A Quantitative Method for Calculating Cumulative Pulmonary Oxygen Toxicity Use of the Unit Pulmonary Toxicity Dose (UPTD)

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In analyzing the development of pulmonary oxygen toxicity under changing conditions of pressure and exposure duration, it is helpful to use a "unit pulmonary toxicity dose" (UPTD). One UPTD is defined as the degree of pulmonary toxicity produced by breathing pure oxygen at a partial pressure (P_{O_2}) of 760 mm Hg (1 ata) for one minute. This same toxicity can be achieved by exposure to various other combinations of P_{O_2} and time.

It is here assumed that the lowest P_{O_2} which will produce a demonstrable pulmonary toxicity within some finite time is 0.5 ata, i.e., the asymptote of pressure on time is 0.5 ata. In this situation all combinations of P_{O_2} and time which have a toxicity of 1 UPTD fall along a curve

$$\log (P - .5 \text{ ata}) = m \log t + \log b \qquad (1)$$

which may also be written

$$P - .5 \text{ ata} = bt^m \qquad (2)$$

where P = inspired P_{O_2} in ata
t = time in minutes
b = intercept constant for t = 1
m = slope constant

Breathing 1 ata P_{O_2} for two minutes produces 2 UPTD. Once again, there is a curve of form (2) which includes all combinations of P_{O_2} and time. This curve is considered to be parallel to the first, i.e. the slope constant "m" is

the same in both equations. Otherwise, at some pressure, an increase in O_2 breathing would lessen toxicity. The intercept constant "b", on the other hand, will be larger for 2 UPTD's than for 1. This concept can be extended to any number of UPTD's (Figure 1).

One of the effects of a toxic dose of P_{O_2} is to decrease vital capacity. Since all points along a curve of form (2) represent the same pulmonary toxicity dose, the points on one curve also represent the same influence of oxygen exposure upon vital capacity. Clark has plotted equal toxicity curves (Figures 2 and 3) for the following doses:

UPTD	Corresponding ΔVC in 50% of subjects
615	-2
825	-4
1035	-6
1230	-8
1425	-10
1815	-15
2190	-20

The ΔVC response to varying "doses" of oxygen exposure is not a linear function, but rather the classical sigmoid dose-response curve (Figure 4).

All lines of equal pulmonary toxicity are linear (on log-log transform), are parallel, and have the same

asymptotes of 0 time and 0.5 ata. Therefore, any P_{O_2} x time exposure can readily be converted into UPTD units, and these units are for the present considered to be additive. To convert from an exposure of $P_{O_2} = P_2$, time = t_2, to a dose of equal toxicity at some P_1 and t_1, we get

$$\frac{P_1 - .5 \text{ ata}}{P_2 - .5 \text{ ata}} = \frac{bt_1^m}{bt_2^m} \qquad \text{[from (2)]} \qquad (3)$$

$$\text{or} \quad t_1 = t_2 \sqrt[m]{\frac{P_1 - .5 \text{ ata}}{P_2 - .5 \text{ ata}}} \qquad (4)$$

If t_2 is expressed in minutes, then the toxicity of exposure (P_2, t_2) in UPTD units is given by

$$t_2 \sqrt[m]{\frac{.5 \text{ ata}}{P_2 - .5 \text{ ata}}} \qquad (5)$$

On the basis of the empirical evidence now available, the choice of a value, currently

$$m = -1.2, \qquad (6)$$

is reasonable. This, the slope constant, also is called a "pulmonary index".

The toxicity expressed in UPTD is sometimes referred to as the "sea-level equivalent" or "1 ata equivalent" oxygen toxicity.

Figures 5 and 6 illustrate the cumulative buildup of

pulmonary toxicity, as measured in UPTD's during Prototype Decompressions I and II for the Tektite II 100-foot open-sea project.

This report draws heavily on the PhD theses of J.N. Feld (in preparation) and J.M. Clark (University of Pennsylvania, 1970).

Figure 1

Curves of Equal Pulmonary Toxicity Dose for Varying Oxygen Exposures

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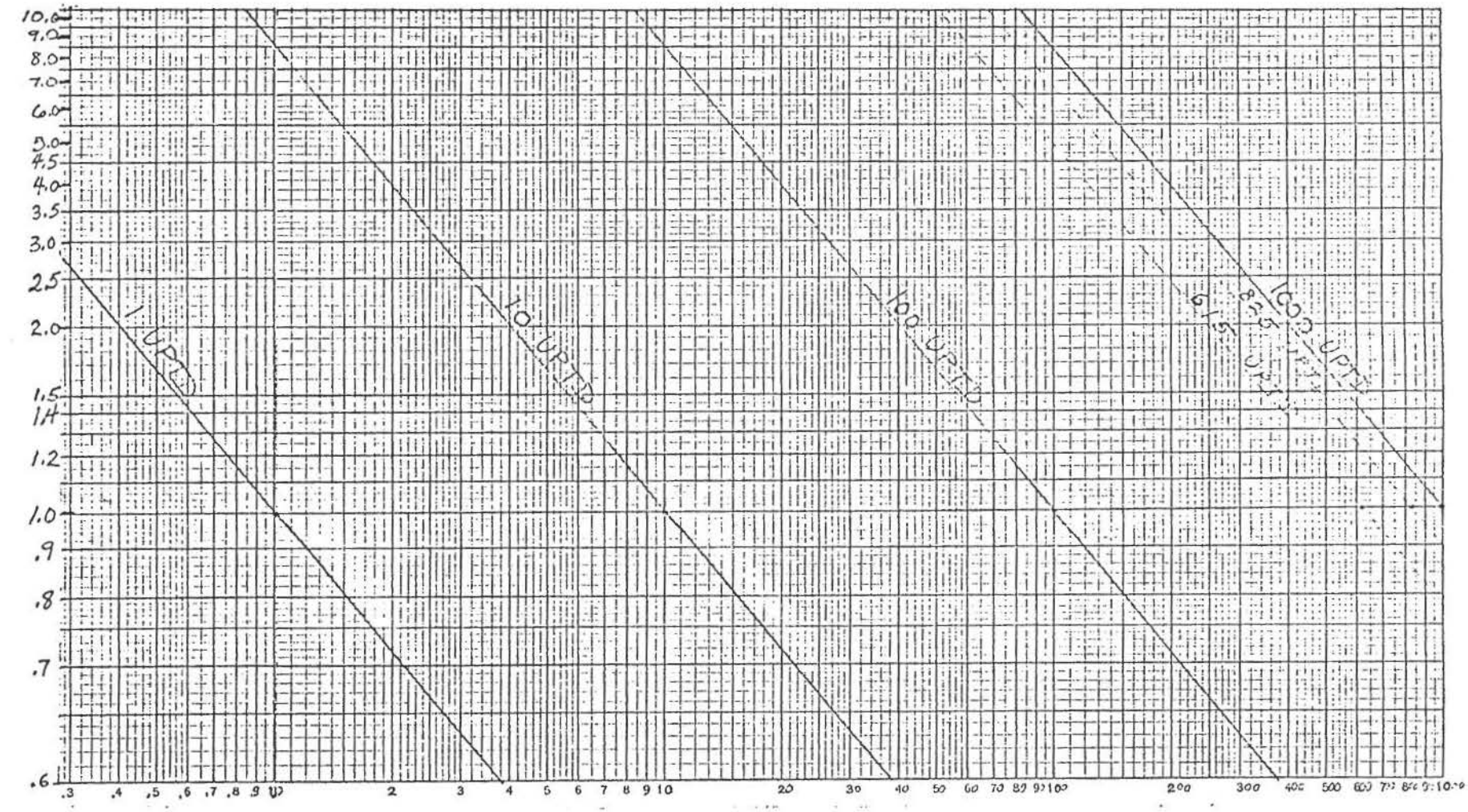
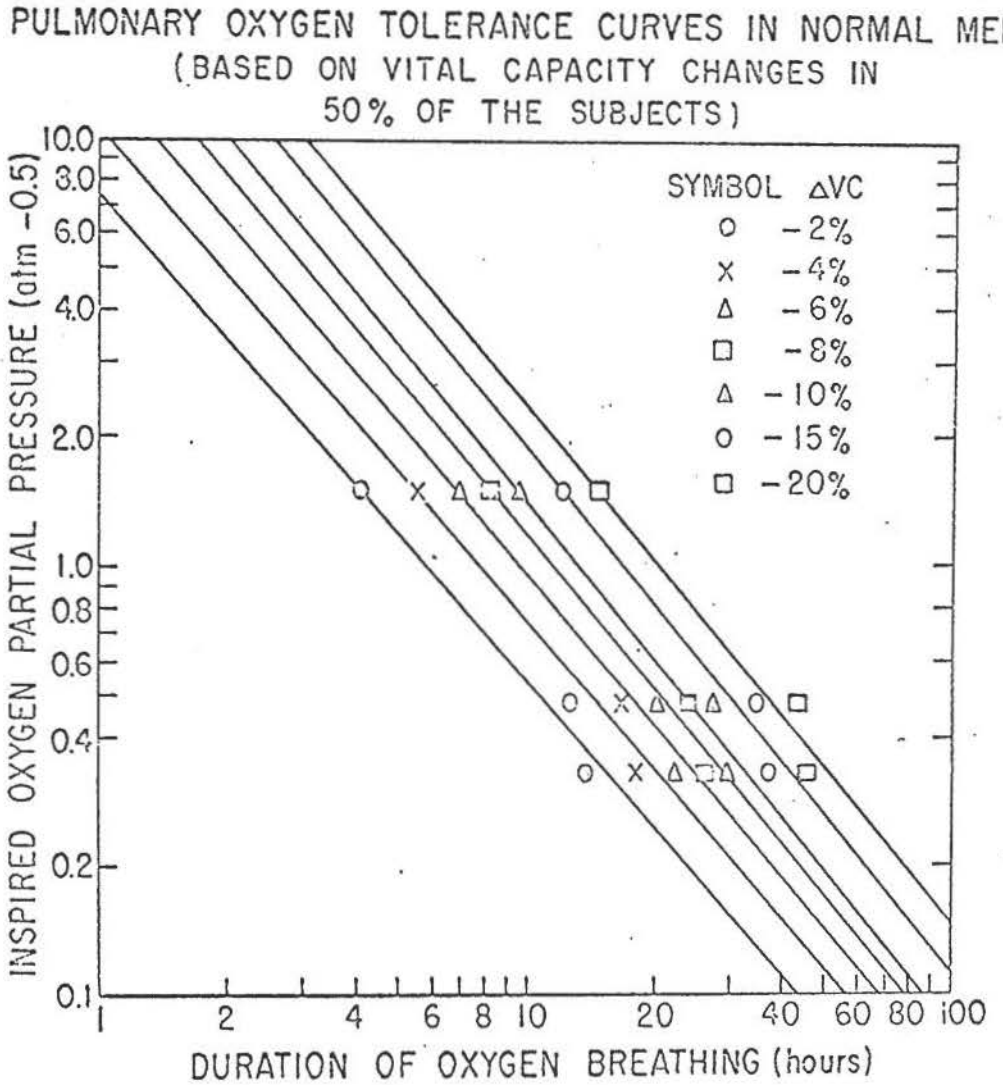
UPTD = Unit Pulmonary Toxicity Dose



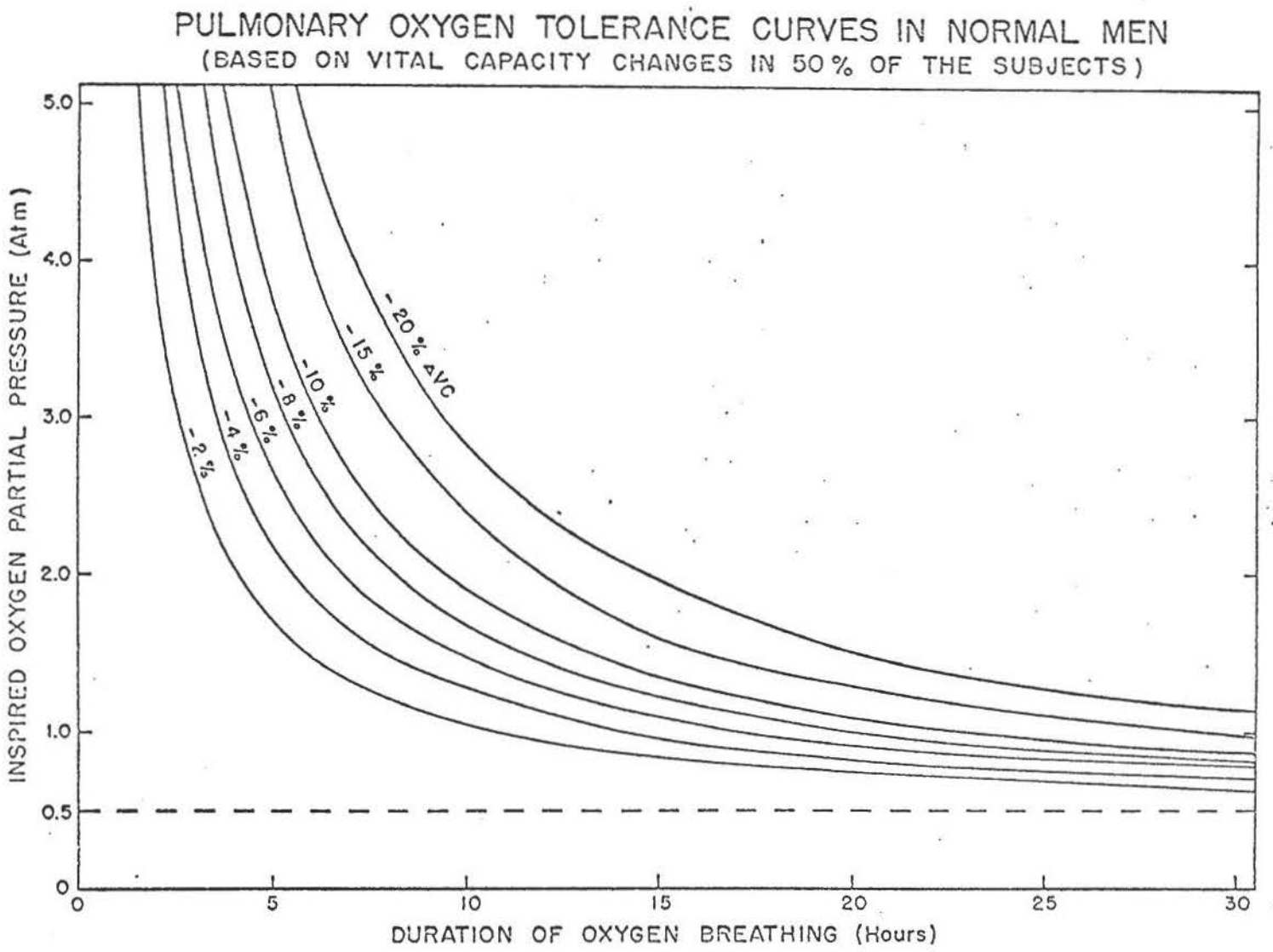
Note: Doses of 615 and 825 UPTD produced vital capacity responses of 2% and 4% decrement respectively in 50% of Clark's subjects.

Figure 2 : Seven selected curves of differing but constant toxicity.



From: J.M. Clark PhD thesis, p.164, Fig. 18A.

Figure 3



From: J.M. Clark PhD thesis, p. 165, Fig. 18B.

Figure 4

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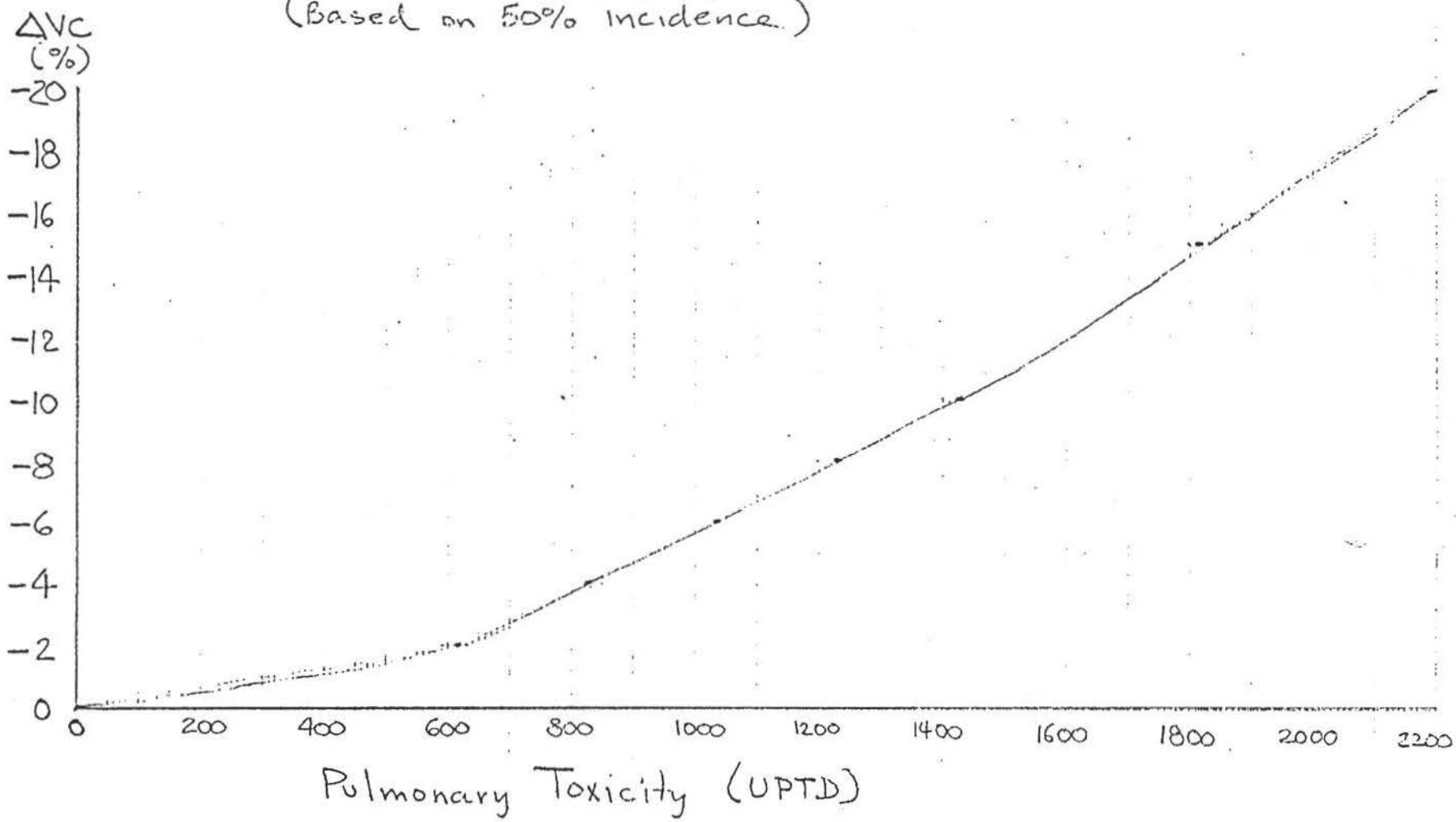
Vital Capacity Decrement as a Response to Varying Toxic Oxygen Doses

(Based on 50% incidence.)



Data adapted from Clark thesis, p 155, Table 19A.

Figure 5

Tektite II
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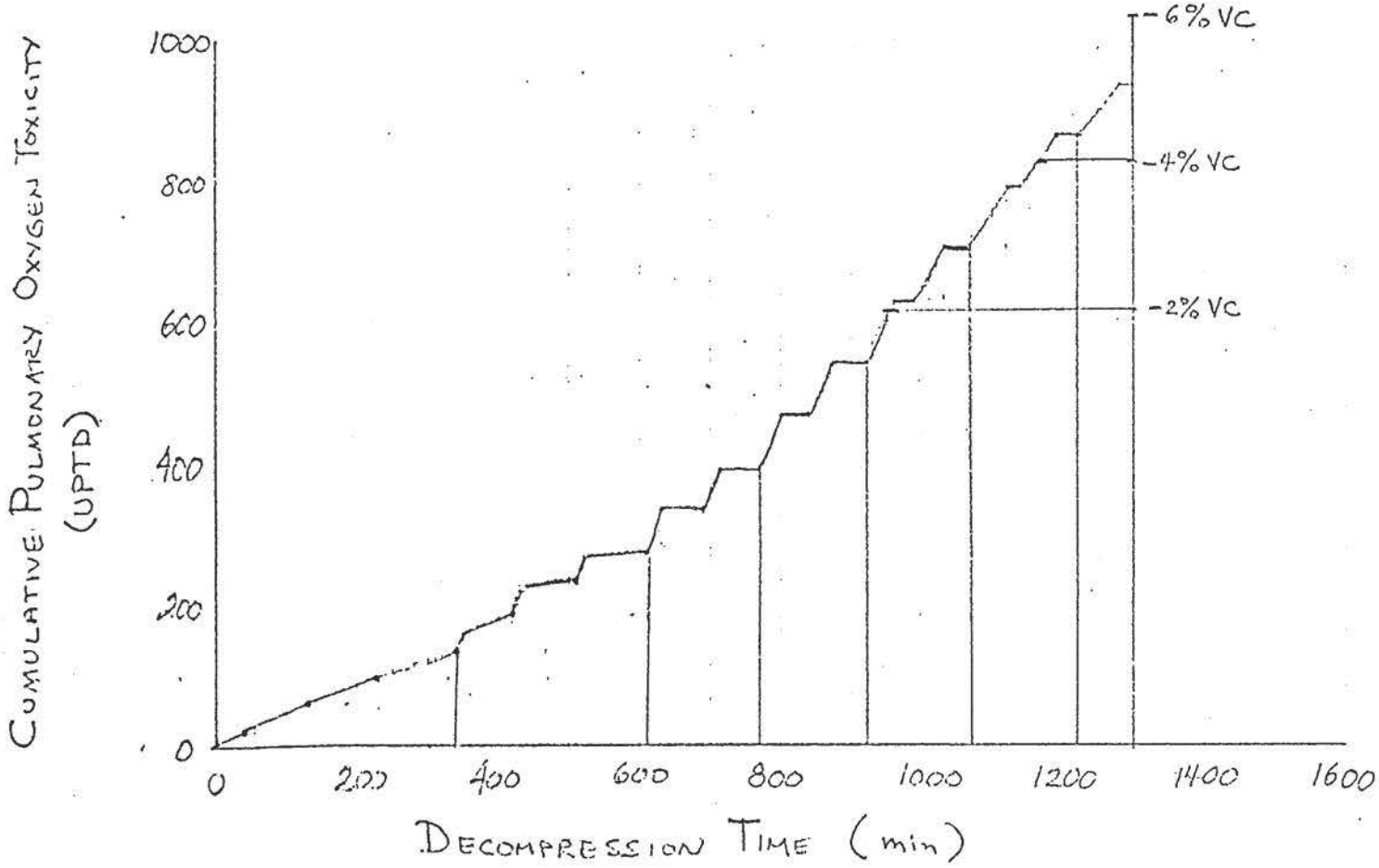
BUILD-UP OF PULMONARY OXYGEN TOXICITY
DURING PROTOTYPE DECOMPRESSION I
(M-VALUE = 50 FSWA)



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Build-up of Pulmonary Oxygen Toxicity During Prototype Decompression II

(M-value = 50 FSWA)