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Submarines, spacecraft, and exhaled breath

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Background

The International Association of Breath Research (IABR) meetings are an eclectic gathering of researchers in the medical, environmental, and instrumentation fields; our focus is on human health as assessed by the measurement and interpretation of trace chemicals in human exhaled breath. What may have escaped our notice is a complementary field of research that explores the creation and maintenance of artificial atmospheres practiced by the Submarine Air Monitoring and Air Purification (SAMAP) community. SAMAP is comprised of manufacturers, researchers, and medical professionals dealing with the engineering and instrumentation to support human life in submarines and spacecraft (including shuttle craft and manned rockets, high altitude aircraft, and the International Space Station (ISS)). Here the immediate concerns are short-term survival and long term health in fairly confined environments where one cannot simply "open the window" to get fresh air. As such, one of the main concerns is air monitoring, and the main sources of contamination are CO_2 and other constituents of human exhaled breath.

Since the inaugural meeting in 1994 in Adelaide Australia, SAMAP meetings have been held every two or three years alternating between the North American and European continents. The meetings are organized by Dr. Wally Mazurek (a member of IABR) of the Defense Systems Technology Organization (DSTO) of Australia, and individual meetings are co-hosted by the navies of the countries in which they are held. An overriding focus at SAMAP is life support (oxygen availability and carbon dioxide removal). Certainly, other air constituents are also important, for example, the closed environment of a submarine or the ISS can build up contaminants from consumer products, cooking, refrigeration, accidental fires, atmosphere maintenance, and propulsion. However, the most immediate concern is sustaining human metabolism: removing exhaled CO_2 and replacing metabolized O_2. Another important concern is a suite of products from chemical reactions among oxidizing compounds with biological chemicals such as amines, thiols, and carbonyls.

SAMAP meeting

We (Armin and Joachim) attended the 2011 SAMAP conference in Taranto Italy (Oct. 10-14), which occurred just a few weeks after the IABR meeting in Parma, Italy (Sept. 11 – 15, 2011). It was held at the Officers' Club of the Taranto Italy Naval Base under the patronage of the Italian Navy; the local host was Prof. Lucio Ricciardi of the University of Insubria, Varese, Italy.

At the 2011 SAMAP meeting, the theme was "air independent propulsion (AIP)" meaning the capability of recharging the main batteries of the submarine without the need to surface. Only a few navies (e.g. US, UK, France, Russia, China) have historically had this capability using nuclear powered submarines that can function underwater for extended periods of time (months). Most navies operate submarines with conventional diesel-electric propulsion wherein diesel powered generators charge battery banks which then drive an electric motor connected to the propeller. The batteries are charged while the boat is on the surface or during snorkeling when the boat is submerged a few meters below the surface and a snorkel tube is extended to the surface. The period between battery charges can vary from several hours to one or two days depending on the power requirements and the nature of the mission. The process is necessary for breathing air revitalization (flushing out accumulated contaminants) and for the operation of the diesel engines. However, during this period the submarine is vulnerable to detection. Since the 1940s there have been various attempts to develop a power generation system that is independent of external air (AIP). To this end hydrogen peroxide was initially used and later liquid oxygen (LOX). Currently, most AIP submarines use fuel cell technology (LOX and hydrogen) to supplement the conventional diesel-electric system in order to extend the underwater endurance to 2-3 weeks. These propulsion engineering changes also reduce periodic ventilation of the submarine's interior and thus put greater burden on the various maintenance systems. We note that the spaceflight community has similar issues; their energy production mechanisms are essentially air independent in that they rely almost entirely on photovoltaic arrays for electricity generation with only emergency back-up power from alcohol fuel cells.

In response to prolonged underwater submarine AIP operations, months-long spaceflight operations onboard the ISS, and planning for future years-long missions to Mars, there has been an increasing awareness that bio-monitoring is an important factor for assessing the health and awareness states of the crewmembers. SAMAP researchers have been proposing various air and bio-monitoring instruments and methods in response to these needs. One of the most promising new methodologies is the non-invasive monitoring of exhaled breath.

So, what do the IABR and SAMAP communities have in common?

> Inhalation toxicology: We are both concerned with contamination from the environment, either as a direct health threat or as a confounder for diagnostic

assessments. For example, the exhaled breath from subjects in a contaminated and enclosed artificial environment (submarine or spacecraft) can serve as a model system and a source of contamination for their peers in a cleaner environment. In a similar way, exhaled anesthetics can serve as a source of contamination in hospital/clinical settings or exhalation of occupational exposures to tetrachloroethylene can impact family members at home.

Instrumentation development: We both have similar needs for better, more specific and more sensitive instruments. Certainly, the analytical instruments to be used onboard submarines and spacecraft have severe restrictions on energy use, physical size, and ease of operation. The medical and clinical communities have similar long term plans for their analytical tools, in this case to take breath analysis away from the large complex instruments in the laboratory to the outpatient clinic and eventually to the home care market. Similarly, for environmental and public health research, it is always desirable to have easily operated and deployable instruments that can be taken to the field, rather than bringing numerous subjects to a central laboratory.

Bio-monitoring: Although the SAMAP community is much more focused on air rather than breath measurement, this is changing because of the realization that longer deployment times (on submarines and spacecraft) will affect more than just acute health. To monitor longer-term health outcomes, there is a great deal of commonality between our respective research communities. Any instrument that monitors for contaminants in environmental air could certainly be adapted to breath analysis for assessing exposures and health state. Instruments that simultaneously provide rapid response and high specificity to a broad range of analytes, such as those based on optical spectroscopy and mass spectrometry, are particularly valued.

The path forward

We found the SAMAP meeting to be a worthwhile experience in large part from the discovery that there exists another high-tech community with similar needs as the IABR community. Some collaboration could well be fruitful for us; we suggest that IABR folks stay in contact with SAMAP in the future and attempt to attend each other's meetings if possible. SAMAP meetings tend to run on a 2-year cycle and so the next one has not as yet been announced. We will let the IABR community know when the next meeting is scheduled, and will certainly make the SAMAP folks aware of IABR meetings and the Journal of Breath Research.

This article has been subjected to (EPA) Agency review and approved for publication. Statements do not necessarily reflect official Agency policy.