Operational Field Testing for Human Exploration

(a.k.a., NASA Analog Projects)

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Agenda

- What Are Operational Field Tests?
- Active EVA-Focused Operational Field Tests
- Past EVA-Focused Operational Field Tests
- Active Field Tests with Environments Applicable to EVA
- Past Field Tests with Environments Applicable to EVA
- Summary

WHAT ARE OPERATIONAL FIELD TESTS (“ANALOGS”)?

What Are Operational Field Tests?

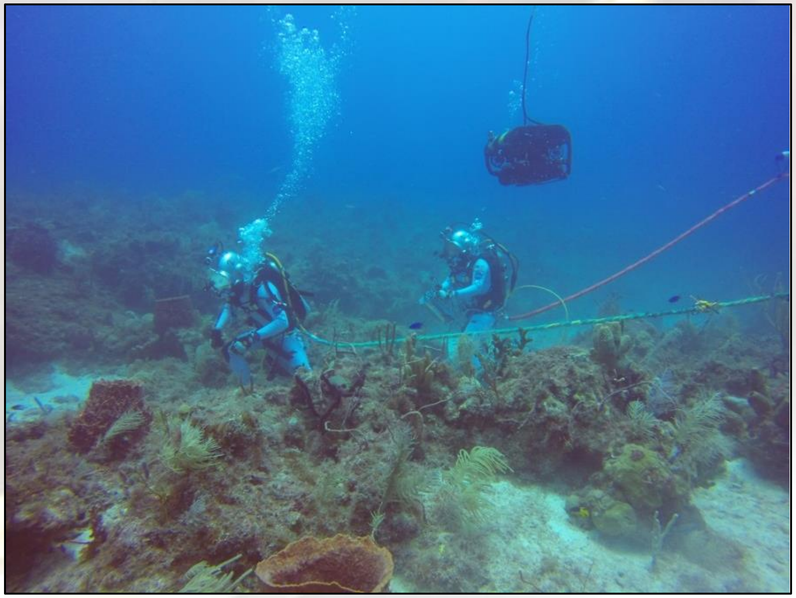
Background

- Future Exploration missions will potentially take humans to destinations where EVA work will be done on non-engineered natural bodies
- These missions will also be at distance that precludes instantaneous real-time communication with the crew
- There are numerous technology and operations gaps associated with translation and stabilization tools, science sampling tools, and operational techniques for dealing with comm latency

Operational Field Testing

An analog mission is an integrated multi-disciplinary operational field test that allows for early end-to-end testing of concepts of operations and hardware in a true operational scenario

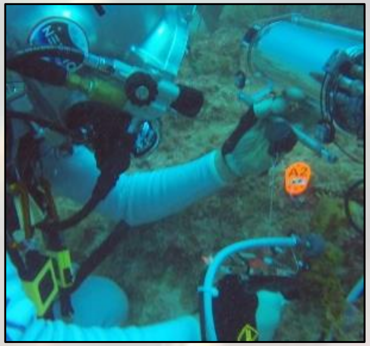
- Evaluates objectives mapped to specific needs and knowledge/technology gaps
- Has the crew in-situ and a ground team separated from them in a mission-like manner
- Provides an understanding of system and architectural interactions between Operations, Engineering, and Science
- Drives out results not found in standalone testing, including things that do and do not work in a mission environment
- Benefits programs from ISS to Exploration



Goals for Operational Field Tests

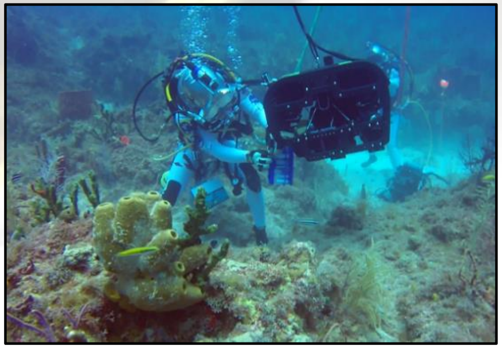
EVA Goals

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



Benefits of Operational Field Testing

- Concepts of operations can be accurately tested to determine their viability and changes
- Utilization of real science allows for investigation of end-to-end concepts of operations, from both an Earth-based Science Team and the in-situ EVA crew
- Purpose-built prototype hardware can be evaluated in a field test to provide data for design maturation
- Communication latencies can be simulated in an operational environment in order to assess the con ops and needs associated with EVAs
- A range of destinations can be evaluated



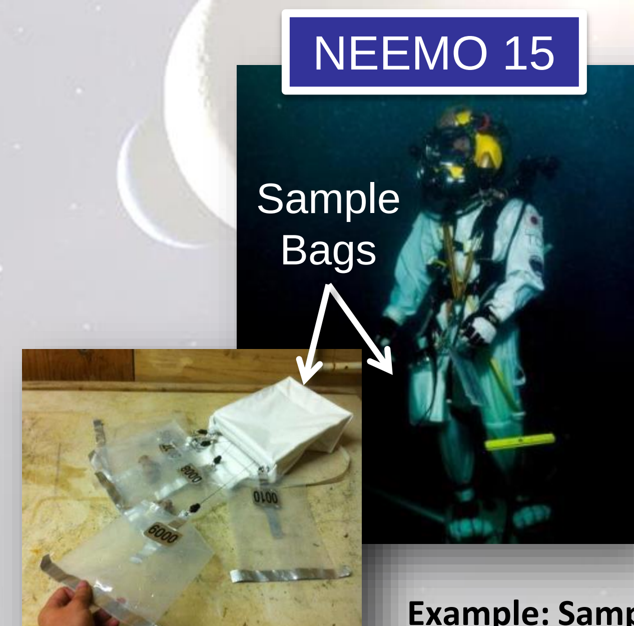
Integrated Analog Testing: Inputs to Operationally Driven Design

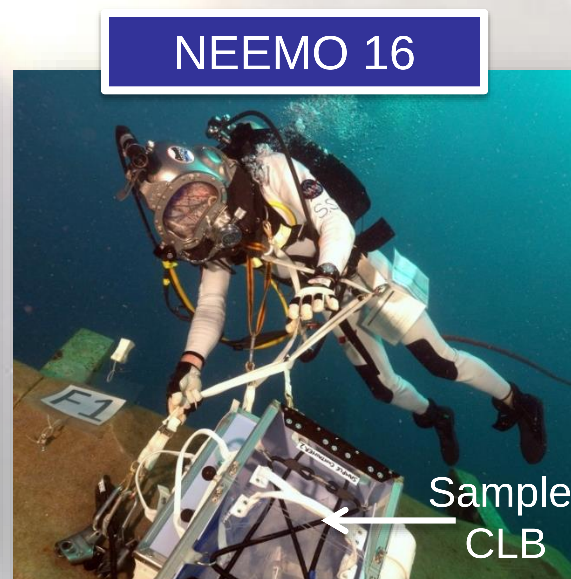
- By developing and simulating integrated operations and evaluating systems and technologies within that operational environment we are able to:
  - Understand what systems and technologies are required
  - Understand what systems and technologies are <u>not</u> required
  - Understand how the use and interactions of those systems and technologies affects their requirements and subsequent development

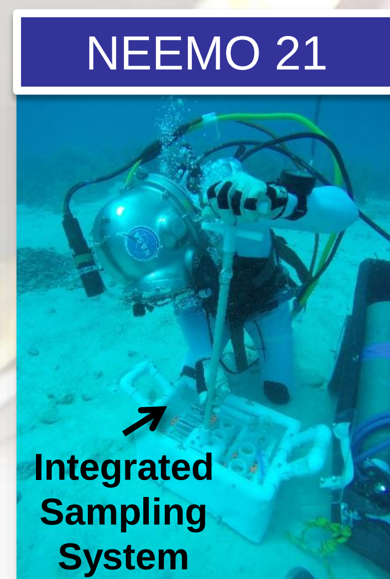
By learning these things early in the development process, limited resources can be directed more efficiently and the resulting technologies and systems will be more affordable and effective

Planning and Executing Operational Field Tests

- Define questions of interest to close technological or architectural gaps
- Design and execute test to address questions of interest
- Rigorously/systematically evaluate results
- Use models to extend results (where applicable)
- Based on results, define/refine requirements & improve technology on the road-to-flight
- Distribute results via NASA documents, NASA technical presentations, reports, conferences, & journal articles







Example: Sample Stowage Capability Technology Evaluation & Evolution

EVA Utilization of Operational Field Tests

The primary utilization of operational field tests for EVA is to evaluate potential closures for knowledge gaps (including the EVA SMT, CAPTEM, and FAST) while testing concepts of operations within a mission-like flexible environment

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

Integrated EVA Operations

The goal for EVA in an operational field test is to explore the combined aspects of Science, Operations, and Equipment in a mission-like environment in order to evaluate:

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

Heritage & Background

Low communication latency (~1.25 sec OWLT)

Apollo Surface Operations

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

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

Mars Robotic Missions

- Remote science operations
- Instrumentation / sample selection

MER A - Spirit

MER B - Opportunity

MSL - Curiosity

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

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

NASA Extreme Environment Mission Operations

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

Science

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

Tested a variety of communication latencies for geo-science operations

Research and Technology Studies

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

Science

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

Science Field Campaigns

- Science focused
- Funded though grant programs
- Utilized as analogs

Test a variety of communication latencies

Other NASA Analog Programs

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

Science at Operational Field Tests

SCIENCE

PLANETARY SCIENCE RELEVANCE

- EVA science activities include deployment of handheld instrumentation, context descriptions, imaging, and sampling
- Operational field testing allows for evaluations of sample collection tools, deployable instruments, and EVA concepts of operations
- Geoscience activities at analogs such as RATS and RISE directly correlate to planetary exploration
- The marine science activities and associated research objectives at NEEMO serve as a appropriate proxy for planetary surface exploration activities

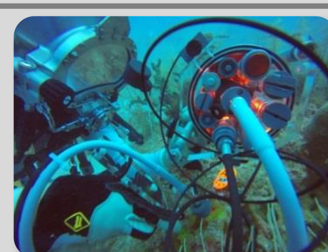
- **Integration, coordination, and education from diverse disciplines and organizations**

Astromaterials

Curation

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

Research



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

Exploration

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

Operations at Integrated Field Tests

OPERATIONS

CONCEPTS OF OPS AT NEEMO

INTEGRATED EVA SCIENCE OPERATIONS

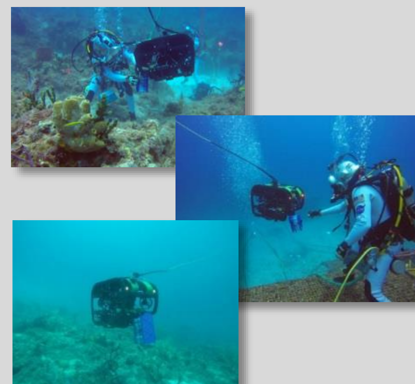
- Examine con ops that enable interaction between the MCC & the crew over a long comm latency including:
  - Interaction with an integrated Science Team
  - Authentic scientific objectives and hypothesis
  - “Flexecution” methodology

PIONEERING TASKS

- Evaluate early prototype construction hardware and techniques

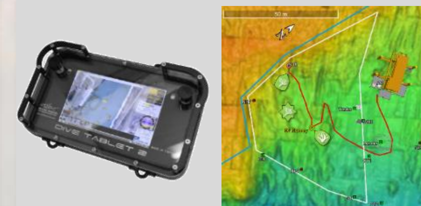
- Deploy, test, and evaluate a prototype comm system
- Simulated a multi-phased “pioneering” task

JOINT ROBOTIC-EVA OPERATIONS



- Joint human-robot operations
- Autonomous site navigation and precision execution for tool handoff/delivery & diver leading
- IV-control for localization, detailed navigation, situational awareness, inspection, and intervention

NAVIGATION, MAP, & TRAVERSE PLANNING



- Assess tool needs (hardware & software) for navigation

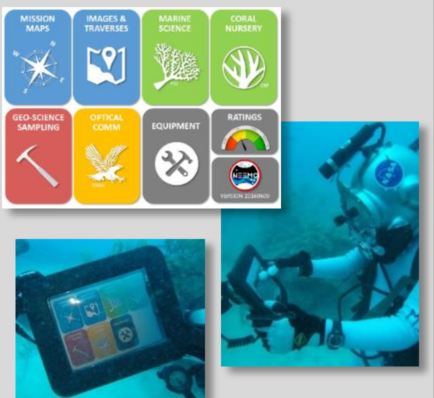
WITH COMMUNICATION LATENCY CON OPS

Hardware at Operational Field Tests

EQUIPMENT

HARDWARE EVALUATIONS AT NEEMO

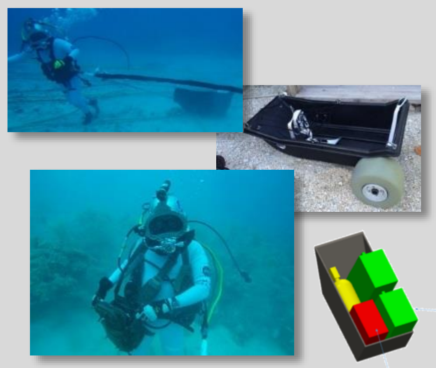
ELECTRONIC CUE CARDS



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

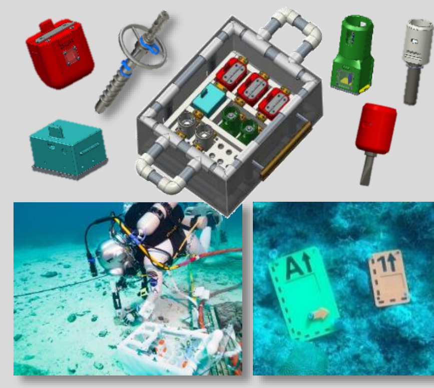
DEMO

TRANSPORTATION & STOWAGE OF TOOLS



- Appraise EVA hardware and operations for transporting and stowing tools and samples
- Sled/cart options for large equipment transport (drill/tank, PAM instrumentation, sample collection/preservation box)
- Sling bag options for small items & easy access (sample markers, hand tools, electronics, etc.)

SCIENCE SAMPLING TOOLS & GEOLOGY SAMPLING KIT



- Test EVA tools and hardware for science sampling
- Evaluate Integrated Geology Sampling System for collecting geology & astrobiology samples
- Sample Briefcase houses various end effectors with two different drivers (manual and powered)
- Analyze methods to minimize EV crew contaminating an area

IV SUPPORT SYSTEM

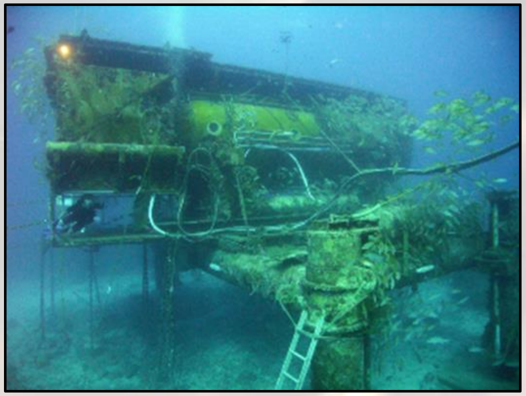
- Evaluate what kind of tools the IV crewmember needs to effectively handle the large amount of EVA information while actively directing the EVA
- Evaluating effective setup in a constrained location
- Multiple displays include camera feeds, timeline, nav/comm/sub systems, procedures, logs, etc.)

ACTIVE EVA-FOCUSED OPERATIONAL FIELD TESTS

NASA Extreme Environment Mission Operations

NEEMO is a project that utilizes Aquarius, the only operational undersea research facility in the world, as a setting for accomplishing a host of NASA and synergistic partner objectives

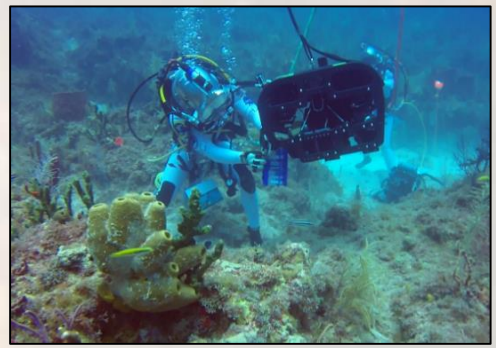
- Funded by partners and collaborators from across NASA centers, DoD, universities, and industry
- 1-2 missions/year, 10 – 20 days in length
- Shore side Mission Control, staffed by experienced operators
- Crew largely consists of astronauts from CB and IPs, along with PIs and engineers
- Missions have high operational rigor by design (timelines, procedures, etc.)
- Enables evaluation of both IVA and EVA objectives
- Allows for evaluations of end-to-end concepts of operations with crew that are in-situ in a true extreme environment
- Provides for flight-like interactions between the crew and an MCC Science Team, including over comm latencies
- Enables a testing ground for hardware and tool concepts on the start of the road to flight
- Analog Testing Details:
  - Previous mission: July 21- Aug 5, 2016
  - Next mission: TBD (July 2017)
- Points of Contact:
  - Project Manager & Mission Management: Bill Todd (USRA/NASA JSC)
  - Mission Director & Mission Management: Marc Reagan (NASA JSC)
  - EVA Lead & Mission Management: David Coan (EVA/SGT/NASA JSC)
  - Science Lead & Mission Management: Trevor Graff (ARES/Jacobs/NASA JSC)
  - Metrics & Mission Management: Steve Chappell (Wyle/NASA JSC)
  - https://www.nasa.gov/mission_pages/NEEMO/index.html

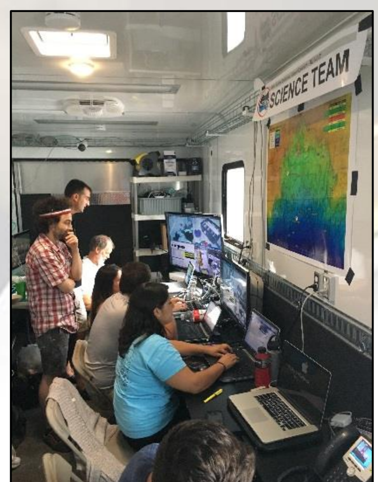


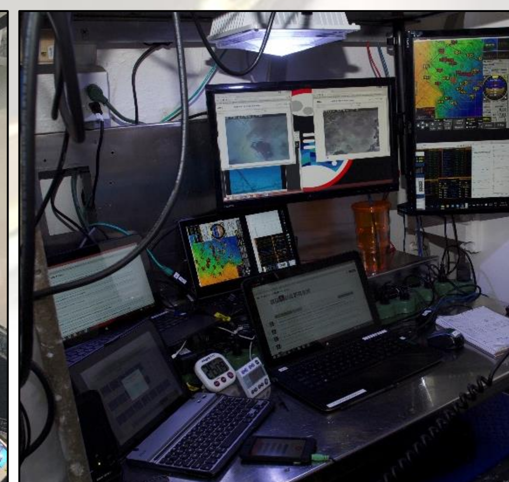
Recent Objectives Evaluated at NEEMO

- EVA tools and hardware for science sampling (EVA Integrated Geology Sampling System)
- Science Team integrated with EVA operations and providing input during an EVA
- Flexible execution methodology
- Electronic cue cards for EVA crew
- IV support system workstation
- Joint robotics-EVA operations
- EVA navigation and planning data
- Integrated Geographic Information System (GIS)
- EVA hardware and operations for transporting and stowing tools and samples
- EVA tools for marking and high grading samples
- Incapacitated crew rescue
- Building EVA hardware in situ (3D printer)
- Multi-day crew self-scheduling of EVAs
- Phobos habitat EVA-deployable boom







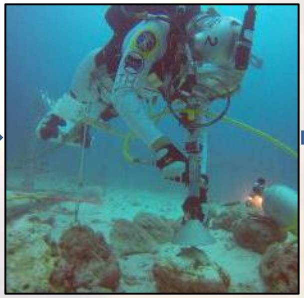


Example of Progression Across Missions

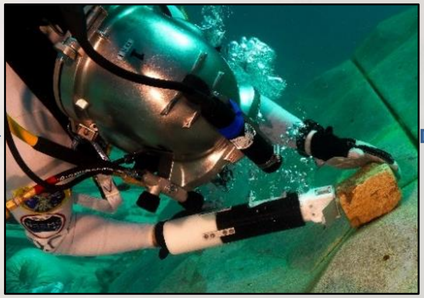
- Objective:
  - Evaluate EVA hardware and operations for science sampling (EVA Integrated Geology Sampling System)
- Gaps addressed
  - EVA SMT: Tools for Science Sampling on a Surface EVA
  - EVA SMT: Micro-g tool for chip samples
  - CAPTEM: Collection of 1000 g from two sites
- Summary Take-Away for EVA
  - Concept proved feasible for EVA collection of geology and astrobiology samples
  - Provides a viable method for minimizing sample contamination
  - Tool improvements will be incorporated into designs for the next generation of hardware on the road-to-flight

Pneumatic chip hammer - NEEMO 17 (SEATEST 2)

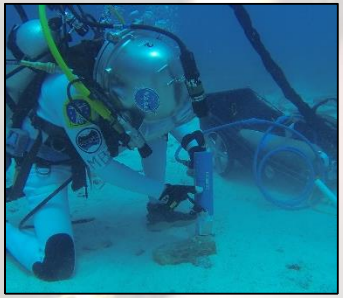
Pneumatic chip hammer - NBL/MACES



Pneumatic chip hammer - NEEMO 18/19



Pneumatic chip hammer - NEEMO 20



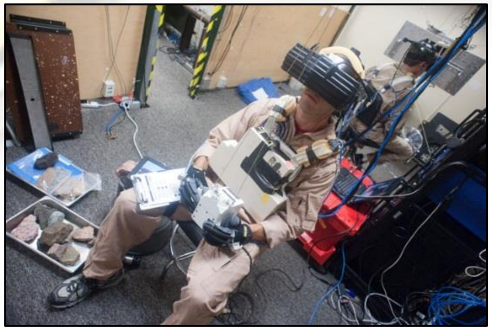
Pneumatic chip hammer - NEEMO 21

Powered rock chip hammer/core drill concepts (ARM DRM animation)

PAST EVA-FOCUSED OPERATIONAL FIELD TESTS

Research and Technology Studies (RATS)

- Research & Technology Studies
  - Mission tested techniques, tools, planning, and communication protocols
  - Matured operational concepts and technologies through integrated demonstrations
  - Exercised overall ‘MCC style’ coordination between hardware, procedures, crew operations, mission control operations, science team operations, and engineering team
- RATS 2012 was an asteroid analog mission
  - Took place at NASA JSC
  - EVAs conducted in VR Lab and on ARGOS
  - Vehicle/asteroid sim was tied to VR lab/EVA sim to allow vehicle and EV interaction
  - Reliable and cost-efficient test and validation of NASA next-generation human exploration mission concepts
- Analog Testing Details
  - Mission took place in 2012
- Points of Contact
  - Mission Manager: Barbara Janoiko (NASA JSC)
  - Exploration EVA Testing: David Coan (EVA/SGT/NASA JSC)
  - Science Operations: Trevor Graff (ARES/Jacobs/NASA JSC) & Kelsey Young (ARES/UTEP/NASA JSC)
  - https://www.nasa.gov/exploration/analogs/desertrats/



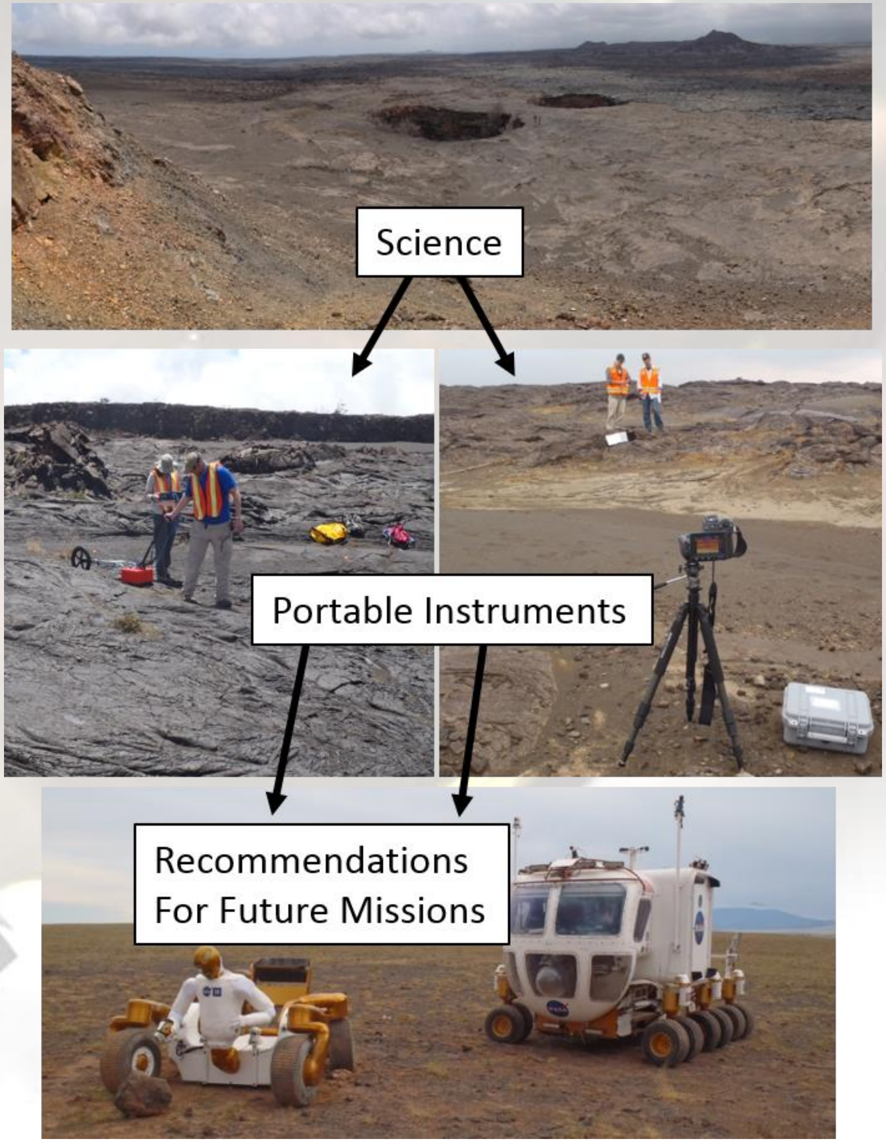
Desert RATS

- Desert RATS missions were a planetary analog
  - Took place at the Black Point Lava Flow near Flagstaff, AZ
  - Provided environment analogous to Moon and/or Mars, with crew conducting geoscience operations
  - Allowed immersion of whole team, both flight crew and flight controllers
  - Geoscience data still utilized for research
- Analog Testing Details
  - Final Desert RATS mission took place in 2011
- Points of Contact
  - Mission Manager: Barbara Janoiko (NASA JSC)
  - Exploration EVA Testing: David Coan (EVA/SGT/NASA JSC)
  - Science Operations: Trevor Graff (ARES/Jacobs/NASA JSC) & Kelsey Young (ARES/UTEP/NASA JSC)
  - https://www.nasa.gov/exploration/analogs/desertrats
  - https://www.nasa.gov/analogs/desert-rats

ACTIVE FIELD TESTS WITH ENVIRONMENTS APPLICABLE TO EVA

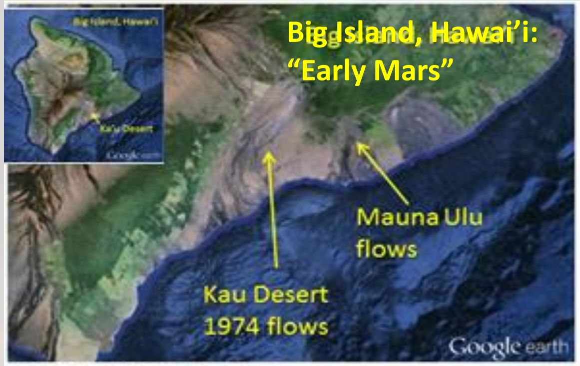
SSERVI RIS^{4}E

- RIS^{4}E: Remote, In Situ and Synchrotron Studies for Science and Exploration
- SSERVI-funded project that investigates the effects of incorporating field portable instrumentation into scientific EVA timelines
- New science investigation
  - Fundamental science questions serve as basis for understanding how to operate on planetary surfaces
  - RIS^{4}E analog work at Kilauea, HI, and Potrillo Volcanic Field, NM
- Evaluate role of new technologies
  - Portable instruments for in situ measurements
  - How they integrate with the larger mission architecture
  - What are the most effective instruments for answering science questions
- Recommendations for science operations, technology development and crew training
- Analog Testing Details
  - Previous field tests at December 1974 flow, Kilauea Volcano, HI, in 2014, 2015, 2016, and Potrillo Volcanic Field, NM, in 2016
  - Future field tests at Kilauea in Fall 2016 and at Potrillo Volcanic Field in 2017 and 2018
- Points of Contact:
  - Jacob Bleacher (NASA GSFC)
  - Kelsey Young (ARES/UTEP/NASA JSC)
  - ris4e.labs.stonybrook.edu/



Biologic Analog Science Associated with Lava Terrains

- Objectives: Investigate terrestrial volcanic terrains and their habitability as analog environments for early and present-day Mars through 4 field deployments in 2015–2019.
- Science: Seek, identify, and characterize life and life-related chemistry in basaltic environments representing these two epochs of Martian history.
- Science Operations: Conduct the science within simulated Mars exploration conditions based on current architectural assumptions. Identify which human-robotic ConOps and supporting capabilities enable scientific return and discovery.
  - Do the baseline ConOps, systems, and communication protocols developed and tested during previous NASA analogs work acceptably during real scientific exploration? Do they remain acceptable across the range of Mars mission comm latencies and bandwidth considerations?
  - Which capabilities (utilized by EV, IV, Science Team, and MCC) are enabling and significantly enhancing for Mars scientific exploration? Does the degree of enabling and enhancing vary as comm latency and bandwidth availability changes?
- Technology: Incorporate and evaluate technologies directly relevant to conducting the science, including mobile science platforms, extravehicular informatics, display technologies, communication and navigation packages, remote sensing, advanced science mission planning tools, and scientifically-relevant instrument package
- Funded by NASA SMD ROSES-2014 Program Element C.14 (PSTAR)
- Analog Testing Details
  - Prior field test in June 2016 in Craters of the Moon, Idaho
  - Future field tests in Idaho and in Hawai'i (2016 and 2017)
- Points of Contact
  - PI: Darlene Lim (NASA ARC)
  - Deputy PI: Andrew Abercromby (NASA JSC)
  - Leads: Steve Chappell (Wyle/NASA JSC) & Kara Beaton (Wyle/NASA JSC)



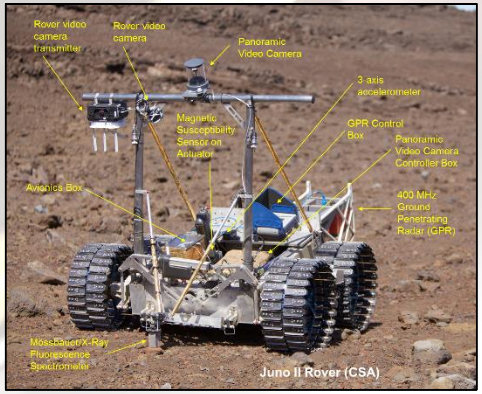
PAST FIELD TESTS WITH ENVIRONMENTS APPLICABLE TO EVA

In-Situ Resource Utilization

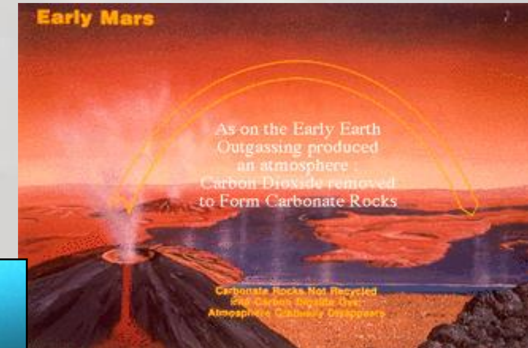
- Summary
  - Planetary analog mission
  - Hardware tested under stressful environmental conditions
- Objectives
  - Expand scope of international involvement and mission criticality for hardware and remote test operations
  - Expand integration of science and technology
  - Streamline path to flight
- Analog Testing Details
  - Hawai'i deployment in July 2012
- Point of Contact
  - www.nasa.gov/exploration/analogs/isru/

Analog Site for 3rd International Hawaii Field Testing: "Apollo Valley" in Mauna Kea Hawaii

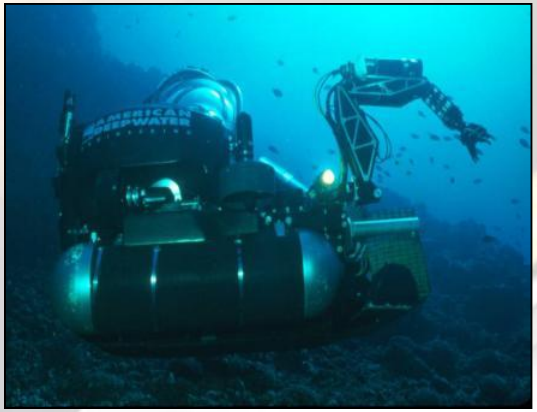
Pu'u haiwahini in Hawaii



Pavilion Lake Research Project



- Summary:
  - An international, multi-disciplinary, science and exploration effort to explain the origin of freshwater microbialites in Pavilion Lake, British Columbia, Canada
- Objectives
  - Used DeepWorker submersibles as analogs to the MMSEV
  - Evaluated comm delays and the effects on doing effective science
  - Evaluated pilot workload and effects on doing effective science
- Analog Testing Details
  - Final mission took place in 2015
- Points of Contact
  - PI: Darlene Lim (NASA ARC)



SUMMARY OF OPERATIONAL FIELD TESTS FOR EVA

Benefits of Operational Field Tests

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

Future of Operational Field Tests

- EVA Office
  - Currently looking at next round of integrated testing
  - Continued focus on objectives that facilitate closure of SMT gaps and updates to the Exploration EVA Concepts of Operations document
  - Will further evaluation different types of EVA tasks
    - Science operations
    - Pioneering
  - Will start putting together objectives for NEEMO 22 in anticipation of securing funding
  - Examining other potential testing opportunities
- NEEMO
  - Potential mission in July 2017 (and subsequent years)
  - Significant focus on EVA and Science objectives
- SSERVI RIS^{4}E
  - Upcoming deployments in 2016, 2017, and 2018
  - EVA will be looking at possible collaboration
- BASALT
  - Upcoming deployments in 2016 and 2017

Collaborating with Operational Field Tests

- NASA is always looking for collaboration with external groups to help facilitate development of the next generation spaceflight systems for EVA
  - https://www.nasa.gov/suitup
  - Primary EVA POCs: Brian Johnson (EVA/NASA JSC) and Jesse Buffington (EVA/NASA JSC)

- Current NASA operational testing programs
  - EVA will continue to evaluate concepts for closing knowledge gaps
  - Possible testing during NEEMO 22
  - Link to list of existing NASA analog projects: https://www.nasa.gov/analogs
  - Primary EVA POC: David Coan (EVA/SGT/NASA JSC)
  - Primary Science Operations POCs: Trevor Graff (ARES/Jacobs/NASA JSC) and Kelsey Young (ARES/UTEP/NASA JSC)

- Solar System Exploration Research Virtual Institute (SSERVI)
  - Addresses basic and applied scientific questions fundamental to understanding the Moon, Near Earth Asteroids, the Martian moons Phobos and Deimos, and the near space environments of these target bodies
  - Funds investigators at a broad range of domestic institutions, bringing them together along with international partners via virtual technology to enable new scientific efforts
  - http://sservi.nasa.gov/
  - Continuing EVA relevant testing through RIS^{4}E

- Planetary Science and Technology Through Analog Research (PSTAR)
  - Exploring objectives to further development in science, technology, and operations
  - https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={B0EE1F61-F9A7-AB2B-1695-ACD354C484E0}&path=open

- Human Exploration Research Opportunities (HERO)
  - Examining objectives related to human factors and physiology
  - https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={9927D6DC-C2F9-5D3E-8BF1-EA4EE3EE0A37}&path=open