NEEMO 21 EVA Mission Debrief

EVA-EXP-0053
EVA Exploration Working Group
November 8, 2016

BACKGROUND & OVERVIEW

Operational Field Testing and NEEMO 21

Overview

- Successful 16 day mission living and working from Aquarius Reef Base
- Completed a combination of Exploration EVA and ISS/Orion related objectives
- International crew with partial crew rotation mid-mission
- Numerous participating organizations across NASA, JSC, ESA, DoD, Research Institutions, Universities, and Industry Partners

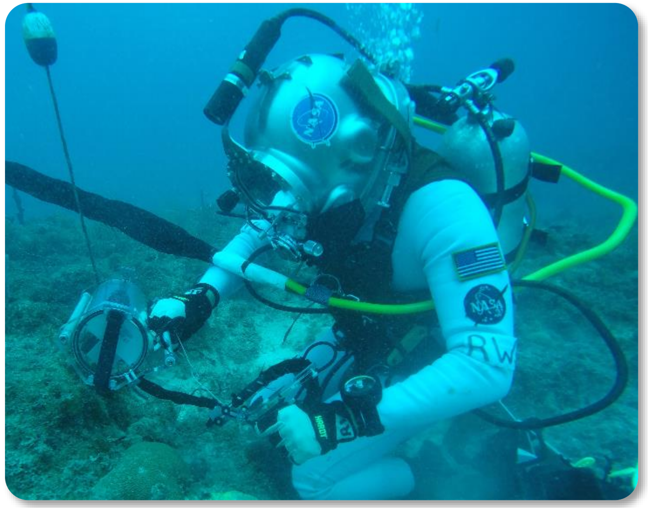
Key Dates

- Engineering Week: May 16-21
- JSC Crew Training Week: June 6-10
- Test Readiness Review: June 24
- Aquarius Reef Base Training Week: July 10-15
- NEEMO 21 Mission: July 21-Aug 5

Crew Members

Megan Behnken*	
Matthias Maurer	
Reid Wiseman*	Dawn Kernagis
Marc O Griofa	Noel Du Toit

*Mission Commander (Change of Command conducted mid-mission)



Partners / Collaborators

- **NASA**
  - JSC
    - XX: Investigating partial gravity EVA operations, tools development
    - XM: Leadership, EVA tools and techniques, (esp. related to Mars moon)
    - XI: Science Team leadership, consulting for tools development
    - EA (EC, ER): PI for multiple evaluation objectives, building EVA tools
    - CB: Crewmembers
    - SK: Co-investigator on some mission objectives
    - PAO: Public Affairs activities
  - ARC: Mission planners and timeline tool
  - JPL: Co-investigator on some mission objectives
  - KSC: Communications, data management, and logistics support
  - GSFC: Science team support
- **IPs:** Crewmembers, research objectives, funding
- **Academia**
  - Embry-Riddle Aeronautical University (ERAU): Research objectives, funding
  - Naval Postgraduate School (NPS): Synergistic robotic objectives (ROV & AUV), crewmember, funding
  - Johns Hopkins University: Research objectives, funding
  - Florida International University (FIU): Aquarius owner and operator, marine science support
  - Georgia Institute of Technology: EVA Cognitive Work Analysis graduate study
- **Institutions**
  - Florida Institute for Human & Machine Cognition: Research (epigenetics), crewmember, funding
  - Coral Restoration Foundation: research and mission objectives
- **Military**
  - Veteran's Administration w/ Non-invasive Medical Technologies: Research, crewmember, funding
- **Industry**
  - Preferred Medical Solutions/VEGA Telehealth: Research, crewmember, funding
  - Teloregen: Funding, mission objectives
  - Microspace Solutions: PI for research objective with ERAU
  - SubGravity: Providing diver propulsion system
  - Shark Marine: Providing a navigation system, in-kind contribution

XI Astromaterials Research & Exploration Science (ARES)

XX EVA Strategic Planning & Architecture

XM Mission Planning, Develop & Integration

EC Crew & Thermal Systems - Tools

Heritage & Background

Leveraging experience and lessons learned from ...

Apollo Surface Operations

Low communication latency (~1.25 sec OWLT)

- 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

High communication latency for Mars (~4-22 min OWLT)

- 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

Tested-bed for a variety of communication latency for detailed EVA/Science evaluations

- 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

Tested a variety of communication latencies for geo-science operations

- 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

Test a variety of communication latencies

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

ISRU

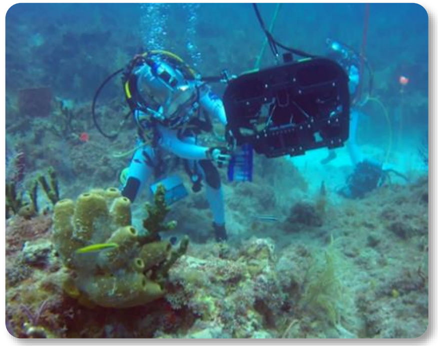
EVA Goals

- Advance the future of the EVA system and operations
- Understand EVA gaps and concepts of operations for a wide range of Exploration destinations being considered by NASA
- Determine and document closures to gaps in EVA capabilities for Exploration missions and inform the EVA Systems Maturation Team (SMT)
- Develop and document concepts of operations for EVA at the Exploration destinations
- Realize the needs of EVA tools and hardware and enable the development of requirements and designs

Benefits of Operational Field Testing

- Evaluates objectives mapped to specific needs and knowledge/technology gaps
- Concepts of operations can be accurately tested to determine their viability and changes
- Utilization of real science allows for investigation of end-to-end concepts of operations, from both an Earth-based Science Team and the in-situ EVA crew
- Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
- Drives out results not found in standalone testing
  - Able to understand in a mission environment what systems and technologies are and are not required
  - Understand how the use and interactions of those systems and technologies affects their requirements and subsequent development
- Purpose-built prototype hardware can be evaluated in a field test to provide data for design maturation
- Communication latencies can be simulated in an operational environment in order to assess the con ops and needs associated with EVAs
- Benefits programs from ISS to Exploration





Mission Program Relevancy

Category	Gap/Risk	Experiment	Sponsor	Beneficiary
Technology Maturation for Ops	Planetary Protection	✓ EVA Swab Tool	HAT/JPL	Exploration
	Exercise Countermeasures	✓ MED	ER	ISS, Orion
	Telemedicine	✓ VEGA	Corp/Vet Adm.	ISS ------> Exploration
		✓ AirDocs	Corp/Vet Adm.	ISS ------> Exploration
Ops Tools Maturation	Mobile Crew Planning Tool	✓ Playbook	ARC	ISS ------> Exploration
	Crew Task Efficiency	✓ MobiPV (ESA)	ESA	ISS ------> Exploration
		✓ HoloLens Cargo Transfer Ops	CO/ER/SF	ISS ------> Exploration
	ISS Water Sampling	✓ Aquapad	ESA	ISS
	ISS nutritional tracking	✓ Nutritional Assessment	ESA	ISS
	Sensorimotor degradation	✓ PSAP	Johns Hopkins	ISS ------> Exploration
	in situ DNA sequencing	✓ mini DNA Sequencer	SF	ISS ------> Exploration
Ops Concept Maturation	**Exploration Surface Ops w/ Comm Delay**	✓ **Crew Self Scheduling**	XX/ARC	ISS ------> Exploration
		✓ **Integrated Science Team**	XI/XX	Exploration
		✓ **Man-machine work systems**	XX/NPS	Exploration
		✓ **Electronic EVA cue cards**	XI/XX	Exploration
		✓ **IV Support Tools**	XI/XX	Exploration
		✓ **Navigation Tool needs**	XI/XX	Exploration
Pure Science	Oxidative Stress	✓ Multi-Omics study	IHMC	ISS ------> Exploration
	Telomere damage	✓ Telomere Regeneration study	Teloregen	ISS ------> Exploration
	Reef mortality	✓ Coral Science	FIU, CRF	N/A
Crew Preparation	Expeditionary Training	✓ CDR upgrade	CB (+IPs)	ISS ------> Exploration
		✓ Rookie mission experience	CB (+IPs)	ISS ------> Exploration
Outreach Opportunities	N/A	✓ PAO events	PAO	ISS ------> Exploration
		✓ Educational Outreach	PAO	ISS ------> Exploration

EVA OBJECTIVES

Science, **Operations**, and **Equipment**

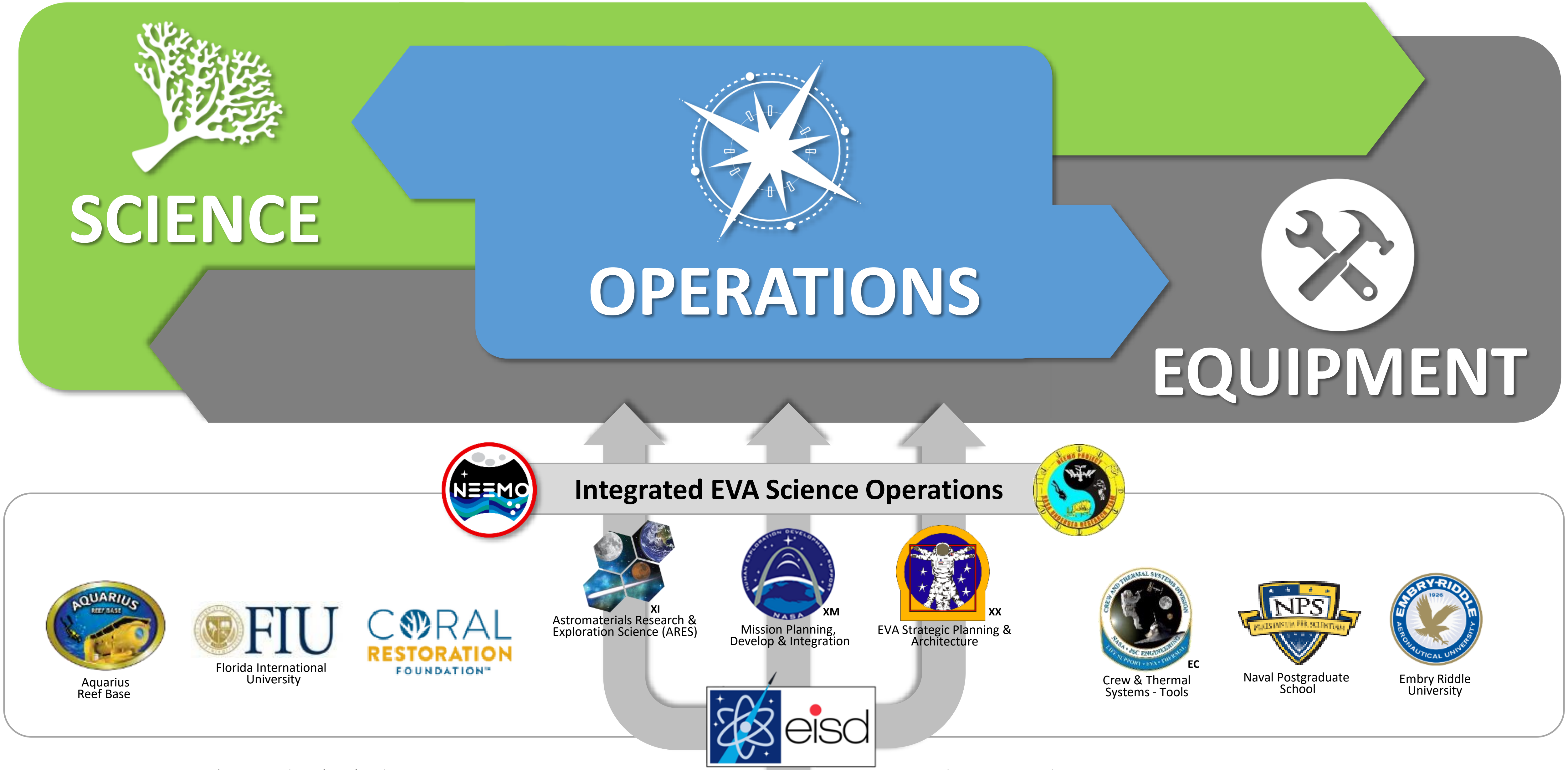
XX – Exploration EVA Objectives & Gaps for NEEMO 21

The primary objective for EVA at this operational field test was to explore the combined aspects of **Science**, **Operations**, and **Equipment** in a mission-like environment in order to evaluate:

- Concepts of operations on a natural surface
- Hardware and tools for pioneering and science tasks
- Tools and techniques that enable effective and efficient communication between the ground (MCC and Science Team) and the crew (IV and EVA) during an EVA over an appropriate communication latency utilizing a flexible execution methodology in order to enable successful science

NEEMO 21 EVA Objectives		EVA SMT Gap
Tools (software and hardware) and techniques needed to effectively communicate over a comm latency during an EVA • **Integrated EVA Science Operations** • **EVA Digital Cue Cards** • **IV Support System**	✓ Examine how EVA operations will be directed/controlled at destinations with comm latencies, including EVA interaction with a Science Team and crew-driven multi-day planning of EVAs	128: EVA Integration New: Integrated EVA Flight Control Methodology
	✓ Evaluate the tools (hardware and software) MCC, the IV, and the EVA crew will need in order to conduct operations at destinations with comm latencies; including texting, file transfer, audio, video, still imagery, suit data (placeholder), and an EVA tool for identifying and relaying information about samples	128: EVA Integration New: Tools for Interacting with EVA Over a Comm Latency 92: Avionics Systems for EVA Tasks 93: Display (Integrated EVA Camera System)
	✓ Evaluate what kind of tools (support system) the IV crewmember will need in order to effectively handle the amount of information and tasking the IV crewmember must contend with while actively directing the EVA	128: EVA Integration New: IV Support System for EVA Operations
Flexible execution methodology for EVA science operations ("flexecution")	✓ Develop a flexible execution methodology ("flexecution") for the Exploration EVA System, Crew, and Flight Control Team to operate in natural environments where things are not well defined and may require significant deviation from any plan	128: EVA Integration Flexible Execution Methodology for EVA Science Operations in Undefined Environments
EVA tools and hardware for science sampling • **Integrated Geology Sampling System** • **EVA Tool Caddy**	✓ Evaluate EVA hardware and operations for science sampling in a surface/partial-g environment • Loosely adhered particles (surface, float, soil) • Chip samples • Subsurface samples (core)	107: Tools for Surface EVA New: Tools for Science Sampling on a Surface EVA
	✓ Evaluate EVA hardware and operations for transporting and stowing tools and samples	107: Tools for Surface EVA 108: Tools (Tool Carrier Device)
Hardware and tools to assist EVA operations • **Joint Robotic-EVA Operations** • **EVA Navigation** • **Traverse Planning**	✗ Examine uses of robotic assets for EVA operations	128: EVA Integration New: EVA-Robotic (Man-Machine) Work System
	✓ Assess tool needs (hardware and software) for short distance navigation data to support rover based geology/science	92: Avionics Systems for EVA Tasks 96: Navigation (EVA Short Range Navigation)

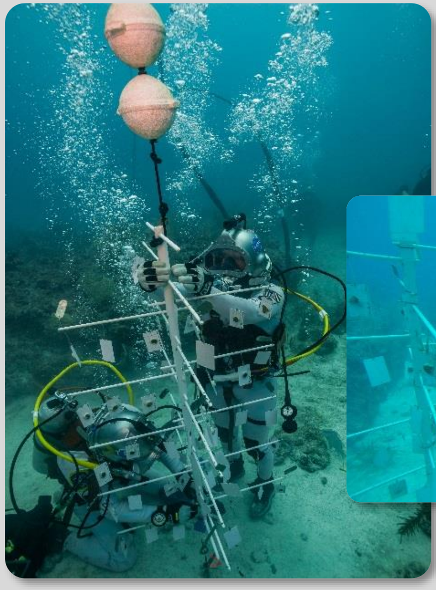
Integrated Science EVA Operations

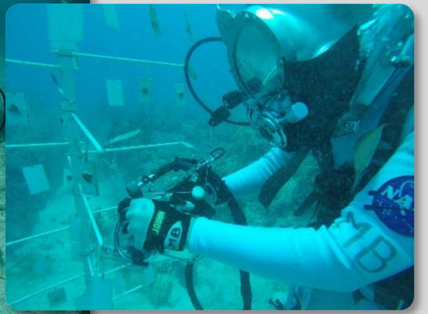


SCIENCE

OVERVIEW AND RESULTS

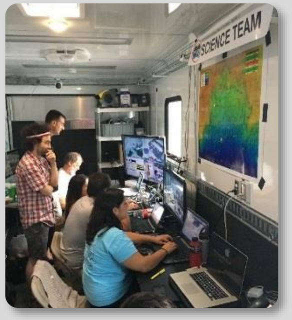
NURSERY CONSTRUCTION & SCIENCE





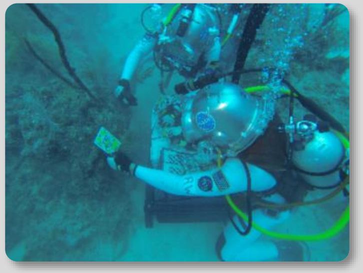
- Constructed, populated, and conducted initial science investigation on two long-term coral nurseries near ARB
  - 50’ nursery
  - 90’ nursery (deepest in the world)
- Constructed 5 tree-structures at each site; emplaced 600 samples for scientific research

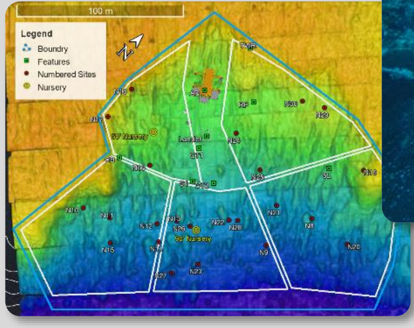
REEF FOLLOW-UP SCIENCE



- Continued research and sampling conducted during NEEMO 20
- 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 expand into new sites and new coral species; coral science was correlated to nurseries as a natural baseline
- Described, documented, and sampled over 80 additional samples

Authentic science now fully integrated into NEEMO EVA operations

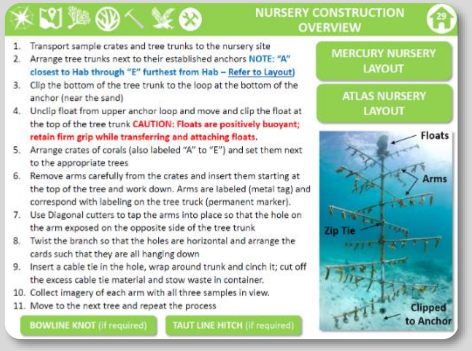
Successfully completed all science objectives during 60+ hours of science driven EVA operations

SCIENCE

NURSERY CONSTRUCTION & SCIENCE

Plan/Training → Pioneering → Science

Prepare, Process, and Train



NURSERY CONSTRUCTION OVERVIEW

1. Transport sample crates and tree trunks to the nursery site
2. Arrange tree trunks next to their established anchors NOTE: "A" closest to Hab through "E" furthest from Hab – Refer to Layout)
3. Clip the bottom of the tree trunk to the loop at the bottom of the anchor (near the sand)
4. Unclip float from upper anchor loop and move and clip the float at the top of the tree trunk **CAUTION: Floats are positively buoyant; retain firm grip while transferring and attaching floats.**
5. Arrange crates of corals (also labeled "A" to "E") and set them next to the appropriate trees
6. Remove arms carefully from the crates and insert them starting at the top of the tree and work down. Arms are labeled (metal tag) and correspond with labeling on the tree truck (permanent marker).
7. Use Diagonal cutters to tap the arms into place so that the hole on the arm exposed on the opposite side of the tree trunk
8. Twist the branch so that the holes are horizontal and arrange the cards such that they are all hanging down
9. Insert a cable tie in the hole, wrap around trunk and cinch it; cut off the excess cable tie material and stow waste in container.
10. Collect imagery of each arm with all three samples in view.
11. Move to the next tree and repeat the process

MERCURY NURSERY LAYOUT

ATLAS NURSERY LAYOUT

Floats

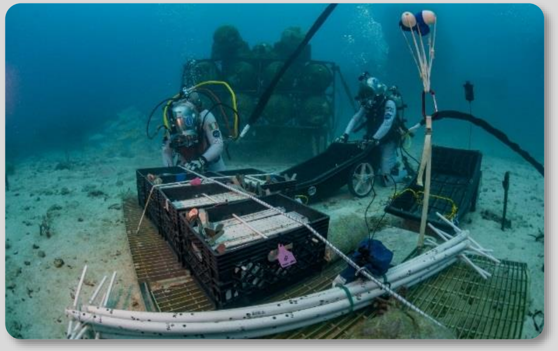
Arms

Zip Tie

Clipped to Anchor

BOWLINE KNOT (if required) | TAUT LINE HITCH (if required)

Transport and Build



Science and Operations

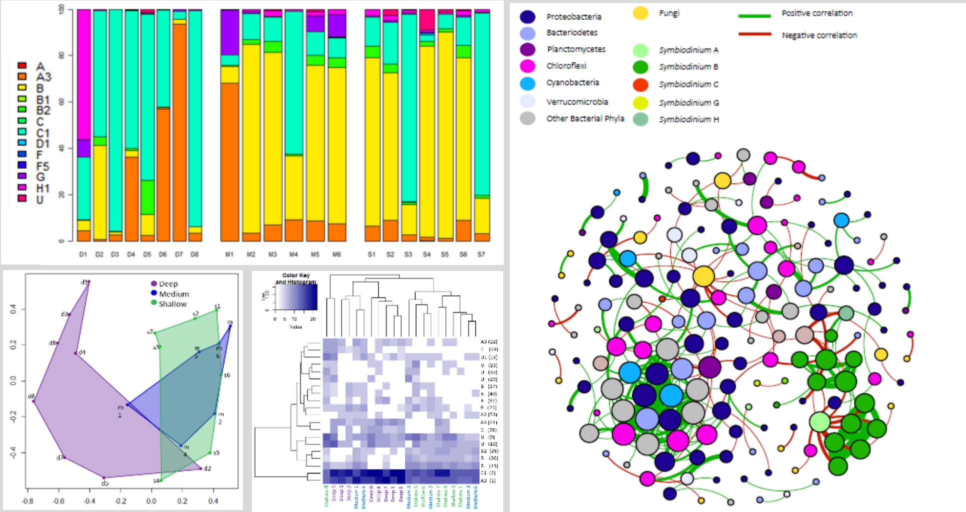
SCIENCE

MARINE EXPLORATION SCIENCE

FIU
FLORIDA INTERNATIONAL UNIVERSITY

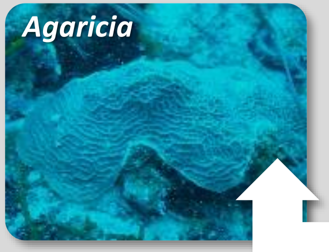
- Laboratory of Integrative Marine Genomics and Symbiosis (IMaGeS)
- Focuses on the study of the symbiotic interactions between microbial organisms and cnidarian hosts, in particular reef-building corals, from different perspectives, including cell biology, eco-physiology and ecology.
- Crew comment: "Have to sustain real science on an analog."
- Crew comment: "VERY cool to revisit NEEMO 20 site. Definitely keep that. Going back to previous work ties it all together and gives feeling of cool ongoing science."

NEEMO 20
RESULTS AND FOLLOW UP



NEEMO 21
EXPLORATION SCIENCE

NEEMO XXI



- 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**

SCIENCE

PLANETARY SCIENCE RELEVANCE

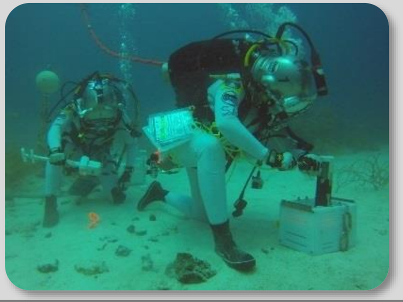
Astromaterials Research & Exploration Science (ARES)

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

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

Astromaterials

Curation

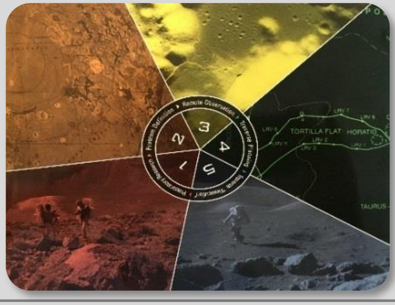


- Sampling Procedures
- Sampling Techniques
- Collection Tools
- Contamination
- Storage & Transport

Research

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

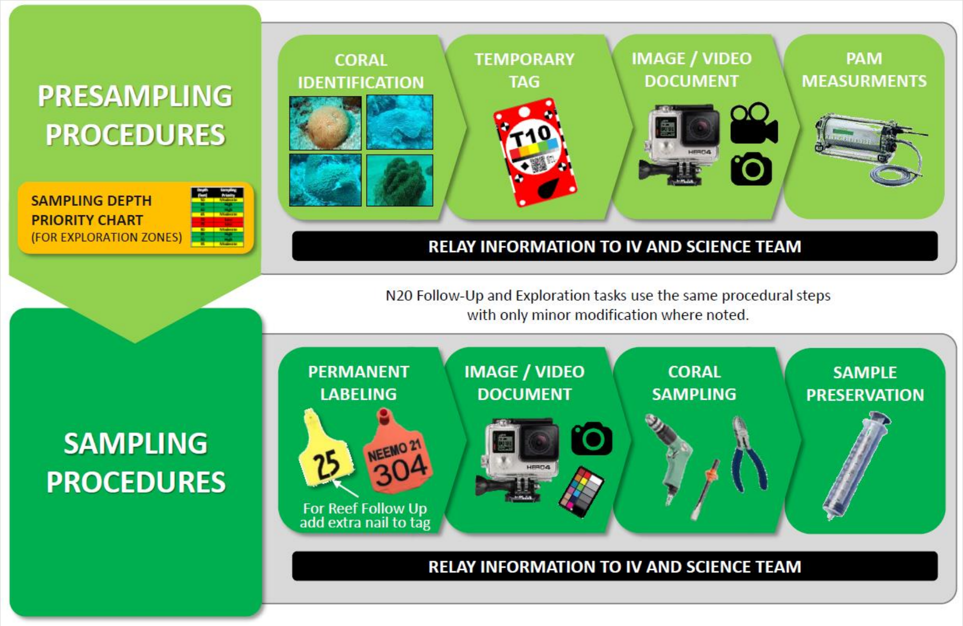
Exploration

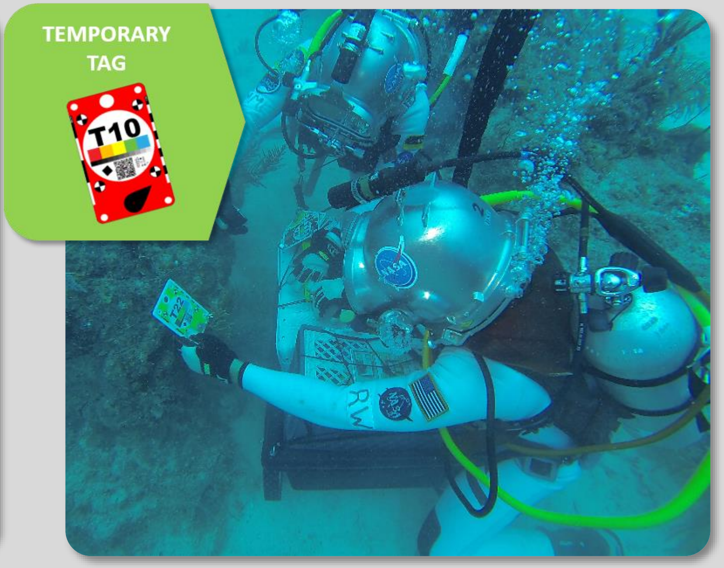


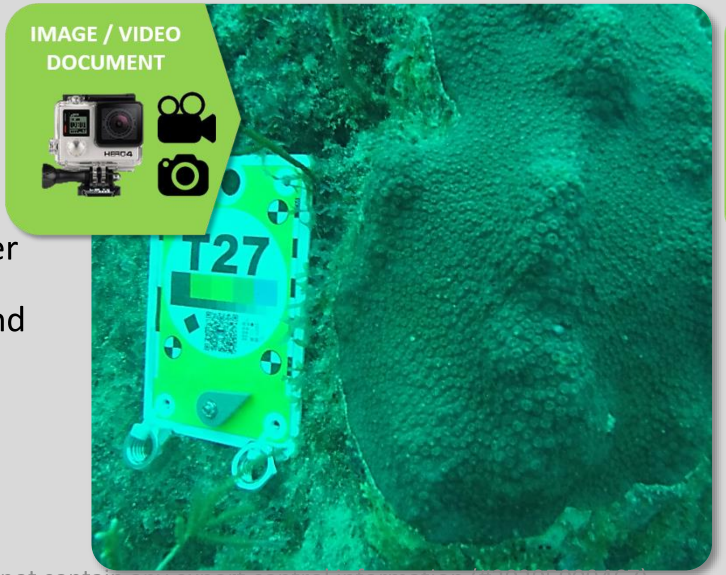
- Science Operations
- Traverse Planning
- Operational Flexibility
- Human-Robot Ops
- Crew Science Training

Marine science proved to be an excellent analog for planetary science operations

SCIENCE PRESAMPLING



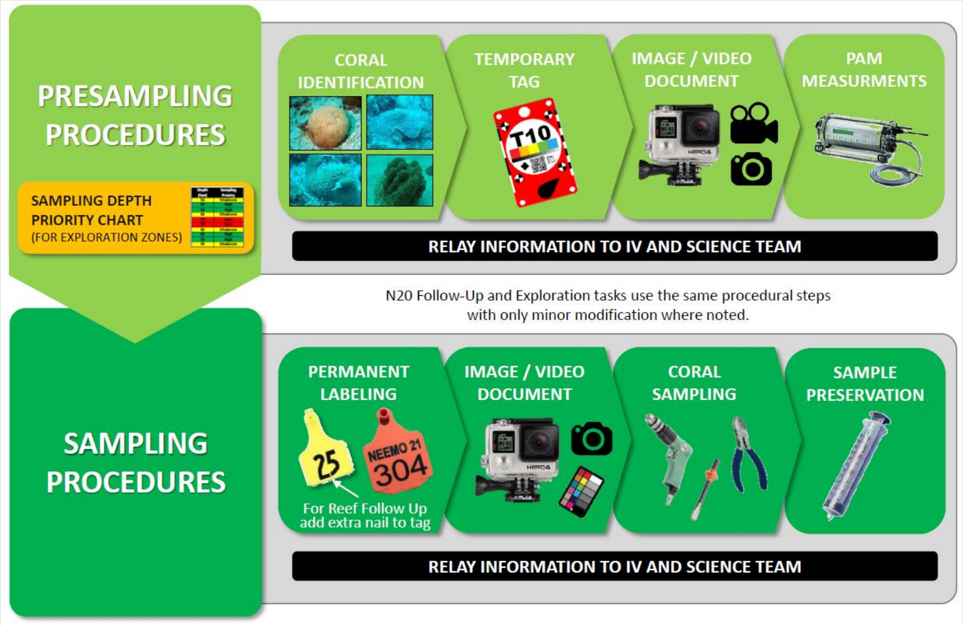


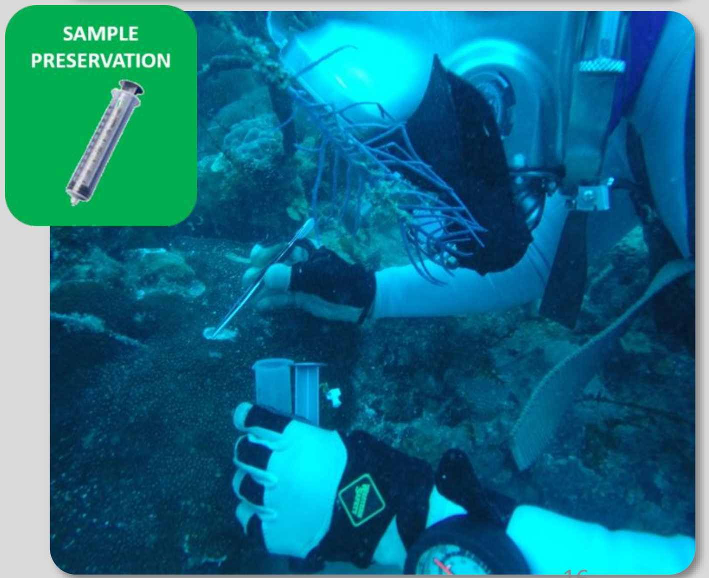


Key Take-Aways

- Crew science training is crucial
- Science Team input over 15 min com latency was successfully conducted during a single 4hr EVA
- Science planning/re-planning was required frequently in order to respond to operational changes and science discoveries
- Digital cue card interface was successful for increasing EVA and crew autonomy
- Gap closures addressed
  - Integrated EVA Flight Control
  - Tools for Interacting with EVA Over a Comm Latency
  - Flexible Execution Methodology for EVA Science Operations in Undefined Environments

SCIENCE SAMPLING





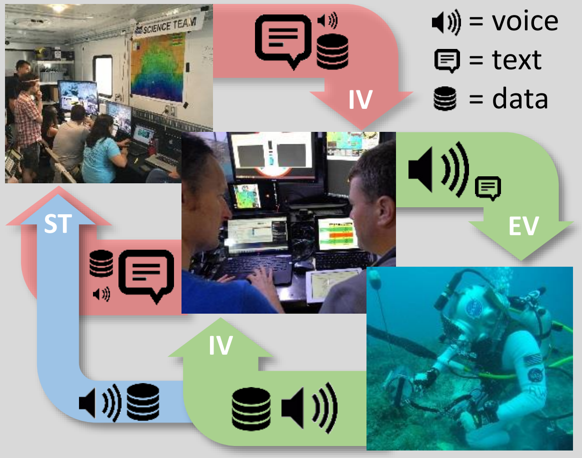
Key Take-Aways

- Efficient transportation, access, and stowage of tools, instruments, and sampling equipment is critical for increased science sampling; numerous lessons learned were documented
- Detailed imaging of sampling process is crucial for proper documentation and resulting science
- Continue to develop and evaluate methods to minimize sample contamination
- Gap closures addressed
  - Tools for Interacting with EVA Over a Comm Latency
  - Tools for Science Sampling on a Surface EVA

OPERATIONS

OVERVIEW AND RESULTS

INTEGRATED EVA SCIENCE OPERATIONS



- Examined con ops that enable interaction between the MCC & the crew over a long comm latency including:
  - Interaction with an integrated Science Team
  - Authentic scientific objectives and hypothesis
  - Flexecution methodology

NAVIGATION, MAP, & TRAVERSE PLANNING

- Assessed tool needs for navigation
- Traverse plan and map on cue cards showed crew regions and paths, and tasks to complete
- Utilized Doppler relative nav system for crew to find ROI/zones

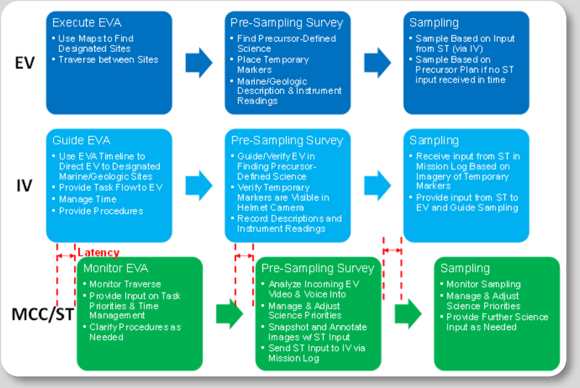
OPTICAL COMMUNICATIONS

- Successfully deployed, tested, and evaluated a prototype optical communications system

JOINT ROBOTIC-EVA OPERATIONS

- Utilized an ROV as a robotic asset for IV and ST situational awareness of the EVA

COMM STUDY DESIGN & ASSESSMENT



Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement		No Rating
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.		Unable to assess capability
1	2	3	4	5	6	7	8	9	10	NR

- Assessed the effects of communication latencies on operations concepts, timelines, and tasks
- Collected operational acceptability ratings for the overall operations concepts, as well as various components
- Data is being evaluated and will be incorporated into a 2017 IEEE conference presentation

WITH LONG (15 MIN) COMMUNICATION LATENCY CON OPS

OPERATIONS

INTEGRATED EVA SCIENCE OPS

Objectives

- Develop techniques and determine what functions/capabilities are needed to enable an MCC integrated Science Team to effectively operate and actively direct EVA science operations over a long comm latency
- Determine what functions/capabilities and techniques are needed to enable the EVA crew to effectively operate and communicate information to the Science Team over a long comm latency
- Evaluate flexible execution methodology for EVA science operations

Key Take-Aways

- Evaluated integrating ST feedback during an EVA, between EVAs, and sampling without direct ST input
  - Pre-sampling followed by sampling with ST feedback during the same EVA was borderline acceptable
    Note: Minimal training was available for the NEEMO crew, which contributed to the challenge of this con op
  - Pre-sampling in one EVA and sampling in a subsequent EVA, with ST feedback between the EVAs was acceptable
  - Sampling only with pre-sampling completed on the previous mission was acceptable/borderline
  - Flexecution was not specifically rated, but was found by EVA & ST to be a good model for operations
- EVA crew is capable of operating more autonomously than on ISS while simultaneously incorporating input from an Earth-based ST
- Science Team can effectively communicate critical data and direction over a 15-min com latency to execute science sampling operations during a 4-hr EVA
- Science planning/re-planning may be required frequently in order to respond to operational changes and science discoveries
- Crew science training is crucial, and detailed geoscience knowledge will be required
- Flexecution flight rules will be critical for addressing the decision making authority for dynamically changing plans in a natural environment (crew versus MCC/ST)
  - New paradigm for EVA flight control
  - Crew training and geoscience knowledge will be crucial for operating in a flexecution environment
- **Provided critical input for updates to the *Exploration EVA Concepts of Operations* document**
- Gap closures addressed
  - Integrated EVA Flight Control
  - Tools for Interacting with EVA Over a Comm Latency
  - Flexible Execution Methodology for EVA Science Operations in Undefined Environments

Objectives

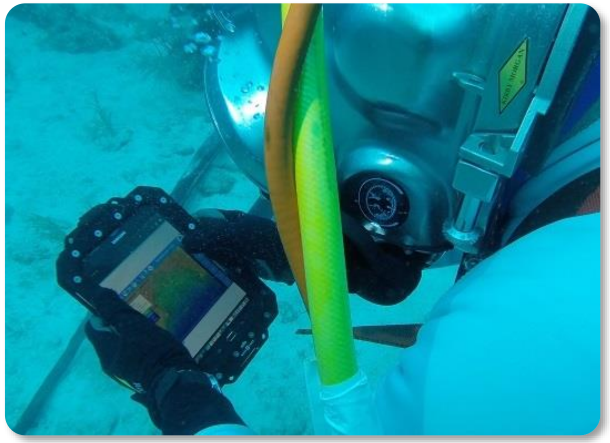
- Develop techniques and determine what functions/capabilities are needed to enable an MCC integrated Science Team to effectively operate and actively direct EVA science operations over a long comm latency
- Determine what functions/capabilities and techniques are needed to enable the EVA crew to effectively operate and communicate information to the Science Team over a long comm latency
- Evaluate flexible execution methodology for EVA science operations

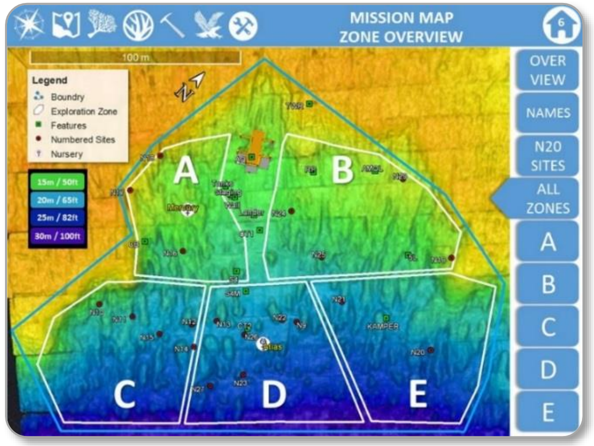
Key Take-Aways

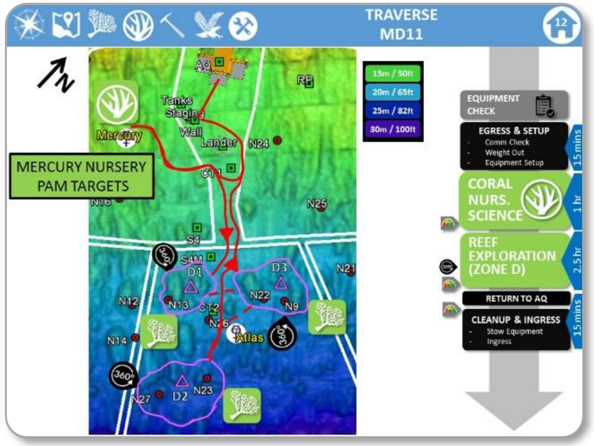
- Video from EVA helmet cams is required for the Science Team
  - Warranted improvements are higher resolution video to enable more accurate/reliable candidate sample identification
- High resolution imagery (photos) will be need to be transmitted during an EVA to enable the ST to make informed decisions
- Need ability to precisely locate the specimens to be re-sampled, including imagery of the targeted samples and overall area
- EVA digital cue cards enabled EV crew to conduct general navigation, identify specimens to sample, and guide themselves through procedures, permitting increasing EVA and crew autonomy
- IV support system will be key for Exploration EVA operations with comm latencies to address the challenges facing future IV crewmembers with a high workload and to allow for management of the large task volume
- For recording science data, warranted improvements are an integrated system that IV and ST can both view and edit for tracking/recording of presampling and sampling tags, PAM data, etc.
- A tool to record, track, and communicate science data is essential
- For modifying the plan during an EVA, warranted improvements are a system to allow ST to modify a traverse real-time and have that sent to the crew for use during the EVA
- Temporary sample markers were critical for allowing the ST to review the crew inputs over the delay and still get the species required
- Gap closures addressed
  - Integrated EVA Flight Control
  - Tools for Interacting with EVA Over a Comm Latency
  - Flexible Execution Methodology for EVA Science Operations in Undefined Environments
  - IV Support System for EVA Operations
  - Display (EVA Integrated Camera)
  - Navigation (EVA Short Distance Navigation)

Objective

- Assess tool needs (hardware and software) for short distance navigation data to support rover based geology/science







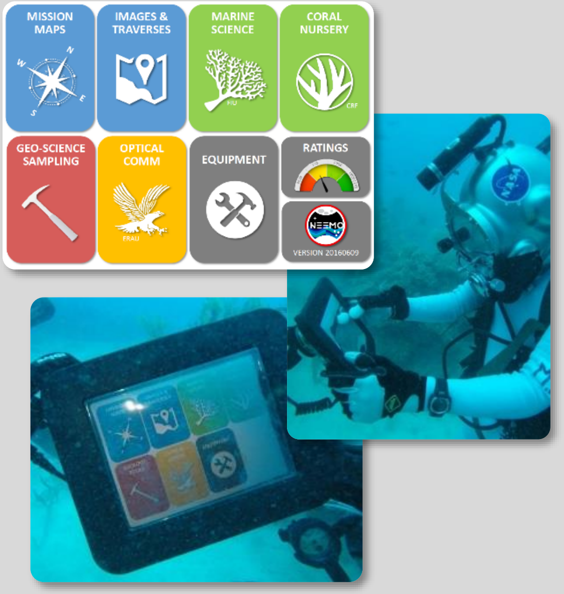
Key Take-Aways

- A combination of digital maps, a traverse plan, and an active navigation system will allow an EV crew to locate the pertinent sampling zones
- EVA digital cue cards enable EV crew to conduct general navigation, identify specimens to sample, and guide themselves through procedures
  - Digital maps with timeline assist EV crew in efficiently understanding exploration area and tasks
- Relative navigation system enables crew to reliably find sampling zones and relocate marked samples, which will be critical on Exploration missions
- Key lessons learned for MCC ST on the time-latent planning cycle and developing a process for updating the plan in timely manner under time pressure and in a manner that the crew can effectively utilize
- For creating planned traverses, desired improvements are a Google Earth type mapping capabilities integrated w/ better a traverse planning tool to show remaining consumables, traverse time and distance, etc.
- Gap closures addressed
  - Integrated EVA Flight Control
  - Navigation (EVA Short Distance Navigation)

EQUIPMENT

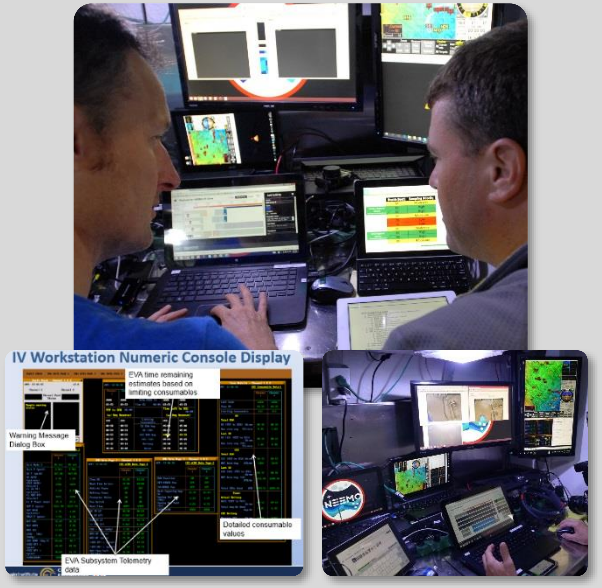
HARDWARE & TOOL EVALUATIONS

DIGITAL CUE CARDS



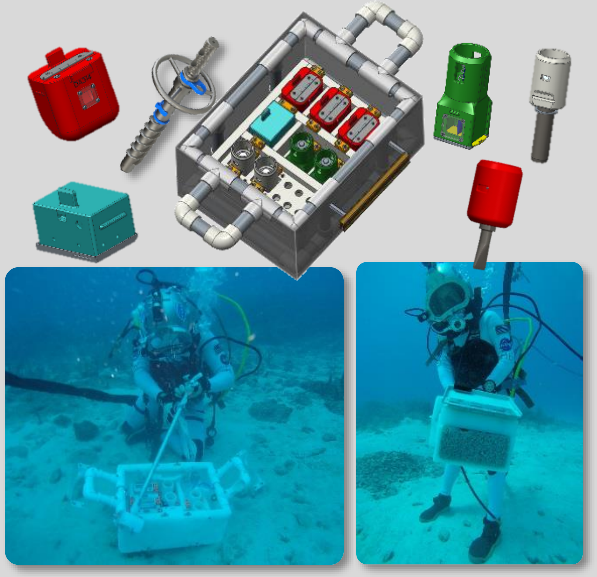
- Evaluated digital cue cards for EVA crew that allowed crew to operate more effectively and offload IV tasks
- Additional crew autonomy requires further access to information in their hands
- Potential "one-device" for cue cards/procedures, images/video, instrument control, etc.

IV SUPPORT SYSTEM



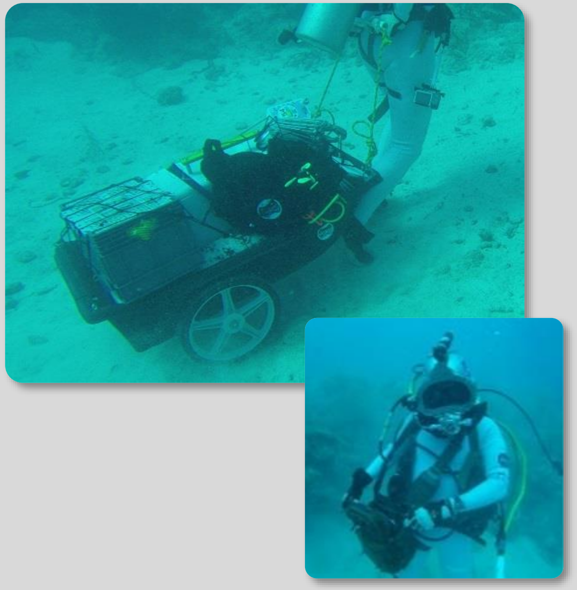
- Evaluated types of tools the IV crewmember needs to effectively handle the large amount of EVA information while directing EVA
- Evaluated effective setup in a constrained location
- Multiple displays included camera feeds, timeline, nav/comm/sub systems, procedures, logs, etc.

SCIENCE SAMPLING TOOLS & GEOLOGY SAMPLING KIT



- Evaluated EVA tools and hardware for science sampling
- Evaluated Integrated Geology Sampling System for collecting geology & astrobiology samples
- Sample Briefcase housed various end effectors with two different drivers (manual and powered)
- Analyzed methods to minimize contamination of sample and area

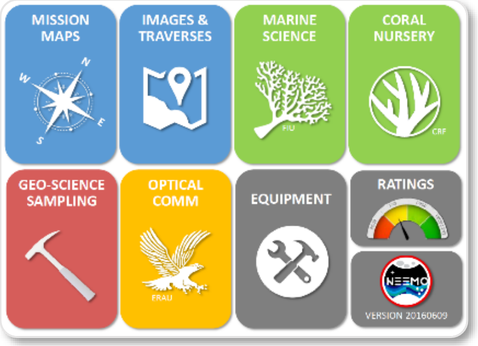
TRANSPORTATION & STOWAGE OF TOOLS



- Evaluated EVA hardware and operations for transporting and stowing tools and samples
- Initial look at sled/cart options for large equipment transport
- Evaluated sling bag options for small items & easy access (sample markers, hand tools, electronics, etc.)

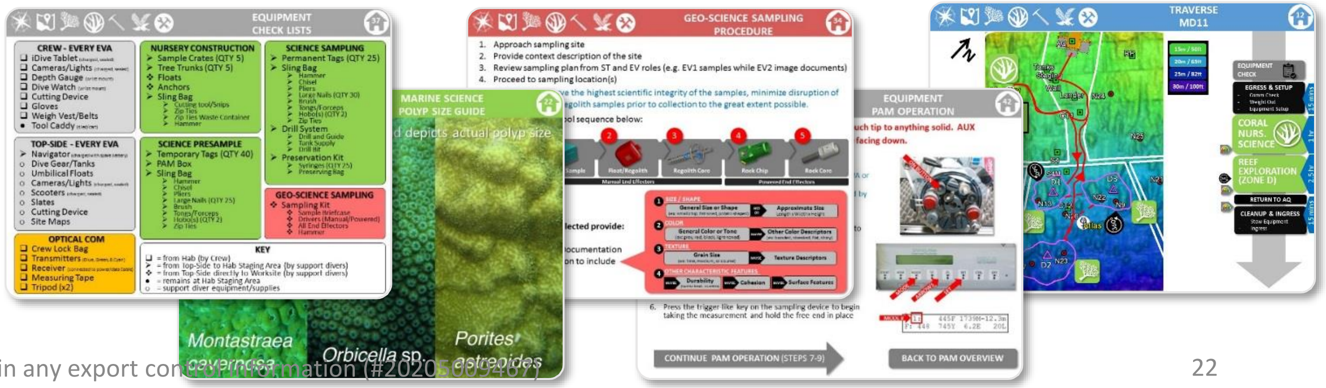
Objectives

- Evaluate the tools the EVA crew will need in order to conduct operations at destinations with comm latencies



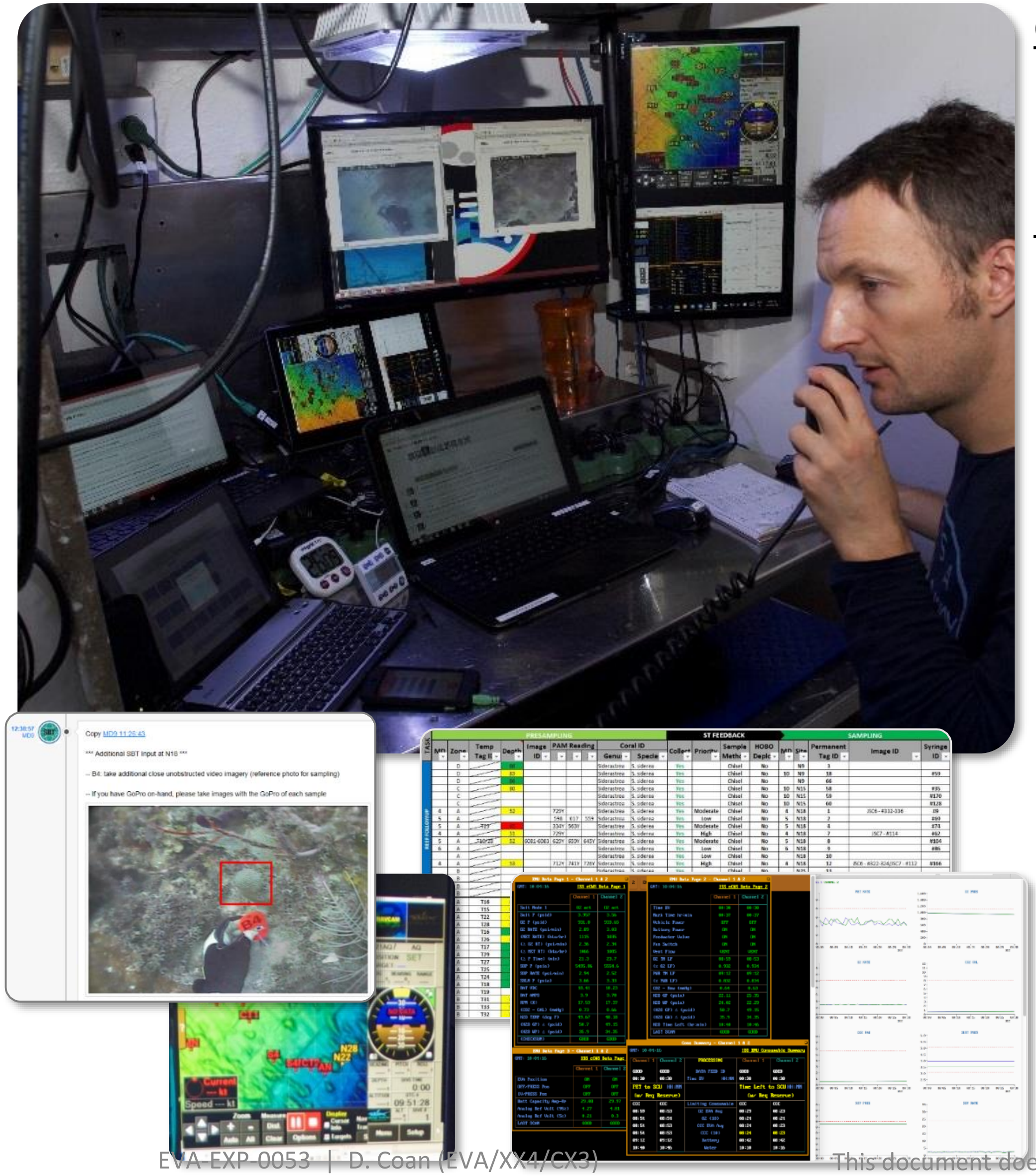
Key Take-Aways

- EVA digital cue cards enable EV crew to conduct general navigation, identify specimens to sample, and guide themselves through procedures
  - Digital maps with timeline assist EV crew in efficiently understanding exploration area and tasks
  - Ability for EV crew to view annotated images from the ST would be significantly enhancing
- Permits increasing EVA and crew autonomy
  - Geoscience cue cards and guides enable the crew to make better autonomous decisions
- Efficient mechanism for MCC ST to upload ever evolving data for the EV crew
- Crew feedback:
  - Appreciated the single-page traverse plan with hyperlinks for each activity's details
  - While it's helpful for IV to have access to a full set of mission data, the EV crew preferred to only have what is crucial for that particular EVA
  - A way to toggle between the traverse plan and procedures would be helpful
  - Crew appreciated cue cards with photos taken on previous days to enable them to find sampling locations and specimens
  - Rated as essential/enabling
- Gap closures addressed
  - Integrated EVA Flight Control
  - Tools for Interacting with EVA Over a Comm Latency



EQUIPMENT

IV SUPPORT SYSTEM WORKSTATION



Objectives

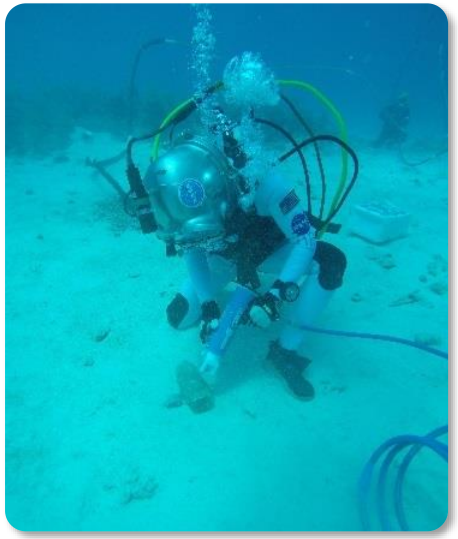
- Evaluate what kind of tools (support system) the IV crewmember will need in order to effectively handle the amount of information and tasking the IV crewmember must contend with while actively directing the EVA

Key Take-Aways

- IV support system will be key for Exploration EVA operations with comm latencies to address the challenges facing future IV crewmembers with a high workload
  - Computer assets will be required on Exploration missions to enable the IV to guide the EVA, which affects current architecture studies
- Evolution of IV workstation from NEEMO 20 improved crew's ability to manage data and direct the EVA
- Effective setup in a constrained location allowed for multiple displays that included Camera feeds, Timeline and Procedures, Navigation information, Spacesuit subsystem data, Communication, Mission logs, and Datasheeets
- Key lessons learned were recorded that will be incorporated into the concept that is evolving into a future capability
  - Mission demonstrated that the capability was able to be utilized by a single crewmember once crew was familiar/trained enough
  - Workstation should be more configurable
  - Balancing two datasheets on the same computer was too difficult
- IV support system will be further evaluated during controlled laboratory settings and the next generation should be tested at NEEMO
  - Improvements needed in applications and operational layout of assets
  - Determine needed assets (computers) for a realistic MEL of hardware
- Gap closures addressed
  - Integrated EVA Flight Control
  - Tools for Interacting with EVA Over a Comm Latency
  - IV Support System for EVA Operations

GEOSCIENCE SAMPLING SYSTEM






Objectives

- Evaluate EVA hardware and operations for science sampling in a surface/partial-g environment
  - Loosely adhered particles (surface, float, soil)
  - Chip samples
  - Subsurface samples (core)

Key Take-Aways

- Integrated Geology Sampling System worked well for taking and storing samples
  - Now being incorporated into the ARCM con ops
  - Relevant for missions to Mars
- While initially designed for microgravity, key lessons learned were captured for refining tool system for better use in partial gravity in a spacesuit
  - Sampling tools concept worked well, but the tools may be bulky for Mars gravity
  - Having the sample briefcase on the ground will make it difficult to use when wearing a pressure suit
  - Further refinement is needed on the chip sample end effector to effectively capture a liberated sample
  - A “stamper” mechanism should be further investigated for obtaining surface samples
  - IRIS tool worked well for capturing a core sample and maintaining stratigraphy
  - Marine science drill worked well for sampling, though indication marks would help crew achieve appropriate depth without damaging the sample surface
- Enabled direct cooperation between core set of EC7/Engineering, XI/Science, and XX/EVA personnel for development and evolution of concepts and designs
- Gap closures addressed
  - Tools for Science Sampling on a Surface EVA
  - Tool Caddy Device on a Surface EVA
  - Flexible Execution Methodology for EVA Science Operations in Undefined Environments

EQUIPMENT

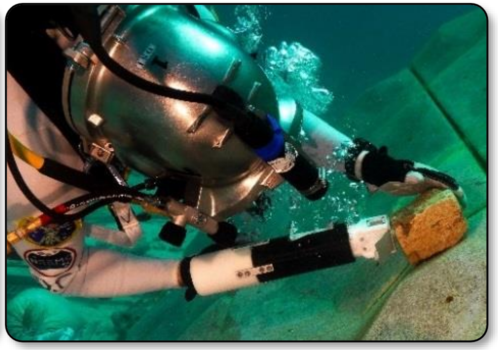
EVOLUTION OF SAMPLING TOOLS

Example of Evolution Across Missions: Powered Rock Chip Hammer


SEATEST 2


NBL/MACES


NEEMO 18/19

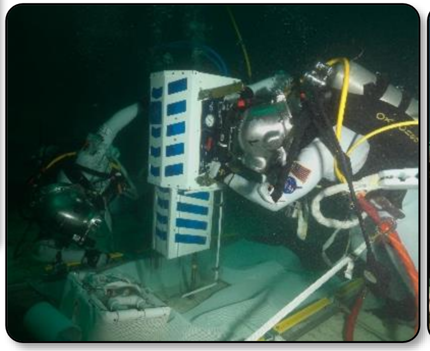

NEEMO 20

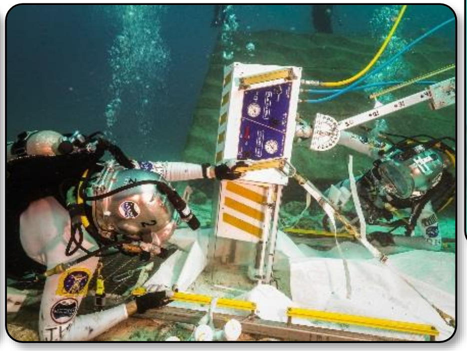

NEEMO 21

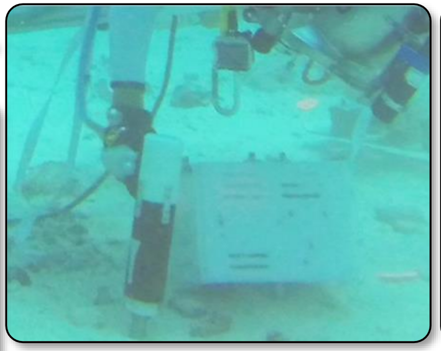
Powered Core Sampler

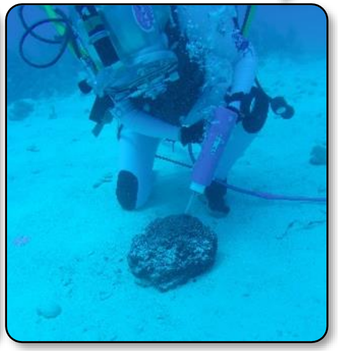

SEATEST 2

Deep Core Drill


NEEMO 18

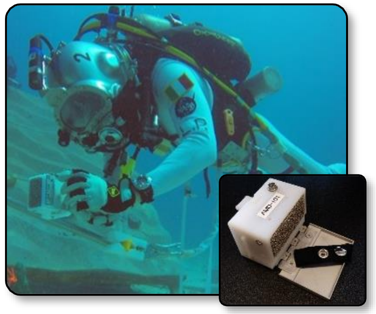

NEEMO 19

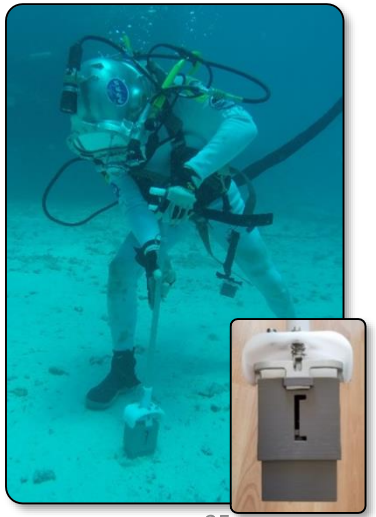

NEEMO 20


NEEMO 21

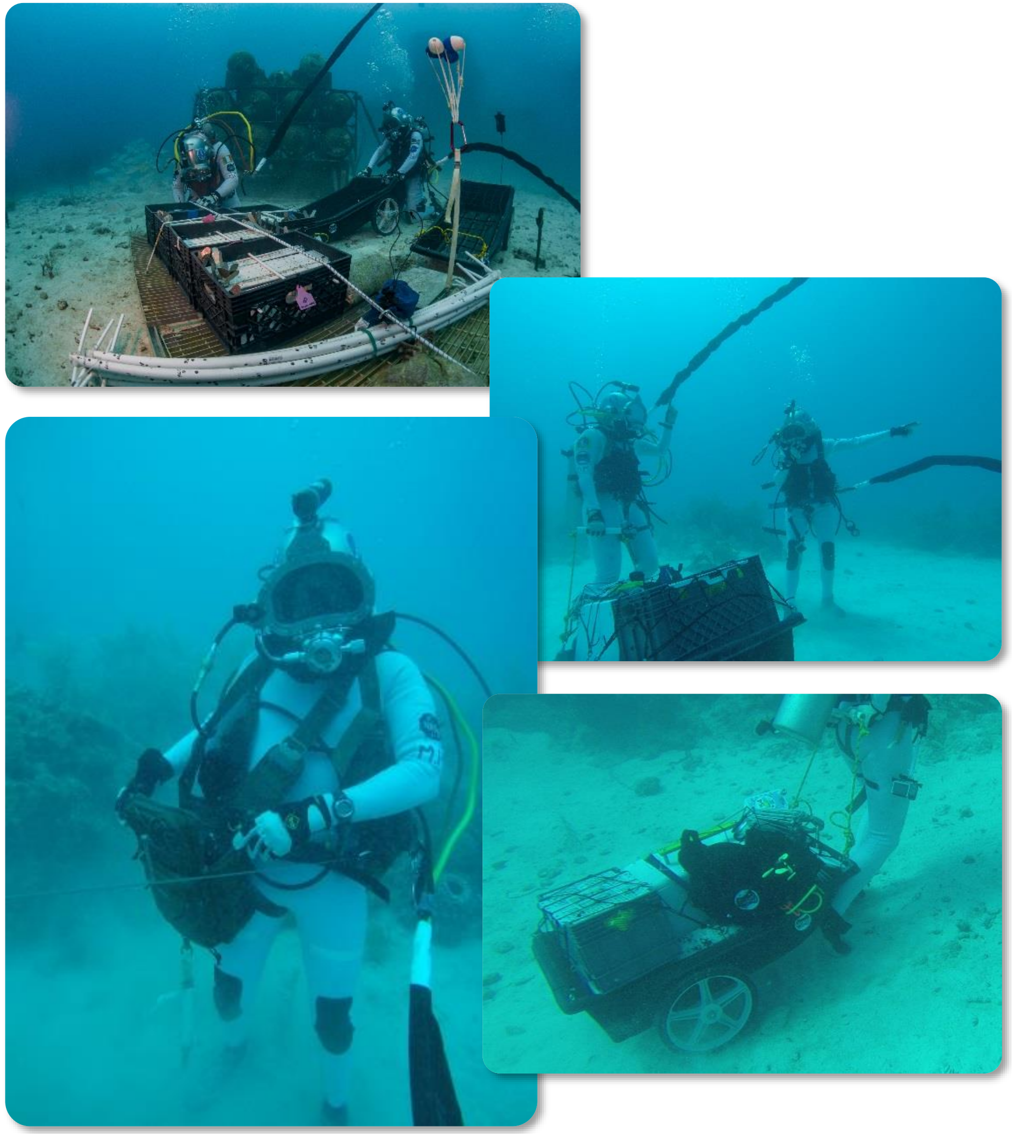
Surface Sampler Evolution


2014


NEEMO 20


NEEMO 21

TRANSPORTATION OF TOOLS



Objectives

- Evaluate EVA hardware and operations for transporting and stowing tools and samples

Key Take-Aways

- Initial look at sled/cart options for large equipment transport
  - Several variations: No wheels, 2 wheels, 4 wheels, rope handle, solid handle
  - Tool caddy worked well, but adjustability will be a critical feature to accommodate different crew preferences
  - Packing plan was critical
  - Handle was an issue
  - Customizable handle that you can mount computer (iDive) or navigation system (Navigator) to would be good
- Evaluated sling bag options for small items & easy access (sample markers, hand tools, electronics, etc.)
  - A way to carry small amount of tools on the suit is critical
  - The sling bag for small items (sample markers, hand tools, electronics, etc.) was conceptually good, but challenging to use with the dive system
  - A vest to which things could be clipped on would work, used much like a mini workstation
- Need to determine the tool compliment for each phase of the EVA operations, and how those tools are best transported and stowed
- Gap closures addressed
  - Tool Caddy Device on a Surface EVA
  - Flexible Execution Methodology for EVA Science Operations in Undefined Environments

SUMMARY

EVA Gap Closure Inputs & Recommendations

SCIENCE

- Nursery Construction
- Nursery Science
- N20 Reef Follow-up Science
- Reef Exploration Science

OPERATIONS

- Integrated EVA Science Operations
- EVA Traverse Planning & Maps
- EVA Navigation
- Joint EVA-Robotic Operations
- Effects of Comm Latency on Ops

EQUIPMENT

- EVA Digital Cue Cards
- IV Support System
- Science Sampling Tools
- Geoscience Sampling Kit
- Tool Transportation & Stowage

EVA Gap Closure Inputs

Integrated EVA Flight Control

Flexible Execution Methodology for EVA Science Operations in Undefined Environments

Tools for Interacting with EVA Over a Comm Latency

IV Support System for EVA Operations

Display (EVA Integrated Camera)

Navigation (EVA Short Distance Navigation)

Tools for Science Sampling on a Surface EVA

Tool Caddy Device on a Surface EVA

EVA-Robotic (Man-Machine) Work System

EVA Gap Closure Updates and Recommendations

EVA SMT GAP	GAP CLOSURE UPDATES	RECOMMENDATIONS
Integrated EVA Flight Control	Formalize gap and update closure with demonstrated capabilities and methods for enabling a Science Team to provide input to EVA operations	Evolve the systems needed for directing operations and evaluate at a future NEEMO/operational field test
Flexible Execution Methodology for EVA Science Operations in Undefined Environments	Formalize gap and update closure with need for data systems and flight rules to govern decision making process during flexible science operations	Evaluate a mission utilizing a true flexecution methodology over multiple days/EVAs with more complicated science operations at a future NEEMO mission
Tools for Interacting with EVA Over a Comm Latency	Update gap closure with results for the MCC/ST systems, IV support system, and EVA digital cue cards	Evolve the systems (MCC console, IV support, EVA digital cue cards) needed and evaluate at a NEEMO mission/operational field test utilizing true flexecution over multiple days/EVAs
IV Support System for EVA Operations	Formalize gap and update closure with results of computer assets and applications needed	Iterate the workstation configuration and applications to enable more efficient science operations, and evaluate at a future NEEMO mission

EVA Gap Closure Updates and Recommendations

EVA SMT GAP	GAP CLOSURE UPDATES	RECOMMENDATIONS
Display (EVA Integrated Camera)	Update gap closure with results and need for a way to stream high-resolution photos along with video	Test a camera system that is capable of streaming high-res imagery at an operational field test
Navigation (EVA Short Distance Navigation)	Update gap closure with results and need for EVA digital maps, a relative nav system for EV crew, and a way for IV and ST to track and guide EV crew	Assess a method for EVA and IV crew to track EV relative location, and use that data to locate sampling regions and previously marked specimens at a future NEEMO
Tools for Science Sampling on a Surface EVA	Update gap closure with the surface version of the Integrated Geology Sampling System, "stamper" mechanism, IRIS tool, and lessons from marine science tools	Evaluate tools while wearing pressurized EVA suits, possibly on ARGOS Iterate tools and evaluate at a future NEEMO/operational field test
Tool Caddy Device on a Surface EVA	Update gap closure with lessons learned for a tool caddy to carry larger items and sling bag/harness for smaller tools	Test a purpose-built tool caddy at NEEMO Develop a vest/bag/harness system to carry smaller tools and evaluate at NEEMO
EVA-Robotic (Man-Machine) Work System	Gap closure unchanged	Assess a robotic system to give better SA of EV crew and also provide high-res imagery for the ST at a NEEMO mission

Benefits of NEEMO for Exploration EVA

- Provides a means of advancing Human Spaceflight objectives by evaluating Exploration EVA concepts of operations and hardware/tool prototypes
- Enables authentic science objectives by directly conducting geoscience operations or utilizing proxy marine science to test relevant operations concepts
- Allows for end-to-end testing of techniques and hardware in an operational scenario
  - Has the crew in-situ and a ground team separated from them in a mission-like manner
  - Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
  - Drives out results for things that do and do not work in a mission environment
- Evaluates objectives mapped to specific <u>needs</u> and <u>knowledge/technology gaps</u>
  - Informs updates to the **NASA Exploration EVA Concepts of Operations** document by having crewmembers test relevant concepts in mission environments
  - Facilitates **SMT gap closures** by tying all EVA-relevant objectives to specific gaps and testing potential closures
  - Addresses **CAPTEM findings** by assessing tools and techniques for science sample collection
  - Provides data for hardware design maturation to assist in road-to-flight, especially the **EVA science sample collection tools**
    - Evaluations of prototype EVA hardware are directly leading towards more refined tools that allow for sample containment and a more flight-like contamination protocol
  - Assesses concepts of operations associated with science EVAs that require input from an MCC Science Team over a comm latency
- Ties in the right expertise to evaluate concepts being worked on across the agency
- Benefits programs from ISS to Exploration
- Enhances relationships with international partners, academia, and other NASA orgs

Benefits of NEEMO for Human Exploration Integration & Science

- **NEEMO provides an operational mission to integrate Exploration EVA and Science objectives**
  - 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)

BACKUP

EVA Gap Closures

Metrics & Data Analysis

IVA Objectives & Tasks

Additional Backup

Collaborators for EVA

David Coan

Exploration Integration and Science – Extravehicular Activity (EVA)

Trevor Graff

Kelsey Young

Exploration Integration and Science – Astromaterials Research and Exploration Science

Marc Reagan

Exploration Integration and Science – Exploration Mission Planning

Drew Hood

Adam Naids

Mary Walker

Engineering – EVA & Advanced Exploration Tools

Matthew Miller

Guggenheim School of Aerospace Engineering, Georgia Institute of Technology

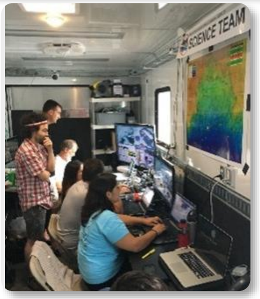
Steve Chappell

Kara Beaton

Mars Study Capability

EVA Gap Closures

Knowledge & Technology Gaps Addressed at NEEMO 21



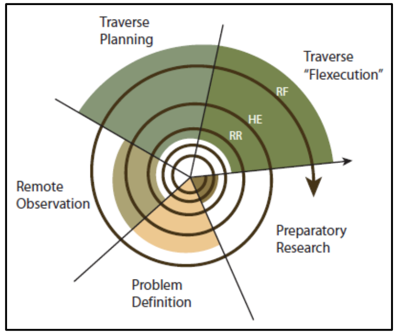
Integrated EVA Flight Control

- Under #128 EVA Integration
- Gap description:
  - Need to address how EVA operations will be directed/controlled at destinations with comm latencies.
- NEEMO 21 closure inputs
  - Results and inputs from operational field testing will help define how integrated EVA science operations will be conducted and close the gap in defining the flight control methodology
  - EVA crew is capable of operating more autonomously than on ISS while simultaneously incorporating input from an Earth-based ST
  - Science Team can effectively communicate critical data and direction over a 15-min com latency to execute science sampling operations during a 4-hr EVA
  - High resolution imagery (photos) will be need to be transmitted during an EVA to enable the ST to make informed decisions
  - Science planning/re-planning may be required frequently (daily) in order to respond to operational changes and science discoveries
    - Will need to be factored into the time-latent planning cycle
    - Will require developing a process for updating the plan in timely manner under time pressure and in a way that the crew can effectively utilize
  - Need ability to precisely locate the specimens to be re-sampled, including imagery of the targeted samples and overall area
  - Crew science training is crucial, and detailed geoscience knowledge will be required
  - EVA digital cue cards enabled EV crew to conduct general navigation, identify specimens to sample, and guide themselves through procedures
    - Digital maps with timeline assist EV crew in efficiently understanding exploration area and tasks
    - Digital cue cards permit increasing EVA and crew autonomy
    - Concept of operations for having MCC develop a plan and the crew downloading it to the EVA electronic cue cards work well
  - IV support system will be key for Exploration EVA operations with comm latencies to address the challenges facing future IV crewmembers with a high workload and to allow for management of the large task volume
  - Flexecution flight rules will be critical for addressing the decision making authority for dynamically changing plans in a natural environment (crew versus MCC/ST), which is a new paradigm for EVA flight control
- Recommendations/Forward Work:
  - Evolve the systems needed for directing operations and evaluate at a future operational field test
    - MCC/ST console systems
    - IV support system
    - EVA digital cue cards
  - Develop flight rules to govern decision making process during science operations and evaluate at an operational field test
  - Refine the planning cycle and process for updating the plan in timely manner under time pressure and in a manner that the crew can effectively utilize and evaluate at a future NEEMO mission

SMT EVA Gap Closure Input: Flexible Execution Methodology

Flexible Execution Methodology for EVA Science Operations in Undefined Environments

- Under #128 EVA Integration (or a new category)
- **New** – based on integrated work between EVA and Science during the preparation and execution of NEEMO missions utilizing real science operations
  - EVA science operations on natural surfaces, especially Earth's Moon and the surface of Mars, will entail exploring relatively undefined environments. While there will be precursor imagery of the zones where the EVA crew will operate, there will likely be differences between the actual landscape and remote sensing data, or things not resolved/seen in the photographs. Current EVA operational methods involve highly scripted tasks on well known engineered surfaces. The Exploration EVA System, Crew, and Flight Control Team will need to develop a flexible execution methodology (flexecution) in order to operate in environments where things are not as well defined and may require significant deviation from any plan.
  - Follows up on Hodges and Schmitt paper (A new paradigm for advanced planetary field geology developed through analog experiments on Earth) with recommendations based on Schmitt's experience conducting EVA science operations on the moon during Apollo 17.



- NEEMO 21 closure inputs
  - Similar inputs as for *Integrated EVA Flight Control*
  - The nature of an underwater mission with real science forced flexecution aspects into the operations
  - EVA crew is capable of operating more autonomously than on ISS while simultaneously incorporating input from an Earth-based ST
  - Science Team can effectively communicate critical data and direction over a 15-min com latency to execute science sampling operations during a 4-hr EVA
  - High resolution imagery (photos) will be need to be transmitted during an EVA to enable the ST to make informed decisions
  - EVA digital cue cards enabled EV crew to conduct general navigation, identify specimens to sample, and guide themselves through procedures, permitting increasing EVA and crew autonomy
  - IV support system will be key for Exploration EVA operations with comm latencies to address the challenges facing future IV crewmembers with a high workload and to allow for management of the large task volume
  - Flexecution flight rules will be critical for addressing the decision making authority for dynamically changing plans in a natural environment (crew versus MCC/ST), which is a new paradigm for EVA flight control

- Recommendations/Forward Work:
  - Evaluate a mission utilizing a true flexecution methodology over multiple days/EVAs with more complicated science operations at a future NEEMO mission
  - Evolve the systems needed for directing operations (MCC/ST console systems, IV support system, EVA digital cue cards, etc.) and evaluate at a future operational field test
  - Develop flight rules to govern decision making process during science operations and evaluate at an operational field test
  - Refine the planning cycle and process for updating the plan in timely manner under time pressure and in a manner that the crew can effectively utilize and evaluate at a future NEEMO mission

Tools for Interacting with EVA Over a Comm Latency

- Under #128 EVA Integration
- Gap description:
  - Need to address what kinds of tools MCC, the IV, and the EVA crew will need in order to conduct operations at destinations with comm latencies.
    - Investigate using texting and audio/video tools to allow MCC/Science Team to interact with the EVA crew via the IV over a comm latency.
    - Develop an EVA tool for identifying and high grading samples
- NEEMO 21 closure inputs
  - A combination of digital maps, a traverse plan, and an active navigation system will allow an EV crew to locate the pertinent sampling zones
  - EVA digital cue cards enable EV crew to conduct general navigation, identify specimens to sample, and guide themselves through procedures
    - Digital maps with timeline assist EV crew in efficiently understanding exploration area and tasks
    - Permits increasing EVA and crew autonomy
    - Efficient mechanism for MCC ST to upload ever evolving data for the EV crew (as opposed to pen & ink of paper cue cards)
    - Geoscience cue cards and guides enable the crew to make better autonomous decisions
  - Relative navigation system enables crew to reliably find sampling zones and relocate marked samples, which will be critical on Exploration missions
  - An IV support system is critical and allows for management of the large task volume
- Recommendations/Forward Work:
  - Evolve the systems needed for directing operations and evaluate at a future NEEMO mission/operational field test
    - MCC/ST console systems
    - IV support system
    - EVA digital cue cards
  - Evaluate the ops tools during a NEEMO mission utilizing a true flexecution methodology over multiple days/EVAs with more complicated science operations

SMT EVA Gap Closure Input: IV Support System for EVA Operations

IV Support System for EVA Operations (new)

- Under #128 EVA Integration
- Gap description:
  - At destinations with long comm latencies, the IV crewmember will be more heavily loaded than in current real-time comm operations, with the primary responsibility of receiving and addressing EVA suit data along with replanning the timeline during the EVA. Essentially, the IV will perform the roles of an IV, partial Flight Director, partial EVA Officer, and partial BME.
  - Need to address what kinds of tools (support system) the IV crewmember will need due to the amount of information and tasking the IV crewmember must contend with while actively directing the EVA.
- NEEMO 21 closure inputs
  - IV support system will be key for Exploration EVA operations with comm latencies to address the challenges facing future IV crewmembers with a high workload
  - Computer assets will be required on Exploration missions to enable the IV to guide the EVA, which affects current architecture studies
  - Effective setup in a constrained location should allow for multiple displays that include Camera feeds, Timeline and Procedures, Navigation information, Spacesuit subsystem data, Communication, Mission logs, and Datasheets
  - Key lessons learned were recorded that will be incorporated into the concept that is evolving into a future capability
    - Mission demonstrated that the capability was able to be utilized by a single crewmember once crew was familiar/trained enough
    - Workstation should be more configurable
    - Balancing two datasheets on the same computer was too difficult
    - Paper and pencil is still useful to have at the workstation
- Recommendations/Forward Work:
  - Evolve the IV support system evaluate utilizing a true flexecution methodology over multiple days/EVAs with more complicated science operations

Display (#93, EVA Camera System)

- Under #92 Avionics Systems for EVA Tasks
- Gap description:
  - NEEMO 20 began looking at what a science team in MCC needs in the capability of an EVA camera system. The Science Team observed that while video is great for situational awareness, high-resolution still imagery is largely preferred for most science requirements. A method should be developed to capture and send high-speed real-time (over a latency) imagery for optimal science planning and integration.
- NEEMO 21 closure inputs
  - Streaming photo stills may be more useful than video from the EV helmet cameras
  - A robotic asset gives the IV better situational awareness
  - A robotic asset would give the MCC ST better overview and detailed imagery

- Recommendations/Forward Work:
  - Examine ways to stream high-resolution stills along with lower-resolution video

Navigation (#96, EVA Short Range Navigation)

- Under #92 Avionics Systems for EVA Tasks
- Was gap closure #214 Navigation Short Range
- Gap description:
  - Need short distance highly accurate navigation data (<1m position error for a 200 m distance from a known starting point (rover)) which operates in the relevant environment to support rover based geology/science. Location of science samples is critical to the geology task.
  - Since the planetary science goal of an Exploration mission is to characterize an area more than pick up a specific rock, a navigation system more needs to get the crew close to a target that landmarks an area rather than locate a specific sample. Electronic navigation will be critical in areas where the terrain looks similar, especially when marking new locations and returning to a site.
- NEEMO 21 closure inputs
  - Digital maps with timeline assist EV crew in efficiently understanding exploration area and tasks
    - Map included regions and paths, along with timeline of tasks to complete (and hyperlinks to tasks)
    - Enabled EV crew to understand the area and have a good sense for the location of the regions to be explored
    - Gave crew a quick view of the timeline and tasks
  - Relative navigation system enables crew to reliably find sampling zones and relocate marked samples, which will be critical on Exploration missions
- Recommendations/Forward Work:
  - Refine the methods for utilizing digital maps and evaluate on a future NEEMO mission
  - Evaluate a system for allowing the IV to see the relative position of the EVA crew on a future NEEMO mission

Tools for Science Sampling on a Surface EVA (new)

- Under #107 Tools for Surface EVA
- Related to former gap closures:
  - #502 Micro-g Tool for Loosely Adhered Particles
  - #503 Micro-g Tool for Chip Samples
  - #504 Micro-g Tool for Subsurface Samples
- Gap description:
  - Need EVA Tools to sample loosely adhered particles from a destination's surface. Need EVA Tools to capture "chip" sample released during EVA sampling efforts. Need an EVA tool to collect and capture a "subsurface" sample taken on a surface. Known issue, there is an integration disconnect between engineering development and the science community as it relates to determining detailed requirements of sampling tools from a science perspective.
- NEEMO 21 closure inputs
  - Integrated Geology Sampling System worked well for taking and storing samples
  - Sampling tools concept worked well, but the tools may be bulky for Mars gravity
  - Having the sample briefcase on the ground will make it difficult to use when wearing a pressure suit
  - Further refinement is needed on the chip sample end effector to effectively capture a liberated sample
  - A “stamper” mechanism should be further investigated for obtaining surface samples
  - IRIS tool worked well for capturing a core sample and maintaining stratigraphy
  - Marine science drill worked well for sampling, though indication marks would help crew achieve appropriate depth without damaging the sample surface
- Recommendations/Forward Work:
  - Iterate the tools based on feedback from NEEMO 21 and evaluate the new prototypes
  - Begin testing tools with a pressurized spacesuit

Tools (#108)

- Under #107 Tools for Surface EVA
- Was gap closures:
  - #505 Sample Storage and Curation
  - #510 Tool Management Device
- Gap description:
  - Need EVA tools caddy device for each destination based on results of a trade study to determine if, and what type of, a tool caddy is needed, as compared to leaving EVA Tools on the local vehicle (rover, MOEV, truss-mounted tool box, etc.) and having the crew translate/walk back and forth with tools in hand.
- NEEMO 21 closure inputs
  - Initial look at sled/cart options for large equipment transport
    - Several variations: No wheels, 2 wheels, 4 wheels, rope handle, solid handle
    - Tool caddy worked well, but adjustability will be a critical feature to accommodate different crew preferences
    - Packing plan was critical
    - Handle was an issue
    - Customizable handle that you can mount computer (iDive) or navigation system (Navigator) to would be good
  - Evaluated sling bag options for small items & easy access (sample markers, hand tools, electronics, etc.)
    - A way to carry small amount of tools on the suit is critical
    - The sling bag for small items (sample markers, hand tools, electronics, etc.) was conceptually good, but challenging to use with the dive system
    - A vest to which things could be clipped on would work, used much like a mini workstation
  - Need to determine the tool compliment for each phase of the EVA operations, and how those tools are best transported and stowed
- Recommendations/Forward Work:
  - Develop a harness that could be attached to the suit in order to carry tools
  - Look at ways to attach a small satchel to the suit for use in carrying a small load of tools a short distance

EVA-Robotic (Man-Machine) Work System

- Under #128 EVA Integration
- Gap description:
  - Need to address the use of robotic assets for EVA operations.
- NEEMO 21 closure inputs
  - A robotic asset gives the IV better situational awareness
  - A robotic asset would give the MCC ST better overview and detailed imagery
- Recommendations/Forward Work:
  - Evaluate a robotic system for providing situational awareness and high-definition detailed science imagery
  - Test using a robotic asset to scout a local area in preparation for an EVA, both driven by the crew and by MCC/ST

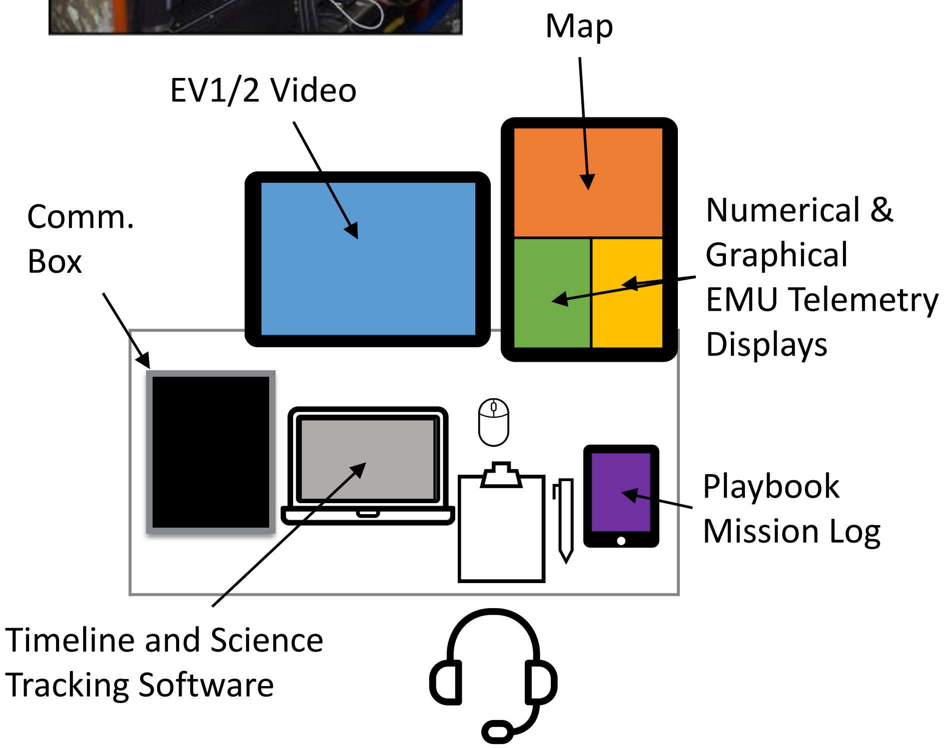
Metrics & Data Analysis

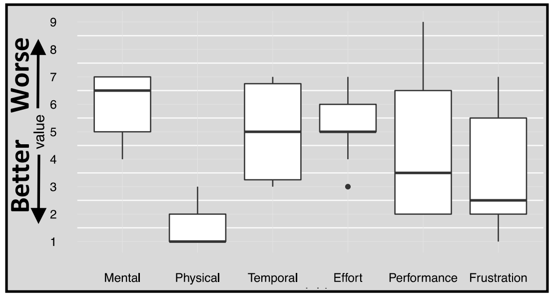
Acceptability and Capability Ratings

N21 – IV Workstation Design and Evaluation

High-Level Support Capabilities Provided
- Timeline Management
- Life Support System Monitoring
- Communication (real-time & delayed)
- Science Operations Support

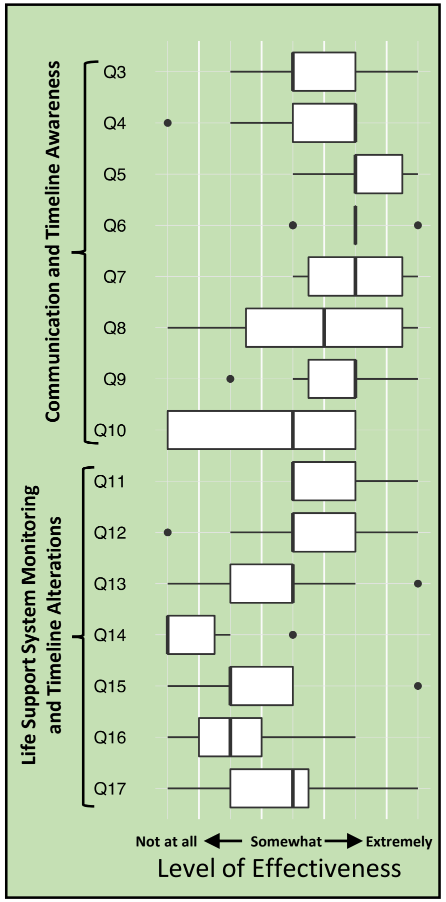
(*N*=10) 4-hour EVAs were evaluated using the following 3 Assessments
- NASA TLX Assessment
- Cognitive Support Assessment
- Workstation Interaction Assessment





Question Order: Lvl 1 -> Lvl 2 -> Lvl 3	Yes	No
Lvl 1: Is the displayed information in the IV workstation easily acquired?	4	6
Lvl 2: Is the workstation what is needed to analyze and operate the EVA?	1	3
Lvl 3: Does the IV workstation facilitate efficient decision making?	1	0

Exemplar Response: "Information visualization or automated alerts failed to direct my attention in a timely manner. Deficiencies degraded my performance **that threatened mission success**."



Preliminary Results
- IV workstation provides limited mental and temporal support
- Integration of Life Support System data with Timeline status is burdensome and creates undue overhead
- Overall, the provided IV workstation capabilities as they are currently designed rank in the "Not very" to "Somewhat" effective

Specific deficiencies are still being articulated to help inform future enhancements and redesign efforts

Acceptability Ratings should reflect the extent to which the condition overall was considered an "Acceptable" approach to conducting human exploration and the extent to which improvements, if any, are

Operational Acceptability *: Able to reliably conduct operations with accurate exchange of all pertinent information and without excessive workload or (in-sim) avoidable inefficiencies or delay.*

Scientific Acceptability *: Able to reliably complete and record scientific observations, measurements, and/or sampling with sufficient quantity, distribution, resolution, accuracy, and/or integrity to test the scientific hypothesis/hypotheses.*

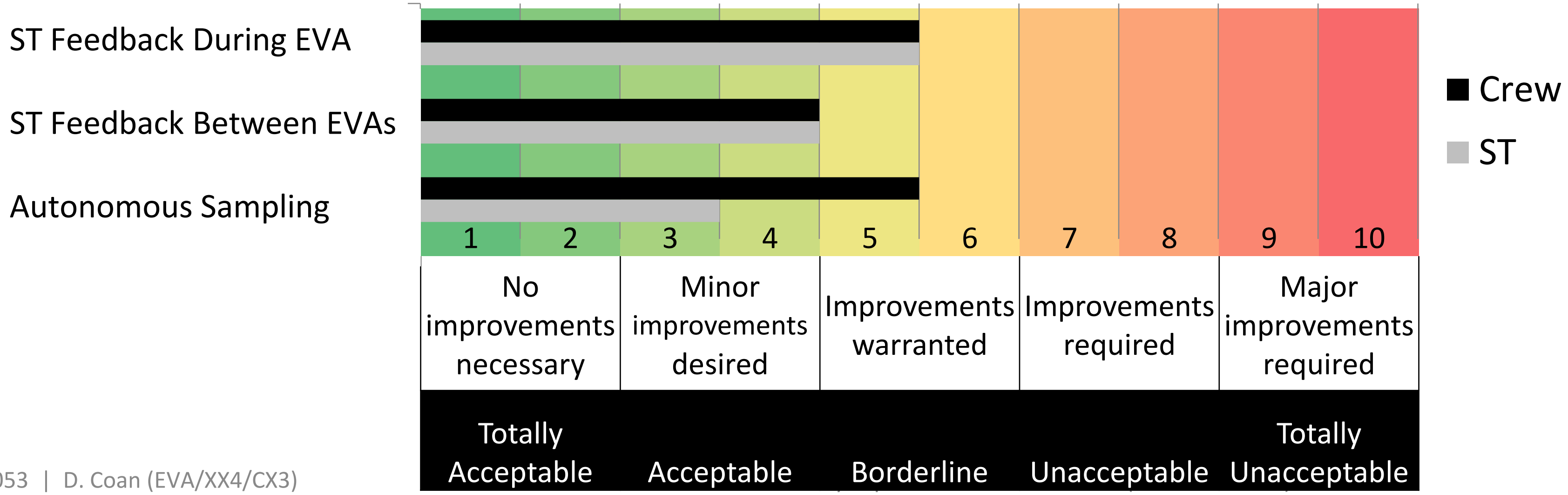
Task Acceptability *: Able to reliably complete a task without significant discomfort, exertion, fatigue, or avoidable inefficiencies, and without risk of injury to self or damage to equipment.*

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable		No Rating
No improvements necessary		Minor improvements desired		Improvements warranted		Improvements required		Major improvements required		Unable to assess
1	2	3	4	5	6	7	8	9	10	NR

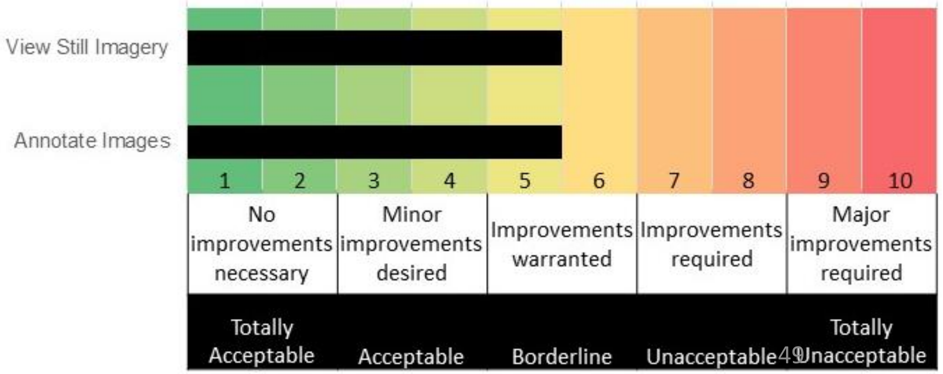
Capability Assessment should reflect the extent to which a capability or potential capability could be useful specifically during a human exploration mission

Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement		No Rating
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions.		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.		Unable to assess
1	2	3	4	5	6	7	8	9	10	NR

- **ST Feedback During EVA** (Intra-EVA Pre-Sampling + Sampling)
  - Con ops: Crew completes pre-sampling surveys followed by sampling with ST feedback during the same EVA
  - Rating: Borderline acceptable
  - Comments: Improvements are warranted; schedule pressure and workload are high from real-time sampling requests; there are schedule impacts due to the need to carry all hardware for both presampling and sampling to each site
  - Crew Note: Limitations in given tools and training made it challenging to conduct presampling and sampling tasks on the same day at a 15-min comm latency
  - EVA Note: Minimal training was available for the NEEMO crew, which contributed to the challenge of this con op
- **ST Feedback Between EVAs** (Inter-EVA Pre-Sampling + Sampling)
  - Con ops: Crew completes pre-sampling surveys in one EVA and sampling in a subsequent EVA, with ST feedback between the EVAs
  - Rating: Acceptable
  - Comments: Having extra time prior to sampling for EV and IV to formulate and discuss the most efficient sampling plan for sampling is an improvement; allows for focusing of hardware that is needed for each phase to increase efficiency; improvements in relocation of candidate sample locations are needed the longer time has passed since initial visit or if different EVA crew does sampling
  - Crew Note: It’s tough to come back to an area that someone else pre-sampled
- **Autonomous Sampling** (Sampling Only)
  - Con ops: Crew completes sampling only – pre-sampling survey was done on the previous mission (NEEMO 20)
  - Rating: Acceptable/Borderline
  - Comments: Improvements are warranted in the ability to locate sampling targets (imagery, navigation to location)

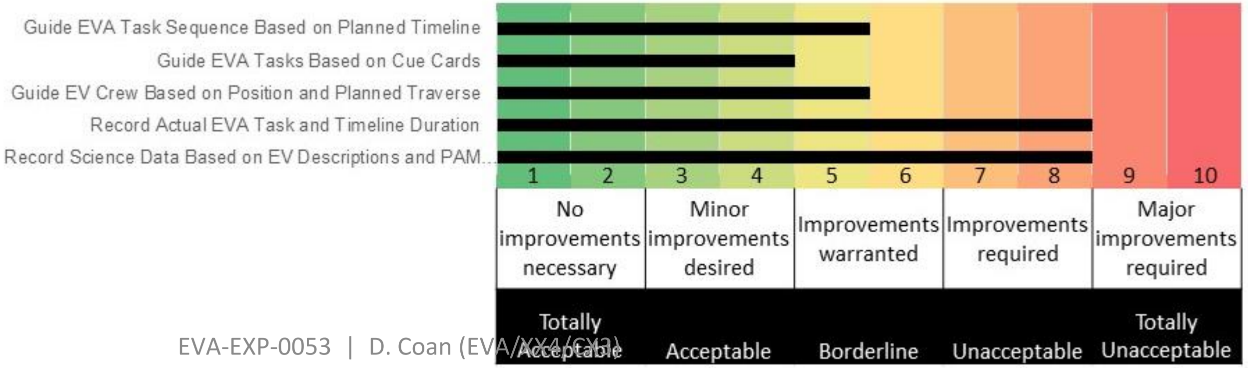


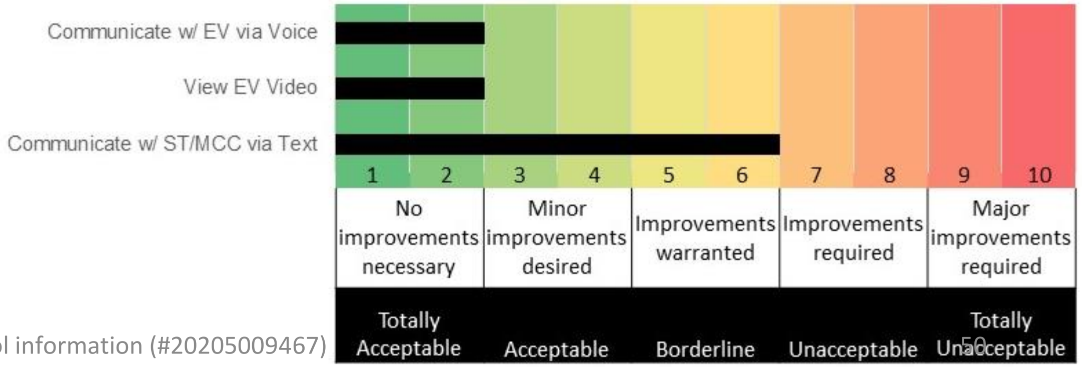
- **Creation of Planned Traverses**
  - Rating: Acceptable
  - Comments: Desired improvements are a Google Earth type mapping capabilities integrated w/ better a traverse planning tool to show remaining consumables, traverse time and distance, etc.
- **Modification of Planned Traverses during an EVA**
  - Rating: Borderline
  - Comments: Warranted improvements are a system to allow ST to modify a traverse real-time and have that sent to the crew for use during the EVA
- **View Video including Verbal Descriptions**
  - Rating: Borderline
  - Comments: Warranted improvements are higher resolution video to enable more accurate/reliable candidate sample identification
- **Record Science Data**
  - Rating: Borderline
  - Comments: Warranted improvements are an integrated system that IV and ST can both view and edit for tracking/recording of presampling and sampling tags, PAM data, etc.
- **View Still Imagery**
  - Rating: Borderline
  - Comments: Warranted improvements are to get high-definition imagery during EVA rather than as a data dump at the end of the day; this would allow for better validation of candidate samples and improved quality of annotated images
- **Annotate Images**
  - Rating: Borderline
  - Comments: Without ability to annotate images themselves, a better system to edit video screen grabs from helmet cams is warranted



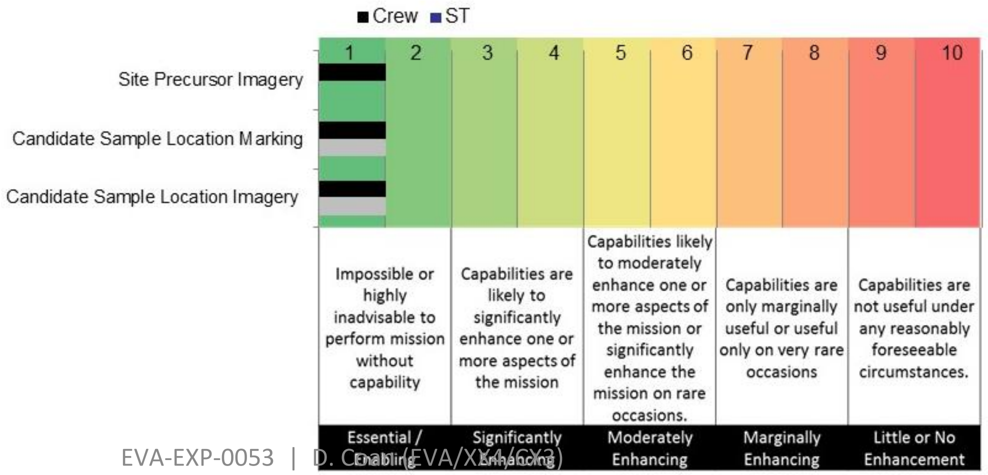
- **Guide EVA Task Sequence Based on Planned Timeline**
  - Rating: Borderline
  - Comments: Warranted improvements include the ability for the crew to review the planned EVA timeline sooner (than the evening before).
- **Guide EVA Tasks Based on Cue Cards**
  - Rating: Acceptable
  - Comments: Improve page-to-page navigation
- **Guide EV Crew Based on Position and Planned Traverse**
  - Rating: Borderline
  - Comments: Need more reliable EV crew tracking in relation to the planned traverse
- **Record Actual EVA Task and Timeline Duration**
  - Rating: Unacceptable
  - Comments: Tactical EVA Management Tool requires more flexibility to allow IV to change tasks, ordering, and durations, along with adding tasks
- **Record Science Data Based on EV Descriptions and PAM Readings**
  - Rating: Unacceptable
  - Comments: Science data tool should only have required information for each EVA; need ability to order/hide data once samples are completed; need better tracking of candidate sample markers that have been picked up
  - EVA Note: Minimal training was available for the NEEMO crew, which contributed to the challenge of this task

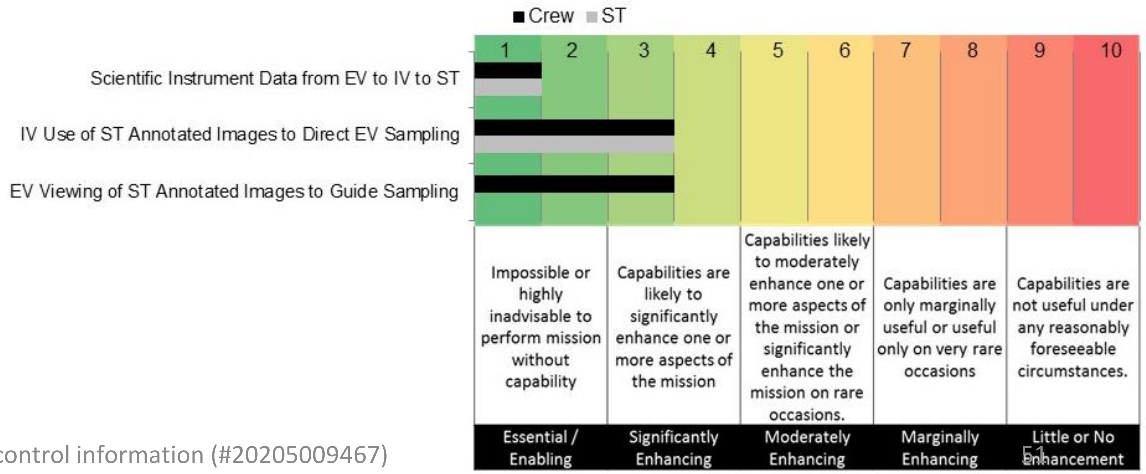
- **Communicate w/ EV via Voice**
  - Rating: Totally acceptable
- **View EV Video**
  - Rating: Totally acceptable
- **Communicate w/ ST/MCC via Text**
  - Rating: Borderline/Warranted improvements
  - Comments:
    - Better ordering of mission log/text information should be instituted so that when input from MCC/ST is received by IV it does not appear off the screen
    - Methods for acknowledging a message are required and also an indication in the message that it has been replied to
    - Messages should indicate who/what they are for; have separate thread for EVA
    - Quindar tones should only go off when messages are received, not sent





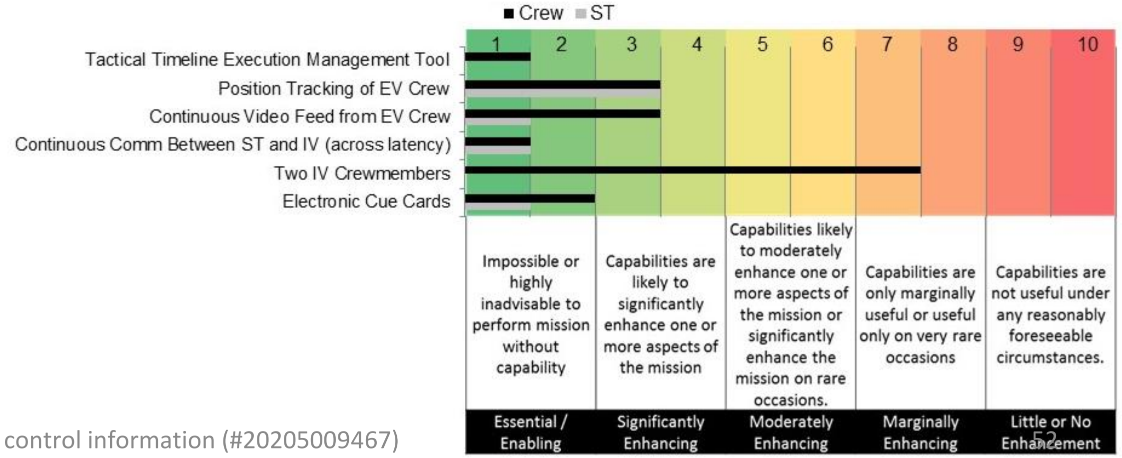
- **Site Precursor Imagery**
  - Rating: Essential/Enabling
  - Comments: High-resolution imagery should have been available for previously visited sites; this should be combined with candidate sample location marking and EV crew position tracking in relation to traverse and targets
- **Candidate Sample Location Marking**
  - Rating: Essential/Enabling
  - Comments: Being able accurately mark and relocate candidate sample locations is enabling to the ops con
- **Candidate Sample Location Imagery**
  - Rating: Essential/Enabling
  - Comments: Ability to have candidate sample location imagery (or screen grabs of video) of sufficient resolution is enabling
- **Scientific Instrument Data from EV to IV to ST**
  - Rating: Essential/Enabling
  - Comments: A tool to record, track, and communicate science data w/ the ST is essential
- **IV Use of ST Annotated Images to Direct EV Sampling**
  - Rating: Significantly enhancing
  - Comments: Significantly enhanced the ability to precisely direct EVs to sampling sites
- **EV Viewing of ST Annotated Images to Guide Sampling**
  - Rating: Significantly enhancing
  - Comments: Not simulated during this mission but crew believed this capability would be significantly enhancing



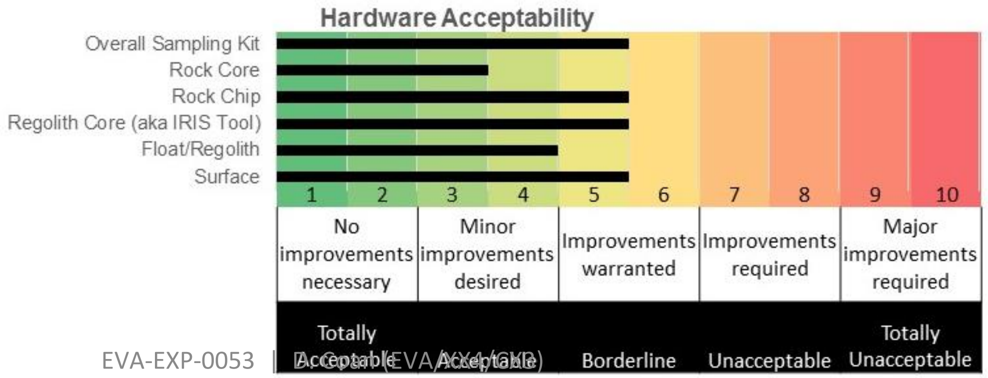


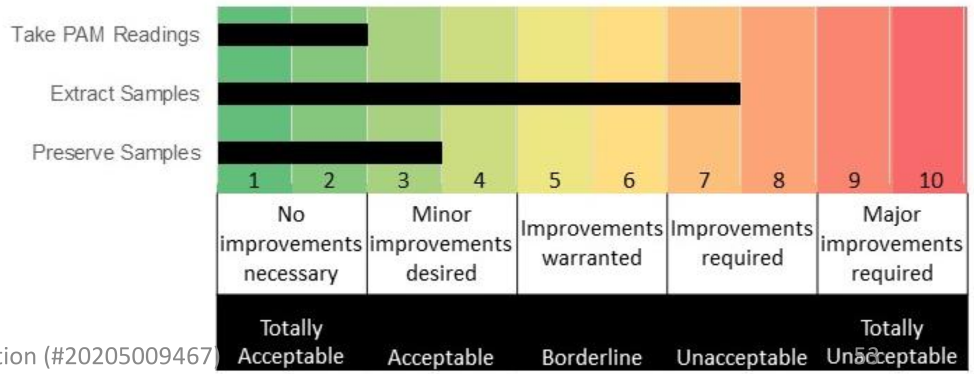
- **Use Electronic Cue Cards**
  - Rating: Borderline
  - Comments: warranted improvements include leaner design of only what is needed by the EV crew for that EVA and better navigation between pages
- **Navigate to Site/Region via Planned Traverse**
  - Rating: Borderline
  - Comments: Warranted improvements include the use of one device that shows the planned traverse and current crew location in relation to that plan
- **Translate w/ Crew Worn Equipment & Sled**
  - Rating: Acceptable
  - Comments: If a pulled cart is used, desired improvements include a fixed rather than flexible cart handle and reducing workload of pulling the cart uphill; ideally, robotic assistants could carry tools as needed
- **Mark Locations of Interest**
  - Rating: Unacceptable
  - Comments: Required improvements include the ability to electronically mark every potential and actual sample location and guide the crew to those locations

- **Timeline Management Tool**
  - Rating: Essential/enabling for IV crew
  - EVA Note: Multiple tools for managing the EVA timeline were utilized, but only the spreadsheet was rated – a way to manage the timeline will be required
- **Position Tracking of EV Crew**
  - Rating: Significantly enhancing
  - Comments: IV crewmember can help guide EV crew if needed
- **Continuous Video Feed from EV Crew**
  - Rating/Comment: Essential for ST in absence of images during EVA
- **Continuous Comm between ST & IV**
  - Rating/Comment: Essential if presampling and sampling are done w/in an EVA
- **Two IV Crewmembers**
  - Rating: Marginally enhancing
  - Comment: w/ the right tools, IV is a once person job except in emergency
- **Electronic Cue Cards**
  - Rating: Essential/enabling



- **Rock Core**
  - Rating: Acceptable
  - Comments: Containment system improvements needed
- **Rock Chip**
  - Rating: Simulation quality = 4 - earth gravity, water effected behavior of sample
  - Comments: Better design for capture of the sample are warranted
- **Regolith (aka IRIS Tool)**
  - Rating: Borderline
  - Comments: "Tool is superb"; improvements warranted in having a reliable number of turns required to close off the aperture
- **Float/Regolith**
  - Rating: Acceptable
  - Comments: Improvements could include "single squeeze on the handle to cause the container to open and a claw to extend with jaws open. Releasing the handle to a first stop would have the jaws close & grab the sample, then the full closed detent would cause the lid to close."
- **Surface**
  - Rating: Borderline
  - Comments: Improvements warranted to have squeeze handle to open and close stamp surface
- **Take Pulse Amplitude Modulation (PAM) Fluorometry Readings**
  - Rating: Totally acceptable
  - Comments: Worked acceptability
- **Extract Samples**
  - Rating: Unacceptable
  - Comments: Improvements required in training would include photos/video of sampling discussion of best techniques and more hands on sampling; drills required significant exertion
- **Preserve Samples**
  - Rating: Acceptable
  - Comments: Desired minor improvements include methods to ensure proper securing of samples in sample containment bags





Detailed Post-Test Objective Timing Data Analysis

MD6 — EVA Duration 4:21:00

Presampling - IntraEVA (B1)

temp tag placed	15
total time (avg. EV1+EV2)	0:46:00
Candidate Sample Search	20%
Observation	24%
Temporary Tag Search	7%
Instrument Utilization	24%
Navigation/Translation	12%
Site Clean-Up	8%
Other	7%

Presampling - InterEVA (E1)

temp tags placed	5
total time (avg. EV1+EV2)	0:35:30
Candidate Sample Search	33%
Observation	9%
Temporary Tag Search	2%
Instrument Utilization	10%
Navigation/Translation	7%
Site Set-Up	2%
Site Clean-Up	1%
Other	8%
Unknown (Due To Comm Dropouts)	7%

Sampling - IntraEVA (B1)

ST Assim. Time from Presamp. Start	1:01:00
ST Assim. Time from Presamp. End	0:16:00
ST Input Received before Sampling	0:28:00
requested samples	9
samples in B1 (5 plier, 3 drill)	8
total time (avg. EV1+EV2)	1:17:00
Temporary Tag Search	8%
Observation	33%
Sample Collection	29%
Sample Preservation	24%
Navigation/Translation	12%
Site Set-Up	12%
Site Clean-Up	33%
Other	8%
Unknown (Due To Comm Dropouts)	16%

MD7 — EVA Duration 4:26:00

Presampling - IntraEVA (B2)

temp tags in B2	13
total time (avg. EV1+EV2)	0:54:00
Candidate Sample Search	27%
Observation	25%
Temporary Tag Search	6%
Instrument Utilization	15%
Navigation/Translation	12%
Site Clean-Up	7%
Other	2%

Sampling - InterEVA (E1)

ST Assim. Time	1-day
samples in E1	3
total time (avg. EV1+EV2)	0:52:00
Temporary Tag Search	13%
Observation	14%
Sample Collection	14%
Sample Preservation	7%
Navigation/Translation	7%
Site Set-Up	13%
Site Clean-Up	24%
Other	24%
(different EVA team)	

Sampling - IntraEVA (B2.1)

ST Assim. Time from Presamp. Start	1:15:00
ST Assim. Time from Presamp. End	0:21:00
ST Input Received before Sampling	1:08:00
requested samples (5 drill, 4 plier, 1 chisel)	10
samples in B2 (3 drill)	3
total time (avg. EV1+EV2)	0:42:30
Observation	12%
Sample Collection	11%
Sample Preservation	5%
Navigation/Translation	5%
Site Set-Up	20%
Site Clean-Up	15%
Other	26%
Unknown (Due To Comm Dropouts)	26%

MD10 (2 EVAs) — EVA Duration 2:19:00

Sampling Only (N9)

requested samples	3
sampling at N9	1
total time (avg. EV1+EV2)	0:22:30
Permanent Tag Search	9%
Observation	18%
Sample Collection	9%
Navigation/Translation	2%
Site Set-Up	18%
Site Clean-Up	13%
Other	31%

Sampling - InterEVA (B2.2)

ST Assim. Time	1-day
requested samples (5 pliers, 1 chisel)	6
sampling at B2 (4 pliers)	4
total time (avg. EV1+EV2)	1:00:30
Temporary Tag Search	8%
Observation	18%
Sample Collection	21%
Sample Preservation	7%
Navigation/Translation	4%
Site Set-Up	7%
Site Clean-Up	17%
Other	17%

2nd EVA — EVA Duration 2:30:00

Sampling Only (N15)

requested samples (3 chisel)	3
sampling at N15 (3 chisel)	3
total time (avg. EV1+EV2)	0:37:00
Permanent Tag Search	38%
Observation	1%
Sample Collection	24%
Sample Preservation	4%
Navigation/Translation	3%
Site Set-Up	12%
Site Clean-Up	7%
Other	11%

Presampling - InterEVA (C1)

temp tags in C1	14
total time (avg. EV1+EV2)	0:34:00
Candidate Sample Search	24%
Observation	24%
Instrument Utilization	24%
Navigation/Translation	9%
Site Clean-Up	4%
Other	16%

MD11 — EVA Duration 3:45:00

Presampling - InterEVA (D1)

temp tags in D1	24
total time (avg. EV1+EV2)	1:54:00
Candidate Sample Search	34%
Observation	16%
Temporary Tag Search	14%
Instrument Utilization	17%
Navigation/Translation	5%
Site Clean-Up	4%
Other	11%

MD12 — EVA Duration 2:05:00

Sampling - InterEVA (C1)

ST Assim. Time	2-days
requested samples (5 pliers, 1 drill)	6
sampling in C1 (5 pliers, 1 drill)	6
total time (avg. EV1+EV2)	0:59:00
Temporary Tag Search	5%
Observation	25%
Sample Collection	16%
Sample Preservation	9%
Navigation/Translation	9%
Site Set-Up	9%
Site Clean-Up	8%
Other	14%
Unknown (Due To Comm Dropouts)	13%

MD13 — EVA Duration 4:46:00

Sampling - InterEVA (D1*)

ST Assim. Time	2-days
requested samples (2 drill, 1 chisel, 14 pliers)	17
sampling in D1 (2 drill, 2 chisel, 14 pliers)	18*
added temp tags in D1	3
total time (avg. EV1+EV2)	3:49:30
Candidate Sample Search	1%
Observation	16%
Temporary Tag Search	8%
Sample Collection	18%
Sample Preservation	6%
Navigation/Translation	5%
Site Set-Up	4%
Site Clean-Up	8%
Other	12%
Unknown (Due To Comm Dropouts)	22%

MD14 — EVA Duration 4:11:00

Presampling - IntraEVA (C2)

temp tags in C2	14
total time (avg. EV1+EV2)	1:04:00
Candidate Sample Search	17%
Observation	30%
Temporary Tag Search	2%
Instrument Utilization	19%
Navigation/Translation	2%
Site Set-Up	5%
Site Clean-Up	1%
Other	24%

Sampling - IntraEVA (C2)

ST Assim. Time from Presamp. Start	0:26:00	0:35:00	0:54:00
ST Assim. Time from Presamp. End	0:10:00	0:01:00	-00:15:00
ST Input Received before Sampling	0:10:00	0:01:00	-00:15:00
requested samples (3 drill, 7 pliers)	10		
samples in C2 (3 drill, 6 pliers)	9		
total time (avg. EV1+EV2)	1:27:00		
Temporary Tag Search	7%		
Observation	24%		
Sample Collection	18%		
Sample Preservation	9%		
Navigation/Translation	5%		
Site Set-Up	6%		
Site Clean-Up	18%		
Other	13%		

- Color coding shows new reef exploration site pre-sampling surveys and subsequent associated sampling, some within an EVA and some across EVAs
- Detailed task duration statistics are shown for each EVA
- Also shown are ST assimilation times that reflect the time that the ST had and took to send sampling priorities to the crew
  - For assimilation times across days, the ST reviewed high-res imagery and created cue cards to direct sampling (~2 hours)
- Continued analysis in work for input to modeling efforts

1. Mars mission operations concepts, capabilities, and communications protocols developed and tested during previous analog tests with **strategically designed to include additional ST assimilation time are borderline acceptable** from a science and operations perspective for 15 min OWLT latency. Improvements desired, warranted, or required include (full list and details earlier in presentation):
   - The ability to re-locate a candidate sample is a technique we will have when we go to Mars. Improvements are desired for methods in which this can be done more efficiently in-sim.
   - ST sampling requests must match sampling time available in the EVA timeline (e.g., ST should not request more samples than the crew can actually collect in a given time period). Clear understanding of the time it takes to complete a sampling task is important

1a. Acceptability of the Mars mission baseline ops con is **acceptable** based on giving extra time to the ST to provide input to the crew and additional data (i.e. high-res imagery) to be used to provide that input.

- In order to operate more effectively and efficiently with less time between pre-sampling and sampling tasks, the right capabilities (e.g., technologies, number of personnel and division of responsibility) need to be provided to IV and the ST to reduce workload and facilitate concurrent tactical and strategic planning. This is especially true across longer communication latencies.
  - ST used high-resolution still imagery of candidate samples (as opposed to low-resolution video only) to refine their sampling priorities (in approximately 10-15% of the cases) and created annotated imagery to guide sampling.
  - This could have been accomplished within an EVA with the capability for image transmission and enough ST personnel to perform the required tasks of review and annotation.
    - ST input was sent/received prior to when it was needed by the crew.

2. Mars mission operations concepts, capabilities, and communications protocols **designed to only allow for reactive ST feedback across latency work acceptably** (from a science and operations perspective) for 15 min OWLT latency. Improvements desired, warranted, or required include (full list and details earlier in presentation):
   - Warranted improvements were noted in the ability to precisely locate the corals to be re-sampled (which should be available for previously visited sites). Specifically, imagery of the targeted samples and overall area in addition to a reliable means of navigating to these locations are needed.

3. Which capabilities are enabling and significantly enhancing for the Mars mission operations concepts and protocols being tested? (full list and details earlier in presentation)
   - Site Precursor Imagery
   - Candidate Sample Location Marking
   - Candidate Sample Location Imagery
   - Scientific Instrument Data from EV to IV to ST
   - IV Use of ST Annotated Images to Direct EV Sampling
   - EV Viewing of ST Annotated Images to Guide Sampling
   - Tactical EVA Management Tool
   - Position Tracking of EV Crew
   - Continuous Video Feed from EV Crew
   - Continuous Comm between ST and IV
   - Electronic Cue Cards

IVA Objectives & Tasks

Enabled full mission simulation and time pressure for EVA

Intra-Vehicular Activities: Overview

Portable Sensorimotor Assessment Platform (PSAP)

HoloLens for Cargo Transfer Assessment

Miniaturized Exercise Device MED 2.0

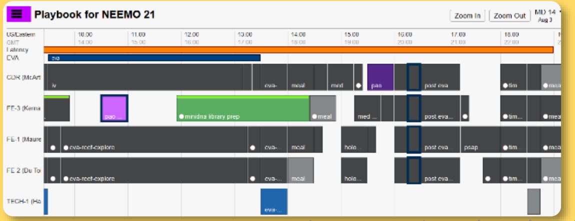
EVA Swab Tool

VEGA Telehealth - Portable monitoring devices

IHMC - Multi-Omic Study

Teloregen - Regeneration Study

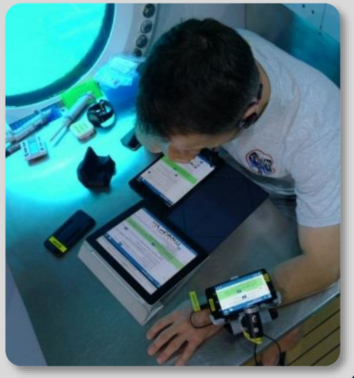
Playbook - Timeline Tool



Miniaturized DNA Sequencer

esa Evaluations

MobiPV Evaluation



Aquapad Evaluation

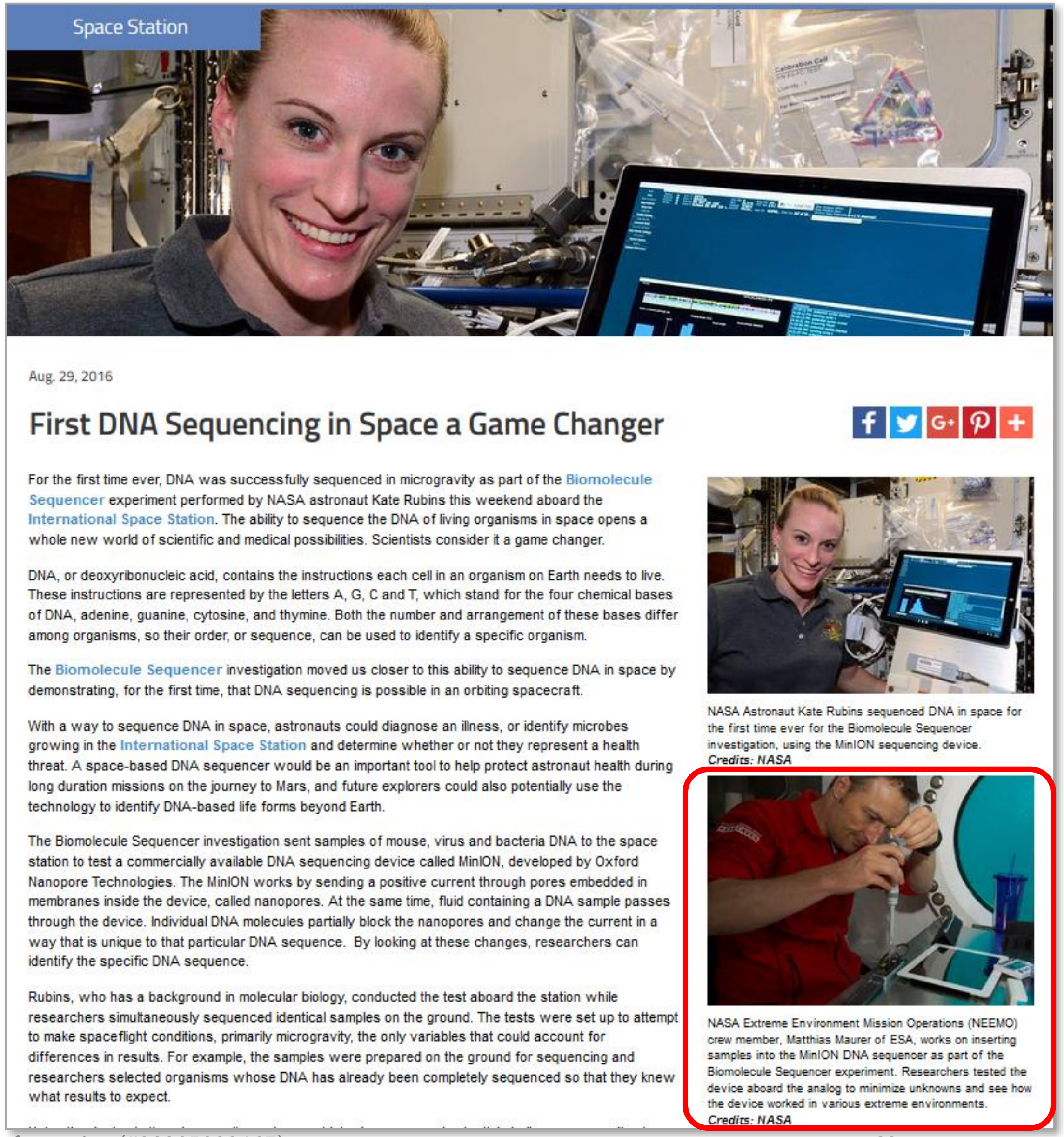
Nutritional Assessment Tool

Miniaturized Exercise Device MED 2.0

- **Potential Safety issues raised by the crew caused changes to upcoming ISS eval:**
  - New Caution Block added to flight procedures
  - Ground training modified
  - Shoulder presses will be eliminated from in-flight eval
- **Other ISS ops changes that will result from this eval:**
  - “How to” videos will be easy to find and can be updated without changing flight software
  - Identified shortcoming of the MED 2 heart rate monitor Bluetooth pairing with the Microsoft Surface Pro 3 => all MCC operators will be familiar with troubleshooting steps required, and step-by-step procedures will be available for the crew
  - Accomplished extensive procedure verification which closed numerous holes in the procedures
  - Additional training/simulation opportunity for MED 2 ISS ops and engineering support teams
  - Add flexibility to change ops parameters remotely

Intra-Vehicular Activities: Miniaturized DNA Sequencer

- **Validated a usable swab-to-sequencer protocol (procedure) in which environmental samples are collected**
  - Currently applying numerous suggestions from crew feedback to streamline procedure execution on ISS
    - Developing "just in time" training videos
    - Improving packaging
    - Targeted improvements to crew training
    - Assessing alternate enzymes that are all stable at a common temperature
    - Simplifying labeling and increased use of color coding
- **Demonstrated that a crew member, regardless of background, can collect an environmental sample, extract DNA from that sample, amplify the DNA, prepare the amplified DNA to be sequenced, and, finally, sequence DNA in an extreme environment.**
  - Normally requires trained molecular biologists with a complete suite of sophisticated equipment



Space Station

Aug. 29, 2016

First DNA Sequencing in Space a Game Changer

For the first time ever, DNA was successfully sequenced in microgravity as part of the Biomolecule Sequencer experiment performed by NASA astronaut Kate Rubins this weekend aboard the International Space Station. The ability to sequence the DNA of living organisms in space opens a whole new world of scientific and medical possibilities. Scientists consider it a game changer.

DNA, or deoxyribonucleic acid, contains the instructions each cell in an organism on Earth needs to live. These instructions are represented by the letters A, G, C and T, which stand for the four chemical bases of DNA, adenine, guanine, cytosine, and thymine. Both the number and arrangement of these bases differ among organisms, so their order, or sequence, can be used to identify a specific organism.

The Biomolecule Sequencer investigation moved us closer to this ability to sequence DNA in space by demonstrating, for the first time, that DNA sequencing is possible in an orbiting spacecraft.

With a way to sequence DNA in space, astronauts could diagnose an illness, or identify microbes growing in the International Space Station and determine whether or not they represent a health threat. A space-based DNA sequencer would be an important tool to help protect astronaut health during long duration missions on the journey to Mars, and future explorers could also potentially use the technology to identify DNA-based life forms beyond Earth.

The Biomolecule Sequencer investigation sent samples of mouse, virus and bacteria DNA to the space station to test a commercially available DNA sequencing device called MinION, developed by Oxford Nanopore Technologies. The MinION works by sending a positive current through pores embedded in membranes inside the device, called nanopores. At the same time, fluid containing a DNA sample passes through the device. Individual DNA molecules partially block the nanopores and change the current in a way that is unique to that particular DNA sequence. By looking at these changes, researchers can identify the specific DNA sequence.

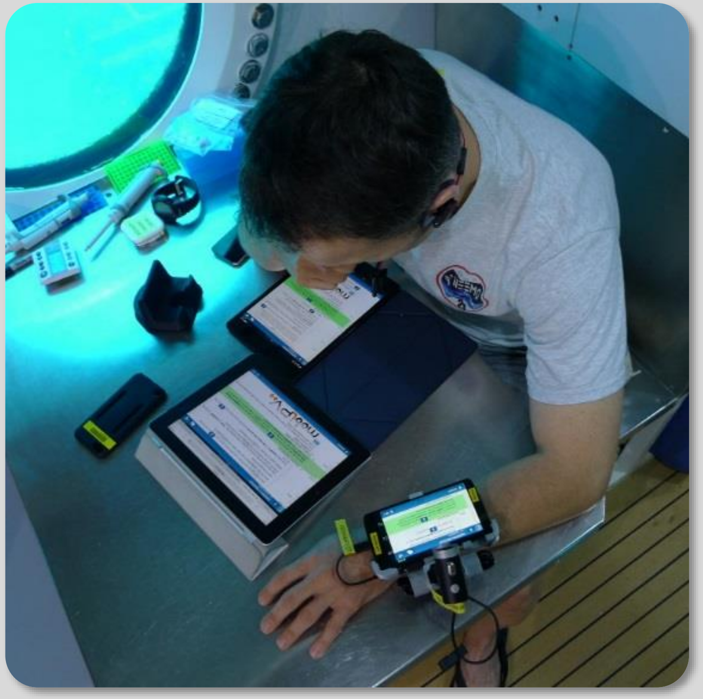
Rubins, who has a background in molecular biology, conducted the test aboard the station while researchers simultaneously sequenced identical samples on the ground. The tests were set up to attempt to make spaceflight conditions, primarily microgravity, the only variables that could account for differences in results. For example, the samples were prepared on the ground for sequencing and researchers selected organisms whose DNA has already been completely sequenced so that they knew what results to expect.

NASA Astronaut Kate Rubins sequenced DNA in space for the first time ever for the Biomolecule Sequencer investigation, using the MinION sequencing device.
Credits: NASA

NASA Extreme Environment Mission Operations (NEEMO) crew member, Matthias Maurer of ESA, works on inserting samples into the MinION DNA sequencer as part of the Biomolecule Sequencer experiment. Researchers tested the device aboard the analog to minimize unknowns and see how the device worked in various extreme environments.
Credits: NASA

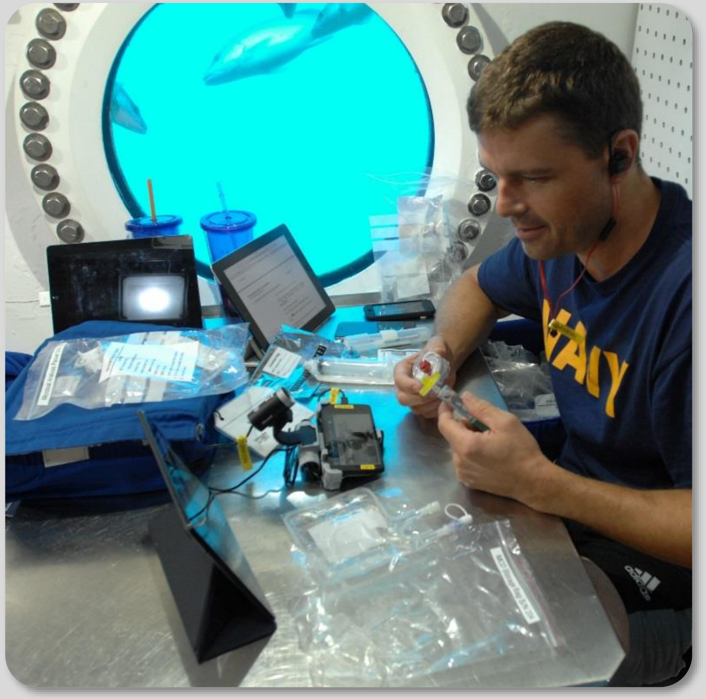
Intra-Vehicular Activities: ESA Evaluations

MobiPV Evaluation



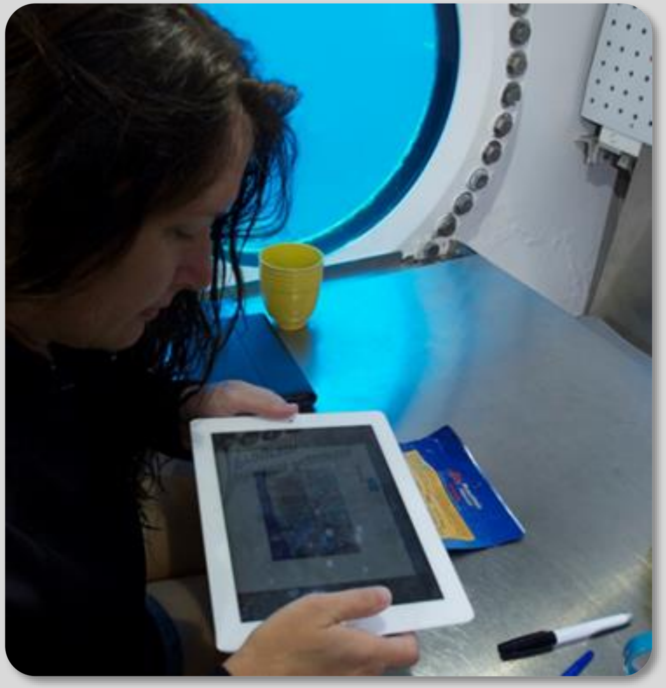
- Procedure viewer tool for ISS use (CY 17)
- Concept has operational value and holds the potential to greatly simplify and speed up the execution of intensive, hands-busy activities
- Validated multiple concurrent ground mobiPV systems (e.g. Capcom on the top side, engineering support in Europe)
- Ops environment provided extensive feedback that is being incorporated into FSW

Aquapad Evaluation



- Water sampling protocol for ISS (Inc. 50)
- Validated Aquapad is faster and simpler to use than current ISS method
- Trash reduction of > 50% realized from crew feedback

ESA Nutritional Assessment Tool Evaluation



- Nutrition tracking tool for ISS use (Inc. 50)
- Validated approach and received concrete feedback for improvements
- Maintaining food database was difficult with mid-mission resupplies
- Database on Ground (vice Onboard) server improved software updates, data transfer without sacrificing reliability

Additional Backup

CORAL RESTORATION FOUNDATION™

Education

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

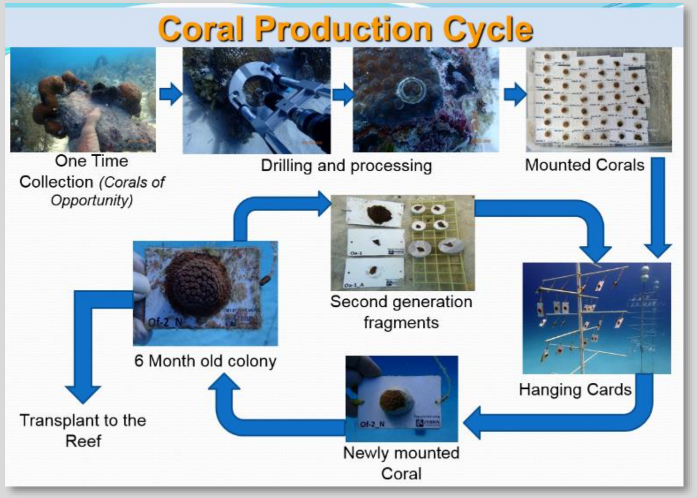
Action

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.

- 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.



Crew Considerations: Astronauts as Aquanauts

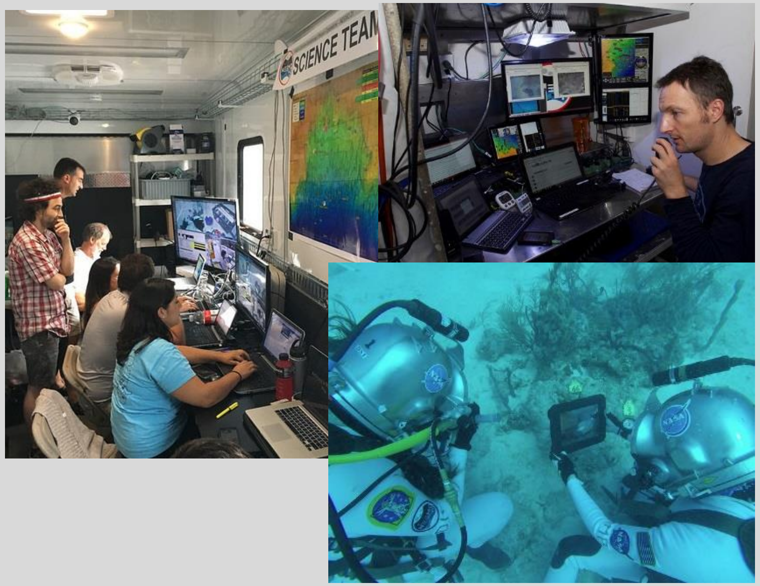
NEEMO EXPERIENCE CONTRIBUTES TO CREW READINESS

- Living aboard Aquarius in saturation is superb analog for life aboard ISS.
- Multi-national Crew conducted real research for Principal Investigators within NASA and for outside agencies and universities.
- Potential element in ISS Commander Upgrade training.

CREW HELPS MATURE CONCEPTS & EQUIPMENT FOR ISS

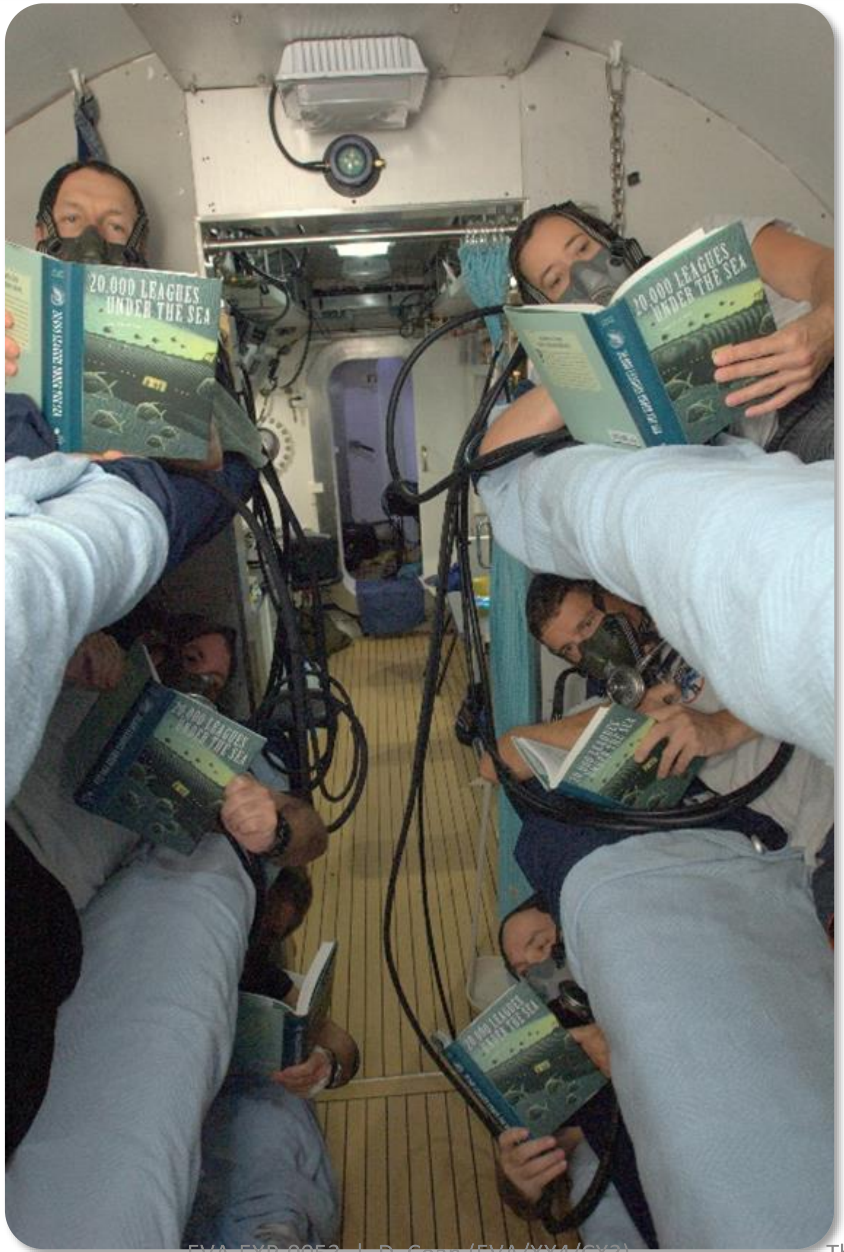
- Crew evaluated and provided feedback on software and hardware that is being developed for use aboard ISS, e.g. Playbook, mini DNA Sequencer, MED, mobiPV, AquaPad, ENA, HoloLens use for cargo transfer
    - N21 in situ DNA sample preparation and sequencing experience just in time to inform operations aboard ISS.

CREW HELPS REFINE OPS CONCEPTS FOR EXPLORATION



- Crew conducted complex EVAs including real sample collection under Mars-similar time delay.
- Local IV directed real-time operation with time-delayed input from Science Team.
- Experienced Crewmembers contribute critical feedback to overall operations concepts being assessed.

Outreach



20,000 LEAGUES UNDER THE SEA
20,000 LEAGUES UNDER THE SEA

NEEMO
TWEETS 1,608
FOLLOWING 82
FOLLOWERS 25.1K
LIKES 1,497
LISTS 1
Follow
NASA_NEEMO
@NASA_NEEMO
Atlantic Ocean
nasa.gov/mission_pages/...
Joined April 2010
288 Photos and videos
Tweets
Tweets & replies
Media
NASA_NEEMO @NASA_NEEMO · Aug 6
"So long, and thanks for all the fish!"
New to Twitter?
Sign up now to get your own personalized timeline!
Sign up
You may also like · Refresh
Johnson Space Center @NASA_Johnson
ISS Research @ISS_Research
NASA Marshall News
Ellen Ochoa @Astro_Ellen · Aug 4
An impressive milestone! @NASA_NEEMO latest mission will be wrapping up soon.
SPACE.com @SPACEdotcom
Astronaut-Aquanauts: 50 People Have Now Orbited Earth and Lived Undersea @astro_reid goo.gl/8Wn2RI

Aquarius

Micro-g NExT
LOS MEDANOS COLLEGE

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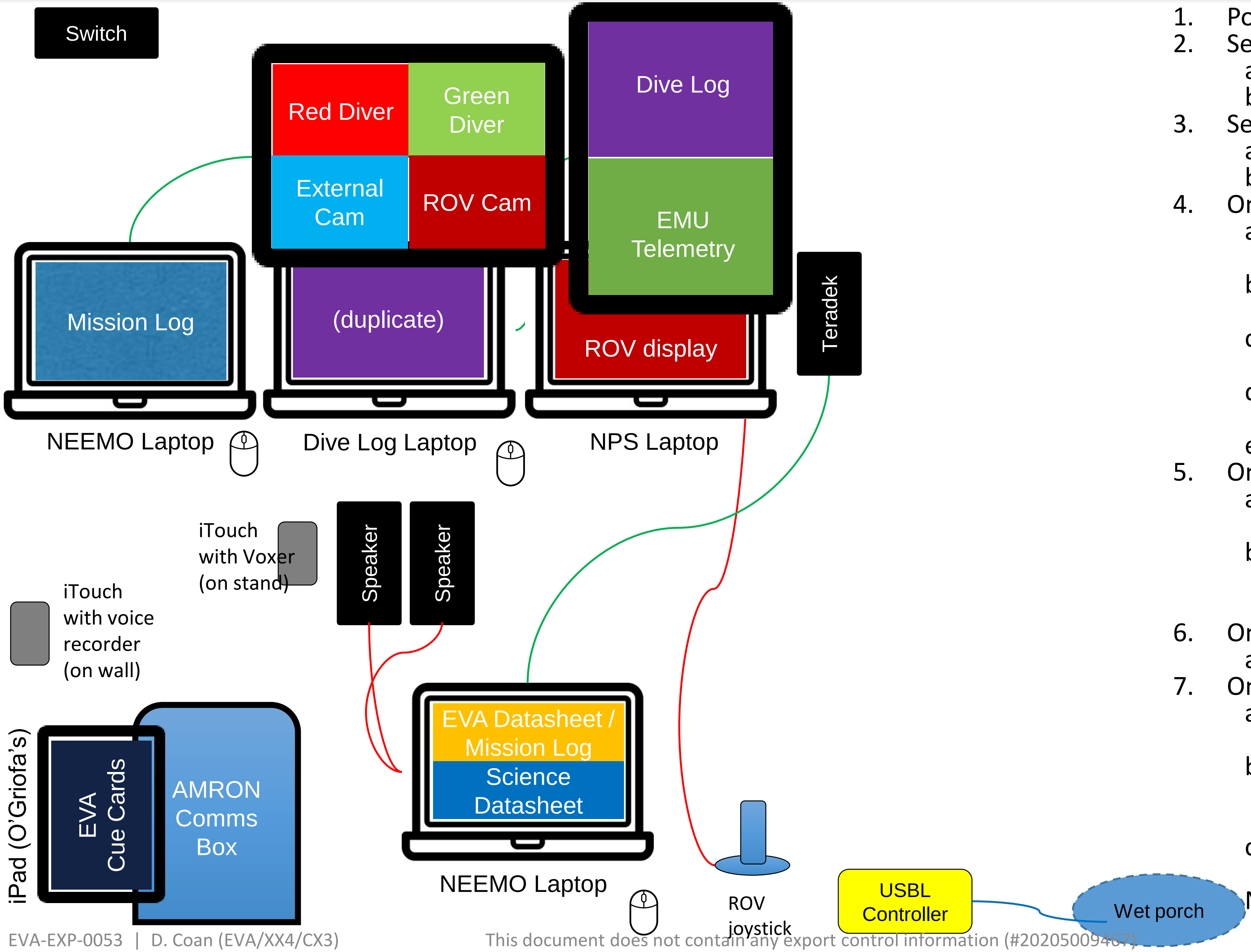
NEEMO Life: Above and Below



1. Power on all laptops
2. Set up iPad (O'Griofa's) in Amron box lid
   a. Plug in charging cable
   b. Load EVA cue cards
3. Set up iTouches
   a. 1 Velcroed to wall (for voice recorder)
   b. 1 on stand (for VCOM)
4. On back NEEMO laptop:
   a. Start red diver video: 192.168.0.15 (Verify with Hab Tech)
   b. Start green diver video: 192.168.0.16 (Verify with Hab Tech)
   c. Start preferred external video (Obtain IP from Hab Tech)
   d. Start ROV video (Check with MCC for IP)
   e. Start Mission Log
5. On Dive Log laptop:
   a. Configure Dive Log and size to fit ½ of screen
   b. Load appropriate EMU telemetry video per execute note and size to fit ½ of screen
6. On NPS laptop:
   a. Contact MCC for instructions if utilizing
7. On fwd NEEMO laptop:
   a. Open Mission Log and keep in background unless sending a message
   b. Open current day's Tactical EVA Management Tool and size to fit on top half of screen
   c. Open current day's Science Datasheet and size to fit bottom half of screen

Note: This laptop is screen-shared with MCC