RESEARCH REPORT 1-59

EFFECTS OF EXPOSING MEN TO COMPRESSED AIR AND HELIUM-OXYGEN MIXTURES FOR 12 HOURS AT PRESSURES OF 2-2.6 ATMOSPHERES

PROJECT NS186-201 SUBTASK 2 TEST 2

G. J. DUFFNER AND H. H. SNIDER

18 SEPTEMBER 1958

U.S. NAVY

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NGF WASHINGTON 25.DC

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ABSTRACT

Five enlisted navy divers, age 21-34 yrs., were exposed for 12 hours in a recompression chamber to increasingly greater pressures until they contracted decompression sickness. The pressure in all cases was reduced at a rate of 25 ft. (11.12 lbs) per minute. The exposures were performed first while breathing compressed air and then later 80% helium - 20% oxygen. Greater exposures were tolerated with the H_eO_2 mixtures than with air. The differences amounted to pressures equivalent to 3, 4, 6, 10, and 14 ft. of sea water. (1 ft. = 0.445 p.s.i.) Data on helium elimination disclosed that a large fraction (over 50%) of the dissolved helium is contained in a tissue component which desaturates very rapidly (half-time 1.5-5 min.) The existence of a slow component (half-time 95-115 min.) appears likely. The use of helium-oxygen mixtures in mixed gas scuba and the utilization of a single mathematical expression to compute decompression stops are considered feasible.

SUMMARY

PROBLEM

To analyze previously unpublished data from experiments in which men were exposed for 12 hours at pressures equivalent to 34 to 52 feet while breathing compressed air and helium-oxygen mixtures.

FINDINGS

The use of helium-oxygen in diving subjects the diver to no greater, and perhaps less of a decompression sickness hazard than diving with compressed air. The distribution of helium among the body tissues is such that it is feasible to compute decompression procedures for scuba diving by considering only a single tissue sample.

RECOMMENDATIONS

(a) The use of helium-oxygen mistures for mixed gas scuba diving is considered feasible.

(b) That further experiments be undertaken to determine the proper decompression procedures for helium-oxygen mixed gas scuba diving.

ADMINISTRATIVE INFORMATION

This is the first report submitted under this sub-task which is entitled "USE OF HELIUM-OXYGEN IN MIXED GAS SCUBA. It contains a description and analysis of previously unpublished data collected at the Naval Medical Research Institute during 1947-48.

The estimated man-power requirements are as follows:

DESCRIPTION	MANHOURS
Bibliographic research	40
Data reduction and analysis	160
Writing report	20
Drafting	8
Publication	20
TOTAL	248

Most of the work described in this report was actually completed before the project outline was submitted. The original intent was to submit a single report covering both this work and more recent studies of helium decompression. However, it was later considered more convenient to prepare two reports of which this is the first.

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1. INTRODUCTION

1.1 Object

1.1.1 For reasons which will be elucidated in a subsequent report it appeared desirable to explore the feasibility of utilizing helium-oxygen mixtures as the breathing media in mixed gas scuba. Before undertaking such a study it was considered essential to obtain such further information as was available on the subject of helium decompression. One source of such information was data collected by the authors about ten years ago. This data had not been analyzed or published previously because there appeared little operational interest in or necessity for revising the standard helium-oxygen decompression tables. The idea of using helium-oxygen mixtures in scuba had previously been considered but discarded because it was believed there existed an unacceptable hazard of decompression sickness with this breathing media. The data described in this report did not support this belief.

1.2 Scope

1.2.1 Two groups of data were analyzed, first that collected by the authors, and later this data was compared with helium elimination data discovered in the files of the Unit. This latter data was undated but it is believed to have been collected by Behnke and Willman in the 1930's. These authors have published a number of papers on this subject, one of which is cited later in the report. In order to make this report more intelligible to the average reader an attempt has been made to cover all of the essential features in the narrative portion of the report. Mathematical formulations are contained in an appendix. Each equation is numbered and will be referred to in the report as (e-1, e-2, etc.). This system also circumvents the difficulty usually encountered in reproducing mathematical symbols.

2. DESCRIPTION

2.1 Naval Medical Research Institute (NMRI) data

2.1.1 This study was undertaken to determine whether decompression sickness was more likely to occur following a saturation exposure while breathing air or while breathing an 80% helium 20% oxygen mixture. Data on helium elimination was also collected with a view to determining approximately how long it would take a man to rid himself of the helium following a saturation exposure. The type of analysis described in this report was not envisaged at the time the experiments were performed.

2.1.2 Five subjects participated in these experiments. They were all navy divers 21-34 years of age (Table 1). Prior to each exposure the men were carefully examined to rule out the possibility that a disease condition might influence the results. The men were also weighed carefully before each experiment. Little variation in body weight was found during the study. The subjects were exposed to only one experiment each week.

2.1.3 The exposures were carried out in a navy standard recompression chamber. The pressure inside the chamber was indicated on a special mercury manometer which was calibrated in feet of sea water (assuming a specific gravity of 1.025). Decompression was at a rate of 25 ft./min.

2.1.4 During the compressed air studies the men were exposed in pairs. The experiments were conducted at night and the subjects slept during the 12 hour period in the chamber. Each man was first exposed at a pressure equivalent to 34 feet and then later to progressively greater pressures until upon subsequent decompression he developed symptoms of decompression sickness requiring recompression. The exposure pressures were increased in two foot steps, i.e. 34, 36, 38.

2.1.5 During the helium-oxygen exposures the subjects breathed the mixture through a demand valve utilizing an A-14 oxygen mask. The helium concentrations in the breathing mixtures varied from 79.1% to 80%. The majority of the mixtures were exactly 80%. This was possible due to the availability of a special gas mixing plant. The two gases were admitted to a large spirometer and then mixed by a fan. Samples were taken and anlyzed. If necessary the concentrations were adjusted. When the desired mixture was obtained the mixed gas was compressed into cylinders. Due to the large demand for helium-oxygen only one man was exposed at a time. These experiments were also carried out at night but due to the discomfort and restrictions imposed by the mask and hose the subjects were quite uncomfortable and slept fitfully. Since all of the men had contracted decompression sickness at depths of 34 to 38 feet during the compressed air series, it was decided to first expose them all to 36 feet on helium-oxygen. These exposures were also increased in two foot steps.

2.1.6 Samples of expired gas were collected during various periods following the exposures to helium-oxygen, and analyzed to determine their helium content. This was accomplished by having the subject rebreathe oxygen from a closed circuit apparatus. This apparatus consisted of a large spirometer, a baralyme canister to remove carbon dioxide and the necessary tubing and check valves. At the end of the time period being studied the volume of gas in the spirometer was measured and the helium content of the gas determined by means of a Cady apparatus. This method of analysis utilizes the low freezing point of helium. All other gases are removed by freezing them in an activated carbon trap which is immersed in liquid air. The remaining gas (helium) is measured. All volumes were corrected to standard conditions of temperature and pressure. The complete data on one subject (S.U.G.) is presented in table 2.

2.2 Experimental Diving Unit (EDU) data

2.2.1 This data was included in this study for several reasons. It is from this data that the first and most widely accepted helium elimination curve was constructed. It appeared desirable to compare the results of subjecting this classical data to the same treatment as our data. These experiments were conducted for the sole purpose of constructing the helium elimination curve while ours were not. All of the available data was not included in this study. The data from five experiments was selected because it was the most complete and consistent.

2.2.2 These subjects breathed 73-76% helium mixtures in an open circuit at atmospheric pressure for 3½ hours. Following this, the amount of helium in the expired air was determined during alternate 30 minute periods. The method employed was essentially the same as that described in 2.1.6 The next day the experiment was repeated and the periods were studied which had been missed on the previous day. This was true of all subjects except one (B.E.H.), in this case the data was collected continuously over a period of six hours. This data is presented in table 3. In these experiments the values for the first three minutes were computed from an average third minute value of 21 cc. Average values for the fourth to the sixth minute were applied to all of the subjects.

3. PROCEDURE

3.1 NMRI data

3.1.1 The first problem encountered in analyzing this data was to find some means of pooling the data from all subjects. One essential piece of information was missing, namely what was the total amount of helium contained in the subjects' bodies at the end of the exposures. Finally it was found possible to approximate this value by computation. Behnke and Willmon (1) state that the body is capable of absorbing 3.6 cc (plus or minus 0.6 cc.) of helium per pound per atmosphere. Since we knew the weight of the subjects and the partial pressure of the helium to which they were exposed it was possible to compute the amount of helium the subjects contained at the end of the exposure. (See e-1).

3.1.2 Two further steps were necessary to reduce the data to useable form. In order to utilize the method of analysis intended, the helium elimination must be expressed as a rate. First the number of cc of helium recovered in each period was divided by the number of minutes in the period. This then gives us the mean rate of helium elimination during that period in cc/min. (See e-2) If we now take this value and determine what part of the total amount of helium originally present it is, we then have a useable figure which is the fraction of the computed total helium content eliminated per minute during a given period of time. (See e-3) The end result of all these manipulations can be seen in table 2.

3.1.3 These values were then plotted on semi-logarithmic paper. The logarithm of the fraction of the computed total helium content eliminated per minute being plotted versus time. The mid-point of the period (time during which the sample was collected) was assumed to be the time when the mean rate of elimination took place. For example, if during the period 30 to 60 minutes after exposure 38.9 cc of helium were recovered, the mean rate then is 1.3 cc per min. and it is assumed that the subject was actually eliminating helium at this rate 45 minutes after the expposure. It is recognized that this is not entirely correct but is believed to be a reasonable assumption under the circumstances. Next, as smooth as possible a curve was drawn between the plotted points. The origin and slope of the number of component curves necessary to obtain a fit of the data were determine by drawing tangents to the plotted curve. This method is described by Hardin Jones (2) and is based on the mathematical principle i.e.; that when a point is moving on a curved path of any kind so that its direction is continually changing, then the direction at any instant is that of the tangent to the path. This is what is occurring in this situation. The body eliminates helium at a progressively slower rate with the passage of time after the exposure. Therefore the slope (direction) of the curve is continually changing. If the data justified it, and one wanted to obtain a very precise equation, this could be accomplished by drawing a large number of tangents to the curve. In this instance however the aim is to find the minimum number of component curves the sums of which will be equal to the experimentally determined curve. Each of these component curves is an exponential one. Therefore the rate at which each hypothetical component is eliminating helium at any given time can be determined by using the equation for the exponential curve (e-4). The sums of the rates of all of these component curves is equal to the overall rate of elimination at any given time (e-5). The results of this type of manipulation can be seen in figure 1. It will be noted that a fit of the data was obtained by employing four different curves each with a different slope. This will be discussed further in results.

3.2 <u>EDU data</u>

3.2.1 Except that in this case the total amount of helium eliminated by each subject was known, this data was treated essentially the same as the NMRI data. Here it was possible to determine and plot the fraction of the total helium content eliminated per minute during each collection period. The number and slope of the component curves necessary to obtain a fit of the data was determined by the same method as described in para. 3.1.3.

4. RESULTS

4.1 <u>Tolerance to increased pressures</u>

4.1.1 Each of the five subjects tolerated a greater pressure without symptoms of decompression sickness while breathing helium-oxygen than when breathing compressed air. When exposed for 12 hours during the compressed air series, the subjects contracted decompression sickness after the following exposures: 34 ft., 36 ft. (2 subjects) and 38 ft. (2 subjects). The picture was quite different during the helium-oxygen series. The first case of decompression sickness did not occur until after the 38 foot exposure. The next subject became ill following an exposure at 42 feet. The two most resistant subjects did not contract decompression sickness until they were exposed at depths of 46 and 52 feet. One man (M.O.R.)

who contracted decompression sickness following the 38 foot exposure on air completed a 40 foot exposure on helium-oxygen without event. He, however, was transferred before completing the entire series of experiments. This data is tabulated in table 1.

4.2 NMRI helium elimination data

4.2.1 In order to obtain an equation which fits this data it was necessary to employ four terms. (see fig. 1) These four exponential curves have constants of 0.5, 0.135, 0.025, and 0.0073. The complete equation which predicts the rate of helium elimination at any given time is in figure 1. Jones (2) states that in this case the constant k is the tissue perfusion factor. Therefore by dividing the constant into the rate at zero time one can determine the value of the unexchanged fraction of each component at that (zero) time. (See e-7) If one does this, the above data takes on more meaning. However, before doing this let us make another point. There is also a relationship between the time constant and the half-time. If one knows the time constant the half-time can be determined by dividing this value into the natural logarithm of 2 (0.693). If these two manipulations are performed we find that 50% of the helium is contained in a component that half-saturates in about 1.4 minutes. Also that about one-third of the helium is contained in a body component which half-saturates in five minutes. The remaining helium is about equally divided between two further components which half saturate in about 28 and 95 minutes respectively (e-8).

4.3 EDU helium elimination data

4.3.1 In analyzing this data it was found that a fit of the data could be obtained by employing an equation with only three terms (e-6). The constants of the three component curves are 0.3, 0.02, and 0.006. Employing the same manipulations described in 4.2.1 it is found that about 28% of the helium is contained in a component which half saturates in about 2.3 minutes, 46% of the helium is contained in a component which half saturates in about 35 minutes and 25% of the helium is contained in a component which half-saturates in about 115 minutes.

4.4 Additional information

4.4.1 Jones (3) has studied the whole-body exchange of inert gases measured for two inert gases during the same experimental time. In these experiments the subject was first denitrogenated by breathing oxygen, then breathed helium for several hours and then again breathed oxygen, during which time exchange of the helium was studied. These experiments disclosed the following time constants: 0.50, 0.094, 0.022, 0.00 If these are now expressed in half-times we find that they are (e-10) 1.4 min., 7.4 min., 31.5 min., and in excess of 70 min. All of this data is compared in table 4.

5. DISCUSSION

5.1 Decompression sickness data

5.1.1 A first glance at this data (table 1) leads one to make two general observations. It appears that subjects breathing helium-oxygen mixtures are less likely to contract decompression sickness than when breathing compressed air during equally hazardous exposures. There is also considerably more variability when breathing helium-oxygen. During the compressed air series of exposures all of the subjects contracted decompression sickness at pressures equivalent to 34 to 38 feet, a spread of four feet. On the other hand, in the helium-oxygen series symptoms were produced at exposures from 38 to 52 feet, a spread of 14 feet.

5.1.2 With the limited number of subjects in this study and the great variability sweeping generalizations are hazardous. With this degree of variability among five subjects one could logically expect even more variance among a larger group. It is unlikely that all possible extremes could have been encountered in the limited number of experiments with this small sample. Therefore any isolated observation might lead one to conclude that helium-oxygen mixtures were more or less hazardous than compressed air. The correct assumption probably is, there is no difference. Jones (3) reports, "Regardless of the gas used, the similarity of the time constant is apparent. Thus to no discernable extent are the values fixed by diffusion rate or by factors of permiability. Additional evidence that the gas-exchange-rate constants are determined by the blood-tissue-perfusion rates is that the summated circulation to the body tissues calculated from the gas-exchange rates closely approximates cardiac output, and the regional perfusion rates so calculated from the gas exchange are uniformly in agreement with other existing measurements." It is easy to see why earlier investigators, on the basis of uncontrolled observations, concluded that there was a greater hazard of decompression sickness with helium-oxygen than with compressed air. On the other hand it is equally easy to see, that in light of our more recent knowledge, this conclusion is illogical.

5.2 Helium elimination data

5.2.1 There is not much agreement between the two sets of data presented. The time constants obtained from the NMRI data however are more nearly in agreement with Jones (3) than the EDU data (table 4). A helium elimination curve constructed from the NMRI equation (e-8) bears a close resemblance to Behnke and Willmon's helium elimination curve with exercise.

5.2.2 There are a number of reasons which could explain the difference in results of analyzing these two sets of data. There is obvious difference in length of time and the pressure of the exposures. The EDU data was collected in a more systematic manner and hence is probably more accurate. There is however one outstanding weakness in both sets of data. The EDU group estimated the helium elimination for the first six minutes. Their estimates were based on sound observations (1) but were, nevertheless, estimates and hence sources of error. We also were forced to make approximations for the helium elimination during the first few moments. A number of attempts were made to determine how much helium was eliminated during the ascent and immediately following the ascent. These all ended in failure and the data obtained is considered so unreliable that it was not included in this study. We fear that our approximations are less well founded than the EDU group. The rate of elimination curve was simply extended up to unity on an empirical basis (fig. 1). In other words we said, "This is what must have happened during the early part of the elimination to account for what we observed later."

5.2.3 The magnitude of the various components is also open to some question. All investigators are not agreed that the time constant is really the tissue perfusion rate. Most notable of those taking issue with this view is Kety (4). He states ". . . direct and conclusive proof is still to be obtained that the empirical constants (k) of Jones are in fact simply tissue perfusion rates. . . . none of the A's and k's of an expression like that of Jones is in general defined exclusively by the parameters of a single tissue or group of tissues. It is probable, however, that Jones, by a combination of relatively insoluble gases and an initial period of hyperventilation, succeeded in achieving arterial concentrations of the inert gases which were practically constant over most of the experimental period. Under such special circumstances the general equation could be approximated by one in which each of the j terms could be referred to a single tissue or group of tissues." There are two factors however which lead us to conclude that we can assume that k is the tissue perfusion rate and that equation 8 is valid. Helium is not readily soluble in the body tissues. Since the gas was breathed under pressure for 12 hours, the arterial concentration must have arisen to the maximum value within a minute fraction of the total exposure time, and remained so.

5.3 Limitations

5.3.1 There is one great limitation inherent in all of these theoretical studies when one presumes to apply them to a practical situation. Biological systems are not very precise. A single measurement in a single individual at one time may be quite precise. However, we can expect both intra and inter individual variability as we test and retest. The fact that one can devise a mathematical formulation which fits a group of data, while it makes it more logical, does not make the data or conclusions derived therefrom correct. It must be remembered that the formulations in this report are applicable within a certain range and with a certain amount of error to the subjects participating in the experiment and under the conditions it was performed. The equations cannot be considered applicable to all men under all circumstances. However, it is an intriguing pastime and one is at times hard put to resist the temptation to subject the data to all of the manipulations one can master. Nevertheless there are certain useful general conclusions which can be drawn.

6. CONCLUSIONS

6.1 Conclusions

6.1.1 The use of helium-oxygen in diving subjects the diver to no greater and perhaps less of a decompression sickness hazard than diving with compressed air.

6.1.2 In helium-oxygen diving a large fraction of the helium dissolved in the body is most likely contained in groups of tissues which saturate and desaturate very rapidly, a half time of 1.5 to 5 minutes. These tissues probably limit the rate of ascent.

6.1.3 Following a prolonged exposure to helium-oxygen a small quantity of the helium is contained in tissue groups which saturate and desaturate very slowly, a half time of 95 to 115 minutes.

6.1.4 The remaining helium is contained in tissue groups which half saturate in about 30 minutes.

6.1.5 If the most rapidly desaturating tissues are disposed of during the ascent, they need not be taken into account in formulating any further decompression. The duration of scuba dives at great depths is of such a time that the slowest saturating components might not be significantly affected. It is therefore feasible to compute decompression procedures for scuba diving by considering only a single tissue sample.

TABLE I

MAXIMUM DEPTH OF 12 HR. EXPOSURES TOLERATED WITHOUT SYMPTOMS OF DECOMPRESSION SICKNESS, WHILE BREATHING AIR AS COMPARED TO HELIUM-OXYGEN MIXTURE. ASCENT (DECOMPRESSION) WAS AT A RATE OF 25 FT./MIN.

		AIR	HELIUM-OXYGEN	EXCESS
SUBJECT	AGE(yrs)	(depth Ft.)	(depth ft.)	He over Air
D.R.A.	28	33	36	3
B.T.L.	34	36	40	4
M.O.R.	28	34	40	6
R.O.B.	25	34	44	10
S.U.G.	21	36	50	14

TABLE I

TABLE II

HELIUM ELIMINATION BY ONE SUBJECT (SUG) FOLLOWING 12 HR. EXPOSURES AT VARIOUS DEPTHS WHILE BREATHING H_eO_2

Depth of exposure (ft. sea water)		38	40	42	44	46	48	50
Partial Pressure He(at)		1.72	1.77	1.81	1.86	1.91	1.96	2.01
Computed He content (cc)		960	987	1,010	1,040	1,065	1,090	1,120
HELIUM ELIMINATION period after surfacing								
0-5	CC (1)			266.0				
	r (2)			53.2				
	Rt (3)			0.0526				
5-15	CC					107.5		
	r					10.75		
	RT					0.0101		
5-35	CC			[illegible]			165.4	192.2
	r			[illegible]			5.51	6.41
	Rt						0.00506	0.00573
15-25	CC			51.4	40.0			
	r			5.14	4.0			
	Rt			0.00509	0.00385			
30-60	CC		38.9			45.03		
	r		1.30			1.50		
	Rt		0.00132			0.00141		
60-90	CC	29.46						
	r	0.984						
	Rt	0.00102						
90-120	CC			13.92			16.5	23.3
	r			0.465			0.55	0.777
	Rt			0.00046			0.000504	0.000695
150-180	CC		5.87		6.49	5.75		
	r		0.196		0.216	0.192		
	Rt		0.000199		0.000208	0.00018		
180-210	CC			4.91			8.59	6.72
	r			0.164			0.286	0.224
	Rt			0.000163			0.000262	0.00020
210-240	CC		1.96					
	r		0.0654					
	Rt		0.000065					
240-270	CC							
	r				1.65	2.46		
	Rt				0.055	0.082		
					0.000053	0.000077		
330-360	CC		1.58					
	r		0.0526					
	Rt		0.000054					

(1) CC = CC. He eliminated during period
(2) r = rate CC/min
(3) Rt = fraction of computed He content eliminated/min

TABLE III

HELIUM ELIMINATION FOLLOWING 3½ HOURS OF HELIUM (73-76%) BREATHING AT 1 ATMOSPHERE

SUBJECTS		(1) EEH	(2) CRD	(3) CRO	(4) FOR	(5) PAR
Dates of Experiments						
Helium Elimination Periods (min.)						
0-1	* CC	42.0	42.0	42.0	42.0	42.0
	Rt	0.10226	0.15102	0.14118	0.18261	0.15713
1-2	* CC	30.0	30.0	30.0	30.0	30.0
	Rt	0.07305	0.10787	0.10084	0.13043	0.11223
2-3	* CC	21.0	21.0	21.0	21.0	21.0
	Rt	0.05113	0.075512	0.07059	0.09130	0.07856
3-4	** CC	15.0	15.0	15.0	15.0	15.0
	Rt	0.03652	0.05394	0.05042	0.06522	0.05612
4-5	** CC	10.0	10.0	10.0	10.0	10.0
	Rt	0.02435	0.03596	0.03361	0.04348	0.03741
5-6	** CC	8.0	8.0	8.0	8.0	8.0
	Rt	0.01948	0.02877	0.02689	0.03478	0.02993
6-30	CC	104.0	61.3	70.3	29.2	39.6
	Rt	0.01055	0.00918	0.00985	0.00529	0.00617
30-60	CC	66.1	32.0	39.8	33.2	36.9
	Rt	0.00537	0.00384	0.00446	0.00481	0.00460
60-90	CC	31.7	22.1	19.7	17.6	16.9
	Rt	0.00257	0.00265	0.00221	0.00255	0.00211
90-120	CC	22.8	10.3	14.6	9.9	16.8
	Rt	0.00185	0.00123	0.00164	0.00143	0.00210
120-150	CC	17.2	8.9	9.2	6.0	9.8
	Rt	0.00140	0.00107	0.00103	0.00087	0.00122
150-180	CC	10.5	4.5	5.8	3.5	8.7
	Rt	0.00085	0.0054	0.0065	0.00051	0.00108
180-210	CC	7.4	3.8	4.2	2.8	3.5
	Rt	0.00060	0.00046	0.00047	0.00041	0.00044
210-240	CC	6.7	3.3	3.6	1.8	3.7
	Rt	0.00054	0.00040	0.00040	0.00026	0.00046

TABLE III (CONTINUED)

240-270	CC	4.9	2.4	1.9		2.2
	Rt	0.00040	0.00029	0.00021		0.00027
270-300	CC	4.9	2.0	2.4		1.9
	Rt	0.00040	0.00024	0.00027		0.00024
300-330	CC	3.7	1.5			1.3
	Rt	0.00030	0.00018			0.00016
330-360	CC	2.9				
	Rt	0.00024				
TOTAL		410.7	278.1	297.5	230.0	267.3

* Computed values

** Average values

TABLE IV

COMPARISON OF VARIOUS DATA ON HELIUM ELIMINATION

	NMRI DATA	EDU DATA	JONES (3)
Ro '	0.25	0.085	-
Ro ''	0.045	0.0095	-
Ro '''	0.0022	0.0015	-
Ro ''''	0.0006	-	-
Aoo '	0.5	0.283	-
Aoo ''	0.33	0.475	-
Aoo '''	0.088	0.25	-
Aoo ''''	0.082	-	-
K_1	0.50	0.30	0.50
$T_{\frac{1}{2}}(1)$	1.387	2.31	1.387
K_2	0.135	0.02	0.094
$T_{\frac{1}{2}}(2)$	5.13	34.6	7.37
K_3	0.025	0.006	0.022
$T_{\frac{1}{2}}(3)$	27.7	115.5	31.5
K_4	0.0073	-	0.00?
$T_{\frac{1}{2}}(4)$	95	-	?

$T_{\frac{1}{2}}$ = half-time

APPENDIX A

EQUATIONS

1. $$Q_cH_e = \frac{D}{33} \times C_{he} \times W_b \times 3.6$$

$QcHe$ = Computed Helium Content
C_{he} = Concentration Helium (%)
W_b = Body weight (lbs)
D = Depth (ft.)

2. $$r = \frac{Q_{he}}{t}$$

r = Rate of helium elimination
Q_{he} = Helum recovered (cc.)
t = Time in period (min)

3. $$Rt = \frac{r}{Q_cH_e}$$

Rt = Fraction of computed total H_e content eliminated per min.

4. $$R = R_oe^{-Kt}$$

R = Rate at time (t)
R_o = Rate at zero time
K = Constant
t = Time elapsed since elimination started

5. $$R_t = R'_oe^{-K1t} + R''_oe^{-K2t} + R'''_oe^{-K3t} + R''''_oe^{-K4t}$$

6. $$R_t = 0.0085e^{-0.3t} + 0.0095e^{-0.02t} + 0.0015e^{-0.006t}$$

7. $$Aoo = \frac{Ro}{K}$$

Aoo = Amount (fraction of inert gas in a tissue component after an infinitely long exposure

8. $$K = \frac{\ln 2}{\text{half-time}} \qquad \text{half-time} = \frac{\ln 2\,(0.693)}{K}$$

9. $$A_t = 0.5e^{-0.5t} + 0.33e^{-0.135t} + 0.088e^{-0.025t} + 0.082e^{-0.0073t}$$

A_t = Unexchanged fraction at any time

10. $$A_t = 0.0283e^{-0.3t} + 0.475e^{-0.02t} + 0.25e^{-0006t}$$

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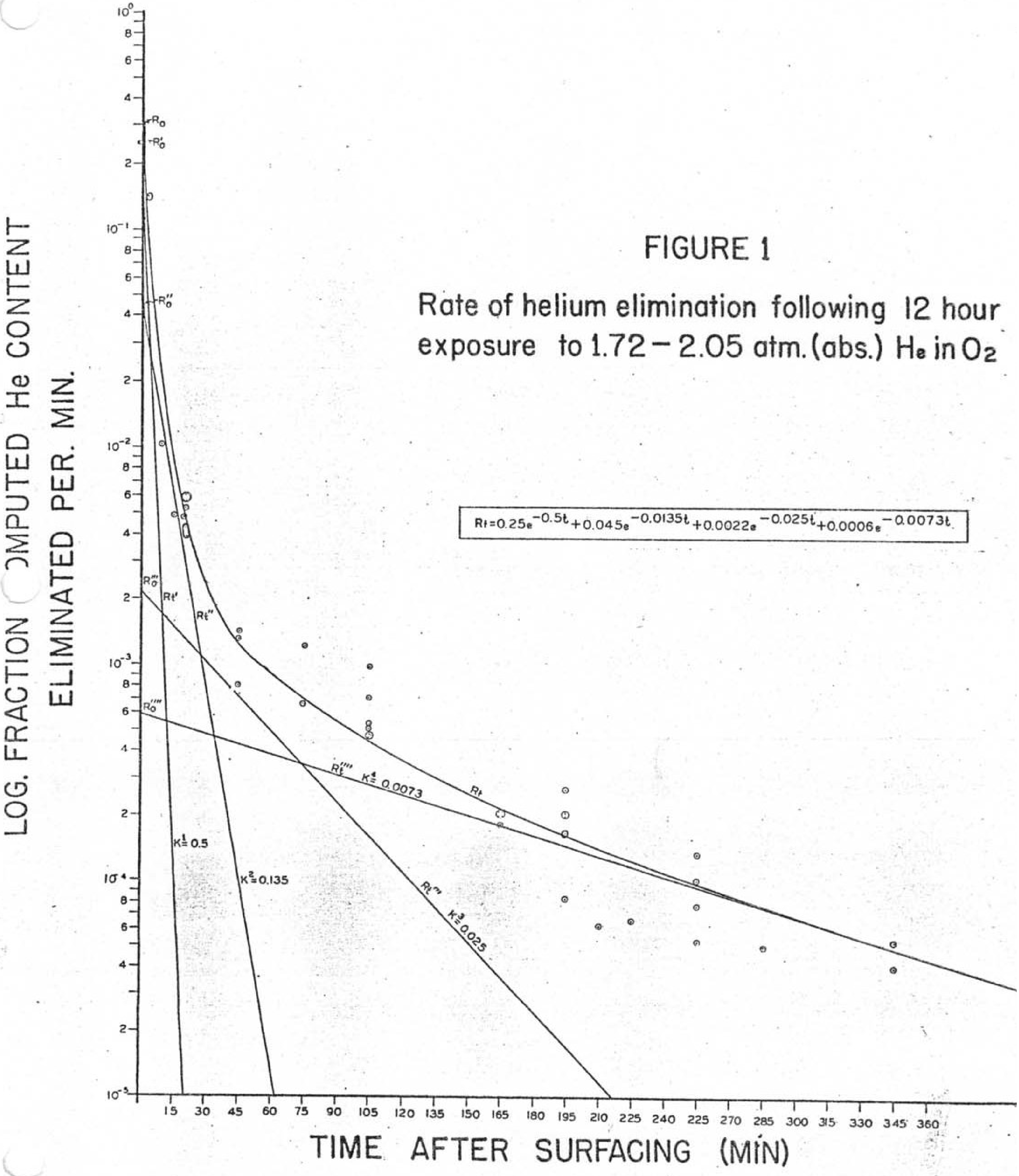

FIGURE 1

Rate of helium elimination following 12 hour exposure to 1.72 − 2.05 atm. (abs.) He in O_2