Breathing

Breathing is a subject that not too many people think about. The ability to take air in and let it out again is pretty much taken for granted. On submarines not so much, and again there is a difference between the "concern" on diesel compared to nuclear powered submarines.

The primary component of air when dealing with the human factor is of course the oxygen portion. The composition of air is 78% Nitrogen, 21% Oxygen, and less than 1% other gases including carbon dioxide, which is the gas we give off by "breathing".

On the diesel boats the issue of getting breathable air was not a major concern due to the idea that air was also needed to run the diesels; and time on the batteries was limited. If the batteries needed to be charged – then air would be available, by either running the diesels on the surface or during snorkeling. When the "missions" of submarines took on a more covert nature, the issue of breathing became important, because the boats would operate to the absolute maximum of battery life. To address the "new" issue of extended time "on the batteries" the issue of breathable air had to be addressed. It was addressed by adding "scrubbers". In the aft torpedo room, (that doubled as a berthing space), and the forward torpedo room (also a berthing space) Lithium Hydroxide "scrubbers" were added. These "scrubbers" consisted of six metal canisters that were "fired up" when oxygen became low and CO_2 got "too high"; and "too high" will be defined later.

On nuclear submarines the process was a little more important and an entire "system" was added to the boat. Monoethanolamine (MEA) "systems" were added as well as electrochemical Oxygen Generators, the production of oxygen accomplished by the electrolysis of water. Essentially breaking down water into Hydrogen and Oxygen, where the Oxygen is added to the atmosphere and the Hydrogen is safely disposed of back into the ocean.

Diesel – As mentioned above when at the end of the battery life, but before the atmosphere was broken to take on air for the diesels – oxygen got pretty low. So low that the ability to sustain combustion was very difficult. I distinctly remember having to get up on tippy-toes next to one of the many air ventilation ducts to get the freshest air possible to light my good ol' trusty Zippo lighter, and in turn light my cigarette. Then I would have to keep puffing on the cigarette to keep it going. If I didn't, it would go out.

Nuclear- I remember on one of the boats making friends with one of the crew-men responsible for the scrubbers. I remember sitting with him on a couple of watches where we "played" with the atmosphere. It was pretty interesting. In the space of a couple of hours we changed the mood of the crew from giddy (oxygen rich) to very depressed (oxygen poor). Also of particular interest was some of the "other" things in the atmosphere. The monitoring system did an excellent job of breaking down the atmosphere coming into the system into very small measurement quantities, measured in Parts Per Million (PPM). My friend produced several past measurements where he could fairly accurately tell me what the crew had for the last meal, by the methane content, which was very different from "the venting of sanitaries" which was the other offensive odor on the boat, that took place periodically.

As I mentioned at the beginning the subject of "breathing" is a subject that is pretty much a given in life. I am certain that you probably have not spent too much time thinking about it.
My two stories are pretty trivial and create many other questions I'm sure. So I have appended to this a section of a "paper" on the subject. Should you be interested in the more technical aspects of the "issue of breathing".

The following is an unclassified Technical Description of the "Issues" by the Massachusetts Institute of Technology on the subject of breathing on a submarine:

1. Submarine Atmosphere Characteristics

Within a submarine, the atmospheric control system assumes importance equal to the propulsion, weapons, and navigation systems. An efficient and reliable system will insure, the health and safety of the crew and prevents damage to the ship's machinery from atmospheric contaminants. To accomplish these goals, the atmospheric control system maintains air in the submerged submarine at a composition that is close to that of clean surface air. The equipment used to measure and maintain this air quality is based on applications of principles taught in general chemistry.

In order to create an atmosphere close to that of clean surface air; we must establish the composition of clean dry air shown in Table 1. Variations to this normal composition occur in nature, due to the presence of water vapor, dust, pollen, and particulate matter.

Table 1 – Composition of Clean Dry Air

Component	**Symbol**	**Specific Gravity**	**Volume %**	**Partial Pressure (Torr)**
Nitrogen	N_2	**0.967**	**78.09**	**593**
Oxygen	O_2	**1.105**	**20.95**	**159**
Argon	Ar	**1.38**	**0.93**	**7**
Carbon Dioxide	CO_2	**1.53**	**0.03**	**1**

GENERAL NOTES:
(1) Data is for standard dry air weighing 0.075 $lbs \cdot ft^{-3}$ (1.2 $kg \cdot m^{-3}$) at 70°F (21°C) and at a barometric pressure of 29.92 in. of mercury (760 Torr).
(2) The table omits very minute quantities of other gases (neon, helium, methane, krypton, nitrous oxide, hydrogen, xenon, and ozone) with a combined total of 28 ppm.
(3) The composition shown will vary slightly because of the presence of a small percentage of water vapor normally present. Thus, clean air at 50 percent relative humidity will have an oxygen content of approximately 20.5 percent.
(4) Specific gravity data is based on reference of air having a specific gravity of 1.000.
The atmosphere in a submarine differs from that in nature in three important respects:

a) Greater variability in the oxygen and carbon dioxide content;
b) The presence of a wide range of organic and inorganic contaminants and;
c) The potential problem associated with the toxicity of certain substances (see below).

The last two categories are significant since the volume of air in the submarine is limited and there is no place for “the wind to carry the toxic gases away.” More than fifty chemicals, including such reactive materials as HF, CO, NO_2, and O_3, were found to be present in measurable quantities in atmospheres measured on board operating submarines.

Tracing the sources of some forty of these contaminants indicated they came from smoking, sanitary tanks, battery gassing, lubricants, paints, adhesives, cooking, engine exhaust, electric arcing, refrigerants, fuel oils, and, frustratingly, as products from the atmosphere purification systems when improper materials were released in the closed atmosphere of the submarine. The remainder are suspected to be from cigarette smoke although they have not been quantitatively verified.

Even the least reactive and toxic of these compounds is neither pleasant nor necessarily safe to breath for long periods. The more toxic components represent a real threat even on a short-term basis. The effect of any substance to which a person might be exposed depends on:

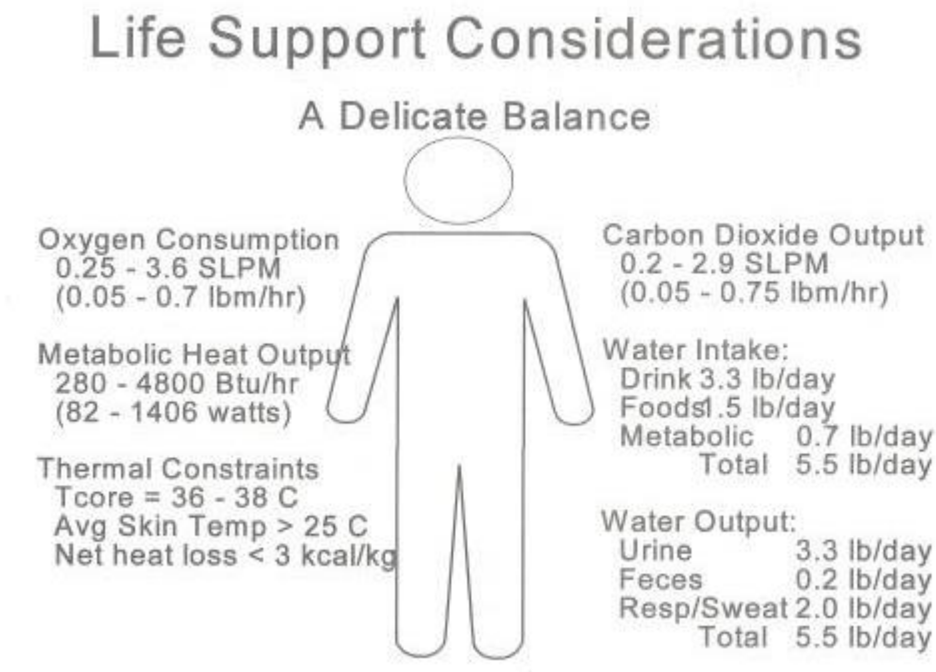
a) Length of exposure,
b) Concentration,
c) Solubility or *permeability* in tissue and body fluids, and
d) Type of gas or toxic medium.

2. Medical/Toxicological Considerations

Let's begin with a simple description of the human respiratory process. Air taken into the lungs reaches very small dead-end spaces called *alveoli.* These tiny sacs have extremely thin walls filled with *capillaries* (very fine blood vessels). The total alveoli provide a large surface area through which gases pass into the capillaries' blood and, hence, into the general blood stream. As a result, the gases establish almost immediate equilibrium with the blood: both oxygen in and carbon dioxide out. In the red blood cells, oxygen unites chemically with *hemoglobin* to form a relatively weak chemical bond. When the red blood cell has been carried to regions of the circulatory system remote from the lungs, the oxygen is freed and consumed by the cells at that point. The blood, returning to the lungs, carries CO_2 and other waste products back to the lungs for expulsion. Figure 1 is a material balance for the average submarine crewmember.

Under ordinary conditions, the respiratory rate is about 15 breaths/minute, or about 20 SCFH (standard cubic feet per hour of air a shown in Table 1) per person. Air intake is only about 0.02 ft^3 per breath (SCFB), only a small fraction of the total lung capacity. A raised level of activity requires energy, which creates a larger demand for oxygen. This need is met by both greater rate of breathing and greater volume per breath. At a minimum, the human body must absorb sufficient oxygen to support the biochemical activity of the brain and other vital organs.

As a reflection of the equilibrium constant for such absorption, it is the partial pressure of the oxygen (P_{O_2}) in the atmosphere that determines how much oxygen is carried in a unit of blood. In normal, healthy individuals, *arterial* blood has above 90% of its holding capacity for oxygen when P_{O_2} is 110 Torr or higher (Sea Level, P_{O_2} = 16 Torr). Oxygen levels in submarine atmospheres at 110 Torr or higher will insure against *hypoxia* (see section 3).



Notes: SLPM – standard liters per minute
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Figure 1 – Submarine Material Balance

Deployed submarine atmospheres undergo fluctuations of ${}_{O_2}P$ and ${}_{B}P$ (Barometric Pressure). Such fluctuations must be controlled to insure adequate life support for the crew.

Although the partial pressure of oxygen is the critical factor physiologically, the % of oxygen is more critical in propagation of oxygen-supported fire where the inert gasses interfere with the mechanism of burning. The safe operating zone, or boundary conditions, for a submarine
(Submarine Atmosphere Zone) is defined by the ranges:

${}_{O_2}P$ = 119 to 160 Torr
${}_{B}P$ = 700 to 810 Torr
% O_2 = 17.0 to 21.0 %

This corresponds to a range for ${}_{O_2}P$ from roughly sea level to the level maintained in a commercial aircraft cabin or a point similar to the atmospheric conditions in Bogota, Columbia at 9000 feet above sea level. The ${}_{B}P$ levels are more restrictive and the normal atmosphere for Denver, Colorado at an altitude of 1 mile would be outside of the Submarine Atmosphere Zone.

3. Physiological Problems

Important acute problems that may arise from improper atmospheric conditions are:

a) Hypoxia – Insufficient delivery of O_2 to the body is the result of atmospheres with low ${}_{O_2}P$. Symptoms vary with ${}_{O_2}P$ level and can include: impaired night vision, heavy breathing, impaired judgment, dizziness, slow thinking, impaired muscular coordination, unconsciousness, and death.

b) Decompression Sickness – This malady is due to the formation of gas bubbles in the body due to gases such as nitrogen coming out of solution in body fluids. It results from an excessive reduction in ambient pressure (P_B).
c) Oxygen Poisoning – Lung injury results from P_{O_2} values over 380 Torr, and generally with excessive P_B as well. Oxygen poisoning is a possible problem for aviators with an improper gas mixes in their oxygen masks, however, it is not likely in a submarine, but it is not impossible.
d) Carbon Dioxide Buildup – Most of the CO_2 produced in a submarine results from respiration. An average person produces about 0.83 SCFH. An increase in activity raises the CO_2 partial pressure in the blood, which stimulates rapid respiration. Exposures to atmospheres with high P_{CO_2} have the same effect as hypoxia. Symptoms can range from increased respiration, through mild discomfort, to dizziness, stupor, unconsciousness, and death. Both concentration and exposure time to CO_2 are important. Acute symptoms arise from sustained exposure at high concentration and are the result of upsetting pH and the biochemical balances related to O_2 and CO_2. Increased CO_2 will cause impairment and danger before reduced P_{O_2} will have an effect in contained, untreated atmospheres.
e) Carbon Monoxide Buildup – The *affinity* of CO for hemoglobin is about 210 times that of oxygen. As a consequence, relatively low concentrations of CO lead to deprivation of oxygen carriers in the blood. Toxic exposure causes tissues to be deprived of oxygen although the P_{O_2} is adequate.
f) Excess Refrigerants – Halocarbons such as dichlorodifluoromethane, CCl_2F_2, a commercial refrigerant known as R-12 and dichlorodifluoroethene, $CClF_2CClF_2$, a commercial refrigerant known as R-114, can act as simple asphyxiants, causing dizziness as low concentration and death at high concentrations. Products of the thermal decomposition of these materials can be highly corrosive and toxic, e.g., HCl and HF.
g) Excess Hydrocarbons – Aromatic and aliphatic hydrocarbons appear in trace amounts from a number of sources, including paints and thinners, fuels, lubricants, sealing compounds, solvents, adhesives, etc. The *aliphatic compounds,* as a class, are considered relatively non-toxic in trace amounts; but high levels show an impact on liver function. *Aromatics* are generally more dangerous because they do enter into the metabolism of various organs and irritate the skin and mucous membranes. Although most of the exposure will be from respiration, some of these materials penetrate the skin.
h) Excess Ozone – Ozone is produced by any spark that passes through an oxygen containing atmosphere. Electric motors and the electrostatic precipitators used to remove particles from the air are the major producers on a submarine. Ozone is highly irritating to all mucous membranes and can cause skin and eye irritation, respiratory irritation, and may produce coma at concentrations above 1-ppm. It also causes cracking of natural rubber products such as hoses, gaskets, seals, etc.
i) Excess Hydrogen – Although hydrogen does not offer significant physiological risk, it is highly flammable and explosive if the P_{H_2} rises above 4%. It is generated by battery charging and is a product of electrolytic oxygen generators. The oxygen bled to the atmosphere may contain as high as 1% hydrogen, which is then significantly diluted by the nitrogen in the ship.

4. Classification of Materials by Biological Effect

Some of the major categories used by the Navy for toxic materials are based on the biological effects that they have on the exposed organism. Some examples are presented here with the primary source listed.

a) Irritants – These are characterized by corrosive action when in contact with moist or mucus surfaces.

1) Respiratory Tract or Eyes (NH_3, SO_2, HC1, HF, NO_2, N_2O, Freon) Sources include smoking, sanitary tanks, refrigerants, product of CO-H_2 burners when other hydrocarbons react.

2) Upper Respiratory Tract, and Lungs (O_3, Cl_2, those in "1" above). Sources include electric arcs in machinery, salt water in batteries, sterilizing solutions and bleaches.

3) Air Sacs/Terminal Respiratory Passages in Lungs. Sources include tobacco mists and dusts, aerosols of many things.

b). Asphyxiants – These interfere with oxidative metabolism.

1) Inerts – These displace the oxygen in the air being breathed. (CO_2, N_2, hydrocarbon vapors, Freons and other refrigerants) The quantity required to be effective is typically larger than that usually found in submarine atmospheres but these do represent a very real threat to personnel working in closed spaces. There are several fatalities a year in which the death was caused by entering a closed space where oxygen had been displaced by some other gas.

2) Chemical Asphyxiants – These are toxic agents, which interfere with the normal transport of oxygen by the blood. (HCN, H_2S, and CO) CO is the biggest threat since it comes from smoking, cooking, engine exhaust, and missile launch systems (See abatement effort below).

c) Anesthetics and Narcotics – These are depressants acting on the central nervous system and are generally reversible. Their effect depends on their partial pressure in the blood. (grain alcohol, hydrocarbons, methyl chloroform) Sources include solvents used in cleaning systems, fuels and lubricants, and adhesives.

d) Systemic Poisons – These are materials, which react irreversibly with specific organs and hinder the function of that organ.

1) General Muscle Effect – These inhibit normal muscle function or interfere with transport properties; especially in the liver. (Freons and other halocarbons) Sources include cleaning solvents and refrigerants.

2) Damage to the Blood Forming System – These generally target the *bone-marrow*. (benzene and other aromatic hydrocarbons) Sources include paints, fuels, solvents, lubricating oils.

3) Nerve Poisons (methanol, phosgene) Sources include cleaners and cigarette smoke.

4) Toxic Metals – These interfere with enzyme function and other protein related activity. (Hg, Cd, Pd, Se) Sources include products of wear of batteries and various alloys. These can be especially dangerous if they are found in organic molecules.

5) Toxic Anions – These compete for important biological reactants. (sulfides and fluorides, in particular). Sources include metal impurities in various materials.

For these and other contaminants, there are specific limits described by Navy regulations so they are monitored frequently while the submarine is under way.