CC2e

Preliminary comments to MSC Cabin Atmosphere, [illegible] first meeting held February 3, 1967, with Mr. [illegible] presiding.

1. <u>Physiological considerations that establish the optimum partial pressure of oxygen in a mixture of respirable gases</u>.

Appended here is a graphic presentation of the relation of oxygen partial pressure to percentage saturation of human blood with oxygen. It is obvious that when the oxygen tensions are above approximately 60 mm Hg an increase in tension serves to increase the blood oxygen saturation only a small amount. Below about 50 mm Hg oxygen tension a relatively small decrease serves to unsaturate the hemoglobin molecule rather precipitously. Three curves are shown, with the center curve (B) describing the case when the blood plasma pH is 7.4 units, a condition considered normal for human blood.

Atmospheric air at sea level pressure contains approximately 21 per cent oxygen by volume. When air is inspired into the trachea it is immediately saturated with water vapor by contact with the moist lining of the respiratory tract. Assuming that dry air had been inspired at a pressure of 760 mm Hg, the addition of moisture to the trachea air lowers the total pressure of the other gases (nitrogen and oxygen) so that their combined pressures total 713 mm Hg (the vapor pressure of water at body temperature is 47 mm Hg. (So, 760-47=713)

After moistening in the trachea, the gas contains a partial pressure of oxygen of 149 mm Hg (0.21 x 713 = 149). When this gas reaches the alveolar spaces and gas exchange takes place across the pulmonary membranes which separate the respiratory gases from the blood perfusing the lungs, oxygen is absorbed by the hemoglobin contained within the red blood cells according to the curve (B) in Figure 1. As oxygen is absorbed, carbon dioxide is released from the blood and diffuses into the alveolar spaces per unit of time is equal to the volume of oxygen leaving the alveolar spaces in that time the exchange ratio is said to be 1. Thus:

$$\text{Respiratory Exchange Ratio (R)} = \frac{\text{Volume } CO_2 \text{ produced}}{\text{Volume } O_2 \text{ consumed}}$$

Because of factors relating to complex metabolic processes and the fact that when a diet of fats, proteins and carbohydrates is consumed and metabolized by a variety of organs, each with its own pattern of metabolism, the net effect is that the gas exchange in the lungs does not produce a Respiratory Exchange Ratio of 1, but more nearly 0.84. When air, or a similar gas mixture is breathed, the effect of R being less than one (unity) has a minor, but significant influence on the calculation of composition of alveolar gas. So taking this into consideration, we calculate the composition of alveolar gas with respect to oxygen as:

$$P_{A_{O_2}} = F_{I_{O_2}} \left[P_B - P_{A_{H_2O}} \right] - P_{A_{CO_2}} \left[F_{I_{O_2}} + \frac{1 - F_{I_{O_2}}}{R} \right]$$

Where:

$P_{A_{O_2}}$ = partial pressure, alveolar oxygen

$F_{I_{O_2}}$ = mole fraction, inspired oxygen

P_B = barometric pressure mm Hg

$P_{A_{H_2O}}$ = partial pressure water at 37° C

$P_{A_{CO_2}}$ = partial pressure alveolar carbon dioxide (this is normally about 40 mm Hg, regulated to relative constancy by the action of the nervous system in regulating the rate and depth of breathing)

R = Respiratory Exchange Ratio

2. Influence of oxygen saturation of the blood on performance.

It can be shown by the above formula that when air is breathed at sea level, the oxygen partial pressure in the alveolar gas is about 102 to 104 mm Hg. Because some blood traverses the lungs without coming in contact with alveolar gas for exchange, the arterial blood reaching the left ventricle for ejection into the body systems never quite reaches 100 per cent saturation, but rather may be saturated to the extent of about 97.5 per cent. This descrepancy has no influence in the effectiveness of the blood to carry oxygen to the tissues. However, when the oxygen tension of the alveolar gas is decreased from any of several reasons (reduction in the total atmospheric pressure, intentional or accidental alteration of composition of the inspired gas, tracheobronchial obstruction, disease, etc.) the oxygen carrying capacity of the blood is impaired and the saturation falls accordingly. It is quite evident that the hemoglobin molecule taken together with the other properties of the respiratory system provides the human being with a considerable built-in safety factor and that it is not generally likely that symptoms of lack of oxygen (hypoxia) will intervene until the oxygen saturation of the blood has fallen to a level which affects the most sensitive organ, the brain. Thus, symptoms of hypoxia begin to appear as the oxygen tension falls in the blood and the symptoms become more severe the lower the oxygen saturation and the longer the time of exposure to the low oxygen tension.

Attention is drawn to Figure 2. It is evident from these curves that there is an "equivalent altitude" breathing oxygen in which the arterial oxygen saturation is the same as would be found breathing air at a correspondingly lower altitude. For example, a saturation of about 87 per cent is attained breathing air at 10,000, while the same saturation accompanies oxygen breathing at an altitude of 40,000 feet. Aircraft oxygen systems are designed to meter oxygen with ambient air so that as the altitude increases the amount of oxygen increases to maintain saturation of the hemoglobin within tolerable levels. This pair of curves illustrates that the saturation of hemoglobin cannot be maintained even while breathing 100 per cent oxygen if the altitude exceeds about 35,000 feet. But there is little impairment in performance at an altitude of 5,000 feet breathing air except some decrement in visual performance, and it is not entirely out of the question to breathe air at 8,000 or 10,000 feet, but performance is curtailed to a noticeable degree and especially in an individual called upon to do increased muscular or even mental activity. But there is very little threat to life itself, except that the natural built-in safety factor has been lost, and further hypoxic stress would very likely precipitate complete failure and unconsciousness.

3. <u>The Question of Mixed Gases for use in Spacecraft</u>.

It is evident from Figure 3 that a satisfactory and very normal alveolar oxygen tension may be obtained at any cabin "altitude" from sea level to about 35,000 feet equivalent, by mixing oxygen with an inert diluent gas in proportions that satisfy the alveolar gas equation for 104 mm Hg, for example. It can be shown that breathing 100% oxygen at 5 psia results in an alveolar oxygen tention some 71 mm Hg higher than is required for full saturation of the blood. This small "hyperoxia" has had some influence on the medical findings during spaceflight, but these findings are generally considered less than serious(for the duration of exposures to date). Certainly, the added safety obtained by flying a cabin pressure higher than the pressure used in the suits may be considered laudable, for a small leak in the cabin with subsequent loss of cabin pressure would permit some valuable time for the pilots to fasten the helmet visors and 'button up' generally in anticipation to going onto the pressurized suite mode.

Addition of a diluent gas which is biologically inert has been suggested as a more natural environment for prolonged spaceflights. The question arises, then, what would be the optimum, minimum and maximum partial pressures of oxygen that would most adequately satisfy the physiological requirements in a maximum number of flight circumstances? If one is willing to admit that during some emergency or unusual circumstances it might be wise or necessary to permit the cabin pressure to be lowered (with special respect to the lowering of the oxygen pressure) to a level that might be equivalent to an altitude of between 5 and 10 thousand feet, it would be reasonable to set the minimum alveolar oxygen specification to about 80 mm Hg. This can be accomplished at a total cabin pressure of five pounds per square inch using oxygen at 59 percent of that atmosphere.

We believe it is unwise to consider the use of such a circumstance except as a means of overcoming a more dire emergency. It is with great reluctance that we suggest that the natural built-in safety features of the blood and respiratory systems be abrogated. But for purposes of this study we recommend that the oxygen pressure go no lower than 80 mm Hg in the alveolar spaces and that this be accomplished only for a short time (minutes), and be rectifiable by persons other than the individuals subjected to this hypoxia state, for reasons of possible impairment to judgment in those exposed.

4. Alveolar oxygen tensions that produce optimum saturation of the blood.

Using the equation for calculation of alveolar partial pressure of oxygen, it can be shown that at sea level pressure the normal alveolar oxygen pressures lies between 100 to 110 mm Hg. This Directorate recommends that 105± 5 mm Hg be regarded as the design goal for environmental control systems which furnish, process or condition respirable gases.