Air Quality Monitoring: Risk-based Choices

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When monitoring spacecraft air quality, we first focus on controlling the risk of toxic exposure. We are also careful to learn from adverse events. For example, we use nontoxic chemicals wherever we can and limit access to those chemicals that are toxic; the use of ethylene glycol on the Russian Space Station *Mir* taught us this lesson. This chemical leaked episodically on *Mir* and caused crew symptoms; therefore, it was replaced in the International Space Station (ISS) systems by a much less toxic fluid consisting of glycerol and water (triol). It is also important that materials do not off-gas significantly. Toxicants (such as in batteries) are contained in payloads according to their risk, and we use nontoxic utility compounds.

We provide both a robust air-scrubbing capability and personal protective equipment for the crew to don if needed, as well as the ability to abandon the spacecraft if needed.

When adverse events occur, we intentionally learn from them. Toxic propellants, fires, pyrolysis events, thermal control system leaks, excess carbon dioxide (CO_2), formaldehyde accumulation, and dust have all proven (predictably) to be issues in past space flights. Crew members may be particularly sensitive to CO_2 in the closed environment of space because of fluid shifts.

The following adverse events are a few of those from which we have learned vital lessons:

> In 1975 during the Apollo-Soyuz Program, the Apollo capsule was contaminated with nitrogen tetroxide in the course of repressurization. One crew member was unconscious at landing, and the other two crew members had delayed pulmonary issues that were later resolved. The lesson we learned from this was to keep the pressurization equalization port as far from the thrusters as possible.
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> In 1997 the solid fuel oxygen generator fire aboard *Mir*, from a toxicology perspective, was a minor fire. Few toxic contaminants were released into the air. The "beauty" of this fire was that it was a hot fire and, because it was an oxygen generator, carbon monoxide (CO) became CO_2.
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> Also in 1997, a small fire in the trace contaminant purification system on board *Mir* generated a puff of smoke. At 10 hours post-event, the crew reported nausea and headache, consistent with a serious CO exposure. From this we learned that the physiological effects of exposure are delayed until the carboxyhemoglobin builds up in the human system.
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> Ethylene glycol leaks were also very common on *Mir* in the 1990s. Levels were measured with Draeger-Tubes®. The leaks occurred in the Kvant module, and the contaminant was not distributed evenly through the space. Our lesson learned from this was that the ethylene glycol was seeking cold surfaces, condensing, and then slowly revolatizing again until it reached equilibrium.

While these types of events could have been anticipated, other events have proven more unpredictable. For example, post-extravehicular activity (EVA) the crew of ISS Increment 7A re-entered the station and started to desorb the metal oxide (Metox) canisters used to purify suit air during EVAs. The Metox regeneration system (by design) desorbed pollutants into the vehicle, not into space. The system was particularly loud, however, and the crew turned it off during the process – leaving the canisters inside. Another crew came on board station several months later, performed an EVA, and prepared to desorb their own canisters. As they started the process, because of the old canisters, the environment became incredibly noxious, and they had to go into the Russian segment for 30 hours.

We are now in the process of transitioning to real-time, on-board analysis. Grab-sample canisters enable us to aspirate samples through a valve by vacuum in <5 seconds to later analyze by gas chromatography. The primary weakness of these instruments is that air particulates occasionally clog the valve, preventing it from seating properly. Formaldehyde badges are another cheap and effective solution to detecting air particulates. We fly them in pairs on station, and crew members can wear them on their suit or fix them to a wall that has a good cross flow of air. Badges, while effective on station, will prove less effective in long-duration missions to the moon to Mars because they still have to be returned for analysis.

Current ISS on-board analysis technologies

Compound specific analyzer-combustion products (CSA-CP): The CSA-CP is a handheld monitor, adapted from a commercial product, that can perform at low pressures. We have experienced some problems with its electrochemical sensors.

CO_2 monitor: This handheld commercial monitor is very rugged, using infrared spectrometry to measure CO_2 levels.

Drager chip measurement system: This unit, flown by our Russian partners, has a 2-year shelf life. It is very quick and reliable, but can only monitor one analyte at a time. The unit is not good at high humidity levels and not sensitive enough to follow nominal atmospheric pollutants.

Major constituent analyzer (MCA): The MCA is a large, one-of-a-kind instrument flown by Life Support engineers. It is used to monitor life support gases and also CO_2.

Volatile organic analyzer (VOA): The VOA is a large, one-of-a-kind instrument flown by the Johnson Space Center toxicology group. It is a double-channel gas chromatograph ion mobility spectrometer that measures many trace organic compounds. Although the VOA has the advantage of not requiring a lot of pumps, it has only worked about half the time.

The European Space Agency's ISS instrument is the ANITA [ammonia and nitrification analyzer], adapted from commercial technology to deconvolute the optical spectrum, but only one individual can interpret it, thus limiting its usability. Another instrument is the electronic nose, but it targets only a few compounds and lacks specificity. The air quality analyzer, a gas chromatograph differential mobility spectrometer, is unproven as it is about to fly.

Another key issue in air quality on current and future missions revolves around how monitors present data to the crew in the absence of ground support and interpretation. Crew members need to be fairly autonomous and able to solve their own problems, so we must present data to them in a clear and meaningful way.

We must weigh the pros and cons of commercial vs. one-of-a-kind instruments as we change our approach to environmental monitoring. Commercial items tend to be smaller and less expensive than one-of-a-kind versions; they also are likely to have experience history and established support that we cannot get for our own inventions. While one-of-a-kind units have the advantage of being built to requirements, commercial versions are generally adaptable to requirements and are much easier to sustain.

Finally, lunar dust will be a major future issue for environmental quality. It is tiny, is easily inhalable, is porous, and has great surface area. High iron content gives it magnetic properties, which may enable us to solve control problems with magnets. Mars is likely to have greater dust issues than the moon, which is problematic for both hardware and crew health. Mars has global dust storms and local dust devils that move the dust into everything on a massive scale.

In conclusion, air monitoring is secondary to maintaining rigid control of risks to air quality, and it requires us to target the credible residual risks. We must transition from archival to real-time, on-board monitoring, although the constraints we have on monitoring devices are severe. We must provide data to a crew in a way that allows that crew to interpret the findings. Finally, dust management and monitoring may be a major concern for Exploration-class missions to the moon and Mars.

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