Neoteric eXploration Technologies (NXT) Feasibility Mission (FaM) EVA & Science Operations Summary of Results

EVA-EXP-0072

EVA Exploration Working Group
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- NXT Feasibility Mission Overview & Goals
- EVA & ARES Objectives and Results
- Summary and Recommendations
  - Summary of Results for Subsea Assets (Exosuit & DeepWorker)
  - Summary of Results for EVA Equipment and Geology Training
  - Summary of Results for NXT FaM and Mission Location (Catalina)
  - Findings for NXT Concept
  - Relevance of NXT to Artemis
  - Recommendations for NXT and Potential Future Missions
- Questions & Answers
- Backup Materials and Additional Information

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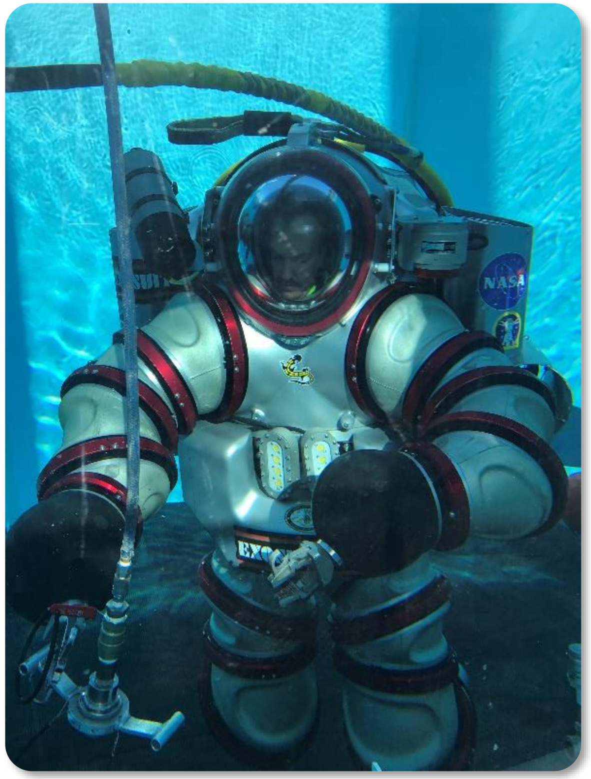
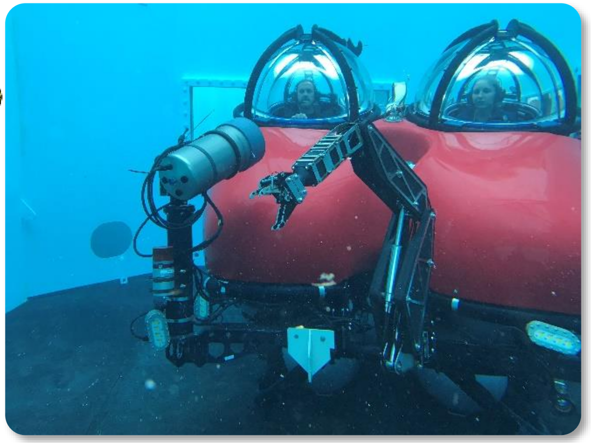
NXT Feasibility Mission Overview

NEEMO Neoteric eXploration Technologies (NXT) Concept (pre-FaM)

- Concept currently in development for a potential add-on and possible follow-on for NEEMO
- Focuses on Exploration operations development and training, xEVA informatics, xEVA con ops, and integration of science operations
- Offers a high intensity operationally challenging environment, with high workload, elevated stress, high band-width, time pressure, and unexpected external perturbations
- Utilizes Nuytco Research Exosuit Atmospheric Diving System (ADS) and Dual DeepWorker submersible
- Exosuit provides a restrictive suit that requires effort for positioning and working somewhat analogous to an EVA suit, along with a relatively large helmet volume at 1 ATM to evaluate off-the-shelf informatics hardware





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Development & Integration Themes (4-T's) Potentially Addressed by NXT Concept

TOOLS

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

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

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

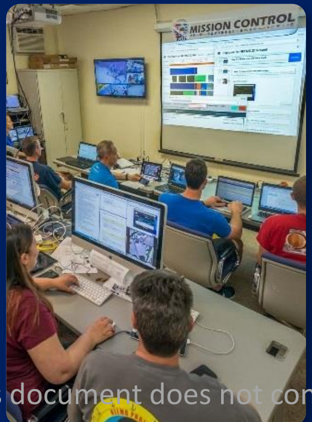
TECHNIQUES

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

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

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

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

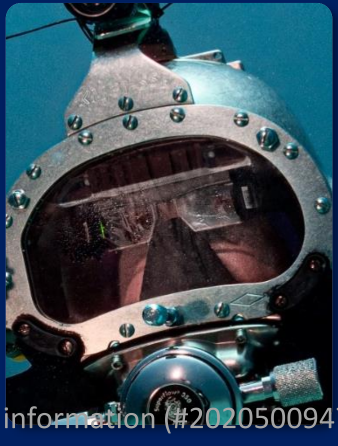


TECHNOLOGIES

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

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

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



TRAINING

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

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

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

NXT Feasibility Mission (FaM) Overview

Overview

- 10-day feasibility evaluation based out of USC Wrigley Marine Science Center on Catalina Island, CA
- Objectives focused on mission feasibility, crew experience and exploration training, science operations, and potential Exploration EVA capabilities
- Operations take place separately on both land and in water (“surf & turf”)
- Partners with NASA include ESA, JAXA, and Nuytco Research
- No commercial partners involved in FaM

Key Dates

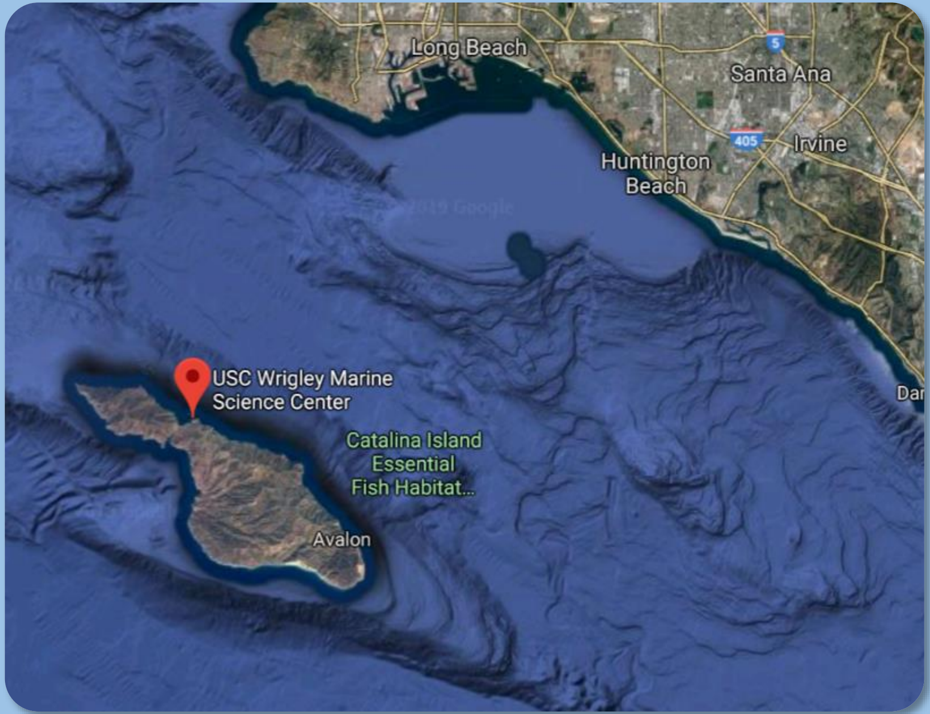
- Training Readiness Review (TrRR): August 6, 2019
- Feasibility Mission dates: August 19 – 28, 2019

Mission Management Team (MMT)

- David Coan (XX/EVA Lead)
- Trevor Graff (XI/Integration Lead)
- Jordan Lindsey (XX/EVA)
- Marc Reagan (XM/Mission Director)
- Bill Todd (XM/Project Specialist)
- Kelsey Young (XI/Science Lead)

Location

- Catalina Island, CA
- USC Wrigley Marine Science Center
  - Used as base of operations and for housing, with everything from maintenance facilities to working labs
  - Decompression chamber onsite at USC
- Local cove used for operations
- Allowed for “surf & turf” model



EXOSUIT

- Atmospheric Diving System (ADS) that's an analogous restrictive suit
- Requires effort for positioning and working, as does an EVA suit
- Helmet volume at 1 ATM allows for evaluation of off-the-shelf informatics hardware (Lumus DK-52, similar to DAVD)
- Potential to continue collaboration with the U.S. Navy (e.g., DAVD & suits)
- Potential partnership with Nuytco for spacesuit develop (e.g., joints)

Dual Deepworker

- Two person submersible analogous to an excursion rover, with a Pilot and an Observer
- Pilot and Observer split flying, camera, manipulator, and observation duties
- Requires effort for positioning and working
- Utilized during NEEMO 15 & 16
- Feasibility evaluated by NASA READy MMT (Todd, Young, Coan, Graff, Reagan)
- Used for Science Operations

Surf – Subsea EVA & Science Operations

- Crew utilized Exosuit and Dual DeepWorker for subsea operations
- Operated Exosuit from USC's dock in Fisherman's Cove and nearby islands (unable to secure a ship to access deeper waters as previously discussed)
  - Exosuit constrained to within < 1250' of dock (umbilical length)
  - DeepWorker was constrained to within comm umbilical length for eval of informatics
  - Limits depths of Exosuit to ~25'-120'
  - Not able to access Sea Fan Grotto (prime dive site)

Turf – Geology Field Observations

- Crew conducted geologic field observations on land (by foot and vehicle) and by water (kayaks and boat)
- Provided an island geologic overview; concentrated on the volcanic region near USC campus
- Established observational skills and knowledge that could be extended to the subsea environment

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Submersible Operations Team at NXT FaM

Exosuit Pilots
- Drew Feustel (NASA Astronaut)
- Norishige Kanai (JAXA Astronaut)
- Thomas Pesquet (ESA Astronaut)
- David Coan (NASA EVA Lead)
- Trevor Graff (NASA Integration Lead)

Exosuit Pilots in Training
- Jordan Lindsey (NASA EVA)
- Adam Naids (NASA EVA Tools)

DeepWorker Pilots and Flight Engineers
- Thomas Pesquet (ESA Astronaut)
- Drew Feustel (NASA Astronaut)
- Kelsey Young (NASA Science Lead)
- Marc Reagan (NASA Mission Director)
- Bill Todd (NASA Project)
- David Coan (NASA EVA Lead)
- Trevor Graff (NASA Integration Lead)

DeepWorker Pilots in Training
- Norishige Kanai (JAXA Astronaut)
- Jordan Lindsey (NASA EVA)
- Adam Naids (NASA EVA Tools)

DeepWorker Science Observers
- None

DeepWorker Passengers
- Herve Stevenin (ESA EVA)
- John Council (Avalon Diving History Exhibit)
- Adam Naids (EVA Tools)
- Sean Conner (USC)

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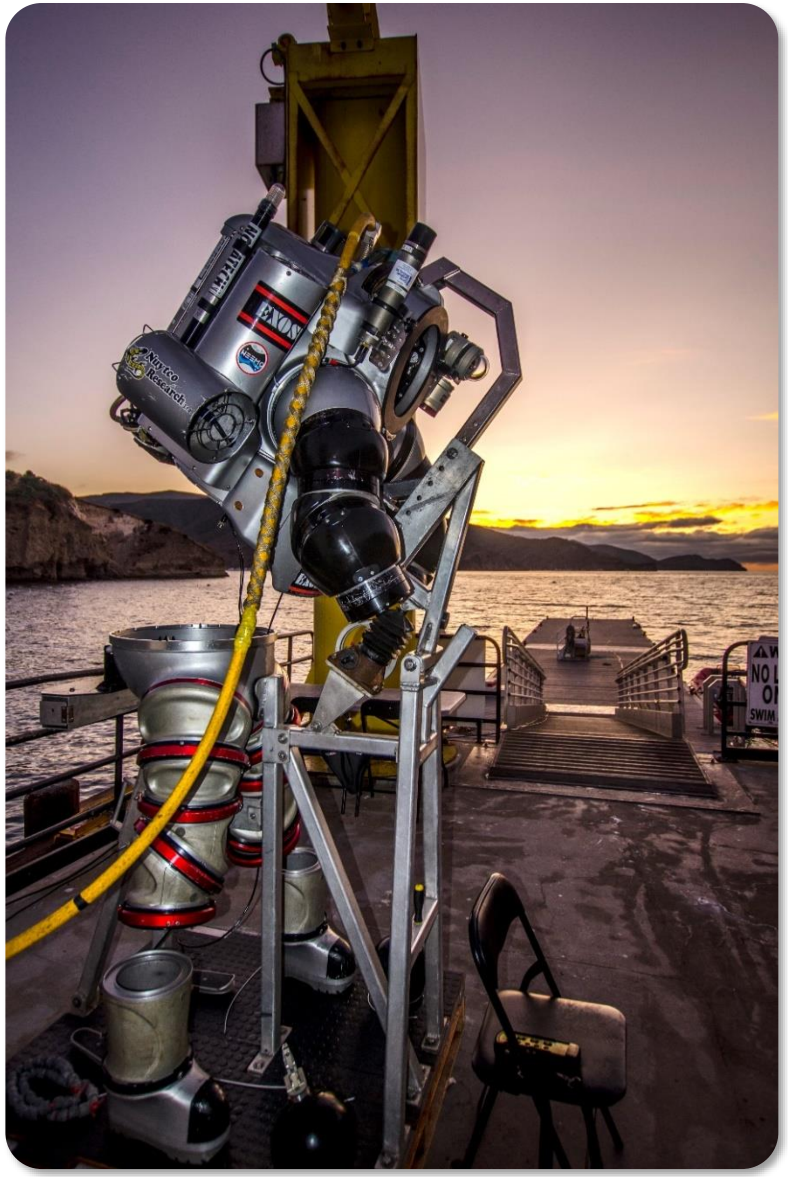
EVA & ARES Objectives

EVA (XX) & Science (XI) Objectives

- **Tools**
  - Development of a heads-up display (HUD) concept (e.g., Lumus DK-52/DAVD) in an encumbered suit (Exosuit) for potential expansion into the xEMU
  - Development of an IV Workstation and Support System needed for EVA and Science operations, especially at destinations with long signal/comm latencies
- **Techniques**
  - Evaluation of planetary pioneering and science operations while conducting tasks with a restrictive suit in an extreme environment
  - Development of integrated operations and capabilities between EVA and Science, with operations being directed by an MCC Science Team
- **Technologies**
  - Evaluation of concepts for hands-free advanced informatics with real-time data that could be applied to future Exploration spacesuit systems
- **Training**
  - Science/Geology training – begin to develop the subsea-based curriculum and tasks; develop and execute the terrestrial geology training to provide a baseline for subsea curriculum
  - Exploration operations training for personnel that don’t have extensive direct operational experience



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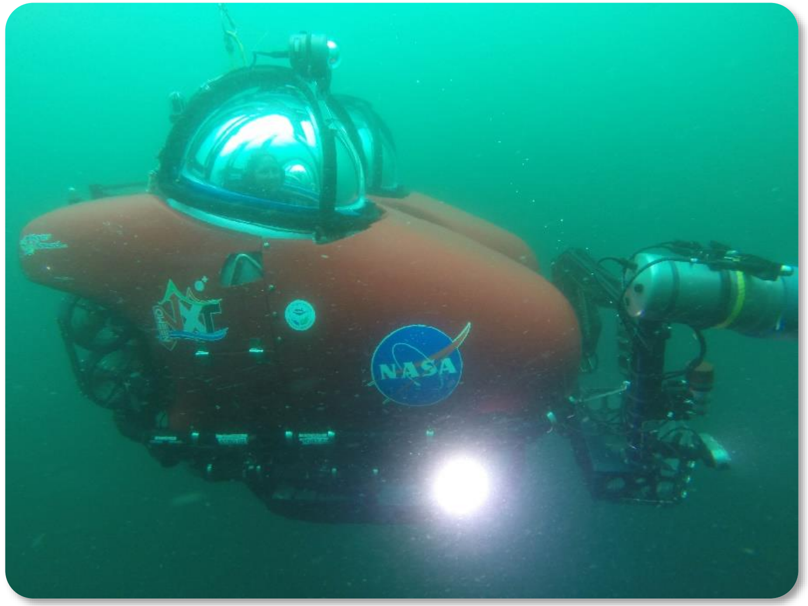
Concept Validation

- Determine the applicability and relevance of the NXT concept to the EVA Exploration Office
- Understand the relevancy of NXT specifically to the Lunar 2024 mission, including as it relates to EVA
- Identify specific xEVA gaps that could be addressed by NXT
- Assess the effectiveness (“bang for the buck”) of NXT for the EVA Exploration Office
- Understand reasonable capability expectations over 8 days of ops, and determine the optimal number of crew for future missions and roles for partner crewmembers
- Determine the value and relevancy of Catalina Island for NASA-relevant EVA objectives
- Assess the logistics (shipping, transportation, etc.), including support of the EVA objectives and team
- Assess the facilities at USC Wrigley Marine Science Center (shop, dock, boats, housing, dive locker, etc.) for EVA objectives and team support
- Assess the leadership model for effectively enabling the EVA Exploration Office and EVA-related objective



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EVA Office Objectives for NXT FaM

Capability Objectives

- Determine the applicability of utilizing an Exosuit for Exploration EVA evaluations, including xEVA Informatics and xEVA Concepts of Operations
  - Assess the relevancy of using an Exosuit for analog lunar surface EVA operations, specifically engineering/pioneering tasks
  - Assess the relevancy of using an Exosuit for analog lunar surface EVA operations, specifically science tasks
  - Determine the feasibility of training Exosuit pilots in the field such that they can provide valuable evaluations for EVA before the end of the mission (training days vs. execution days)
  - Develop a training plan for enabling new Exosuit pilots to execute xEVA tasks
  - Determine whether the sortie time (hours) a novice pilot can spend in the Exosuit is long enough to allow for meaningful evaluations of EVA objectives
  - Determine the optimal sortie length, number, rotations, and positions
- Determine the applicability of utilizing a Dual DeepWorker for Exploration EVA evaluations, including xEVA Informatics and xEVA Concepts of Operations
  - Assess the relevancy of utilizing a Dual DeepWorker as an “EVA platform” (i.e., as an analog EV crewmember and as an EVA support asset)
  - Understand the relevancy of using a Dual DeepWorker for lunar surface operations, including science tasks
  - Determine the feasibility of training Dual DeepWorker pilots, FEs, and Observers in the field such that they can provide valuable evaluations for EVA before the end of the mission
  - Determine the optimal sortie length, number, rotations, and positions.
  - Understand the value of the Dual DeepWorker Flight Engineer position for Exploration EVA
  - Understand the value of the Dual DeepWorker Observer position for Exploration EVA

Capability Objectives

- Understand whether the Exosuit and Dual DeepWorker can reasonably operate together for dual EV tasks, and the relevance of that mode of operations
- Assess the topside/shore capabilities and positions for enabling EVA objective evaluations
- Evaluate the applicability of the Lumus DK-52 glasses as an Informatics system (heads-up display) for xEVA capability testing
  - Determine whether data can be pushed from a topside position (IV/MCC) to the Lumus DK-52 in the Exosuit such that it’s usable for evaluations of lunar surface EVA operations
  - Determine whether data can be pushed from a topside position (IV/MCC) to the Lumus DK-52 in the Dual DeepWorker such that it’s usable for evaluations of lunar surface EVA operations
  - Look at potential 1-G field uses of the Lumus DK-52
- Assess the xEVA Aquatic Pressurized Task Board for evaluations of xEVA Informatics (Lumus DK-52 in the Exosuit)
  - Evaluate deploy and retrieve of the EVA aquatic task pressure board
  - Evaluate diver support for the EVA aquatic task pressure board
  - Assess potential use of EVA aquatic task pressure board for use in other analogs (e.g., in the NBL)
- Determine if it’s possible for the Exosuit to evaluate any EVA tools
- Evaluate EVA science sampling tools during land-based geology tasks

Results & Lessons Learned

Utilization of Exosuit for xEVA

Objective

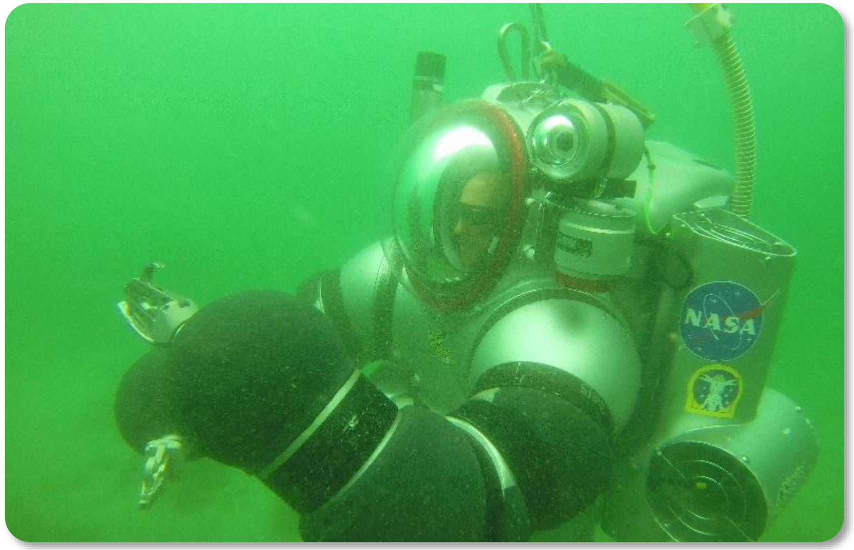
- Determine the applicability of utilizing an Exosuit for Exploration EVA evaluations, including xEVA Informatics and xEVA Concepts of Operations

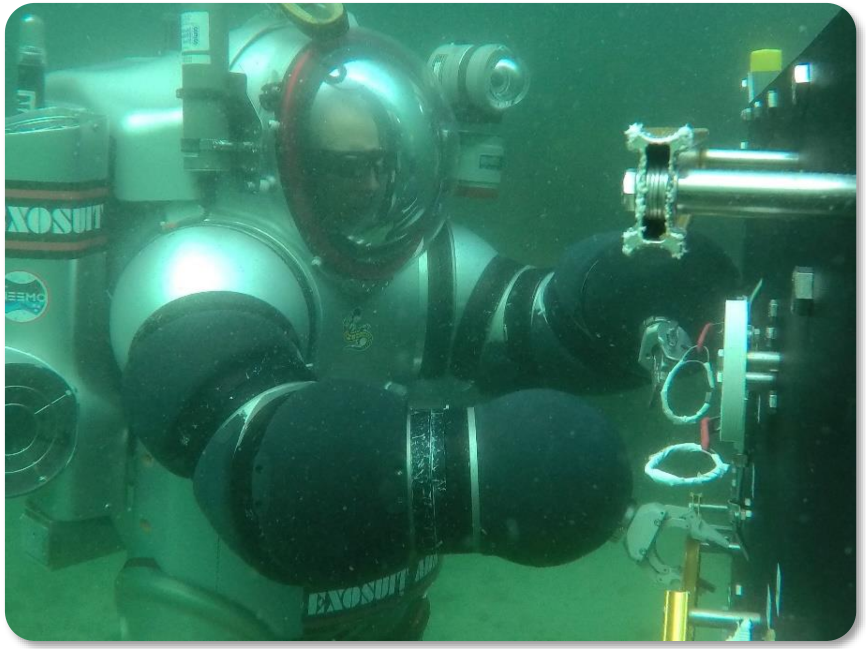
Mission Implementation & Summary

- Conducted training runs in the Exosuit with both experienced and new pilots
- Utilized the EVA aquatic pressurized task board for both training and pioneering tasks
- Pioneering tasks executed by EVA SME (Coan) and Science SME (Graff)
- Pioneering tasks executed by 3 EVA-experienced astronauts (Feustel, Pesquet, Kanai)
- Made preliminary notes about conducting science observation tasks
- Science observations examined by an scientist-astronaut (Feustel) and Science SME (Graff)

Crew Debrief Comments

- Exosuit is similar to EVA in a lot of ways, but not in relation to the hands
- Value of Exosuit is concentration, focus, making several things work together – good skill for operators to have
- Lends more to general crew training than realistic flight-specific training or evaluating tools and techniques
- If looking at 2024, need to find a way around the hands limitation (pinchers) in order to handle objects and use relevant tools or scanners – would be much better if able to use the lunar geology sampling tools (made by EC7/EVA Tools)
- Need to be able to conduct science operations with Exosuit [i.e., operate in clear water near relevant geology]
- Flying instead of walking in Exosuit is not as bothersome (from astronaut perspective)
- Could spend up to ~2 hours in suit – need to learn how to take breaks
- Should get assets together in proximity operations due to the complexity it adds to the decision making process – potential of impacting is more realistic and good, but adds to risk





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Utilization of Exosuit for xEVA

Results (Key Take-Aways)

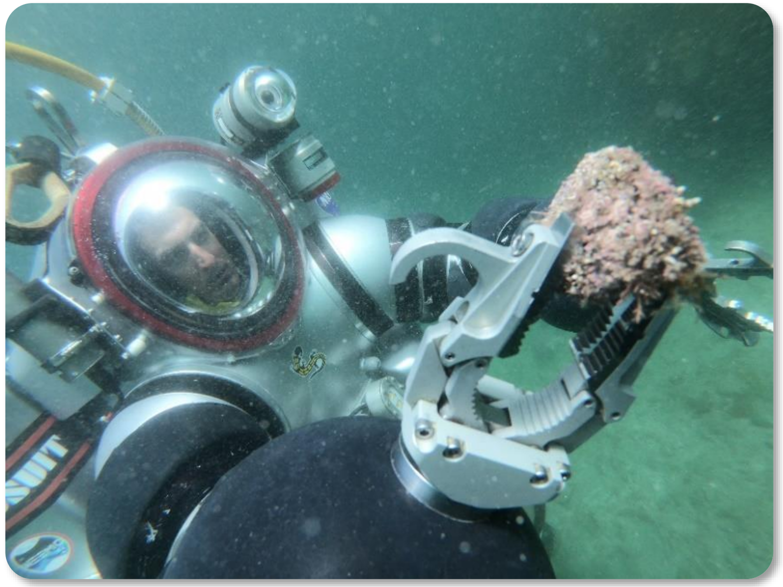
- Exosuit provides a reasonable platform for xEVA informatics development and testing
- Using a HUD (e.g., Lumus DK-52) in the Exosuit worked well
- Suit mobility is different from an Exploration Spacesuit (e.g., xEMU), and lack of dexterous fingers is a limitation
- Exosuit may be viable for early generic training for lunar surface EVAs

Recommendations

- Evaluate HUD display, information, and layout with DK-52 in Exosuit
- Operate Exosuit in clearer water near more relevant geology (i.e., out of USC cove) and utilize for science ops, specifically contextual observations
- Incorporate pre-hensors (fingers) when those become available (currently in development by Nuytco and NAVSEA)
- Utilize the form-fitting Lightweight 1ATA Dive Suit (LADS) being developed by Nuytco and NAVSEA when/if it is completed

Lunar 2024 Relevance

- As stated in the crew debrief, the Exosuit and NXT are not directly relevant to the Artemis 3 mission (2024)
- Training crew to conduct scientific observations while wearing a restrictive suit is relevant to all lunar surface missions
- Development of xEVA informatics is relevant to lunar surface missions subsequent to the initial 2024 mission, and potentially even for the Artemis 3 mission



Objectives Completion Status: Utilization of Exosuit for xEVA

Determine the applicability of utilizing an Exosuit for xEVA evaluations, including xEVA Informatics and xEVA Concepts of Operations		
Completed	**Partially Completed**	**Not Completed**
	Determine the applicability of utilizing an Exosuit for Exploration EVA evaluations, including xEVA Informatics and xEVA Concepts of Operations [#10]	
Assess the relevancy of using an Exosuit for analog lunar surface EVA operations, specifically engineering/pioneering tasks [#11]		
	Assess the relevancy of using an Exosuit for analog lunar surface EVA operations, specifically science tasks [#12]	
	Determine the feasibility of training Exosuit pilots in the field such that they can provide valuable evaluations for EVA before the end of the mission (training days vs. execution days) [#13]	
	Develop a training plan for enabling new Exosuit pilots to execute xEVA tasks [#14]	
	Determine whether the sortie time (hours) a novice pilot can spend in the Exosuit is long enough to allow for meaningful evaluations of EVA objectives [#15]	
	Determine the optimal sortie length, number, rotations, and positions [#16]	

Objective

- Evaluate the applicability of the Lumus DK-52 glasses as an Informatics system (heads-up display) for xEVA capability testing

Mission Implementation & Summary

- During most Exosuit events, the Lumus glasses were utilized to display varying amounts of information
- Data was displayed in two scenarios, generic and task specific
- For generic: a local map, compass, suit data, clocks, turns, and anticipated gauge readings were displayed
- For specific tasks: cue cards were projected for pioneering task direction on task board

Crew Debrief Comments

- Heads-up display is a good tool [for lunar surface EVA operations]
- Value of pushing data to a HUD (e.g., Lumus glasses)
    - Everything seen was of value (map, compass, suit data, clocks, turns, gauge readings, cue cards)
    - Needs to be a way to acknowledge steps in procedures
    - Visual representation (graphic) of data was valuable
    - Step by step instructions/procedures were not as valuable, as there is still a need to acknowledge steps with someone
- Need to have CAPCOM pushing cue cards to the HUD from MCC or have two crew sitting side by side at IV workstation
- Nav was great in suit
- A 3D map that can be tagged with specific locations and shared between MCC and assets would be beneficial
- Integrate activity statusing (PET start/stop) into EVA informatics
- Lumus glasses were great for Exosuit, not so much for DDW sub

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Lumus DK-52 as an xEVA Informatics HUD Capability Concept Platform

Results (Key Take-Aways)

- A heads-up display is valuable and useful
- Beneficial data included suit data (consumables, gauge readings, umbilical turns) and navigation information (map and compass)
- Task-specific cue cards projected via a HUD are advantageous
  - Graphics were intuitive
  - Step-by-step instructions were not seen as being as helpful, especially given that critical steps need to somehow be actively acknowledged/statused
- Content needs to be optimized for EVA operations
- Need to understand who is in control of pushing content to the HUD based on the task or time
- Lumus glasses worked well in both the Exosuit and DDW sub, however they were uncomfortable for extended periods of time (~ >1 hr) in the DDW due to the comm headset being used

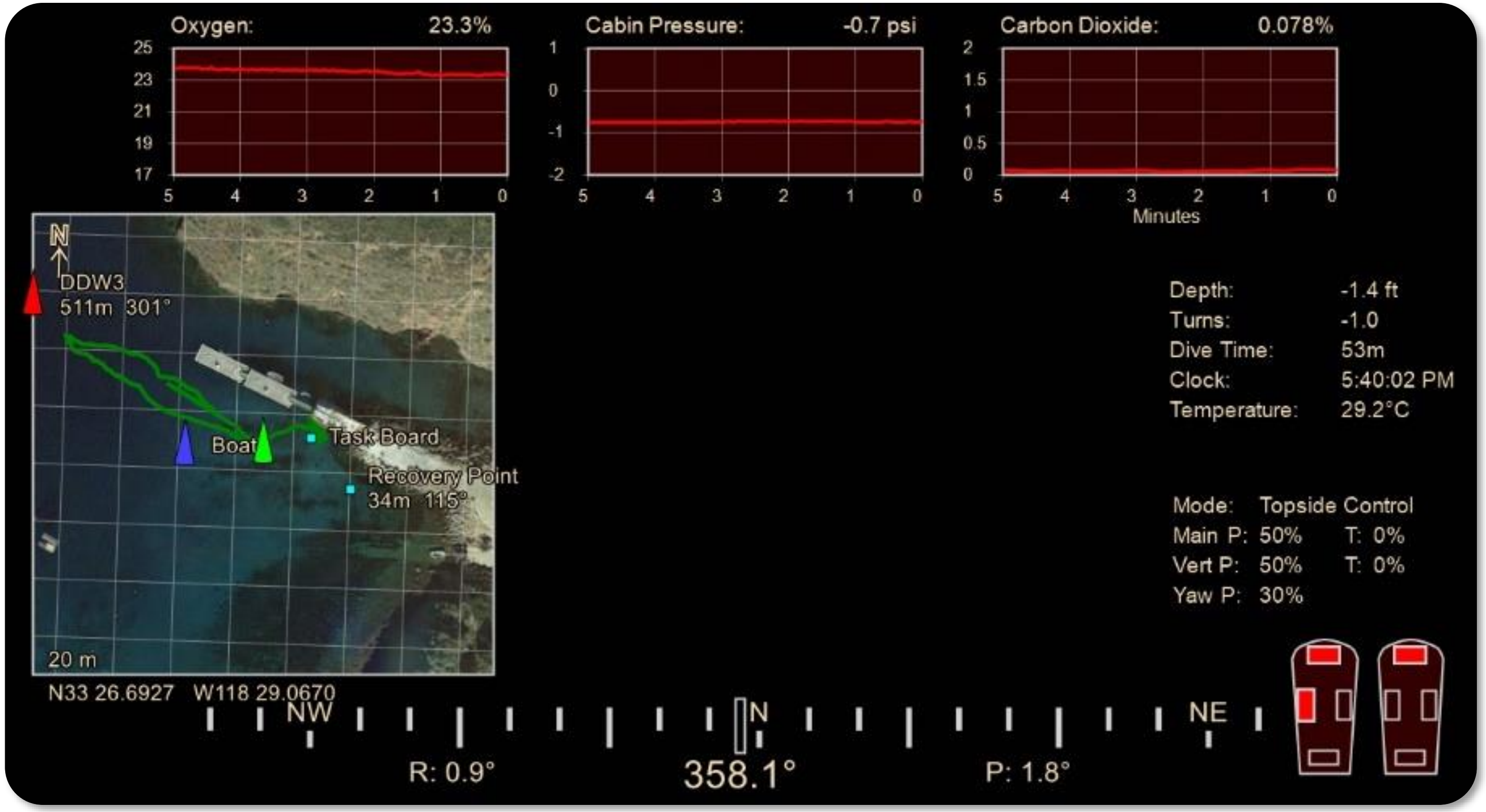
Recommendations

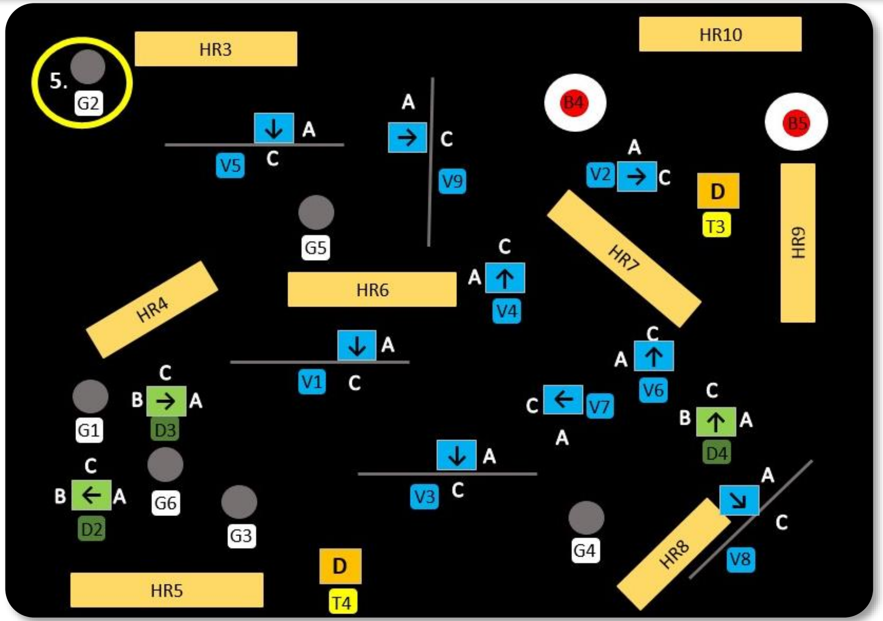
- Continue evaluating HUD-like concepts for xEVA informatics
- Conduct in-depth studies and tests to understand the amount of data needed and required
- Incorporate lessons learned into helmeted testing (e.g., DAVD in KM37)

Lunar 2024 Relevance

- Development of xEVA informatics with a HUD-type display system is potentially relevant to the Artemis 3 mission (2024, and definitely relevant to subsequent lunar surface missions (Artemis phase 2)
- A capable xEVA informatics system will allow for both increased crew autonomy and for enhanced interaction with a Earth-based Science Team

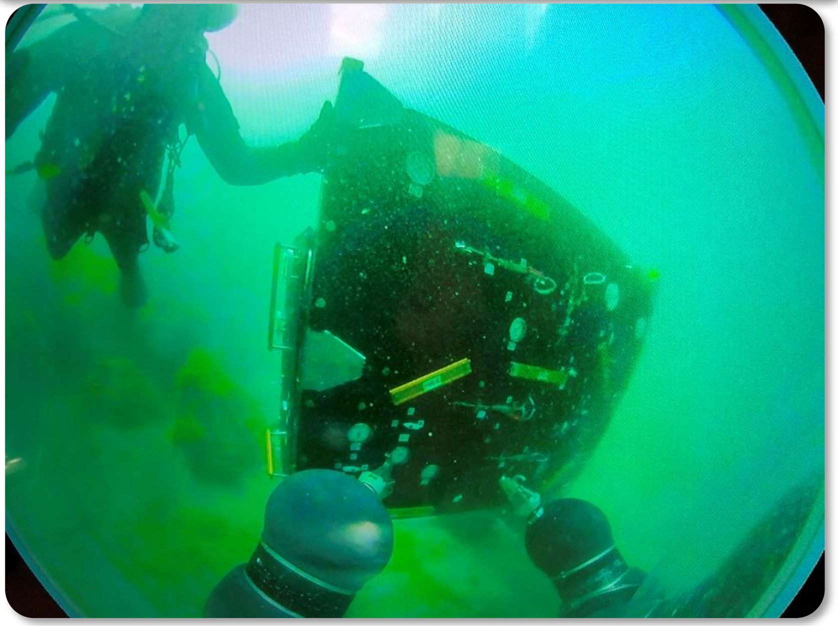
HUD Displays Used with DK-52 for xEVA Informatics





1. LEFT Panel, T1 ↑
2. D1 → A
3. Press B2 (victory bubbles)

1. D1 → B
2. D2 → A
3. Read G1
4. D2 → B
5. Read G2
6. D3 → A
7. Read G3
8. **Get Ahead: <u>Xlate</u> to Foot Pedal**



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Evaluate the applicability of the Lumus DK-52 glasses as an Informatics system (heads-up display) for xEVA capability testing		
Completed	**Partially Completed**	**Not Completed**
	Evaluate the applicability of the Lumus DK-52 glasses as an Informatics system (heads-up display) for xEVA capability testing [#26]	
Determine whether data can be pushed from a topside position (IV/MCC) to the Lumus DK-52 in the Exosuit such that it's usable for evaluations of lunar surface EVA operations [#27]		
	Determine whether data can be pushed from a topside position (IV/MCC) to the Lumus DK-52 in the Dual DeepWorker such that it's usable for evaluations of lunar surface EVA operations [#28]	
	Look at potential 1-G field uses of the Lumus DK-52 [#29]	

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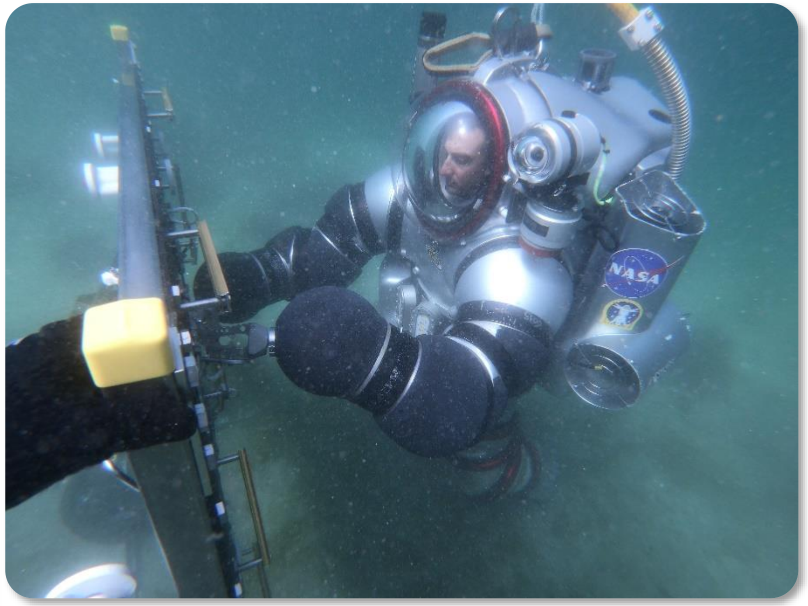

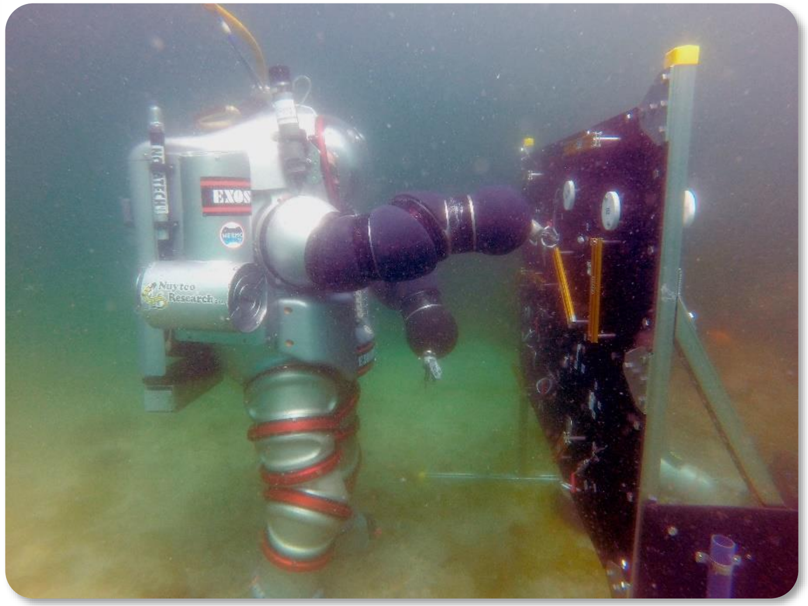

Objective

- Assess the xEVA Aquatic Pressurized Task Board for evaluations of xEVA Informatics (Lumus DK-52 in the Exosuit)

Mission Implementation & Summary

- Placed via crane in 20 ft of seawater without issue
- Subjects in Exosuit operated board and executed procedures displayed via Lumus glasses
- Divers reconfigured board as needed
- Board was evaluated by each crew member

Crew Debrief Comments

- Some of the valves were difficult to operate in the Exosuit
- Some crew enjoyed the challenge, others did not

Results (Key Take-Aways)

- The task board worked as designed and provided a great platform to allow the evaluation of a heads up display in a suit

Recommendations

- Utilize the pressurized task board for future Exosuit training and for other aquatic analogs (e.g., NBL and NEEMO)
- Redo the labels to make hard mounted

Lunar 2024 Relevance

- Relevant as a pioneering task for Artemis 3 (2024) and subsequent missions
- Also provides a means to evaluate heads-up display objectives

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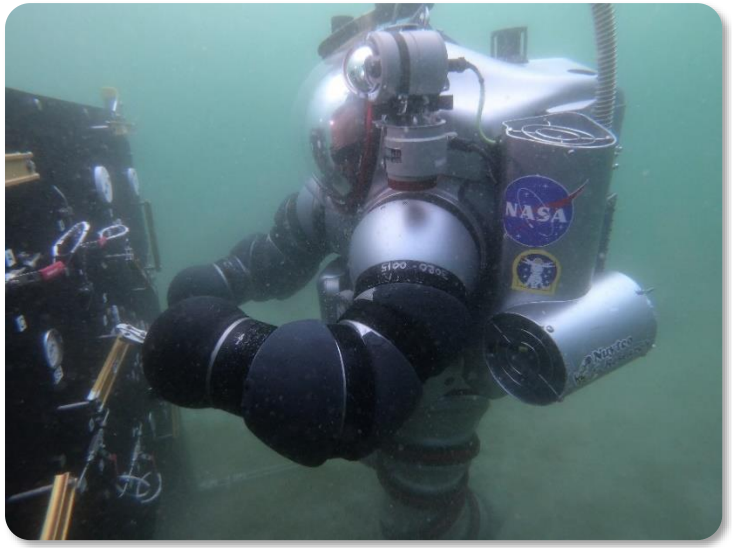
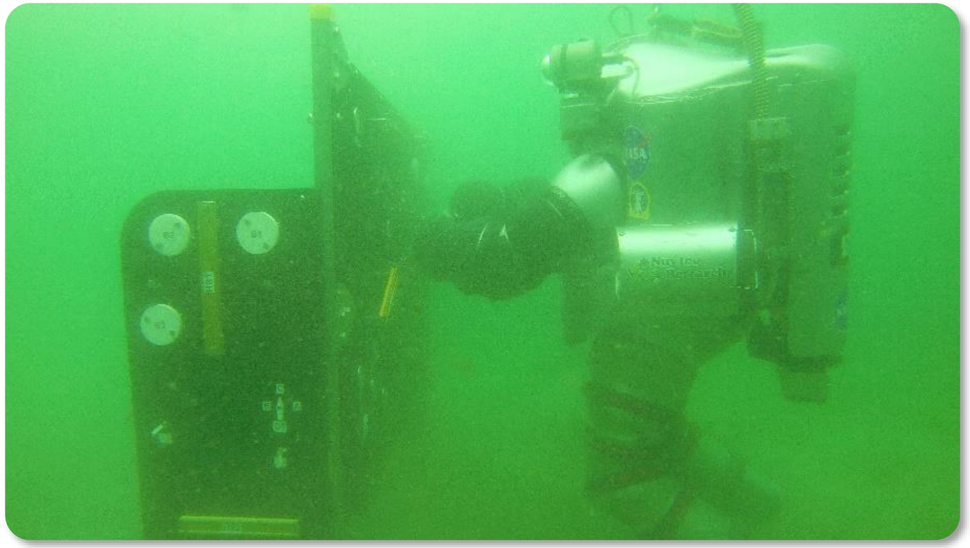
Assess the xEVA Aquatic Pressurized Task Board for evaluations of xEVA Informatics (Lumus DK-52 in the Exosuit)		
Completed	**Partially Completed**	**Not Completed**
Assess the xEVA Aquatic Pressurized Task Board for evaluations of xEVA Informatics (Lumus DK-52 in the Exosuit) [#30]		
	Evaluate deploy and retrieve of the EVA aquatic task pressure board [#31]	
Evaluate diver support for the EVA aquatic task pressure board [#32]		
Assess potential use of EVA aquatic task pressure board for use in other analogs (e.g., in the NBL) [#33]		





Objective

- Determine the applicability of utilizing a Dual DeepWorker for Exploration EVA evaluations, including xEVA Informatics and xEVA Concepts of Operations

Mission Implementation & Summary

- Dual DeepWorker used on excursions as a “rover”
- Positions in DDW included Pilot and Flight Engineer (pilot qualified)
- Passengers were taken in DDW, however Observer role (non-pilot science expert) was not exercised
- Lumus DK-52 attempted early on as a HUD for the Flight Engineer, but uncomfortable to wear for extended periods of time (functionality was replaced with an iPad solution)

Crew Debrief Comments

- Operating DDW
  - Shouldn’t do stuff up the wall [vertical plane], since won’t be flying on the moon
  - Doesn’t really drive on bottom and doesn’t add any extra value [to drive with wheels]
  - Using wheels and only driving on bottom is more realistic
- Informatics
  - Lumus glasses on Flight Engineer was not a good setup – pilot needed info
  - Tablet worked better for pilot than Lumus glasses ergonomically
  - Solutions for suit and sub are different – Lumus glasses were great for suit, not so much for sub
- Navigation
  - Nav on the Flight Engineer side was misplaced – pilots needs that info more

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Results (Key Take-Aways)

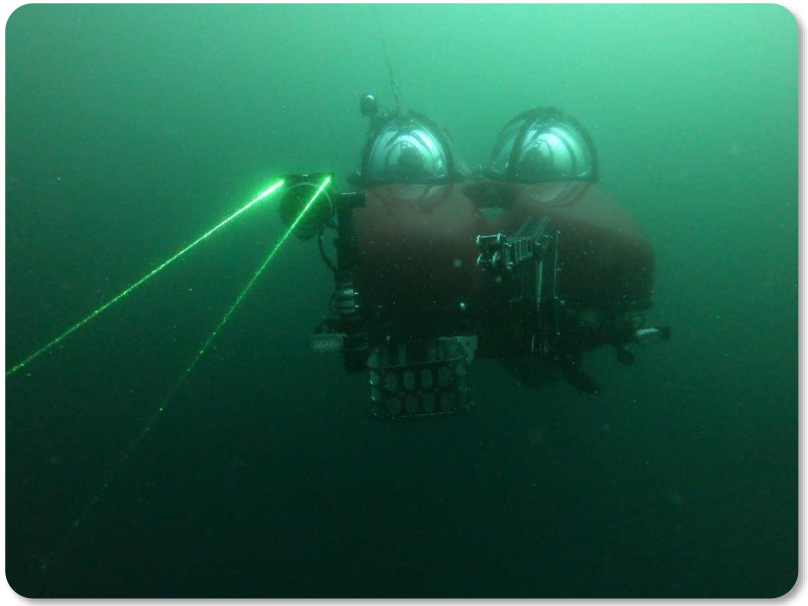
- DDW can be used for longer traverses with science context observation tasks
- Need to get closer to rocks for science
    - DDW doesn't allow crew to get up close
    - Could get closer in Exosuit
- Real-time video was valuable for MCC and Science Team
- Requires umbilical in order to transmit data back and forth
- Tethered operations were more valuable and relevant than untethered

Recommendations

- Use the DDW as a platform for evaluating rover operations that are focused on science contextual observation tasks
- Utilize data tether in order to transmit data back and forth between DDW and MCC, much like would be in actual spaceflight

Lunar 2024 Relevance

- Not directly relevant to Artemis 3 mission (2024)
- Relevant to Artemis Phase 2
- Enables examination of utilizing a rover for science observations on subsequent Artemis missions



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Objectives Completion Status: Utilization of Dual DeepWorker for xEVA

Determine the applicability of utilizing a Dual DeepWorker for xEVA evaluations, including xEVA Informatics and xEVA Con Ops		
Completed	**Partially Completed**	**Not Completed**
	Determine the applicability of utilizing a Dual DeepWorker for Exploration EVA evaluations, including xEVA Informatics and xEVA Concepts of Operations [#17]	
		Assess the relevancy of utilizing a Dual DeepWorker as an “EVA platform” (i.e., as an analog EV crewmember and as an EVA support asset) [#18]
Understand the relevancy of using a Dual DeepWorker for lunar surface operations, including science tasks [#19]		
	Determine the feasibility of training Dual DeepWorker pilots, FEs, and Observers in the field such that they can provide valuable evaluations for EVA before the end of the mission [#20]	
	Determine the optimal sortie length, number, rotations, and positions [#21]	
Understand the value of the Dual DeepWorker Flight Engineer position for Exploration EVA [#22]		
		Understand the value of the Dual DeepWorker Observer position for Exploration EVA [#23]

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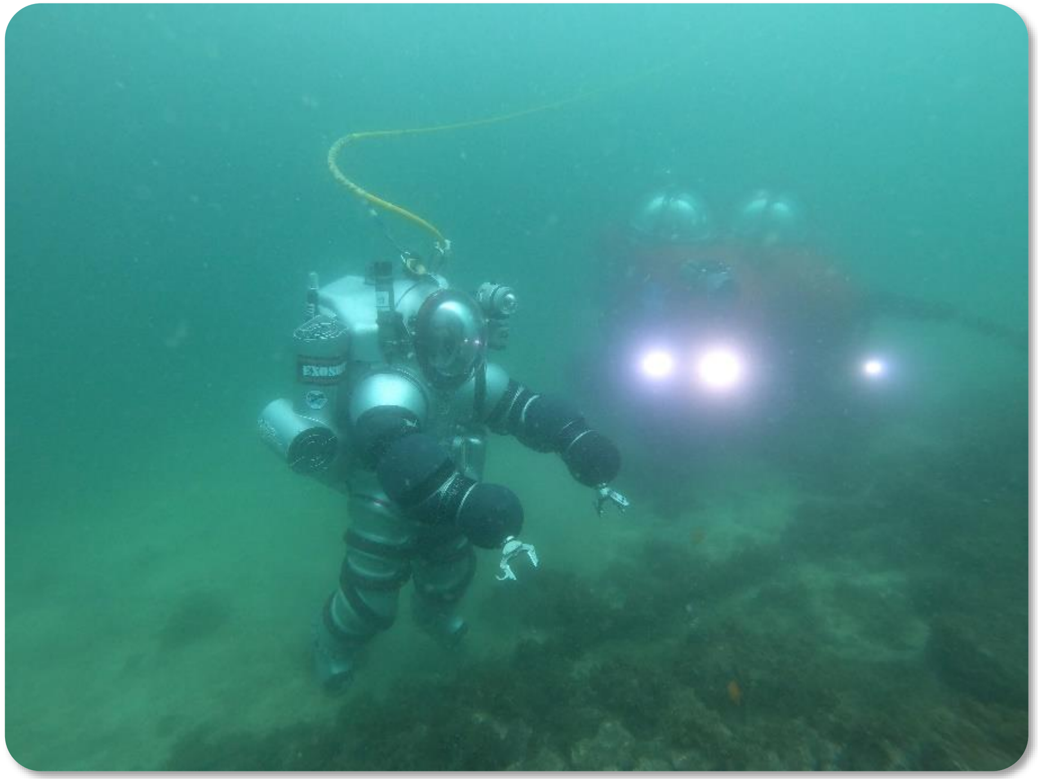
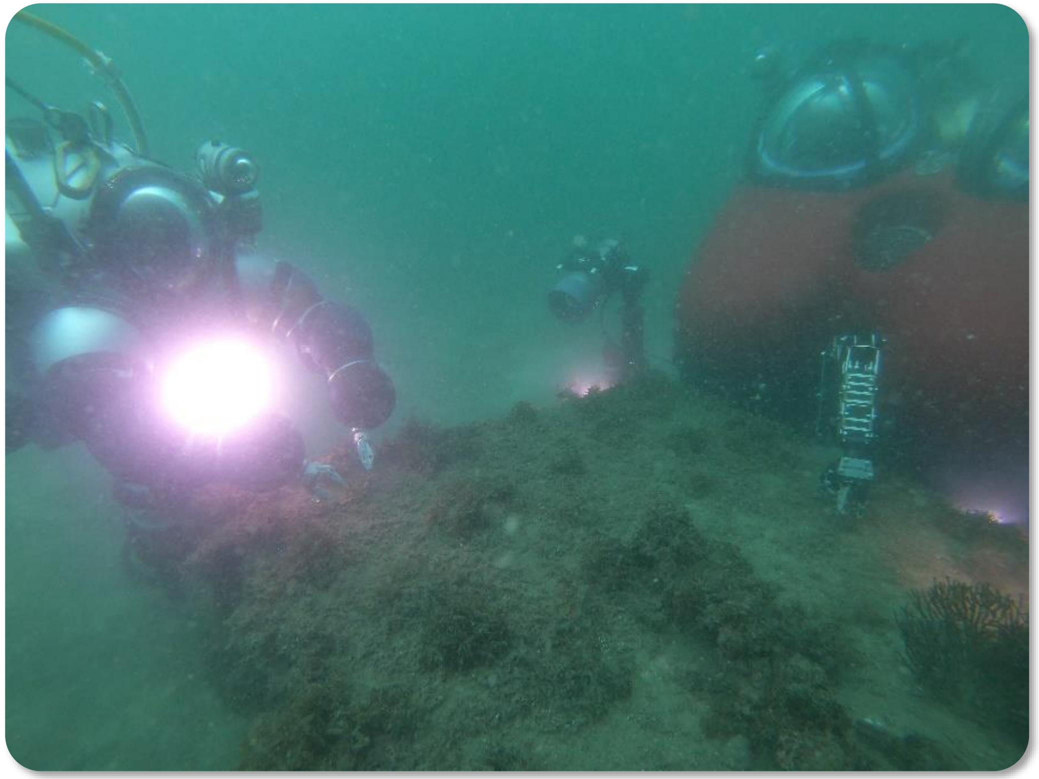
Objectives Completion Status: Operating Exosuit and Dual DeepWorker Together

Understand whether the Exosuit and Dual DeepWorker can reasonably operate together for dual EV tasks		
Completed	Partially Completed	Not Completed
		Understand whether the Exosuit and Dual DeepWorker can reasonably operate together for dual EV tasks, and the relevance of that mode of operations [#24]





Exploration Capability at NXT

- “Sub [DDW] was better [than Exosuit] because of its "unlimited" range [due to Exosuit being restricted to the USC cove]”
- “It felt real…to be out there [in the DDW]…actively looking for things and discovering the landscape as we went”
- “Staying in the cove made the suit less of an asset, in strict terms of exploration”

Con Ops Development at NXT

- “It's too easy with just the sub”
- “Interaction, relative navigation of the two assets, challenging com setups when both were interacting was the interesting ops”
- “Need two heterogeneous assets to make progress ”

Crew Training at NXT

- “The sub is just too easy”
- “The suit, on the other hand, is challenging at the beginning”

Potential mission with DeepWorker but w/o an Exosuit

- “It’s still valuable, but less”
- “DeepWorker is too comfortable and relaxing”
- “Exo is not like EMU we have in space but it gives physical discomfort and mental/psychological challenge to manage the life support systems, requires attention/focus which is similar to the space walk”
- “Winning ticket is really a combination of both [Exosuit and DDW], especially seen from the control center / operations point of view”

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Objective

- Evaluate EVA science sampling tools during land-based geology tasks

Mission Implementation & Summary

- The crew were briefed on the tool set and EC7s plan for developing Artemis geology tools in FY20
- Crew evaluated each tool in geologically interesting areas

Crew Debrief Comments (a few examples)

- Consider smaller rake head
- Add a feature to the tongs that allow them to remain locked in open position
- Consider adding a stop to the hammer to prevent it from being flung out of hands, or ridges that match profile of fingers like a steering wheel

Results (Key Take-Aways)

- Great feedback was received and recorded

Recommendations

- Continue bringing EVA tool prototypes to analogs to get crew evaluations

Lunar 2024 Relevance

- The crew feedback received on these tools will be taken into consideration during development of tools for 2024

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Evaluate EVA science sampling tools during land-based geology tasks		
Completed	Partially Completed	Not Completed
Evaluate EVA science sampling tools during land-based geology tasks [#35]		

Determine if it's possible for the Exosuit to evaluate any EVA tools		
Completed	Partially Completed	Not Completed
		Determine if it's possible for the Exosuit to evaluate any EVA tools [#34]

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Exploration Science Training

Objective

- Conduct terrestrial Exploration-relevant geology training
- Tie terrestrial geology ('turf') to subsea geology ('surf')

Mission Implementation & Summary

- A local geology expert and XI planetary scientists conducted geology field training with crewmembers on foot and by vehicle (island-wide)
- Crew used small boats and kayaks to observe geology near sea-air boundary not accessible by foot

Crew Debrief Comments

- Moon geology doesn't look anything like this geology
- 1 week of geology before coming here – need basics before getting here
- Just do 1 geology day here on island

Results (Key Take-Aways)

- Complex geology enabled science observational skills and general field skills
- The crew's geologic expertise ranged from minimal to PhD; need to account for skill diversity and provide additional procedural based-approach to geologic tasks (observations and sampling) that transfer to sub-sea tasks

Recommendations

- If returning to Catalina, use complex geology to continue to train general field geology and science ops skills
- Potential for additional NXT locations with better representative surf-turf geology (ex. Hawaii)

Lunar 2024 Relevance

- Geological training/ops in complex geological areas is relevant to all lunar surface missions

Utilizing Topside Capabilities (MCC & IV) for xEVA Evaluations

Objective

- Assess the topside/shore capabilities and positions for enabling EVA objective evaluations

Mission Implementation & Summary

- Used Nuytco workstation as a partial IV workstation
- Partial MCC set up away from dock

Crew Debrief Comments

- MCC
    - Need mission direction to be provided from MCC – too many people on dock and decisions made on dock
- Communication
    - Everybody with a hot mic on the same loop is not realistic (topside, support, boats, mission, etc.)
    - For MCC, want to have ability to select comm loops, like we do now
    - Must have consistent comm and data exchange between the crew and MCC [i.e., DeepWorker needs fiber optic connection]
    - Once assets are deployed everyone should be up in MCC on same mission loop talking with each other
- Navigation
    - Nav was intermittent in MCC (at times)

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Results (Key Take-Aways)

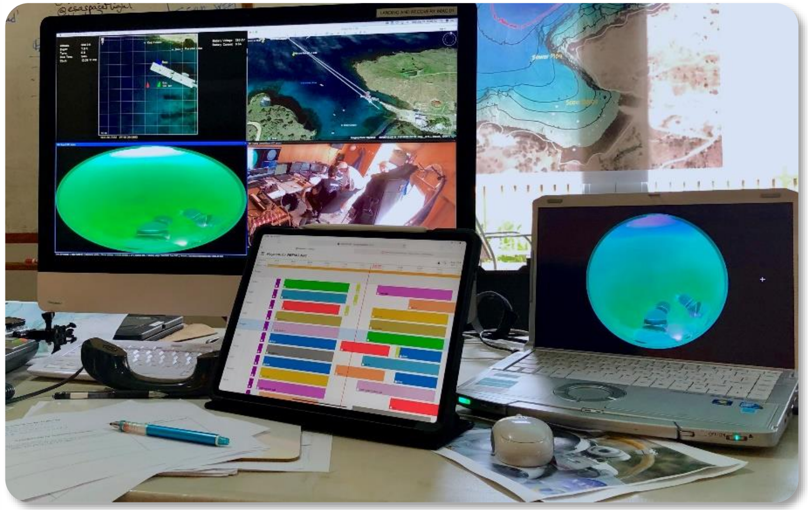
- MCC
  - Configuration in USC's Boone house worked for an MCC
  - Capabilities of pushing data to the assets needs to be enabled in MCC
- Communication
  - Communications, video, tracking, navigation and data channels were demonstrated
  - Lessons learned for further work to tie all of them into the integrated operations scenarios
  - Communications between MCC and the assets where noisy and not completely reliable throughout the mission
  - Communication between assets was not always solid or reliable – areas for future improvement noted
- Navigation
  - Navigation was intermittent at beginning, but improved as mission progressed – needs to be reliable to enable exploration con ops

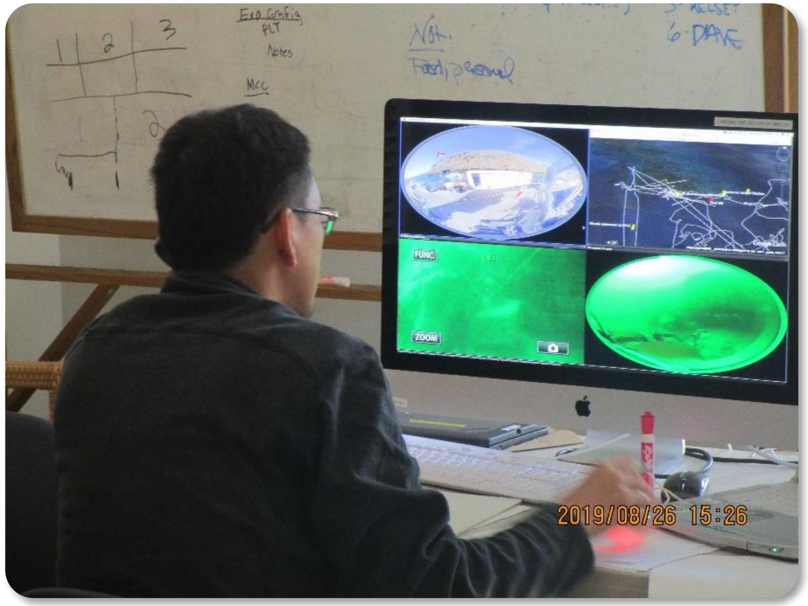
Recommendations

- Evaluate full MCC leading mission
- Ensure comms are reliable to and between assets
- Configure MCC to be able to push data to the assets
- Use DeepWorker in fiber optic tethered configuration in order to transmit data back and forth
- Conduct an engineering run with core team to ensure everything functions properly

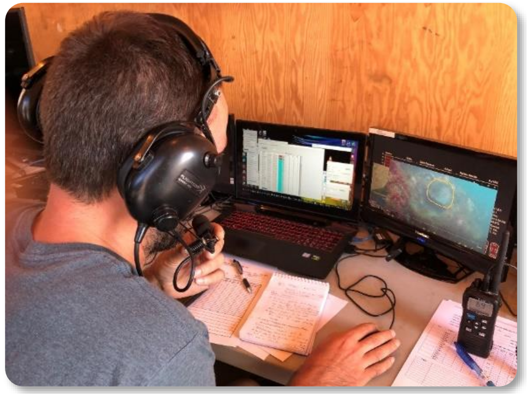
Lunar 2024 Relevance

- MCC and comm capabilities are relevant to Artemis 3 (2024) and subsequent missions
- Navigation will be needed on later, longer missions





Assess the topside/shore capabilities and positions for enabling EVA objective evaluations		
Completed	Partially Completed	Not Completed
	Assess the topside/shore capabilities and positions for enabling EVA objective evaluations [#25]	



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Location (Catalina and USC) Lessons Learned & Recommendations

- Infrastructure at USC-Wrigley Marine Science Center is well-suited for enabling this type of operation, and deployment effort is reasonable (e.g., travel, logistics, etc.), though there are challenges with the isolation of the facility (access, transportation, lack of hardware store, lack of general store, etc.)
- Crew debrief comments:
  - Take general path, which is great here, but geology is not what will find on moon – if want a moon analog, take it to Hawaii
  - Good for general training, not specific for moon
- Visibility was not good near USC cove
- Not able to operate Exosuit beyond USC cove area where water is clearer and deeper due to constraints on anchoring a boat/barge
  - Not going to be able to get the Exosuit to "exploration" quality terrain w/o a ship
  - Ship must be anchored to deploy the Exosuit
  - Areas scouted with exceptionally high quality sites, such as Sea Fan Grotto, are in a protected zone where anchoring is not permitted
- Not able to have the Exosuit and DeepWorker work together, which was a major component of the model

Summary and Recommendations

Summary of Results for Subsea Assets

Exosuit Atmospheric Diving System/Suit (ADS)

- Exosuit provides a reasonable platform for xEVA informatics development and testing
- Using a HUD (e.g., Lumus DK-52) in the Exosuit worked well
- Exosuit is similar to EVA in a lot of ways, however suit mobility and pinchers (lack of fingers) are not equivalent to an Exploration Spacesuit (e.g., xEMU)
    - If looking at 2024, need to find a way around that limitation
    - Incorporate pre-hensors (fingers) when those become available (currently in development by Nuytco and NAVSEA)
    - Utilize the form-fitting Lightweight 1ATA Dive Suit (LADS) being developed by Nuytco and NAVSEA when/if it is completed
- Viable for supporting aspects of training for lunar surface EVAs
    - Value of Exosuit, focus and compartmentalization, a lot effort to be task loaded – good skill for operators to have
    - Per experienced astronauts, “If you target crew training as part of the objectives, you need the suit”
    - Need to operate Exosuit in exploration quality terrain (beyond USC cove in areas where water is clearer and deeper)

Dual DeepWorker Submersible

- Was valuable as a platform for evaluating rover operations that are focused on science contextual observation tasks
    - Useful for exploration capability development
    - Can be used for some training of observational science operations
    - Good for exploration traverses, but is too easy to pilot for some aspects of crew training
- Was not able to get close enough to the rocks for detailed geological descriptions
- Tethered operations were more valuable and relevant than untethered – allows for real-time video and data exchange with MCC and Science Team
- Doesn’t really drive on the bottom and it doesn’t add any extra value to have wheels (which may have been an artifact of the weigh-out), though ops should be on bottom to replicate rover on lunar surface

Summary of Results for EVA Equipment and Geology Training

xEVA Informatics (Lumus DK-52)

- Lumus DK-52 worked well for xEVA testing
- DK-52 system worked well in the Exosuit, but not as well in the DeepWorker, primarily due to fit/comfort issues ("Lumus glasses were great for suit, not so much for sub ")
- EVA-experienced astronauts stated that a HUD would be a useful EVA capability for lunar surface missions
- Lumus not a good setup for the Flight Engineer (tablet/iPad worked better)

Lunar Geology Tools

- Baseline lunar geology tools worked well
- Operator feedback received from astronauts is driving changes to tools for Artemis

Geology Training

- Allowed for training of science operations and general geology field skills
- Geological processes in Catalina were not similar to the moon
- Complex geology enabled development of science observational skills

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Summary of Results for NXT FaM and Mission Location (Catalina)

NXT FaM (general)

- Demonstrated feasibility of conducting a mission analog utilizing subsea vehicles
- Provided initial look at a HUD system for xEVA informatics capability development
- Need to train people about risks during ops [with Exosuit and DDW flying in proximity]
- Difficult for Nuytco team to run simultaneous operations while attempting to troubleshoot various systems on two different assets

Catalina Island (USC)

- Subsea and terrestrial geology exists to potentially provide meaningful exploration scenarios
  - However, the geology in Catalina is not directly relevant to the lunar surface
- Communications, video, tracking, navigation and data channels were demonstrated
  - However, further work is needed to tie all of them into a reliable integrated operations scenario
- Infrastructure at USC-Wrigley Marine Science Center enabled operations, and deployment effort is reasonable
  - There are challenges with the isolation of the facility (access, transportation, lack of hardware store, lack of general store, etc.)
- Underwater visibility was poor near USC cove
  - Not able to operate Exosuit beyond USC cove in exploration quality terrain (areas where water is clearer and deeper) due to constraints on anchoring a boat/barge that would be required for Exosuit deployment

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Findings for NXT Concept

NXT Concept

- Allows for exploration analog missions that trains crew on complex terrestrial geology ('turf') and then extends that experience into exploration techniques into a subsea operationally challenging environment ('surf')
- Enables development of Exploration capabilities and con ops
- Provides generic exploration training and expeditionary skills
- Operations run per sortie (i.e., part task), not a continuous immersed mission over several days (as in a spaceflight)
- Concept "not so valuable for 2024 mission", however could help develop "the 4-T's for missions later than 2024"
- Assets provide mentally taxing operational challenges
  - Exosuit operations enabled evaluation of xEVA informatics display concept
  - DeepWorker operations allowed for science observations on longer traverses, similar to a rover, but was almost too easy to fly
- Exploration Capability Development
  - Exosuit was critical for technology development, such as an EVA HUD
  - DeepWorker enabled longer traverses and development of science ops
- Exploration Con Ops Development
  - For crew, interaction of an Exosuit and DeepWorker would be the critical aspect
- Exploration Crew Training
  - Per the crew, the Exosuit was the critical component for training (physically and mentally challenging)
- Value for NASA
  - For READy, allows for mission to evaluate sorties and specific techniques and technologies
  - For EVA, provides an intense operational environment to examine use of informatics
  - For ARES, provides an environment with complex geology to further train crew on field geology and science operations
  - Need to understand cost of mission as compared to other analogs in order to asses the "bang for the buck"

Relevance of NXT to Artemis

Relevance to Artemis Lunar Surface Missions

- NXT does not directly address the Artemis 3 (2024) mission, but may be useful for developing and training general lunar operations and crew training experience (applicable to Artemis Phase 2 concepts)
  - Suit not representative of xEMU in terms of mobility (walking) and hands (lack of fingers)
  - DeepWorker mimics a pressurized rover, which will not be on first mission(s), but is planned for Phase 2
- Training crew to conduct scientific observations while wearing a restrictive suit is relevant to all lunar surface missions
  - Exosuit provides physical and mental challenges similar to a spacesuit
  - Enables operator skill training in focus and compartmentalization
  - Limitations (hands especially) need to be mitigated if developing con ops for a 2024 mission
- Training crew to conduct scientific observations while flying a submersible is relevant to all lunar surface missions that have a rover
  - Dual DeepWorker allows for crew to perform detailed geological observations while simultaneously maneuvering in an extreme environment and maintaining life support systems
- Development of xEVA informatics is relevant to lunar surface missions subsequent to the initial Artemis 3 mission

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NXT Concept

- Change emphasis of NXT to focus missions towards crew experience, early general exploration training, and generic science observation skills
- For Exploration Capability Development:
  - Utilize the Exosuit for xEVA informatics evaluations (HUD display, information density, layout, etc.)
  - Utilize the DeepWorker for assessing rover-based science operations on longer traverses, incorporating the fiber optic tether in order to transmit data back and forth between DDW and MCC to be more spaceflight relevant
- For Exploration Con Ops Development
  - Utilize the Exosuit for examining data transfer to/from EVA crew, and evaluate information density and layout
  - Evaluate the interaction between an Exosuit and DeepWorker during dual asset operations
- For Exploration Crew Training
  - Utilize the Exosuit as a complex asset that provides both physical and mental challenges, and incorporate geology contextual observations
  - Use the DeepWorker for additional crew experience in cockpit resource management
- Schedule an engineering run prior to the mission for core team evaluations and to ensure assets are functioning as needed, and set up reliable com and data transfer between the assets and MCC

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Recommendations for NXT and Potential Future Missions

Mission Operations

- Staff a ‘full’ MCC that leads the missions
- Incorporation a Science Team to make tactical and strategic decisions
- Conduct dual ops with both the Exosuit and DDW
- Reduce the number of daily sorties and make them longer

Location

- Scout locations more geological features more relevant to lunar surface operations
- Operate Exosuit in clearer water near more relevant geology (i.e., out of USC cove)

Fiscal Year 2020

- Capability was demonstrated at the Feasibility Mission, but resources and team bandwidth should be focused on testing that is directly relevant to Artemis 3 (2024)
- If the READy MMT/core team unanimously determines that the best use of resources is to run an NXT mission in FY20, then:
  - EVA (XX): Support during engineering run and mission as EVA SMEs, integrate any EVA objective with the assets, and participate as asset pilots and support divers (including as NEEMO Dive Safety Board member)
  - ARES (XI): Support during engineering run and mission as Science SMEs, conduct surface geology portion of mission, participate as asset pilots and support divers
  - EVA Tools (EC7): Support during engineering run and mission, and participate as asset pilots and support divers

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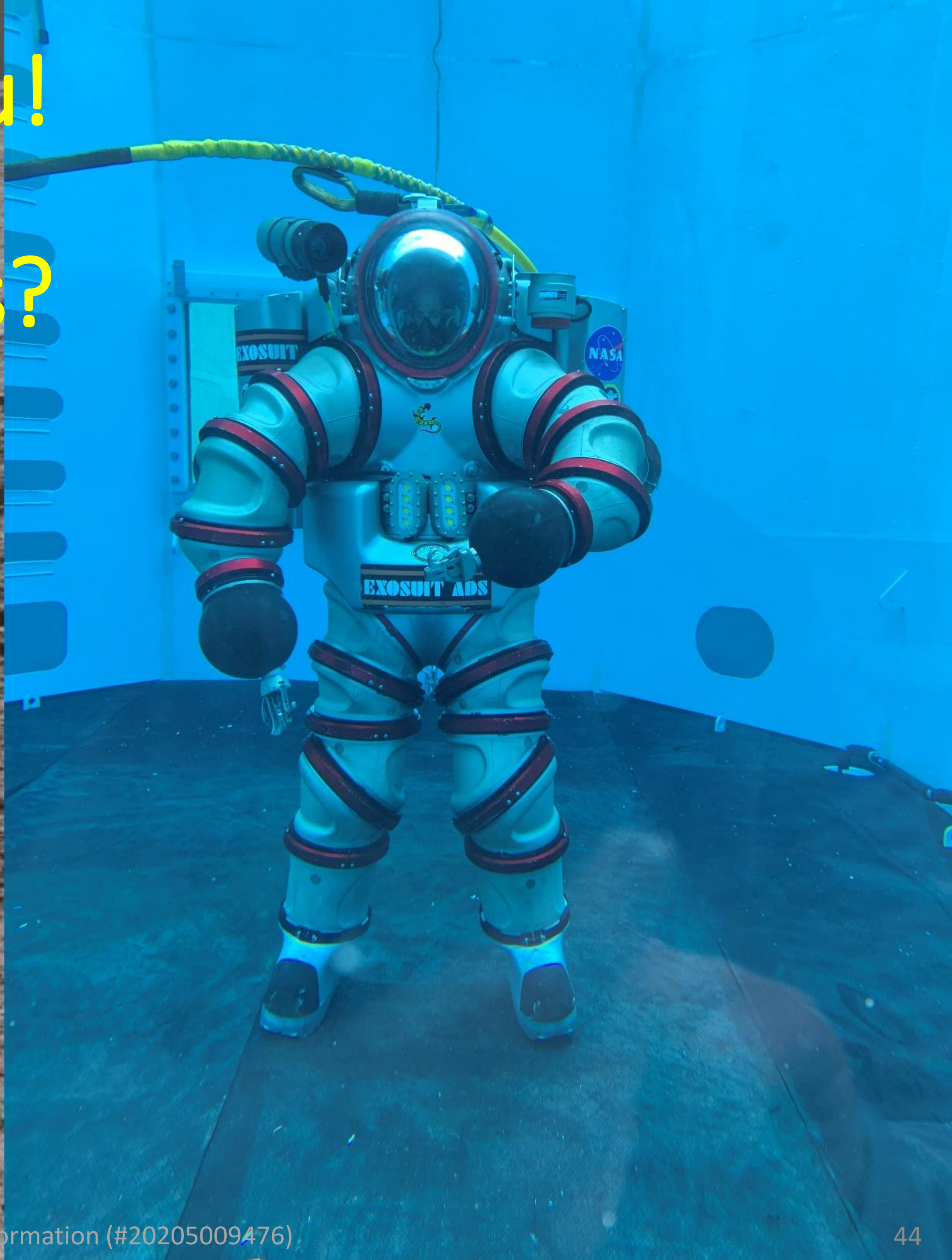
Thank you!

Questions?



- **Additional NXT FaM Lessons Learned**
  - **NXT Concept Lessons Learned & Recommendations (Astronaut Comments)**
  - **NXT Concept Lessons Learned & Recommendations (Team Comments)**
  - **Dive Support and Imagery Lessons Learned & Recommendations**
  - **Mission Plan/Timeline Lessons Learned & Recommendations**
- **NXT FaM at EEWG on 22 July 2019**

Additional NXT FaM Lessons Learned

NXT Concept Lessons Learned & Recommendations (Astronaut Comments)

- Valuable for development, but concern about how it relates to 2024
- NXT gives a place to look at generic exploration concepts (different kind of ops concept than ISS) – new tactics on how to plan missions and push data
- Need to develop skills and technologies for exploration
- Data exchanges between science room and operators
- Can't develop geology tools here, because don't have a realistic suit here
- Would be great to be able to pick up geology tools and do sampling underwater
- Tools: HUD, data, comm links between assets, sharing of info between assets, manipulator on rover, more about exploration concepts for data push/exchange
- Only 2-3 NXT missions before 2024, so maybe not so valuable for 2024 (a bit late for 2024)
- The 4-T's for missions later than 2024
- Utilization of Exosuit
  - Exosuit similar to EVA in a lot of ways, but not in hands
    - If looking at 2024, need to find a way around that limitation
    - Can barely hand between assets, and no way to use tools or scanners
    - Would be great to be able to pick up geology tools and do sampling underwater
    - Biggest limitation of entire analog
  - Flying instead of walking in Exosuit is not as bothersome from astronaut perspective, it's the hands
  - If able to pick up tools (like what EC7 made) it would be so much better
  - Exosuit lends more to general crew training than evaluating or training tools and techniques
  - Could spend ~2 hours in suit – need to learn how to take breaks
  - Need to be able to conduct science operations with Exosuit
  - Need to get assets together, though now worried about proximity – potential of impacting is more realistic and good, but adds to risk (liability)
  - Exosuit good for general training, not realistic training
- Hard hat diving system would be helpful
- 3-4 runs in water to get to point of enough training to do exploration tasks
- Crew rotated through roles, but should have specific dedicated roles (as in an actual mission)
- Could see more in depth geology training before coming to NXT. You learn theory and then come here to learn specifics. Requires several days/week of geology
- For the Exosuit, could be susceptible to injury (e.g., shoulder) – risk of limb injury, would be good idea to train people about risks during ops (different from EMU)
- Dock master is doing mission director and cove coordinator – need to separate the two
- Support team needs to have assigned roles
- ESA comments are important for any NXT mission
- Exploration Capability:
  - Sub [DDW] was better [than Exosuit] because of its "unlimited" range [due to Exosuit being restricted to cove]
- Con Ops Development:
  - It's too easy with just the sub
  - Interaction, relative navigation of the two assets, challenging com setups when both were interacting was the interesting ops
  - Need two heterogeneous assets to make progress
- Crew Training:
  - The sub is just too easy
  - The suit, on the other hand, is challenging at the beginning
  - If you target crew training as part of the objectives, you need the suit – should find a way to increase its range for exploration purposes
- Potential mission with DeepWorker but without an Exosuit
  - It's still valuable but less
  - DeepWorker is too comfortable and relaxing
  - Exo is not like EMU we have in space but it gives physical discomfort and mental/psychological challenge to manage the life support systems, requires attention/focus which is similar to the space walk

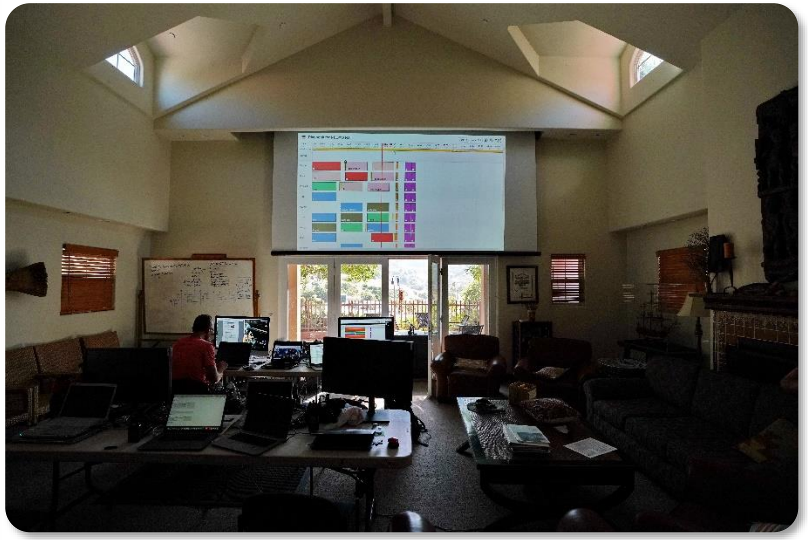
NXT Concept Lessons Learned & Recommendations (Team Comments)

- ESA
  - NXT will not be able to prepare for 2024, but useful to prepare for a sustainable set of operations on the Moon in the next decade
    - Should not focus on 2024
    - Geology in Catalina not relevant ("this isn't the moon")
    - Not representative suit
    - Should focus on crew training experience
  - Need mission that enables scientists to be in MCC and support crew like they would in realistic mission
  - Geology part should be more focused and intensified
    - Should go somewhere that we know something is there, not try to make it work based on what's around
    - Only did description, missing other pieces of geology puzzle
    - Need to go all the way with geology story – observation, exploration, sampling, review of sample
    - Need more training on geology
  - Keep assets as is – fly, not drive, the DDW
  - Crew needs to be out in assets on excursions, and engineers and scientists need to be in MCC
  - Need to have mission management in MCC at all times
    - Need to protect position in schedule
    - Schedules deviated after morning meeting, roles changes, with no coordination amongst team
  - Recommendation for potential future NXT missions:
    - Run as geology operational training for astronauts in a complex geological environment with geologists support in MCC
    - Add in significant geology training (classroom, rocks, field trips and traverses with sample collection) to give crew the geological awareness for understanding the environment with scientist support
    - Keep the assets as they are to optimize their use and benefit from their space vehicle like complexity, safety management, and operation in an hostile environment
    - Use the DeepWorker as the sample collector (robotic ops) and the Exosuit as a vehicle to recover the samples from the sub basket to bring them back into pre-assigned separated sample containers
    - Set up reliable com and data transfer between the assets and MCC
    - Have a sustainable team of geologist in MCC to support the crew every day
    - Ensure clear exploration objectives underwater for relevant and interesting sites based on previous scouting on surface on boat with the crew and even underwater with rovers, making crew aware about what is above the surface in order to assume what could be underwater
    - Later NXT missions can be used as a platform to test new technologies and ops tools to "immerge more" the scientist at MCC into the crew environment and to better bring the scientist in MCC virtually closer to the crew
    - Schedule an engineering week one week before NXT to let the core team test the assets and comms and scout the sites
    - Once the mission starts, only the crew should get into the assets for the mission duration (except for first sun training runs with an experienced copilot)
      - NASA core team should recertify on the assets and/or explore before crew arrival
      - For the crew, only 1 day in MCC is required for ops awareness
      - Crew should be the only explorer team underwater
- Nuytco
  - Difficulty for Nuytco team to run simultaneous operations while attempting to troubleshoot various systems on two different assets
    - Playbook view in the Nuytco trailer for real-time tracking helped with the pace
    - NASA personnel were trained to help with simple Exosuit tasks
  - Recommendation: Provide a forum in which the Nuytco team and NASA team can provide realistic daily schedules based on repairs, adjustments and changes to the next day's timeline
- Need to analyze the metrics and correlate them to objectives
- NXT is not a one-for-one replacement for NEEMO (Aquarius)

- Dive Support
  - Review dive plan and roles for the mission with NEEMO Dive Safety Board before the mission.
  - Conduct a detailed dive team briefing on or before MD 01.
  - Brief roles and responsibilities of Dive Supervisor with dive team before start of diving operations.
  - Conduct a detailed dive briefing with the chase boat and dive boat crew before each excursion.
  - Furnish each diver with safety sausages, lights, and compasses.
  - Provide all of the appropriate and properly sized equipment for divers (e.g., gloves) or make sure divers bring their personal gear.
  - Ensure each diver is comfortable with open water diving where there are no references.
  - Ensure divers are comfortable in low visibility conditions and have adequate skill with a compass.
  - Ensure divers are comfortable with deep and cold dives when called upon to conduct those.
  - Train dive team on use of a compass and underwater navigation
  - Train dive team on live boat operations
- Imagery
  - Topside imagery was great!
  - Underwater imagery turned out good – need to plan around that many of those are taken in deeper colder water

Mission Plan/Timeline Lessons Learned & Recommendations

- No mission plan or timeline was sent to the operators before the mission.
- Timeline evolved day-by-day, with crew sometimes not knowing their role until the morning.
- Ensure the mission timeline is focused on the NASA objectives.
  - Review preliminary plan/timeline with the team before the mission.
  - Review the detailed timeline with the crew at the evening big team meeting (or before).
- Core team meetings
  - Continue with the practice of a daily core team meeting, and have that meeting timelined in Playbook.
  - Include key personnel in the core team meetings – MMT, EVA, EVA Tools, Playbook, Science



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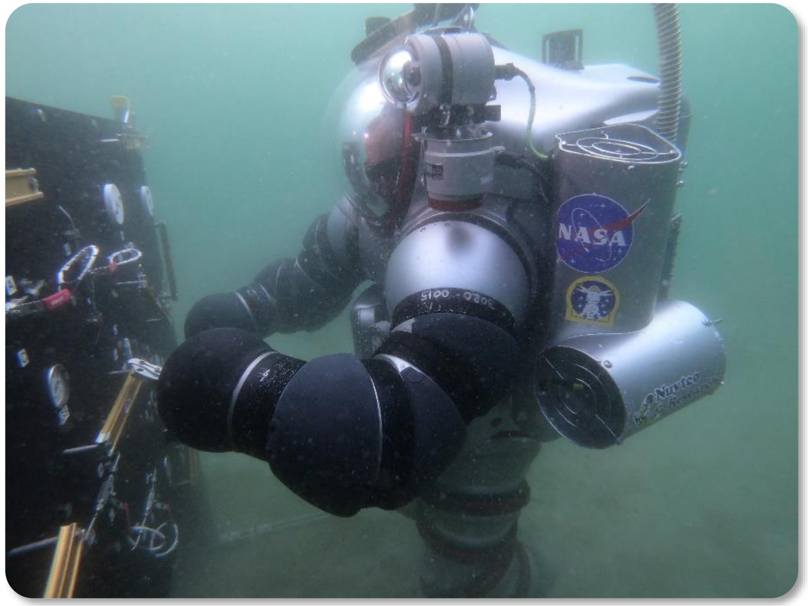
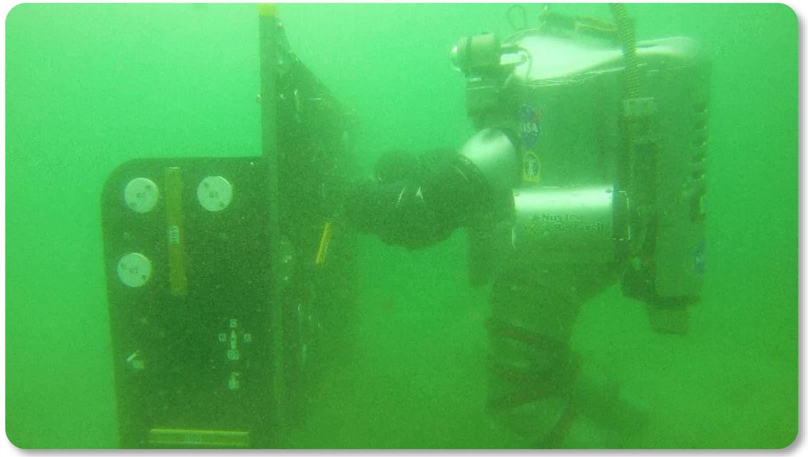
- Multiple locations within the Exosuit cause discomfort or bruising after prolonged use.
  - Problem: Reported from multiple users, various locations within the Exosuit caused bruises or soreness including: elbows, knees, forearms, bridge of the nose.
  - Recommendation: Going forward supplying knee pads, elbow pads, forearm sweat bands, gloves and pads for the nose. These items should be added to a XX/CX pre-dive checklist for future use.





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NXT FaM at EEWG on 22 July 2019

Additional backup slides from the pre-mission briefing at the EEWG

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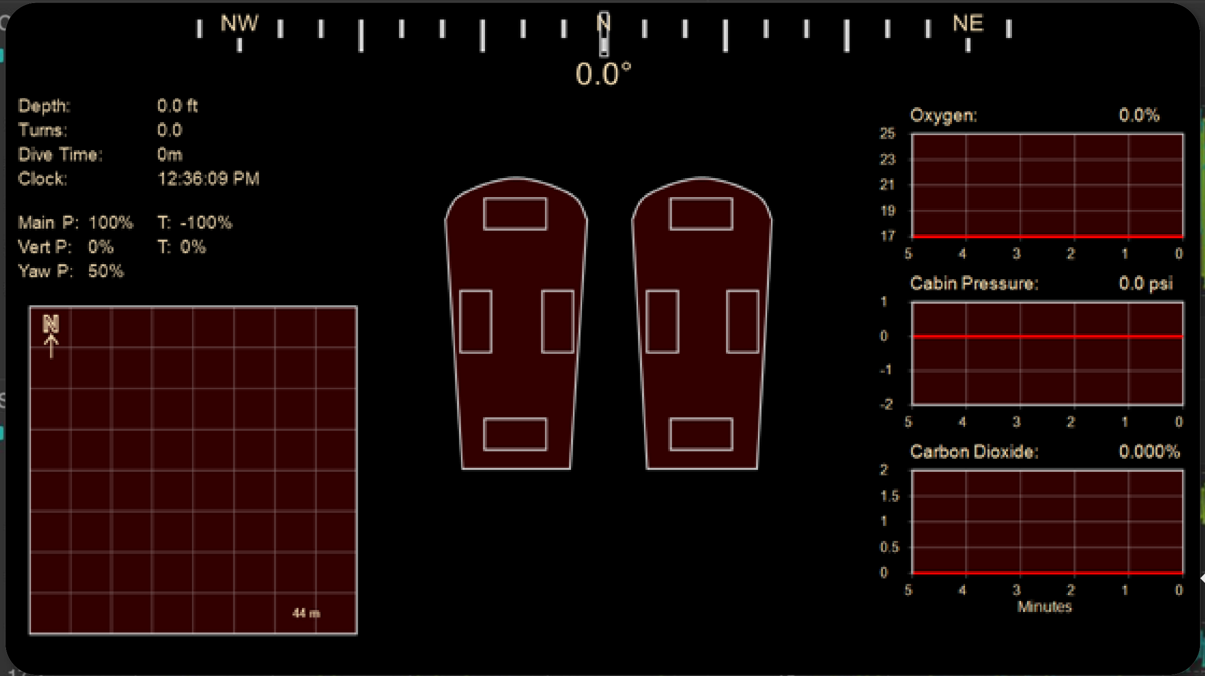
xEVA HUD

- Utilizing Lumus DK-52 displays as an xEVA HUD capability evaluation platform
- Objectives include evaluating xEVA con ops for incorporating an informatics HUD capability for suit data, pioneering tasks, and science tasks
- DK-52 provides the basis/backbone for the Navy's DAVD system, which was tested in cooperation with the EVA Office during NEEMO 23
- One NASA/EVA-owned unit is currently at JSC for evaluation and one is at Nuytco for integration and testing with the Exosuit



Nuytco confirmed with XX/EVA that Lumus glasses and telemetry are working well in Exosuit

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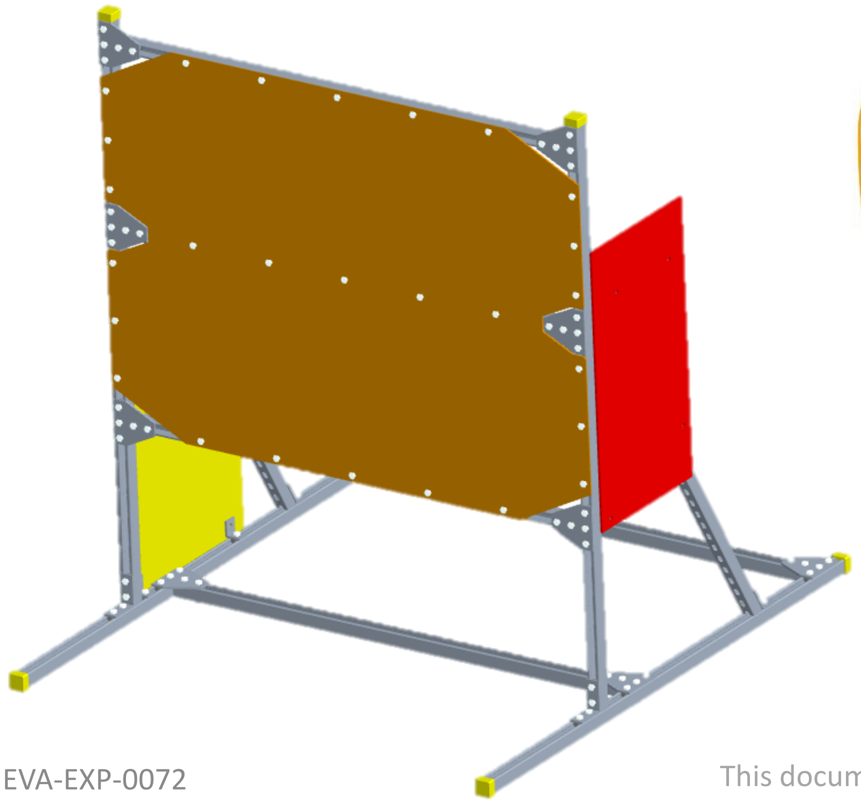
xEVA Underwater Task Board

EVA task board designed to be used in various aquatic analogs, such as the NBL, NEEMO, and NXT

Will be used at NXT for Exosuit training and xEVA HUD evaluations

Design and build led by EC7/EVA Tools

EC7/Naids, XX/Coan, and XI/Graff will have responsibility of board during deployment



EC7 Preliminary Design Overview

- The goal of this project was to provide a challenging task in which the use of a heads-up display would be valuable.
- This board is being designed to be utilized in the NBL and at NEEMO NXT.
- It is a pressure system that will be powered by a SCUBA tank.
- The frame (pictured to the left) will have a series of challenges mounted to it for the test subject to work through. If they complete tasks successfully, “victory bubbles” will be released.
- These challenges involve configuring valves in a proper orientation and order, reading gauges to verify proper pressure readings, pressing foot pedals to actuate linear pistons, and the ability to be reconfigured to provide different flow paths and order of operations.
- It will be placed on a surface and weighed down with sand bags or weights for stability.
- It is being designed to be rugged to handle interactions with an Exosuit, surface supplied hard hat diver, or a spacesuit.

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National Aeronautics and Space Administration

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READy
Relevant Environments for Analysis & Development
Integration for Exploration
TOOLS TECHNIQUES TECHNOLOGIES TRAINING

READy: Relevant Environments for Analysis and Development

Integrated Operational Testing for Space Exploration

Project Status 11/8/18

Marc Reagan
David Coan
Bill Todd
Trevor Graff
Kelsey Young

1

NXT Proof of Concept Milestones for FY 18-19

FY 18

- ☑ November 28, 2017: Nuytco site visit and TIM {Vancouver, Canada} [XM, XX]
  - Basic premise is possible
  - Better understanding of asset capabilities and constraints (Exosuit and DeepWorker)
- ☑ September 2018: Site selection visits {Avalon, CA} [XM]
- ☑ September 2018: Hazard analysis with Nuytco {Vancouver, Canada} [XM]

FY 19

- ☑ September 2018: Brief XI and XM management on concept and get approval to proceed with feasibility assessment
  - Approved by both XI/ARES and XM/EMPO
- ☑ October 2018: Brief XX management on concept and get approval to proceed with feasibility assessment
- ☐ November 27-28, 2018: TIM with Navy to finalize an interagency agreement and start planning DAVD testing with Exosuit {JSC}
- ☐ January 20-25, 2019: Terrain scouting trip to assess potential site and plan feasibility mission {Avalon, CA}
- ☐ February, 2019: Funding mechanism in place
- ☐ March 21-31, 2019: Core team + CB feasibility assessment/trng at Nuytco and TIM to discuss feasibility mission {Vancouver, Canada}
- ☐ July 2019 (TBD): TIM with Nuytco and Navy to discuss integrating DAVD into the Exosuit for testing at NXT feasibility mission {TBD}
- ☐ August 19-30, 2019: NXT feasibility mission (w/ TBD IP Astronaut and external partner crew) {Avalon, CA}

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EXPLORATION INTEGRATION AND SCIENCE DIRECTORATE

XA MONTHLY ACTIVITY REPORT

March 2019

READY/NEEMMO

- The READy Team have focused on three main areas:
  - Resumption of mission planning and integration activities for NEEMO 23.
  - Development of the NEEMO NEXT concept.
  - Development of a concept for Exploration cross-training for the Directorate.
- The READy team has developed a proposal for Exploration Training. Management discussions need to be scheduled next.
- READy team members Todd and Reagan supported the Lockheed Gateway HAB ground engineering tests 2/27 and 28.
- The READy team is submitting a paper to the International Conference on Environmental Systems (ICES) this year, with inputs due 3/15.

UPCOMING EVENTS

3/2–9	IEEE Aerospace Conference, Big Sky, MT
3/5	NGIS NextSTEP BAA Prototype Draft Test Report Milestone Meeting
3/7	NGIS Prototype delivery to JSC Bldg 9N (weather permitting)
3/7	NGIS Guidance, Navigation & Control (GNC) Avionics SME Demo
3/18	NGIS Mockup Technical Readiness Review
3/18-3/22	50th Lunar & Planetary Science Conference
3/18-19	Bigelow Aerospace face-to-face
3/20-21	Sierra Nevada face-to-face
3/19	NASA Space Technology Research Fellowship proposals review
3/20	Mars Integration Group (MIG) Quarterly Review (HQ)
3/20-21	NASA/Sierra Nevada F2F
3/21 – 31	NEEMO Neoteric Exploration Technologies (NXT) Feasibility Assessment
3/25-29	Lockheed Martin Crew Test at KSC
3/25-26	NextSTEP BAA Boeing Final Architecture RAC-3 Milestone Meeting
3/26 – 28	Design Analysis Cycle 2 (DAC2) Kickoff
3/26-28	EMPT Performance TIM
3/26-28	Advanced Cislunar Surface Capabilities (ACSC) Phase 2 Kickoff (KSC)
3/27	Hermes Payload Delivery
3/28	NextSTEP Outbrief to Gateway

NEEMO NXT: Neoteric eXploration Technologies

- NEEMO NXT
  - Addresses the gaps of:
    - Representative planetary geology environment with unrestricted real estate to explore
    - Human/machine work systems
    - Restrictive EVA suit
  - Utilizes both terrestrial and subsea environments
  - Adds <u>exploration</u> ops training appropriate for ARES scientists and other select EISD personnel
  - Maintains astronaut end-user involvement
  - Furthers technology and capability development for exploration EVA
    - Tasks
    - Tools
    - Science
    - Robotics
    - Informatics
  - Proactively postures for possible loss of access to Aquarius in the not-too-distant future
  - Smaller operation than NEEMO, with a lighter footprint

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EVA & Science Ops READy Leadership

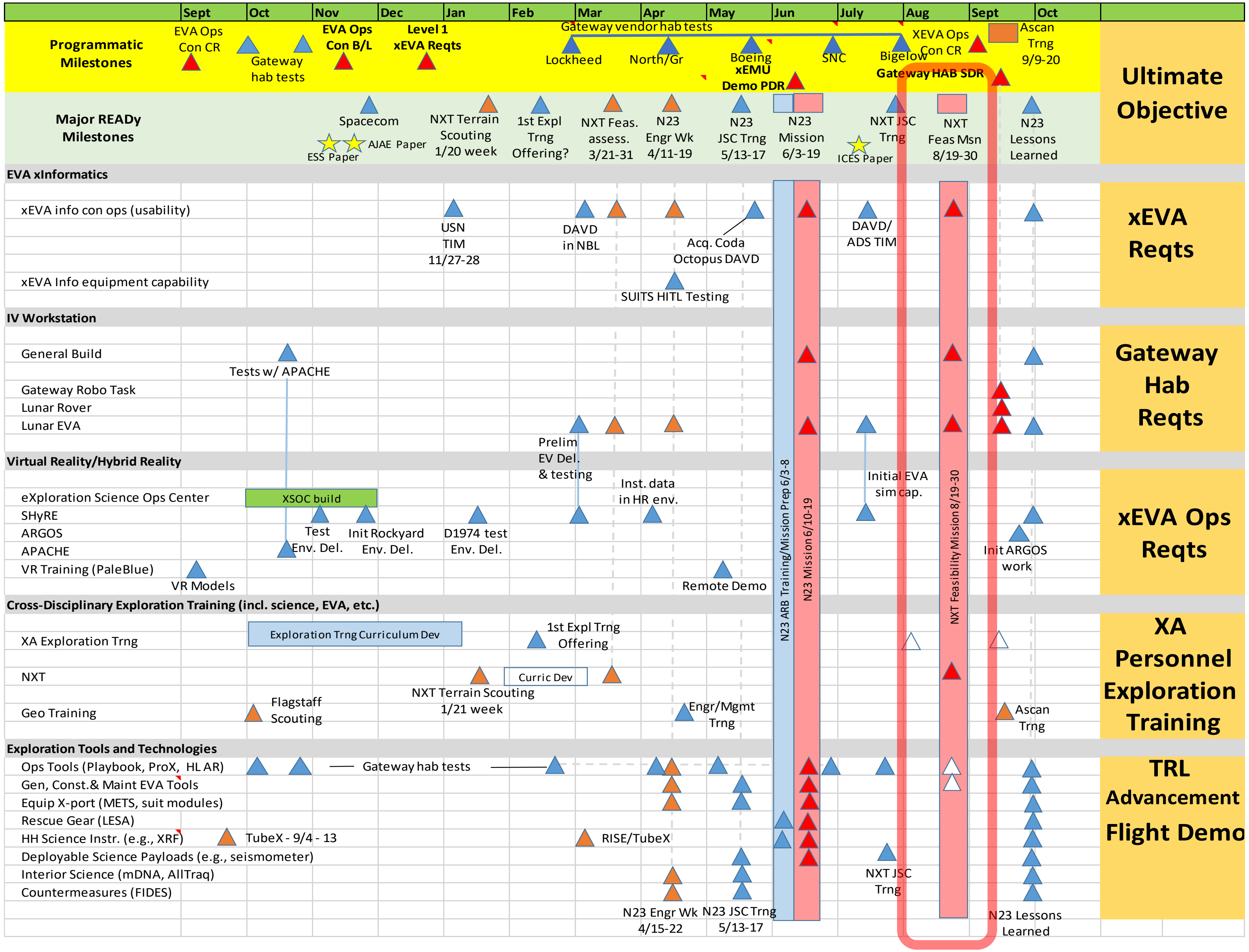
- David Coan (XX)
  EVA Lead
- Jordan Lindsey (XX)
  EVA Ops SME
- Trevor Graff (XI)
  Integration Lead
- Kelsey Young (XI)
  Science Lead

EVA Tools & Equipment

- Adam Naids (EC7)
  EVA Tools Lead
- Mary Walker (EC7)
  EVA Tools
- Holly Newton (EC7)
  EVA Tools Intern

EVA Partners & Collaborators (POCs)

- Jeff Heaton
  Nuytco Research Submersible Operations Manager
- Mark Arnott
  Nuytco Research Engineer
- Paul McMurtrie
  U.S. Navy Diving Equipment RDT&E Program Manager



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Quick Lessons Learned from NXT Feasibility Assessment & Training (FAT)

Dates and Location

- March 21 – 31, 2019
- Nuytco Research, Vancouver, Canada
  https://nuytco.com/

Exosuit Operator/Pilot Qual

- David Coan (XX)
- Trevor Graff (XI)
- Marc Reagan (XM)

DeepWorker Operator/Pilot Qual

- Bill Todd (XM)
- Kelsey Young (XI)
- David Coan (XX)
- Trevor Graff (XI)
- Marc Reagan (XM)

FAT Lessons Learned

- Exosuit
  - Fit seems similar to EMU
  - Arms are more challenging to move and position
  - Pinchers are more challenging than gloved hands
  - Constant flying is challenging, with inadvertent inputs
  - Skills required
    - Fine movement
    - Manipulating arms and tools
    - Combining movement and manipulation
  - Informatics
    - HoloLens won't fit
    - Lumus DK-52 (backbone of DAVD) likely candidate
  - Training
    - Build a step approach for skill level development
    - Design a task board – consist of levers, valves, and buttons with feedback to the crew, such as flowing air (valves) or lights (buttons)
  - Emergency procedures – put on cue cards and stow inside suit
  - Gouge
    - Memorize the gauges to help with reading close up
    - Utilize position hold
- Enough potential exists to evaluate NASA-relevant objectives to warranty attempting a feasibility mission (FaM)

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Draft NXT FaM Objectives

Concept Validation

- Evaluate deploying Nuytco assets
- Team and Crewmembers
  - Understand reasonable crew and topside roles
  - Understand reasonable capability expectations over 8 days of ops
    - Can crew get up to speed fast enough to provide valuable evaluations before the end of the mission?
    - Determine optimal sortie number and length
    - Determine DDW/Exosuit rotations
    - Determine optimal number of crew for future missions
    - Determine rotations through all rolls
    - Determine roles for partner crewmembers and partners who bring test objectives
- Understand comm solution for a full mission analog
- Understand how to integrate Playbook and tools teams
- Verify ops locations – which dive sites meet which objectives
- Develop ideas for appropriate task content for future missions
  - Training tasks
  - Surface geology tasks
  - Subsea geology tasks
  - Subsea pioneering/engineering tasks
- Determine practicality and roles for future DDW observers
- Obtain astronaut feedback on value as an exploration training
- Determine value of Catalina as a geologic training site
- Determine value and relevancy of Catalina to NASA-relevant objectives

Capability Objectives

- xEVA Informatics Heads-Up Display (HUD)
  - Lumus DK-52 objectives – verify the functional capability of the following:
    - Lumus in DDW with data pushed
    - Lumus in Exosuit with data pushed
- Science/Geology training
  - Surface-based
    - Curriculum development
    - Project development
  - Subsea-based
    - Curriculum development
    - Project development
  - Develop the tie between the surface and subsea components
- Tools & Equipment
  - Surface geology tool demo
  - Subsea geology tool demo
  - Pioneering/engineering tasks
- Collect participant feedback to drive mission design
- Demonstrate dual EV tasks – DDW and Exosuit working together simultaneously on a common task

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NXT FaM Operators / Evaluators

Exosuit Operators (Pilot in Command)

- Astronauts
  - **Drew Feustel** (NASA Astronaut)
  - **Norishige Kanai** (JAXA Astronaut)
- MMT
  - David Coan (XX/EVA Lead)
  - Trevor Graff (XI/Integration Lead)
  - Marc Reagan (XM/Mission Director)
- Backup Astronaut
  - **Thomas Pesquet** (ESA Astronaut)

Qualifications required for Observers are in work and still need concurrence by entire MMT
Observers must be relevant to NASA objectives
Likely need scuba qual and NASA test subject/diver physical (or equivalent, e.g. from ESA)
All Observers will be approved by entire MMT

DeepWorker Operators (Pilot in Command)

- Astronaut
  - **Thomas Pesquet** (ESA Astronaut)
- MMT
  - Bill Todd (XM/Project Specialist)
  - Kelsey Young (XI/Science Lead)
  - David Coan (XX/EVA Lead)
  - Trevor Graff (XI/Integration Lead)
  - Marc Reagan (XM/Mission Director)
- Backup Astronauts
  - **Drew Feustel** (NASA Astronaut)
  - **Norishige Kanai** (JAXA Astronaut)

Potential Dual DeepWorker Observers (2nd Seat)

- All qualified PIC (Astronauts, MMT)
- ESA EVA (Herve Stevenin)
- ESID Management (XI, XM, XX)
- EVA SME (XX)
- EVA Tools (EC7)

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Exosuit Training Plan

Training at Nuytco of NXT MMT

- Classroom training on Exosuit/sub systems, focused on environmental systems and safety
- Workshop:
    - Exosuit fit check
    - Suited/hatch closed training and experience with operating environmental systems
- Training runs in water tank:
    - Run #1: Suited thruster fam in tank
    - Run #2: Emergency drills
        - Lung powered scrubber
        - Through water comm
        - Simulated umbilical cut
        - Switching O2 supply
        - Umbilical release
        - Jettison of thruster
    - Run #3: Task drills
        - Fluid QD
        - Cam-lock fluid connector
        - Hook
- Training run in open water

NXT Training Plan

- Classroom training
- Fit check
- Topside experience with environmental systems
- Training run in open water
    - Fam dive
    - Gross translation
    - Fine translation
    - Arm joint movement
    - Stabilization
    - Retrieval
    - EVA task board

Detailed Training Plan In Development

Preliminary Notional Schedule

	17-Aug-19	18-Aug-19	19-Aug-19	20-Aug-19	21-Aug-19	22-Aug-19	23-Aug-19	24-Aug-19	25-Aug-19	26-Aug-19	27-Aug-19	28-Aug-19	29-Aug-19
	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
	Travel	Travel	FaM	FaM	FaM	FaM	FaM	FaM	FaM	FaM	FaM	FaM	Travel
Crew			Geology Training	Geology Training	Suit/Sub Training	Suit/Sub Training	Suit/Sub Training	Suit/Sub Training	Exploration Pioneering	Exploration Science	Exploration Science	Exploration Scenario	
			Sys Training & Fitcheck	Sys Training & Fitcheck									
NXT ARES		Geo Planning	Geology Training	Geology Training	Suit/Sub Refresher	Suit/Sub Evals	Mission Prep	Suit/Sub Evals	Suit/Sub Evals	Exploration Pioneering	Exploration Science	Exploration Scenario	
NXT EVA		Lumus HUD Prep	Mission Prep	Suit/Sub Refresher	Mission Prep	Suit/Sub Evals	Mission Prep	Suit/Sub Evals	Suit/Sub Evals	Exploration Pioneering	Exploration Science	Exploration Scenario	
NXT EMPO			Mission Prep	Suit/Sub Refresher	Mission Prep	Suit/Sub Evals	Mission Prep	Mission Prep	Suit/Sub Evals	Exploration Pioneering	Exploration Science	Exploration Scenario	

NXT Training and Hazard Analysis Approval for DeepWorker

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

Hazard Analysis Report

Date: 02/22/19

Hazard Analysis of: NUYTCO Deep Worker and Dual Deep Worker

Prepared By: Bill Todd

Building/Room:

Organization: USRA

Revision: 1

Approved By:____________________

Approved By: 2/28/19 Thu Nguyen, NS Test Safety

Approved By:____________________

Approved By:____________________

Approved By:____________________

Signed at Division level by XM/Ess

HA reviewed by XA and CB on 7/18/19

Updates for missing hazards in work

FUNCTION STATEMENT

Introduction:

The NEEMO NXT Project is a Lunar and Mars EVA and science exploration analog that exists subsea. The Deep Worker and Dual Deep Worker Submersibles will be utilized as EVA planetary analog tools to answer questions about NASA exploration initiatives and assess EVA capabilities during basic science and EVA tasks.

The DeepWorker normally operates as an autonomous, one-person atmospheric diving system. However, DeepWorker is capable of operating in either tethered or un-tethered mode. The DeepWorker incorporates a soft buoyancy system for vertical control in the water column. Soft ballast is utilised for maintaining positive buoyancy at the surface, minor buoyancy adjustments at depth, or emergency ascent from depth.

In addition to the soft buoyancy system, the DeepWorker is equipped with four (4) thrusters: two (2) aft, horizontally-fixed thrusters, and two (2) angled vertical thrusters. Thruster functions are actuated by a set of foot controls.

Life support consists of a redundant mechanical automatic oxygen injection system and two (2) CO2 scrubbers. Environmental monitoring is accomplished through an electronic O_2 monitor, oxygen pressure gauges, cabin pressure gauge and an optional electronic CO_2 monitor.

Purpose:

This document serves as the Hazard Analysis for review for use of the Deep Worker Subs into science and EVA analogues during upcoming NEEMO NXT tests and missions.

Scope:

This document is the baseline Deep Worker Sub HA. It should be noted that each NEEMO NXT mission are required to perform a hazard assessment on their individual science research or engineering evaluation activities and compare them to the base line HA to determine if any new hazards are created or existing controls must be changed.

Applicable Documents:

JPR 1700.1, L JSC Safety and Health Requirements
NUYTCO Deepworker Pilot Training Manual

Summary:

The hazard analysis performed for normal and emergency conditions for the NEEMO Project Deep Worker Sub and determined that there are no open Category 1 or 2 RAC's for ongoing engineering evaluations or routine research activities.

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

Hazard Analysis Report

Date: 2/22/19	**Approved By:**__________
Hazard Analysis of: NUYTCO EXOSUIT	**Approved By:** [signature] 2/28/19 Thu Nguyen, NS Test Safety
Prepared By: Bill Todd	**Approved By:**__________
Building/Room:	**Approved By:**__________
Organization: USRA	**Approved By:**__________
Revision: Original	

Signed at Division level by XM/Ess

HA reviewed by XA and CB on 7/18/19

FUNCTION STATEMENT

Introduction:

The NEEMO NXT Project is a Lunar and Mars EVA and science exploration analog that exists subsea. The EXO Suit will be utilized as an EVA planetary analog tool to answer questions about NASA exploration initiatives and assess EVA capabilities during basic EVA tasks. Exosuit is a self-contained atmospheric diving suit (ADS) developed by Nuytco Research Ltd. (NRL). Exosuit allows subsea tasks to be performed at water depths to 1000 feet. The Exosuit operator remains at atmospheric pressure during the dive, so decompression is not required. Exosuit has a life-support endurance of 53 hours based on the quantity of carbon dioxide absorbent carried.

A lightweight torso and unique rotary joint design are innovative features of Exosuit. The joints permit low-friction rotation of the limb spacers and remain watertight under high external pressure. If necessary, a joint can be easily removed and replaced with a spare. Waist ring extensions may be inserted to accommodate different operators.

Exosuit is built in accordance with the *Rules and Regulations for the Construction and Classification of Submersibles and Diving Systems* issued by Lloyd's Register of Shipping. The suit consists of an aluminum body incorporating 18 rotary joints, parallel and V-jaw manipulators (optional prehensor), jettisonable thrusters, a self-contained life support system, and hard-wired and through-water communications links

The self-contained life support system includes independent and identical port and starboard oxygen circuits, a scrubber for carbon dioxide removal, oxygen and carbon dioxide analyzers displaying the percentage of the respective gasses in the Exosuit atmosphere, and a suit internal pressure gauge.

Exosuit safety features include dual oxygen circuits, umbilical release and thruster jettison mechanisms, thruster cable cutter, an oral-nasal ask for scrubber use in a lung-powered mode, and dual communications links. An emergency battery is automatically switched to power the oxygen analyzer, through-water communications, and scrubber fan if main power from the surface is lost.

Purpose:

This document serves as the Hazard Analysis for review by the Test Readiness Review Board prior to integration of the EXO Suit into EVA analogues during upcoming NEEMO NXT missions.

Scope:

This document is the baseline EXO Suit HA. It should be noted that each NEEMO mission will be required to perform a hazard assessment on their individual science research or engineering evaluation activities and compare them to the base line HA to determine if any new hazards are created or existing controls must be changed.

Applicable Documents:

JPR 1700.1L JSC Safety and Health Requirements
NUYTCO EXOSuit Atmosphere Diving Suit Operation Manual

Summary:

The hazard analysis performed for normal and emergency conditions for the NEEMO NXT Project EXO Suit and determined that there are no open Category 1 or 2 RAC's for ongoing engineering evaluations or routine research activities.

EXOSUIT
Atmospheric Diving Suit
Operation Manual

July 21, 2014
Revision 2

Nuytco Research Ltd.
North Vancouver, BC Canada

Nuytco Research
DeepWorker Pilot Training Manual
Release 3

Nuytco Research Ltd. North Vancouver B.C. Canada 1

NEEMO NXT Data Capture

version 20190318

Dive Data

Dive #: Date: Pilot Name:
Asset Type/#: Observer:
Max Depth: Supervisor:
Location: Dive Platform / Vessel:
Time Start (Dome Closed): Time Leave Surface:
Time End (Dome Opened): Time Arrive Surface:
Total Time in Asset: Total Dive Time:
Dive Plan Summary:

Dive Conditions

Weather: Air Temp:
Sea State: Water Temp:
Visibility: Current:
Bottom Conditions:

Asset/Equipment Notes

Asset Setup/ Configuration Notes (ballast, floats, spacers, communication/network, etc.):
Asset Equipment Notes (lights, cameras, tools, grippers, etc.):
Pilot Kit/Equipment Notes (cloths, water, references, electronics, etc.):

General Comments/Notes

Completed Dive Activities/Objectives/Tasks:
Comfort Notes:
Anomalies or Aborts:
Next Time Reminders:

Mission Notes

Post Dive thoughts or reflections on NXT Project Objectives/Activities:
Follow Up Actions:

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NXT Proof of Concept Milestones for FY 18-19

FY 18

- [x] November 28, 2017: Nuytco site visit and TIM {Vancouver, Canada} [XM, XX]
- [x] September 2018: Site selection visits {Avalon, CA} [XM]
- [x] September 2018: Hazard analysis with Nuytco {Vancouver, Canada} [XM]

FY 19

- [x] September 2018: Brief XI and XM management on concept and get approval to proceed with feasibility assessment
  - Approved by both XI/ARES and XM/EMPO
- [x] October 2018: Brief XX management on concept and get approval to proceed with feasibility assessment
- [ ] November 27-28, 2018: TIM with Navy to finalize an interagency agreement and start planning DAVD testing with Exosuit {JSC}
- [x] January 21, 2019: Terrain scouting trip to assess potential site and plan feasibility mission {Avalon, CA}
- [x] February, 2019: Funding mechanism in place
- [x] February 19, 2019: NASA crew assignments
- [x] February 28, 2019: Hazard Analyses approved by Safety
- [x] March 1, 2019: HA and NXT feasibility assessment & training approved by XM/Ess
- [x] March 21-31, 2019: Core team feasibility assessment & training at Nuytco, and TIM to discuss feasibility mission {Vancouver, Canada}
- [x] April 2019: Feasibility mission objectives defined
- [x] April 2019: Dive safety manual updates
- [ ] July 2019 (TBD): TIM with Nuytco and Navy to discuss integrating DAVD into the Exosuit for testing at NXT feasibility mission {TBD}
- [ ] September 9-20, 2019: NXT feasibility mission {Avalon, CA}

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Unique blend of capability and skill sets within …

Leverage extensive knowledge and experience from …

XI - ASTROMATERIALS RESEARCH & EXPLORATION SCIENCE

XX - EXTRAVEHICULAR ACTIVITY

XM - MISSION PLANNING & DEVELOPMENT

Other **XA** components

HISTORICAL MISSIONS
Apollo Surface Operations

HUMAN SPACE FLIGHT
ISS, Shuttle

ROBOTIC MISSIONS
Mars Missions, OSIRIS-REx

"ANALOG" MISSIONS
D-RATS, NEEMO & others

READy core management and execution is a collaboration between NASA JSC's ARES, EMPO, and EVA divisions

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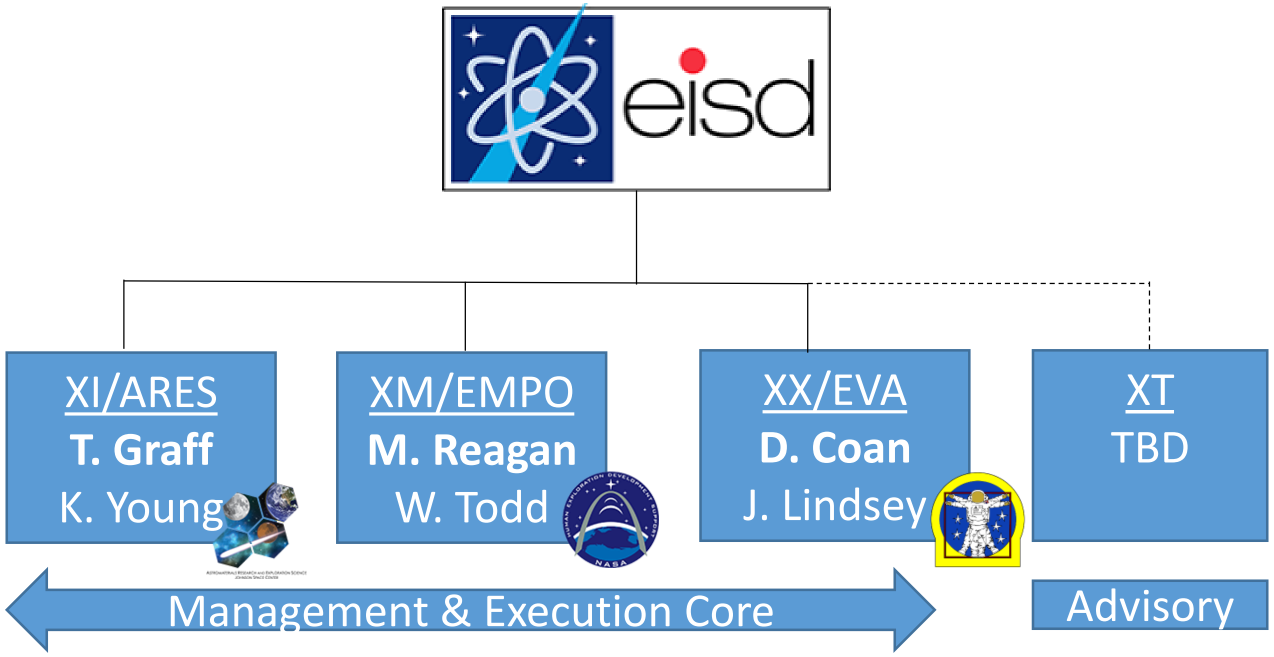
READy Core Team Concept

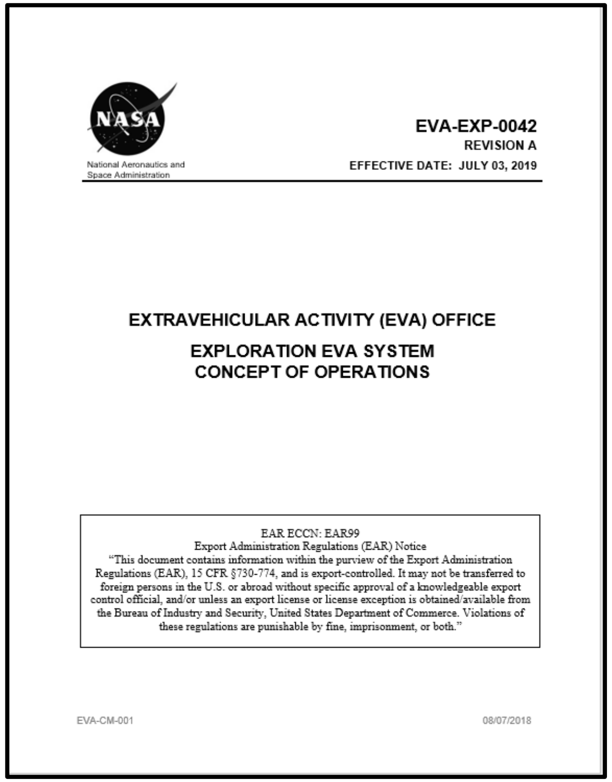
- **XI/ARES, XM/EMPO, XX/EVA team members are the core management and execution team**
- **Skills include**
  - Identifying applicable mission objectives
  - Establishing contributing partnerships
  - Developing mission timelines and supporting products (e.g., procedures, mission rules, crew training, etc.)
  - Mission operations & execution
  - Capturing post mission lessons learned and briefing appropriate audiences
  - Leverage and expand existing proposals/grants



- **Non-READy duties include staying plugged in to HSF ops and architectural activities and feeding READy lessons learned back into them as appropriate:**
  - ISS Ops
  - EVA Ops
  - Mars Science Ops (e.g., MSL)
  - Gateway (DSG)
  - BAA NextStep Hab
  - EVA Strategic Planning and Architecture Integration
  - xEVA System Development
  - Mars Study Capability
  - Lunar Science objectives
  - Lunar Human Landing System
  - Emerging…

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

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


National Aeronautics and Space Administration

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

EXTRAVEHICULAR ACTIVITY (EVA) OFFICE

EXPLORATION EVA SYSTEM
CONCEPT OF OPERATIONS

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

NEEMO Neoteric eXploration Technologies (NXT) as Presented to EISD

NEEMO NXT

- Concept currently in development for an add-on and eventual follow-on for NEEMO
- Focuses on Exploration operations development and training, xEVA informatics, xEVA con ops, and integration of science operations
- Offers a high intensity operationally challenging environment, with high workload, elevated stress, high bandwidth, time pressure, and unexpected external perturbations
- Utilizes Nuytco Research Exosuit and DeepWorker submersibles
  - Potential partner for spacesuit develop, especially for joints
  - Submitted a response to the EVA Spacesuit RFI (#80JSC018EVASUIT)
- Exosuit provides an analogous restrictive suit that requires similar effort for positioning and working in an EVA suit, along with a relatively large helmet volume at 1 ATM to evaluate off the shelf informatics hardware (e.g., DAVD, HoloLens, etc.)
- Provides operations training and experience for XA/EISD personnel (managers, engineers, scientists) without extensive ops experience, including flying as co-pilot with a crewmember/astronaut in a Dual DeepWorker sub
- Expands partnership with Navy for development of xEVA informatics
- READy FY19 plans include
  - Terrain scouting and feasibility mission planning
  - Feasibility assessment of assets and core team training
  - Feasibility mission as a 'test flight' of the concept

xEVA System Con Ops & Capabilities Development

➢ **Tools**
- Development of a heads-up display (HUD) concept (e.g., HoloLens and DAVD) in an encumbered suit (Exosuit) for potential expansion into the xEMU
- Development of an IV Workstation and Support System needed for EVA and Science operations, especially at destinations with long signal/comm latencies

➢ **Techniques**
- Evaluation of planetary pioneering and science operations while conducting tasks with a restrictive suit in an extreme environment
- Development of integrated operations and capabilities between EVA and Science, with operations being directed by an MCC Science Team

➢ **Technologies**
- Evaluation of concepts for hands-free advanced informatics with real-time data that could be applied to future Exploration spacesuit systems (e.g., DAVD)

➢ **Training**
- Exploration operations training for personnel that don't have extensive direct operational experience

Nuytco Assets for NXT

EXOSUIT

Developed and built in North Vancouver by **Nuytco Research Ltd**, this hard metal dive suit allows divers to operate safely down to a depth of 1000 feet and yet still have exceptional dexterity and flexibility to perform delicate work. The amazing technology of the **EXOSUIT** atmospheric diving system (ADS) maintains a cabin pressure of the surface and still allows the suit to bend due to a unique rotary joint invented by Dr. Phil Nuytten.

ADS 'Exosuit' Specifications

General:
• 1000 Foot depth rated
• A536 Aluminum Alloy
• Weight 500-600 LBS depending on config

Life support:
• 2 Redundant oxygen systems, total capacity 50 hours
• 50 hour Carbon Dioxide scrubber
- Back up battery with automatic change over on power failure
- Lung powered scrubber back-up

Propulsion:
• 4 x 1.6 HP thrusters (expandable to 8)
• Direct drive, magnetically coupled thrusters
- Quiet operation
- Responsive (quick windup)

Telemetry/Control System:

• Distributed control system (Omron PLC) allows for uninterrupted operation in case of telemetry failure
• Gigabit Ethernet over Fiber optic
- Network attached High definition camera
- Network attached Imagenex 852 SONAR
- Easy integration of IP and POE (Power Over Ethernet) devices
• Remote (topside) control of: thrusters, thruster trim, lights and tooling
- Lightens pilot workload
• AMS (Atmospheric Monitoring System)
- Real time monitoring topside of cabin pressure and Oxygen %
- Lightens pilot workload
- Enhances safety

Communication:

• Full duplex intercom - over copper
- 6 intercom stations (pilot +5)
- Highly reliable
- No subsea power required
- Excellent voice quality (low noise)
- Aux In and Out jacks (topside)
• IP intercom out
- Allows audio to be recorded synchronously with project video
• Acoustic thru water communications
- Backup in case of hardwire communications failure
- Compatible with communications hardware used commonly by manned submersibles

Umbilical:

• 1250 feet long nominal
• OD 0.980" nominal
• Minimum bend radius 27"
• Breaking strength 7200lbs
• Neutrally buoyant

Power Requirement:

• 208-240 3 phase, 50 A, 50-60 HZ

Emergency Equipment:

• Umbilical jettison capability
• Thruster jettison capability
• Emergency battery
- Powers thru water comms, O2 analyzer and carbon dioxide scrubber

Ancillary Equipment:

• HD camera, H.264 (Blu-Ray Codec) camera
• SONAR
- Imagenex miniature 852 scanning sonar
• Newtsun LED lights
- 2 x 150 W LED lights
- 9,600 lumens (each)
• For comparison - a 250W quartz lamp produces 3,500 lumens
- 4500 deg K (cool white)

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Dual Deepworker

The **Dual DeepWorker 2000** is a two-person, one atmosphere submersible manufactured by Nuytco Research Ltd. The submersible can operate in depths up to 600 metres. Each person has a 24-inch diameter acrylic viewing dome, which gives an expansive field of view and is used to enter/exit the submersible. The **Dual Deep Worker 2000** has a favourable weight to power ratio and six thrusters, giving it superb manoeuvrability. **Dual DeepWorker 2000** is equipped with PAX controls, meaning the pilot can pass the control to the passenger. The **Dual DeepWorker 2000** is ideally suited for underwater scientific research, survey, salvage and film work.

Specifications

General:

- 600m depth-rated
- 1 Pilot, 1 Passenger
- A516 grade 70 steel
- Weight in air 7500lbs
- Length: 8.6 ft. (2.6 m)
- Beam: 7.0 ft. (2.1 m)
- Height: 6.7 ft. (2.0 m)
- PAX control: passenger may pilot
- 1,000 lbs Payload Capacity

Life Support:

- 2 Redundant oxygen systems, total capacity 80 man-hours
- Carbon Dioxide removed via scrubbers
- Emergency breathing gas via air BIBS

Propulsion:

- Four main horizontal thrusters, plus two vertical/lateral thrusters
- 680 cu.ft. ballast air provided for surface buoyancy/trim

Viewing:

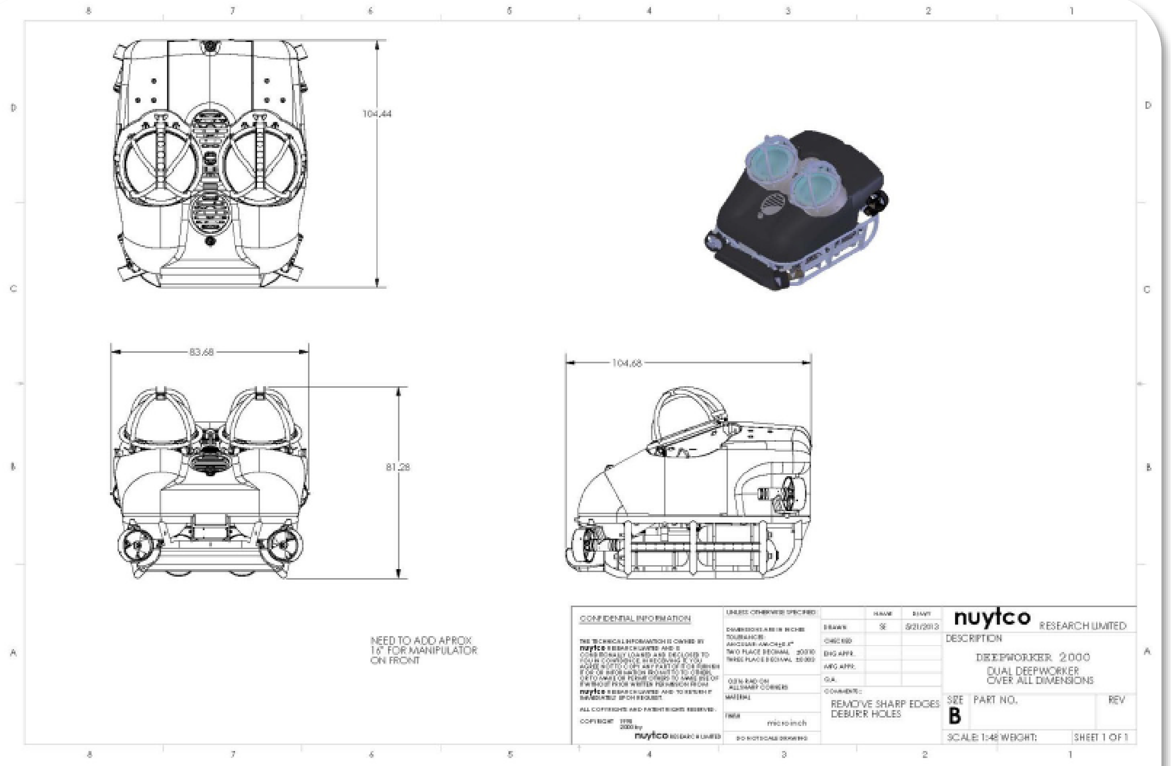
- Two 24" dia. Acrylic domes; serve as entry hatches

Communication:

- Surface: Marine VHF
- Sub-surface: UQC and 27 KHZ Acoustic

Power:

- 22 KW, 270 V DC On board Li-Ion battery supply



Emergency Equipment:

- Drop weight jettison capability
- Main battery jettison capability
- Emergency battery
  - Powers comms and CO2 scrubber

Umbilical:

Vehicle may be operated tethered or untethered

Optional Equipment:

- HD Camera, H.264 (Blu-Ray Codec) camera
- SONAR, modified Imagenex, standard scan and ultra-high resolution short range scan
- 1 x 6 Function plus 1 x 4 Function Manipulators
- Tracking Beacon
- Strobe/RF/Iridium beacon
- Electro magnet
- Magnetometer
- Burial/ excavation pumps
- Sampling equipment
- Precision laser measuring system
- Pipe tracker
- Lift bag salvage module
- U/W cutting module
- Acoustic thickness/CP/EMF Probe
- Other optional equipment available

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NXT FaM Operators / Evaluators Roles & Responsibilities

Exo PLT roles:
- Exo PLT
- IV Console
- MCC Scicom?
- Exo Deck Suppt
- DW Deck Suppt
- DDW Pax

DDW PLT roles:
- IV Console
- DW PLT
- MCC Scicom?
- DW Deck Suppt
- Exo Deck Suppt
- DDW Pax

Boat roles:
- Deck support – DW
- Deck support - Exo
- ROV pilot
- Passenger

READy Team roles:
- Pilot
- Pax
- IV Console
- MCC Scicom
- Suppt Diver
- Boat driver
- Geo Trainer
- ROV

Topside roles:
- Test timeline
- Metrics
- Photo mgmt.
    - Hardware
    - Files
    - Keywords
    - Scene list

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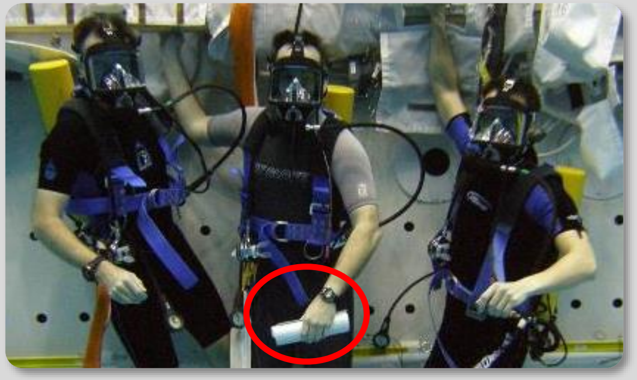
NASA Exploration EVA Spacesuit and Operations

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

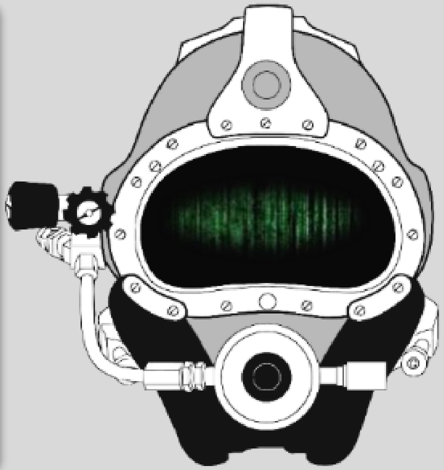
Enhanced ISS EVA Training

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

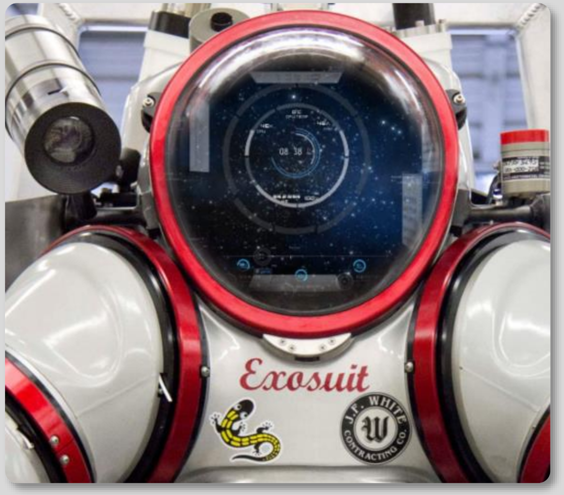


Potential Spacesuit (xEMU) Development

DAVD Mounted Lenses



DAVD Projection System



DAVD System in Suit

xEMU HUD

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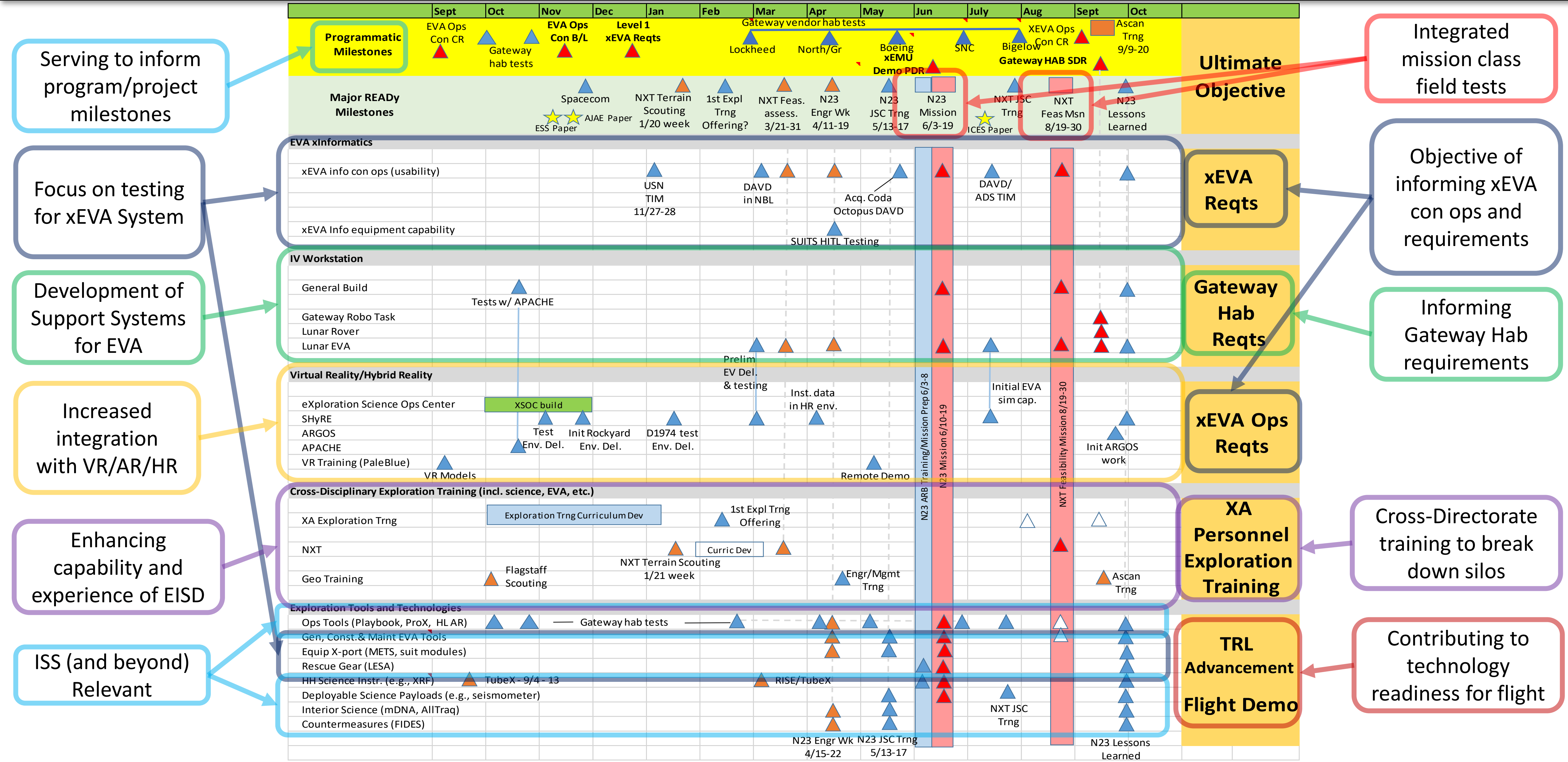
Draft READy Implementation Plan for FY19



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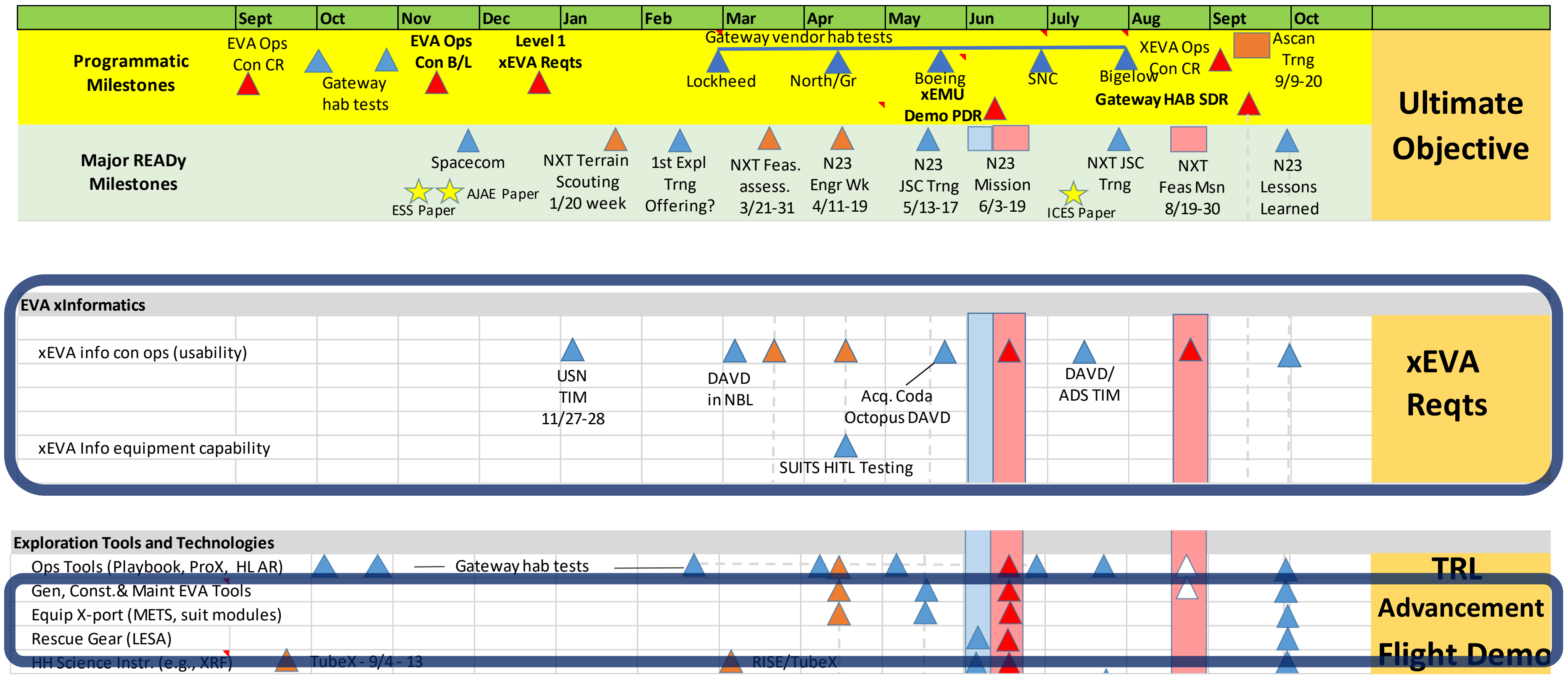
xEVA Capabilities and System Testing



- Divers Augmented Vision Display (DAVD) and Digital Cue Cards
- HoloLens (SUITS)
- Science Sample Acquisition Tools
- xEVA Equipment Transport
- Lunar Evacuation System Assembly

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