



Environmental Health in Manned Spacecraft

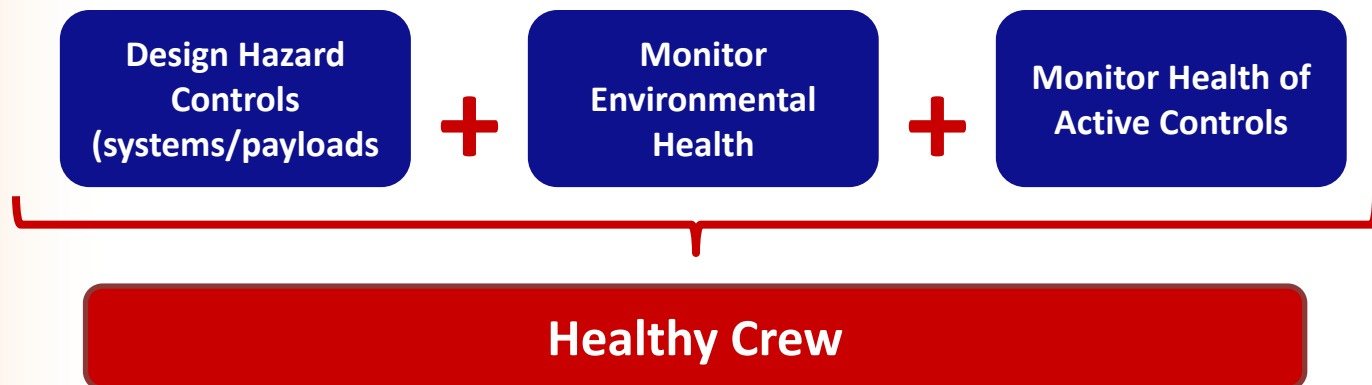
March-2015

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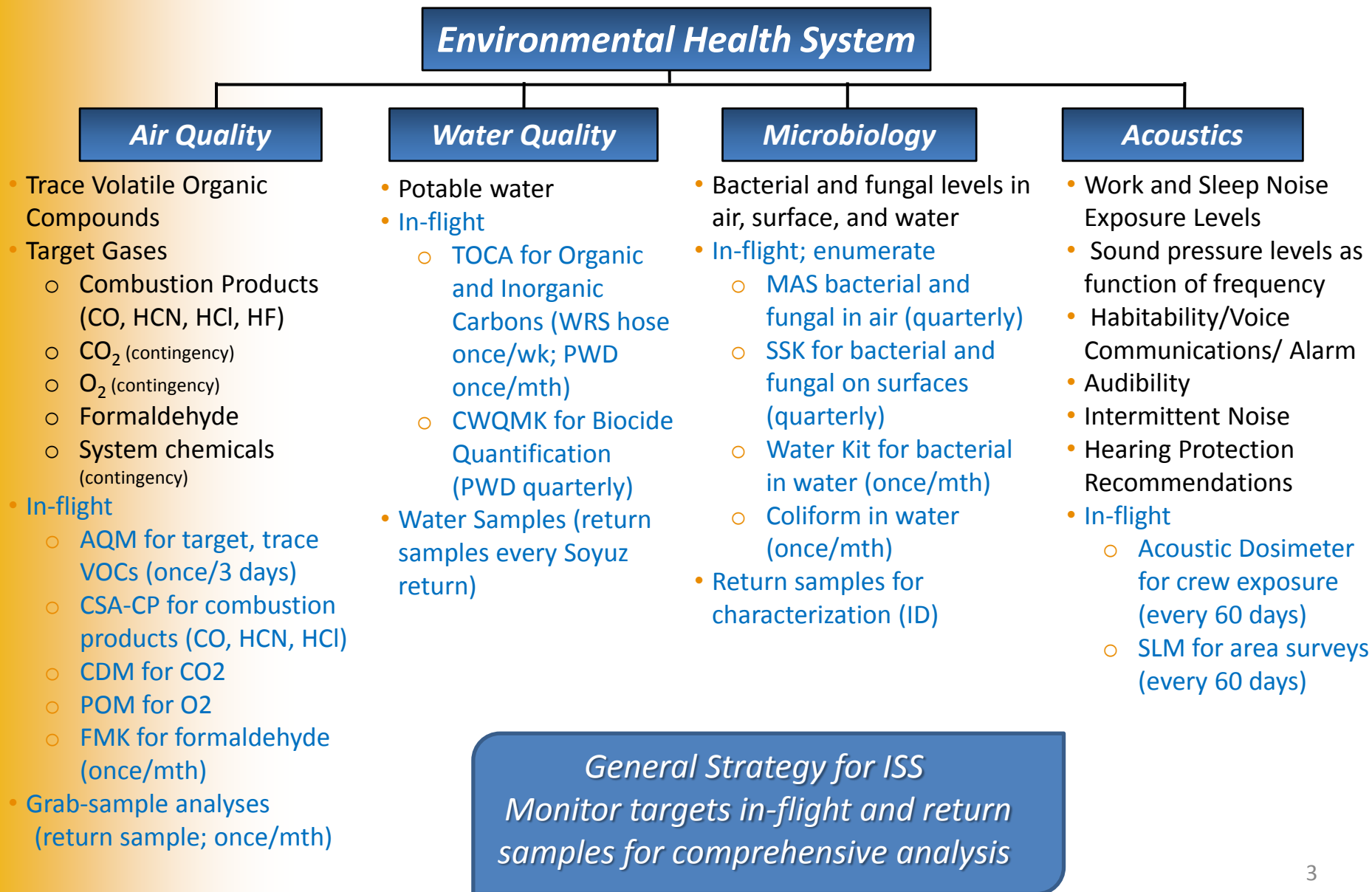
Environmental Health for Human Spaceflight



- Environmental Health addresses physical, chemical, and biological risks, external to the human body, that can impact health of a person by assessing and controlling these risks to generate and maintain a health-supportive environment.....a primary requirement of human spaceflight
- Environmental health risks are mitigated through active controls...
 - By establishing environmental standards (SMACs, SWEGs, microbial and acoustics limits), which define acceptable limits specifically for human spaceflight.
 - By providing reliable ECLS systems to maintain the environmental parameters within standards.
 - By selecting materials and equipment with minimum off-gassing characteristics, and performing off-gas testing.
 - By identifying hazards and providing appropriate controls.
- ... AND through environmental monitoring
 - Provides early warning of excursions from the norm when active controls degrade or fail, or an environmental threat appears needing crew action.
 - Provides necessary data to assist in correcting failures and determine root cause.
 - Provides data on a variety of toxicological compounds and environmental factors that may have specific crew health impacts.



Environmental Health System (EHS)



Beyond ISS....



- Trying to match ground capability to in-flight capability is currently unrealistic
 - Operational aspect is very important
 - What kind of in-flight information on environmental health do we need to ensure crew health?
- Provide crew what's required to manage Environmental Health during nominal and off-nominal situations
- *Risk-based*, Environmental Health Roadmap
 - Multi-center effort to ID risks to crew health associated with quality of air, water, microbial, and acoustic environment
 - Needs, hardware, and knowledge determined from identified risks associated with missions
 - Assessed capability of current technology to mitigate risks
 - *Assessment generated "gaps" in current technology that need to be addressed*
 - Assumption: once mission is better defined, then risks and gap analysis will be refined

Generic Design Reference Missions



- **Key to Monitoring Strategy is the mission**
- ***DRMs.....Generic mission defining duration and conditions***
- ***Reference Mission 1: Short Duration (< 3 - 4 weeks)***
 - Examples: MPCV, MMSEV, SEV, Lander
 - Other considerations
 - EVA via an airlock or suitport
 - 8 – 14.7 psia range of cabin pressures depending on specific mission
 - MPCV ECLSS proposed as the Point of Departure design for this general scenario
- ***Reference Mission 2: Long Duration, Micro-Gravity (6 month to years)***
 - “Derivative increments” will have some differences
 - Limited or no resupply available (need for high self sufficiency and reliability)
 - Examples: ISS, Deep Space Habitat, Long-duration transit vehicle
 - Other considerations
 - EVA via an airlock or suitport
 - 8 psia/32% O₂ working atmosphere capability is the objective
 - ISS ECLSS proposed as the Point of Departure design for this general scenario
- ***Reference Mission 2a: Medium Duration, Micro-Gravity (>1 month to ~6 months)***
- ***Reference Mission 3: Long Duration, Partial Gravity (6 month to years)***
 - Similar requirements to the microgravity habitat
 - Evaluate use of advanced or gravity dependent technologies

Identified Environment-Related Crew Health Risks in Exploration-class Missions



Environmental Health

Air Quality

- 1) Risk of system leak or contamination due to failure of mission-specific equipment
- 2) Excess exposure to carbon dioxide, formaldehyde, other gases
- 3) Exposure to toxic products of combustion
- 4) Risk of hypoxia
- 5) Exposure to accumulated air pollutants
- 6) Exposure to toxicants during EVA
- 7) Risk of Adverse Health Effects of the Destination Environment, e.g., Lunar Dust, Asteroid, ISRU

Water Quality

- 1) Risk of crew injury due to elevated biocide concentrations in water
- 2) Risk of crew injury due to ingestion of recovered water that doesn't meet appropriate water quality requirements
- 3) Risk of crew injury due to exposure to recovered water that contains unanticipated organic contaminants
- 4) Risk of having insufficient chemical water quality monitoring data to make informed operational decisions
- 5) Risk of crew injury due to leaching of contaminants from stored water systems

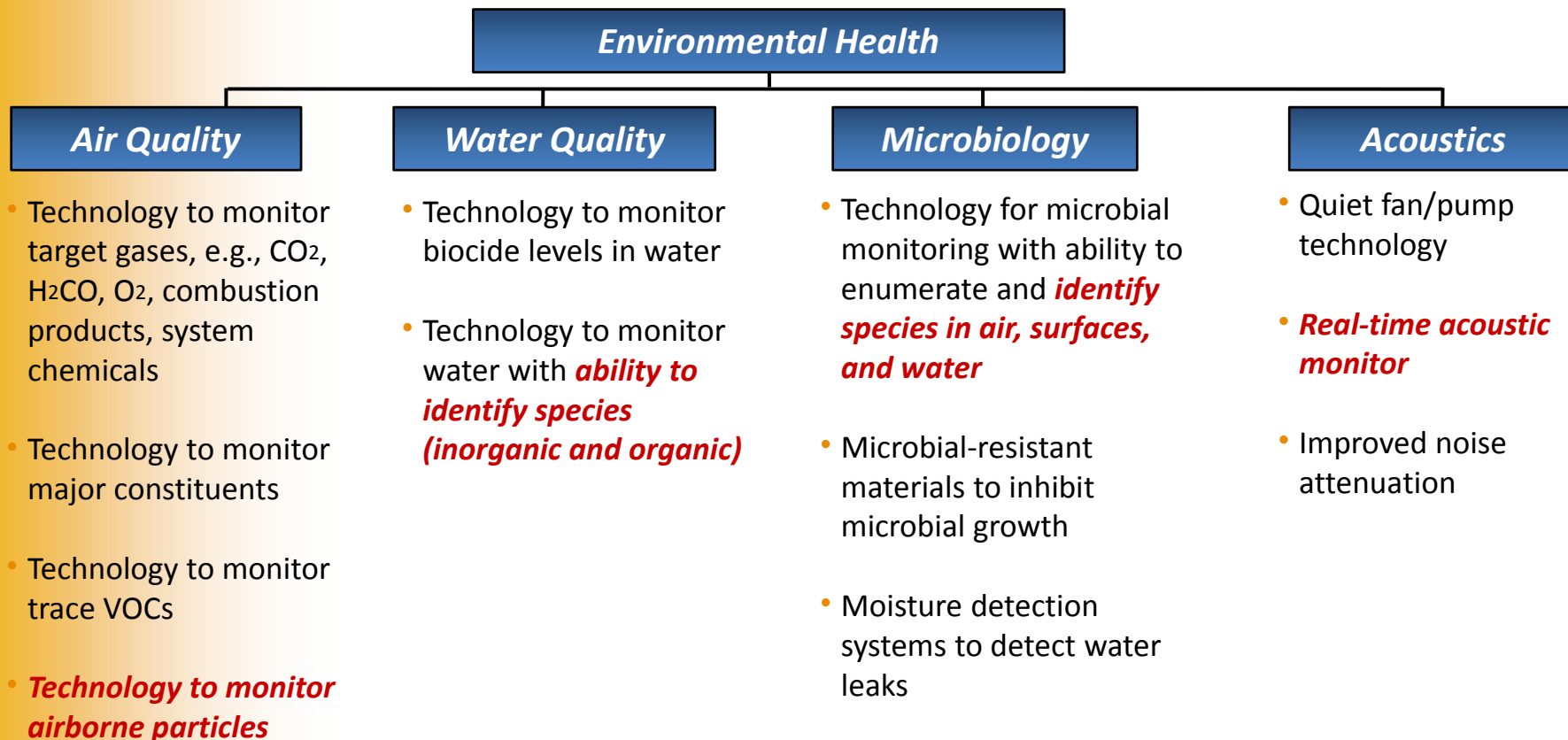
Microbiology

- 1) Risk of exposure to microorganisms in potable water and environmental air and surfaces
- 2) Risk of degraded vehicle system performance due to microbial growth on material surfaces
- 3) Risk of condensate buildup, or other uncontrolled water accumulation during missions
- 4) Risk of adverse health effects due to alterations in host microorganism Interaction
- 5) Risk of altered host immune response
- 6) Risk of crew illness due to exposure of the crew to microorganisms from other crewmembers
- 7) Risk that antimicrobial countermeasures may be inappropriate or less effective during missions.
- 8) Risk of insufficient spaceflight food requirements for foods with elevated microbial content and complex microbial diversity

Acoustics

- 1) Risk of degraded comm due to interference from background noise
- 2) Risk of off-nominal situation causing increased noise level
- 3) Lack of real-time acoustic monitoring may result in crew exposures to high noise levels
- 4) Risk of increased sound levels as vehicle systems age during mission
- 5) Risk of increased sound levels caused by accumulation of dust in hardware systems
- 6) Crew-desensitization to gradual increases in noise may cause exposure to increased noise levels
- 7) Risk of sleep disturbance due to high continuous or intermittent noise
- 8) Increased intracranial pressure, caused by weightlessness, may cause temporary hearing loss which may result in decreased voice communication effectiveness

Technology Identified to Mitigate Environment-Related Crew Health Risks in Exploration-class Missions



Environmental Health for Human Spaceflight....

Risks are a moving target and other unknowns...



- Effects of integrated risks
 - understanding of long-term, integrated system risks; e.g., ototoxicity
 - Applicability of standards, limits, etc. for various mission
 - *Human System Interface Requirements (HSIR), Human Integration Design Handbook (HIDH), NASA STD-3001, OCT Roadmaps, Global Exploration Roadmaps (GER), SMACs, SWEGs, microbial limits, acoustic limits, and radiation limits*
- Risks can vary between missions, and change over time.
 - Variation of one person to another can be extremely large
 - Physiological changes occur in the micro-gravity environment
 - Health of crew may change during mission, i.e., illness can impact the crew's immune system
 - Limited data on long-term effects (>>6 months) of constant exposure to the spacecraft environment, and the variety of chemicals, microbes, sound and radiation present in that environment
 - Limited data on long-term (>>6 months) infectivity capacity of microorganisms in spaceflight
 - New contaminant(s) may enter environment (i.e. contaminants from destination) that may not be effectively removed from the system, or which impact system performance
 - Sound levels increase as systems age during long-during mission
- **Flight experience has shown that despite robust ECLS systems, environmental issues can happen both when the ECLSS is operating nominally or off-nominally**



Addressing Gaps....

- ***What we don't have and need....***

- Advanced in-flight water analysis to identify and quantify aqueous species
 - What do we need monitor?
 - Dependent on vehicle water system, materials, system chemicals, etc.
 - Incorporate biocide monitoring?
- In-flight microbial characterization
 - Need to analyze samples from air, surfaces, and water
- In-flight airborne particle monitoring.....especially true for surface missions
 - Need NASA standard for particulate exposure
 - Nanoparticles
- Advanced acoustic environment management
 - Analyze frequency or spatial coverage to recognize noise level increases
 - Alerting functionality
- Transition from electrochemical-based sensors to consolidated, optical-based technology
 - Improves calibration life
 - Real-time formaldehyde monitoring
 - Combustion Products
 - Consolidation of several monitors into single package

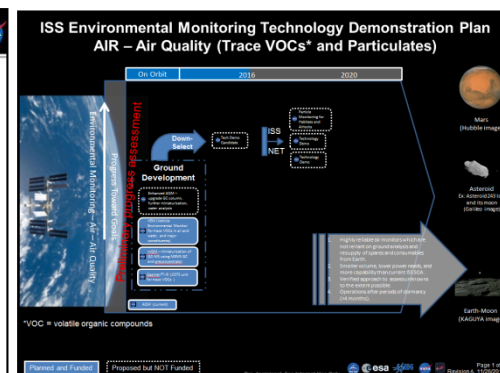
- ***What we're close to having.....***

- Trace VOC Monitoring
 - Great performance from AQM in it current configuration
- Major Constituents Monitoring
 - Great performance from MCA

Addressing Other Issues....



- Constraints imposed by vehicle, e.g., size, mass, and power
- Operations after period of dormancy
- Viable way to handle unknown chemicals that may appear in routine analyses
- Ops concept is even more critical
 - Greater autonomy
 - Maintaining and checking calibration
 - Need for consumables (resupply issue)
 - Interpretation of environmental Information
 - *Hardware/software which organizes, interprets, and presents environmental health data easily interpreted and correlated to crew health like physiological symptoms*
 - Need to validate operation of hardware
 - *Built-in protocols/hardware to automatically validate proper operation of monitoring technology to ensure data integrity*



2013.....ISS Strategic Implementation Plan (SIP) called for dev ISS Technology Demonstration Plan based on gap analysis



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- The collage features a central NASA presentation slide titled "NASA Human Exploration and Operations System Maturation Team Products" dated July 10, 2013. The slide shows a space scene with a satellite, a rocket, and Earth. Overlaid on the right are several documents: a NASA logo, a table with a green arrow pointing to "Program Implementation", and a document titled "Academia".



Backup

Flight experience provides many examples of environmental risks



- Freon 218 Leak from SM SKV, 2001 and 2008
 - Freon 218 leak during servicing of SM air conditioning system SKV
 - The release was detected and followed by ESA's ANITA (FT-IR) payload
 - Levels of Freon 218 were ~700 mg/m³ after the release
 - well below the US SMAC limit (acceptable-risk levels), but ~4½X greater than the Russian health standard limit (zero-risk levels) of 150 mg/m³
 - ANITA continued to follow Freon 218 levels during its time on ISS, even showing a decrease in Freon 218 levels as a result of dilution due to the addition of JEM-PM.
- Odor Detected During METOX Regeneration, 2002
 - EVA metal oxide (METOX) canister regeneration caused noxious air with many pollutants when canisters were baked out after 6 months exposure to the cabin air
 - Unclear whether the noxious air was because the METOX canister had absorbed and concentrated nominal ISS trace pollutants (butanol, xylenes, etc.), or because of degradation of the material in the METOX canister occurred and released
 - Crewmembers had to evacuate to Russian segment for 30 hours while the TCCS was switched on to scrub the air
 - Determined by VOA that the main contributors to the noxious air were n-butanol, toluene, and xylenes, typical ISS contaminants and not products from the degradation of the METOX as some speculated
 - Analysis of the Grab Samples returned on Shuttle in late April, confirmed the VOA results
 - Based on results ISS Program decided replacement METOX canisters not needed on the next Shuttle mission.

Flight experience provides many examples of environmental risks



- FGB “Shower” causes fungal contamination, 2004
 - Potential fungal contamination on FGB panels 406 & 408 reported by Expedition 9 crew
 - This area was located near the crew made “shower”, and used by for drying towels and clothing.
 - Remediation performed twice using Russian Fungistat wipes, and the SSK was again used to verify that the cleaning was successful

- TOC Build-Up in WPA Product Water, 2010
 - Continuously increasing TOC levels indicated by TOCA reached 2.6 ppm vs 3 ppm limit in drinking water
 - Eventually determined to be dimethylsilanediol (DMSD); a chemical previously not known to be in waste water, and not included on the monitoring list
 - Required change of WPA multi-filtration beds sooner than anticipated
 - Source suspected to be trace gases (Polydimethylsiloxane & Volatilemethylsiloxane) that off-gas from various plastics and crew items on ISS.

Refinement of the on-board air monitoring list is an on-going process



Late 1980s	1990's	1998	2003
223 compounds	30 compounds	28 compounds	37 compounds
Space Station Freedom (SSF) specification. Based primarily on Skylab and Shuttle air quality measurement results reported in grab samples and evaluations of Spacelab equipment off-gassing and human metabolic loads.	SSF to ISS. ECLS and Toxicology worked to refine the target list considering frequency of compounds in grab samples from Shuttle and Spacelab, eventually settling on 30 compounds proposed for the ISS System Specification. Monitoring functional responsibility transitioned from ECLS to CHeCS.	Following bilateral discussions with the Russians, a list of 28 compounds was ultimately put in the ISS MORD, containing compounds of interest to both toxicology (25) and ECLS trace contaminant control engineering (3).	ISS Program monitoring RFI released with 3-tiered priority target list containing compounds of interest to toxicology and ECLS (near real-time monitors should successfully monitor 90% of Priority 1 compounds and 80% of the P2/P3 compounds) – MORD capture of the RFI list is 91% P1/71% P2/8% P3.
2007 through present			
26 compounds			
Monitoring hardware available was not able to provide data on some of the most critical ISS compounds, so NASA ECLS and toxicology have worked to refine the list based on ISS flight experience. The current "ECLS/TOX" list has 26 trace contaminants. On-going negotiations with the International Partners to document this updated list in the MORD.			

Identified Environment-Related Crew Health Risks in Exploration-class Missions due to Knowledge Gaps



Environmental Health

Air Quality

- 2) Excess exposure to carbon dioxide, formaldehyde, other gases
Knowledge Gap: Better understanding on physiological effects of elevated CO₂ for long-term missions

Water Quality

- 5) Risk of crew injury due to leaching of contaminants from stored water systems
Knowledge Gap: Shelf-life studies are conducted to help anticipate future challenges from contaminant leaching. Inflight monitoring resources can help alleviate concerns as well

Microbiology

- 4) Risk due to alterations in host microorganism Interaction
Knowledge Gap: Assessment of microbial hazards and their characteristics; dose-response characteristics of organisms for a better assessment of crew exposure
- 5) Risk of altered host immune response
Knowledge Gap: Better understanding of host susceptibility.
- 6) Risk due to exposure of the crew to microorganisms from other crew
Knowledge Gap: Managing medical-related microbial issues
- 7) Risk that antimicrobial countermeasures may be inappropriate or less effective during missions
Knowledge Gap: Studies in pharmaco-kinetics and dynamics
- 8) Risk of insufficient spaceflight food requirements for foods with elevated microbial content and complex microbial diversity
Knowledge Gap: Definition of how to microbiologically monitor various foods where high counts do not necessarily disqualify samples, e.g., yogurt

Acoustics

- 1) Risk of degraded comm due to interference from background noise
Knowledge Gap: Acoustic modeling techniques are being developed and validated
- 2) Risk of off-nominal situation causing increased noise level
Knowledge Gap: Acoustic modeling techniques are being developed and validated
- 3) Lack of real-time acoustic monitoring may result in crew exposures to high noise levels
Knowledge Gap: Acoustic modeling techniques are being developed and validated
- 4) Risk of increased sound levels as vehicle systems age during mission
Knowledge Gap: Acoustic modeling techniques are being developed and validated
- 8) Increased intracranial pressure, caused by weightlessness, may cause temporary hearing loss which may result in decreased voice communication effectiveness
Knowledge Gap: Ground-based studies on links between increased intracranial pressure and effects on hearing