# Environmental Monitoring as part of Life Support for the Crew Habitat for Lunar and Mars missions

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**Like other crewed space missions, future missions to the moon and Mars will have requirements for monitoring the chemical and microbial status of the crew habitat. Monitoring the crew habitat becomes more critical in such long term missions, when resupply from earth and return to earth are highly difficult or impossible. It is expected that some of the requirements will be similar to previous space missions. Additional requirements will result from the dusty nature of the lunar or Martian surface. This paper will describe the state of technology development for environmental monitoring of lunar lander and lunar outpost missions, and the state of plans for future missions.**

## Nomenclature

| | | |
|---|---|---|
| *AEMC* | = | Advanced Environmental Monitoring and Control |
| *COTS* | = | Commercial Off the Shelf |
| *CSPE* | = | Colorimetric Solid Phase Extraction |
| *ETDP* | = | Exploration Technology Development Program |
| *ESMD* | = | Exploration Systems Mission Directorate |
| *FTIR* | = | Fourier Transform InfraRed spectroscopy |
| *FPDS* | = | Fire Prevention, Detection, and Suppression |
| *GC/MS* | = | Gas Chromatograph/Mass Spectrometry |
| *VCAM* | = | Vehicle Cabin Atmosphere Monitor |

## I. Introduction

ENvironmental Monitoring is the primary focus of the Advanced Environmental Monitoring and Control (AEMC) Project of NASA's Exploration Technology Development Program (ETDP), which in turn is guided by the Advanced Concepts Division (ACD)of the Exploration Systems Mission Directorate (ESMD). The habitat volume of a spacecraft is necessarily closed from the outside, and must be maintained at conditions suitable for human life. In order to assure that those conditions are being met, monitoring technologies are required to continually observe cabin conditions, with particular emphasis to the status of air and water. The information is used not only to assess whether or not the air and water conditions are safe for human health, but are also used as data for life support processing system operation, e.g. feedback control. AEMC develops monitoring technologies needed for future NASA missions, and, as part of that development, demonstrates technology where appropriate on testbeds such as the International Space Station (ISS). AEMC's current portfolio consists of technology areas identified by mission projects, i.e. technology pull. Future AEMC work may include some attention to developing more fundamental technology push areas as well.

## II. Monitoring Technology Needs for Human Lunar Missions

Future NASA mission projects were conceived within the Constellation Program (CxP) which was part of ESMD. Future vehicle areas within Constellation included the Orion crew exploration vehicle, the Altair lunar lander, and Lunar Surface Systems. Mission phases were known as Initial Capability (IC), Lunar Transport (LT), and Lunar Surface (LS). A fairly assessment of technology needs, including environmental monitoring, has been published by Constellation [1]. The monitoring needs identified are shown in Table 1 below:

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<table>
<tr><th>Need</th><th>IC</th><th>LT</th><th>LS</th></tr>
<tr><td>Post Fire Cleanup Monitor</td><td></td><td style="background:gray"></td><td style="background:gray"></td></tr>
<tr><td>Smoke Detector with no false positives*</td><td style="background:gray"></td><td style="background:gray"></td><td style="background:gray"></td></tr>
<tr><td>Improved oxygen monitor</td><td></td><td style="background:gray"></td><td style="background:gray"></td></tr>
<tr><td>Particulate Monitor (lunar dust)</td><td></td><td style="background:gray"></td><td style="background:gray"></td></tr>
<tr><td>Biocide monitor</td><td></td><td></td><td style="background:gray"></td></tr>
<tr><td>On-line TOC monitor (water process control)</td><td></td><td></td><td style="background:gray"></td></tr>
<tr><td>Trace Contaminant Monitor</td><td></td><td></td><td style="background:gray"></td></tr>
<tr><td>Microbial monitor</td><td></td><td></td><td style="background:gray"></td></tr>
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**Table 1 Environmental monitoring needs identified by Constellation projects.**
***supported by AEMC but led by FPDS.**



Table 1 represents a reasonably comprehensive list of monitoring needs for any significant future mission of human space flight. It is worth noting that as missions and vehicles progress in their development, priorities will shift.

Post Fire Cleanup Monitor refers to a scenario in which a fire has occurred onboard the spacecraft, and has been extinguished. Products of combustion, including acid gases, remain in the atmosphere and are being removed by an onboard process. The Post Fire Cleanup Monitor is needed to determine when the atmosphere is safe to breathe again. Smoke Detector with no false positives is an application area led by a different ETDP project, namely Fire Prevention, Detection and Suppression (FPDS). Since AEMC monitoring information may help prevent false positive detection of fire, AEMC supports FPDS in this area.

An important factor is that cabin pressure for future missions will be lower than atmospheric pressure. As the total pressure decreases, the partial pressure of oxygen must remain the same in order to sustain the crew. Therefore, the proportion of oxygen is higher, thereby increasing the risk of combustion. The percentage of oxygen must be high enough to sustain the crew, yet not high enough to compromise fire safety. Hence, more precise and accurate oxygen monitoring is needed. Lunar dust entry must be controlled, and monitoring is required to maintain the effectiveness and efficiency of that control. The growth of microorganisms in the water supply is kept in check by the addition of a biocide, which is typically based on iodine or silver. The biocide must be kept at a level that is high enough to be effective, but not high enough to endanger the health of the crew. The quality of the water in general is also indicated by a total organic carbon (TOC) measurement. Microbial growth can occur not only in the water supply, but also on surfaces. Microbial monitoring is important not only for the health of the crew, but also the proper functioning of hardware (for example, fluid delivery lines can be clogged by biofilm buildup.)

Monitoring of particulates is always important as a means to help determine if a fire is starting. It has additional importance in lunar missions, which must be designed to minimize the introduction of harmful lunar dust. This particulate monitoring efforts leverages the history of work in smoke particle monitoring. Particulate monitoring will also be relevant to Mars missions.

Quality of processed water on earth and on ISS is indicated by the Total Organic Carbon (TOC) measurement. This test is currently performed manually on ISS[2]; future missions will need an online automatic capability.

The closed environment of a space habitat makes it susceptible to trace contaminant buildup[3], especially as the mission length increases. Trace contaminant monitoring is already an important function on ISS[4], and will be needed by the longer lunar surface missions as well. It is possible that longer missions will occur using mobile as well as fixed habitats. Mission length also increases the possibility of the microbiological threats described above, hence keeping a watch on the microbial status is important.

## III. Monitoring Requirements for human missions.

The choice of technology is influenced by several factors. When the vehicle is quite small, such as Orion or a lunar rover, mass and volume are extremely limited, and miniaturization is important. Larger habitats such as ISS or a lunar outpost may have somewhat more mass allocation, and additional functionality may be accommodated in the monitoring system [5,6].

Miniaturization can be accomplished through a number of approaches. The sensing technology itself can be reduced in size. This must be done very carefully in order not to impact sensitivity and performance. As the size is reduces, surface area increases relative to volume, making surface cleanliness more critical. Also, accuracy of machining tolerances can become crucial for very small instruments.

It is also possible to focus on the overall size of the monitoring system. For example, in some cases a single technology is suitable for more than one application. Then the mission can plan for fewer instruments, or can accommodate redundancy to reduce risk without causing significant mass impact.

The duration of the mission is important: missions of less than two weeks have little time for buildup of trace chemicals or microorganisms. Missions in low earth orbit have the option of returning the crew to earth in a short time; more distant missions will require the crew to stay and address emergency situations. There is also the time spent prior to activation that must be considered. A monitor may have to wait in storage for several months, perhaps years, on earth or in space, before it is activated. Once activated, minimal need for calibration is desirable.

## IV. Technology Solutions

The AEMC Project has been pursuing a number of technologies which address future Exploration needs. These are shown in Table 2. In addition, the AEMC Project leverages development which may be sponsored by other funding sources, described below.

| Need | GC/MS | Sensor Array | Optical Spectroscopy | Colorimetric Solid Phase Extraction | LOCAD |
|---|---|---|---|---|---|
| Post Fire Cleanup Monitor | | | | | |
| Smoke Detector with no false positives* | | | | | |
| Improved oxygen monitor | (no GC) | | | | |
| Particulate Monitor (lunar dust) | | | | | |
| Biocide monitor | | | | | |
| On-line TOC monitor (water process control) | | | | | |
| Trace Contaminant Monitor | | | | | |
| Microbial monitor | | | | | |
| Potential for mass reduction over current practice | medium | high | high | TBD | TBD |

**Table 2. Technology Development current underway under AEMC. Greyed boxes depict how each technology often has more than one application. Also shown is an estimate of the potential for reducing the mass of the instrument.**

### A. Gas Chromatograph/Mass Spectrometer (GC/MS)

The Gas Chromatograph/Mass Spectrometer (GC/MS) is a well established technology commonly found in chemistry laboratories. It is capable of identifying and quantifying a wide variety of trace gases, including some of the acid gases produced by combustion. The mass spectrometer portion alone is suitable analyzing the major constituents of air, such as nitrogen, oxygen, and carbon dioxide. Thus, GC/MS technology is a candidate for Post Fire Cleanup Monitor, Improved Oxygen Monitor, and Trace Contaminant Monitor.

An implementation of GC/MS technology called the Vehicle Cabin Atmosphere Monitor (VCAM) has been developed by AEMC[7]. VCAM addresses a target list of chemicals for use in ISS. The VCAM instrument was shipped in early September and will be delivered to ISS in 2010.

### B. Sensor Array

The sensor array approach is one that has been made practical in part due to the availability of cheap, relatively power, yet tiny, processors. An array of several sensing elements, which are purposely not very specific, is exposed to the target environment. The totality of response of each of the sensing elements constitutes a pattern which may be considered analogous to an image. The range of patterns can be calibrated quantitatively to a variety of targets, or mixtures of targets. The sensing elements can be of various types, including conducting polymers, doped polymers, microhotplates, and fluorescent dyes. More complex sensing elements are also feasible, but in the AEMC project, the sensor array approach fits into a niche of being small, robust, and highly functional. The target chemicals can be volatile organics as well as inorganic gases.

An AEMC implementation of the sensor array approach has been named the Electronic Nose, or ENose. The ENose has operated for over six months on ISS[8].

## C. Optical Spectroscopy

Volatile organics in air, as well as some other compounds, can be measure by FTIR or other spectroscopic methods. The ANITA instrument was an FTIR built by ESA and flown on ISS[9]. The ANITA demonstrated the ability of FTIR to simultaneously detect a wide range of compounds at fairly sensitive levels. However, it was not able to monitor the major constituents Oxygen and Nitrogen. FTIR requires a complex, precise mechanism including a moving mirror. It is believed that the vibration environment on ISS impacted the performance of ANITA, which nevertheless was able to produce useful data.

If only a few target gases need be monitored, it may be more mass and cost effective to employ a few dedicated measurement devices. A dedicated device would employ a solidstate laser and would target one or two species, with a high degree of specificity and accuracy[10].

## D. Colorimetric Solid Phase Extraction (CSPE)

The CSPE technology is used to measure the concentration of target chemicals in water. CSPE uses filter material that has been impregnated with an indicating chemical. A known volume of water is forced through the filter, causing a color change in the filter's indicating chemical. The intensity of the color change is proportional to the concentration of target chemical, as read from a handheld calibrated spectrometer. CSPE has been developed and flown on the International Space Station to measure iodine and silver biocides[11]. Chemistry for other target chemicals has been developed as well[12]. Although this approach uses disposables, this is not too large a problem since measurements are fairly infrequent. Storage life of the reagents remains to be demonstrated and may be an area for further work.

## E. Lab on a Chip Advanced Development (LOCAD) platform

This effort leverages advances in the commercial world in microfluidics and biotechnology. A commercial handheld platform was modified for use in microgravity space flight. The platform was capable of measuring an indicator for gram negative bacteria, and additional biological targets have also been in development. The platform was launched to ISS and yielded experimental results during 2009 [13].

## F. Particulate Monitoring

Particulate matter in some size ranges is hazardous to human health. It is of special concern for missions to exploration sites with dusty environments, such as the moon or asteroids. Particulate monitoring development has begun this year in agreement with programmatic scheduling. The technology development leverages work that was targeting particules generated by in space combustion[14].

## G. Technology Development for Future Missions

Under the President's 2010 budget proposal[15], NASA would give increased emphasis to research and development of more fundamental, potentially breakthrough areas. At this writing, future missions are unclear, in terms of both destinations and schedules. Nevertheless, if one assumes that human space flight will continue, it is desirable to develop a general framework for technology development. This section discusses some of the issues with technology management for a broad range of future applications.

In the area of chemical/biological monitoring and control, the community is driven by microelectronics, biotechnology, industrial process control, and other large industries. NASA is a relatively small participant, and the community as a whole is large and progresses on its own. We can show this graphically as follows: In figure below the vertical axis represents performance. We can pick a familiar example, computer processing speed. The state of the art in processing speed continues to increase at a steady rate. The horizontal axis is time.

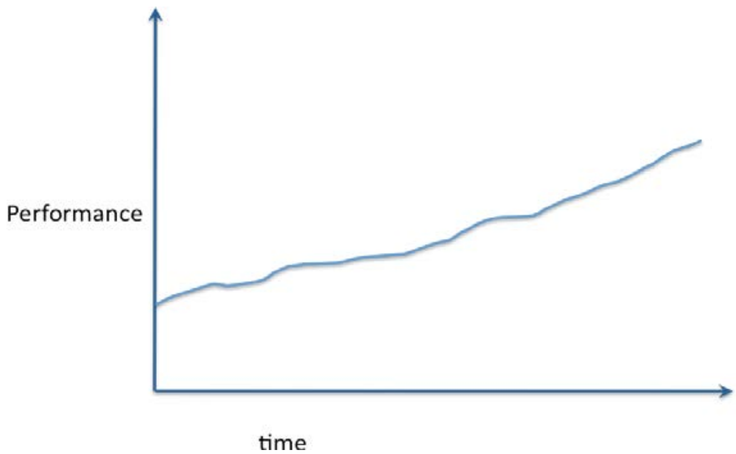


**Figure 1. Technological advancement with time.** *The curve is generic. Well known examples include computer processor performance or genetic screening capability.*

Now consider a set of NASA missions, set for successive timeframe, labeled (1), (2), and (3), as seen below. Technology for Mission1 is selected, or frozen, at some point in time prior to launch, so that there is time to design and build a flight deliverable. The process can be repeated for Mission2 and Mission3.

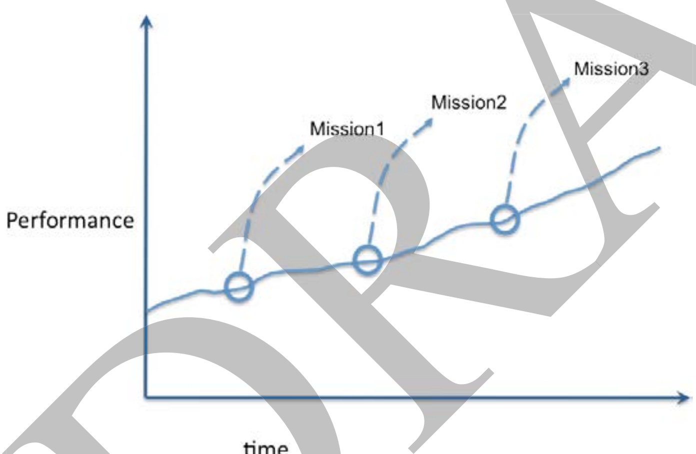


**Figure 2. Freezing technology.** *Prior to flight, a mission's technology selection is frozen from further development, and is adapted to the mission.*

Sometimes it is possible to simply continue to fly the first version. Although this may appear to save money, there are risks to this approach. In a rapidly advancing technology field the following can occur:

- The supporting community (industry and academia) may quickly move on.
- Expertise and replacement parts and materials may evaporate.
- Older technology no longer performs to acceptable levels.

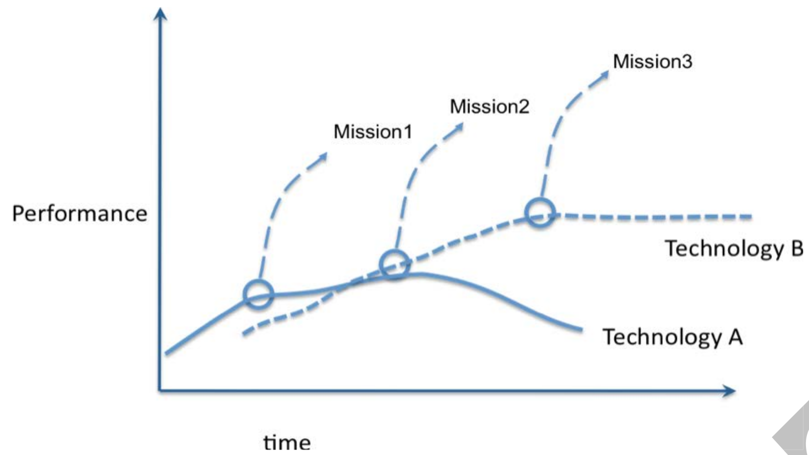

**Figure 3. Competing technolgies**.

An example is shown in the figure above. Here, Mission1 planners chose Technology A over Technology B due to its superior performance. But by the time the Mission2 decision point rolls around, Technology B has caught up with Technology A. How should they choose? Technology A, for its greater flight history, or Technology B, for its as yet unproven performance potential? In this example, Technology B continues to improve, while Technology A peaks out, languishes, and begins to go out of business. Mission3 planners face a much easier decision.

An appropriate NASA role is to engage and leverage the technology development community, knowing well enough so that NASA can take the technological developments and adapt, direct, or improve them beyond their terrestrial customer base, toward usage in space. In an example from the NASA space science area[16], NASA workers perform some of the research and development, and also track the progress in the community, projecting estimates for when flight readiness will be achieved. Incorporation of technology can be done at various levels. For example, LOCAD used a commercial terrestrial platform, but changed the materials and developed a microgravity sampler. VCAM used a design customized for ISS, but employs many COTS components. Either way, the NASA community needed to be sufficiently engaged with the larger academia/commercial community in order to effectively adapt technology to space flight usage.

The low TRL innovative community must continually feed into the mission operations/production community, which in turn must stay efficient. Consider the case of a company private industry. If the company cannot produce products efficiently, it goes out of business. If its products are superceded by better products from competitors, it will also fail. The NASA version is that NASA must sustain a high success rate in its missions. At the same time, NASA must incorporate technology developments in order to continually improve value returned from its missions. NASA must be what Tushman and O'Reilly call an Ambidextrous Organization[17, 18]. The organization's leadership must recognize the appropriate contribution of the entire spectrum of technology development, from fundamentally new idea to efficient and reliable daily operation.

## V. Conclusion

Environmental monitoring for human space missions is an important part of mission design and development. Environmental monitoring technology development has been underway for the Constellation Program. Future development will continue to examine the monitoring needs developed for Constellation [19, 20,21], and will continue to leverage similar development efforts both within[22] and outside NASA.

## Acknowledgments

Valuable discussions were held with Mr. Craig Peterson. The research reported in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration and supported by the Advanced Environmental Monitoring and Control Project, ESMD, NASA.

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