Microbial Monitoring of the International Space Station

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Humans living and working in the harsh environment of space present many challenges for habitability engineers and microbiologists. Spacecraft must provide an internal environment in which physical (gas composition, pressure, temperature, and humidity), chemical, and biological environmental parameters are maintained at safe levels. Microorganisms are ubiquitous and will accompany all human-occupied spacecraft, but if biological contamination were to reach unacceptable levels, long-term human space flight would be impossible. Prevention of microbiological problems, therefore, must have a high priority.

Historically, prevention of infectious disease in the crew has been the highest priority, but experience gained from the NASA-Mir program showed that microbial contamination of vehicle and life-support systems, such as biofouling of water and food, are of equal importance. The major sources of microbiological risk factors for astronauts include food, drinking water, air, surfaces, payloads, research animals, crew members, and personnel in close contact with the astronauts. In our efforts to eliminate or mitigate the negative effects of microorganisms in spacecraft, the National Aeronautics and Space Administration (NASA) implemented comprehensive microbial analyses of the major risk factors. This included the establishment of acceptability requirements for food, water, air, surfaces, and crew members. A robust monitoring program was then implemented to verify that the risks were within acceptable limits.

Prevention of microbiological problems is preferred over mitigation of problems during flight, and preventive steps must begin very early in the design phase. Spacecraft development must include requirements to control free water from humidity, condensate, hygiene activities, and other releases. If water is available, microbes are likely to grow because sufficient nutrients are potentially available. Materials selected for the spacecraft must not promote or support microbial growth. Air filtration can dramatically reduce the number of airborne bacteria, fungi, and particulates in spacecraft breathing air. Waterborne bacteria can be reduced to acceptable levels by thermal inactivation of bacteria during water processing, along with a residual

biocide, and filtration at the point of use can ensure safety. System design must include onboard capability to achieve recovery of the system from contamination. Robust housekeeping procedures that include periodic cleaning and disinfection will prevent high levels of microbial growth on surfaces. Food for consumption in space must be thoroughly tested for excessive microbial content and pathogens before launch. Thorough preflight examination of flight crews, consumables, payloads, and the environment can greatly reduce pathogens in spacecraft.

Many of the lessons learned from the Space Shuttle and previous programs were applied in the early design phase of the International Space Station, resulting in the safest space habitat to date. This presentation describes the monitoring program for the International Space Station and will summarize results from preflight and on-orbit monitoring.

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Book Chapter

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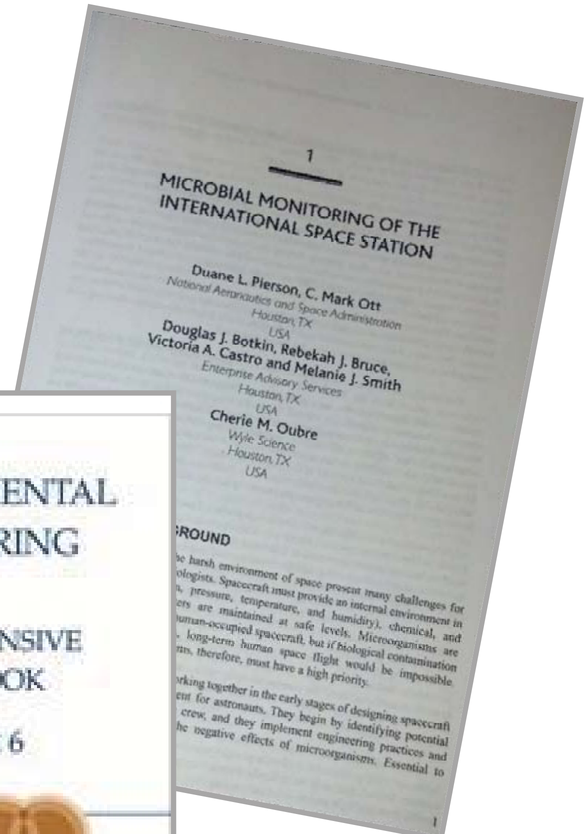

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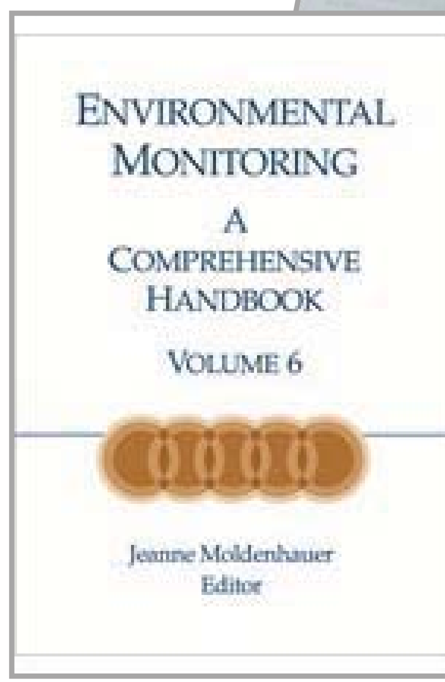
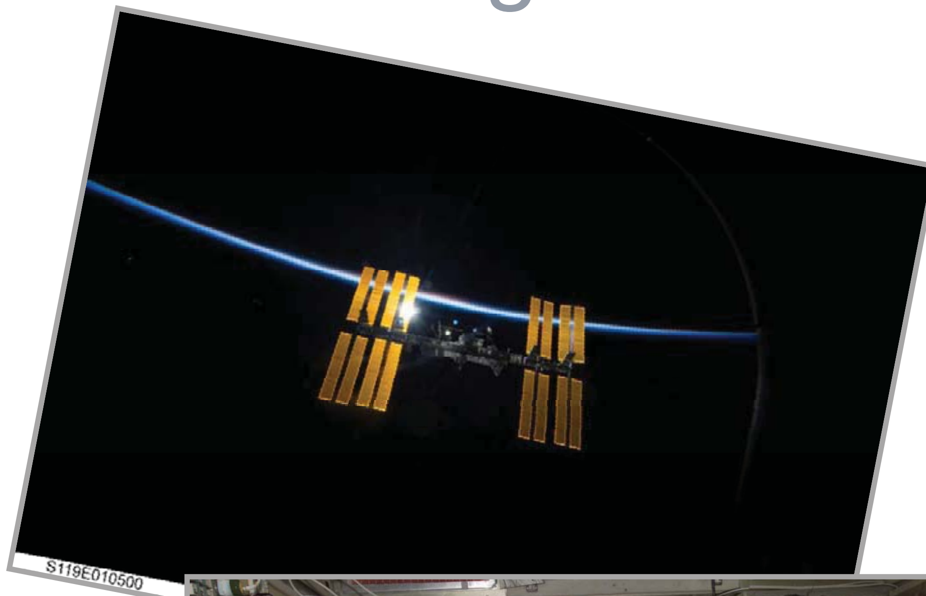


The Impact of Infectious Disease

Mission	Published Incident	Consequence
Apollo 7	Upper respiratory infection in 2 crewmembers prior to flight. Influenza symptoms within a few days after return	Preflight antibiotic therapy
Apollo 8	All crewmembers experienced preflight viral gastroenteritis which was	Believed to cause one crewmember's vomiting and GI distress during flight
Apollo 9	Rhinitis and pharyngitis in one crewmember	3 day launch delay
Apollo 13	Urinary tract infection during flight	Incapacitation
STS- 36	Upper respiratory infection	4 day launch delay
-	Shingles (thoracic zoster) in 47-year-old healthy astronaut 2 days prior to flight	-

NASA Microbiological Monitoring

- Preflight
  - Clinical
  - Food
  - Potable water
  - Vehicle surfaces
  - Vehicle air
  - Cargo
- Biosafety review of payloads
  - In-flight
  - Potable water
  - Vehicle surfaces
  - Vehicle air

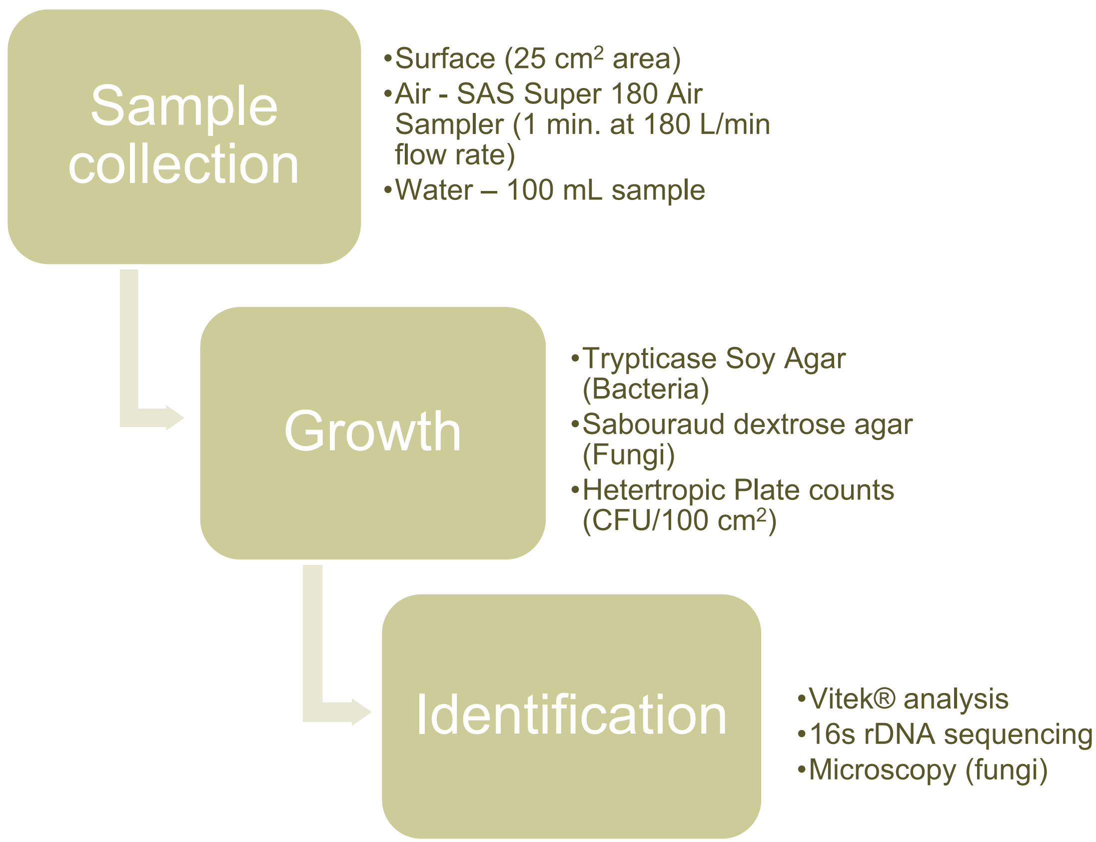


NASA Environmental Monitoring

- Air assessments
- Surface assessments
  - Multiple locations within the vehicles
- Hardware assessments
  - Random samples to ensure quality control
- Payload assessments
  - Biosafety Review Board

Preflight Sample Collection

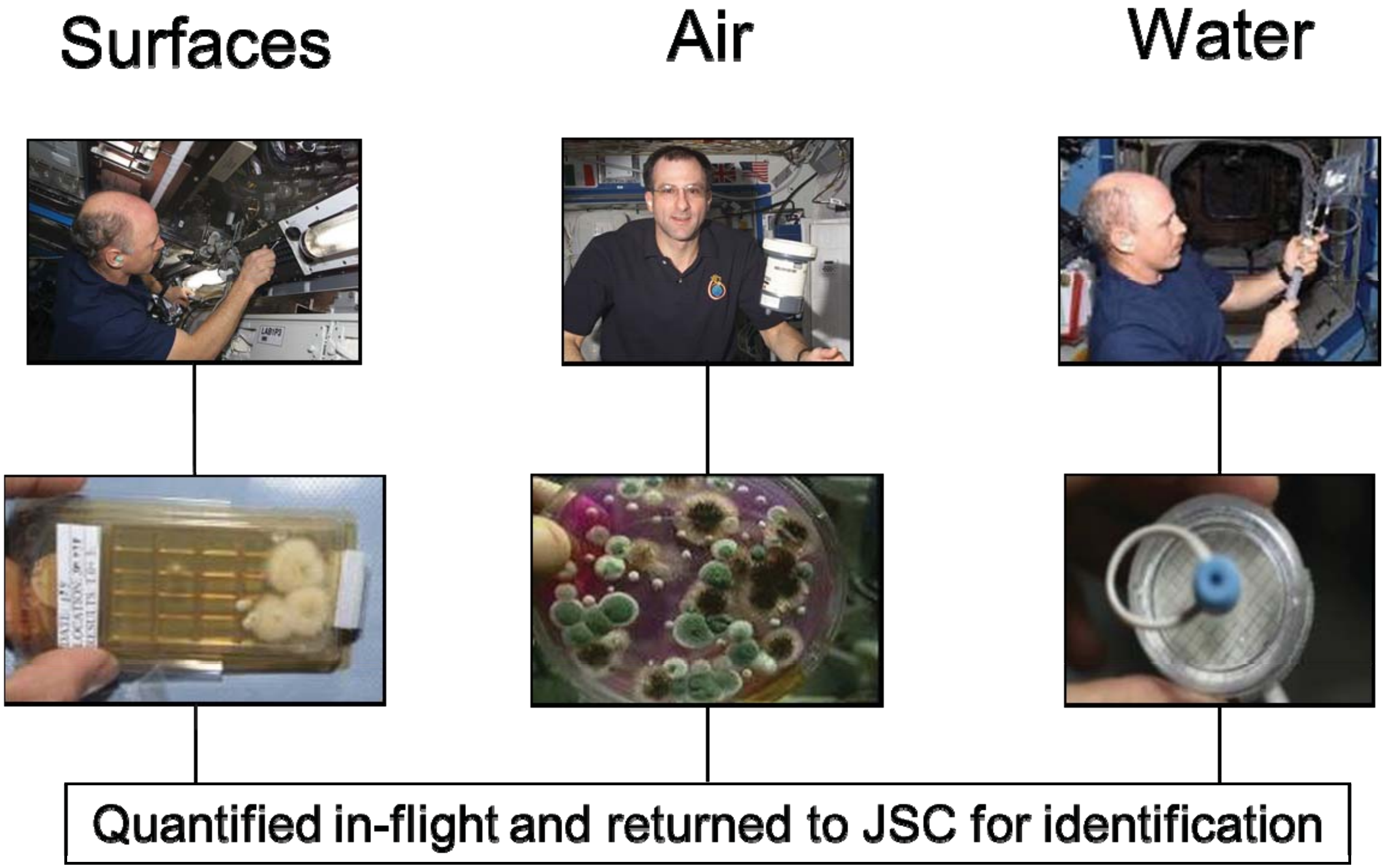
- Surface
  - Randomly selected hardware items
  - Habitable environment of vehicles or modules 10 – 15 days before launch
- Air
  - Habitable environment of vehicles or modules 10 – 15 days before launch
- Water



Preflight acceptability limits

Sample type	Acceptability Limit	
	Bacteria	Fungi
Air	300 CFU/m^3	50 CFU/m^3
Surface	500 CFU/100 cm^2	10 CFU/100 cm^2
Water	50 CFU/mL No detectable coliforms	

ISS In-Flight Monitoring



Inflight acceptability limits

Sample type	Acceptability Limit	
	Bacteria	Fungi
Air	1000 CFU/m^3	100 CFU/m^3
Surface	10,000 CFU/100 cm^2	100 CFU/100 cm^2
Water	50 CFU/mL No detectable coliforms	

* As defined in the ISS Medical Operations Requirements Document, NASA, 2003

Inflight Air Sample Collection

Inflight Surface Sample Collection

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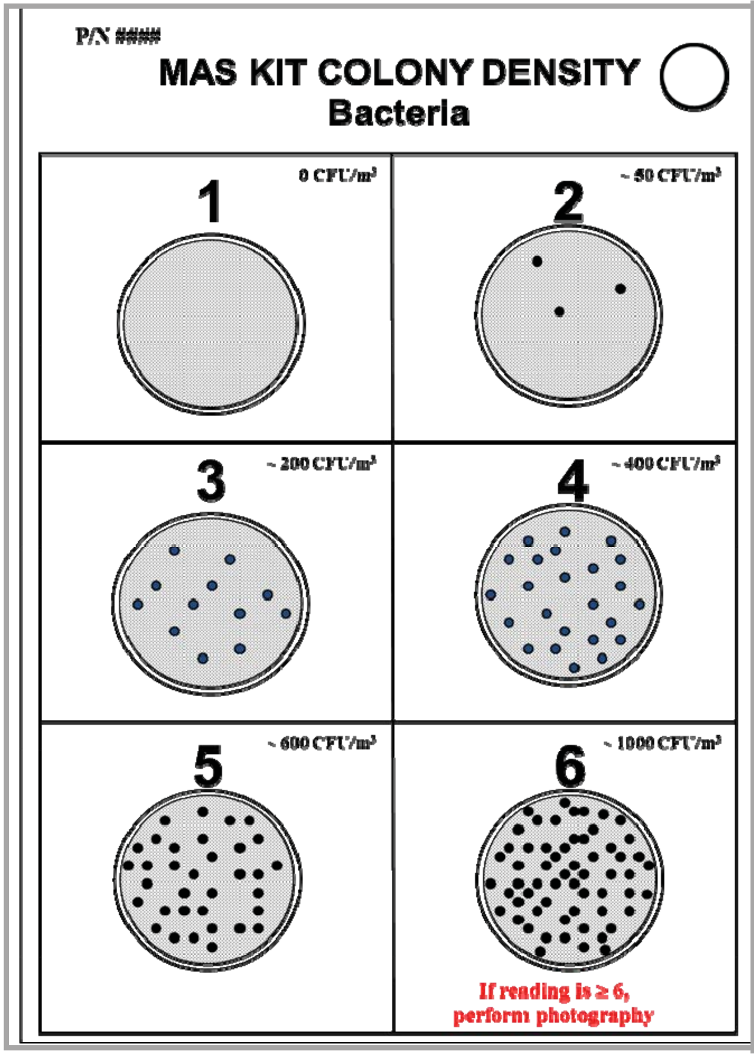
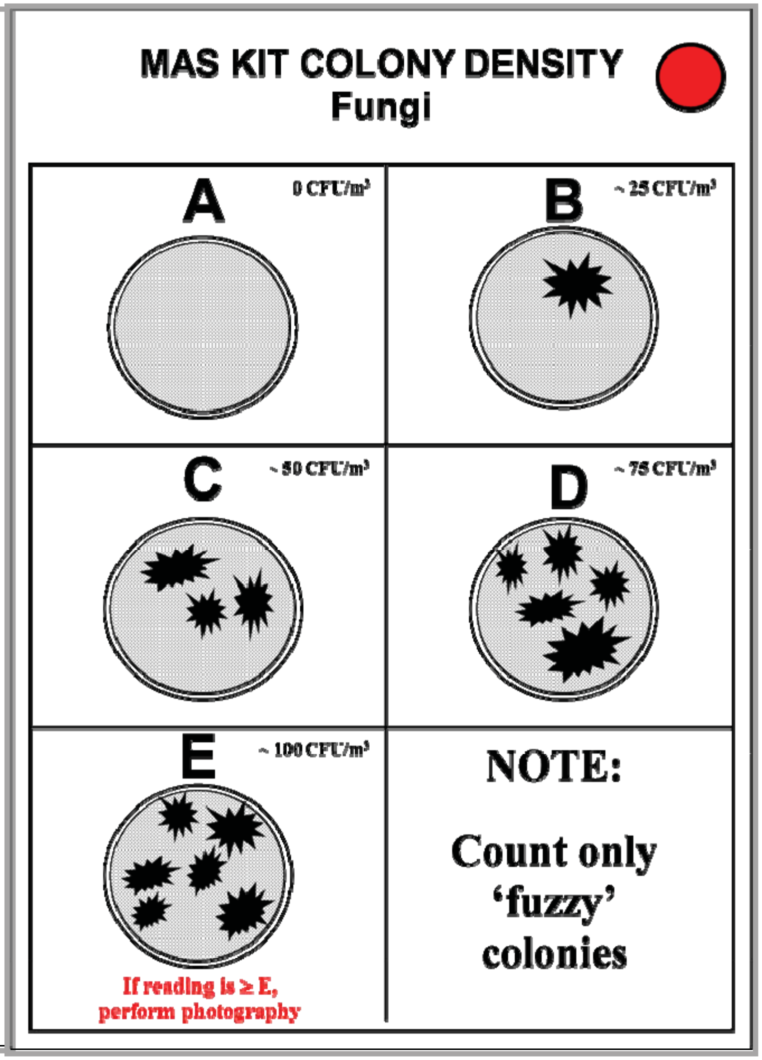
Surface and Air Sample Analysis





Inflight Water Sample Collection

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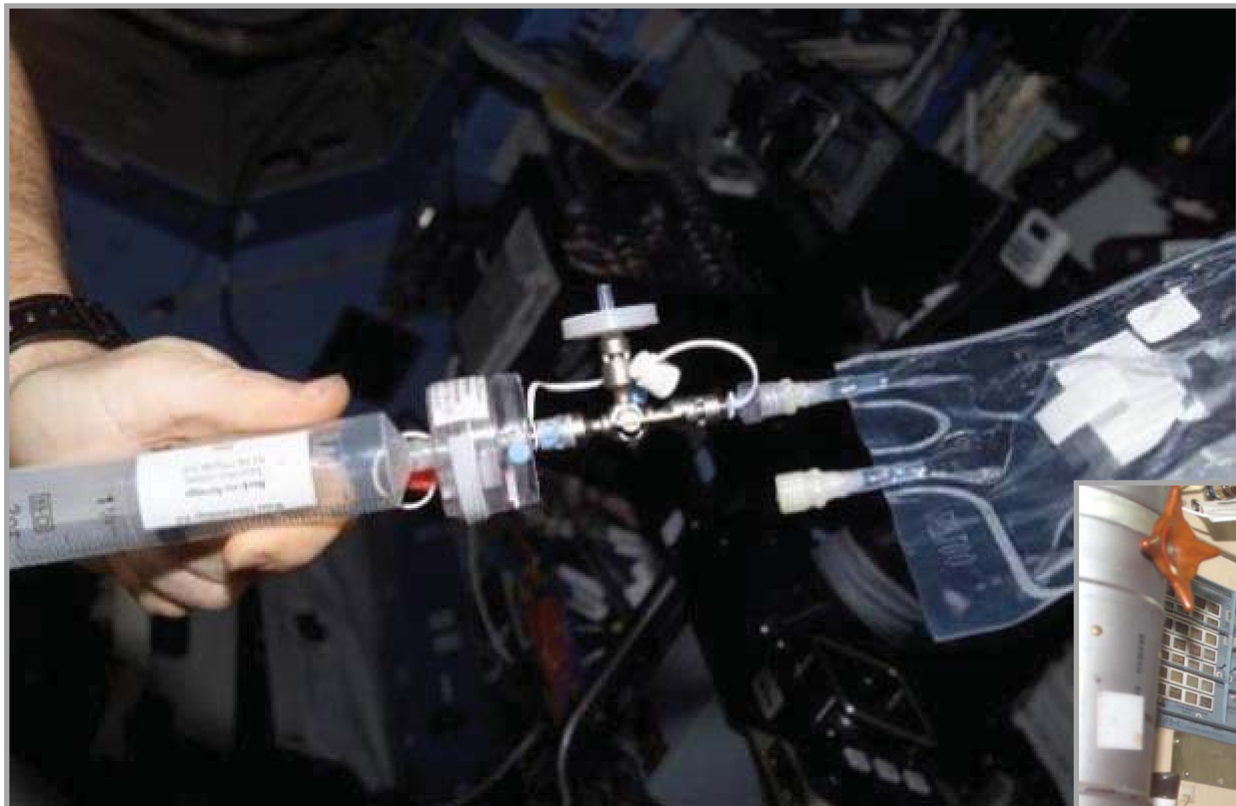
http://www.youtube.com/watch?v=wuIzl53Za80

Inflight Water Sample Collection



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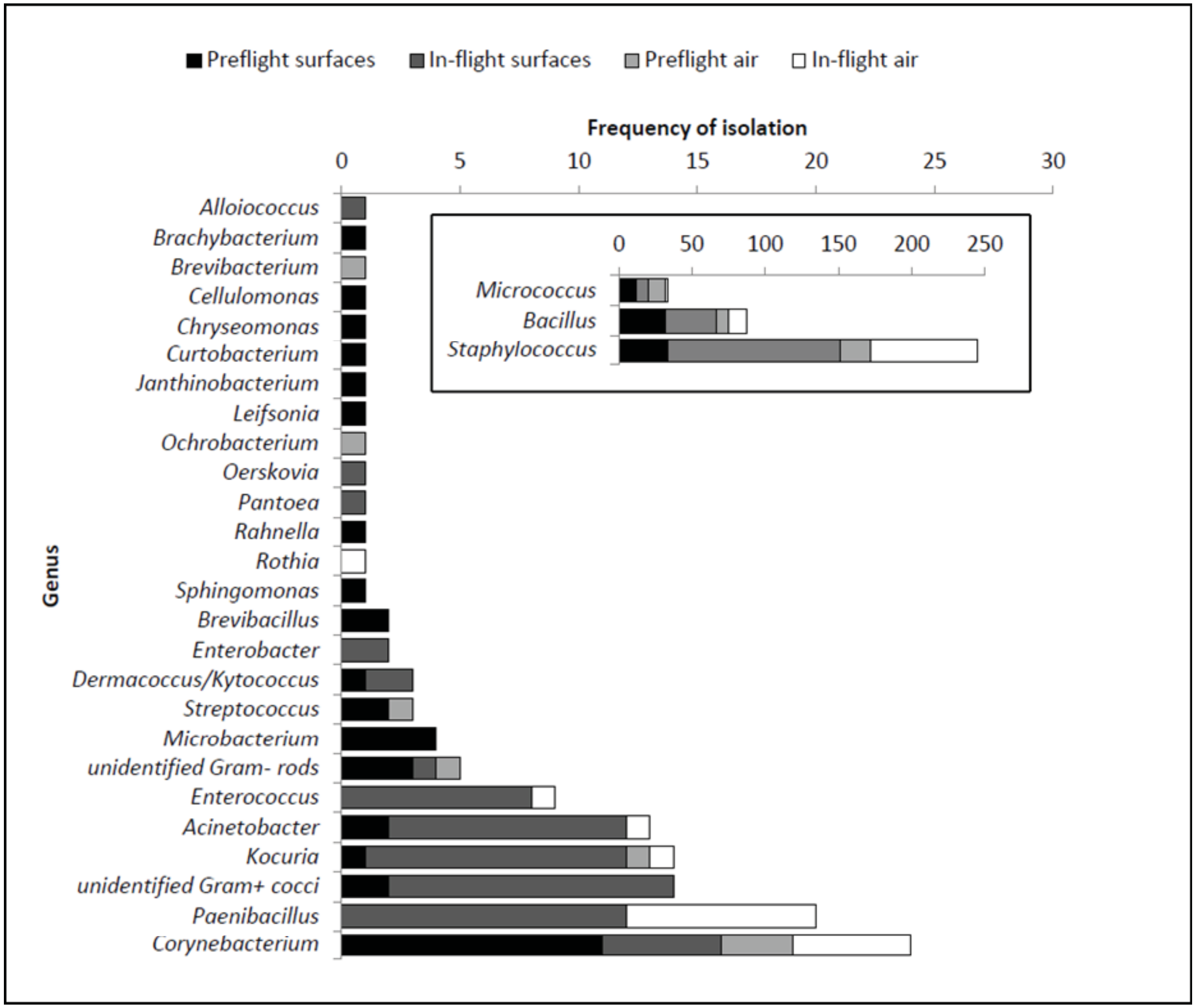
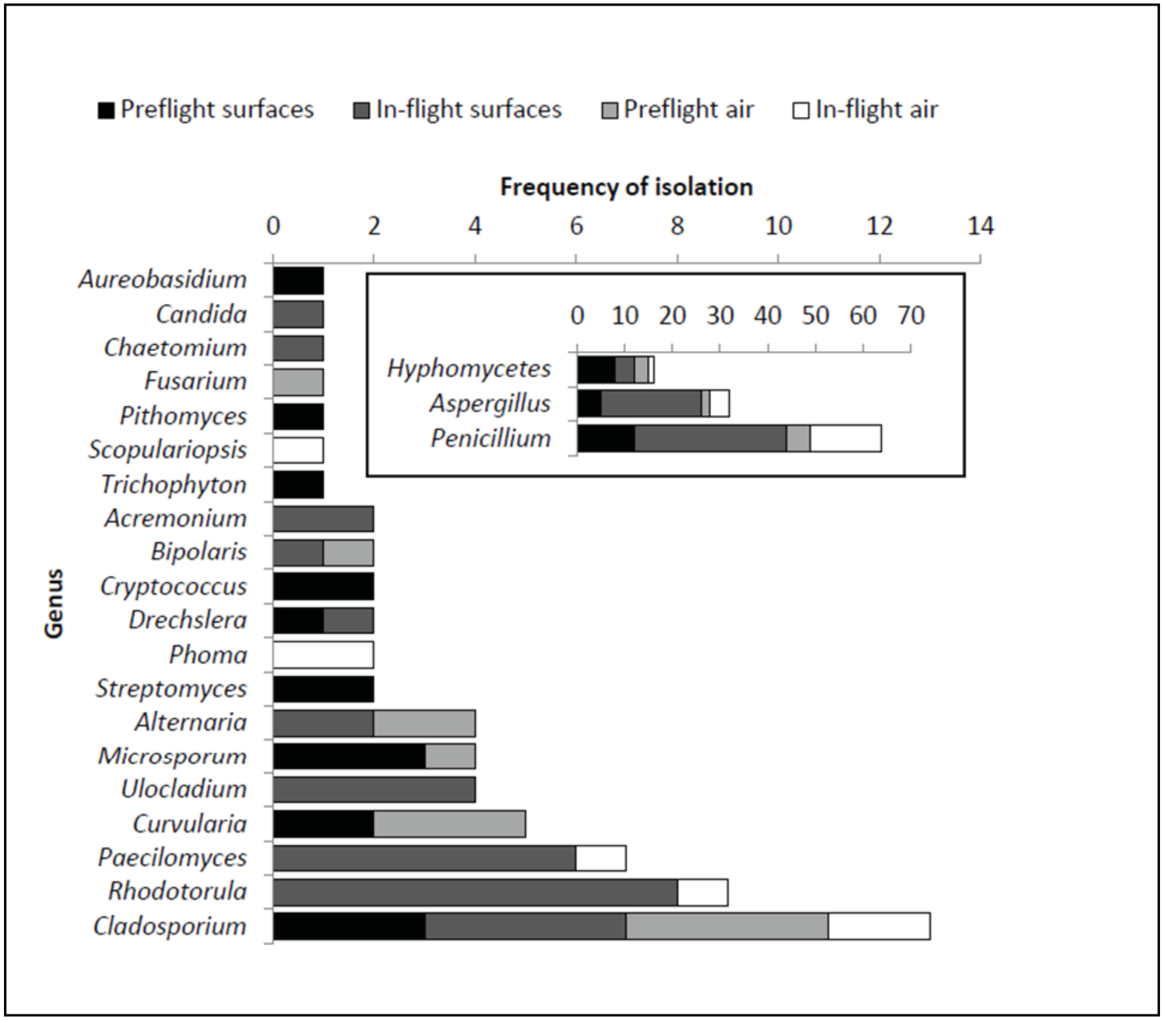
Air and Surface Results - Bacteria



- August 1998 to August 2011.
- The inset illustrates the top 3 most frequently isolated genera of bacteria.

Air and Surface Results - Fungi



- August 1998 to August 2011.
- The inset illustrates the top 3 most frequently isolated genera of bacteria.

ISS Bacterial Isolates – Potable Water

SRV-K Hot

Acidovorax temperans
Acinetobacter radioresistens
Burkholderia gladioli
Caulobacter vibrioides
Comamonas testosteroni
Cupriavidas eutropha
Flavobacterium ferrugineum
Methylobacterium lusitanum
Methylobacterium species
Sphingomonas paucimobilis
Sphingomonas stygialis
Staphylococcus species

SRV-K Warm

Acidovorax temperans
Burkholderia gladioli
Caulobacter leidyi
Comamonas testosteroni
Corynebacterium species
Cupriavidus basilensis
Cupriavidus eutropha
Cupriavidus metallidurans
Dechlorosoma suillum
Flexibacter species
Methylobacterium lusitanum
Methylobacterium podarium
Methylobacterium species
Microbacterium species
Pseudomonas aeruginosa
Ralstonia mannitolilytica
Ralstonia pickettii
Sphingobacterium species
Sphingomonas paucimobilis
Sphingomonas species
Sphingomonas stygialis
Sphingomonas xenophaga
Sphingomonas yanoikuyae

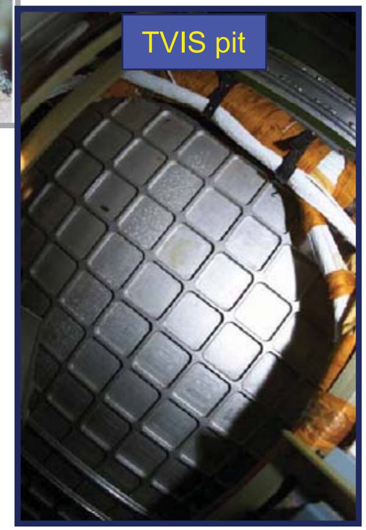
SVO-ZV

Acinetobacter lwoffii
Bradyrhizobium betae
Brevumdimonas species
Caulobacter species
Chryseobacterium gleum
Comomonas testosteroni
Cupriavidas paucula
Leifsonia xyli
Methylobacterium fugisawaense
Methylobacterium lusitanum
Methylobacterium species
Proteobacterium, alpha-subgroup
Pseudomonas fluorescens
Pseudomonas species
Ralstonia pickettii
Rhizobium radiobacter
Sphingomonas capsulata
Sphingomonas cloacae
Sphingomonas paucimobilis
Sphingomonas species
Sphingomonas stygialis
Sphingomonas yanoikuyae
Staphylococcus warneri
Stenotrophomonas maltophilia

Predominant genera
Methylobacterium
Sphingomonas
Cupriavidus/Ralstonia

Anomalies

- Fungal contamination of Russian smoke detector (~2001)
- Suspected fungal contamination on SM structure in TVIS pit area (March 2002)
- Fungal contamination of panel fronts in 'hygiene area' of FGB; remediation performed (2004)
- Clogged lines in Russian condensate recovery system suspected to be of microbial composition (2005, 2007)



Anomalies (continued)

- High bacteria counts noted in archive samples from CWCs (2007 - 2008); silver-resistant Cupriavidas species isolated
- Suspected fungal contamination on Russian air conditioning system ductwork and BOK-3 Command Processing Unit; some condensation pooling behind panels reported (August 2007)
- Fungal contamination on Payloads Water Reservoir (April 2008)

Future Goals

- Evaluating new microbial monitoring technologies for flight implementation
  - Molecular-based microbial monitoring (MiDAS, MMS, WetLab 2, etc)
  - Paper-based technology
- Updating requirements to allow for new monitoring technologies
- Lifetime Surveillance of Astronaut Health

JSC Microbiology Laboratory

- Goal: Mitigate microbial risk to crew health, safety, and performance during the human exploration of space

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