NASA System Maturation
Teams:
ECLSS & Environmental Monitoring

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Robyn Gatens
Deputy Director, International Space Station Division
Human Exploration and Operations Mission Directorate
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)
Asteroid Redirect-Crewed Mission Marks Move from Phase 1 to Phase 2

Phase 0: Exploration Systems *Testing on ISS*

Phase 1: *Cislunar Flight Testing* of Exploration Systems

Phase 2: *Cislunar Validation* of Exploration Capability

Phase 3: Crewed Missions Beyond Earth-Moon System

Phase 4a: Development and robotic preparatory missions

Phase 4b: Mars Human Landing Missions

Today

Ends with testing, research and demos complete*

Ends with one year crewed Mars-class shakedown cruise

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

Human Space Exploration Phases

2016 2020 2030
The Habitation Development Challenge

**800-1,100 Days**
Total time crew is away from Earth – for orbit missions all in Micro-g and Radiation

**500 Days**
Long Surface Stay

**HABITATATION CAPABILITY**

**Habitation Systems – AES/ISS/STMD**
- Environmental Control & Life Support
- Autonomous Systems
- EVA
- Fire Safety
- Radiation Protection

**Habitation Systems - Crew Health – HRP**
- Human Research
- Human Performance
- Exercise
- Nutrition

**Habitation Capability – NextSTEP BAA / Int. Partners**
- Studies and ground prototypes of pressurized volumes

Integrated testing on ISS
Validation in cislunar space
Habitation Systems

NextSTEP Habitation Overview

NextSTEP Phase 1: 2015-2016

Cislunar habitation concepts that leverage commercialization plans for LEO

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

NextSTEP Phase 2: 2016-2018

Initial discussions with international partners

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

Define reference habitat architecture in preparation for Phase 3.

ONE CONCEPT STUDY

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

1. **LIFE SUPPORT**
   - Atmosphere Management
   - Water Management
   - Waste Management
   - Food Management

2. **ENVIRONMENTAL MONITORING**
   - Pressure
   - Moisture
   - Particles
   - Microbes
   - Chemicals
   - Sound

3. **CREW HEALTH**
   - Monitoring
   - Exercise
   - Diagnostics
   - Treatment
   - Food Storage

4. **RADIATION PROTECTION**
   - Monitoring
   - Tracking
   - Modeling
   - Mitigation

5. **FIRE SAFETY**
   - Detection
   - Protection
   - Suppression
   - Cleanup

6. **LOGISTICS**
   - Tracking
   - Clothing
   - Packaging
   - Trash

7. **CROSS-CUTTING**
   - Autonomy
   - Power
   - Communication
   - Docking
   - Common Interfaces

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

**TODAY**

**ISS**
- 42% O₂ Recovery from CO₂
- 90% H₂O Recovery
- < 6 mo mean time before failure (for some components)

**FUTURE**

**Deep Space**
- 75%+ O₂ Recovery from CO₂
- 98%+ H₂O Recovery
- >30 mo mean time before failure

**ISS**
- Limited, crew-intensive on-board capability
- Reliance on sample return to Earth for analysis

**Deep Space**
- On-board analysis capability with no sample return
- Identify and quantify species and organisms in air & water

**ISS**
- Bulky fitness equipment
- Limited medical capability
- Frequent food system resupply

**Deep Space**
- Smaller, efficient equipment
- Onboard medical capability
- Long-duration food system

**ISS**
- 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

**Deep Space**
- 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

**ISS**
- 2-cartridge mask
- Obsolete combustion prod. sensor
- Only depress/repress clean-up

**Deep Space**
- Automatic, autonomous RFID
- Long-wear clothing & laundry
- Bags/foam repurposed w/3D printer
- Resource recovery, then disposal

**ISS**
- Manual scans, displaced items
- Disposable cotton clothing
- Packaging disposed
- Bag and discard

**Deep Space**
- Minimal on-board autonomy
- Near-continuous ground-crew comm
- Some common interfaces, modules controlled separately

**ISS**
- Up to 40-minute comm delay
- Widespread common interfaces, modules/systems integrated

**Deep Space**
- Ops independent of Earth & crew
- Near-continuous ground-crew comm
- Some common interfaces, modules controlled separately

**ISS**
- Monitoring
- Exercise
- Diagnostics
- Treatment
- Food Storage

**Deep Space**
- Monitoring
- Exercise
- Diagnostics
- Treatment
- Food Storage
Phase 0 – Habitation Systems Testing on ISS

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology 1</th>
<th>Technology 2</th>
<th>Technology 3</th>
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<td>2016</td>
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<td>Technology 1</td>
<td>Technology 2</td>
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<tr>
<td>2019</td>
<td>Technology 1</td>
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<td>2020</td>
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<td>2024</td>
<td>Technology 1</td>
<td>Technology 2</td>
<td>Technology 3</td>
</tr>
</tbody>
</table>

Build Habitation Systems in 2018

Test Habitation Systems on ISS in 2019

Systems feed into Phase 2 Cislunar Validation of Exploration Capability

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

Crew Systems
- Hygiene water
- Potable Water Dispenser

Water Quality Monitors

Ag Biocide

Potable Water Processing

Processed Urine

Brine Water Recovery

Brine & Urine Sensors

Urine Recovery

Waste

Temp & Humidity Control

Filtration & Heavy VOC Removal

Cabin Return

Air

TCCS

CO₂ Removal

CO₂ Reduction

Fire Detection & Suppression

Particulate Monitor

Atmosphere Monitors

O₂/N₂ Control

Microbial Monitor (Water & Surfaces)

Oxygen Generation

Oxygen

Nitrogen

Product Water

By-products

CO₂

H₂

Water

Condensate

Recovered H₂O

Waste Return
Current ISS Capabilities and Challenges: Atmosphere Management

- **Circulation**
  - ISS: Fans (cabin & intermodule), valves, ducting, mufflers, expendable HEPA filter elements
  - Challenges: Quiet fans, filters for surface dust

- **Remove CO₂ and contaminants**
  - ISS: Regenerative zeolite CDRA, supports ~2.3 mmHg ppCO₂ for 4 crew. MTBF <6 months. Obsolete contaminant sorbents.
  - Challenges: Reliability, ppCO₂ <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 O₂**
  - ISS: Oxygen Generation Assembly (H₂O electrolysis, ambient pressure); high pressure stored O₂ for EVA
  - Challenge: Provide high pressure/high purity O₂ for EVA replenishment & medical use

- **Recovery of O₂ from CO₂**
  - ISS: Sabatier process reactor, recovers 42% O₂ from CO₂
  - Challenge: >75% recovery of O₂ from CO₂
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
<table>
<thead>
<tr>
<th>Function</th>
<th>Capability Gaps</th>
<th>Gap Criticality as applicable to μg transit Hab</th>
<th>Orion Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Removal</td>
<td>Bed and valve reliability; ppCO₂ &lt; 2 mmHg</td>
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<tr>
<td>O₂ recovery from CO₂</td>
<td>Recover &gt; 75% O₂ from CO₂</td>
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<tr>
<td>Urine brine processing</td>
<td>Water recovery from urine brine &gt; 85%</td>
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<tr>
<td>Metabolic solid waste collection</td>
<td>Low-mass, universal waste collection</td>
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<td>X</td>
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<tr>
<td>Trace Contaminant Control</td>
<td>Replace obsolete sorbents w/ higher capacity; siloxane removal</td>
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<td>X</td>
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<tr>
<td>Condensing Heat Exchanger</td>
<td>Durable, chemically-inert hydrophilic surfaces with antimicrobial properties</td>
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<tr>
<td>Water microbial control</td>
<td>Common silver biocide with on-orbit redosing</td>
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<tr>
<td>Contingency urine collection</td>
<td>Backup, no moving parts urine separator</td>
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<tr>
<td>Urine processing</td>
<td>Reliability, 85% water from urine, dormancy survival</td>
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<tr>
<td>Atmosphere monitoring</td>
<td>Small, reliable atmosphere monitor for major constituents, trace gases, targeted gases</td>
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<tr>
<td>Water monitoring</td>
<td>In-flight identification &amp; quantification of species in water</td>
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<tr>
<td>Microbial monitoring</td>
<td>Non-culture based in-flight monitor with species identification &amp; quantification</td>
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<tr>
<td>O₂ generation</td>
<td>Smaller, reduced complexity, alternate H₂ sensor</td>
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<td>High pressure O₂</td>
<td>High pressure (3000 psi) O₂ for EVA/on-demand O₂ supply for contingency medical</td>
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<td>Wastewater processing (WPA)</td>
<td>Reliability (ambient temp, reduced pressure catalyst), reduced expendables, dormancy survival</td>
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<td>Non-metabolic solid waste</td>
<td>Volume reduction, stabilization, resource recovery</td>
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<td>Particulate monitoring</td>
<td>On-board measurement of particulate hazards</td>
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<td>Particulate Filtration</td>
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<td>Atmosphere circulation</td>
<td>Quiet fans</td>
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<td>Logistics Reduction</td>
<td>10:1 volume reduction logistical and clothing</td>
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<tr>
<td>Metabolic solid waste treatment</td>
<td>Useful products from metabolic waste</td>
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</table>
Progress – Atmosphere Management

• CO2 Removal
  – improved sorbents
  – alternate technology development
• Oxygen Generation & High Press O₂
  – testing to reduce complexity
  – high pressure cell stack development
  – oxygen concentrator development
• Oxygen Recovery/CO₂ 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
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