NASA

Cislunar Habitation & Environmental Control & Life Support Systems

NASA Advisory Council Human Exploration & Operations Committee 29 March 2017

Jason Crusan, Director, Advanced Exploration Systems Division Robyn Gatens, Deputy Director, International Space Station

Exploring Space In Partnership

Now Using the

International Space Station

2020s Operating in the Lunar Vicinity Advancing technologies, discovery and creating economic opportunities Advancing technologies, discovery and creating economic opportunities

2030s Leaving the Earth-Moon System and Reaching Mars Orbit

Phase 0

Solve exploration mission challenges through research and systems testing on the ISS. Understand if and when lunar resources are available

Phase 1

Conduct missions in cislunar space; assemble Deep Space Gateway and Deep Space Transport

Phase 2

Complete Deep Space Transport and conduct Mars verification mission

Phases 3 and 4

Missions to the Mars system, the surface of Mars

HABITATION CAPABILITY

Systems to enabling the crew to live and work safely in deep space. Capabilities and systems for use in conjunction with Orion and SLS on exploration missions in the Proving Ground and beyond.

Deep-Space Habitation Development Strategy



Habitation Development Approach



Hab Development Phase 1

- Obtain Innovative Cislunar Habitation Concepts that leverage Commercialization Plans for LEO (NextSTEP Phase 1)
- Developed required deliverables including Concept Description with concept of operations, Phase 2 proposal and SOW
- Initial discussions with international partner contributions

2015-2016

Hab Development Phase 2

Continue concept refinement and development of domestic ground prototype module(s) and lead the development of standards and common interfaces (US/International)

• Contractor (NextSTEP Phase 2): Concept description with concept of operations, provide Phase 3 proposal and SOW, delivery of ground prototype module(s)

• NASA: Define reference habitat architecture based on contractor and international concepts and identified GFE in preparation for Phase 3

2016 - 2018

Hab Development Phase 3

- Determine acquisition approach including domestic and international partnerships
- Development of Deep Space Habitat for Proving Ground Phase 1 Objectives
- Deliverables include Flight Unit(s) (note may be multiple modules integrated via common interfaces and standards)

2018+

Ends with Industry Developed Concepts – Decision on contract(s) continuation Ends with: 1) Domestic Developed Ground Prototype Module performing integrated tests, 2) identified standards and common interfaces, 3) identification of NASA provided GFE-Decision point on contract continuation and focus, and 4) Understanding of International Contribution potential

Ends with Deployment and Operational Status of Deep Space Habitation and Habitation Systems

NextSTEP Habitation Overview



Cislunar habitation concepts that leverage **NextSTEP Phase 1:** 2015-2016 commercialization plans for LEO









FOUR SIGNIFICANTLY DIFFERENT CONCEPTS RECEIVED

Partners develop required deliverables, including concept descriptions with concept of operations, NextSTEP Phase 2 proposals, and statements of work.

NextSTEP Phase 2: 2016-2018

BOEING



- Partners refine concepts and develop ground prototypes.
- NASA leads standards and common interfaces development.

ONE CONCEPT STUDY



Initial discussions with international partners





Define reference habitat architecture in preparation for Phase 3.

Phase 3: 2018+

- · Partnership and Acquisition approach, leveraging domestic and international capabilities
- Development of deep space habitation capabilities
- Deliverables: flight unit(s)

Standards Development Approach



- Standards development approach is acquisition strategy neutral
- An iterative process to develop a set of standards that will include external feedback from industry and the International Partners
- Established a Habitation Capability Standards Working Group (WG) led by the International Space Station (ISS) and Advanced Exploration Systems (AES) Divisions with support from the Technical Authorities (TA) to define a suite of standards
- Technical Authority Standards: Used HEOMD-CSD-10001 standards as guide, taking into account aspects of deep space mission to assess applicability
- High Priority Interoperability Standards: Future Capabilities Team continuing work with International Partners
- The Associate Administrator for HEOMD will be the approving authority for the standards

NextSTEP BAA Habitation GFE Areas

• In Line GFE – Contractor Specific

Cross Cutting GFE

- ECLSS
- Avionics
- Softgoods Testing
- Window Material Database
- Radiation Analyses
- Exercise Equipment
- Ground Testing



Develop a deep space habitat for ground-based testing by 2018, while simultaneously stimulating commercial habitat development in LEO

- Develop long-duration deep-space habitation <u>capabilities</u> that lead towards a deep-space transit habitat and can be flown on SLS flight(s) (or alternative launch vehicles) starting by the early to Mid 2020s.
- Advance the long duration deep space habitation capability concepts and mature the design and development of the integrated system(s) to achieve a high level of fidelity.
 - Developing prototype deep space habitation capability options to test a full size ground prototype unit(s) by the end of Phase 2 in 2018 to support first flight opportunities in Early to Mid 2020s
- Potential for different capabilities from domestic and international suppliers will require standards and common interfaces for aggregation. NASA led standards working group will be implemented during Phase 2.



Ground Prototype units delivered to NASA for testing and integration of NASA developed habitation systems

- Testing includes form, fit, volumetric, subsystem integration, and interface standards
- May use NASA-developed node/airlock and hab mockups for integration testing with contractor modules
- Ensures consistent test and interface verification approach, allows us to incorporate and test other AES subsystems, facilitates crew training and feedback on human factors, shows stakeholders progress

Ground Testing Execution Plan





NextSTEP Phase II Bigelow Aerospace B330 / XBASE





OBJECTIVES & TECHNICAL APPROACH

- 330 m³ habitat that will attach to the ISS as a testing platform for deep space exploration technologies and procedures.
- Technical approach includes refinement of the concept of operations, a series of tests including structural tests and ECLSS prototype tests, full scale prototype development activities, and integration studies in Virtual Reality.
- Phase II will involve active support from Bigelow Aerospace for standards and common interfaces working groups.

TEAM

- Robert Bigelow: President of Bigelow Aerospace / Program Manager
- Colm Kelleher, PhD: Deputy Program Manager and Chief Scientist ECLSS
- Lisa Thomas: Deputy Program Manager
- Uy Duong: Deputy Program Manager Structures

KEY ATTRIBUTES

- Provides opportunity to develop and test an inflatable-based integrated deep-space Spaceship that incorporates new structures and exploration capabilities (e.g. Liquid Processing System, CO2 Removal systems)
- · Supports both LEO Commercialization and future human exploration mission objectives
 - Provides opportunity to test NASA exploration class ECLSS and other exploration systems while docked to ISS
 - Once exploration systems validated, the module could then be detached from ISS and become a LEO free flyer and continue to test exploration systems while supporting commercial needs
 - Second copy of module could be developed as the Spaceship Habitat and flown to Spaceport for assembly and outfitting
- 2018 Ground Test to be performed at BA facilities

NextSTEP Phase II The Boeing Company





TEAM

- Boeing leads a global team of companies, each contributing valuable habitat systems experience, subject matter expertise, and services
- The Boeing NextSTEP-2 team includes support from NASA centers, including JPL, JSC, KSC, and MSFC
- Boeing has engaged industry and university partners focused on advanced concepts and exploration technologies for joint study and collaboration

KEY ATTRIBUTES

- Concept uses existing technology
 - Already developed ISS assets
 - Boeing's commercial GEO satellite bus for power/propulsion module
- Provides innovative modular approach for subsystem integration into habitat module
- · Performs long duration missions in cislunar space when fully assembled
- Good leverage of NASA workforce
- 2018 Ground Test to be performed at MSFC facilities

OBJECTIVES

Develop input to NASA's reference architecture for long duration, deep space human spaceflight exploration missions and develop habitation element concepts for cislunar space

- Build a full scale ground demonstrator prototype habitat
- Define standards and common interfaces
- Describe intersections between the NextSTEP-2 partnership and industry interest in commercial activities in LEO

TECHNICAL APPROACH

- Design and analyze modular habitation system concepts and assess requirements relative to NASA's exploration architecture
- Validate designs and interface standards
- Test habitat functionality in Boeing's full scale ground prototype demonstrator



NextSTEP Phase II Lockheed Martin





OBJECTIVES

- Refine design concept over three design and analysis cycles. Utilize virtual prototyping in order to rapidly iterate on core design. Incorporate lessons learned from IWG and prototype builds. Identify LEO and cislunar commercialization intersections.
- · Work with NASA to define common interface standards.
- Refurbish NASA provided MPLM as a full-scale habitat module prototype, with integrated avionics and ECLSS, to provide risk reduction and form/fit testing.
- Prove out command and data handling between HSV and Orion. Demonstrate crew interface commonality between DSTH and Orion.
- Build and test a high-fidelity prototype to demonstrate the integrated habitat and Orion operations and to characterize subsystem performance, interactions, and behaviors when the modules share a common atmosphere.

KEY ATTRIBUTES

- · Provides a concept using existing technology
 - Use existing ISS assets (e.g., MPLM) for the primary module concept
 - Leverages LM's commercial and deep space bus heritage for power/propulsion module
 - Uses Orion command and control capability to leverage NASA investment
- Concept provides innovative approach for EVA module and airlock functions
- Once fully assembled, can perform long duration missions in cislunar space, serving as a lunar space portal and construction platform for Mars elements (flexible design)
- Provides good leverage of NASA workforce
- 2018 Ground Test to be performed at KSC facilities
 - Leverages ISS Donatello MPLM as prototype module

TEAM

- Lockheed Martin: Prime contractor responsible for entire system concept and prototypes
- Thales Alenia Space Italy: Habitat module primary and secondary structure
- **ILC Dover:** ECLSS engineering services, EVA, inflatable technologies integration
- Thin Red Line Aerospace: Inflatable Technologies
- Airbus Defense & Space: Habitat science integration lunar surface exploration, advanced habitation systems integration
- Made in Space: in-space material recycling
- MDA: Habitat robotic systems
- NASA JSC: ECLSS, EVA, power avionics and software, crew displays and controls
- NASA LaRC: Radiation mitigation and inflatable technologies

NextSTEP Phase II Orbital ATK





OBJECTIVES

Develop long-duration deep space habitation capabilities that enable the deployment of a deep space transit habitat in the early 2020s

- Advance the long duration deep space habitation system concepts and mature the design and development of the integrated system(s)
- Apply standards and common interfaces defined by the NASA-led standards working group during Phase 2
- Develop high fidelity ground prototype units and deliver to NASA for additional testing and integration
- Further define and develop deep space habitation and logistics capabilities that can be flown as co-manifested payloads on SLS Block 1 B or on other independent launch vehicles
- Identify options to maximize NASA and commercial LEO opportunities such as demonstration missions at the ISS or in cislunar space

KEY ATTRIBUTES

- Designed to perform long duration missions in cislunar space
- · Utilizes existing technology in vehicle design
- Leverages Orbital ATK's human-rated and operational commercial cargo spacecraft
- Provides innovative approach for EVA module and airlock functions
- Supports 2018 Ground Test to be performed at NASA facilities
- Evolvable to support future Exploration needs



NextSTEP Phase II Sierra Nevada Corporation





KEY ATTRIBUTES

- New to NextSTEP Hab activity will have to accelerate concept refinement to meet milestones
- Provides innovative solution for deep space habitation
 - Leverages off of SNC's cargo resupply development activities
 - Uses advanced inflatable materials for habitat
 - Flies initial habitat to ISS for assembly and check-out and then meets up with remaining elements in LEO and is then sent to cislunar space
- 2018 Ground Test to be performed at JSC facilities

OBJECTIVES & TECHNICAL APPROACH

- Matures and refines SNC's deep space habitat concept through system trades and full-scale ground prototyping and testing
- Leverages a modular and flexible architecture that builds on NextSTEP-1, CRS2 and cooperative commercial investments.
- Requires four launches to complete the mission; able to co-manifest with SLS/CRS2 or utilize commercial launch vehicles to provide NASA flexibility in assembling habitat that supports Orion mission timelines
- Uses mature system building blocks and evolving capabilities to achieve long-duration mission objectives
- Includes ongoing technology evaluation to further LEO and deep space commercialization

TEAM

- **SNC** CCDev, CCiCap, and CRS2 contracts with NASA to deliver a human-rated flight systems for LEO
- ORBITEC SNC business unit, provides ECLSS subsystem for CRS2 contract, and also awarded NextSTEP-1 contract to develop a habitat plant growth system.
- Aerojet Rocketdyne Awarded NextSTEP-1 contract to advance electric propulsion capabilities through EP thruster development
- ILC Dover Applies TransHab, Lunar Habitat Study and Resilient Tunnel Plug technology to develop inflatable habitat for SNC's concept
- NASA LaRC Considerate experience with inflatables and longduration radiation mitigation.

NextSTEP Phase II NanoRacks





KEY ATTRIBUTES

- Provides study to look at feasibility of converting spent upper-stages into habitats while in space
- Uses advances in robotics to perform the upper-stage safing and outfitting
- Leverages partners' extensive knowledge in robotics, launch vehicle upper-stages, and commercial use of low-earth-orbit
- Concept provides innovative approach for development of future large habitats at a potentially great cost savings
- Study will finish in four months, contractor to continue afterwards to support interface and standards working group
- · Activity will not result in development of a ground prototype unit

OBJECTIVES

- Leverage proven, affordable, and safe flight hardware by converting a Centaur and other rocket stage into a habitat;
- Perform feasibility assessment of habitat outfitting via robotics;
- Transform the LEO commercial marketplace by combining Nanoracks and SSL's unique private sector experience and customer base for next-generation orbital satellite manufacturing, assembly, and deployment; space tourism; media activities; and orbital experiments.
- Explore cost/benefit analysis in differing space regimes of this proposed approach in comparison to other current approaches/technologies

TEAM

- NanoRacks, LLC
 - Prime contractor, habitat systems design, LEO commercial operations
- Space Systems Loral
 - Robotics, Solar Electric Propulsion, LEO/GEO commercial satellite manufacturing
- United Launch Alliance
 - Centaur tank, launch services, and mission design

Deep Space Habitation Systems





Bigelow Expandable Activity Module (BEAM): Test of inflatable module structures on ISS (JSC).



Atmosphere Resource Recovery & Environmental Monitoring: Integrated ground testing of ISS-derived life support system components (MSFC).



Water Recovery: Development of processes and systems for recycling wastewater (JSC).



Radiation Protection: Development and testing of radiation sensors and shielding (JSC).



Logistics Reduction: Waste processing to reduce logistics mass (JSC).



Spacecraft Fire Safety: Flight experiment on Cygnus to investigate how largescale fires propagate in microgravity (GRC). 17

Bigelow Expandable Activity Module – 2 Year Demonstration Launched April 2016 • Installed May 2016



Module is performing as expected

- Maintaining pressure
- Radiation readings indicate
 Galactic Cosmic Ray exposure
 is same as other space station
 modules
- Thermal analysis shows module is slightly warmer than predicted, but does not pose any risk to crew or station.



- Eight ingresses as of March 2017. Astronauts conduct modal tests, take microbial samples, and inspect structural stability.
- Ground stations regularly receive data, which is analyzed by the NASA and Bigelow Aerospace teams.
- Forward focus is on continued radiation exposure analysis and orbital debris data.

Life Support Systems



Currently in Development for Demonstration on ISS

- Aerosol Sampler: Demonstration of modified COTS Aerosol Sampler on ISS to gather quantitative data on ambient air quality (launched Oct. 2016). Collected samples will be returned on SpaceX-10.
- Brine Processor: Demonstration of Ionomer Membrane Water Processor to purify and recover 98% of the available water from brine (Aug. 2018).
 - \$5.1M Phase 3 SBIR contract awarded to Paragon (Jun. 2016).
 - Completed System Design Review (Oct. 2016).
- Spacecraft Atmosphere Monitor: Demonstration of miniature mass spectrometer for detecting trace gas contaminants in ISS air (Jun. 2018).
 - Completed System Design Review (Apr. 2016)
 - Next milestone: Complete development model (Feb. 2017)
- **Demonstrator for Ionized Inert Gas**: Investigate the effects of microgravity on an inert gas plasma. This information will be used to design a plasma pyrolysis reactor that will recover hydrogen from methane (Oct. 2018).



Aerosol Sampler



Brine Processor



Spacecraft Atmosphere Monitor

NextSTEP Life Support Systems





Dynetics:

- Miniature atmospheric scrubbing system to remove CO₂.
- Fabricated separation units for laboratory test bed.
- Planning ISS demo.
- <u>FY17 Milestone</u>: Complete fifth generation design for CO₂ separation.



UTC Aerospace Systems:

- Study of modular life support system concepts.
- Planning to incorporate AES-developed life support system into modular pallet design.
- <u>FY17 Milestone</u>: Deliver mockup pallet for verifying interfaces with prototype habitats.



Orbitec:

- Hybrid life support system using plant growth modules in habitat wall.
- Completed prototype "Greenwall" plant growth module.
- Featured in Nov. issue of *National Geographic*.
- <u>FY17 Milestone</u>: Identify flight equivalent materials.

Expect to award Phase 2 contracts for all three projects in March.

Radiation Sensors (RadWorks)



- Launched Fast Neutron Spectrometer (FNS) on OA-5 mission and activated on ISS. FNS will measure the energy of secondary neutrons generated when galactic cosmic rays interact with the spacecraft structure.
- Completed validation testing of Hybrid Electronic Radiation Assessor (HERA) being developed for EM-1 and EM-2. Sensors were exposed to helium, carbon, and proton beams at NASA Space Radiation Lab.
- RadWorks will provide radiation transport modeling and analysis support to NextSTEP-2 contractors developing prototype cislunar habitats.
- The Radiation Assessment Detector (RAD) has operated for 1585 sols on Mars. The radiation dose rate has increased 35% since the summer of 2015 due to decrease in the solar cycle.



Fast Neutron Spectrometer



Hybrid Electronic Radiation Assessor (HERA)



Logistics Reduction



- The Radio Frequency Identification Enabled Autonomous Logistics Management (REALM-1) will be used to track inventory and locate missing items quickly.
 - REALM-1 hardware (RFID hatch readers, antennas, and cables) was launched to ISS on Dec. 9. and installed in late Jan.
- The Universal Waste Management System (UWMS) is a compact toilet being developed for ISS, Orion, and deep space habitats.



REALM-1 flight reader (1 of 6)



Saffire-I, II, and III Overview



Needs:

- Low-g flammability limits for spacecraft materials
- Definition of realistic fires for exploration vehicles
 - Fate of a large-scale spacecraft fire

Objectives:

- ✓ Saffire-I: Assess flame spread of largescale microgravity fire (spread rate, mass consumption, heat release)
- ✓ Saffire-II: Verify oxygen flammability limits in low gravity
- Saffire-III: Same as Saffire-I but at different flow conditions.

Data obtained from the experiment will be used to validate modeling of spacecraft fire response scenarios

• Evaluate NASA's normal-gravity material flammability screening test for low-gravity conditions.



Saffire module consists of a flow duct containing the sample card and an avionics bay. All power, computer, and data acquisition modules are contained in the bay. Dimensions are approximately 53- by 90- by 133-cm

Saffire-IV, V, and VI Overview



Needs:

- Demonstrate spacecraft fire detection, monitoring, and cleanup technologies in a realistic fire scenario
- Characterize fire growth high O₂/low pressure atmospheres
- Provide data to validate models of realistic spacecraft fire scenarios

Objectives:

- Saffire-IV:Assess flame spread of largescale microgravity fire (spread rate, mass consumption, heat release) in exploration atm
- Saffire-V: Evaluate fire behavior on realistic geometries
- Saffire-VI:Assess existing material configuration control guidelines
- All flights will demonstrate fire detection, monitoring, and cleanup technology



Conceptual design of Saffire-IV-VI experiment module. Dimensions are approximately 53- by 90- by 133-cm.

additions from previous Saffire include side view of sample card and oxygen addition.



Spacecraft Fire Safety: Saffire-II

- The Saffire-II fire safety flight experiment was successfully conducted on board the Cygnus vehicle after it undocked from ISS on Nov. 21.
- The experiment investigated the flammability of nine material samples consisting of four different materials: Silicone, PPMA (acrylic), SIBAL (cotton on fiberglass substrate), and Nomex. Over 38 Gb of image and sensor data were received.
- The silicone samples of varying thickness ignited but did not burn as anticipated based on flammability testing conducted at 1-g. The PPMA samples burned for 12 minutes. The flame spread rates for the SIBAL cloth samples were comparable to Saffire-I.



• Saffire-III launch scheduled for OA-7.

Environmental Control & Life Support Systems Maturation Team Status

NASA

HEO NAC, March 29, 2017 Robyn Gatens | Deputy Director, ISS Division | NASA HQ

Specific Deep Space Habitation Systems Objectives



Specific Habitation Systems Objectives





Exploration ECLSS Diagram





ECLSS & Environmental Monitoring Capability Gaps



Function	Capability Gaps	Gap criticality as applicable to μg transit Hab	Orion Need
CO ₂ Removal	Bed and valve reliability; ppCO ₂ <2 mmHg	5	
O ₂ recovery from CO ₂	Recover >75% O_2 from CO_2	5	
Urine brine processing	Water recovery from urine brine >85%	5	
Metabolic solid waste collection	Low-mass, universal waste collection	5	X
Trace Contaminant Control	Replace obsolete sorbents w/ higher capacity; siloxane removal	4	X
Condensing Heat Exchanger	Durable, chemically-inert hydrophilic surfaces with antimicrobial properties	4	
Water microbial control	Common silver biocide with on-orbit redosing	4	
Contingency urine collection	Backup, no moving parts urine separator	4	X
Urine processing	Reliability, 85% water from urine, dormancy survival	4	
Atmosphere monitoring	Small, reliable atmosphere monitor for major constituents, trace gases, targeted gases	4	X
Water monitoring	In-flight identification & quantification of species in water	4	
Microbial monitoring	Non-culture based in-flight monitor with species identification & quantification	4	
O ₂ generation	Smaller, reduced complexity, alternate H ₂ sensor	3	
High pressure O ₂	High pressure (3000 psi) O_2 for EVA/on-demand O_2 supply for contingency medical	3	
Wastewater processing (WPA)	Reliability (ambient temp, reduced pressure catalyst), reduced expendables, dormancy survival	3	
Non-metabolic solid waste	Volume reduction, stabilization, resource recovery	3	
Particulate monitoring	On-board measurement of particulate hazards	3	
Particulate Filtration	Surface dust pre-filter; regen filter	2	
Atmosphere circulation	Quiet fans	2	
Logistics Reduction	10:1 volume reduction logistical and clothing	2	
Metabolic solid waste treatment	Useful products from metabolic waste	1	

Exploration ECLSS Roadmap





Current Status – Atmosphere Management



CO2 Removal

- Have initiated work on early thermal amine ISS flight demo targeted for 2018
- Downselect among all options planned end of 2017
 - Using NRA thrust area announcement to ensure all options considered

Oxygen Generation & High Press O₂

 Testing to reduce complexity complete; team to assess ISS OGA recommended upgrades as a result

Oxygen Recovery/CO₂ Reduction

- STMD awarded two Phase II oxygen recovery projects:
 - Honeywell methane pyrolysis
 - Umpqua continuous Bosch
- NASA development of methane plasma pyrolysis continues
- ISS on-orbit Sabatier degrading; planning for return and troubleshooting
 - 2 of 3 oxygen recovery options include Sabatier

Current Status – Atmosphere Management, cont.



Condensing Heat Exchanger

- Several options under assessment with downselect in early FY19 for flight demonstration
- Received NRA thrust area proposals SMT evaluating
- Trace Contaminant Control
 - Alternate commercial sorbent testing
 - Supporting efforts to solve ISS siloxane problem
- Particulate Filtration
 - Pre-filter and regenerable filter development ongoing

Current Status – Water Management

Urine processing

- New pretreat formula on ISS improves recovery to 85-90%
- Pump reliability improved by change to planetary gear
- Improvements to distillation assembly in work

Water processing

- Improved catalyst development
- Operational filter life extension
- Alternate technology/reverse osmosis testing & trade

Brine processing

- ISS flight demonstration by Paragon in development - flies in 2018



- development of on orbit injection capability through SBIR projects







Progress – Waste Management

• Commode

- Universal waste management system for ISS demo & Orion (2018) – ISS working integration for permanent ISS installation side by side with current Waste & Hygiene Compartment/Russian Commode
- Minimum mass fecal container development
- Fecal processing
 - Torrefaction SBIR development
- Trash management
 - Heat melt compactor and trash to gas development
- Logistics Reduction
 - Long wear clothing demonstrated on ISS
 - Repurposing of packaging and cargo bags









• RFID Enabled Autonomous Logistics Management (REALM)

- 6 RFID readers and 24 antennas (REALM-1) were launched on HTV6 in December and deployed in February
- Successfully demonstrated end-end data transfer and down linked over 600 million tag reads from over 3,000 unique tags
- Responded to unplanned real-time ISS request to locate missing cargo bag slated for SpX-10 return. Manually searched data to predict missing bag location which demonstrated 'find' capability
- A mobile RFID reader (REALM-2) for the Astrobee free flyer is under development



Location of 24 REALM-1 antennas in Node 1, US Lab, and Node 2



Astronaut Peggy Whitson installing 1 of 24 REALM-1 antennas (tan square in her left hand) 38

Current Status – Environmental Monitoring



Atmosphere Monitoring

- Spacecraft Atmosphere Monitor (SAM) micro GC/MS for major constituents and trace gases ISS tech demo planned (2018)
- Laser-based monitors for combustion products and targeted gases planned for Saffire demonstration, upgrade of ISS combustion products monitor and Orion Anomaly Gas Analyzer implementation
- Improved mass spec for ISS & Orion use
- Water Monitoring
 - Requirements in development
 - Front end to atmosphere monitor for water samples



Development Model of the Spacecraft Atmosphere Monitor (Front-View)

Current Status – Environmental Monitoring, cont

Microbial Monitoring

• RAZOR

- COTS Polymerase Chain Reaction (PCR) unit launched to ISS in July 2016 aboard SpX-9 – detect & identify microorganisms
- First device to perform quantitative PCR using ISS water samples in the microgravity environment of space – "sample to answer"
- 9 successful test runs completed Sept
 2016 March 2017
- Mini-PCR DNA sequencer demonstrated on ISS as part of Genes in Space



Flight testing of RAZOR hardware on 9/20/2016. NASA image iss049e007041





COTS Oxford Nanopore Technologies MinIONTM DNA Sequencer

Current Status – Environmental Monitoring, cont

Particulate Monitor

- Aerosol sampler (flown on OA-5) just completed ISS ops, samples stowed for return on SpaceX-10.
 - Analysis will begin immediately upon return and will include a variety of microscopic techniques to determine particle morphology, composition, and long-term average concentrations
 - Data will inform the design of particulate monitors for future longterm missions
- SBIR particulate monitor development



Progress – ISS Integration



- ISS actively working on integration concepts for Exploration ECLSS
 - Water system will be evolution of current ISS Water Recovery System in Node 3
 - Upgrades to WPA and UPA could require retrofit in a rack space nearby
 - Air system must be co-located and may incorporate new CO2 removal/reduction technologies – plan is to move to USL as Node 3 cannot accommodate this string
 - Oxygen Generation System rack must move to USL to enable integration in adjacent rack space(s)
 - Will require racks in USL to be moved to other locations



Next Steps



- Team is currently refining budget estimates and detailed plans
- Working with International Partners through the I-SMT
 - ECLSS Interoperability standards (e.g. atmosphere quality, water quality)
 - Following partner activities and planned ECLSS ISS demonstrations
- Continue to execute Exploration ECLSS plan!

