SN#12

Fermilab

May 2, 1985

TO: Distribution

FROM: Tim Miller

SUBJECT: Oxygen Deficiency Hazard Index

I was asked by Bill Cooper if it makes more sense to use $\%O_2$ or PO_2 as an oxygen deficiency hazard index in light of potential significant changes in total pressure (which may be expected for large liquid argon spills). The attached analysis shows that, although both are needed for an accurate assessment, PO_2 is clearly the choice if only one is to be used.

TM/jr

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Safety Note 12

%O2 Versus PO2 as an Index of Oxygen Deficiency Hazard

by Tim Miller
May 1, 1985

The question has been raised as to whether %O2 or PO2 is a superior index of oxygen deficiency hazard. If the total, or barometric, pressure (Pb) is constant then both contain the same information, viz.,

$$\%O2 = 100\% * PO2/Pb.$$

This note will show that both %O2 and PO2 are needed to accurately assess the hazard if Pb is not constant. However, it will also be seen that PO2 is superior to %O2 if only one of these values is to be used.

From a physiological standpoint the best index of oxygen deficiency hazard is the concentration of oxygen reaching viable tissues. At steady-state this is directly related to the oxygen concentration in the deep respiratory tract, or alveoli (PaO2). This latter index is the simplest which can be used to describe the dependence of the hazard upon %O2 and PO2.

$$PaO2 = FiO2 * (Pb - PaCO2 - PaH2O) - O2loss$$

where,

FiO2 = fraction of O2 in inhaled air,

Pb = barometric pressure (mmHg),

PaCO2 = partial pressure of CO2 in alveoli (mmHg),

PaH2O = partial pressure of water in alveoli (mmHg), and

O2loss = oxygen pressure decrease caused by uptake into blood (mmHg).

PaO2, FiO2 and Pb are variables. PaCO2 is ususally taken to be 40 mmHg, but is in fact a function of PaO2 (result of author, see attached),

PaCO2 (mmHg)	when PaO2 (mmHg)
24	≤ 32.5
0.56 * PaO2 + 5.8	32.5 - 57.5
38	≥ 57.5

This is due to the quicker washout of CO2 from the deep respiratory tract from increased ventilation at reduced O2 concentrations. PaH2O is constant at 47 mmHg since the temperature of the deep respiratory tract is constant. O2loss depends on PaCO2, FiO2 ahd the respiratory exchange coefficient, R, as follows:

$$O2loss = PaCO2 * (1 - FiO2) / R.$$

The value of R is normally taken to be 0.83, but in fact it increases for a time upon exposure to reduced oxygen atmospheres (result of author, see attached).

R	when PaO2 (mmHg)
0.83 + 0.44 exp(-0.052t)	< 50
0.83	≥ 50

Here t is the time since the start of exposure to reduced oxygen in minutes. The following analysis uses 0.83 to simplify the results. This results in a slightly conservative estimate of PaO2.

The resulting expressions for PaO2 as a function of FiO2 and Pb are as follows:

PaO2 (mmHg)	where PaO2 (mmHg)
FiO2*(Pb-42.1)-28.9	≤ 32.5
(FiO2*(Pb-45.8)-7.0)/(1.7-0.12*FiO2)	32.5 - 57.5
FiO2*(Pb-39.2)-45.8	≥ 57.5

Let's look at an example to see whether %O2 or PO2 is a superior index of hazard. First hold %O2 constant at 18% (FiO2 = 0.18) and vary Pb from 0.5 to 2 atmospheres (380 to 1520 mmHg). At FiO2 = 0.18 and Pb = 380 the value of PaO2 is 32 mmHg (first equation above). At FiO2 = 0.18 and Pb = 1520 the value of PaO2 is 220 mmHg. Therefore, the value of PaO2

changed from 32 to 220 mmHg even though FiO2 was held constant at 0.18.

Now hold PO2 constant at 135 mmHg while Pb is varied from 380 to 1520 mmHg. At the lower pressure PaO2 is 75 mmHg, while at the higher pressure it is 86 mmHg. Since this change is very much smaller than that when %O2 (i.e., FiO2) is held constant, it is concluded that PO2 is the superior index of hazard for oxygen deficiency.

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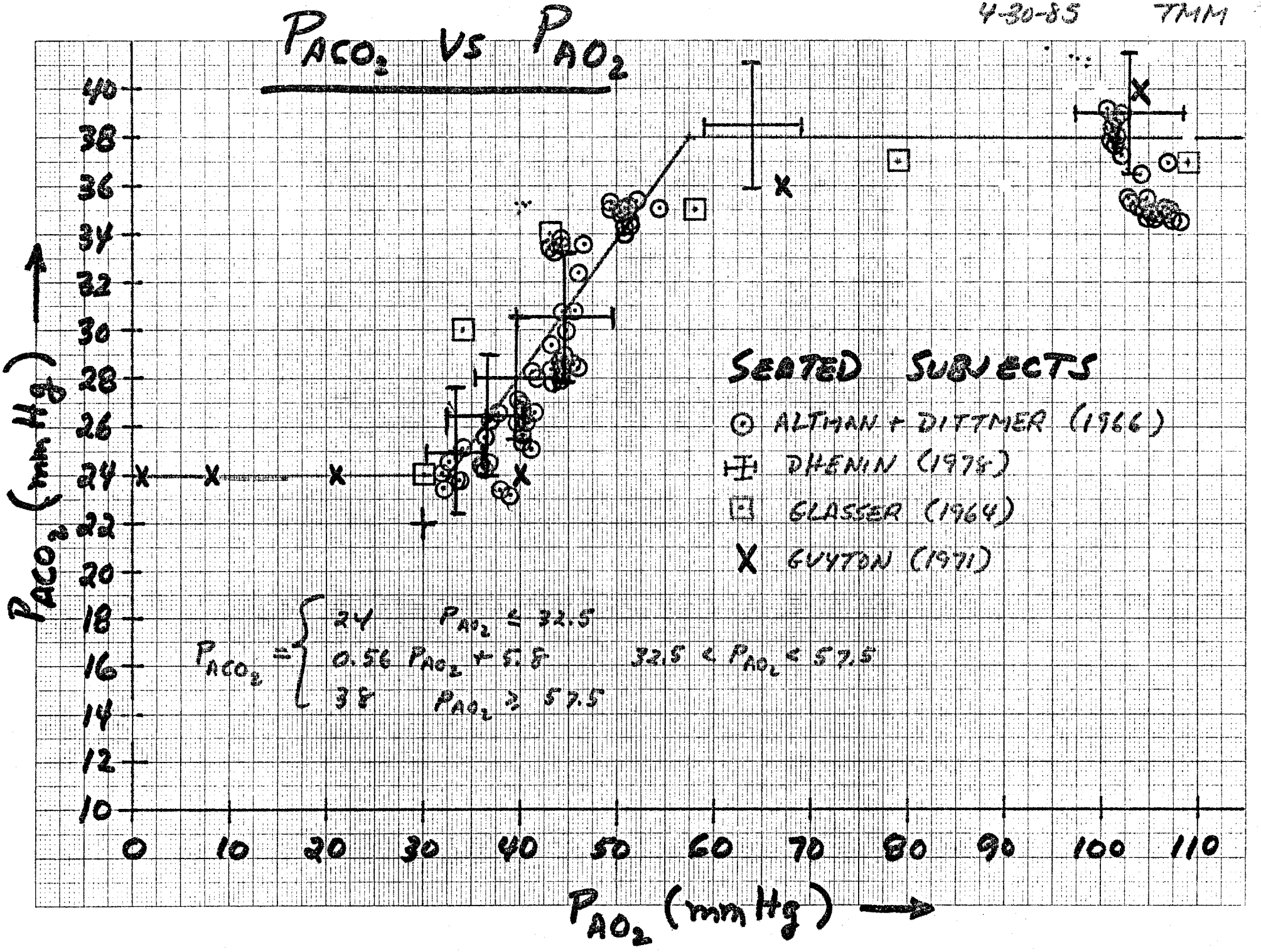

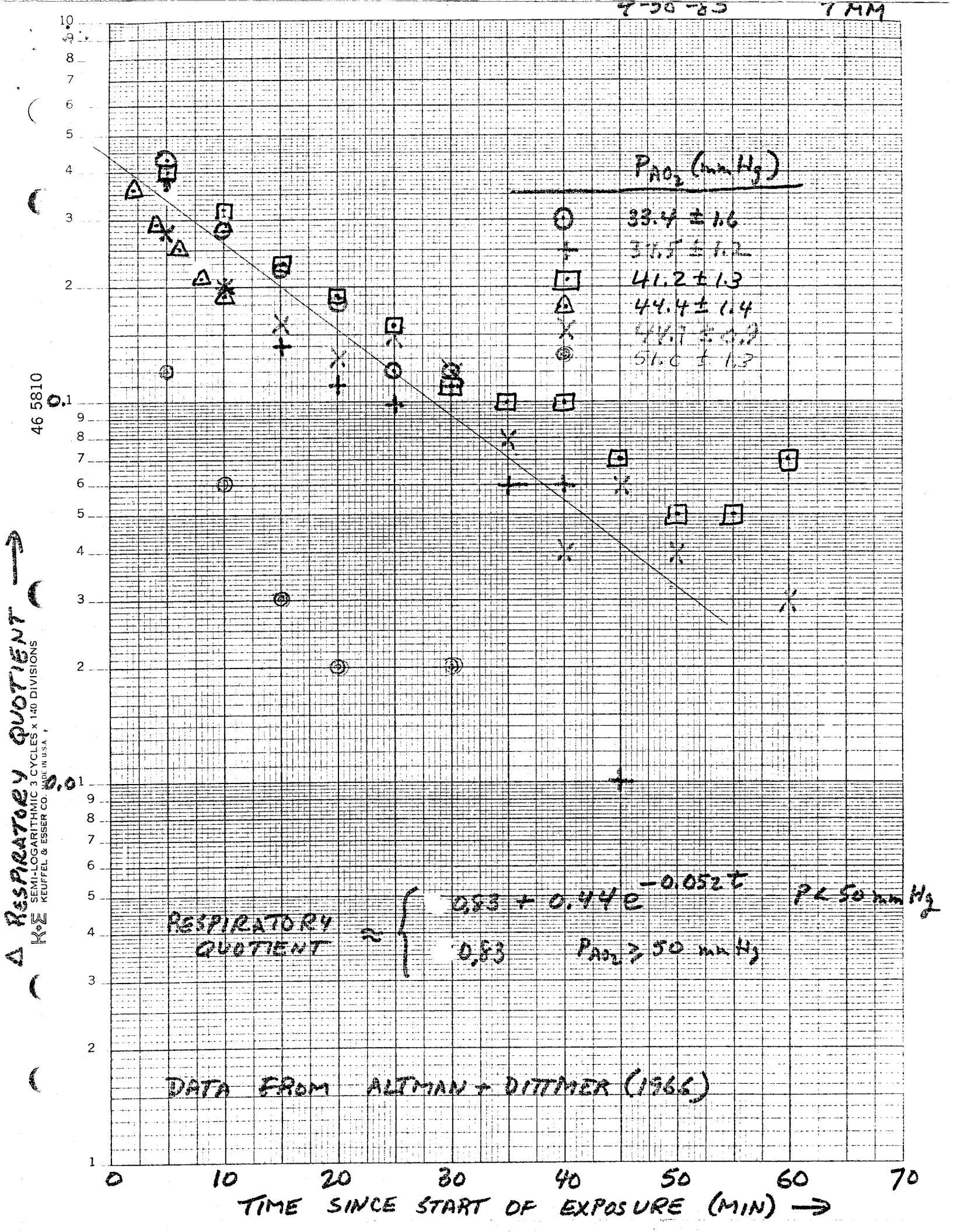
P_{AO_2} (mm Hg)
33.4 ± 1.6
41.2 ± 1.3
44.4 ± 1.4
51.6 ± 1.3
RESPIRATORY QUOTIENT ≈ 0.83 + 0.44 e^{-0.052 t} P < 50 mm Hg
0.83 P_{AO_2} ≥ 50 mm Hg
DATA FROM ALTMAN + DITTMER (1968)
Δ RESPIRATORY QUOTIENT →
TIME SINCE START OF EXPOSURE (MIN) →
0 10 20 30 40 50 60 70
10 9 8 7 6 5 4 3 2 0.1 9 8 7 6 5 4 3 2 0.01 9 8 7 6 5 4 3 2 1
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