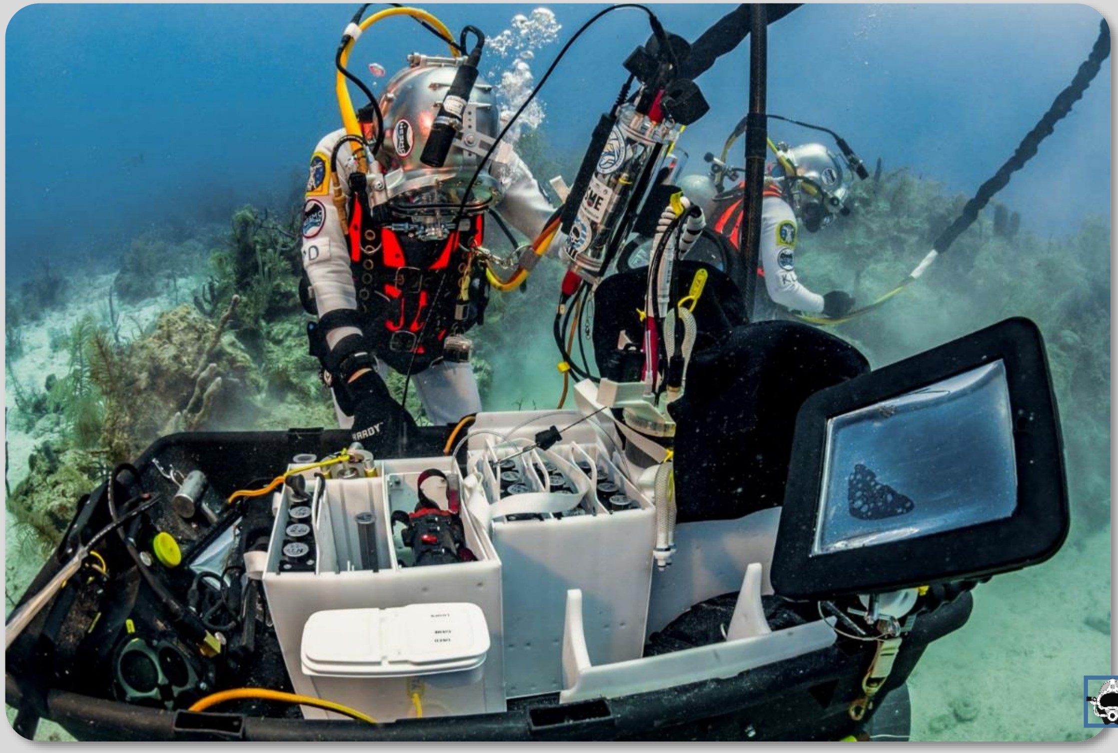


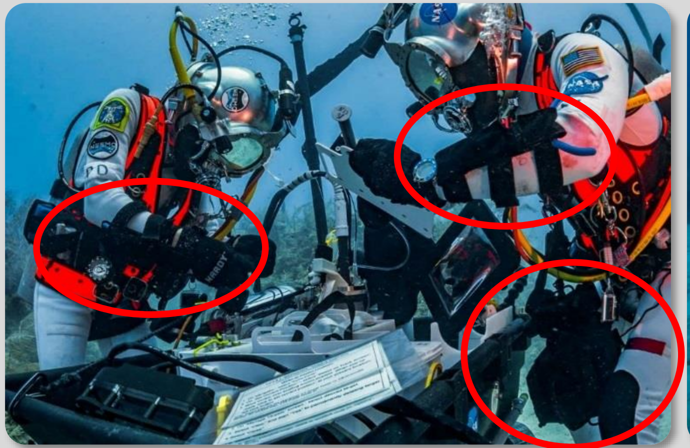
Objective

- Evaluate Modular Equipment Transport System (METS) for manually transporting/stowing tools and samples on exploration traverses
    - Evaluate the Wheeled Equipment Transport (WET) for transport of large equipment in a mobile carrier
    - Evaluate the Suit-mounted Equipment Carrying System (SECS) for transport of small tools on an EVA spacesuit

Implementation

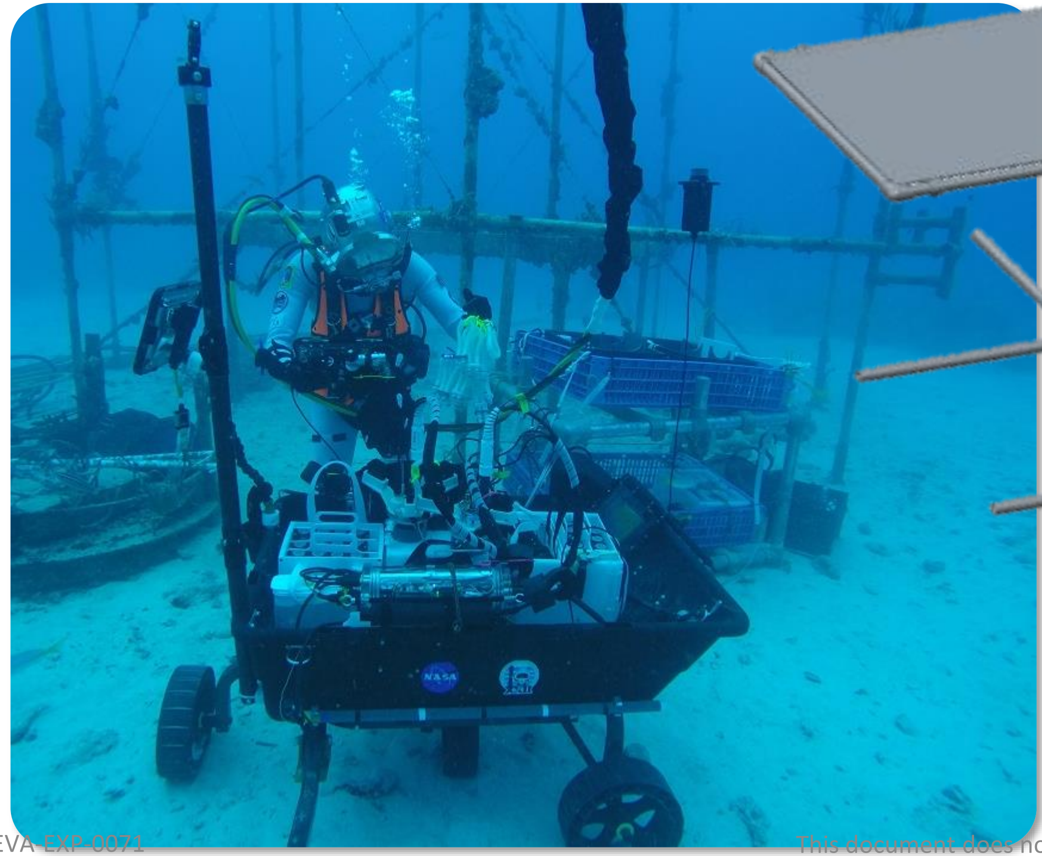
- The Modular Equipment Transport System (METS) is a method for transporting equipment from one location to another, grouping hardware into Modules for the appropriate planned activities
    - WET – Configurable wheeled carrier, with attachments for modules and science instruments
    - SECS – a forearm stowage device and thigh module attached to the suit after egress

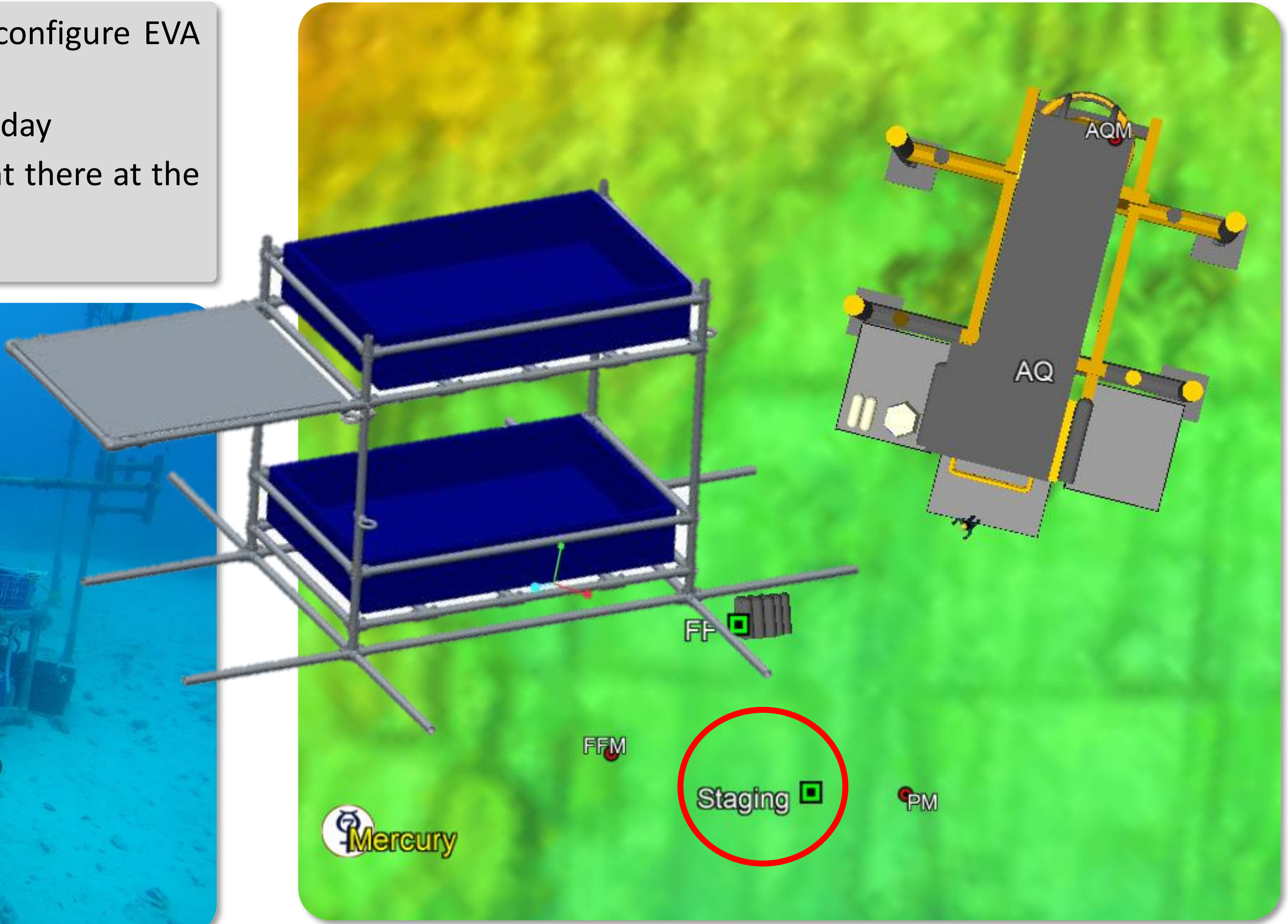




EVA Staging Area

- Structure near hab to stow and configure EVA equipment
- Support divers will populate each day
- Aquanauts will stow all equipment there at the end of each EVA





NEEMO 23 will provide an opportunity for the European Space Agency (ESA) European Astronaut Centre (EAC) EVA group to integrate and evaluate the next version of their crew rescue concept, known as the Lunar Evacuation System Assembly (LESA 2.0). LESA was created by the Neutral Buoyancy Facility (NBF) Operations & EVA Training Unit of the ESA Astronaut Training Division. Among all identified operational requirements for lunar EVA exploration, the capability to rescue an incapacitated EVA crewmember on the Moon's surface is one of the most critical and is applicable to any lunar EVA. LESA is a first prototype of a capability to enable the safe and quick recovery of an incapacitated EVA astronaut (fallen down on the Moon's surface) by only one rescuer wearing an EVA suit, followed by the quick transport of the victim to the closest safe haven (pressurized rover, lander, Moon base, etc.). The NEEMO environment offers the capability to simulate the 1/6G lunar gravity (via negative buoyancy fine-tuning) and to provide a realistic lunar surface environment (sandy, large area and uneven terrain). LESA operations will be evaluated by the aquanauts during several surface EVAs. Crew feedback will help ESA to enhance the LESA hardware and its operations. ESA will also expand upon their lunar surface mission knowledge by integrating and evaluating various geological sampling tools, including scoops and sample markers.

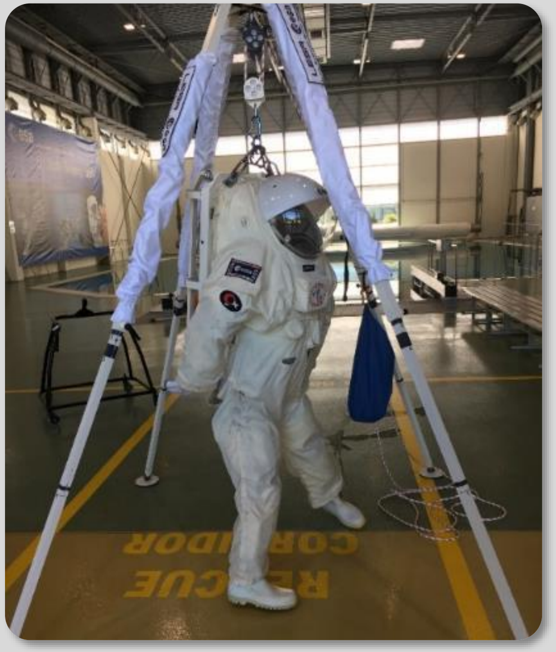
Incapacitated EVA Crew Rescue – Lunar Evacuation System Assembly

Objective

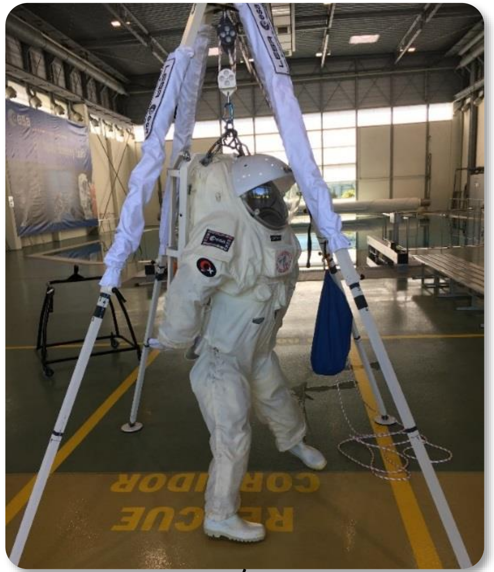
- Evaluate a new EVA incapacitated crewmember rescue concept developed by ESA at the European Astronaut Centre

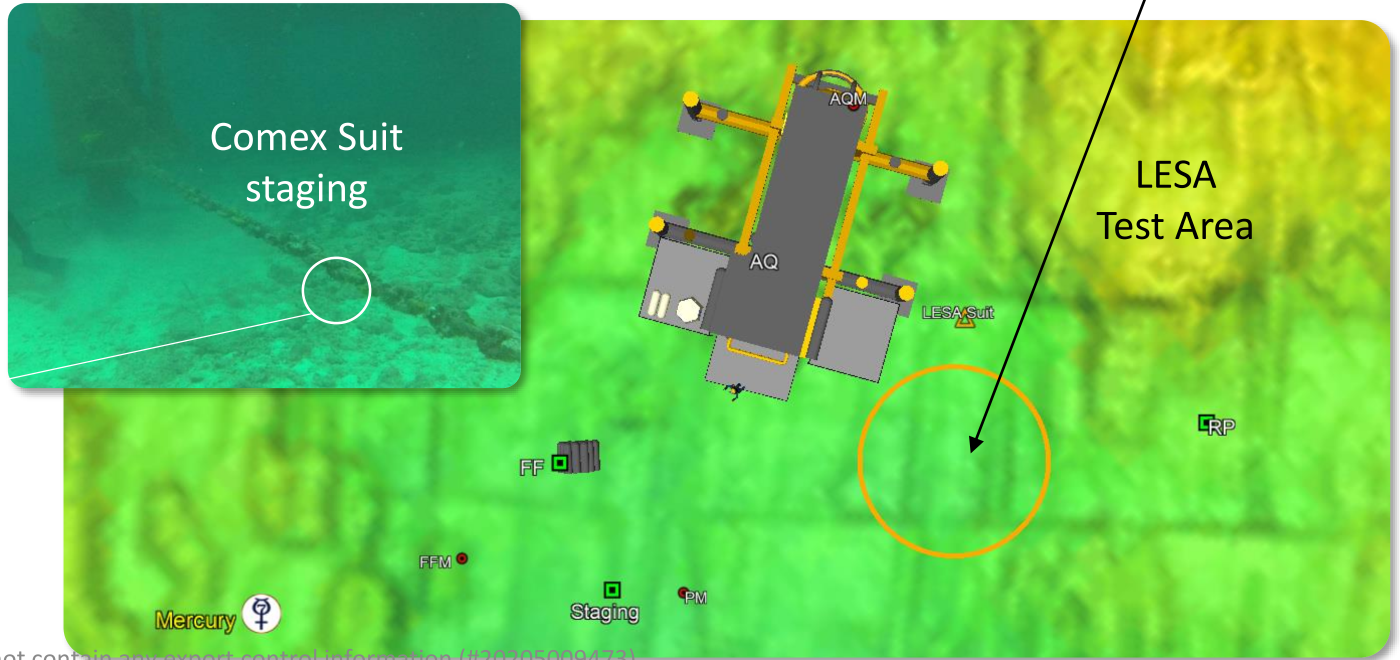
Implementation

- Utilized the new concept Lunar Evacuation Systems Assembly (LESA)
- LESA allows an incapacitated crewmember to be lifted up and secured to a Moon EVA Litter for transport back to a habitat/rover

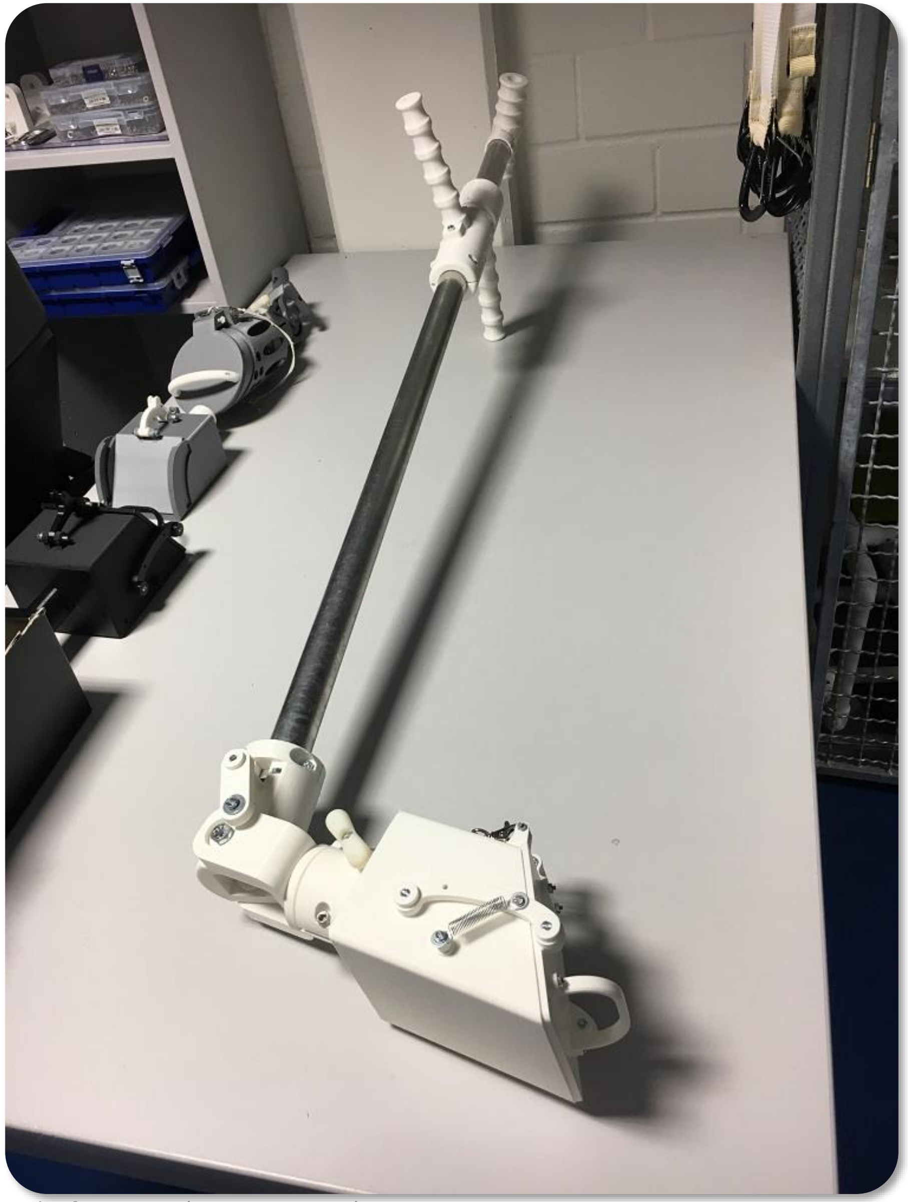


- New feature will of test will have crew utilize an empty spacesuit simulator (Comex suit) as the incapacitated crewmember
- Test area will be near the stbd-aft side of the hab
- Comex suit will need to be restrained overnight, possibly on chain running from stbd side of hab



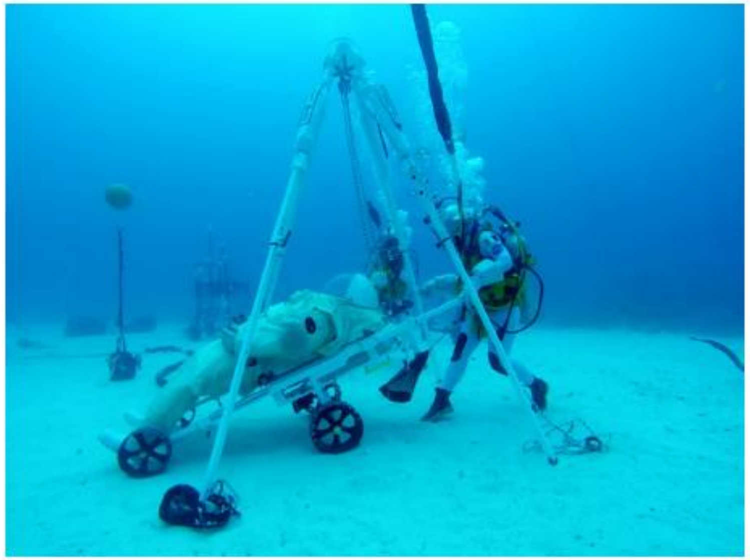


ESA NEST (Nearby Equipment Support Trolley)



Lunar Evacuation System Assembly

The Lunar Evacuation System Assembly (LESA) was created by the ESA EVA Training Unit from the ESA Neutral Buoyancy Facility (NBF) of the Space Training Team located at the European Astronaut Centre (EAC) in Cologne, Germany. Among all identified operational requirements for lunar EVA exploration, the capability to rescue an incapacitated EVA crewmember on the Moon's surface is one of the most critical and is applicable to any lunar EVA. LESA is a first prototype of a capability to enable the safe and quick recovery of an incapacitated EVA astronaut (fallen down on the Moon's surface) by only one rescuer wearing an EVA suit, followed by the quick transport of the victim to the closest safe haven (pressurized lander). A first prototype of LESA was tested in NEEMO 22. Crew feedback from these tests helped ESA to enhance the LESA hardware operations. A second version of LESA was evaluated by the NEEMO 23 astronauts, taking into account their body memory of the EVA suit constraints. In addition ESA brought an EVA Space Suit Simulator from the company COMEX (France), which was used in the COMEX underwater test "Apollo 11 under the sea" off shore of Marseille (France) in 2011. In NEEMO 23 the suit played the role of the Incapacitated Crew to increase the realism of the rescue operation with the suit having an apparent weight underwater equivalent to the weight of an EVA suited astronaut on the Moon.



Samantha performing the simulated rescue of an incapacitated crewmember using LESA

ESA Lunar Surface Geological Sampling Tools

ESA has recently combined the EVA expertise from the Space Training Team of the Neutral Buoyancy Facility (NBF) at European Astronaut Centre with the planetary geological knowledge and skills provided by the ESA PANGAEA astronaut training in order to develop and test prototypes of Lunar Surface Geological Sampling Tools. These EVA tools take into account the legacy of the Apollo geology operations and the EVA suit constraints and movement limitations as well as scientific requirements from state of the art lunar geology sampling operations. A first version of these tools were tested by ESA on a volcanic field of the Lanzarote island (Spain) during Lunar geological traverse EVA simulations in November 2018. Upgraded versions of these Lunar EVA tool prototypes have been further developed to be tested and evaluated in NEEMO 23, taking into account the lessons learned from the Lanzarote Lunar EVA simulations and from underwater tests in the ESA-NBF in simulated lunar gravity. All these tools are integrated into the ESA Nearby Equipment Support Trolley (NEST). This additional prototype is a multi-purpose tool carrier designed to allow easy transport of equipment to the sampling site during a lunar geology traverse and to increase EVA crew autonomy by enabling all lunar geology sampling operations to be done on each site by a single crew member.

Jessica evaluating the NEST and a lunar regolith sample device

The NEEMO environment offers the unique capability to simulate the 1/6G lunar gravity environment (via negative buoyancy fine-tuning) and to provide a lunar surface like environment (sandy areas with rock floats, outcrops and uneven terrain). The NEEMO 23 evaluations will help inform the design of these ESA Lunar tool prototypes on their development path toward their potential use in future geology operations on the Moon surface.

Test Objective Questions – Tools & Equipment

- How effective is the Core Sample Acquisition System (provided by Honeybee Robotics) for taking handheld core samples during an EVA? What improvements are desired, warranted, or required?
  - What improvements are desired, warranted, or required for taking handheld EVA core samples, especially in terms of applying the required force into the tool?
  - What improvements are desired, warranted, or required for curation of core samples?
- How effective is the Modular Equipment Transportation System (METS) for transporting equipment and samples to and from a habitat during a planetary surface EVA?
  - What improvements are desired, warranted, or required in the wheeled Equipment Transport (WET)?
  - What improvements are desired, warranted, or required in the Suit-mounted Equipment Carrying System (SECSy)?

The NEEMO mission will also evaluate the merits of putting the IV crewmember in different locations to support Science Team objectives, alternating between the habitat and the shore-based science trailer (mimicking a Mission Control Center position). Should future exploration architectures include no ground-based habitat with IV support during EVAs, it is likely that those EVAs will need to be coordinated from Earth. This NEEMO mission will include at least two EVAs where the IV position is located in the shore-based science trailer. One of these two EVAs should be a nominal communications day and one should be a day where the 30 minute communication blockage takes place. During the latter case, a habitat IV should be available for one hour to take over before, during, and just after the comms blockage.

INTEGRATED MISSION CONTROL OPERATIONS

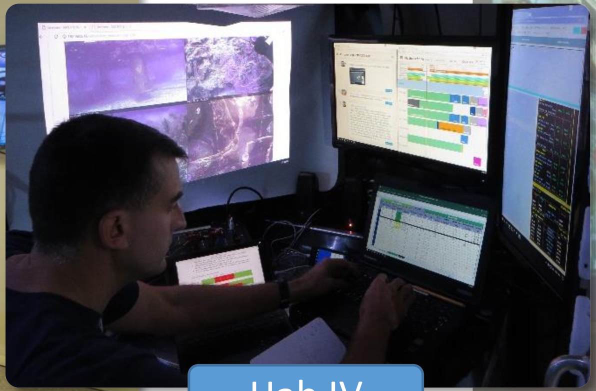
Objective

- Analyze integrated EVA science operations to determine what functions/capabilities are needed to enable a Mission Control Center (MCC) and integrated Science Team to effectively operate and actively direct EVA operations with science tasks over a lunar signal (comm & data) latency and blockage
- Evaluate flexible execution methodology and decision making protocols for science tasks during EVA operations

Implementation

- An onshore MCC Flight Control Team (FCT) that includes a Mission Director, EVA Officer, CAPCOM, and other system/subject matter experts
- An onshore Science Team that includes a Science Lead, subject matter experts, and Science Communicator (SCICOM)
- Mission (flight) rules volume and mission priorities, heightened mission tempo and pressure with additional flight control rigor, spacesuit telemetry, FCT GO/NO GO calls, and IVA task/experiment timeline

Mission Control


Hab IV


Science Team

MM-3 NEEMO MISSION MANAGEMENT TEAM (MMT) AUTHORITY

A. The NEEMO MMT, chaired by the Project Lead, is responsible for policy decisions and strategic planning.

B. The MMT consists of representatives from the Exploration Mission Planning Office, Astromaterials Research & Exploration Sciences, and the EVA Office.

C. The MMT has authority and responsibility for all strategic decisions affecting objectives and mission plans.

D. Any deltas or deviations from the plan will be approved by the MMT.

E. Any mission rule deviations or changes will be approved by the MMT.

F. The MMT determines and designates the roles and responsibilities for team members (e.g., Mission Director, Capsule Communicator (CAPCOM), EVA Lead, EVA Officer, Science Lead, Science Communicator (SCICOM), Science Officer, etc.).

MM-5 MISSION DIRECTOR (MD) AUTHORITY

A. The Mission Director has authority for all mission objectives.

B. The Mission Director will be in charge of the execution of the mission, and is responsible for the Mission Control Center (MCC) and Science Team (ST) operations.

C. The Mission Director is in charge of the mission timeline, and provides final inputs and approval to the Mission Planners

D. The Mission Director is responsible for the communications system and directing support from the Comm Lead

E. The Mission Director may delegate responsibility for tactical operational decisions as required (e.g., to the CAPCOM).

MM-6 CREW COMMANDER AUTHORITY

The NEEMO Crew Commander has direct on-scene responsibility for NASA objectives for the crewmembers selected by NASA, and for maintaining in-situ operations.

MM-7 EXTRAVEHICULAR ACTIVITY (EVA) LEAD/OFFICER AUTHORITY

A. The EVA Lead has authority for all EVA mission objectives and tasks conducted during EVA operations.

B. The EVA Lead has responsibility for integrating all tasks and objectives to be performed during an EVA.

C. All EVA plans and products (e.g., cue cards and procedures) require approval from the EVA Lead (or designee) before being uplinked to the crew.

D. The EVA Lead is responsible for all EVA hardware and tools. The EVA Lead may delegate some responsibility to the EVA Tools Lead.

E. The EVA Lead is responsible for ensuring that the crew and topside dive operations have required equipment and support to complete tasks during the EVA

F. The EVA Lead has responsibility for the EVA Officer, EVA Coordinator, EVA Dive Boat Lead, and all other EVA-related personnel.

   i. The EVA Officer is the flight/mission controller responsible for execution of the EVA

   ii. The EVA Coordinator is the flight/mission controller responsible for coordinating support and out-of-sim activities to ensure successful completion of EVA tasks

   iii. The EVA Tools Lead has accountability for the EVA equipment

   iv. The EVA Dive Boat Lead is the head support diver for the day, is responsible for coordinating dive support operations with the EVA Lead

MM-8 SCIENCE LEAD AUTHORITY

A. The Science Lead has authority for all science tasks conducted during EVA operations and ensuring their successful completion.

B. The Science Lead is responsible for coordinating with external science partners

C. The Science Lead has responsibility for the SCICOM, the Science Officer, Science Documentarian, and all other EVA-related Science personnel.

   i. The SCICOM is the flight/mission controller responsible for providing direction to the crew for science tasks, and has the following duties and responsibilities during the EVA…

   ii. The Science Officer – RESERVED

   iii. The Science Documentarian is the Science Team member responsible for recording science data during the EVA.

D. The Science Lead is responsible for integrating science tasks with the EVA Lead and Flight Control Team.

CHAIN-OF-COMMAND FOR MISSION OPS (REF *1.101 NEEMO MISSION RULES_FINAL*)

MM-10 EVA CHAIN-OF-COMMAND

A. The EVA Lead has final authority for safeguarding EVA equipment.

B. The Science Lead has final authority for safeguarding science equipment.

C. The EVA chain-of-command during the mission is as follows:

1. Mission Director
2. EVA Lead
3. Science Lead

D. The EVA chain-of-command during EVA operations is as follows:

1. Mission Director
2. Crew Commander
3. EVA Officer
4. SCICOM
5. CAPCOM

E. The Science Team chain-of-command during EVA operations is as follows:

1. Science Lead
2. SCICOM
3. Marine Science Principle Investigators

F. Decisions and GO/NO GO for EVA operations and tasks will adhere to the following chain-of-command (in order from start to finish):

1. The Science Team will determine the science and sampling plan and deltas.
2. The EVA Officer (or designee) will determine if the operations, spacesuit consumables, and EVA equipment supports the plan/deltas.
3. Mission Director (or designee) has final authority for implementing/executing any EVA plan or task delta.

EVA-5 MCC AND ST OPERATIONS DURING EVA

A. The MCC Flight Control Team (FCT) has final authority for deciding GO/NO GO before and during an EVA

1. Any continuation or extension will be based on mission timeline for the day.
2. The FCT will evaluate the ability to achieve a full length EVA if the EVA starts late based on the mission timeline for the day.
3. GO/NO GO call for transition between major task blocks on the EVA timeline or to different zones will be based on the best available suit consumables telemetry as determined by the EVA Officer.

B. The Mission Director (or designee) has authority on determining whether an EVA will continue based on the mission timeline and EVA suit status.

C. The EVA Officer (or designee) will determine whether the next task block on the timeline can be started based on spacesuit consumables and timeline status, and will provide recommendations to continue or extend an EVA to the Mission Director (or designee).

D. The Science Officer has responsibility for coordinating science tasks with the rest of the FCT.

E. During science-driven tasks, the Science Team SCICOM has responsibility for science task blocks on the timeline.

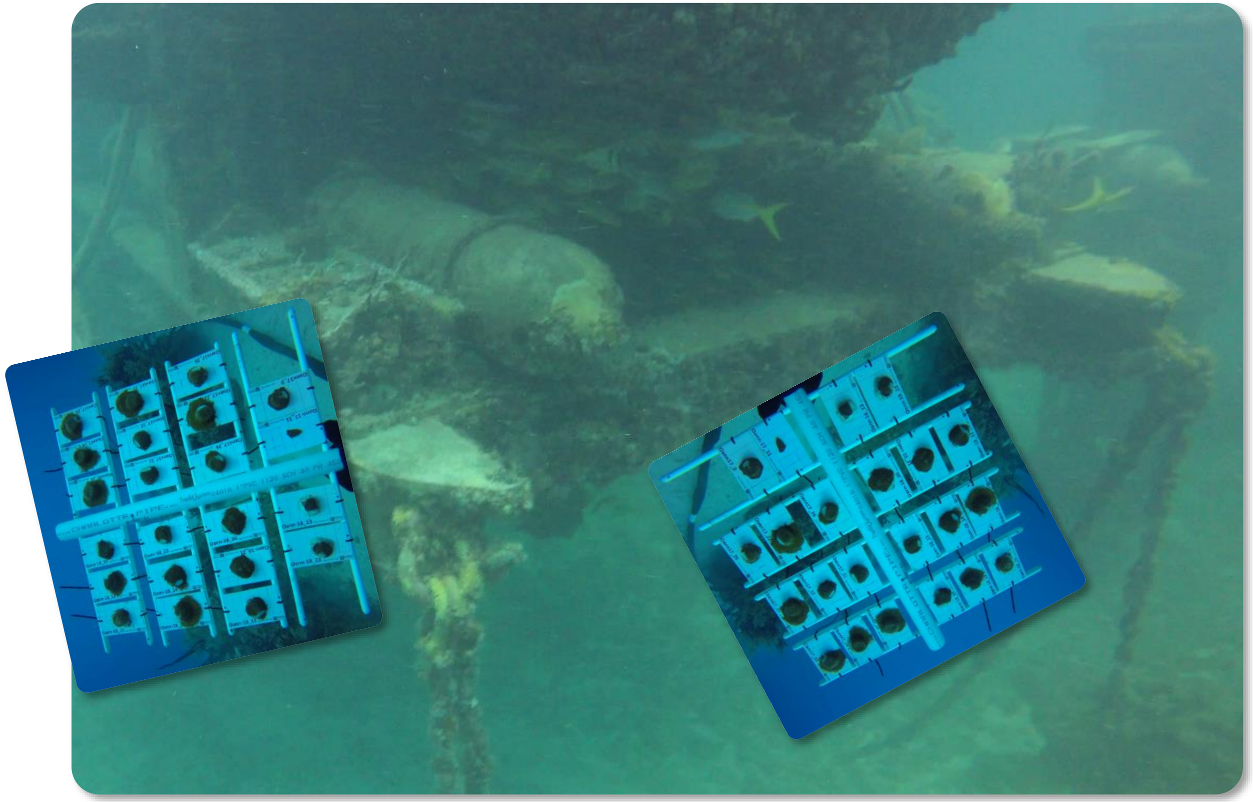
1. SCICOM will directly provide the crew input within any given task block on the timeline.
2. SCICOM will keep the MCC FCT informed of status through voice loop communication with the Science Officer (formerly Science Liaison) in MCC.
3. The ST will receive a GO from the MCC FCT, based on recommendations from the EVA Officer, before instructing the crew to proceed with the next task block on the timeline.
4. Any significant deviations or deltas to the timeline will be discussed between the ST and FCT.

Objective

- Evaluate pioneering/construction tasks on a planetary mission

Implementation

- Build a new coral nursery tree structure on the bow end of the hab
- Rebuild the Mercury Nursery
- Utilize DAVD to direct the crew real-time through the tasks

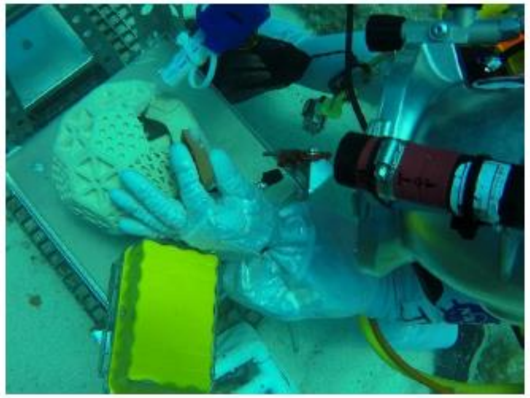


3D Habitat Repair

The "EVA 3DP-HAB Repair" initiative is a feasibility study that evaluates the potential associated tools, methods, and concept of operations required for a Critical Contingency Extravehicular Activity (CCE's) Repair of a 3D-Printed In-Situ Resource Utilization (ISRU) Lunar and Martian Habitat. Additionally, the study investigates solutions for coral reef restoration via 3D-printed biomimetic habitats utilizing ISRU & alternative materials, promoting coral larvae settlement and providing a safe haven for marine species.

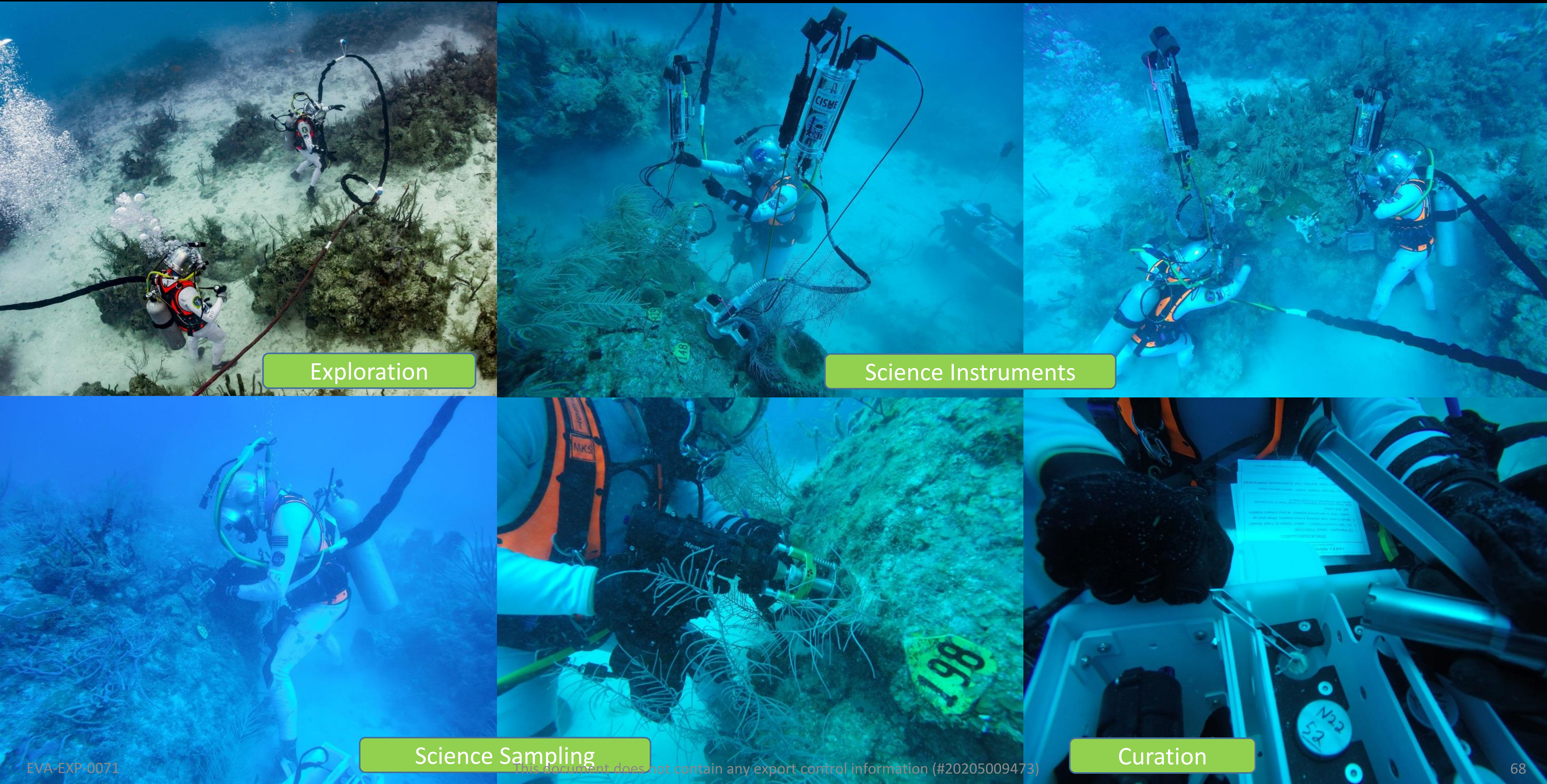
Along with NASA's current space Technology Roadmaps for Habitation & EVAs, NextSTEP's ISRU Technology Research, and the Centennial 3D-Printed Habitat Challenge, this study will provide an initial analysis of this integrated system focusing on the functional abilities, environmental and human factors on a 3D-printed habitat.

With the support of NASA and the Department of Space Studies at the University of North Dakota, the successful outcome will contribute to the design and concept of operations requirements for Deep Space Gateway, long-duration Planetary Missions, and advancement in technologies. These will help answer some of NASA's Human Research Program (HRP) EVA Risks and Lunar & Martian Human Exploration Strategic Knowledge Gaps (SKGs). Additionally, understanding and advancing the nature of 3D-printed habitats will help contribute to habitats for all living things on and off this "Pale Blue Dot we call home."

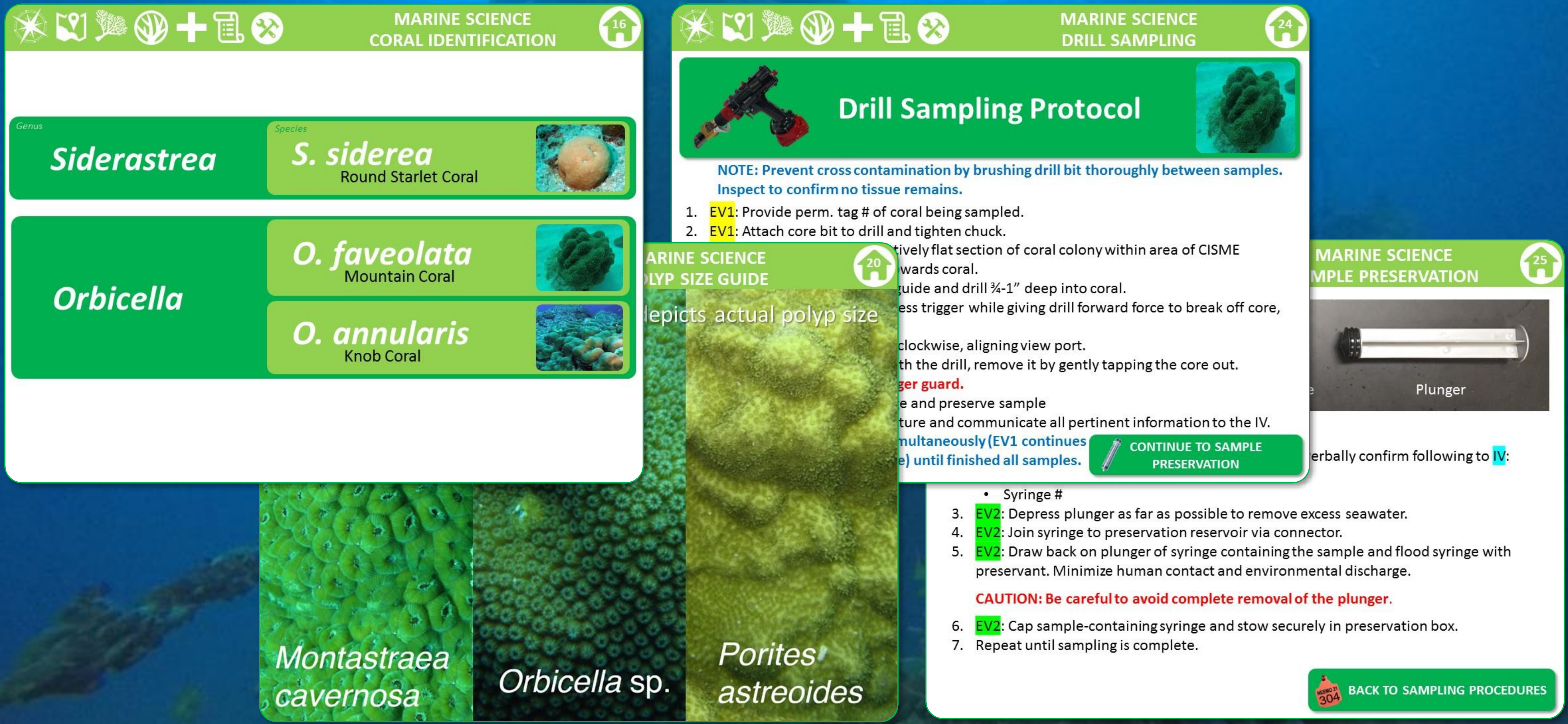


Exploring in-situ repair options on a 3D Printed habitat material

Science Tasks During EVA



MARINE SCIENCE – PROXY FOR GEOSCIENCE & ASTROBIOLOGY



Test Objective Questions – Concepts of Operations

- Is it Acceptable for an MCC Science Team to provide input and direction to the crew during planetary surface integrated EVA science operations with signal (comm) blockage/outages?
  - How doe lunar-relevant signal blockage/outages effect EVA operations?
  - How does utilizing a crew IV compare to using a ground IV
  - What improvements are desired, warranted, or required for decision making protocols?
  - What functions/capabilities are needed (software, hardware, techniques) to enable an MCC Science Team to effectively direct EVA science operations when limited with signal (comm) blockage/outages?
- What functions/capabilities in terms of integrated informatics are needed to enable the EVA crew to effectively operate and communicate information to an MCC Science Team during planetary surface operations with signal (comm) blockage/outages?
  - What advanced informatics concepts are effective for EVA operations?
  - What improvements are desired, warranted, or required for EVA crew self-navigation?
  - What improvements are desired, warranted, or required for IV/MCC tracking of EVA crew?
- What improvements are desired, warranted, or required for decision making protocols that enable effective flexible execution methodology (flexecution) for planetary surface EVA science operations?
- Which capabilities and techniques are enabling and significantly enhancing for the lunar surface mission operations concepts tested?

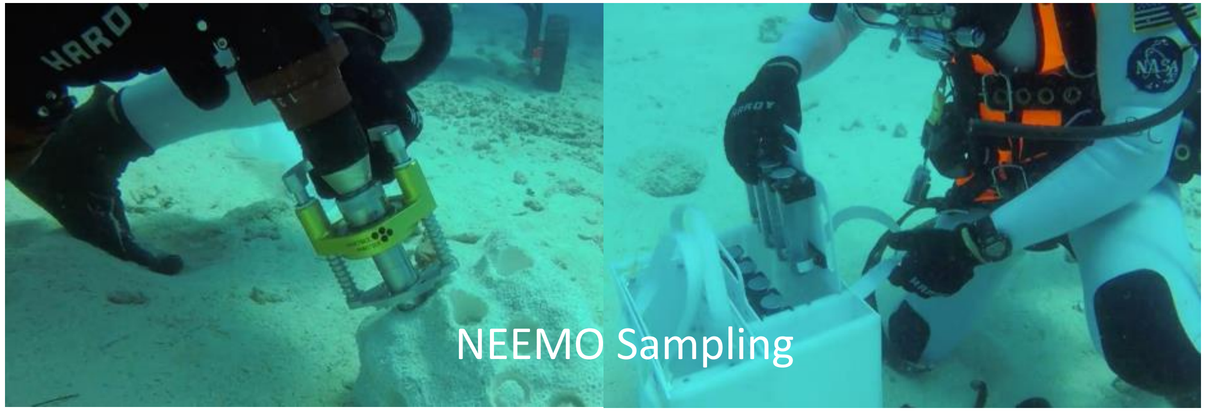
EVA Science Operations

EVA & ARES will evaluate the detailed EVA interaction with an integrated Science Team striving to collect and test authentic scientific objectives and hypotheses, using marine science as a proxy for planetary surface science. These operations will be conducted utilizing a flexible execution methodology for EVA science operations in a natural environment (i.e. an environment that is not completely defined or known prior to arrival, as would be the case in a mission to the surface of the moon or Mars). To enable this interaction, several tools were developed for evaluation, including an augmented vision heads-up display and handheld electronic cue cards for EVA crew that allow them to operate more effectively, and a support system that future IV crewmembers will need in order to effectively handle the amount of information and tasking that must be contended with while actively directing an EVA during signal outages.

NEEMO 23 Proxy Planetary Science Objectives

In Situ Instrumentation Deployment

- Coral In Situ Metabolism (CISME) experiment deployment techniques and time constraints are analogous to high priority geologic instruments (XRF, XRD, LIBS, etc.)
- N23 Science Operations objectives focus on feasibility of EVA deployment of in situ tools real-time and efficacy of 1 vs 2 person operations
- Define areas through crew feedback that can be streamlined in support of future space applications involving non-destructive sample analysis

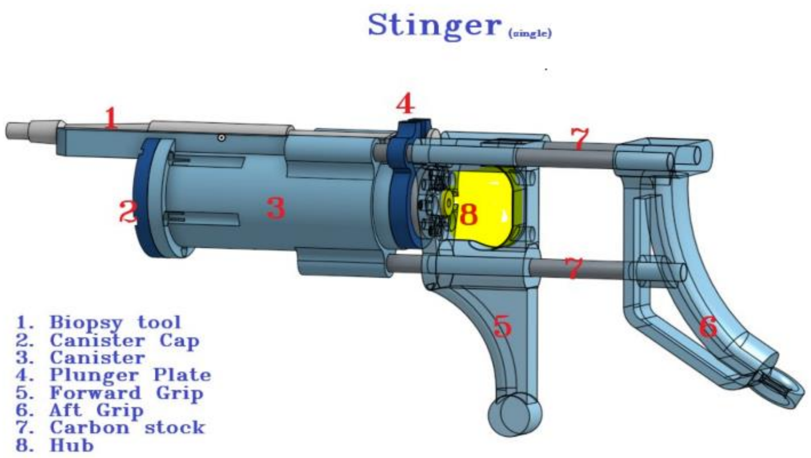


Geological Sampling

- Determine the feasibility for novel sampling science operations techniques including (1) scouting, (2) “sterile” sample collection, and (3) real-time sample preservation by the NEEMO crew.
- Assess multiple sampling techniques including pneumatic coring and chiseling to efficiently collect high volume (~30) of individual samples while simultaneously minimizing contamination risk.
- Assess workload of crew sampling with 1 vs 2 crewmembers

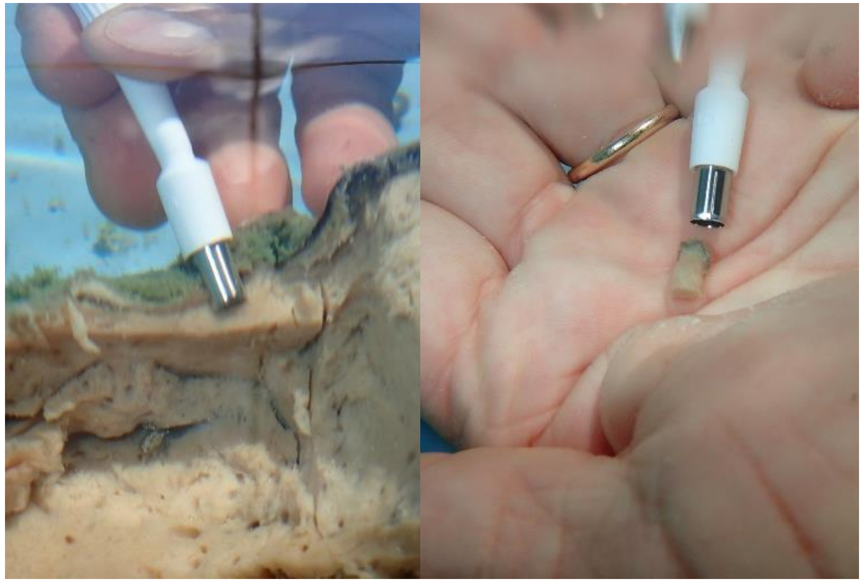
Opportunistic Sampling

- Sponge spawning and fertilization only if observed on EVA
- Specialized crew training and subsequent EVA 'flexecution'



Targeted Geologic and Biomolecular Small-Volume Sampling - The “Stinger”

- Demonstrate the feasibility of collection of a diversity of targets using a new small volume sampler—the “Stinger"
- Enables collection of high-resolution samples without damaging fragile structures
- Collect and preserve samples *in situ*



Minimum Requirements for Success

Completion Status

MOR Minimum Requirements for Success

#1: Diver Augmented Vision Display (DAVD) [EVA AVHUD]		
Completed	Partially Completed	Not Completed
	2 engineering saturation dive evals	2 engineering topside dive evals (before start of ESAT)
		2 saturation mission evals

#2: Conducting science-driven exploration		
Completed	Partially Completed	Not Completed
4 evals – 2 by each astronaut crewmember		

#3: EVA Navigation and Crew Tracking [Navy Sonar]		
Completed	Partially Completed	Not Completed
	2 engineering saturation dive evals	2 saturation mission evals

#4: EVA Support System & IV workstation		
Completed	Partially Completed	Not Completed
4 evals (w/OpenMCT) – 2 by each astronaut crewmember		

#5: Integrating Science Team with EVA during a lunar mission		
Completed	Partially Completed	Not Completed
4 EVAs with near real-time comm and signal blockage/outages for science exploration		

#6: METS (including WET and SECS)		
Completed	Partially Completed	Not Completed
4 evals – 1 by each crewmember		

#7: CISME		
Completed	Partially Completed	Not Completed
4 evals – 1 by each astronaut and the EVA science PI over at least 2 EVAs		

#8: Core sample acquisition system focused on curation		
Completed	Partially Completed	Not Completed
4 evals – 1 by each crewmember		

MOR Minimum Requirements for Success

#9: Nursery construction		
Completed	Partially Completed	Not Completed
Done		

#10: Flexecution during EVA		
Completed	Partially Completed	Not Completed
4 EVAs with near real-time comm and signal blockage/outages for science exploration (overlaps #4)		

#11: EVA digital cue cards		
Completed	Partially Completed	Not Completed
4 evals – 1 by each crewmember		

#12: Suit mounted tool harness		
Completed	Partially Completed	Not Completed
1 eval		

Review of NEEMO as an Analog for EVA

Integrated Operational Testing: Who, What, Where, Why, & How

INTEGRATED OPERATIONAL TESTS (ANALOGS MISSIONS): WHO, WHAT, WHERE, WHY, & HOW

High-fidelity integrated multi-disciplinary operational development missions that closely mimic the space environment of interest, and allow for end-to-end operations, thus developing and testing concepts that enable Exploration spaceflight missions

WHO

MULTI-ORGANIZATIONAL TEAMS

eisd

EXPLORATION INTEGRATION & SCIENCE DIRECTORATE

coordinated integration

- SCIENCE
- EVA
- PLANNING

WHAT

INTEGRATION THEMES

- TOOLS
- TECHNIQUES
- TECHNOLOGIES
- TRAINING

WHERE

RELEVANT ENVIRONMENTS

- AQUATIC
- TERRESTRIAL
- LABORATORY

WHY

To achieve mission readiness through integration and testing of technologies, systems, operations, and science in relevant environments

- Close technology, exploration, and science gaps
- Identify and develop the best systems, innovations, and operational approaches
- Drive out results not found in standalone testing, including things that do and do not work in a mission environment
- Inform strategic architectural and concept of operations development efforts
- Facilitate EVA concepts of operations development

OUTCOME: These efforts will ultimately lead to mission readiness and success, reduce the risk, increase the scientific return, and improve the affordability of NASA programs and missions

HOW

INTEGRATED OPERATIONAL TESTING

eisd READy
Relevant Environments for Analysis & Development

NEEMO

NASA

NEEMO NXT

SHyRE

WHAT: Development & Integration Themes and Focus of NEEMO 23 EVA

TOOLS

EVA Systems
- **EVA tools and equipment**
- **Large equipment transport**
- **Small tool transport on suit**
- **Informatics**
- **Crew rescue**
- **EVA Support System & IV Workstation**
- **Science instruments and sample acquisition tools**

Instrumentation
- Sample identification / high-grading
- ISRU verification

Sample Collection/Curation
- **Collection**
- Contamination Mitigation
- **Preservation/Storage**

TECHNIQUES

Exploration Operations
- Procedure development/refinement
- Signal latency (time delay) & blockage
- Bandwidth limitations

EVA Operations
- **EVA concepts of operations**
- **EVAs in undefined environments**
- **Advanced capabilities & informatics**

Science Operations
- **Flexecution methodology**
- **Decision making protocols**
- **Transverse planning**

Robotic Operations
- Autonomous
- Crew controlled
- Human-Robotic interface & integration

TECHNOLOGIES

Emerging Technologies
- Virtual/Hybrid reality opportunities
- **Relevant cutting-edge systems and capabilities for Exploration and EVA**
- **Rapid testing environment for development of emerging technologies**

Innovations Incubator
- Relevant environments and operational constraints are a breeding ground for innovation

Partnerships
- **Opportunities for external partners to demonstrate current capabilities**
- Direct collaboration leading to proposal and other funding avenues
- Strengthens international partnerships

TRAINING

Cross-Disciplinary Training
- Learning each others language, requirements, and drivers in EISD
- Ex. Geo-Science Field Training for managers and engineers

Astronaut Crew Training
- Additional expeditionary and leadership opportunities
- **Enhances both operational and science training objectives**

Operational Training
- Provides ops training prior to payload flights for payload PIs and teams
- **Enables development of engineers and scientists not normally exposed to operations**

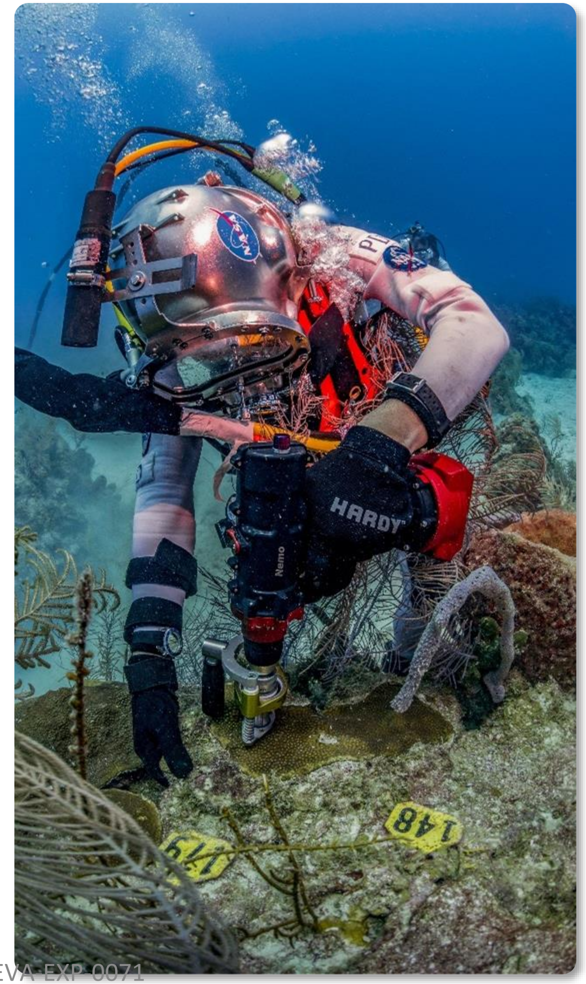
WHAT: Capability Development via Integrated Operations

Integrated EVA Science Operations

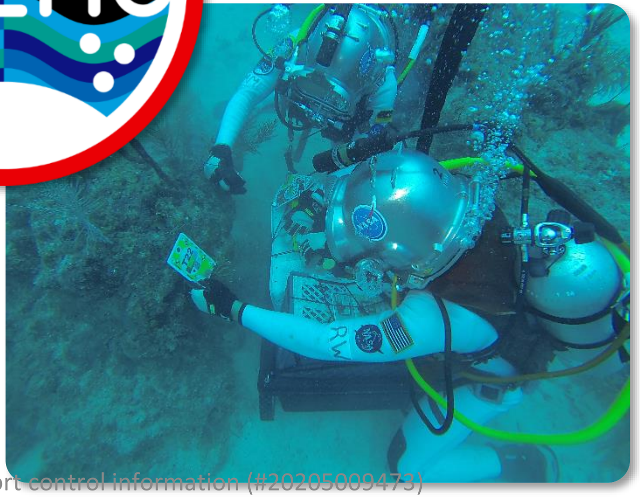
- Aquarius Reef Base
- Florida International University
- Harbor Branch Florida Atlantic University
- ihmc Florida Institute for Human & Machine Cognition
- XI Astromaterials Research & Exploration Science (ARES)
- XM Mission Planning, Develop & Integration
- XX Extravehicular Activity Office
- EC Crew & Thermal Systems - Tools
- NAVSEA Naval Sea Systems Command
- esa
- eisd

WHERE: NASA Extreme Environment Mission Operations (NEEMO)

- NASA undersea high-fidelity spaceflight mission analog – focusing on exploration science and EVA techniques & tools, as well as maturing near term (ISS) flight hardware and ops concepts – that sends groups of astronauts, engineers and scientists to live, work and explore in a challenging environment
- Allows for evaluations of EVA end-to-end concepts of operations with crew that are in-situ in a true extreme environment and provides for flight-like interactions between the crew and an MCC & Science Team
- Series of 22 space exploration simulations conducted since 2001

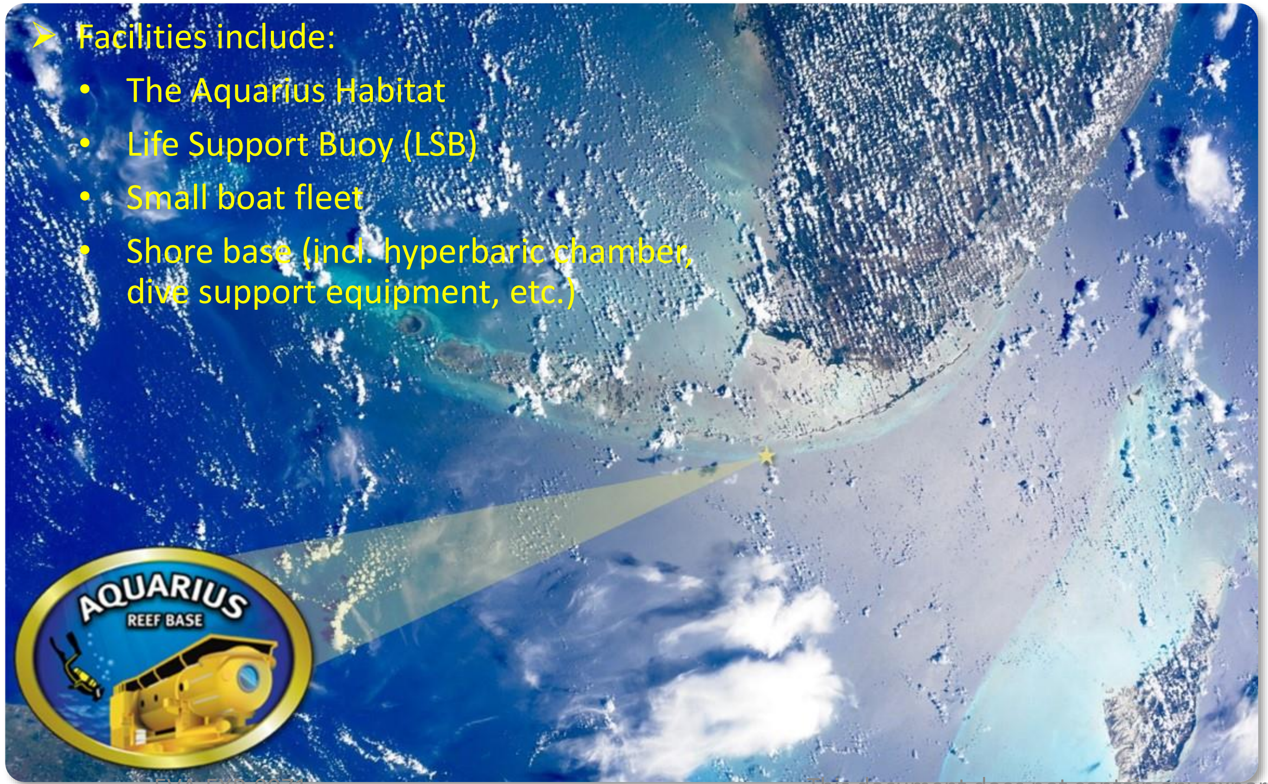




WHERE: NEEMO FACILITIES

- Aquarius Reef Base, the world's only undersea research station
- Located 5.4 miles (9 kilometers) off Key Largo in the Florida Keys National Marine Sanctuary
- 62 feet (19 meters) below the surface next to a deep coral reef named Conch Reef
- Operated by Florida International University



➢ Facilities include:
- The Aquarius Habitat
- Life Support Buoy (LSB)
- Small boat fleet
- Shore base (incl. hyperbaric chamber, dive support equipment, etc.)

Aquarius Habitat

ARB Shore Base

LSB


NEEMO MCC


Support Boats


ARB Watchdesk

WHO: NEEMO 23 PARTNERS/COLLABORATORS

- **NASA**
  - **JSC:**
    - **XM**: Mission leadership and integration
    - **XI**: Science Team leadership, science objectives, mission management
    - **XX**: EVA Leadership, EVA objectives, mission management
    - **EA (EC, ER)**: PI for multiple evaluation objectives, building EVA equipment
    - **CB**: Crewmember and Capcom
    - **SD**: PI for mission objectives
    - **PAO**: Public Affairs activities
  - **ARC**: Mission planners and timeline tool
  - **KSC**: Communications, data management, and logistics support
  - **JPL:** Research objectives
  - **GSFC:** Science Team leadership and expertise
  - **MSFC:** Capcom support
- **ESA:** Crewmember, Capcoms, research objectives
- **Academia**
  - **Florida Atlantic University (FAU) Harbor Branch Oceanographic Institute:** Research and mission objectives
  - **University of South Florida (USF)**: Research objectives
  - **California State University San Bernardino:** Research objectives
  - **Iowa State University:** Research and mission objectives
  - **University of North Dakota:** Research objectives
  - **Lone Star College:** Flight hardware demo
  - **Florida International University (FIU)**: Aquarius owner and operator, science support
- **DoD**
  - **Naval Sea Systems Command (NAVSEA) & Office of Naval Research (ONR)**: Diver Augmented Vision Display and navigation
  - **Naval Surface Warfare Center Panama City (NSWC PC)**: Diver Augmented Vision Display
- **Institutions**
  - **Florida Institute for Human & Machine Cognition (IHMC)**: Research and mission objectives
  - **Charles Stark Draper Laboratory**: Research and mission objectives
  - **Coral Restoration Foundation**: Research objectives
- **Industry**
  - **Honeybee**: Core drilling solution
  - **AllTraq**: Mission objectives
  - **Shark Marine**: Providing a robotic and camera system
  - **Aexa Aerospace**: Providing HoloLens units and expertise
  - **Project Voxa:** Mochii Scanning Electron Microscope

NEEMO XXIII

XI
Astromaterials Research & Exploration Science (ARES)

XX
Exploration EVA

XM
Mission Planning, Develop & Integration

CB

EC

ER

SD

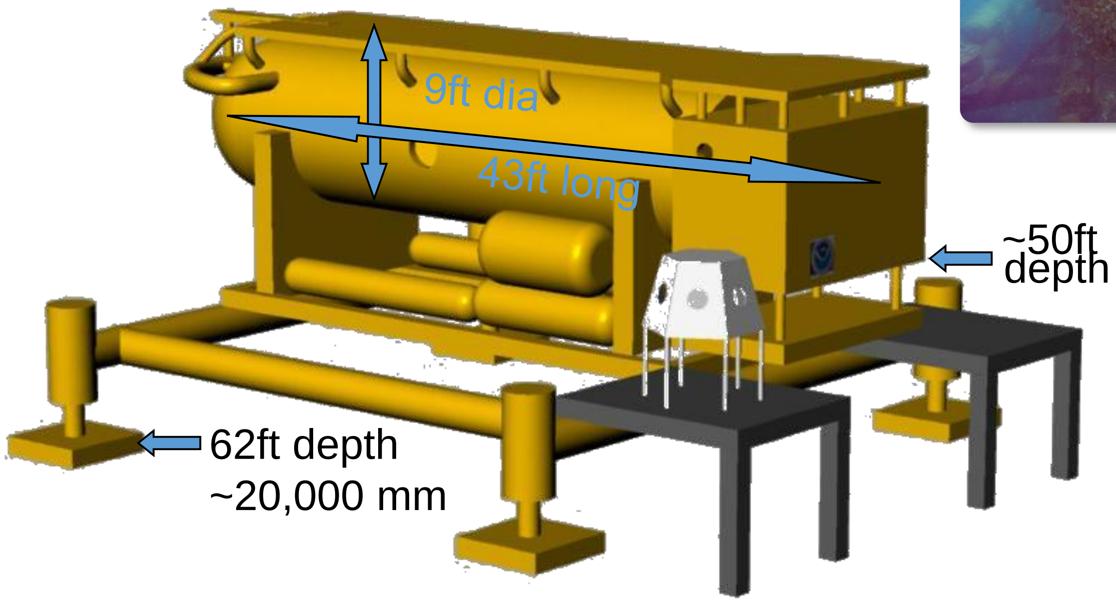
AllTraq

Project Voxa

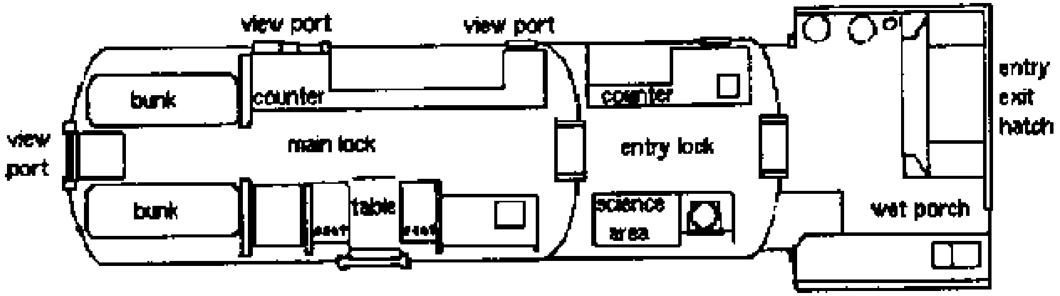
Overview of a NEEMO EVA

Some high level steps and imagery as we examine a day in the life of an aquanaut…

THE "SPACECRAFT": AQUARIUS UNDERWATER HABITAT

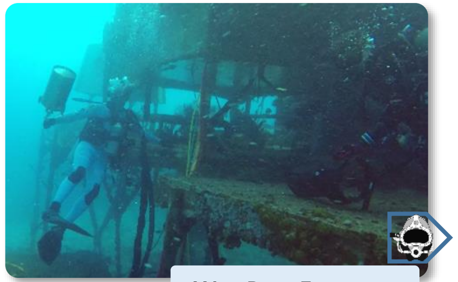


Model courtesy of
Jim Maida and the
GRAF Lab



Aquarius Underwater Habitat

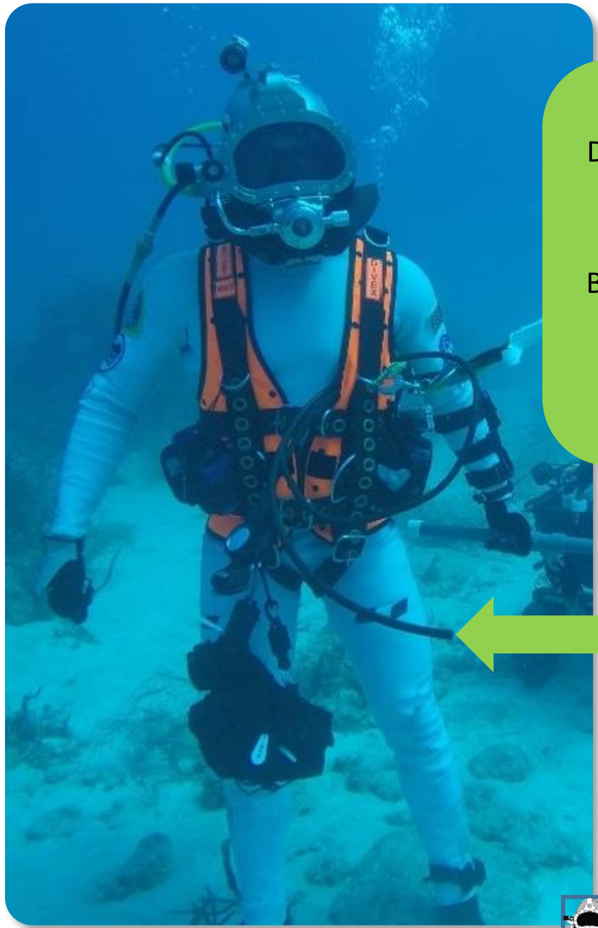
Splashdown Photo



Wet Port Entrance

THE "SPACESUIT": KM 37SS HELMET W/ WETSUIT & HARNESS

KM 37SS



37SS: Narrower FOV, Helmet movable

xEMU: Wider FOV, Helmet fixed

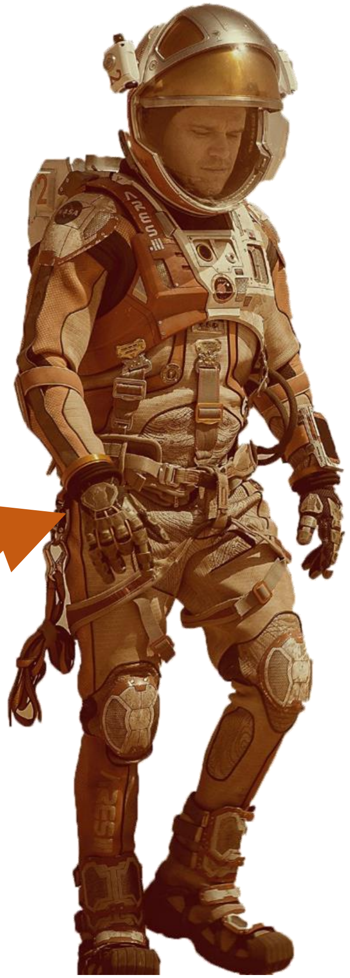
Dive helmet & system provide good analog to a spacesuit for concepts of operations evaluations

Both have different but comparable challenges for operations

Will utilize EMU TMG

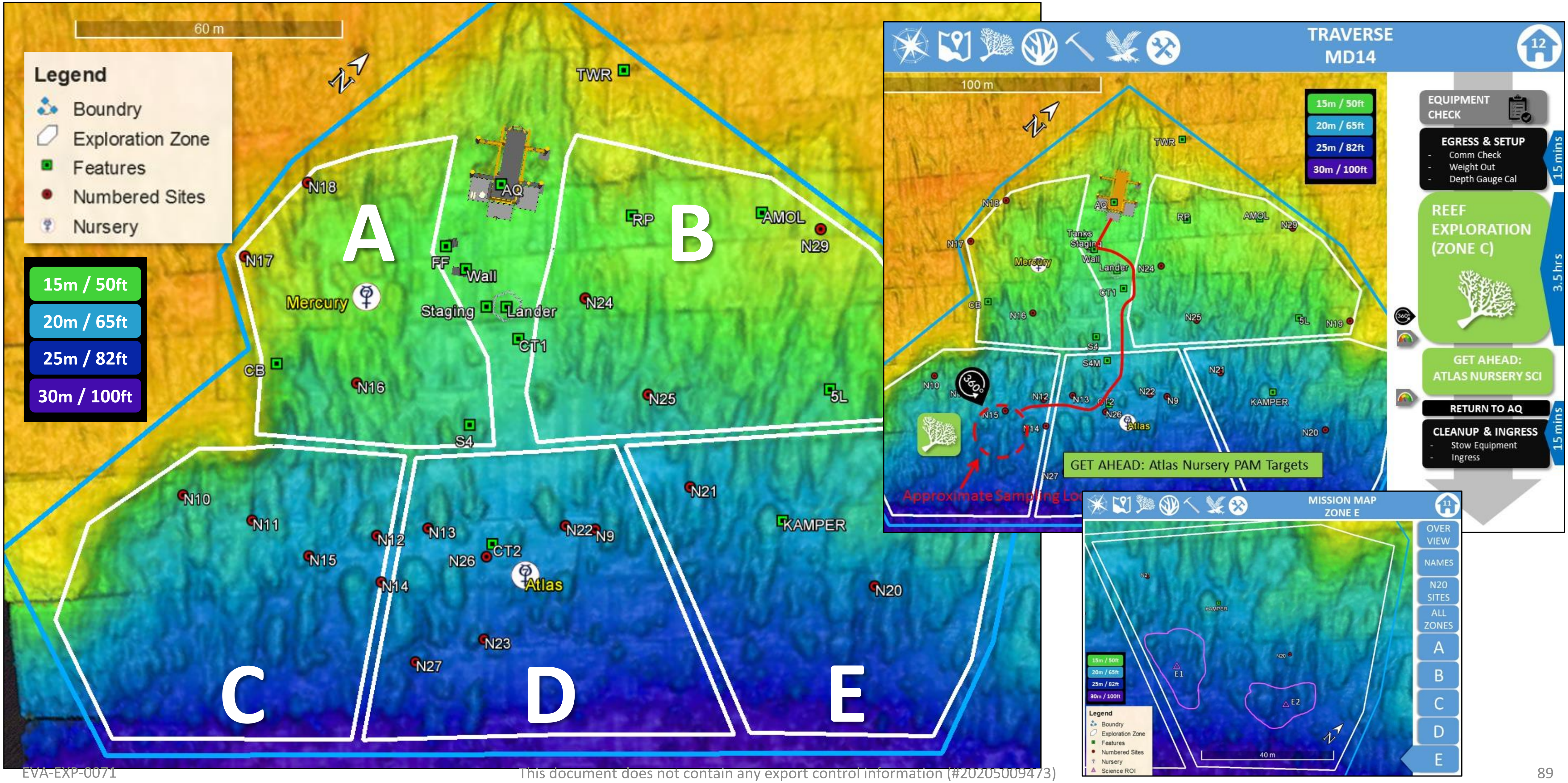
Wetsuit: Very flexible
xEMU: Pressurized, bulky

xEMU concept

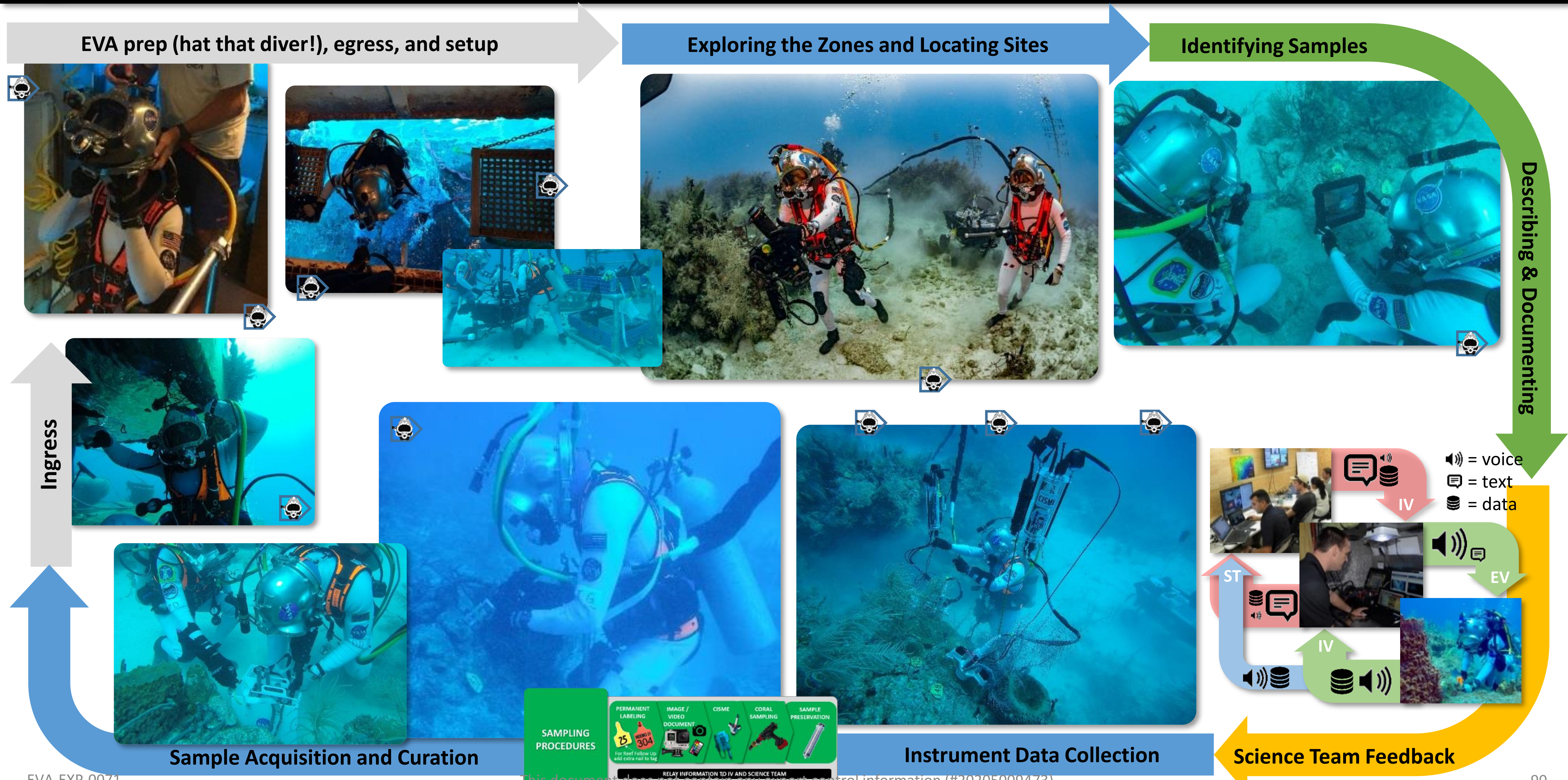


TBD mEMU concept
(courtesy of *The Martian*)

MAPS WITH EXPLORATION ZONES FOR EVA EXCURSIONS (FROM NEEMO 22)



A Day in the Life of NEEMO EVA Operations



EVA CHECK LIST

38

EVA PLANNING
- ❑ Review Tasks/Objectives
  - ❑ Roles/Responsibilities
  - ❑ Required Equipment
  - ❑ METS Load Plan
  - ❑ Science Plan
  - ❑ Robotics Plan
- ❑ Review Traverse
  - ❑ Routes/Navigation
  - ❑ Durations
- ❑ Brief In-Water Hab Tech
  - ❑ Routes
  - ❑ Umbilical Planning
- ❑ Image Planning
- ❑ Contingency Planning

PREPARE EQUIPMENT
- ❑ iDive Tablet
  - ❑ Charged
  - ❑ Cue-Cards Downloaded
  - ❑ Proper Mode Settings
  - ❑ CO_2 Cartridge Changed (If required)
  - ❑ Sealed/Bubble Check
- ❑ Cameras
  - ❑ Charged; Data Space
  - ❑ Handle/Clipped off
  - ❑ Sealed/Bubble Check
  - ❑ In fresh Water Bucket
- ❑ Depth Gauge/Watch
- ❑ Cutting Device

GEAR UP / HATTING
- ❑ Hatting*
  - ❑ Adjust padding and Valsalva
  - ❑ Neck Dam
  - ❑ Don vest
  - ❑ Attach straps (2 chest, 2 crotch)
  - ❑ Don helmet – tender mates fittings
  - ❑ Verify hat is breathing
  - ❑ Comm check (Watch Desk, Periwinkle Diver)
- ❑ Reach Checks
  - ❑ Valves (Steady Flow, Purge, Dial-a-Breath)
  - ❑ EGS pressure gauge
  - ❑ Cutting device
  - ❑ Camera
  - ❑ Other EVA specific equipment
- ❑ System Checks*
  - ❑ Read EGS pressure
  - ❑ EGS functional check
  - ❑ Pneumo check
- ❑ Surface Checks*
  - ❑ Steady Flow
  - ❑ Purge
  - ❑ Dial-a-Breath

ENTER THE WATER

IN-WATER CHECKS
- ❑ Surface checks*
  - ❑ Steady Flow
  - ❑ Purge
  - ❑ Dial-a-Breath
- ❑ EVA specific equipment

*working with ARB Staff

EGRESS / STAGE OUT
- ❑ Comm check w/ IV
- ❑ Comm check w/ MCC (low latency only)
- ❑ Weigh-out (hab tech adds weights)
- ❑ Report water conditions to IV (viz, current)
- ❑ Retrieve Navigator from topside and activate
- ❑ Verify helmet cam w/ IV
- ❑ Verify depth gauge

STAGING AREA
- ❑ Attach iDive to METS
- ❑ CISME activation/calibration
- ❑ Config METS per plan
- ❑ Check drill functions
- ❑ Don thigh module
- ❑ Don forearm module
- ❑ Verify umbilical routing w/ Hab Tech
- ❑ Don PLSS frame (for ICM tasks only)
- ❑ Put CISMEs on METS

1st rule of NEEMO EVA: You do not lay down in your 'pressurized spacesuit'

2nd rule of NEEMO EVA: You do NOT lay down in your 'pressurized spacesuit'

3rd rule of NEEMO EVA: If MCC says "stop" or the Watch Desk calls it, the EVA is over

4th rule: Only two crewmembers on an EVA

5th rule: One EVA at a time

6th rule: No rovers, no robotic arms

7th rule: Science tasks will go on as long as they have to

8th and final rule: If this is your first NEEMO mission, you have to go EVA

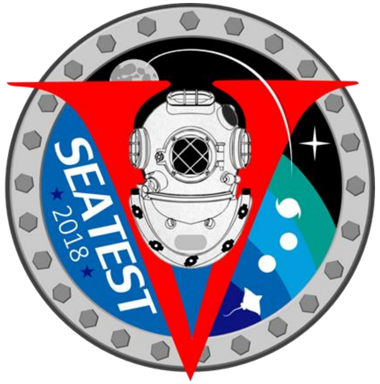
EVA-1 EVA CREW OPERATIONS

C. EVA crew should maintain a body position appropriate for a pressurized surface exploration EVA suit.
   i. Laying down is not permitted, except for the incapacited crewmember (ICM) in an ICM rescue evaluation.
   ii. Kneeling on one knee is permitted, but kneeling on two knees is should to be avoided.
   iii. Movements should be kept to reasonable limitations of a pressurized spacesuit, which are far more restrictive than a wetsuit.

D. Tasks should be completed by the EVA crewmember without assistance from support divers to the extent possible.

Engineering Saturation Run (ESAT)

ENGINEERING SATURATION TESTING (ESAT – AKA SEATEST V)



Overview

- Part of the full suite of hardware and mission concept testing required to prepare for the mission
  - Extended access to habitat for pre-configuration needs
  - Hyperbaric effects on equipment
  - Extended subsea testing time
  - Procedure and timeline development
  - Mission network in place
- Initial EVA and Science SME evaluations
- 5-day test with 4 NASA crewmembers living in the habitat (in saturation)
  - All experienced aquanauts (Todd, Reagan, Coan, Graff)
- Topside dive and MCC-type support as well
- May 23-27, 2019

ESAT Crew

- Bill Todd
  Project Management
  NEEMO 1 Aquanaut
- Marc Reagan
  Mission Director
  NEEMO 2 Aquanaut
- David Coan
  EVA Lead
  NEEMO 20 Aquanaut
- Trevor Graff
  Integration Lead
  NEEMO 22 Aquanaut

ESAT Objectives & Task Matrix

EVA Objective (per MOR)	Engineering Run Task
DAVD (EVA HUD)	
Test dive NASA KM37 with DAVD integrated	Conduct initial test dive of NASA KM37 with integrated DAVD
Functionally test DAVD control box	Test DAVD system compoeents in hyperbaric environment (hab)
	DAVD topside control box
	MS-1000 laptop and electronic controllers
	CODA Echoscope laptops and electronic controllers
Operationally test DAVD HUD system	Test dive NASA KM37 w/DAVD from the habitat
	Evaluate usability of HUD and mission data
	Demonstrate real-time images from Sector Scan
	Demonstrate real-time images from Echoscope 4G C500
	Demonstrate images and drawing pop-ups on HUD display
	Demonstrate text messaging communication with diver
	Demonstrate on-screen navigation direction
	Evaluate HUD layout, amount of data, colors, and dynamic data
	Evalute use of 3D model displayed to diver
Tracking / Sonar	
Deploy sector sonar and test system	Deploy sonar
	Set up the Kongsberg MS-1000 and the CODA Echoscope C-500 (surface) outside the habitat
	Identify the most suitable operational location
	Verify ability to transmit sonar data to the hab and MCC
	Establish connections to send the images up to surface and command center
	Establish connections to control the sonar systems from the surface and send data to hab
	Evaluate use for EVA navigation
	Try out various locations in order to scan the exploration zones
Deploy and test TrackLink	Verify placement and functionality of tracking transponders
IV Workstation (w/DAVD)	
Evaluate EVA support system & IV workstation	Set up system hardware and configure workstation
	Note any changes needed to table overlay
	Test server link to MCC and run example timeline
	Setup initial displays and evaluate functionality
	Import Analox data into workstation
	Verify Playbook ops with EVA timeline tracking features
	Determine how to integrate sonar operation
	End-to-end run through of tasks (nursery and drilling)
Science EVA Tasks	
Develop hab-mounted coral nursery procedures	Determine all equipment and steps for end-to-end process
Scout area for science targets	Scout area for science targets (FAU sampling)
	Map zones for areas of available species
	Collect precursor imagery for map
	Check traverse paths to zones
Test science acquisition tool (Stinger)	Test Stinger sampling device
	Capture imagery/video for procedure

EVA Objective (per MOR)	Engineering Run Task
EVA Tools & Equipment	
Deploy EVA staging area	Deploy EVA staging area
Eval utilizing EMU TMG gloves for EVA crew	Check any interference or issue with tools modules
	Verify operability of core drill with gloves
	Verify operability of Stinger with gloves
	Verify operability of CISME with gloves
Check operation of new Nemo hammer drill	Check operation of new Nemo hammer drill
Evaluate SABRE (ISU)	Evaluate the ISU tools harness
	Check interference with EVA glove (EMU TMG)
Evaluate Suit-mounted Equipment Carrying System	Evaluate upgraded SECS/forearm module
	Check interference with EVA glove (EMU TMG)
Evaluate zip tie cutter	Evaluate zip tie cutter
Add Velcro to white wetsuits	Add velcro strips to NASA wetsuits for use with SABRE
Inventory EVA Office equipment	Inventory all equipment purchased by EVA in the dive locker
General EVA Ops	
Evaluate night EVA operations	Test general night ops
	Evaluate if CISME can be done at night
	Determine practical topside support diving capability
Test dive new diver harnesses	Test dive new diver harnesses
Scout hazards	Map hazards and update EVA map
Verify traverse paths andumbilical routing	
Finalize location for LESA	Look at proposed area for LESA and stowing the Comex suit
Shoreside EVA	
Demonstrate PaleBlue's VR Diver	Demonstrate PaleBlue's VR Diver

Engineering Week Objectives

- Interior
  - IV workstation config and testing (new system)
    - Connectivity w/ DAVD & pushing data
    - Tracking
    - Sonar
  - Comm system config and testing (new system)
    - MCC-to-EV direct link comm (allows Ground IV concept)
  - Experiment Prerequisites and Pre-config
    - Tracking system setup and calibration w/ their engineering team (Alltraq)
    - HoloLens AR – acquire 3D map, apply April stickers, calibrate system, validate procedure (JPL)
    - 3D scanned maps of Aquarius interior (Alltraq & WKS (Draper))
  - Experiment hardware functionality checks
    - DAVD Control Box
    - WKS
    - RTPM laptop
    - Neurocog laptop
    - SEM
  - Firewall/Connectivity checks
    - WKS
    - SEM
    - Med Scenario Telementoring

- Exterior
  - DAVD
    - Checkout KM37 w/ DAVD integrated
    - Test dive KM37 w/ DAVD from habitat
    - Evaluate usability of mission data layouts, sonar, tracking, texting
  - Tracking
    - Verify placement and mounting of sonar head
    - Verify placement and functionality of tracking transponders
    - Solve interference problems between the systems
  - Scouting
    - For science sites
    - Update EVA map
    - Method for marking keepout areas
    - Identify location for LESA ops
  - Nursery
    - Evaluate hab mounted nursery build hardware requirements
    - End-to-end run thru of tasks
  - Pre-config work
    - Build science staging area
    - Verify operability of science tools and instruments using EMU TMG gloves
    - Evaluate new dive harnesses
    - Evaluate new hammer drill
    - Evaluate extended umbilicals, and new traverse paths
    - Solve joggle mount

EVA Objective (per MOR)	Engineering Run Task	Priority	Topside or Saturation	Equip needed	Min/Prime SME Evaluators/Divers	Requirements / Enablers	Products needed	Surface Support
DAVD (EVA HUD)								
Test dive NASA KM37 with DAVD integrated	Conduct initial test dive of NASA KM37 with integrated DAVD	1	Topside	NASA KM37	XX/EVA (Coan)	Completed before start of saturation		NAVSEA/NSWC
				DAVD	XI/ARES (Graff)	KM37 with integrated DAVD		
						Data cable secured to/in umbilical		
						Control box deployed near comm box		
						NAVSEA/NSWC personnel available on site		
Functionally test DAVD control box	Test DAVD system compoenents in hyperbaric environment (hab)	1	Saturation		XX/EVA (Coan)	Saturation with SMEs		NAVSEA/NSWC
	DAVD topside control box				XI/ARES (Graff)			
	MS-1000 laptop and electronic controllers							
	CODA Echoscope laptops and electronic controllers							
Operationally test DAVD HUD system	Test dive NASA KM37 w/DAVD from the habitat	1	Saturation	NASA KM37	XX/EVA (Coan)	Saturation with SMEs	EVA cue cards	NAVSEA/NSWC
	Evaluate usability of HUD and mission data			DAVD system	XI/ARES (Graff)	KM37 with integrated DAVD		NAVSEA (McMurtrie)
	Demonstrate real-time images from Sector Scan			Sonar		Data cable secured to/in umbilical		
	Demonstrate real-time images from Echoscope 4G C500					Sector sonar set up		
	Demonstrate images and drawing pop-ups on HUD display					Control box deployed near comm box		
	Demonstrate text messaging communication with diver					NAVSEA/NSWC personnel available on site		
	Demonstrate on-screen navigation direction					Drilling procedures and cue cards		
	Evaluate HUD layout, amount of data, colors, and dynamic data					NAVSEA/NSWC personnel on support boat		
	Evalute use of 3D model displayed to diver							
Tracking / Sonar								
Deploy sector sonar and test system	Deploy sonar	1	Topside	Kongsberg MS1000	NAVSEA (McMurtrie)	Navy divers to deploy and move sonar		NAVSEA/NSWC
	Set up the Kongsberg MS-1000 and the CODA Echoscope C-500 (surface) outside the habitat			sonar head	XX/EVA (Coan)	NAVSEA/NSWC personnel on support boat		NAVSEA (McMurtrie)
	Identify the most suitable operational location			interface box	XI/ARES (Graff)	IV operator		
	Verify ability to transmit sonar data to the hab and MCC			300' of cable				
	Establish connections to send the images up to surface and command center			CODA Echoscope C-500				
	Establish connections to control the sonar systems from the surface and send data to hab			DAVD				
	Evaluate use for EVA navigation							
	Try out various locations in order to scan the exploration zones							
Deploy and test TrackLink	Verify placement and functionality of tracking transponders	2	Topside		Shark Marine	IV operator (any)		
					XX/EMPO (Todd)			
IV Workstation (w/DAVD)								
Evaluate EVA support system & IV workstation	Set up system hardware and configure workstation	1	Saturation	Monitors	XX/EVA (Coan)	Saturation with SMEs		
	Note any changes needed to table overlay			Monitor bracket	XI/ARES (Graff)	XI/ARES workstation expert topside		
	Test server link to MCC and run example timeline			IV workstation	XM/EMPO (Reagan)			
	Setup initial displays and evaluate functionality			DAVD control box				
	Import Analox data into workstation			Diver comm box				
	Verify Playbook ops with EVA timeline tracking features			DiveLog software				
	Determine how to integrate sonar operation							
	End-to-end run through of tasks (nursery and drilling)							

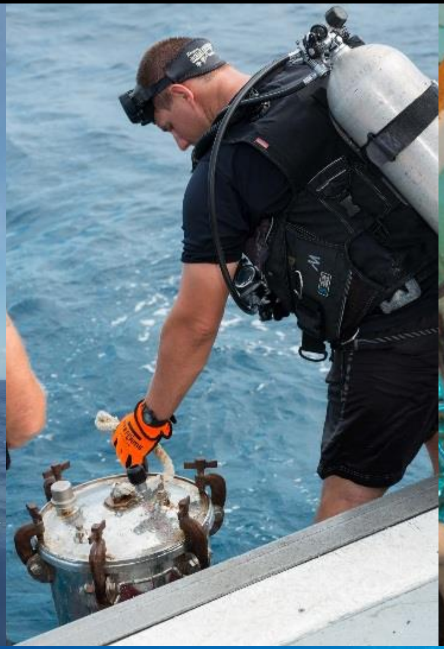
EVA Objective (per MOR)	Engineering Run Task	Priority	Topside or Saturation	Equip needed	Min/Prime SME Evaluators/Divers	Requirements / Enablers	Products needed	Surface Support
Science EVA Tasks								
Develop hab-mounted coral nursery procedures	Determine all equipment and steps for end-to-end process	1	Saturation	Mounting hardware	EC7/Tools (Naids)	Topside dive support (EC7/Naids)		
				Coral tree pole	XI/ARES (Graff)	Shoreside support (EC7/Walker)		
				Ladder	XX/EVA (Coan)			
Scout area for science targets	Scout area for science targets (FAU sampling)	1	Both	Cameras	XI/ARES (Graff)			
	Map zones for areas of available species				XI/ARES (Young)			
	Collect precursor imagery for map				FAU			
	Check traverse paths to zones							
Test science acquisition tool (Stinger)	Test Stinger sampling device	2	Topside	Stinger	XI/ARES (Graff)			
	Capture imagery/video for procedure				XI/ARES (Young)			
					EC7/Tools (Naids)			
EVA Tools & Equipment								
Deploy EVA staging area	Deploy EVA staging area	2	Topside	Staging area	EC7/Tools (Naids)			
Eval utilizing EMU TMG gloves for EVA crew	Check any interference or issue with tools modules	2	Saturation	EMU TMG	EC7/Tools (Naids)			
	Verify operability of core drill with gloves			3mm dive gloves	Any Aquanaut			
	Verify operability of Stinger with gloves			Forearm modules				
	Verify operability of CISME with gloves			Drill				
				Core bit				
				Stinger				
				CISME				
Check operation of new Nemo hammer drill	Check operation of new Nemo hammer drill	3	Topside	Nemo hammer drill	EC7/Tools (Naids)			
Evaluate SABRE (ISU)	Evaluate the ISU tools harness	3	Saturation	Tool Harness	Any Aquanaut			
	Check interference with EVA glove (EMU TMG)			EMU TMG				
				3mm dive gloves				
Evaluate Suit-mounted Equipment Carrying System	Evaluate upgraded SECS/forearm module	3	Saturation	Forearm modules	Any Aquanaut			
	Check interference with EVA glove (EMU TMG)			EMU TMG				
				3mm dive gloves				
Evalute zip tie cutter	Evaluate zip tie cutter	1	Saturation	Zip tie cutter	Any Aquanuat			
Add Velcro to white wetsuits	Add velcro strips to NASA wetsuits for use with SABRE	2	Topside	Aqua Seal				
				Velcro				
Inventory EVA Office equipment	Inventory all equipment purchased by EVA in the dive locker	3	Topside		EC7/Tools (Walker)			

ESAT Objectives & Task Matrix

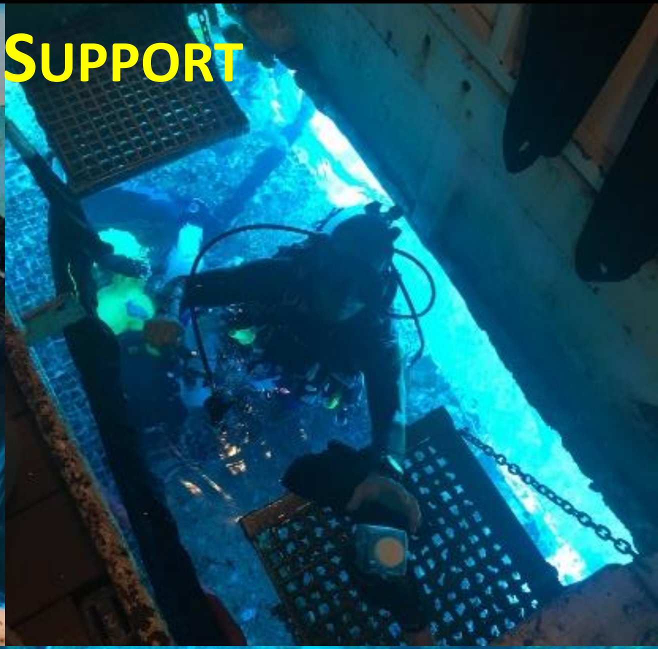
EVA Objective (per MOR)	Engineering Run Task	Priority	Topside or Saturation	Equip needed	Min/Prime SME Evaluators/Divers	Requirements / Enablers	Products needed	Surface Support
General EVA Ops								
Evaluate night EVA operations	Test general night ops	1	Saturation	Lights	XX/EVA (Coan)			
	Evaluate if CISME can be done at night			CISME				
	Determine practical topside support diving capability							
Test dive new diver harnesses	Test dive new diver harnesses	3	Saturation	R-vest harnesses	All Aquanauts			
Scout hazards	Map hazards and update EVA map	3	Both					
Verify traverse paths andumbilical routing		3	Saturation		Any Aquanaut	Waystation		
Finalize location for LESA	Look at proposed area for LESA and stowing the Comex suit	3	Either		Any Aquanaut			
					EC7/Tools (Naids)			
Shoreside EVA								
Demonstrate PaleBlue's VR Diver	Demonstrate PaleBlue's VR Diver	3	Topside		All Aquanauts	Space at ARB		
						Time at the end of ESAT		

Support Dive Operations & Dive Safety


R/V George F. Bond

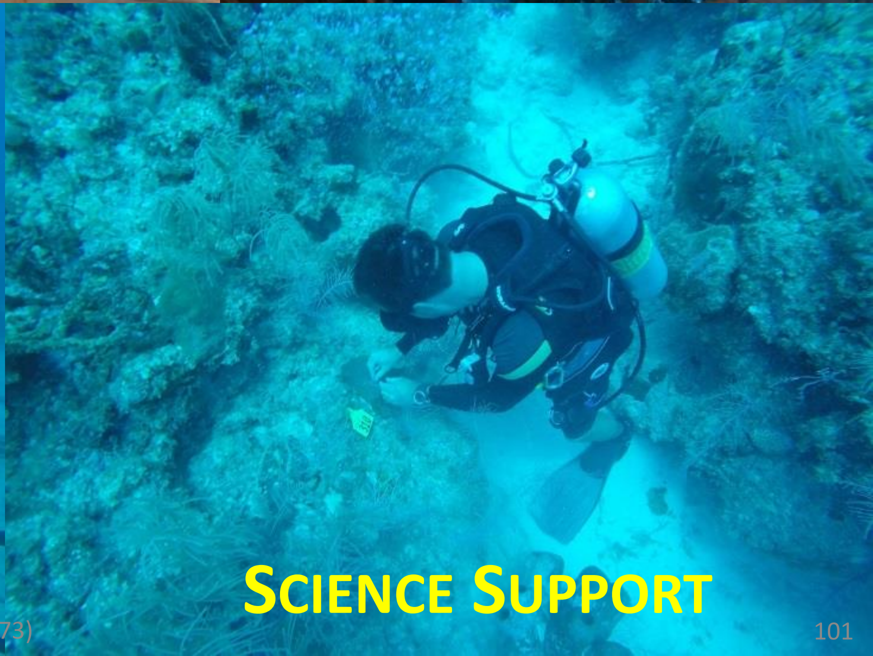



POTTING & HAB SUPPORT




EVA SUPPORT


AQUANAUT SUPPORT


SCIENCE SUPPORT

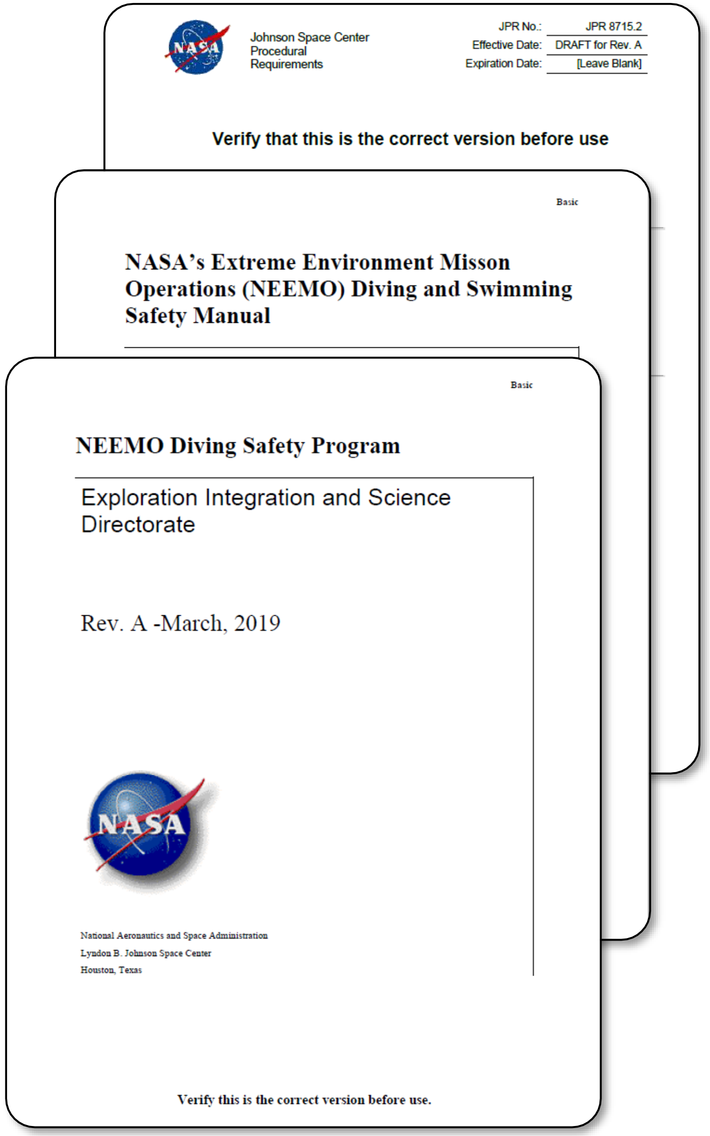
The NEEMO Dive Safety Board (DSB) provides subject matter experts to review any diving operations conducted by or for JSC, including Relevant Environments for Analysis and Development (READy) projects

The majority of the DSB members shall be active divers and shall perform the following functions:

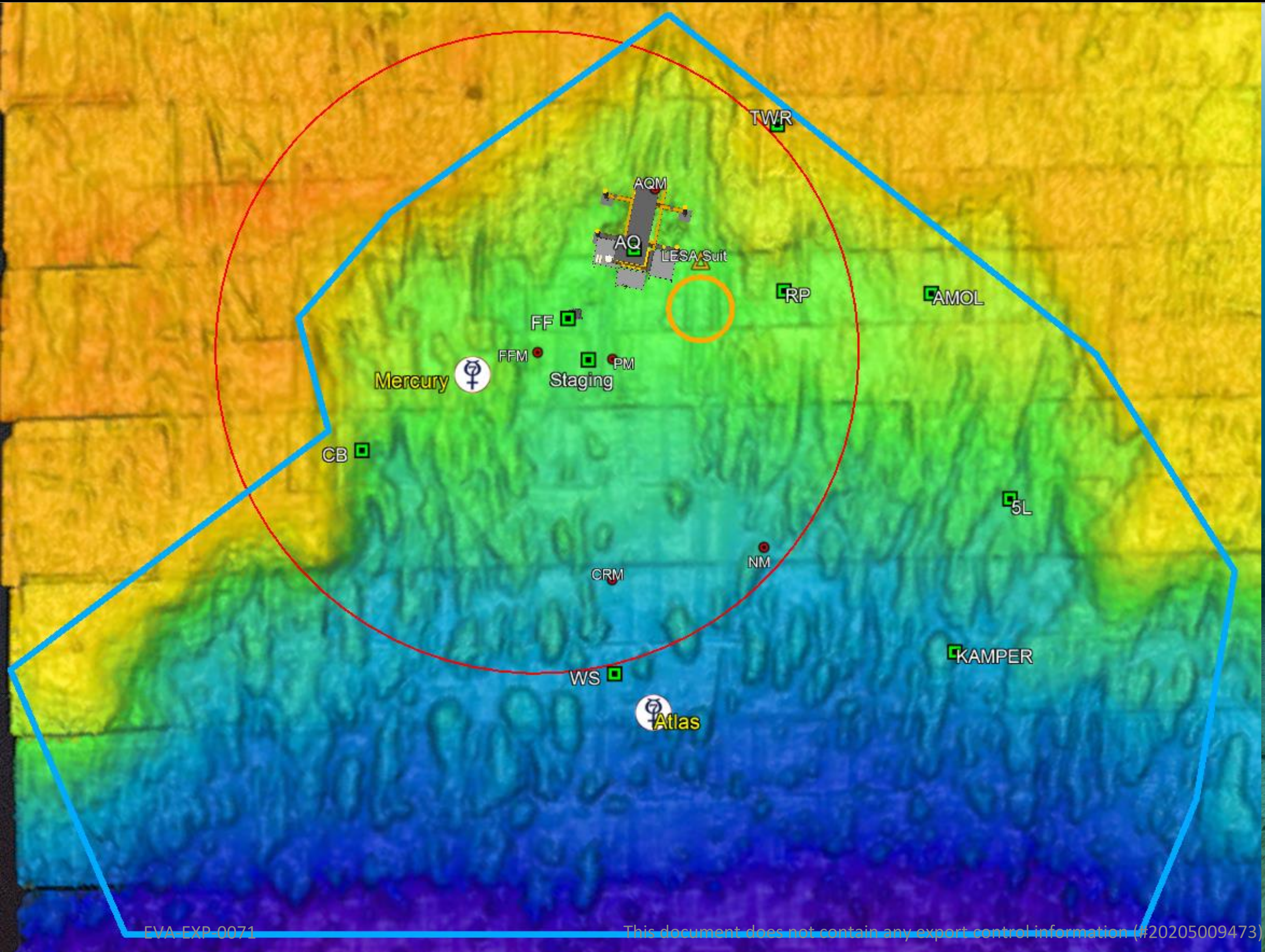
- Approves and monitors diving and snorkeling activities
- Reviews and revises the NEEMO Diving and Swimming Safety Manual
- Assures compliance with the NEEMO Diving Safety Program Manual
- Certifies divers for specific underwater activities

NEEMO Dive Safety Board Members:

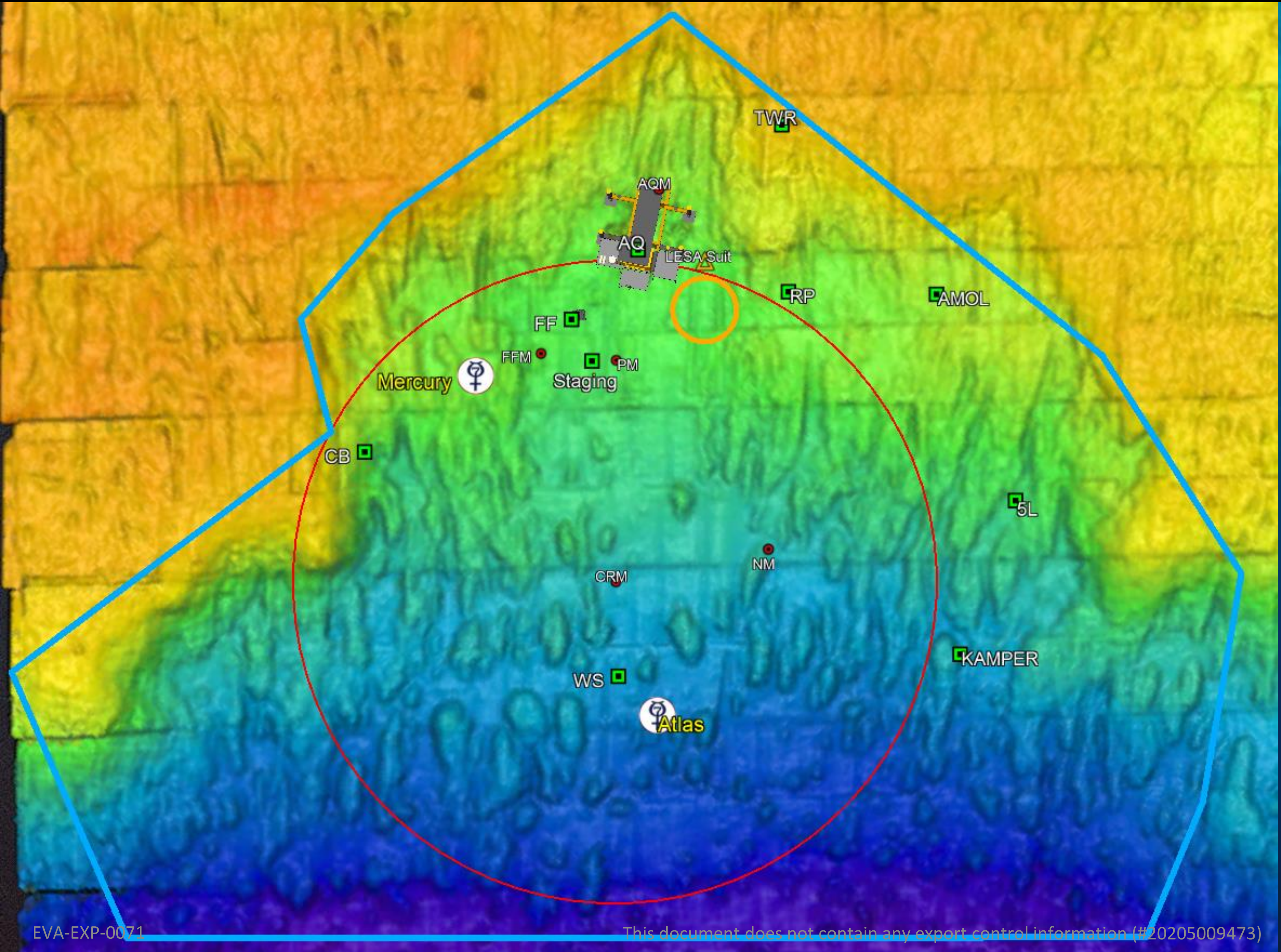
- **Bill Todd** – NEEMO Project Lead, Experienced Aquanaut
- **Jason Poffenberger** – Active Support Diver
- **Joe Schmid** – Medical Doctor, Experienced Aquanaut
- **David Coan** – NEEMO EVA Lead, Experienced Aquanaut, Active Support Diver



Dive Support from Flask Farm Mooring



Dive Support from Cross Roads Mooring



OTHER EVA-RELATED INFORMATION

#16: PaleBlue virtual reality training		
Completed	Partially Completed	Not Completed
		Demonstrate PaleBlue's VR capability for potential use at NEEMO and for EVA

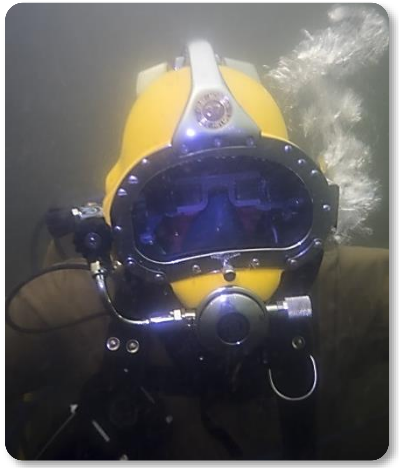
EVA Timeline for NEEMO 23 Mission *(as of 5/1/19)*

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday
10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun	16-Jun	17-Jun	18-Jun	19-Jun
MD 1	**MD 2**	**MD 3**	**MD 4**	**MD 5**	**MD 6**	**MD 7**	**MD 8**	**MD 9**	**MD 10**
CDR/FE-3, FE-1/FE-2	CDR / FE-2	FE-1 / FE-3	CDR / FE-2	FE-1 / FE-3	CDR / FE-2	FE-1 / FE-3	CDR / FE-2	CDR / FE-1, FE-2 / FE-3	
ARB Watch Desk	MCC/ST	MCC/ST	FE-1	CDR	MCC/ST	FE-2	FE-3	MCC/ST	
	FE-1	CDR, FE-2			FE-1			FE-2, CDR	
					Night EVA	Night EVA			
Fam Dive (PM) 1hr **Fam Dive (PM)** 1hr	Egress 0.1 hr Joggle/Dex (0.15 hr) Setup 0.15 hr **LESA** (CDR) 0.75 hr **Sci Recon** 0.5 hr **CISME / Core Sample** (2) 0.75 hr **CISME / Core Sample** (1+1) 0.75 hr **ESA Geo Tools & NEST** 0.75 hr Cleanup 0.15 hr Joggle/Dex (0.15 hr) Ingress 0.1 hr	Egress 0.1 hr Joggle/Dex (0.15 hr) Setup 0.15 hr **LESA** (FE-1) 0.75 hr **Sci Recon** 0.5 hr **CISME / Core Sample** (1+1) 0.75 hr **CISME / Core Sample** (2) 0.75 hr **ESA Geo Tools & NEST** 0.75 hr Cleanup 0.15 hr Joggle/Dex (0.15 hr) Ingress 0.1 hr	Egress 0.1 hr Joggle/Dex (0.15 hr) Setup 0.15 hr **DAVD** 4.0 hr (CDR) / **EVA Cnfg** 0.5 hr **EVA Nav** 1.0 hr **Hab Coral Tree** 1.5 hr **Tool Harness** 0.5 hr **Hab Repair** 0.5 hr Cleanup 0.15 hr Joggle/Dex (0.15 hr) Ingress 0.1 hr	Egress 0.1 hr Joggle/Dex (0.15 hr) Setup 0.15 hr **DAVD** 4.0 hr (FE-1) / **EVA Cnfg** 0.5 hr **EVA Nav** 1.0 hr **Mercury Coral Nursery** 1.5 hr **Tool Harness** 0.5 hr **Hab Repair** 0.5 hr Cleanup 0.15 hr Joggle/Dex (0.15 hr) Ingress 0.1 hr	Egress & Setup 0.25 hr **CISME / Core Sample** (2) 1.75 hr **CISME** (staging) 1.75 hr Cleanup & Ingress 0.25 hr	Egress & Setup 0.25 hr **CISME** (2) (staging area) 1.0 hr **CISME** (1+1) (staging area) 1.0 hr **Stinger** 1.5 hr Cleanup & Ingress 0.25 hr	Egress & Setup 0.25 hr **CISME / Core Sample** (2) (reef) 1.5 hr **Stinger** 1.5 hr **Coral Nursery N23 (TBD)** 1.5 hr Cleanup & Ingress 0.25 hr	Egress & Setup 0.25 hr **DAVD / CISME** 1.5 hr Cleanup & Ingress 0.25 hr Egress & Setup 0.25 hr **DAVD / CISME** (staging) 1.5 hr Cleanup & Ingress 0.25 hr	
					Egress & Setup 0.25 hr **DAVD / CISME** 1.0 hr Cleanup & Ingress 0.25 hr	Egress & Setup 0.25 hr **DAVD / CISME** 1.0 hr Cleanup & Ingress 0.25 hr			

https://neemo23.nasaplaybook.com/?plan=mission

Required Elements for Participation in NEEMO EVA Excursions

Inclusion and priority of all objectives, tasks, techniques, technologies, and equipment evaluated during NEEMO EVAs (excursions from the Aquarius habitat) will be based on relevancy to human space exploration and EVA, ability to be executed within the NEEMO environment and framework, integration with groups across the architecture, and funding



RELEVANT

- Pursues solutions that may enable human space exploration
- Relevant to development of the Exploration EVA System and operations concepts (i.e., objectives mapped to specific needs and capability, knowledge, and technology gaps; along with EVA-EXP-0042)
- Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
- Incorporates acknowledged stakeholders expertise to evaluate concepts being worked on across the agency
- Expands scientific knowledge and involves scientists invested in the proxy science outcome
- Provides NASA with key technology concepts, with potential benefit ISS as well as Exploration

EXECUTABLE

- Executable with the incorporation of signal latency (comm/time delay) and/or blockage
- Able to be conducted in partial gravity in an un-engineered natural (planetary) surface [with potential for microgravity ops]
- Allows for both MCC and Science Team components
- Proxy science with high correlation to planetary science
- Inclusion of appropriate purpose-built prototype hardware for evaluation and maturation
- Any single objective must fit into a complete mission timeline without overtaking or disrupting the host of other objectives
- Trainable to non-familiar crew in a short duration
- Requires less than 4 hours of EVA time during any given mission day

INTEGRATED

- Integrated with groups across Exploration architecture
- Enhances relationships with international partners, academia, industry, other government agencies, and other NASA orgs
- Highlights work in Exploration in a visible and tangible way

FUNDED

- Must come with clear funding that allows for completion of the objective

EVA-Related Roles & Responsibilities (per *NEEMO Mission Implementation Plan*)

Key Personnel

- **Mission Management Team (MMT)** – The NEEMO project is led by a Project Manager, Mission Director, EVA Lead, and Science Lead. Together they make up the MMT.
- **NEEMO Mission Director (MD)** – Responsible for safe and successful execution of the spaceflight analog mission, and all ops and training products, including the timeline and communications with the crew during the mission. The MD has final authority for strategic and tactical decisions during both IVA and EVA operations, and is responsible for the Mission Control Center (MCC) and Science Team (ST) operations, much like a Flight Director. The MD integrates interior objectives, and works with the EVA Lead to integrate exterior objectives into the timeline.
- **NEEMO EVA Lead** – Responsible for all mission objectives and tasks conducted during EVA excursion operations, including integrating an executable EVA timeline with traceability back to EVA gaps and objectives. The Lead is responsible for relevancy of objectives, crew EVA training, EVA tool and equipment development, and daily EVA products during mission execution. The EVA Lead ensures that the crew and topside dive team have the required equipment and support to complete tasks during the EVA excursions, and is responsible for ensuring all EVA excursion equipment is functional and safe for use. The EVA Lead has oversight of the **EVA Tools Lead**, who has direct accountability for the EVA equipment.
- **NEEMO Science Lead** – Responsible for integration of execution of EVA Science objectives, with traceability back to research goals, exploration objectives, and strategic knowledge gaps. Lead of the Science team during mission planning and execution, and oversight of daily Science products.

Primary Planning Meetings

- **Mission Support Meeting (MSM)** – this is led by the Project Lead, and involves the entire team of participants for the upcoming mission. It's used primarily to communicate high level milestones and deadlines, share high level objectives, and status work of general interest to all participants. They happen every 2 weeks starting at about M-4 months.
- **MMT** – this is led by the Project Manager, and includes the Mission Director, EVA Lead, and Science Lead. It is where high level mission decisions, including schedule milestones and mission priorities are made. They happen every 2 weeks year round, but increase frequency to weekly starting at about M-5 months.
- **EVA Ops** – this is led by the EVA lead, and involves the broader EVA community, to include reps from science, EVA tools, exterior objective stakeholders, the Project Lead and the Mission Director. It is where the EVA objectives and mission design are matured. This includes integration of various objectives, development of the mission timeline, oversight of equipment development, saturation excursion dive needs, and planning for the topside dive team support. They happen weekly starting at about M-5 months.
- **EVA Tools** – this is led by the EVA Tools lead, and involves the same participants as the EVA Ops meeting. The intent is to set detailed requirements for new tool development, and ensure they are being designed and built to meet mission EVA objectives. They happen weekly starting at about M-4 months.

Project Coordination

- **EVA Ops & Topside Dive Team Activities** – Dive activities that support the day's EVA are led/managed by the EVA Lead. These include ensuring all required NASA equipment is onboard, that the dive team has the necessary equipment and tanks to conduct their dives, that the dive team understands their assignments and tasks, and that the dive rotation covers the required parts of the EVA.

History of NEEMO Crew

NEEMO Missions & Crewmembers

NEEMO 1 - 6 Days, Oct. 21-27, 2001	DT/B. Todd, CB/M. Lopez-Alegria, M. Gernhardt*, CSA/D. Williams*
NEEMO 2 - 9 Days, May 13-20, 2002	CB/M. Fincke, D. Tani, S. Williams, DT/M. Reagan
NEEMO 3 - 9 Days, July 15-21, 2002	CB/J. Williams, D. Olivas*, G. Chamitoff, SLSD/J. Dory
NEEMO 4 - 5 Days, Sept. 23-27, 2002	CB/S. Kelly*, R. Walheim, DA8/P. Hill, SLSD/J. Meir
NEEMO 5 - 14 Days, June 16-29, 2003	CB/P. Whitson, C. Anderson, G. Reisman, SLSD/E. Hwang
NEEMO 6 - 10 Days, July 12-21, 2004	CB/J. Herrington, D. Wheelock, N. Patrick*, EB/T. Ruttley
NEEMO 7 - 11 Days, Oct. 11-21, 2004	CSA/B. Thirsk, C. Coleman, M. Barratt, CMAS/C. Mckinley
NEEMO 8 - 3 Days, April 20-22, 2005	CB/M. Gernhardt*, S. Kelly*, D. Olivas*,, M. Schultz
NEEMO 9 – 18 days, April 3-20, 2006	CSA/D. Williams*, CB/N. Stott, R. Garan,, TATRC/T. Broderick*
NEEMO 10 – 7 days, July 22-28, 2006	JAXA/K. Wakata, CB/D. Feustel, K. Nyberg,, NOAA/K. Kohanowich
NEEMO 11 – 7 days, Sep. 16-22, 2006	CB/S. Magnus, T. Kopra, B. Behnken, T.J. Creamer
NEEMO 12 – 12 days, May 7-18, 2007	CB/H. Piper, J. Hernandez, SD/J. Schmidt, TATRC/T. Broderick*
NEEMO 13 – 10 days, Aug. 6-15, 2007	CB/N. Patrick*, R. Arnold, JAXA/S. Furukawa, Cx/C. Gerty
NEEMO 14 – 12 days, May 10-23,2010	CSA/C. Hadfield, CB/T. Marshburn, EAMD/A. Abercromby, S. Chappell
NEEMO 15 – 7 days, Oct. 20-26, 2011	CB/S. Walker, JAXA/T. Onishi, CSA/D. Saint-Jacques, NAC/ S. Squyres*
NEEMO 16 – 12 days, Jun 11-22, 2012	CB/D. Metcalf- Lindenburger, JAXA/K. Yui, ESA/T. Peake, NAC/S. Squyres*
NEEMO 17 – 7 days, Sept. 9-13, 2013	CB/J. Acaba, K. Rubins, JAXA/S. Noguchi, ESA/A. Mogensen*
NEEMO 18 – 9 days, July 21-29, 2014	JAXA/A. Hoshide, CB/M. Vande Hei, Jeanette Epps, ESA/Thomas Pesquet
NEEMO 19 – 7 days, Sept. 7-13, 2014	CB/R. Bresnik, ESA/A. Mogensen*, CSA/J. Hansen, ESA/H. Stevenin
NEEMO 20 – 14 days, Jul 20 – Aug 2, 2015	ESA/L. Parmitano, CB/S. Aunon, JAXA/N. Kanai, NASA/EVA/D. Coan
NEEMO 21 – 16 days (split), Jul 21-Aug 5, 2016	CB/R. Wiseman, M. McArthur, ESA/M. Maurer, IHMC/D. Kernagis, NMT/Marc O Griofa, NPS/N. du Toit
NEEMO 22 – 10 days, Jun 18-27, 2017	CB/K. Lindgren, ESA/P. Duque, NASA/ARES/T. Graff, IHMC/D. D'Agnostino
NEEMO 23 – 9 days, Jun 13-21, 2019	ESA/S. Cristoforetti, CB/J. Watkins, FAU/S. Pomponi, USF/C. D'Agnostino

74 Crewmembers:
56 Astronauts (17 IP Astronauts)
20 Engineers, Scientists, Instructors, or MDs

Key
* Repeater
Black – Experienced NASA Astronaut
Blue – Experienced Astronaut CDR upgrade
Green – IP Astronaut
RED – Rookie Astronaut
Gray – NASA (or Related) Engineer or Scientist
Orange –Engineer or Scientist External to NASA

Astronaut-Aquanauts

1. Carpenter (SEALAB II, 8/29/65)
2. Gernhardt (NEEMO 1&8, 10/22/01)
3. Lopez-Alegria (NEEMO 1)
4. D. Williams (NEEMO 1&9, 10/22/01)
5. Tani (NEEMO 2, 5/14/02)
6. J. Williams (NEEMO 3, 7/16/02)
7. S. Kelly (NEEMO 4&8, 9/24/02)
8. Walheim (NEEMO 4, 9/24/02)
9. Whitson (NEEMO 5, 6/17/03)
10. Fincke (NEEMO 2, 4/18/04)
11. Herrington (NEEMO 6, 7/13/04)
12. Thirsk (NEEMO 7, 10/12/04)
13. Coleman (NEEMO 7, 10/12/04)
14. Wakata (NEEMO 10, 7/23/06)
15. Magnus (NEEMO 11, 9/17/06)
16. Patrick (NEEMO 6&13, 12/9/06)
17. S. Williams (NEEMO 2, 12/9/06)
18. Stefanyshin-Piper (NEEMO 12, 5/8/07)
19. Anderson (NEEMO 5, 6/8/07)
20. Olivas (NEEMO 3&8, 6/8/07)
21. Wheelock (NEEMO 6, 10/23/07)
22. Behnken (NEEMO 11, 3/11/08)
23. Reisman (NEEMO 5, 3/11/08)
24. Chamitoff (NEEMO 3, 5/31/08)
25. Garan (NEEMO 9, 5/31/08)
26. Nyberg (NEEMO 10, 5/31/08)
27. Arnold (NEEMO 13, 3/15/09)
28. Barratt (NEEMO 7, 3/26/09)
29. Feustel (NEEMO 10, 5/11/09)
30. Kopra (NEEMO 11, 7/15/09)
31. Hernandez (NEEMO 12, 8/28/09)
32. Stott (NEEMO 9, 8/28/09)
33. Creamer (NEEMO 11, 12/20/09)
34. Hadfield (NEEMO 14, 5/10/10)
35. Marshburn (NEEMO , 5/10/10)
36. Furukawa (NEEMO 13, 6/7/11)
37. Walker (NEEMO 15, 10/21/11)
38. Metcalf-Lindenburger (NEEMO 16, 6/12/12)
39. Acaba (NEEMO 17, 9/10/13)
40. Noguchi (NEEMO 17, 9/10/13)
41. Hoshide (NEEMO 18, 7/22/14)
42. Bresnik (NEEMO 19, 9/8/14)
43. Parmitano (NEEMO 20, 7/21/15)
44. Yui (NEEMO 16, 7/22/15)
45. Mogensen (NEEMO 17&19, 9/2/15)
46. Peake (NEEMO 16, 12/15/15)
47. Onishi (NEEMO 15, 7/7/16)
48. Rubins (NEEMO 17, 7/7/16)
49. M. Behnken (NEEMO 21, 7/22/16)
50. Wiseman (NEEMO 21, 7/22/16)
51. Pesquet (NEEMO 18, 11/17/16)
52. Lindgren (NEEMO 22, 6/19/17)
53. Duque (NEEMO 22, 6/19/17)
54. Vande Hei (NEEMO 18, 9/12/17)
55. Cristoforetti (NEEMO 23, 6/13/19)

Engineer-Scientist Aquanauts

1. W. Todd (NEEMO 1, SEATEST I, III, IV; 10/01)
2. M. Reagan (NEEMO 2, SEATEST III, IV; 5/02)
3. J. Dory (NEEMO 3; 7/02)
4. P. Hill (NEEMO 4; 7/02)
5. J. Meir (NEEMO 4; 7/02)
6. E. Hwang (NEEMO 5; 6/03)
7. T. Ruttley (NEEMO 6; 7/04)
8. C. Mckinley (NEEMO 7; 10/04)
9. M. Shultz (NEEMO 8, 4/05)
10. T. Broderick (NEEMO 9&12; 4/06)
11. K. Kohanowich (NEEMO 10; 7/06)
12. J. Schmidt (NEEMO 12; 5/07)
13. C. Gerty (NEEMO 13; /04)
14. A. Abercromby (NEEMO 14; 6/10)
15. S. Chappell (NEEMO 14; 6/10)
16. S. Squires (NEEMO 15&16; 10/11)
17. H. Stevenin (NEEMO 19; 7/14)
18. D. Coan (NEEMO 20, SEATEST IV; 7/20/15)
19. M. O'groifa (NEEMO 21; 7/16)
20. D. Kernagis (NEEMO 21; 7/16)
21. D. D'Agnostino (NEEMO 22; 6/17)
22. T. Graff (NEEMO 22; 6/18/17)
23. S. Pomponi (NEEMO 23, 6/13/19)
24. C. D'Agostino (NEEMO 23, 6/13/19)