NEEMO 22
EVA Overview & Debrief

EVA-EXP-0054

EVA Exploration Office | XX4
David Coan | NEEMO Mission Management Team, EVA Lead
December 5, 2017

AGENDA

- NEEMO Analog Overview
  - Integrated Operational Testing: Who, What, Where, Why, How
- NEEMO 22 Mission Overview
- NEEMO 22 Integrated EVA
- NEEMO 22 IVA
- Backup

NEEMO ANALOG OVERVIEW

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

ANALOGS: 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 missions

WHO

MULTI-ORGANIZATIONAL TEAMS

eisd
EXPLORATION INTEGRATION & SCIENCE DIRECTORATE

coordinated integration

- PLANNING
- EVA
- SCIENCE
- TECHNOLOGY

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 led 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

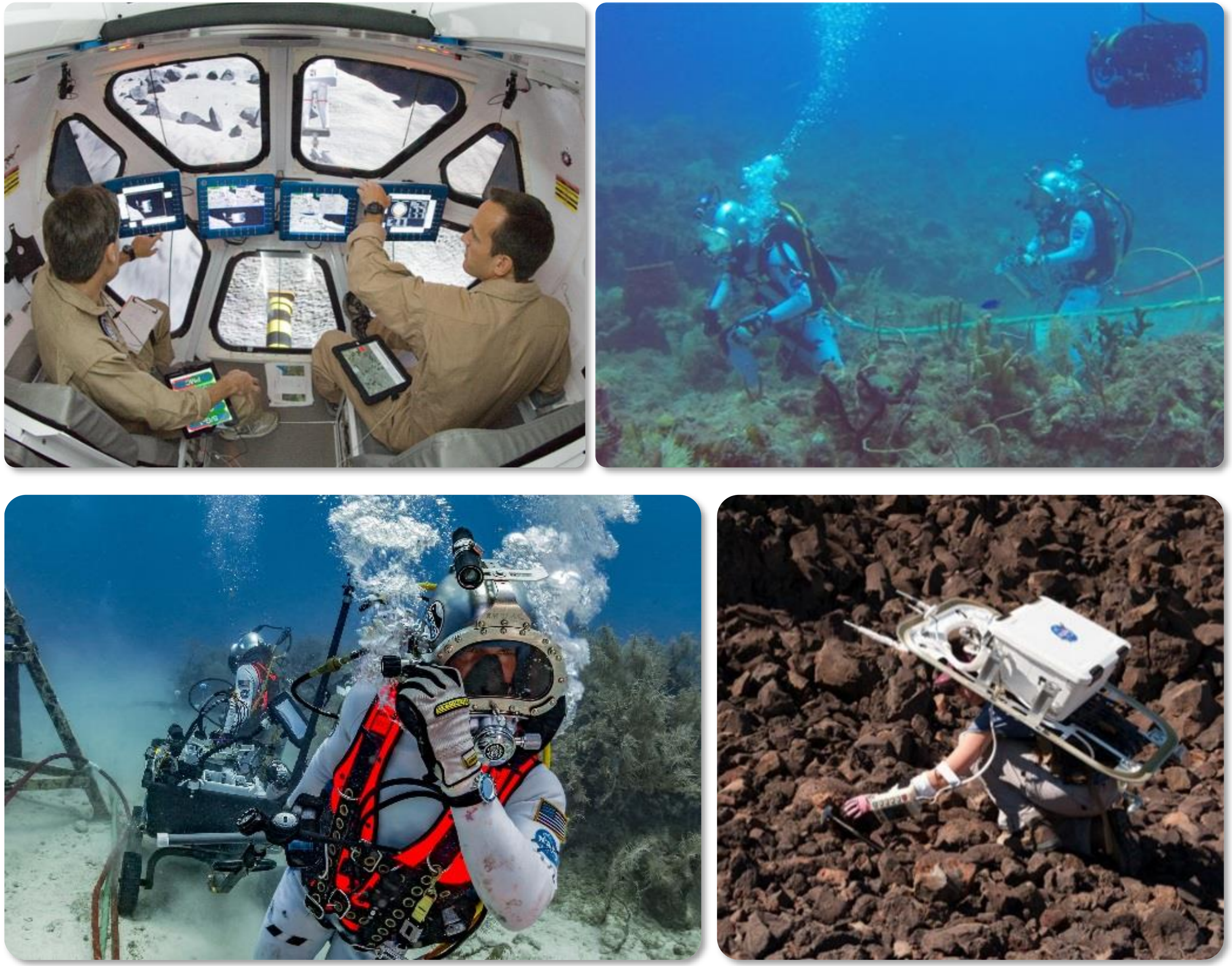
RISE

SHyRE

WHY: EVA GOALS FOR INTEGRATED OPERATIONAL TESTING

EVA Goals

- Advance the future of the EVA System and operations
- Understand EVA capability, knowledge, and technology gaps 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 for Exploration missions
- Develop and document concepts of operations for EVA at the Exploration destinations
- Realize the needs of EVA equipment and enable the development of concepts for design maturation on the road-to-flight



WHO: NASA, ACADEMIA, INDUSTRY, MILITARY @ NEEMO

NASA

JSC GSFC

ARC JPL

KSC

esa JAXA

CSA ASC

FIU FLORIDA INTERNATIONAL UNIVERSITY

XI XM XX

CB EC ER SK

FIU Florida International University

AQUARIUS REEF BASE

HONEYBEE ROBOTICS

NPS

CORAL RESTORATION FOUNDATION

JOHNS HOPKINS UNIVERSITY

ihmc FLORIDA INSTITUTE FOR HUMAN & MACHINE COGNITION

TELOREGEN

VEGA Telehealth

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY

IMaGeS Lab

USF UNIVERSITY OF SOUTH FLORIDA

GT

University of Houston Clear Lake

UNCW

NMT

SHARK MARINE TECHNOLOGIES INC.

AEXA

Micro Aerospace Solutions

AllTraq

WHAT: DEVELOPMENT & INTEGRATION THEMES

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

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

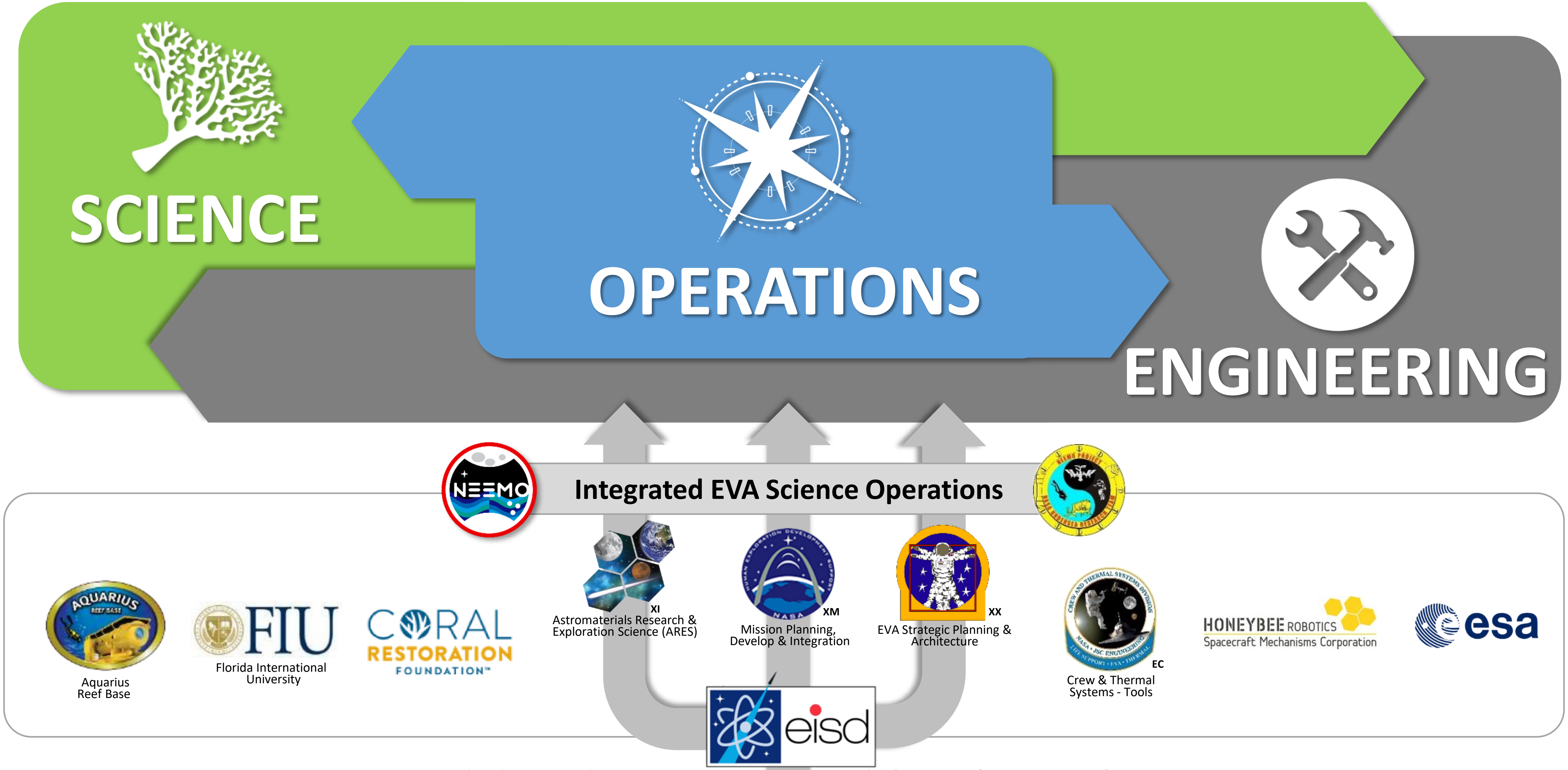
TRAINING

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: INTEGRATED EVA OPERATIONS



SCIENCE

OPERATIONS

ENGINEERING

Integrated EVA Science Operations

Aquarius Reef Base

Florida International University

CORAL RESTORATION FOUNDATION

XI
Astromaterials Research & Exploration Science (ARES)

XM
Mission Planning, Develop & Integration

XX
EVA Strategic Planning & Architecture

EC
Crew & Thermal Systems - Tools

HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation

esa

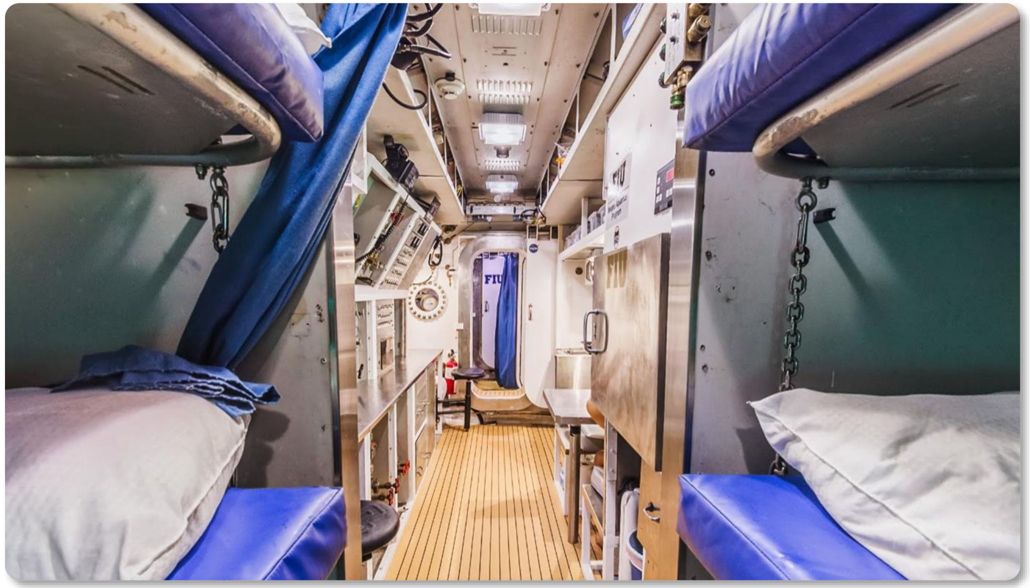
eisd

WHERE: NASA EXTREME ENVIRONMENT MISSION OPERATIONS (NEEMO)

- Premiere analog that 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, including over comm latencies
- NASA analog mission that sends groups of astronauts, engineers and scientists to live, work and explore in a challenging environment
- Series of 22 space exploration simulations conducted since 2001

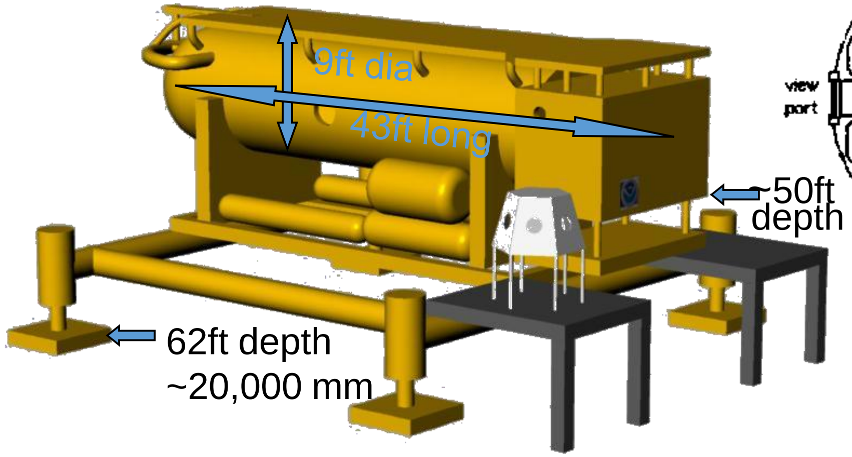
WHERE: NEEMO FACILITIES

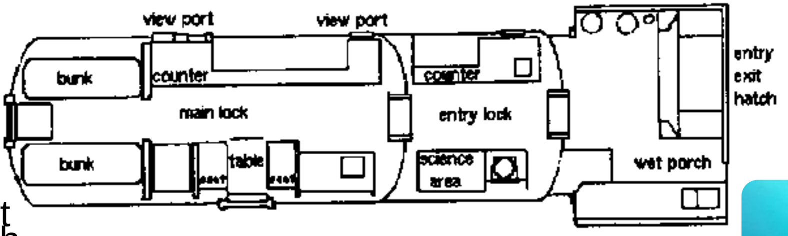
- Aquarius Reef Base, the world's only undersea research station
- Located 5.4 miles (9 kilometers) off Key Largo in the Florida Keys National Marine Sanctuary
- 62 feet (19 meters) below the surface next to a deep coral reef named Conch Reef
- Operated by Florida International University

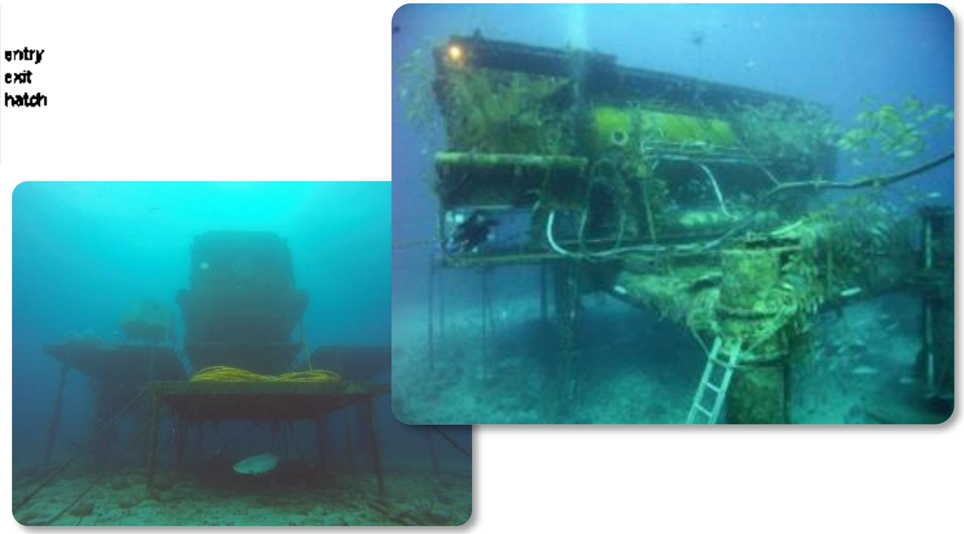


HOW: NEEMO “SPACECRAFT” AND “SPACESUIT”

THE “SPACECRAFT”: AQUARIUS UNDERWATER HABITAT







THE “SPACESUIT”: KM 37SS HELMET W/ WETSUIT & HARNESS FOR SURFACE SUPPLIED DIVING SYSTEM (SSDS)

KM 37SS

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

Both have different but comparable challenges for operations

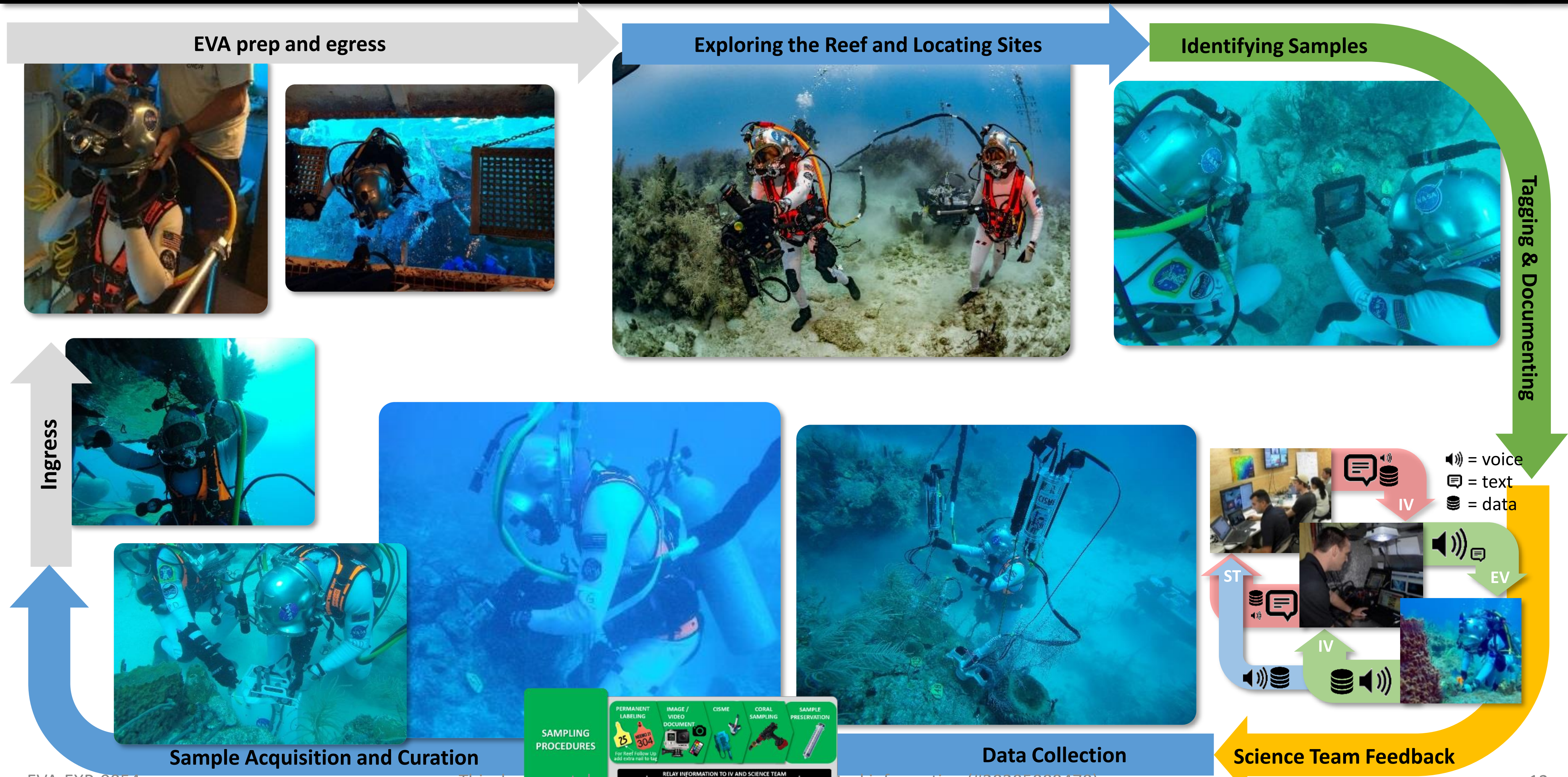
37SS: Narrower FOV, Helmet movable
xEMU: Wider FOV, Helmet fixed

Wetsuit & harness: Flexible, but restrictive
xEMU: Pressurized, bulky

xEMU concept

TBD mEMU concept
(courtesy of *The Martian*)

HOW: A DAY IN THE LIFE OF NEEMO EVA OPERATIONS



NEEMO 22 Mission Overview

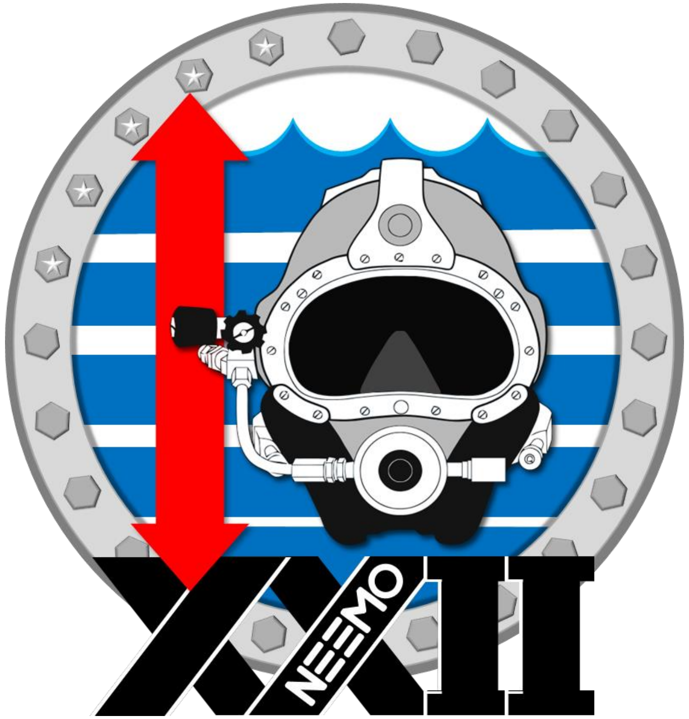
NASA EXTREME ENVIRONMENT MISSION OPERATIONS - NEEMO 22

Overview

- Successful 10 day mission living and working from Aquarius Reef Base
- Completed a combination of Exploration EVA and ISS related objectives
- Numerous participating organizations across NASA, JSC, ESA, JAXA, Research Institutions, Universities, and Industry Partners

Key Dates

- Engineering Week: May 8-16
- JSC Crew Training Week: May 22-25
- Test Readiness Review: May 30
- ARB Crew Training Week: June 12-16
- NEEMO 22 Mission: June 18-27



Crew Members

- Kjell Lindgren NASA
- Trevor Graff NASA JACOBS
- Pedro Duque esa
- Dom D'Agostino ihmc USF UNIVERSITY OF SOUTH FLORIDA

NEEMO 22 PARTNERS/COLLABORATORS

- **NASA**
  - **JSC**
    - **XM**: Mission management, mission director, integration
    - **XI**: Mission management, Science objectives, Science Team leadership, crewmember
    - **XX**: Mission management, EVA leadership, EVA objectives (ops concepts, tools development, informatics)
    - **EA (EC, ER)**: PI for multiple evaluation objectives, building EVA tools
    - **CB**: Crewmember
    - **SK**: PI for mission objectives
    - **PAO**: Public Affairs activities
  - **ARC**: Mission planners and timeline tool
  - **KSC**: Communications, data management, and logistics support
- **ESA**: Crewmember, research objectives
- **JAXA**: Ops Support
- **Academia**
  - **Johns Hopkins University**: Research objectives
  - **University of South Florida**: Research objectives
  - **Florida International University (FIU)**: Aquarius owner and operator, marine science support
  - **Georgia Institute of Technology**: EVA Cognitive Work Analysis graduate study
  - **University of North Carolina at Wilmington:** Science instrumentation
  - **University of Houston Clear Lake:** Research objectives
- **Institutions**
  - **Florida Institute for Human & Machine Cognition**: Research objectives, crewmember
  - **Coral Restoration Foundation:** Research and mission objectives
- **Industry**
  - **Honeybee**: Core drilling solution
  - **AllTraq**: Mission objectives
  - **Shark Marine**: Providing a navigation system
  - **Aexa Aerospace**: Providing HoloLens units and expertise

XI
Astromaterials Research & Exploration Science (ARES)

XX
EVA Strategic Planning & Architecture

XM
Mission Planning, Develop & Integration

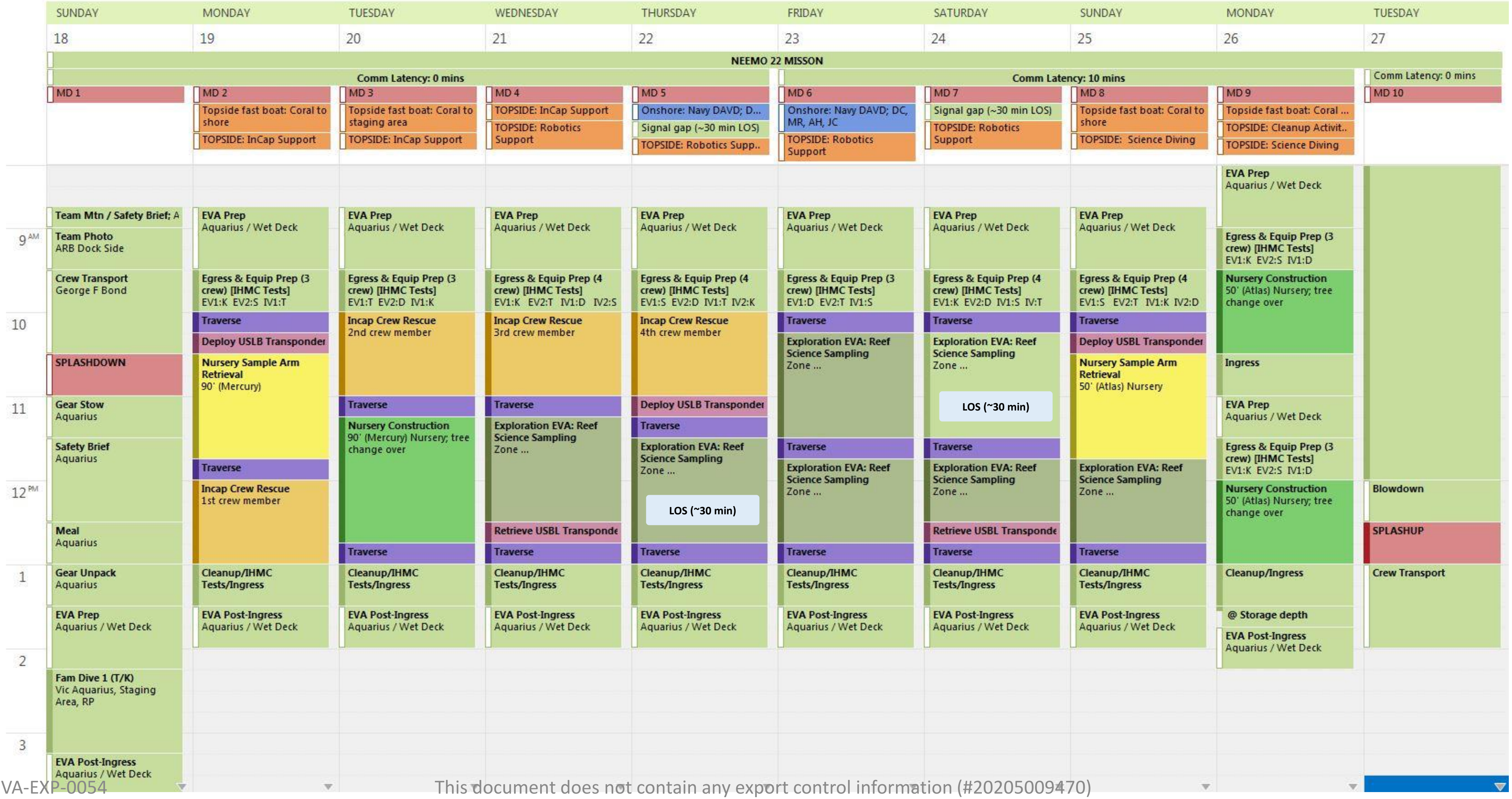
EC
Crew & Thermal Systems - Tools

AllTraq

MISSION PROGRAM RELEVANCY

Category	Gap/Risk	Experiment	Sponsor	Beneficiary
Tool & Technology Maturation for Ops	Exercise Countermeasures	✓ VETSS	SK/ER	ISS, Orion
	Autonomous Procedures	✓ Ultrasound w/ Remote Guidance	ER	ISS ------> Exploration
		✓ Life Supt system procedure	ER	ISS ------> Exploration
	Inventory Management	✓ AllTraq	AllTraq	ISS ------> Exploration
	Mobile Crew Planning Tool	✓ Playbook	ARC	ISS ------> Exploration
	in situ DNA sequencing	✓ mini DNA Sequencer	SK	ISS ------> Exploration
Ops Concept Maturation	Exploration Surface Ops with Comm Delay	✓ Crew Self Scheduling	XX/ARC	ISS ------> Exploration
		✓ Integrated Science Team	XI/XX	Exploration
		✓ Sample Acquisition	XI/XX	Exploration
		✓ Sample Stowage	XI/XX	Exploration
		✓ Small Tool Transport on EVA suit	XX/XI	Exploration
		✓ Large Tool/hardware transport	XX/XI	Exploration
		✓ IV Support System	XX	Exploration
		✓ IV Workstation Support Tools	XX/XI	Exploration
		✓ LESA	ESA	Exploration
Pure Science	Hyperbaric body changes	✓ Body Composition Study	IHMC/USF	N/A
	Hyperbaric sleep effects	✓ Autonomic Function	IHMC/USF	N/A
	Hyperbaric microbiome changes	✓ Microbiome Study	IHMC/USF	N/A
	Dietary influence on psychology	✓ Psych Study	USF	ISS ------> Exploration
	Sensorimotor degradation	✓ RAPSAP	Johns Hopkins	ISS ------> Exploration
	Reef mortality	✓ Coral Science	FIU, CRF	N/A
Crew Preparation	Expeditionary Training	✓ CDR upgrade	CB (+IPs)	ISS ------> Exploration
Outreach Opportunities	N/A	✓ PAO events	PAO	ISS ------> Exploration
		✓ Educational Outreach	PAO	ISS ------> Exploration

PRE-MISSION N22 EVA TIMELINE (FROM 5/23/17)



NEEMO 22 MISSON

Comm Latency: 0 mins (Sunday 18 – Thursday 22) · Comm Latency: 10 mins (Friday 23 – Monday 26) · Comm Latency: 0 mins (Tuesday 27)

9 AM · 10 · 11 · 12 PM · 1 · 2 · 3

SUNDAY 18
- MD 1
- **Team Mtn / Safety Brief; A**
- **Team Photo** ARB Dock Side
- **Crew Transport** George F Bond
- **SPLASHDOWN**
- **Gear Stow** Aquarius
- **Safety Brief** Aquarius
- **Meal** Aquarius
- **Gear Unpack** Aquarius
- **EVA Prep** Aquarius / Wet Deck
- **Fam Dive 1 (T/K)** Vic Aquarius, Staging Area, RP
- **EVA Post-Ingress** Aquarius / Wet Deck

MONDAY 19
- MD 2
- Topside fast boat: Coral to shore
- TOPSIDE: InCap Support
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (3 crew) [IHMC Tests]** EV1:K EV2:S IV1:T
- **Traverse**
- **Deploy USLB Transponder**
- **Nursery Sample Arm Retrieval** 90' (Mercury)
- **Traverse**
- **Incap Crew Rescue** 1st crew member
- **Cleanup/IHMC Tests/Ingress**
- **EVA Post-Ingress** Aquarius / Wet Deck

TUESDAY 20
- MD 3
- Topside fast boat: Coral to staging area
- TOPSIDE: InCap Support
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (3 crew) [IHMC Tests]** EV1:T EV2:D IV1:K
- **Incap Crew Rescue** 2nd crew member
- **Traverse**
- **Nursery Construction** 90' (Mercury) Nursery; tree change over
- **Traverse**
- **Cleanup/IHMC Tests/Ingress**
- **EVA Post-Ingress** Aquarius / Wet Deck

WEDNESDAY 21
- MD 4
- TOPSIDE: InCap Support
- TOPSIDE: Robotics Support
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (4 crew) [IHMC Tests]** EV1:K EV2:T IV1:D IV2:S
- **Incap Crew Rescue** 3rd crew member
- **Traverse**
- **Exploration EVA: Reef Science Sampling** Zone ...
- **Retrieve USBL Transponde**
- **Traverse**
- **Cleanup/IHMC Tests/Ingress**
- **EVA Post-Ingress** Aquarius / Wet Deck

THURSDAY 22
- MD 5
- Onshore: Navy DAVD; D...
- Signal gap (~30 min LOS)
- TOPSIDE: Robotics Supp..
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (4 crew) [IHMC Tests]** EV1:S EV2:D IV1:T IV2:K
- **Incap Crew Rescue** 4th crew member
- **Deploy USLB Transponder**
- **Traverse**
- **Exploration EVA: Reef Science Sampling** Zone ...
- LOS (~30 min)
- **Traverse**
- **Cleanup/IHMC Tests/Ingress**
- **EVA Post-Ingress** Aquarius / Wet Deck

FRIDAY 23
- MD 6
- Onshore: Navy DAVD; DC, MR, AH, JC
- TOPSIDE: Robotics Support
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (3 crew) [IHMC Tests]** EV1:D EV2:T IV1:S
- **Traverse**
- **Exploration EVA: Reef Science Sampling** Zone ...
- **Traverse**
- **Exploration EVA: Reef Science Sampling** Zone ...
- **Traverse**
- **Cleanup/IHMC Tests/Ingress**
- **EVA Post-Ingress** Aquarius / Wet Deck

SATURDAY 24
- MD 7
- Signal gap (~30 min LOS)
- TOPSIDE: Robotics Support
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (4 crew) [IHMC Tests]** EV1:K EV2:D IV1:S IV:T
- **Traverse**
- **Exploration EVA: Reef Science Sampling** Zone ...
- LOS (~30 min)
- **Traverse**
- **Exploration EVA: Reef Science Sampling** Zone ...
- **Retrieve USBL Transponde**
- **Traverse**
- **Cleanup/IHMC Tests/Ingress**
- **EVA Post-Ingress** Aquarius / Wet Deck

SUNDAY 25
- MD 8
- Topside fast boat: Coral to shore
- TOPSIDE: Science Diving
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (4 crew) [IHMC Tests]** EV1:S EV2:T IV1:K IV2:D
- **Traverse**
- **Deploy USBL Transponder**
- **Nursery Sample Arm Retrieval** 50' (Atlas) Nursery
- **Exploration EVA: Reef Science Sampling** Zone ...
- **Traverse**
- **Cleanup/IHMC Tests/Ingress**
- **EVA Post-Ingress** Aquarius / Wet Deck

MONDAY 26
- MD 9
- Topside fast boat: Coral ...
- TOPSIDE: Cleanup Activit..
- TOPSIDE: Science Diving
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (3 crew) [IHMC Tests]** EV1:K EV2:S IV1:D
- **Nursery Construction** 50' (Atlas) Nursery; tree change over
- **Ingress**
- **EVA Prep** Aquarius / Wet Deck
- **Egress & Equip Prep (3 crew) [IHMC Tests]** EV1:K EV2:S IV1:D
- **Nursery Construction** 50' (Atlas) Nursery; tree change over
- **Cleanup/Ingress**
- **@ Storage depth**
- **EVA Post-Ingress** Aquarius / Wet Deck

TUESDAY 27
- MD 10
- **Blowdown**
- **SPLASHUP**
- **Crew Transport**

NEEMO 22 Integrated EVA

NEEMO 22 EVA OBJECTIVES TIED TO KNOWLEDGE & CAPABILITY GAPS

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

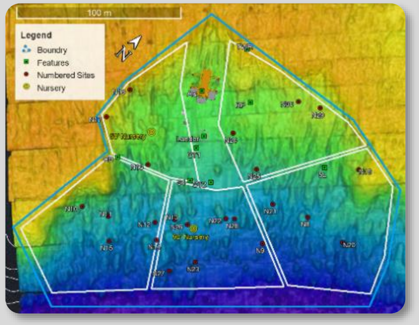
			EVA Objectives	**SMT EVA Knowledge/Capability Gaps**
Primary EVA Objectives	**EVA Tools**		✓ ➢ Integrated Geoscience Sampling System **Core sample acquisition (Honeybee Robotics)* ✓ ➢ Large tool/hardware transport & stowage **EVA Modular Equipment Transportation System* ✓ ➢ Small tool transport on EVA suit	➢ Tools for Science Sampling on a Surface EVA ➢ Subsurface samples (core) ➢ Tool Carrier Device ➢ Tool Attachment/Harness for Surface EVA
	Informatics		✓ ➢ IV Support System & Workstation ✓ ➢ EVA/Science task tracking **Marvin & Playbook* ✓ ➢ EVA Digital Cue Cards ✗ ➢ EVA Navigation **Shark Marine* ✓ ➢ EVA Augmented Vision Heads-Up Display **Navy Diver Augmented Vision Display demo*	➢ IV Support System for EVA Operations ➢ EVA Graphical Display ➢ EVA Short Range Navigation ➢ Mixed / Augmented Reality Capability ➢ EVA Suit Heads-Up Display
	Concepts of Operations		✓ ➢ Integrated EVA Operations with Science Tasks ✓ ➢ Integrating Informatics ✓ ➢ IV support System & Workstation ✓ ➢ Flexecution ✓ ➢ Traverse Planning	➢ Integrated EVA Flight Control Methodology ➢ Tools for Interacting with EVA Over a Comm Latency ➢ Flexible Execution Methodology for EVA Science Operations in Undefined Environments
Secondary Objectives	**Robotic-EVA Ops**		✗ ➢ Situational Awareness for IVA & MCC ✗ ➢ Robotic Payload Transport for EVA **Shark Marine*	➢ EVA-Robotic (Man-Machine) Work System

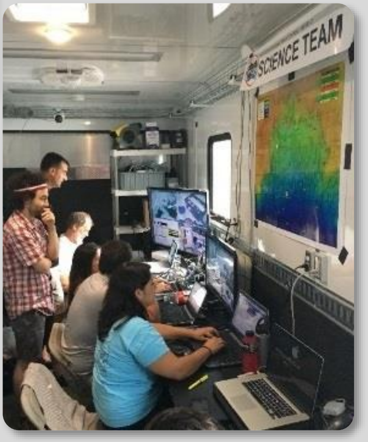
NEEMO 22 EVA SCIENCE OVERVIEW

NURSERY CONSTRUCTION & SCIENCE

- Modified and conducted continued science investigation on two long-term coral nurseries near ARB
  - 50’ nursery
  - 90’ nursery (deepest in the world)

REEF FOLLOW-UP SCIENCE





- Continued research and sampling conducted during NEEMO 20 and 21
- Crew successfully navigated to, located, documented and re-sampled colonies
- Science team developed the overall sampling strategy and traverse plans

REEF EXPLORATION SCIENCE

- Explored and expanded into new sites; coral science was correlated to nurseries as a natural baseline
- Described, documented, and sampled additional samples for long term research

SCIENCE

CORAL RESTORATION FOUNDATION

- Nonprofit conservation organization dedicated to creating offshore nurseries & restoration programs for threatened coral species.
- Their mission is to develop effective coral nursery and restoration techniques and to train & empower others to do the same in their area.

Education

Promote awareness of coral reef health and survival, along with the environmental and social benefits of reef ecosystems.

Action

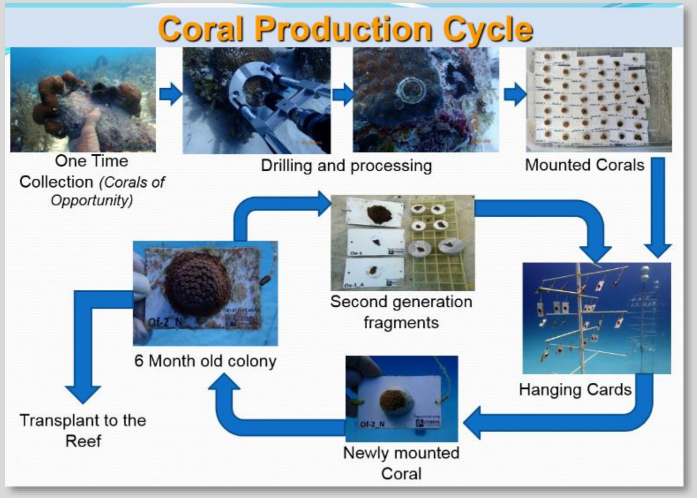
Engage communities and facilitating partnerships in research, restoration, and understanding of coastal resources.

Results

Grow and restore threatened coral species, and enhance reproductive output to stimulate a natural recovery.


Typical Coral Nursery


One Year's Growth of staghorn coral


Coral Production Cycle


Elkhorn Coral Restoration

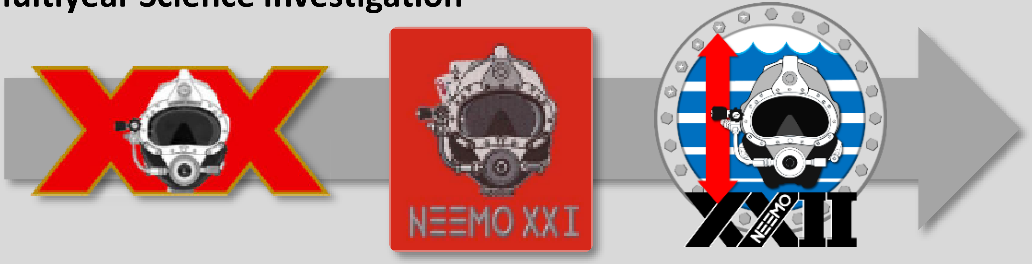
SCIENCE

MARINE EXPLORATION SCIENCE

FIU
FLORIDA INTERNATIONAL UNIVERSITY

- Laboratory of Integrative Marine Genomics and Symbiosis (IMaGeS)
- Focuses on the study of the symbiotic interactions between microbial organisms and cnidarian hosts, in particular reef-building corals, from different perspectives, including cell biology, eco-physiology & ecology.

Multiyear Science Investigation



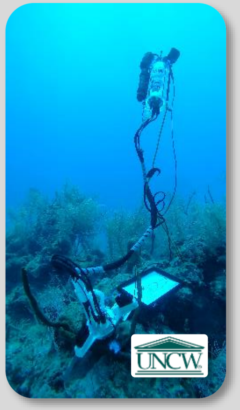
Endangered Coral Species


Agaricia


Siderastrea


Orbicella

Growing Partnerships and Advanced Instrumentation



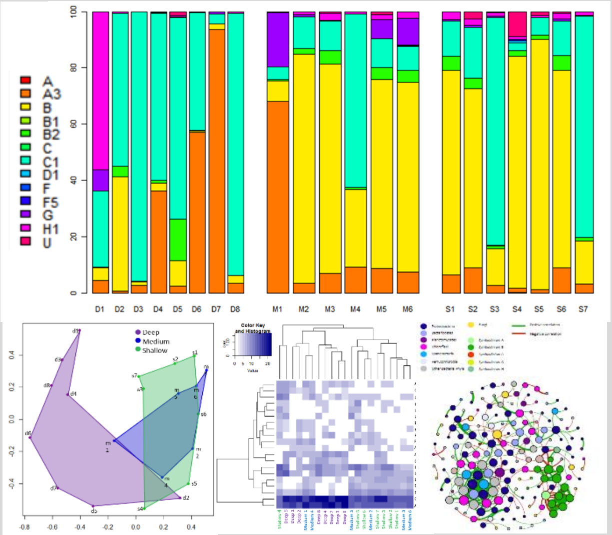
Genetically characterize the coral symbiotic community

Provide time & depth components

Provide a natural baseline for coral restoration efforts

Ultimately inform ongoing coral restoration efforts & understanding of the changing reef environment

Peer Reviewed Results



PLANETARY SCIENCE RELEVANCE

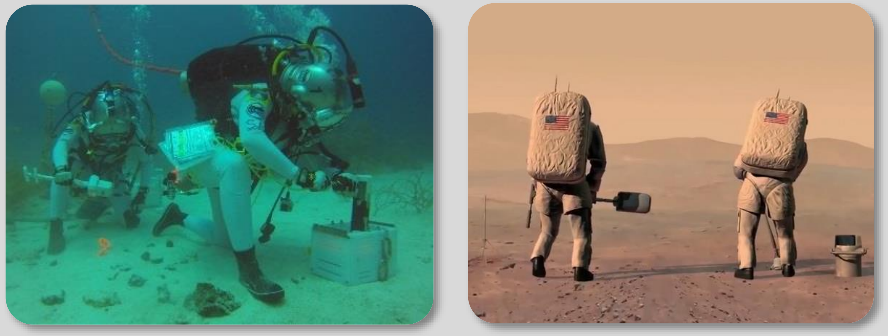
Astromaterials Research & Exploration Science (ARES)

- ➢ 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

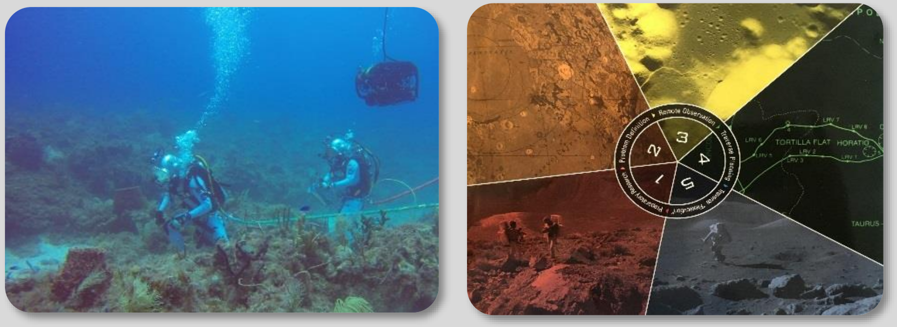


- ➢ Sampling Procedures
- ➢ Sampling Techniques
- ➢ Collection Tools
- ➢ Contamination
- ➢ Storage & Transport

Research

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

Exploration

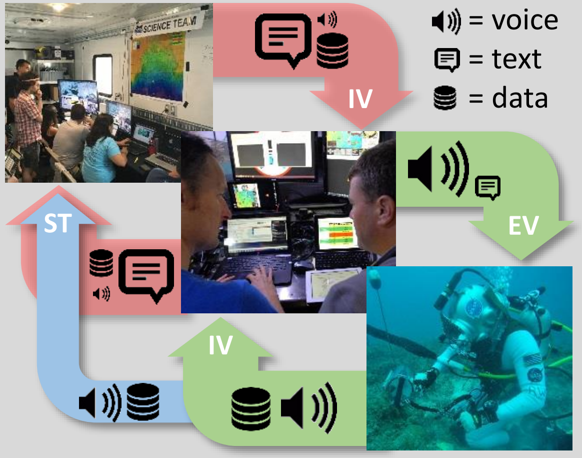


- ➢ Science Operations
- ➢ Traverse Planning
- ➢ Operational Flexibility
- ➢ Human-Robot Ops
- ➢ Crew Science Training

OPERATIONS

NEEMO 22 EVA OPS CON OVERVIEW

INTEGRATED EVA & SCIENCE OPERATIONS

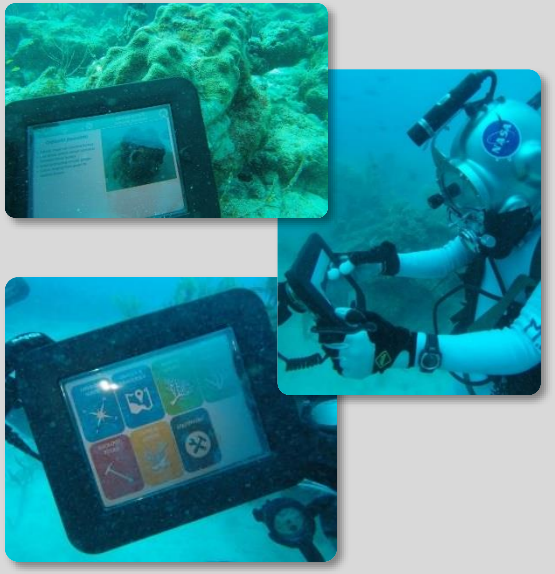


- Evaluated Exploration EVA operations that predominately include science tasks
- Examined con ops that enable interaction between the MCC & the crew over a long comm latency and blockage including:
  - Interaction with an integrated Science Team
  - Authentic scientific objectives and hypothesis
  - Flexecution methodology

EVA/IV SUPPORT SYSTEM & PLANNING FOR EVA

- Evaluated a Support System that utilizes an open-source digital timeline execution and life support system management tool designed to support Intravehicular Activity during EVA
- Examined ways to minimize number of computers and monitors required for operations, hence reducing space and launch mass needed
- Looked at using a projector for crew planning and briefing

EVA DIGITAL CUE CARDS



- Evaluated digital cue cards for EVA crew that allowed crew to operate more effectively and offload IV tasks
- Additional crew autonomy requires further access to information in their hands
- Tested concept for a potential “one-device” for cue cards/procedures, images/video, instrument control, etc.

UTILIZATION OF SCIENTIFIC INSTRUMENTS

- Assessed the effects of incorporating scientific instruments into EVA ops

NAVIGATION & TRAVERSE PLANNING

- Evaluated procedures for navigating both to previously-sampled regions and new exploration zones

WITH LUNAR AND MARS COMMUNICATION LATENCY & BLOCKAGE CON OPS

INTEGRATED EVA OPERATIONS WITH SCIENCE-DRIVEN TASKS

Objective

- Analyze integrated EVA science operations to determine what functions/capabilities are needed to enable a Mission Control Center (MCC) integrated Science Team to effectively operate and actively direct EVA operations with science tasks over a signal (comm & data) latency and blockage
- Determine what functions/capabilities and techniques are needed to enable the EVA crew to effectively operate more autonomously and communicate information to MCC over a signal 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


MCC Flight Control Team


MCC Science Team

Key Take-Aways

- EVA crew demonstrated the capability to operate more autonomously while simultaneously communicating with and incorporating input from an Earth-based MCC and ST
- With science instruments that take time to acquire data, it is possible to plan the EVA such that the crew can successfully receive input from the ST to execute science sampling operations during an EVA over a signal latency
- An EVA support system for an IV crewmember that is directing real-time ops will be critical for management of the large volume of data
- Additional complexity of airlock and spacesuit EVA operations will impact the way operations and science tasks will be planned and directed
- A flight control operations paradigm and decision making protocols will need to be developed in order to integrate science tasks and subject matter experts within the context of an EVA while executing in dynamically changing situations in a natural environment – including how decisions are made between a Mission Director, EVA Officer, and SCICOM/Science Lead

EVA SUPPORT SYSTEM & IV WORKSTATION

Objective

- 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 must contended with while actively directing an EVA
- Assess hardware needs for a workstation, including ways to minimize what's required for operations to reduce space and launch mass
- Look at potential ways to incorporate augmented reality into workstation

Implementation

- Utilized Marvin timeline execution and life support system management tool
- Utilized Playbook Tactical EVA Execution Feature

Key Take-Aways

- An EVA support system for an IV to direct EVA operations will be key for Exploration missions
- A system that utilizes a single computer with multiple ways to display abundant information would enable to single IV crewmember to direct EV ops while incorporating input from an MCC science team
- Augmented Reality systems (such as HoloLens) may hold some promise as a possibility, though were not as useful at this maturity level
- Recommend continued evolution of the system to drive out more detailed capability needs

Evolution of EVA Support System for IV Operator

NEEMO 20

NEEMO 21

NEEMO 22

EVA INTEGRATED INFORMATICS – DIGITAL CUE CARDS & TRAVERSE MAPS

Objective

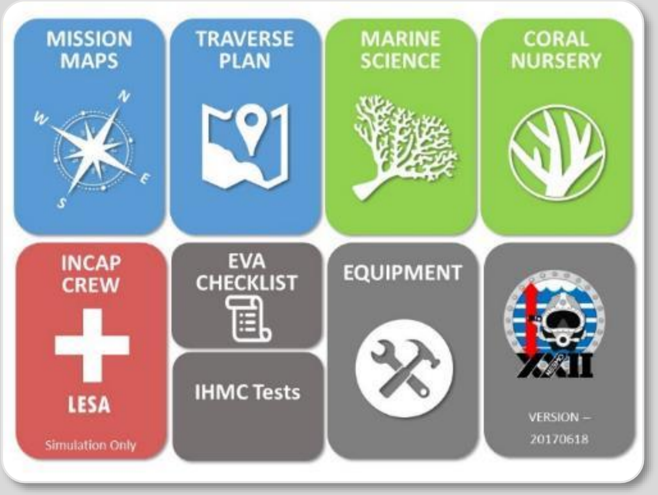
- Evaluate digital cue cards for EVA crew that allowed crew to operate more effectively and autonomously while offloading IV tasking
- Assess tool needs (hardware and software) for short distance navigation data to support EVA geology/science

Implementation

- Utilized 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 was put into a digital cue card set that was loaded on the iPad

Key Take-Aways

- EVA digital cue cards permit increasing crew autonomy by enabling EV crew to efficiently understand exploration areas, conduct general site navigation, identify specimens for potential sampling, and guide themselves through task procedures
- Information layout will need to be modified for different display methods, such as a heads-up display or electronic cuff
- Recommend continuing to look at digital cue card capability, and refining the types of information included in the data set



EVA NAVIGATION AND EVA-ROBOTIC OPS

Objective

- Evaluate EVA navigation and IV/MCC crew tracking

Implementation

- Utilized the Shark Marine Dive Tablet (Navigator) and Dive Log system for relative navigation

Key Take-Aways

- Capability for EVA crew to navigate to a site of interest will be critical
- EVA crew will need a way to mark potential sample sites in order to return to them for sampling
- The aquanauts were not able to use the Navigator/Dive Tablet to reliably navigate, and ended up depending on digital maps
- Digital maps worked well for the relatively small test area
- For future missions, recommend changing from the current relative navigation system and exploring the use of an area scanning system (such as a sector sonar as a proxy to radar/LiDAR), and increasing the fidelity of the maps

Objective

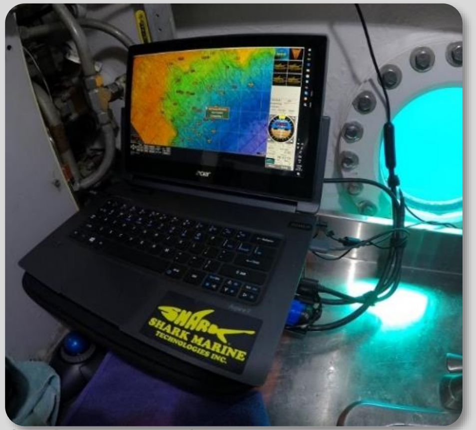
- Evaluate utilization of a robotic equipment carrier during EVA ops

Implementation

- Utilized a Shark Marine ROV with a purpose-built trailer system
- ROV included a video camera for remote use by the IV and MCC

Key Take-Aways

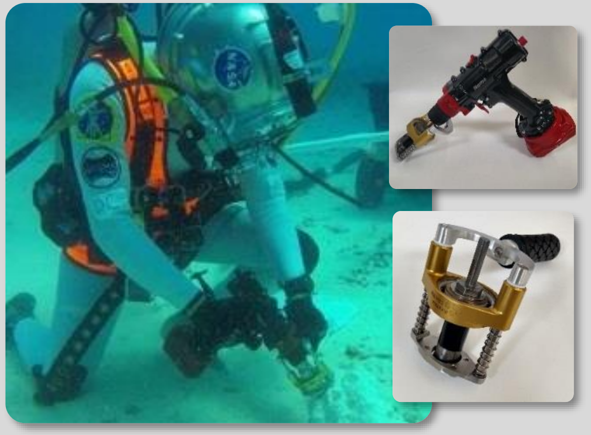
- The ROV was not able to be integrated into the mission due to technical and weather (sea state) issues
- Due to challenges with underwater wheeled and steerable ROV systems that are tethered, focus robotic work system evaluations at terrestrial analogs



ENGINEERING

NEEMO 22 EVA EQUIPMENT OVERVIEW

CORE SAMPLE AQUISITION



- Evaluated EVA tools and hardware for science core sample acquisition
- Leveraged breakaway core bit technology developed by Honeybee Robotics and implemented on Mars rovers to develop a drill bit for an EVA tool

EVA EQUIPMENT TRANSPORTATION

- Tested the Modular Equipment Transport System (METS), a concept for manually transporting & stowing larger tools and samples on exploration traverses
- Evaluated potential concepts for transporting small tools on an EVA suite from a rover/caddy to a worksite

LUNAR EVACUATION SYSTEM ASSEMBLY (LESA)

- Evaluated a new crew rescue concept developed by ESA at the European Astronaut Centre
- This technique is aimed to ease the lifting-up and securing of an incapacitated EVA crewmember on a Moon EVA Litter

EVA AUGMENTED VISION HEADS-UP DISPLAY

- Based on Navy's Divers Augmented Vision Display, which incorporates real-time data input and allows for augmented reality input in a heads-up display
- EVA Office and astronauts evaluated lab version topside for potential incorporation on future missions and spacesuit design

EVA CORE SAMPLE ACQUISITION SYSTEM

Objective

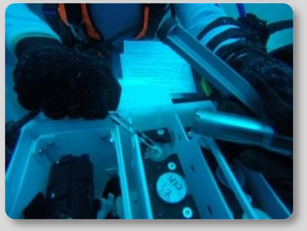
- Evaluate EVA hardware and operations for subsurface (core) science sampling in a surface/partial-g environment

Implementation

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

Key Take-Aways

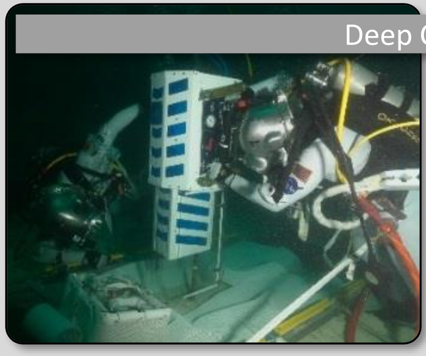
- Breakaway bit with powered tool worked well for taking core samples
- Concept of stowing directly into curation return tubes worked well
- Small tools, such as forceps, were useful for removing cores or picking up small pieces
- Need to consider the limited down-force that crew is able to put into a sampling operation due to lower gravity levels
- Recommend continuing partnership with Honeybee and testing bits in other environments



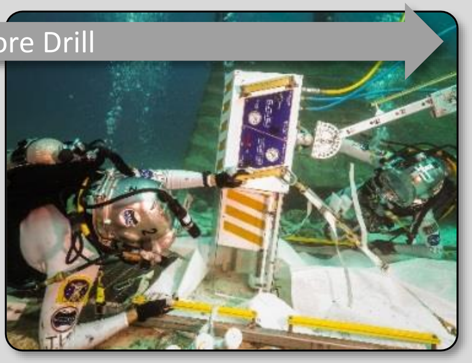
Core Sample Acquisition Tool Evolution

SEATEST 2

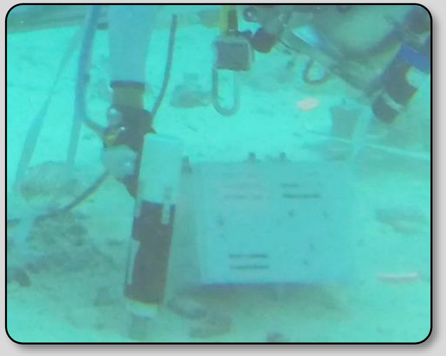
Deep Core Drill



NEEMO 18



NEEMO 19



NEEMO 20

NEEMO 21

NEEMO 22

MODULAR EQUIPMENT TRANSPORT SYSTEM (METS) & SMALL TOOLS ON SUIT

Objective

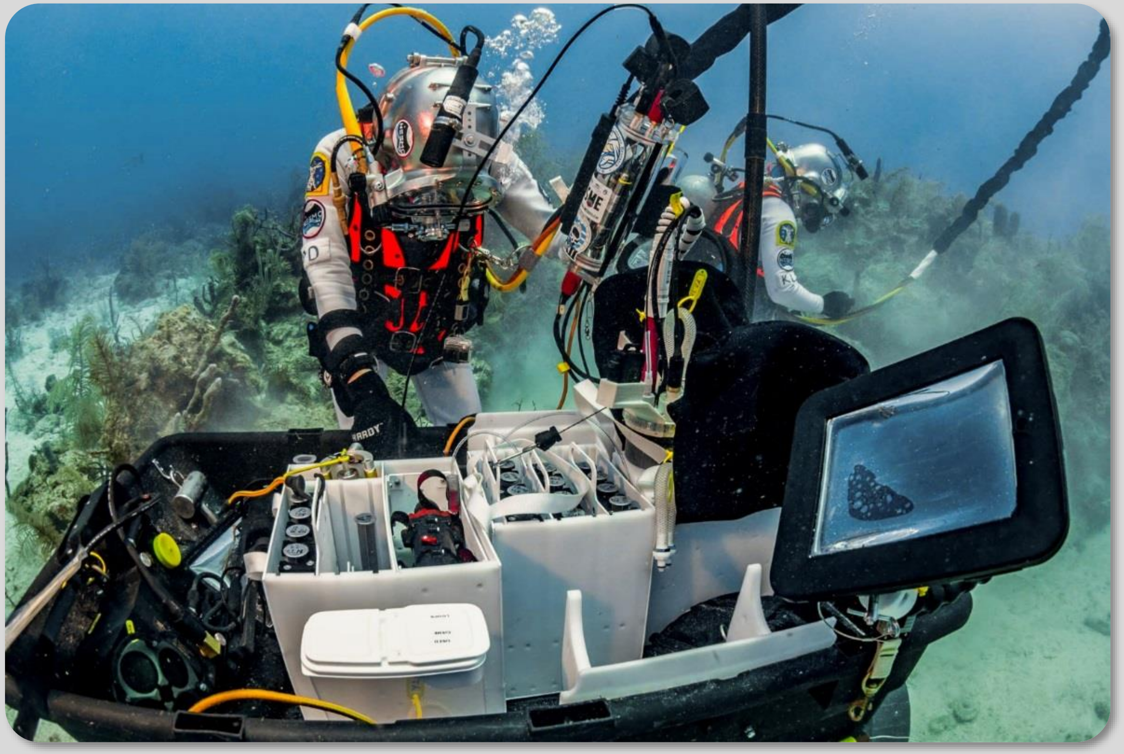
- Evaluate transport of large equipment in a mobile carrier
- Evaluate transport of small tools on an EVA spacesuit

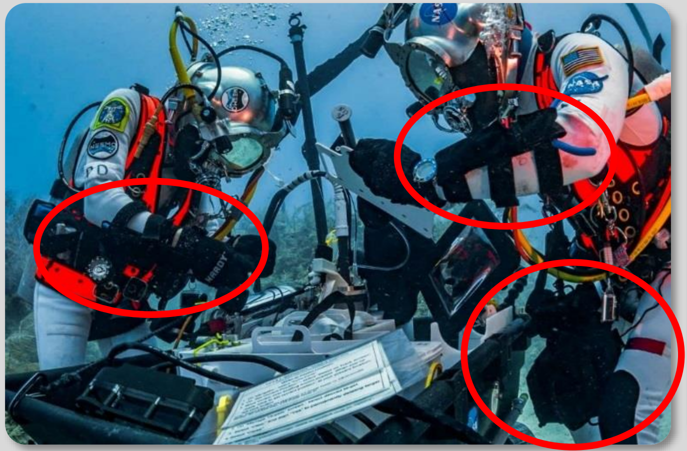
Implementation

- 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
- For small tools transport on the spacesuit, crew utilized a forearm stowage device and thigh module strapped on after egress

Key Take-Aways

- METS concept of putting tools into modules has the potential to provide efficiencies during EVAs
  - A wheeled carrier works well, however future concepts may consider larger wheels or ways to get over/around obstacles
  - Requires close integration for planning to ensure all pieces of equipment are accounted for when populating/arranging the modules, including what's needed for contingencies
- Small, lightweight, generic tools could be carried on the forearm, torso, and other locations to provide easy access and should be considered for partial-g surface operations
  - Small tools carried on the suit forearm work well and enabled crew easy visibility and access to the tools
  - Carrying tools on the thigh (or other areas not easily visible) was challenging due to lack of visibility





INCAPACITATED EVA CREW RESCUE – LUNAR EVACUATION SYSTEM ASSEMBLY (LESA)

Objective

- Evaluated 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

Key Take-Aways

- Concept of hoisting an incapacitated EVA crewmember onto a litter for transport back to a habitat holds promise
- Need to look into making LESA a smaller and more portable package
- Future suit designs will need to take into account attach points for any rescue and hoist device

EVA AUGMENTED VISION HEADS-UP DISPLAY

Objective

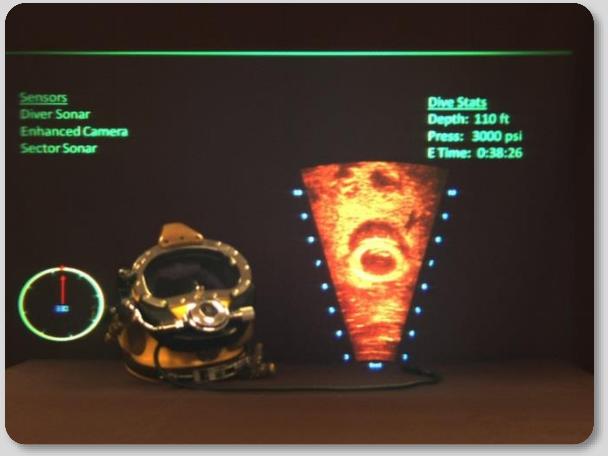
- Evaluate the Navy's Divers Augmented Vision Display (DAVD), which incorporates real-time data input and allows for augmented reality input in a heads-up display, for use in an EVA spacesuit

Implementation

- EVA Office and astronauts evaluated lab version topside for potential incorporation on future missions and spacesuit design

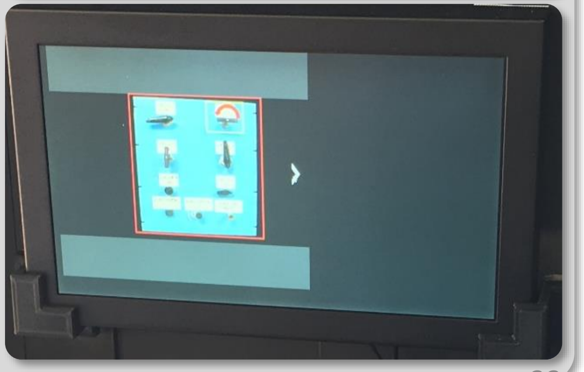
Key Take-Aways

- DAVD provides a capability to Navy divers that would be advantageous to EVA astronauts
- There is a promising collaboration between the Navy and NASA to develop an augmented heads-up display capability for an EVA spacesuit



Post-NEEMO Follow-on Testing Quick-brief

- Manned tests at the Naval Support Activity Panama City (NSA PC) Dive School and Navy Experimental Diving Unit (NEDU)
- Navy divers were able to utilize DAVD for navigation, identification of objects, and for receiving task instructions real-time
- All of the activities tested translate into operations concepts for EVA on Exploration missions
- Identified a use of the full face mask version of the DAVD for significantly enhanced ISS EVA training in the NBL



EVA GAP CLOSURE UPDATES AND RECOMMENDATIONS FROM NEEMO 22

EVA CAPABILITY GAP	GAP CLOSURE UPDATES	RECOMMENDATIONS
Tools for Science Sampling on a Surface EVA – subsurface samples (core)	Update with break-away core bit and the operations concepts for acquiring core samples	Continue collaboration with Honeybee Robotics and development of core bit Evolve the system to include curation
Tool Carrier Device on a Surface EVA	Update with lessons learned from the METS, utilizing a modular system, wheel size, and ability to get equipment near the worksite	Evolve the modular system concept Evaluate alternate concepts for traversing over rough terrain
Tool Attachment/Harness for Surface EVA	Update with application of forearm modules to carry small tools Update with visibility challenges of thigh modules	Evolve the forearm module concept and test at future NEEMO missions Develop a more visible and simple thigh module
IV Support System for EVA Operations	Update with results from utilizing a single computer driving multiple types of displays configurable for various operations	Iterate configuration and applications to enable more efficient operations, and evaluate at a future NEEMO mission and SHyRE
EVA Graphical Display	Update with concept of merging a map and high-level timeline overview into a single reference page with links to task details	Focus on the one-stop page concept and evaluate at a future NEEMO mission
Mixed / Augmented Reality Capability	Formalize a gap to include mixed/augmented reality capability, which goes beyond standard informatics displays	Collaborate with DAVD development and test at future NEEMO missions Incorporate capability into SHyRE testing
EVA Suit Heads-Up Display	Formalize a technology gap to include an EVA suit heads-up display (needed for augmented reality)	Collaborate with DAVD development and test at future NEEMO missions Incorporate capability into SHyRE testing

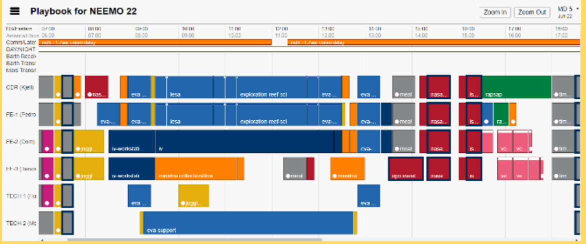
EVA GAP CLOSURE UPDATES AND RECOMMENDATIONS FROM NEEMO 22

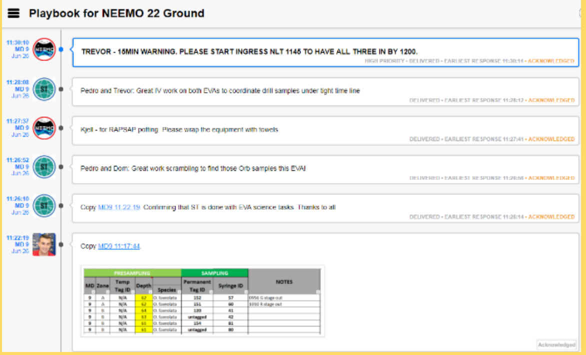
EVA CAPABILITY GAP	GAP CLOSURE UPDATES	RECOMMENDATIONS
Integrated EVA Flight Control Methodology	Update with demonstrated methods for integrating MCC and the Science Team	Increase mission tempo/pressure and flight control rigor, add spacesuit telemetry, and evaluate at future NEEMO missions
Tools for Interacting with EVA Over a Comm Latency	Update with lessons learned from utilizing a Playbook-type system Update the gap to include signal blockage	Factor in increased signal blockage and test at future analogs
Flexible Execution Methodology for EVA Science Operations in Undefined Environments	Update with decision making protocols and how decisions are made between a Mission Director, EVA Officer, and SCICOM/Science Lead	Apply more rigor to integrated decisions, add spacesuit telemetry/consumables, and evaluate at future analogs
EVA Navigation	Gap closure unchanged	Explore utilizing an area scanning system such as a sector sonar (proxy to radar/LiDAR) and evaluate at future NEEMO missions
EVA-Robotic Work System	Gap closure unchanged	Focus robotic work system evaluations at terrestrial analogs

NEEMO 22 IVA

INTRA-VEHICULAR ACTIVITIES: OVERVIEW

Playbook – Planning, Procedure Viewing, and Comm Tool





Playbook for NEEMO 22 Ground

11:30:10 MD 9 Jun 26
TREVOR - 15MIN WARNING. PLEASE START INGRESS NLT 1145 TO HAVE ALL THREE IN BY 1200.
HIGH PRIORITY • DELIVERED • EARLIEST RESPONSE 11:30:14 • ACKNOWLEDGED

11:28:08 MD 9 Jun 26
Pedro and Trevor: Great IV work on both EVAs to coordinate drill samples under tight time line
DELIVERED • EARLIEST RESPONSE 11:28:12 • ACKNOWLEDGED

11:27:37 MD 9 Jun 26
Kjell - for RAPSAP potting. Please wrap the equipment with towels.
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Pedro and Dom: Great work scrambling to find those Orb samples this EVA!
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Copy MD9 11:22:19. Confirming that ST is done with EVA science tasks. Thanks to all
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11:22:19 MD 9 Jun 26
Copy MD9 11:17:44.

PRESAMPLING					SAMPLING		
MD	Zone	Temp Tag ID	Depth	Species	Permanent Tag ID	Syringe ID	NOTES
9	A	N/A	62	O. faveolata	152	57	0956 G stage out
9	A	N/A	62	O. faveolata	151	60	1010 R stage out
9	B	N/A	64	O. faveolata	120	41	
9	B	N/A	63	O. faveolata	untagged	42	
9	B	N/A	65	O. faveolata	154	81	
9	B	N/A	65	O. faveolata	untagged	80	

Acknowledged

AR Assisted Procedures

VETTS

DNA Sequencer

IHMC & USF Studies:

USF UNIVERSITY OF SOUTH FLORIDA

ihmc FLORIDA INSTITUTE FOR HUMAN & MACHINE COGNITION

Sleep
Metabalomics
Body Composition
Psych

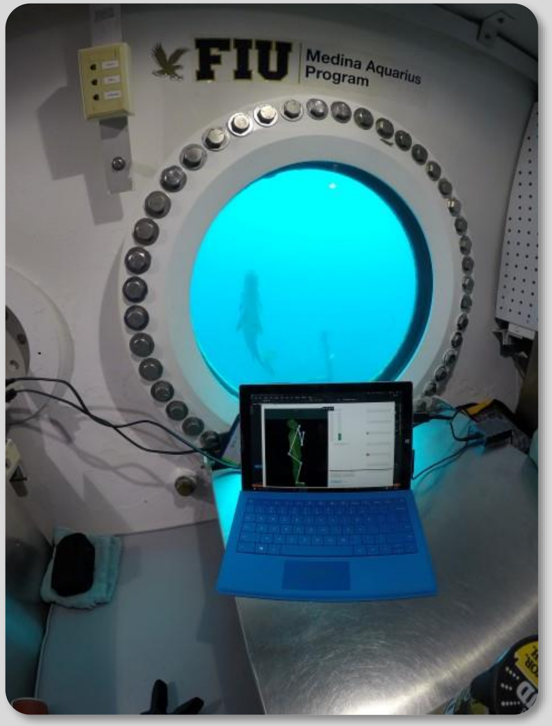
RAPSAP

AllTraq

INTRA-VEHICULAR ACTIVITIES: VIRTUAL EXERCISE TRAINER TOOL & SOFTWARE (VETTS)

Purpose: Evaluate whether a real-time instruction and correctional feedback for crew members in the absence of real-time Astronaut Strength, Conditioning and Rehabilitation Specialist (ASCRS) support during exercise can prevent avoidable injuries, and optimize overall muscle strength outcomes.

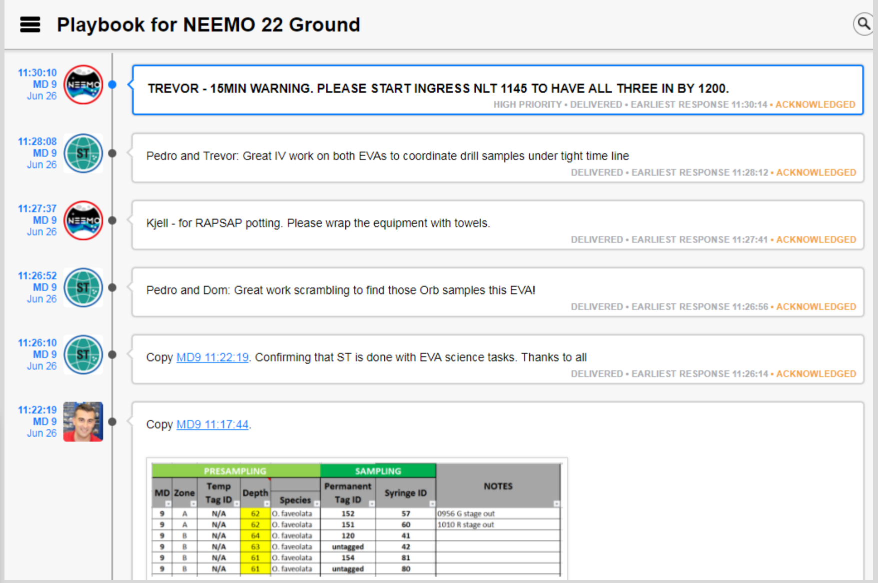
Implementation: An instructional system was developed using a Microsoft Kinect depth-camera device, which provides marker-less 3-D whole-body motion (VETTS).



INTRA-VEHICULAR ACTIVITIES: PLAYBOOK

Purpose: The NEEMO 22 mission Playbook continued to serve dual goals of supporting the operations of the NEEMO 22 mission and conducting applied research to improve crew autonomy.

Implementation: Playbook used for mission planning, procedure storage/retrieval, and text based communication between mission control and crew. Numerous new features were added this year: acknowledgements in the mission log, ordering the mission log by receive time rather than sent time, new feature for representing groups, tactical EVA execution tool, and crew/timeline notes. Two strategies for crew-self planning were tested (Plan Fragments and Functional Activity Groups).



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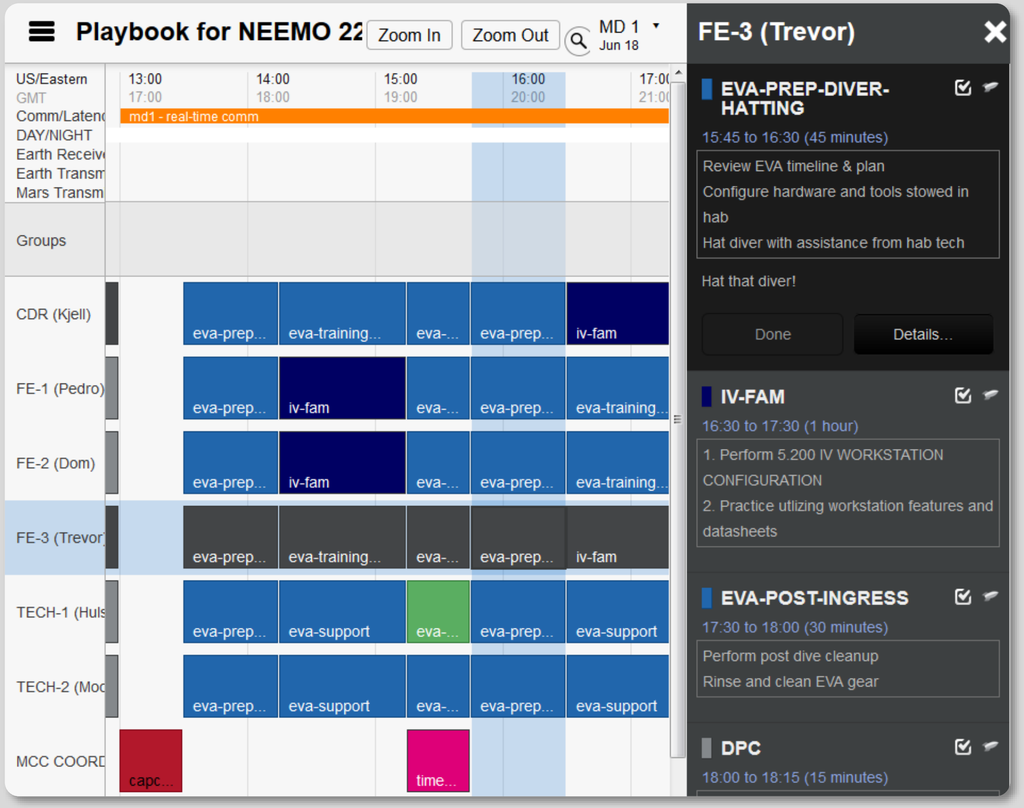


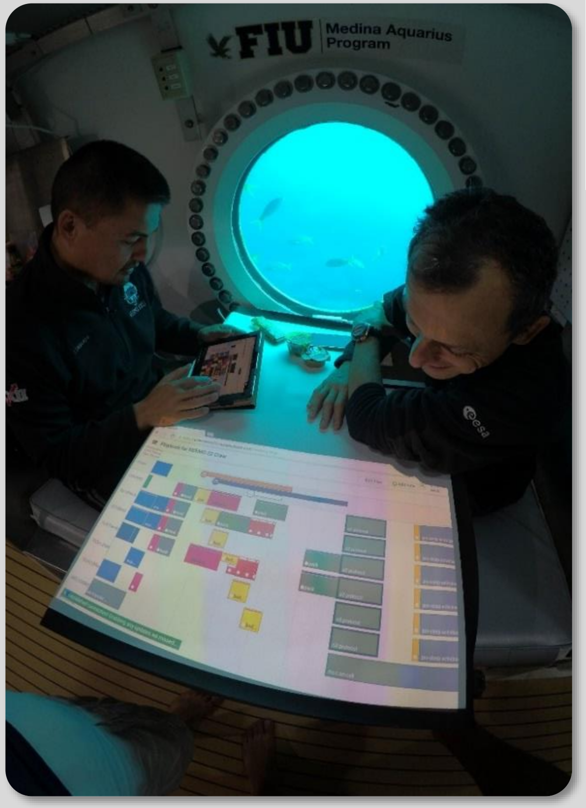
FE-3 (Trevor)

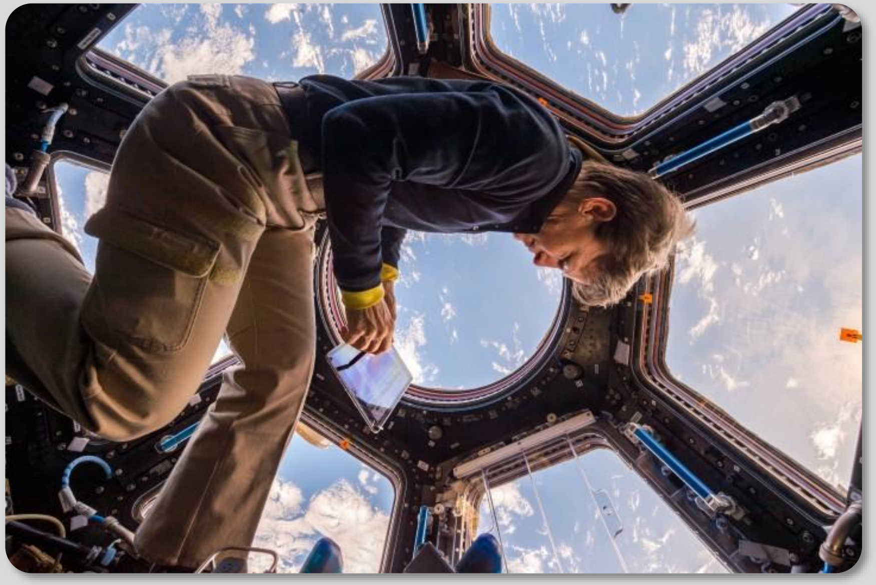
EVA-PREP-DIVER-HATTING
15:45 to 16:30 (45 minutes)
Review EVA timeline & plan
Configure hardware and tools stowed in hab
Hat diver with assistance from hab tech
Hat that diver!

IV-FAM
16:30 to 17:30 (1 hour)
1. Perform 5.200 IV WORKSTATION CONFIGURATION
2. Practice utlizing workstation features and datasheets

EVA-POST-INGRESS
17:30 to 18:00 (30 minutes)
Perform post dive cleanup
Rinse and clean EVA gear

DPC
18:00 to 18:15 (15 minutes)

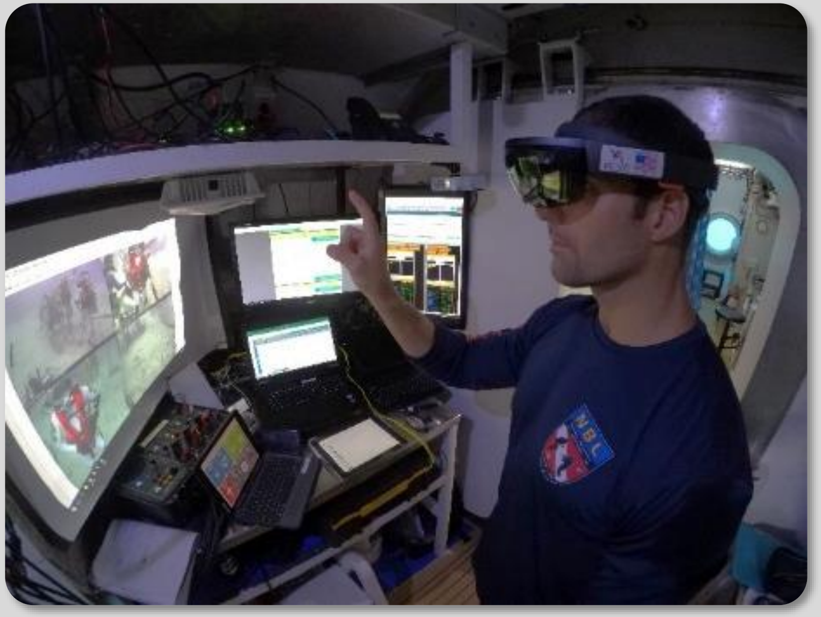




INTRA-VEHICULAR ACTIVITIES: AUGMENTED REALITY ASSISTED PROCEDURES

Purpose: Evaluate augmented reality assisted procedures on the HoloLens to provide advanced guidance and assistance with tasks that emulate those performed on the ISS and on future deep space missions. These tools are designed to reduce reliance on remote support and provide greater crew autonomy.

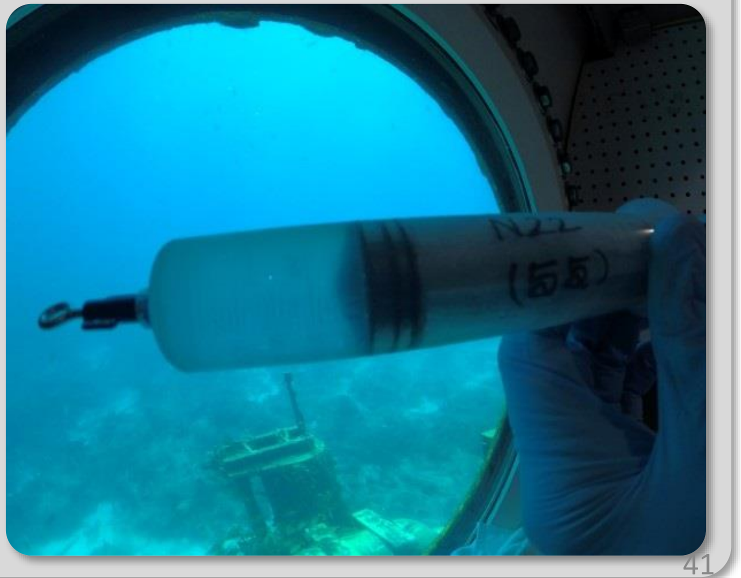
Implementation: Using HoloPD (Holographic Procedure Display) the crew performed medical (ultrasound imaging) and habitat maintenance tasks.



INTRA-VEHICULAR ACTIVITIES: MINIATURIZED DNA SEQUENCER

Purpose: Test an increasingly automated, simplified, and quicker method for implementing a swab-to-sample process. Additionally, demonstrate how the process can be used to systematically characterize the microbiome of a habitat, thereby establishing an application of the technology.

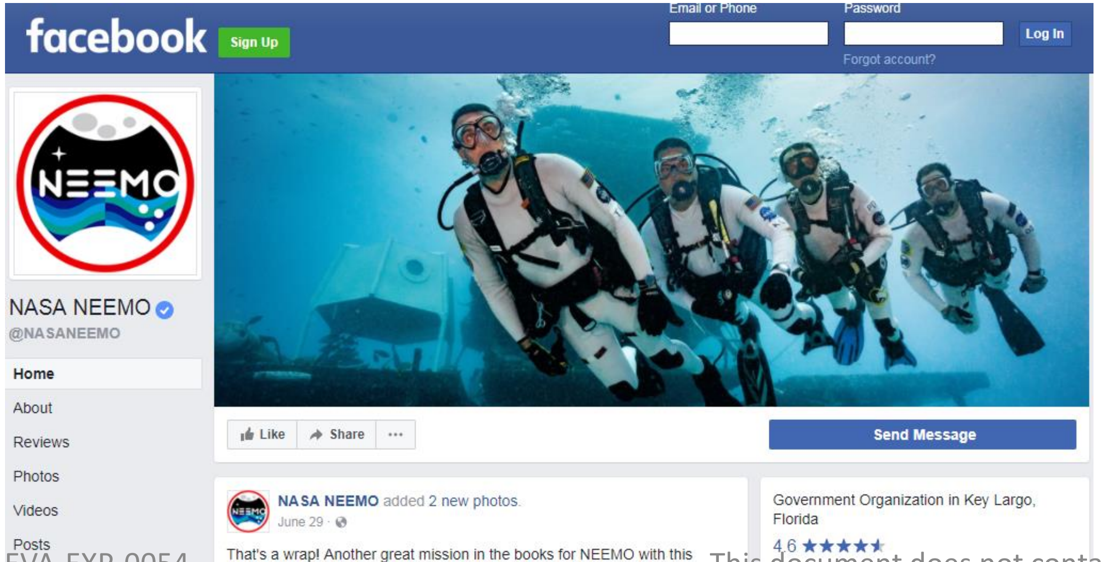
Implementation: Conduct swab-to-sample runs by each crewmember, soliciting their feedback for improvements applicable to spaceflight. Obtain additional samples related to understanding the microbiome of the habitat.



OUTREACH

Dominic D'Agostino
@DominicDAgosti2

NASA's Kjell Lindren and Trevor Graff (both Eagle Scouts) Skype with Boy Scouts of America in Texas. #NASA_NEEMO22 #BoyScouts

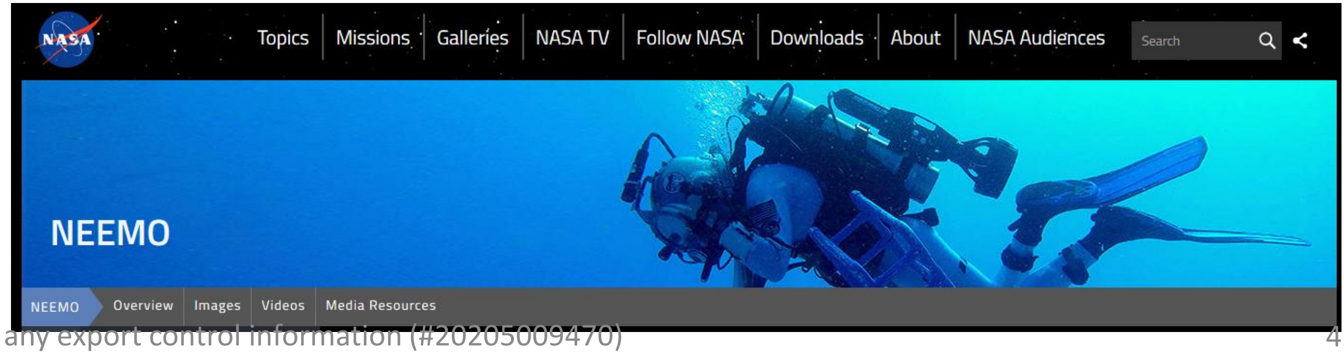


NASA NEEMO
@NASANEEMO

NASA NEEMO added 2 new photos.
June 29

That's a wrap! Another great mission in the books for NEEMO with this

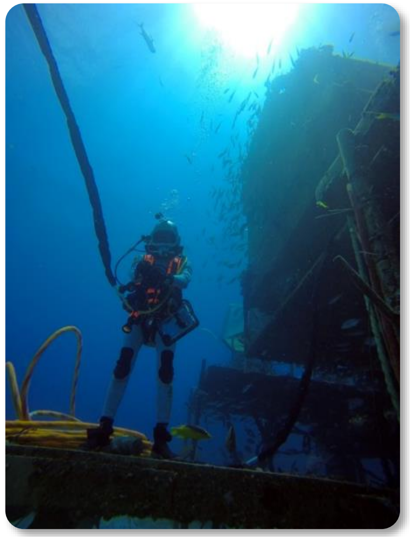
Government Organization in Key Largo, Florida
4.6 ★★★★★



BACKUP

SUMMARY

- **NEEMO provides an operational mission to Integrate Exploration and Science objectives across EISD**
  - Enabled by the unique skill blend found in EISD
  - High “bang for the buck”
  - Science component of missions now fully integrated (driven by authentic science)
  - Well suited to meet a number of EVA exploration needs
  - Plays a role in enabling and maturing ISS Objectives
  - Enables lasting cross-pollination
    - Across EISD
    - Across Engineering/Ops/Science/Crew Office
  - Visible and tangible way to highlight the work in EISD (e.g. national media, social media, events like SpaceCom)



HERITAGE & BACKGROUND

Leveraging experience and lessons learned from …

Apollo Surface Operations

- Exploration traverses were planned in advance using imagery gathered from precursor satellites
- Crews had significant training in geology and science tasks
- An Earth-based science team (ST) supported EVAs (Precursor plans, Feedback during EVA, and changes between EVAs)

Mars Robotic Missions

- Remote science operations
- Instrumentation / sample selection

MER A - Spirit

MER B - Opportunity

MSL - Curiosity

1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

NASA Extreme Environment Mission Operations

- Utilizes unique facility & environment; rapid prototyping; Evaluations of both IVA and EVA objectives

Science

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Research and Technology Studies

- Utilizes terrain appropriate for geo-science tasks; Suit and robotic tested-bed

Science

1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

Other NASA Analog Programs

- Each exploring various aspects of exploration
- Funded though grant programs
- Science focused

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WHO: THE UNIQUE CAPABILITY, EXPERIENCE, AND SKILL SETS OF EISD

Unique blend of capability and skill sets within …

XM - MISSION PLANNING, DEVELOPMENT & INTEGRATION

XI - ASTROMATERIALS RESEARCH & EXPLORATION SCIENCE

XX - EXTRAVEHICULAR ACTIVITY

XT – EXPLORATION TECHNOLOGY

Leverage extensive knowledge and experience from …

HISTORICAL MISSIONS
Apollo Surface Operations

HUMAN SPACE FLIGHT
ISS, Shuttle

ROBOTIC MISSIONS
Mars Missions, OSIRIS-REx

"ANALOG" MISSIONS
D-RATS, NEEMO & others

WHERE: ENVIRONMENTS FOR TESTS

AQUATIC

EXAMPLES

Neutral Buoyancy Laboratory (NBL)

Aquarius Reef Base (NEEMO)

ESA's Neutral Buoyancy Facility

TERRESTRIAL

EXAMPLES

Geo-Science Field Exercises & Sites

Field Training Areas

Extreme Environments (ex. Antarctica)

LABORATORY

EXAMPLES

Active Response Gravity Offload System (ARGOS)

Virtual Reality & Hybrid Reality Laboratories

International Space Station

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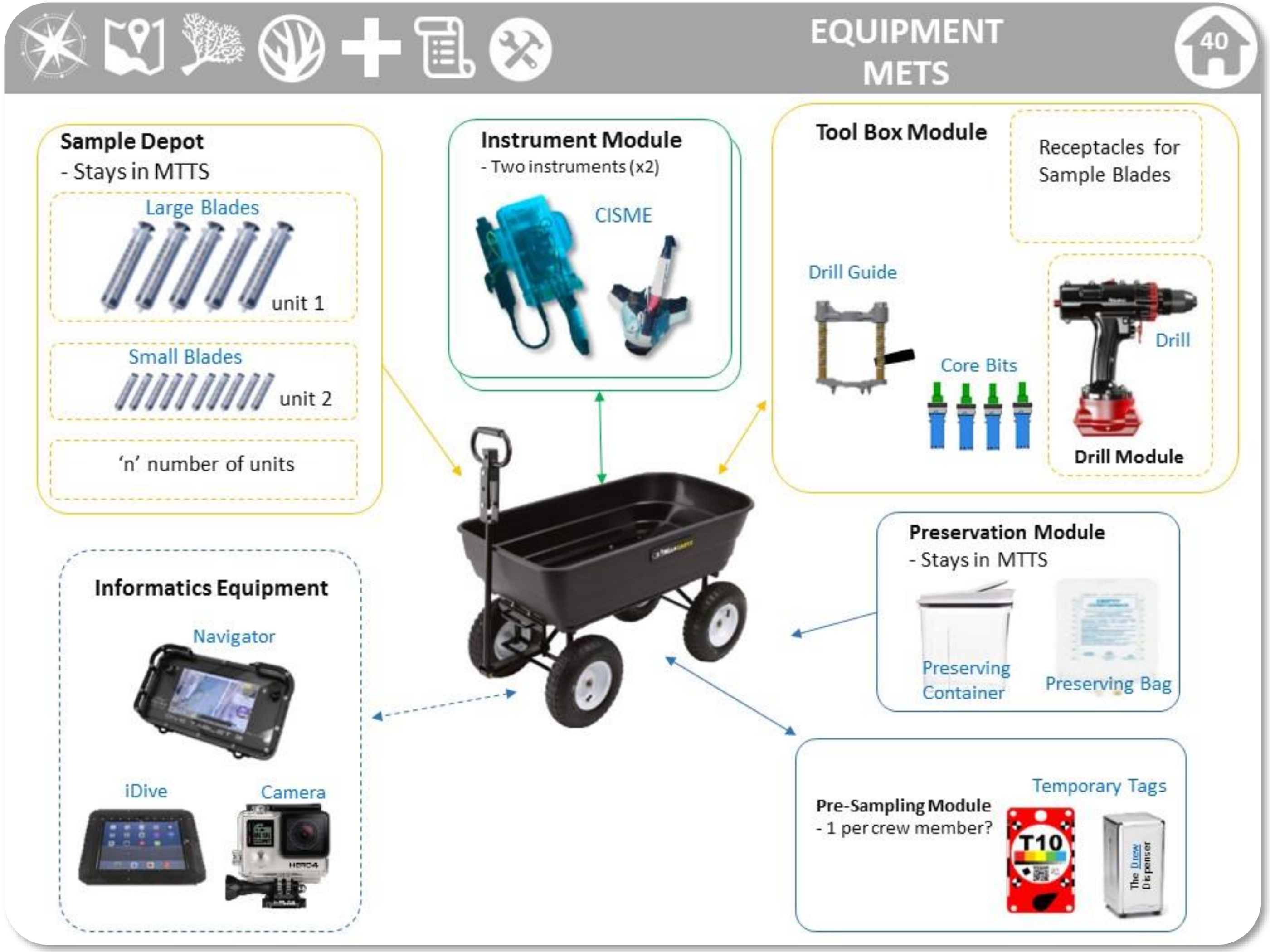
HOW: DESIRED ELEMENTS FOR EVA PARTICIPATION

There are many different types of operational field test activities. EVA is looking for the following qualities when determining which rise to the level of fidelity and return to warrant involvement:

- Responsive to EVA Office input on mission and objective design (i.e., objectives mapped to specific needs and capability, knowledge, and technology gaps)
- Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
- Participation of experienced operators (crew and MCC)
- Participation of acknowledged stakeholders with expertise to evaluate concepts being worked on across the agency (e.g., science community (XI))
- MCC and Science Team components
- Incorporation of signal latency (time delay) and blockage
- Incorporation of partial gravity
- Availability of large area of un-engineered natural (planetary) surface
- Proxy science with high correlation to planetary science
- Participation of scientists invested in the proxy science outcome
- Inclusion of appropriate purpose-built prototype hardware for evaluation and maturation
- Full “mission” environment to drive out things that wouldn’t be found in standalone testing
- Potential to benefit ISS as well as Exploration
- Enhances relationships with international partners, academia, industry, other government agencies, and other NASA orgs
- Highlights work in Exploration in a visible and tangible way (e.g. national media, social media, events like SpaceCom)
- Intersection of the 4Ts

MODULAR EQUIPMENT TRANSPORT SYSTEM (METS)



EQUIPMENT
METS

Sample Depot
- Stays in MTTS

Large Blades
unit 1

Small Blades
unit 2

'n' number of units

Instrument Module
- Two instruments (x2)

CISME

Tool Box Module

Receptacles for Sample Blades

Drill Guide

Core Bits

Drill

Drill Module

Preservation Module
- Stays in MTTS

Preserving Container

Preserving Bag

Informatics Equipment

Navigator

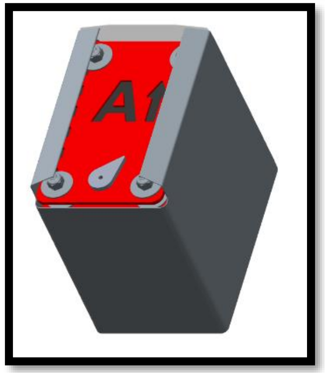
iDive

Camera

Pre-Sampling Module
- 1 per crew member?

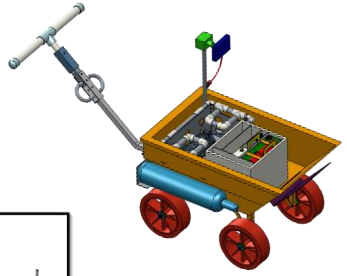
Temporary Tags

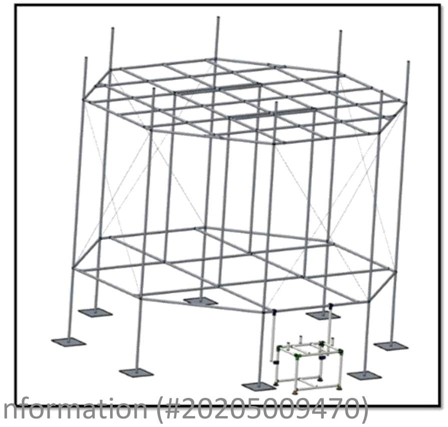
- The Modular Equipment Transport System (METS) is a method for transporting equipment from one location to another, using an understanding of the planned EVA tasks to group hardware into Modules.
- Depending on the planned activities for an EVA the crew would load only those Modules necessary to complete those activities.

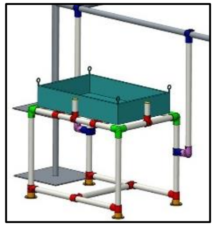


Pre-sampling Module

Sample Depot







Tool Box Module

SMALL TOOLS MODULES FOR EVA SUIT

EQUIPMENT
METS

41

Wrist Tool Set
- 1 per crew member
- Clean sets available (can be changed out, maybe not required for NEEMO)

Forceps

Brush

Small Clippers

Instrumented Cuff

Depth Gauge

Leg Tool Set
- 1 per crew member

Tongs

Diagonal Cutters

Permanent Tags

Hammer

Nails

Chisel

Cable Ties

HOBO

Small Tool Module

Small Tool Module

NEEMO 22 EVA TEAM

Mission Management Team

Bill Todd | Project
Marc Reagan | Mission Director
David Coan | EVA Lead
Trevor Graff | Science Lead

MCC Science Team

Kelsey Young
Liz Rampe
Dan Garrison
Cindy Evans
Lisa Pace
Anthony Bellantuono
Katherine Dougan
Dan Merselis
Thinesh Thangadurai

MCC Flight Control Team

Marc Reagan
David Coan
Herve Stevenin
Andy Mogensen
Andrea Boyd
Josh Cassada
Akihiko Hoshide
Steve Hillenius
Ivy Deliz
Mary Walker
Cameron Pittman

NEEMO 22 Integrated EVA Team

EVA Operations & Integration

David Coan

Crew

Kjell Lindgren
Pedro Duque
Dominic D'Agnostino
Trevor Graff

Hab Techs

Mark 'Otter' Hulsbeck
Sean Moore

Tools & Equipment

Adam Naids
Mary Walker
Drew Hood

Core Drilling

Kris Zacny
Grayson Adams
Philip Chu

HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation

Crew Rescue

Herve Stevenin
Andy Mogensen

EV Support System

Matthew Miller
Cameron Pittman

Playbook

Steve Hillenius
Ivy Deliz
Jessica Marquez

Nav & Tracking

Jim Garrington

Science Tasks

Trevor Graff
Kelsey Young
Liz Rampe
Dan Garrison
Cindy Evans
Lisa Pace

Marine Science

Mauricio Rodriguez-Lanetty
Anthony Bellantuono
Katherine Dougan
Dan Merselis
Thinesh Thangadurai

Sci Instruments

Alina Szmant
Rob Whitehead

Coral Nursery

Ken Nedimyer

Aquarius Management

Jim Fourqurean
Tom Potts
Roger Garcia

ARB Operations

Roger Garcia

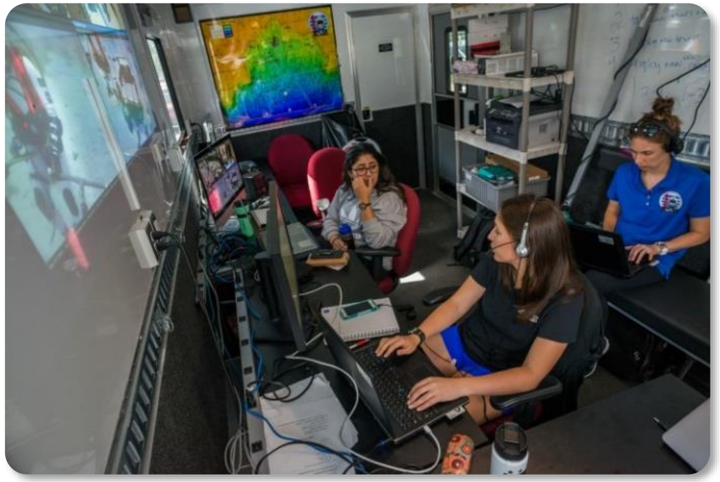
ARB Topside

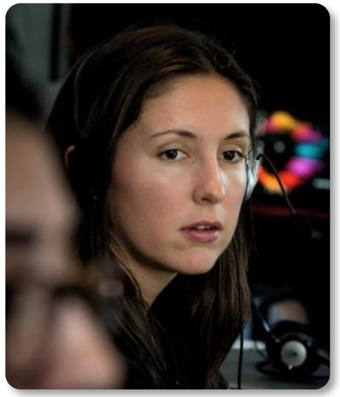
Otto Rutten
Hank Stark
Tom Horn
Tim Gallagher

NEEMO Topside Support Dive Team

David Coan
Marc Reagan
Bill Todd
Adam Naids
Herve Stevenin
Andy Mogensen
Dawn Kernagis
Marc O'griofa
Jim Garrington
Karl Shreeves
Jason Poffenberger
Kelsey Young
Josh Cassada
Csilla D'Agnostino
Kristen Todd

EISD – OUR PEOPLE MAKE IT HAPPEN!

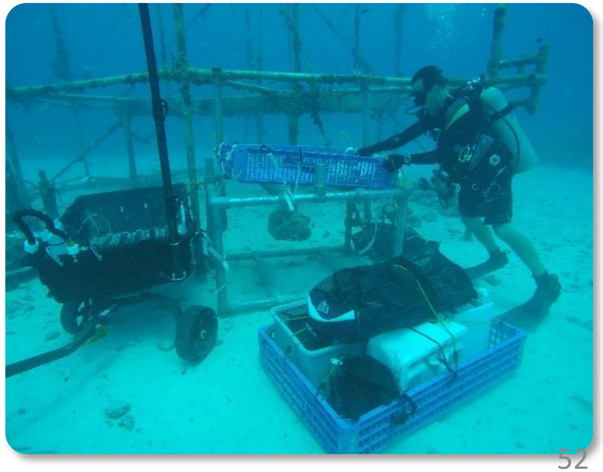










WHO: NEEMO AQUANAUTS

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)

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 12; /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 15; 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)

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, M.D.
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*, M.D.
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*, M.D.
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, XX/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/T. Graff, IHMC/D. D'Agnostino

72 Crewmembers:
54 Astronauts (16 IP Astronauts)
18 Scientists, Instructors, MDs or Engineers

Key
- * Repeater
- Blue – CDR upgrade
- Green – IP
- RED – Rookie
- Gray – non-Astro Engineer or Scientist