Chapter 7
Spacecraft Contamination Monitoring and Control

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Spacecrafts and space stations are exceptional work and living places with unique conditions for the astronauts and equipment including high working pressure, defined diet and restricted hygienic practices, microgravity, and radiation. All of these influence the microflora on board and within humans. Special circumstances need special actions to keep people healthy and spacecraft and space station free from pathogens as far as possible.

7.1 Contamination Monitoring and Control

The possibly affected and contaminated materials and parts of the environment are the air within the spacecraft; all surfaces; the water, if it is for drinking or for cooling or for cleaning; the food that is taken aboard; and, of course, the human beings of the crew. A summary of these affected objects, affecting contaminations and control mechanisms, is shown in Table 7.1.

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Table 7.1 Affected objects, contaminations, and control mechanisms

Object/ spacecraft	Agents	Control/monitoring	Pro/contra
Air			
Mir	Staphylococci, micrococci, and coryneform bacteria: highest occurrence: *Staphylococcus*, *Bacillus*, *Corynebacterium* (Novikova 2004)	System "Potok 150-MK" designed to remove aerosol particles and microorganisms from air	Inactivation using electrostatic pulses and charged ions followed by filtration filters in general have to be replaced periodically
Mir ISS	Opportunistic pathogens: *Staphylococcus aureus*, *S. capitis*, *S. haemoliticus*, *Flavobacterium meningosepticum*, *Escherichia coli*, *Serratia marcescens*, *Streptococcus sp*., *Bacillus cereus* (Novikova 2004) atmosphere recycling	Russian Ecosphere kit included air sampler SAS (FBI product) to collect air by way of aspiration-sedimentation, and Petri dishes with nutrient media Veggie Space Hardware (Massa et al. 2013)	Cheap when established, additional food supply
ISS	Comparable	High-efficiency (HEPA) filters, pleated woven filters for Russian segment (Van Houdt et al. 2012)	Do not inactivate microbial cells
ISS	Comparable	POTOK 150 MK Russian air filtration and disinfection systems (Van Houdt et al. 2012)	Inactivation using electrostatic pulses and charged ions followed by filtration
ISS	Bacterial and fungal cultures in general	ENose	Already tested and established
Surfaces			
Mir	Dominated: *Penicillium*, *Aspergillus*, *Cladosporium sp*.: *Penicillium expansum*, *Penicillium chrysogenum*, *Cladosporium cladosporioides*, *Aspergillus sp*. of group *A versicolor*, *Aspergillus versicolor, Aspergillus niger* (Novikova 2004)	Molds: amenable to drying-out, rubbing dry, use of sanitary means	Must be repeated
ISS	*Staphylococcus aureus*, *Staphylococcus epidermidis*, *Enterococcus faecalis*, *Enterococcus faecium* (Guridi et al. 2015)	AgXX (microgalvanic elements formed by silver and ruthenium with an electroplated silver coating applied onto a V2A stainless steel surface)	Antimicrobial effect superior to that of conventional silver coatings, avoids toxic side effects of high levels of silver ions on eukaryotic cells, very long service life, no external energy used

Table 7.1 (continued)

Object/ spacecraft	Agents	Control/monitoring	Pro/contra
ISS	Biofilm-forming bacteria like *Staphylococcus* and *Bacillus* bacterial species and Penicillium and *Aspergillus* fungal species predominant (Van Houdt et al. 2012)	Either quaternary ammonium compound (supplied by USA) or mixture of hydrogen peroxide and quaternary ammonium compound (supplied by Russia) (Van Houdt et al. 2012)	When cleaning fails repeatedly, removal and replacement of the contaminated surfaces is final countermeasure
ISS	General	Humidity condensate is collected and purified (Van Houdt et al. 2012)	Keeps surfaces dry and water is recycled (e.g., for drinking)
Space vehicles	General	Adenosine triphosphate (ATP) analysis for detection purposes (Birmele et al. 2011)	Fast, no dilutants required
All	General	Preflight: heat, radiation, chemicals (depending on surface-cleaning method compatibility) (Van Houdt et al. 2012)	
All	General	Antimicrobial surface properties (Van Houdt et al. 2012)	May reduce adherence and biofilm formation
Water			
ISS	Dominant: *Methylobacterium*, *Ralstonia*, *Sphingomonas*, *Pseudomonas spp*. (Van Houdt et al. 2012)	Supply of ground-supplied water	Very expensive
ISS	Contamination of water	Addition of silver pre- and in-flight or addition of iodine, which is removed and replaced by silver before consumption	Quality check every month on board and collected for preflight tests
ISS	Contamination of water	UV-A (plus titanium dioxide) LEDs for disinfecting potable water systems (Birmele et al. 2011)	Effective
Food			
ISS	Food commensals (Van Houdt et al. 2012)	Sterilization	Production and packaging rigorously tested and controlled preflight

(continued)

Table 7.1 (continued)

Object/ spacecraft	Agents	Control/monitoring	Pro/contra
ISS	Food commensals	Hazard Analysis Critical Control Point (HACCP) management system (Van Houdt et al. 2012)	
ISS	Food commensals	Gamma irradiation (Mermel 2012)	
Human			
Mir and ISS	*Staphylococcus* (*S. aureus*), *Micrococcus*, *Enterobacter*, *and Bacillus species Aspergillus* and *Penicillium species* → conjunctivitis, infections of upper respiratory tract (Ball and Evans 2001)	Antibiotics broad range	Facilitate emergence and dissemination of antibiotic resistance genes and alter genetic makeup of bacterial populations limited diagnostic feasibility on board
Mir and ISS		Tetrapyrrole dyes such as porphyrins, phthalocyanines, and bacteriochlorins are able to accumulate in and be selectively retained by abnormal cells and by bacteria → Activation of these molecules with visible light in the presence of oxygen leads to the destruction of the target tissue (Taylor and Sommer 2005)	Effective, no resistance, effective against multidrug-resistant bacteria and biofilms
Mir and ISS		Bacteriophages as therapeutic agents (Taylor and Sommer 2005)	Very specific, but not yet well established. Resistance can emerge
Mir and ISS		New antimicrobials (antibiotic efflux pump inhibitors and drugs addressing virulence) (Klaus and Howard 2006)	Specific, increased antibiotic susceptibility, no resistance
Mir and ISS		Hfq (RNA-binding protein) as new drug target (Su et al. 2013)	Specific, addresses virulence
Mir and ISS		Robust vaccination program preflight (Mermel 2012)	

FBI Federal Bureau of Investigation, *HEPA* high-efficiency particulate arrestance, *ENose* *e*lectronical nose, *ATP* adenosine triphosphate, *UV* ultraviolet, *LED* light-emitting diode, *HACCP* Hazard Analysis Critical Control Point, *RNA* ribonucleic acid

7.1.1 Air

Airborne microorganisms can be dispersed through routes like talking, coughing, sneezing, and movement, and can cause irritation of mucous membranes, respiratory infections, and allergic diseases. Additionally, the aerobiology of respiratory droplets is altered in microgravity. In spacecrafts or space stations, the air has to be filtered continuously to keep microbial levels remaining below thresholds and to prevent the spread of microorganisms through aerosols.

There are new approaches to grow vegetables on spacecrafts. The goal of the "Veggie Space Hardware" concept is to grow healthy plants that can provide crew for food production and atmosphere recycling (Massa et al. 2013). This is a prospective approach with two benefits, one for the air and the other for the food supply.

The ENose (Ryan et al. 2004) is an electronic gas sensor system to detect microbial pollution online. Microbial contaminations produced by bacteria or fungi can be recognized in a qualitative and quantitative manner. Tests can be done at any place of the ISS to measure pollution. There is an additional, so-called target-book, with different fixed material probes like aluminum, platinum, and isolation material (of electronic devices and of the ISS in general) to test for settlement of bacterial or fungal colonies on these materials. The target-book can be periodically sent back to earth for analysis. MVOCs (microbial volatile organic compounds), produced by metabolism of biological cultures, can be detected and used to generate an olfactory fingerprint.

The ENose was first tested on the STS-95 (Ryan et al. 2004) and then successfully improved and supported by DLR and used on the ISS.

7.1.2 Surfaces

Many microorganisms are able to adhere to most surfaces and form biofilms. This process promotes persistence and resilience of microbial contamination and may have major implications for many industrial activities (Van Houdt et al. 2012). Equipment and utensils should be resistant to thermal, mechanical, and chemical factors and surfaces should exhibit antimicrobial properties. A rational design of spacecraft and space station integrating and respecting both functional and health-related criteria is fundamental. A very new approach, for example, is surface coating based on microgalvanic elements formed by silver and ruthenium with surface catalytic properties (AgXX®) (Guridi et al. 2015). An advantage of this new method lies in avoiding the toxic side effects of high levels of silver ions on eukaryotic cells. Additionally, the antimicrobial effect of the thin AgXX® coatings (3–5 μm) is not dependent on any substance released from the coating material; therefore, the lifetime of AgXX® is only limited by mechanical destruction of the coating. AgXX® was successfully tested on the ISS (Clauß-Lendzian et al. 2015).

Other approaches, not yet tested in space, but in the field of industry, could also be interesting and useful for spacecraft settings in the future. An example from food industry is polyvinyl acetate, which seems to be ideal as matrix-like carrier material for antimicrobial substances and forms a clear film on the coated surface. Especially benzoic acid and sorbic acid are accredited for food packaging and plastic and additionally offer a wide range of antimicrobic properties (against molds, many bacteria and yeasts). The antimicrobial substance is mixed with the fluid polyvinyl acetate and the mixture is used to coat technical surfaces (Sandmeier and Kensbock 2008). A new technology for antimicrobial furniture comprises a biozidal substance including at least one molybdenum-containing compound and a metal oxide. This coating can be used prospectively for furniture in hospitals, kitchens, bathroom, or plumbing unit floors or other technical surfaces. Molybdenum-containing compounds are not toxic to eukaryotic cells (Guggenbichler and Walter 2015).

7.1.3 Water

Microbial contamination of drinking water is a well-known hazard, both from a health perspective and for microbial-mediated corrosion, and is often accompanied by biofilm formation (Van Houdt et al. 2012). Biofilm formation increases persistence of pathogens and increased resistance to disinfectants. Water is recycled and cleaned with filters and addition of silver or with UV-A exposure (Birmele et al. 2011).

7.1.4 Human

Astronauts are vulnerable through their own commensals, through air pollution and through pathogens in drinking water, on surfaces, and even in their food. They can suffer from microbial infections, including conjunctivitis and acute respiratory and dental infections. In addition, injury and trauma, such as lacerations and open fractures, are likely to occur on long missions and will require prophylactic administration of antibiotics to prevent serious wound infection (Klaus and Howard 2006). Known problems are multidrug-resistant bacteria and biofilms. Additionally, antibiotics in turn influence the composition of intestinal and respiratory microflora in a delicate way. Besides unclear factors of pharmacodynamics, it is also expected that the bioavailability of drugs in weightlessness is less present (Lathers et al. 1989). Antibiotic therapy according to terrestrial standards will therefore be possible only with difficulty under spaceflight conditions. Antimicrobial prophylaxis and therapy should therefore follow new approaches. Conceivable would be the use of photosensitive molecules like porphyrins, phthalocyanines, and bacteriochlorins, which, in presence of visible light and oxygen are activated and destroy target tissues like topic infections or even biofilms (Taylor and Sommer 2005). Newer antimicrobials that inhibit antibiotic efflux pump activity, or modifying a drug so that it is not recognized by the efflux pump, might also increase antibiotic susceptibility, as addressing virulence might do. Additionally, resistance might not develop as quickly as it does for current drugs, because virulence factors are not usually necessary for survival (Klaus and Howard 2006). Also, a well-planned preflight vaccination program may support health (Mermel 2012).

7.2 Conclusion: The Future Space Habitat

In respect to human risk, the importance of monitoring is lower when fast return of the crew is possible, but very important for long-duration missions. Considering economics, the importance is high, as significant losses are linked to up- and download of replacement hardware and water supplies, which were lost for consumption due to contamination.

The THESEUS disciplinary reports (THESEUS Cluster 4 Report 2012) constructed by THESEUS expert groups debate and summarize problems and approaches of human space exploration. One of the goals must be to acquire better knowledge on microbial community and ecosystem dynamics and microbial cell evolution over time in confined manned habitats in space. Another task is to develop efficient materials and methods to prevent environmental microbial contamination and to develop adequate environmental contamination monitoring (prediction, detection, identification) systems for use in space (THESEUS Cluster 4 Report 2012).

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