BIOSIS
BioSafety In Space

Automated biomonitoring of air and water quality in human spacecraft
ESA GSP – AO/1-7182/12/NL/AF

EXECUTIVE SUMMARY

Date: 29/07/2014

1. Overview of BIOSIS study

1.1 Objectives

The objectives of the BIOSIS study funded by the General Studies Programme of ESA were: to review the biological risks for the crew due to biocontamination related to air and water quality, to identify knowledge gaps of non-detected / non-mitigated risks and to provide recommendations for future development of automated instrumentation. The work was shared in 5 tasks covering a review of the current knowledge and risks (WP1), a study of the remaining gaps and needs (WP2), a review (WP3) and trade-off (WP4) on possible ground technologies of interest and recommendations for future R&D for automated biomonitoring of air and water quality in manned spacecrafts (WP5). The study was a one year study, which started in 02/2013.

1.2 BIOSIS consortium

The consortium included 6 partners:

- **MEDES** (French Institute for Space Physiology and Medicine, France) with expertise in space physiology and medicine. MEDES was the coordinator of the study and was responsible for WP5. MEDES was supported by an external expert Pr. Jean-Pierre Flandrois (University of Lyon) especially for the clinical risks.
- **DLR** (Germany) providing expertise in space microbiology.
- **SCK•CEN** (Belgium) providing expertise in space microbiology. SCK•CEN was responsible for WP1 and WP2.
- **Compliance** (Germany) providing expertise in microbiology.
- **VTT** (2 departments involved: department specialised in air filtration and modelling and department specialised in process microbiology and safety, Finland) providing expertise in modelling / air filtration and molecular analysis techniques. VTT was responsible for WP4.
- **University of Eastern Finland:** providing expertise in environmental health and responsible for WP3.

To complete the expertise of the consortium, a workshop with additional external experts was realised in the middle of the project. This workshop gathered 22 attendees including 7 additional external experts representing industrial players, clinical laboratories and additional experts in space microbiology and space medicine.

1.3 BIOSIS deliverables

For more details about the BIOSIS study, please refer to the deliverables, namely:

- TN1: State of the art related to the biocontamination in human spacecraft
- TN2: knowledge gaps and remaining risks associated to biological contamination in human spacecraft
- TN3: state-of-the art of the existing ground technologies and instrumentation to control biological contamination.
- TN4: trade-off and selection of ground technologies and instrumentation to control biological contamination during a manned space mission.
- TN5: roadmap for future technological development to control the biological risks during a manned space mission.

2. Summary of BIOSIS study

Biocontamination in manned spacecrafts and in future habitats could have significant impacts on crew health and biodegradation of equipment. Although there are no reported microbiological events onboard that had a critical impact on the crew, multiple reported contamination events indicate that the current prevention, monitoring and mitigation methods have to be optimized and new methods need to be considered.

The objectives of the BIOSIS study, funded by ESA General Studies Programme were to review the biological risks for the crew due to biocontamination related to air and water quality, to identify knowledge gaps of non-detected or non-mitigated risks and to provide recommendations for future development of automated instrumentation for biological risk management.

Up to now, the current microbial monitoring strategy has been solely based on culture-dependent techniques, which are slow with low throughput and which allow only a partial identification of the microbiome. In addition, this method may induce the production of biohazardous material in the habitat (growth of possibly harmful microorganisms) and is highly dependent on ground support for the analysis, exploitation of results and resupply. A new approach should thus be proposed in view of future exploration missions, where autonomy of the crew will be essential.

The analyses of the remaining risks showed that with the current available data, it is not possible to predict the direct health risk from a given environmental exposure to biocontaminants. The primary focus of the monitoring should thus be on assessing the possible indirect health risks due to biodegradation of the equipment, in particular of the life support system. The new recommended monitoring strategy has thus been focused on microbial environmental monitoring.

To improve the monitoring strategy a new approach based on 2-step monitoring is recommended. The first step aims at routine monitoring of the environmental steady state spacecraft microbiota and at detecting any deviations from this steady state and on monitoring specific indicators. The second step, only triggered in case of emergency (deviation from the steady state), aims at identifying the contamination in more details ensuring implementation of the most relevant countermeasures. An integrated device will have to be developed to integrate these 2 monitoring steps with the sample preparation in a single closed device. A preliminary trade-off was realized on ground technologies of interest.

For the mid-term, in the context of ISS, it is recommended to develop an automated system based on qRT-PCR. This technology is very mature and is fully suitable for the 1st step monitoring. For the deeper identification envisaged for the 2nd step monitoring, this technology is suitable but limits the possible identification to pre-defined targets. Other technologies such as the ones based on nanopore sequencing or micro-arrays would be more powerful and more suitable for this 2nd step monitoring, but due to a lack of maturity or integration cannot be envisaged at this stage for a short to mid-term spatialisation. The recommendation for the mid-term, in the context of ISS, is thus to develop an automated biomonitoring system based on qRT-PCR technology or similar technology such as NASBA proposed by the MIDASS system, in a fully integrated device, including the sample preparation part and allowing analyses of samples from air, water and surfaces. For longer term research and future exploration missions, this system could integrate a deeper analysis method, not limited to the identification of pre-defined targets such as nanopore sequencing. Considering the current significant ground investments in this field, it is recommended to closely follow the ground developments and to perform laboratory evaluations with a deeper analysis of the compatibility of these new technologies with spacecraft environment. The quality of the samples will be essential and requires improved equipment and procedures for sampling in particular for the surfaces.

In parallel of the proposed monitoring system, an alternative back-up system could be developed for redundancy purposes and to provide an on-line monitoring system. This system should be based on a different and complementary technology, such as optical technologies (e.g. fluorescence).

Concerning mitigation actions, our study recommends to start with a deeper analysis of the current mitigation actions under relevant environmental conditions and on cultures with mixed communities or biofilms. Possible complementary methods such as non-thermal plasma, UV-LEDs and other possible ventilation filters should also be evaluated. A predictive model (from the spread to deposition and possible biofilm formation) should be developed to support rational design, to refine the mitigation plans and to contribute to the design and evaluation of complementary control measures. Innovative surfaces seem also of high interest as a possible complementary prevention means to limit adhesion of microorganisms to the surfaces, or to contribute to improved sampling thanks to witness surfaces or to monitoring thanks to early detection capabilities. Ground research in this field is currently very active and ground applications are very wide. It is therefore recommended to perform a specific study on that topic to evaluate more deeply the most interesting technologies of interest and their relevance & possible compatibility for the manned spacecraft context.

In the long term, it would be relevant to develop an expert system able to combine the data from the microbial environmental monitoring with data from the physical environment monitoring and possibly with the crew health monitoring to automatically trigger the most relevant mitigation action or at least to provide a real time biocontamination risk assessment and a support for the crew to decide on or to automate the most relevant countermeasure.

The procedures and standards for monitoring and mitigation actions will have to be refined and regularly maintained during all the proposed developments and research.

Transverse research to support the proposed monitoring strategy has also been identified. Additional knowledge is required on biofilm formation and biofilm behaviour under spacecraft environmental conditions and on the induced increased resistance to mitigation actions and on the impact on the biodegradation risks. Additional knowledge is also necessary to study the evolution of biocontaminants after long exposure to space. In terms of operational space medicine, additional R&D will be required to improve the means for medical infection management, in particular means for following up the evolution of the infection and means for antibiotic susceptibility analysis. For future long duration exploration missions, the identification of the cause of the infection as quickly as possible will be very important both for the patient and to implement the relevant countermeasure to protect the other crew members. The envisaged monitoring system could also contribute for that purpose.

Significant earth applications of the recommended R&D may be expected from the recommended R&D to contribute to indoor air quality for instance for public buildings such as schools, offices, transport hubs but also transportation vehicles, for hospitals (against nosocomial infections) or for industry (food or pharmaceutical industry).