NASA System Maturation Teams: ECLSS & Environmental Monitoring

ASEB, Oct 2016

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Human Exploration and Operations Mission Directorate

Background: Creation of SMT's in 2013

National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

August 13, 2013

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Directors, NASA Center

FROM: Associate Administrator for Human Exploration and Operations

SUBJECT: Establishment of NASA System Maturation Teams

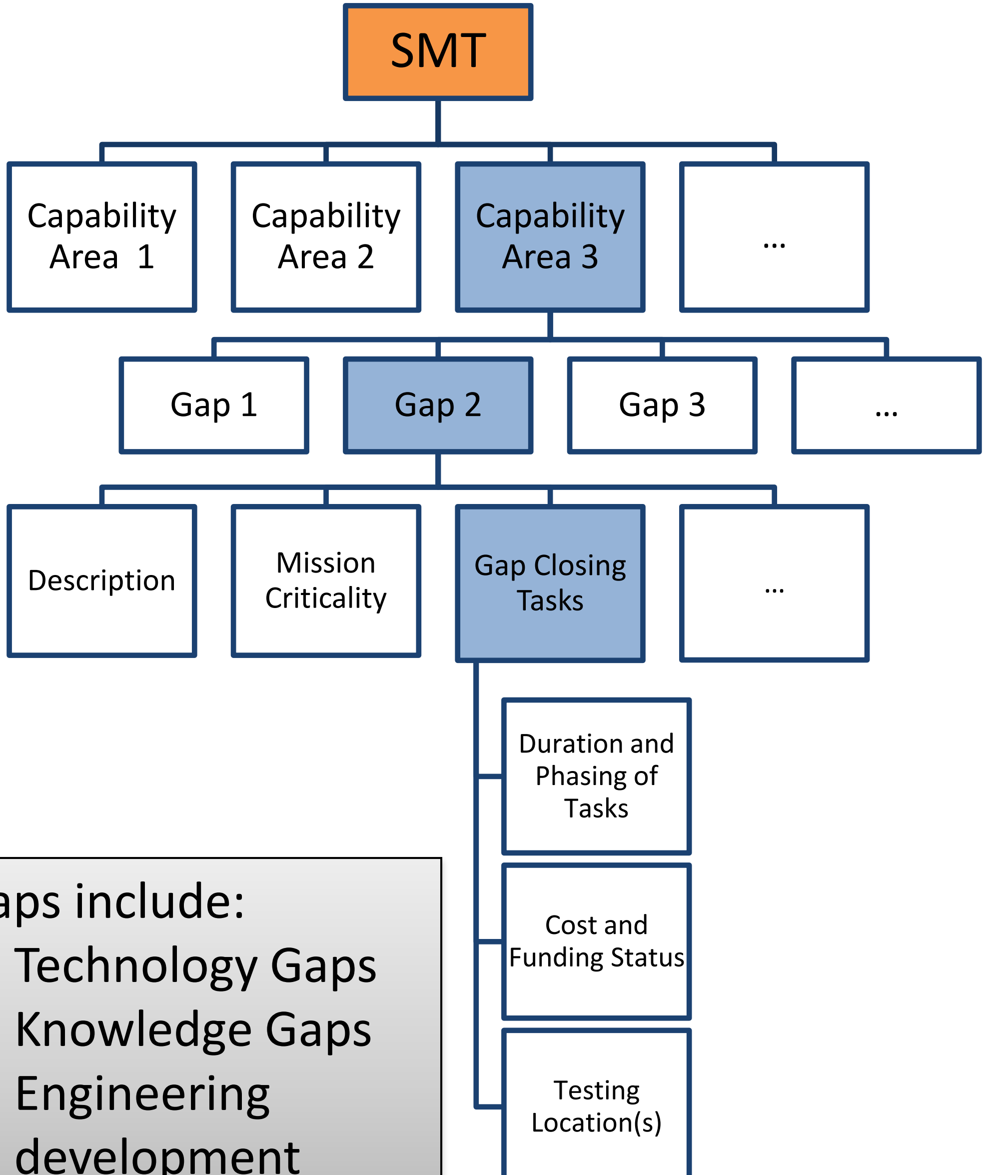
NASA Human Exploration and Operations Mission Directorate (HEOMD) is implementing a capability driven approach to future missions. This capability driven approach provides a framework through which architecture planning can be used to identify critical technology goals. This information, coordinated with the international partner critical technology goals identified in the Global Exploration Roadmap provides a strong foundation for HEOMD strategic planning and investment recommendations in preparation for future human space exploration. The Advanced Exploration Systems (AES) office within HEOMD has been tasked with leading a directorate wide team to develop system maturation roadmaps defining required improvements in design and operability for spaceflight systems to support the needs for future human space exploration. In addition, operation in a spaceflight environment such as on the International Space Station (ISS), when beneficial, should be used to prove the necessary reliability and operating parameters for future missions. These roadmaps will also provide a good foundation for the HEOMD input to the Office of the Chief Technologist technology development roadmap updates scheduled for release next year.

To guide this capability definition, HEOMD is establishing System Maturation Teams (SMT). The purpose of each multi-Center SMT will be to fully develop a roadmap that defines the activities required to advance critical capabilities, the means of demonstrating system performance, and the implementation planning to achieve the steps of the roadmap. These teams will also serve as ongoing subject matter expert teams that will be responsible for providing technical reviews of incoming proposals, recommendations for integrated ISS and ground tests, and inputs to the budget process for their respective areas. The teams will be augmented as required by tasks assigned. For example, international partner representatives may be added to the team to assess the capabilities from a global context. SMT status will be briefed periodically at HEOMD Directorate Program Management Council meetings across the year.

Recognizing that the expertise to accomplish this task is resident across the agency, the candidates to lead the SMTs, identified in the attachment to this letter, have been selected from across the centers. These candidates have been briefed on the goals of the SMT and are in the process of identifying their full team membership across the agency. I request your

- **The purpose of each multi-center SMT is to fully develop a roadmap that defines**
  - Measures of system performance required to execute future missions
  - The activities required to advance critical capabilities
  - The means of demonstrating system performance
  - The implementation planning to achieve the steps of the roadmap
- **The teams also serve as ongoing subject matter expert teams that are responsible for**
  - Providing technical reviews of incoming proposals
  - Recommendations for integrated ISS and ground tests
  - Inputs to the budget process for their respective areas

System Maturation Teams



Gaps include:

- Technology Gaps
- Knowledge Gaps
- Engineering development

System Maturation Team (SMT)
Autonomous Mission Operations (AMO)
Communications and Navigation (Comm/Nav)
Crew Health & Protection - Radiation
Environmental Control and Life Support Systems and Environmental Monitoring (ECLSS-EM)
Entry, Descent and Landing (EDL)
Extravehicular Activities (EVA)
Fire Safety
Human-Robotic Mission Operations
In-Situ Resource Utilization (ISRU)
Power and Energy Storage
Propulsion
Thermal Systems
Avionics (Discipline Team)
Structures, Mechanisms, Materials and Process (SMMP) (Discipline Team)

Human Space Exploration Phases

Today

Phase 0: Exploration Systems ***Testing on ISS***

Ends with testing, research and demos complete*

Phase 1: ***Cislunar Flight Testing*** of Exploration Systems

Asteroid Redirect-Crewed Mission Marks Move from Phase 1 to Phase 2

Phase 2: ***Cislunar Validation*** of Exploration Capability

Ends with one year crewed Mars-class shakedown cruise

Phase 3: Crewed Missions Beyond Earth-Moon System

Phase 4a: Development and robotic preparatory missions

Phase 4b: Mars Human Landing Missions

Proving Ground

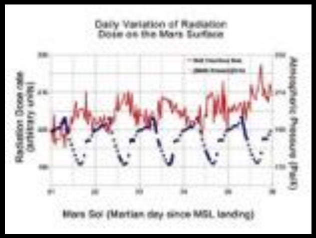
2016 | 2020 | 2030

* There are several other considerations for ISS end-of-life

The Habitation Development Challenge

800-1,100 Days

Total time crew is away from Earth – for orbit missions all in Micro-g and Radiation



Long Surface Stay

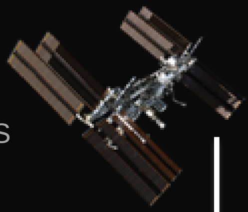
500 Days

HABITATATION CAPABILITY

Habitation Systems – AES/ISS/STMD

- Environmental Control & Life Support
- Autonomous Systems
- EVA
- Fire Safety
- Radiation Protection

Integrated testing on ISS



Habitation Systems - Crew Health – HRP

- Human Research
- Human Performance
- Exercise
- Nutrition

PROVING GROUND

Validation in cislunar space

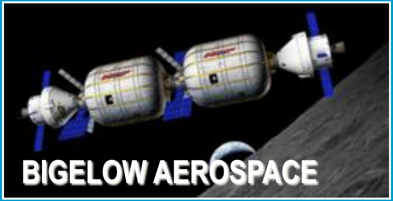
Habitation Capability– NextSTEP BAA / Int. Partners

- Studies and ground prototypes of pressurized volumes

NextSTEP Habitation Overview

NextSTEP Phase 1: 2015-2016

Cislunar habitation concepts that leverage commercialization plans for LEO

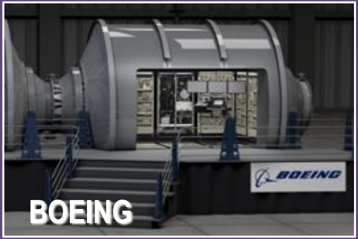


FOUR SIGNIFICANTLY DIFFERENT CONCEPTS RECEIVED

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

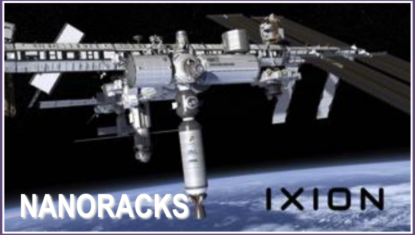
NextSTEP Phase 2: 2016-2018

FIVE GROUND PROTOTYPES BY 2018



- 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)

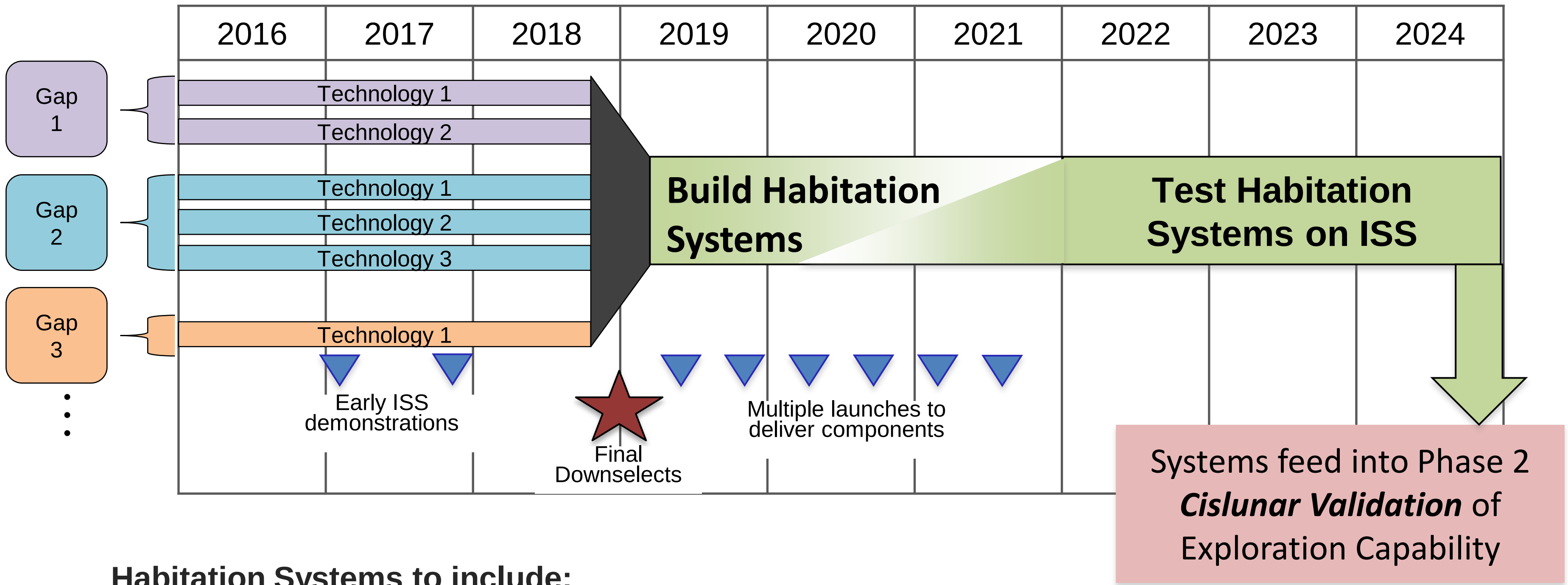
Specific Habitation Systems Objectives

Habitation Systems Elements

The systems, tools, and protections that allow humans to live and work in space and on other worlds.

#	Habitation Systems Elements	TODAY: ISS	FUTURE: Deep Space
1	**LIFE SUPPORT**: Atmosphere Management, Water Management, Waste Management, Food Management	42% O_2 Recovery from CO_2 90% H_2O Recovery < 6 mo mean time before failure (for some components)	75%+ O_2 Recovery from CO_2 98%+ H_2O Recovery >30 mo mean time before failure
2	**ENVIRONMENTAL MONITORING**: Pressure, O_2 & N_2; Moisture; Particles; Microbes; Chemicals; Sound	Limited, crew-intensive on-board capability Reliance on sample return to Earth for analysis	On-board analysis capability with no sample return Identify and quantify species and organisms in air & water
3	**CREW HEALTH**: Monitoring, Exercise, Diagnostics, Treatment, Food Storage	Bulky fitness equipment Limited medical capability Frequent food system resupply	Smaller, efficient equipment Onboard medical capability Long-duration food system
4	**RADIATION PROTECTION**: Monitoring, Tracking, Modeling, Mitigation	Node 2 crew quarters (CQ) w/ polyethylene reduce impacts of proton irradiation. RAD, REM – real-time dosimetry, monitoring, tracking, model validation & verification TEPC, IVTEPC – real-time dosimetry CPD, RAM – passive dosimeters	Solar particle event storm shelter, optimized position of on-board materials and CQ Distributed REM/HERA system for real-time monitoring & tracking CPAD – real-time dosimeter
5	**FIRE SAFETY**: Detection, Protection, Suppression, Cleanup	Large CO_2 Suppressant Tanks 2-cartridge mask Obsolete combustion prod. sensor Only depress/repress clean-up	Unified, effective fire safety approach across small and large architecture elements
6	**LOGISTICS**: Tracking, Clothing, Packaging, Trash	Manual scans, displaced items Disposable cotton clothing Packaging disposed Bag and discard	Automatic, autonomous RFID Long-wear clothing & laundry Bags/foam repurposed w/3D printer Resource recovery, then disposal
7	**CROSS-CUTTING**: Autonomy, Power, Communication, Docking, Common Interfaces	Minimal on-board autonomy Near-continuous ground-crew comm Some common interfaces, modules controlled separately	Ops independent of Earth & crew Up to 40-minute comm delay Widespread common interfaces, modules/systems integrated

Phase 0 – Habitation Systems Testing on ISS



Habitation Systems to include:

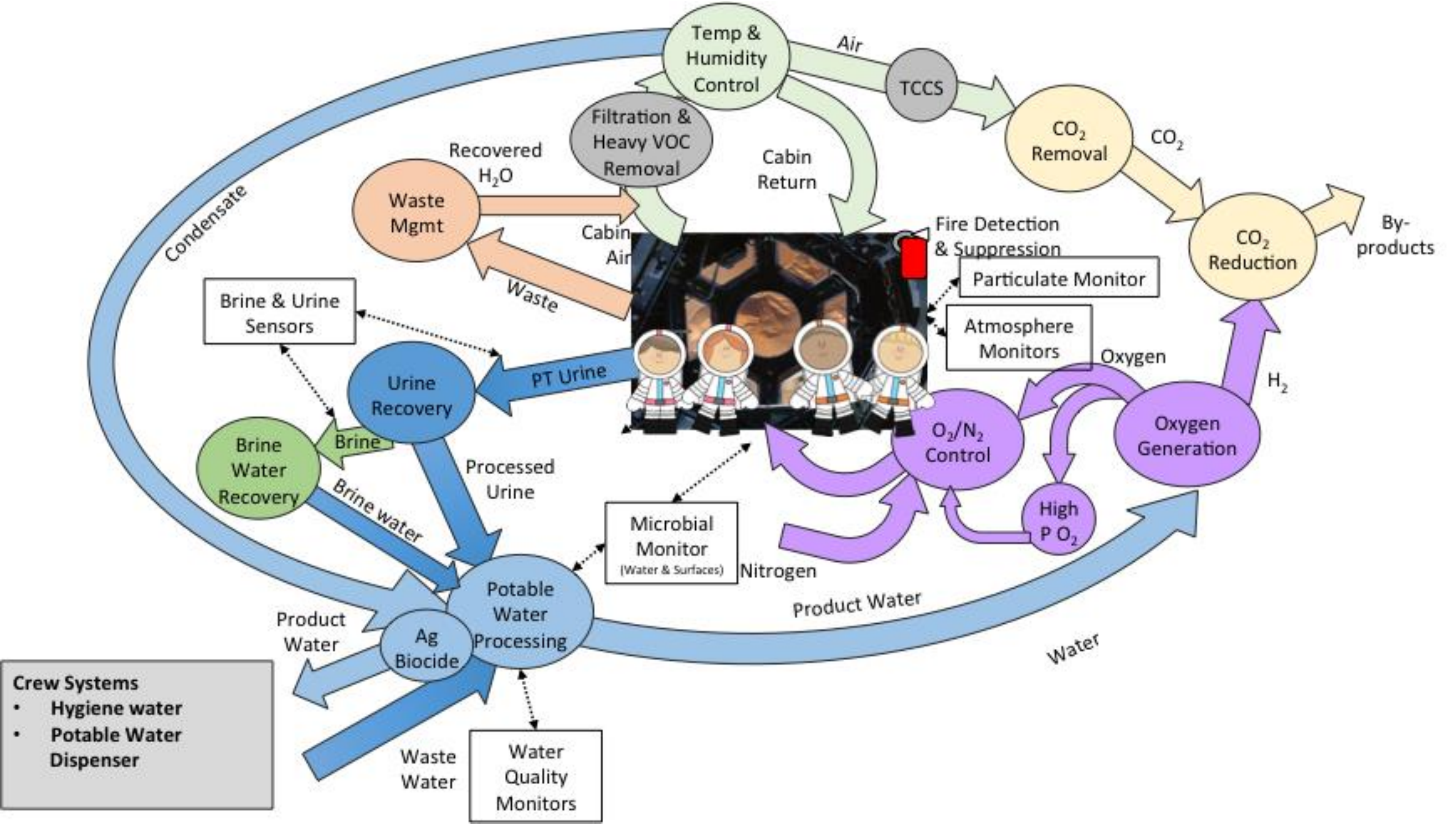
- 4-rack Exploration ECLSS and Environmental Monitoring hardware
- Fire Safety studies and end-to-end detection/suppression/cleanup testing in Saffire series (Cygnus)
- Mars-class exercise equipment
- On-board medical devices for long duration missions
- Long-duration food storage
- Radiation monitoring and shielding
- Autonomous crew operations

Mars is Harder for ECLSS

- Regular resupplies of makeup consumables, spare parts
    - 42% air loop closure
    - 90% water loop closure
    - 6 months of spares
- Return, analyze samples on Earth
- Emergency crew return capability
- Trash disposal

- No resupply
    - 75% air loop closure
    - 98% water loop closure
    - 3 years of spares
- On orbit monitoring
- No emergency crew return
- No trash disposal

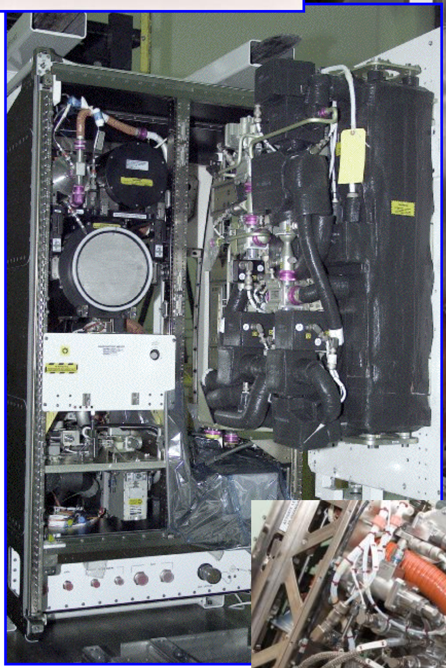
Exploration ECLSS Diagram



Current ISS Capabilities and Challenges: Atmosphere Management

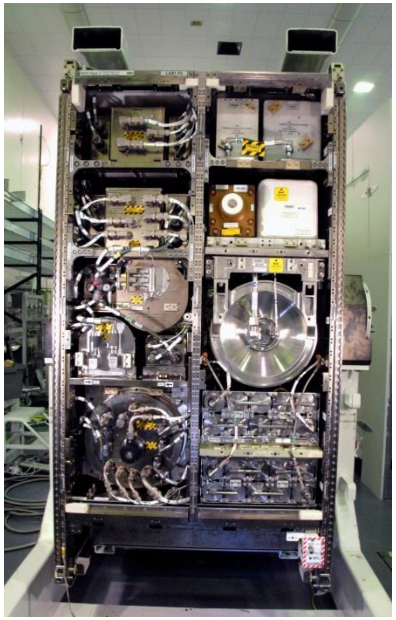
- **Circulation**
  - ISS: Fans (cabin & intermodule), valves, ducting, muffler expendable HEPA filter elements
  - Challenges: Quiet fans, filters for surface dust
- **Remove CO_2 and contaminants**
  - ISS: Regenerative zeolite CDRA, supports ~2.3 mmHg ppCO2 for 4 crew. MTBF <6 months. Obsolete contaminant sorbents.
  - Challenges: Reliability, $ppCO_2$ <2 mmHg, commercial sorbents
- **Remove humidity**
  - ISS: Condensing heat exchangers with anti-microbial hydrophilic coatings requiring periodic dryout, catalyze siloxane compounds.
  - Challenge: Durable, inert, anti-microbial coatings that do not require dry-out
- **Supply O_2**
  - ISS: Oxygen Generation Assembly (H_2O electrolysis, ambient pressure); high pressure stored O_2 for EVA
  - Challenge: Provide high pressure/high purity O_2 for EVA replenishment & medical use
- **Recovery of O_2 from CO_2**
  - ISS: Sabatier process reactor, recovers 42% O_2 from CO_2
  - Challenge: >75% recovery of O_2 from CO_2





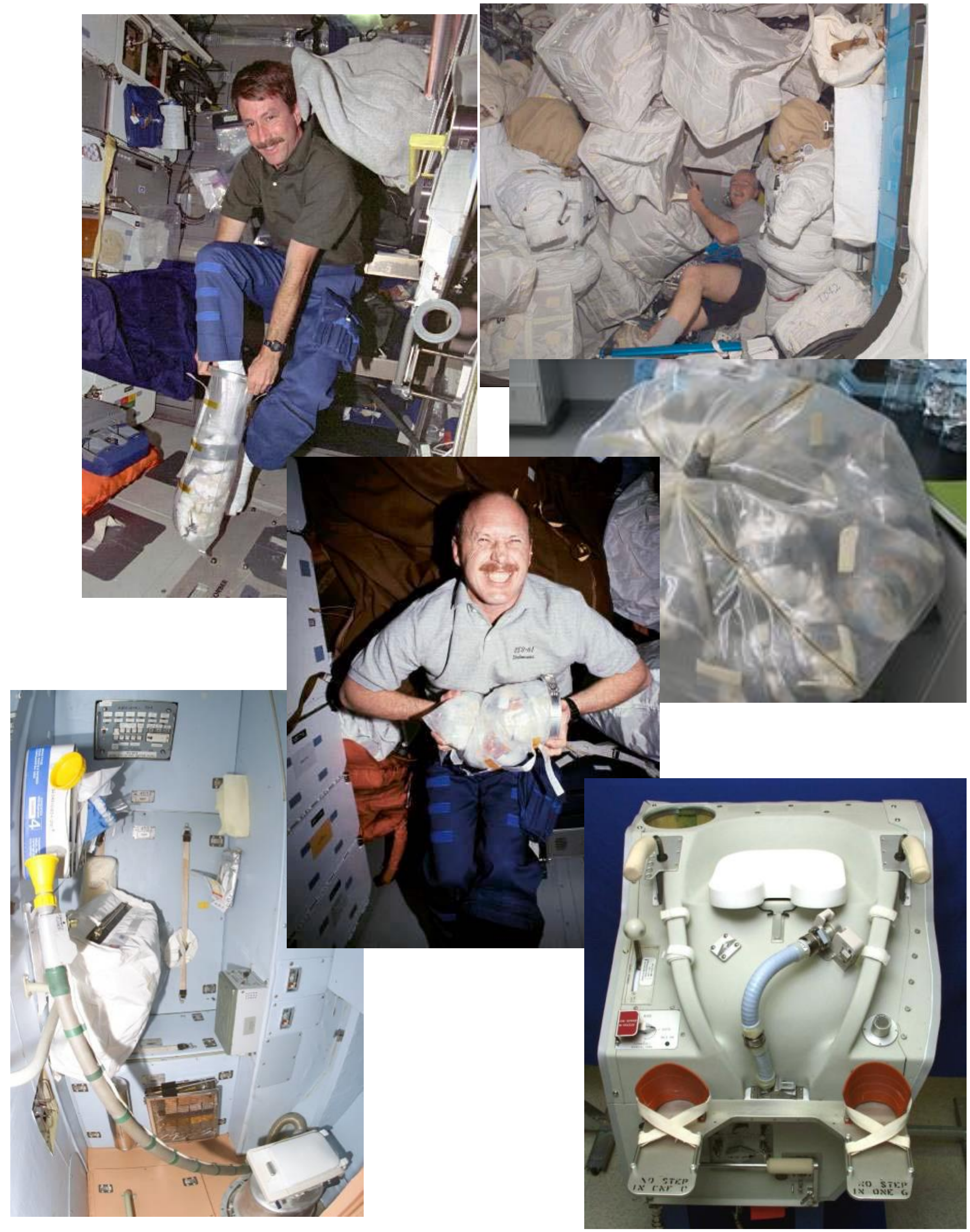

Current ISS Capabilities and Challenges:
Water Management

- **Water Storage & biocide**
  - ISS: Bellows tanks, collapsible bags, iodine for microbial control
  - Challenges: Common biocide (silver) that does not need to be removed prior to crew consumption; dormancy
- **Urine Processing**
  - ISS: Urine Processing Assembly (vapor compression distillation), currently recovers 85% (brine is stored for disposal)
  - Challenges: reliability; recovery of urine brine water
- **Water Processing**
  - ISS: Water Processor Assembly (filtration, adsorption, ion exchange, catalytic oxidation, gas/liquid membrane separators),100% recovery, 0.11 lbs consumables + limited life hw/lb water processed.
  - Challenges: Reduced expendables; reliability



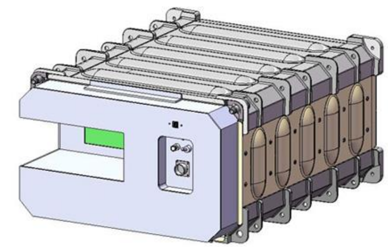
Current ISS Capabilities and Challenges: Waste Management

- **Logistical Waste (packaging, containers, etc.)**
  - ISS: Gather & store; dispose (in re-entry craft)
  - Challenge: Reduce &/or repurpose
- **Trash**
  - ISS: Gather & store; dispose (in re-entry craft)
  - Challenge: Compaction, stabilization, resource recovery
- **Metabolic Waste**
  - ISS: Russian Commode, sealed canister, disposal in re-entry craft
  - Challenge: Long-duration stabilization, potential resource recovery, volume and expendable reduction



Current ISS Capabilities and Challenges: Environmental Monitoring

- **Water Monitoring**
  - ISS: On-line conductivity; Off-line total organic carbon, iodine; Samples returned to earth for full analysis
  - Challenge: On-orbit identification and quantification of specific organic, inorganic compounds.
- **Microbial**
  - ISS: Culture-based plate count, no identification, 1.7 hrs crew time/sample, 48 hr response time; samples returned to earth.
  - Challenge: On-orbit, non culture-based monitor with identification & quantification, faster response time and minimal crew time
- **Atmosphere**
  - ISS: Major Constituent Analyzer (mass spectrometry – 6 constituents); COTS Atmosphere Quality Monitors (GC/DMS) measure ammonia and some additional trace gases; remainder of trace gases via grab sample return; Combustion Product Analyzer (CSA-CP, parts now obsolete)
  - Challenges: On-board trace gas capability that does not rely on sample return, optical targeted gas analyzer
- **Particulate**
  - ISS: N/A
  - Challenge: On-orbit monitor for respiratory particulate hazards
- **Acoustic**
  - SOA: Hand held sound level meter, manual crew assays
  - Challenge: Continuous acoustic monitoring with alerting

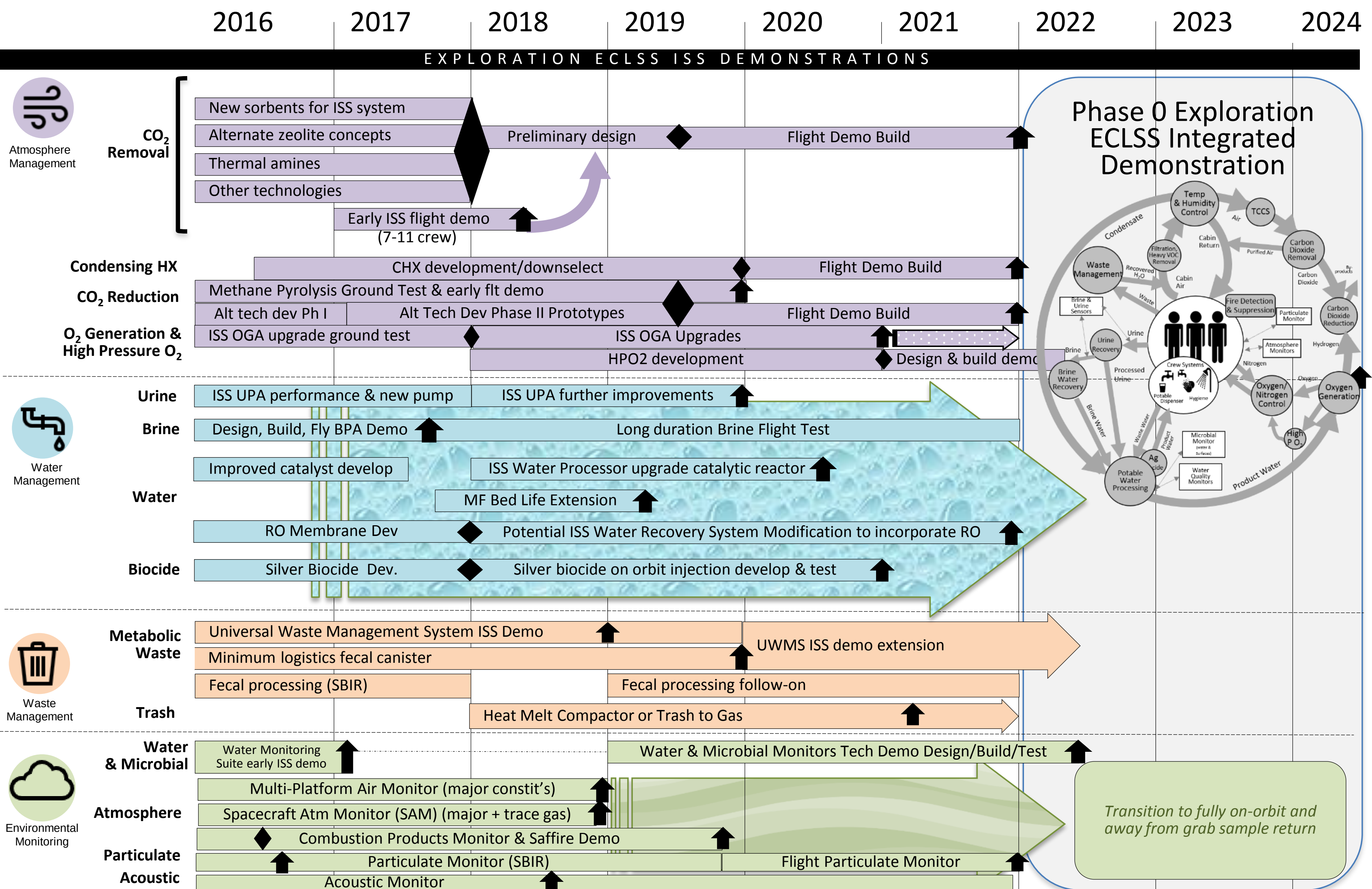


ECLSS & Environmental Monitoring Capability Gaps

Gap Criticality:
5 = high
1 = low

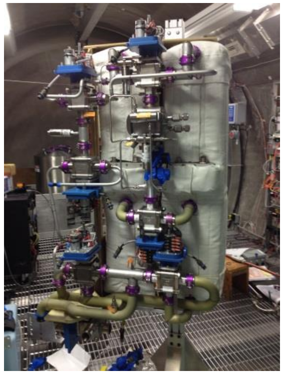
Function	Capability Gaps	Gap criticality as applicable to μg transit Hab	Orion Need
CO_2 Removal	Bed and valve reliability; ppCO_2 <2 mmHg	5	
O_2 recovery from CO_2	Recover >75% O_2 from CO_2	5	
Urine brine processing	Water recovery from urine brine >85%	5	
Metabolic solid waste collection	Low-mass, 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	

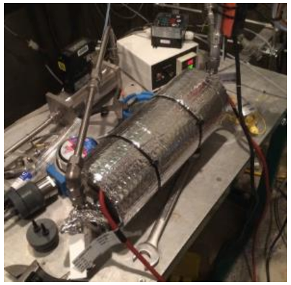
Exploration ECLSS Roadmap



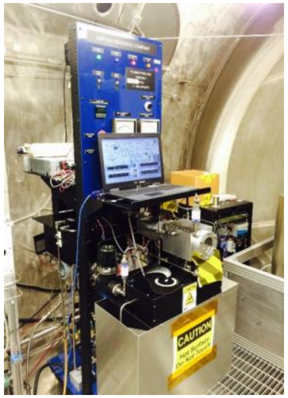
Progress – Atmosphere Management

- **CO2 Removal**
  - improved sorbents
  - alternate technology development
- **Oxygen Generation & High Press O_2**
  - testing to reduce complexity
  - high pressure cell stack development
  - oxygen concentrator development
- **Oxygen Recovery/CO_2 Reduction**
  - new technology development
- **Condensing Heat Exchanger**
  - improved coatings development
- **Trace Contaminant Control**
  - alternate commercial sorbent testing
  - integrated architecture
- **Particulate Filtration**
  - pre-filter and regenerable filter development

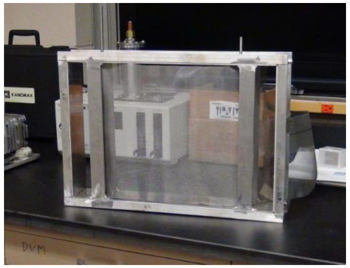




Hydrogen Recombiner



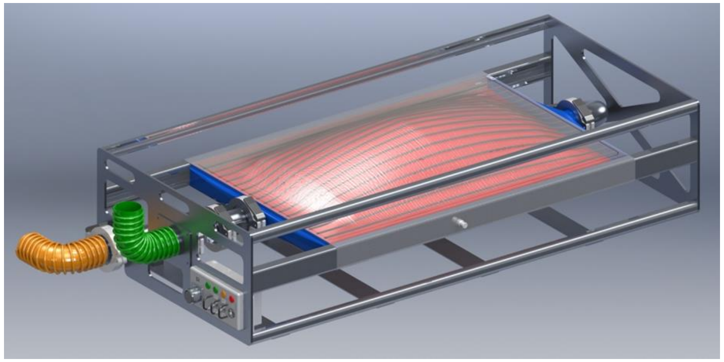
3^{rd} Gen PPA



Scrolling Screen Pre-filter

Progress – Water Management

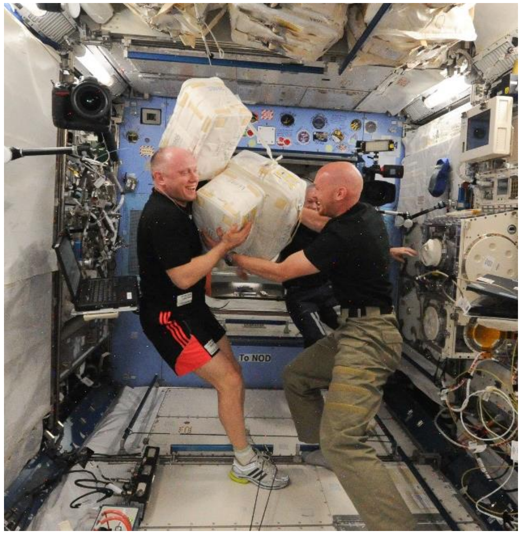
- **Urine processing**
  - new pretreat formula on ISS improves recovery to 85-90%
  - pump reliability improvements
- **Water processing**
  - improved catalyst development
  - operational filter life extension
  - alternate technology/reverse osmosis testing & trade
- **Brine processing**
  - ISS flight demonstration in development – flies in 2017



- **Silver biocide**
  - development of on orbit injection capability

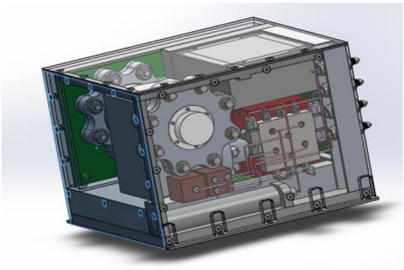
Progress – Waste Management

- **Commode**
  - universal waste management system for ISS demo & Orion
  - minimum mass fecal container development
- **Trash management**
  - heat melt compactor development
  - trash to gas development
- **Fecal processing**
  - torrefaction SBIR development
- **Logistics Reduction**
  - long wear clothing demonstrated on ISS
  - repurposing of packaging and cargo bags
  - RFID-enabled logistics management planned for ISS



Progress – Environmental Monitoring

- **Atmosphere Monitors**
  - micro GC/MS for major constituents and trace gases ISS tech demo planned
  - laser-based monitors for combustion products and targeted gases (planned for Saffire demonstration)
  - improved mass spec for ISS & Orion use
- **Water Monitor**
  - Various technologies in development
  - front end to atmosphere monitor for water samples
- **Microbial Monitor**
  - PCR (Razor) flight demonstration on ISS now
  - DNA sequencer flight demonstration
- **Particulate Monitor**
  - aerosol sampler flight demonstration (OA-5)
  - SBIR particulate monitor development



SAM

Thermophoretic Sampler (TPS)

(Credit: RJ Lee Group)