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RESEARCH REPORT 11-57

CALCULATION OF AIR SATURATION DECOMPRESSION TABLES

PROJECT NS185-005 SUBTASK 5 TEST 7

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CONDUCTED AND PREPARED

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ABSTRACT

A decompression table was developed to provide safe, efficient decompression from exposures of 40 feet for 720 minutes to 300 feet for 180 minutes at suitable increments of depth. On the basis of the results of 46 long exposure dives it was determined that control of such slower half-time tissues as the 160 and 240 minute tissues was required to provide reasonably safe decompression. The control of the allowable tissue tensions at the decompression stops was determined on the basis of the relation of change (S) and differential (E) to known safe tissue tensions at 66 feet and 33 feet absolute for the various half-time tissues. Decompression time required for long exposures calculated on these controls is much greater than provided by the present Air Saturation Table. The tables presented provide safe decompression for all but subjects more susceptible than usual to decompression sickness from long exposures.

SUMMARY

PROBLEM

To develop a safe decompression table for longer exposures than allowed for on the existing standard air tables, as a protection for the trapped diver and other emergencies.

FINDINGS

(1) Control of 160 and 240 minutes half-time tissues is necessary for long exposure dives.

(2) Marked individual variation is susceptibility to decompression sickness following long exposures was observed.

(3) Decompression time for safe decompression from long exposures is much greater than provided by the present Air Saturation Table (Table V)(5).

(4) Roentgenologic study of the long bones of all subjects making dives in this series revealed no evidence of aseptic necrosis developed as a result of prolonged exposures or inadequate decompression.

RECOMMENDATIONS

(1) Approve the decompression tables for field use in emergency decompression for longer and deeper exposures than provided for by the revised standard air decompression tables.

(2) Incorporate the tables presented into Part I of the U.S. Navy Diving Manual now in preparation.

(3) Determine the feasibility of use of the submarine rescue chamber for decompression of the diver requiring long water stops. Provide oxygen decompression to shorten the shallower stops in the rescue chamber.

(4) Determine the correlation of susceptibility of subjects in this series to altitude decompression sickness toward development of a practical susceptibility test for divers.

(5) Test short and long exposures for subjects using decompression schedules based on a constant ratio for each half-time tissue in an attempt to shorten decompression requirements for long exposures.

ADMINISTRATIVE INFORMATION

Ref: (a) EDU Research Report 1-57 of 15 August 1956.

(b) EDU Research Report 5-57 of 3 December 1956.

Reference (a) listed all the administrative details leading up to the development of the single dive tables.

Reference (b) documented further study required in their testing and the results obtained.

This project reports the testing and revision of the method for calculation of decompression schedules for dives longer and deeper than diving operations will normally require. It provides decompression schedules for these dives.

Manpower requirements for this project were as follows:

DESCRIPTION	MANHOURS
TEST DIVES	1507
CALCULATION OF SCHEDULES	680
SUMMARIES AND ANALYSIS	200
DRAFTING	60
PREPARATION OF REPORT	100
DUPLICATION OF REPORT	90
TOTAL	2637

Costs were charged to project order 300 38/57. Work commenced 28 November 1956 and completed 20 June 1957. This report is issued in the Research Report series, with unrestricted distribution. It is the final report of the project.

TABLE OF CONTENTS

	Abstract	ii
	Summary	ii
	Administrative Information	iii
	Table of Contents	iv
1.	INTRODUCTION	
	1.1 Introduction	1
	1.2 Objective	1
	1.3 Scope	1
2.	DESCRIPTION	
	2.1 General	1
	2.2 Present Method	1
	2.3 Proposed Method	2
	2.4 Test Facilities and Methods	2
	2.5 Background	2
3.	PROCEDURE	
	3.1 Initial Calculation and Testing of Decompression Tables	4
	3.2 Further Calculation and Testing of Decompression Tables	5
	3.3 Further Evaluation of Safe Surfacing Tissue Tensions	5
	3.4 Calculation of Final Decompression Tables	7
4.	RESULTS	
	4.1 General	7
	4.2 Testing of Computed Tables	7
	4.3 Results of Long Bone X-rays	9
5.	DISCUSSION	
	5.1 Results of Test Dives	9
6.	CONCLUSIONS	
	6.1 Conclusions	11
	6.2 Recommendations	11
7.	FIGURES	
	7.1 Figures	12
8.	TABLES	
	8.1 Tables	13
	REFERENCES	14
	ACKNOWLEDGMENTS	16

1. INTRODUCTION

1.1 Introduction

1.1.1 Attempts to provide adequate decompression for long exposures at deeper depths have not met with uniform success in preventing decompression sickness. The basic Haldane decompression tables aimed at eliminating the risk of serious symptoms while reducing the chance of bends to a minimum (1). These early workers in the field recognized the probability of slower tissues requiring control than was provided for in their calculations.

1.1.2 Further evidence to support this view appears in the report of calculations and testing of the present U.S. Navy standard decompression table (2). Marked reduction in allowable surfacing tissue tensions for slower tissues was required to provide reasonably safe decompression from long exposures at deeper depths. Extensive testing of decompression schedules presented in EDU Research Report 5-57 (3) validates the necessity of progressive reduction of allowable tissue tensions for each slower half-time tissue upon surfacing. Further reduction was made with increased ambient pressure at the decompression stops.

1.1.3 In view of such recent advances in decompression theory it was apparent that decompression provided by the present U.S. Navy decompression tables (4,5) for longer and deeper exposures is inadequate to prevent decompression sickness.

1.2 Objective

1.2.1 The objective of this project is to develop a safe decompression table for longer exposures than allowed for on the existing standard air decompression table, as a protection for the trapped diver and other emergencies.

1.3 Scope

1.3.1 The calculation, testing, analysis, and revision, if required, of decompression schedules for long exposures at suitable increments of depth and exposure time to provide safe and efficient decompression for these dives.

2. DESCRIPTION

2.1 General

2.1.1 If for some cause a diver has to spend an unusual amount of time at a great depth, the diving supervisor should have available a decompression schedule, which if used, will provide reasonable safety from decompression sickness. The hazards of the situation may force the diving supervisor to take other action, but he should be able to place as much trust in an emergency schedule as any other. The schedules for "optimum" and "maximum" time given in the present Standard Air Table, and the schedules in the present Air Saturation Table, do not lend themselves to any such confidence.

2.2 Present method

2.2.1 The present U.S. Navy Air Saturation Decompression Table (5) provides for the emergency situation of the trapped diver whose exposure is longer than allowed for on the existing standard air decompression table. Analysis of this table in terms of the present method of computation of decompression schedules reveals that it provides what is considered to be adequate decompression for approximately 180 minutes exposure for dives to 140 feet in depth. Decompression provided for deeper dives is adequate for proportionately less exposure time. Therefore it is not reasonable to assume that adequate decompression is provided by these schedules for longer or deeper exposures.

2.3 Proposed method

2.3.1 A revised standard air decompression table is presented in EDU Research Report 5-57 (3) to provide safe decompression for dives up to 190 feet for 60 minutes. Dives between 200 and 300 feet were tested and reported as a part of that study, but are to be included with the remainder of the dives in the present study for acceptance as the second half of the revised U.S. Navy Standard Air Decompression Table. It is considered that air dives to greater depths than 190 feet for 60 minutes will not be a part of routine diving procedure, and should be in a separate table of dives to longer and deeper exposures.

2.3.2 Information has been gained as to the need for reduction of allowable tissue tensions at deeper decompressions stops for the various half-time tissues (3). Application of this information to the calculation of air saturation decompression tables was made and the resulting decompression schedules tested to determine their safety.

2.4 Test facilities and methods.

2.4.1 The test dives in this series were made in the recompression chamber with the divers at rest. This was done because of the many hours of decompression required in addition to the long exposure at depth. Van Der Aue, reporting on the results of a series of long exposure dives made at EDU in 1947, found that work had little effect on the outcome of dives of long duration (6). Thus it is believed that tissue tensions of inert gas resulting from these dives are representative of long exposures in air or water, at work or rest.

2.4.2 The ascent rate was 60 feet per minute to each of the required stops, as provided for the first half of the revised tables.

2.4.3 All dives in this series were conducted at 140 feet for increasing increments of exposure time. 140 feet was chose as a medium depth on air representative of air diving procedures, which are seldom in excess of 190 feet. While making possible a large gradient for nitrogen uptake, it avoided somewhat the problems of nitrogen narcosis and breathing resistance at greater depths.

2.4.4 Subjects who developed decompression sickness requiring recompression were not permitted to dive for a period of two weeks. This was an attempt to avoid the possibility of tissue injury predisposing to further development of symptoms from later dives.

2.4.5 Serial x-rays were taken of the long bones of the legs of all subjects in this series to determine whether or not aseptic bone necrosis had been produced by these long exposures or inadequate decompression.

2.5 Background

2.5.1 Boycott, Damant and Haldane (1) provided a rational basis for calculation of decompression tables. Their theories have resulted in a general calculation procedure known as the "Haldane method" of calculating decompression schedules. Their basic tenets were:

(1) To never allow the computed nitrogen pressure in the tissues to be more than twice the ambient pressure.

(2) To make the fullest use of the permissible difference in pressure to hasten the elimination of nitrogen from the tissues.

They recognized that the rate of saturation and desaturation of some tissues producing decompression sickness was possibly slower than they had assumed. "What we have aimed at is to completely obviate the risk of any serious symptoms, while at the same time reducing the chance of bends to a minimum." (1).

2.5.2 Hawkins, Shilling and Hansen (7) felt a ratio of 2:1 was too conservative for fast tissues and possibly not restrictive enough for slow tissues. On the basis of an analysis of 2,143 experimental dives to depths between 100 and 200 feet, they determined maximum safe surfacing ratios to be as follows:

5 minute tissue	5.5:1
10 minute tissue	4.5:1
20 minute tissue	3.2:1
40 minute tissue	2.4:1
75 minute tissue	1.8:1 to 2.0:1

For calculation of decompression tables, they ignored the 5 and 10 minute tissues and used a ratio of 2.8:1 for the 20 minute tissue, and 2.0:1 for the 40 and 75 minute tissues. Their determination of maximum safe surfacing tissue tensions made possible more efficient decompression in that deeper stops than necessary are avoided, and the fullest use is made of the permissible difference in pressure.

2.5.3 Behnke (8) made a notable contribution to decompression calculation by putting nitrogen elimination on a quantitative basis. From data obtained in a series of studies on dogs and human subjects he concluded:

(1) that nitrogen absorption is proportional to the partial pressure of nitrogen in the lungs

(2) that with the same pressure head, the rate of nitrogen absorption is equal to the rate of nitrogen elimination

(3) that the time for complete nitrogen elimination, and percentage rate of nitrogen elimination, for corresponding periods of time are the same irrespective of the quantity of nitrogen absorbed by the body.

However, the precise end-point of nitrogen elimination could not be measured more accurately than ± 2%, with the result that the longest tissue to be considered in calculation of decompression tables appeared to be one which was 98 ± 2% desaturated at the end of 6 hours. This led him to conclude that it was unlikely that compressed air illness following long exposures to high pressures resulted from an underestimation of the time required for nitrogen elimination. Experimental values for the nitrogen elimination curve gave further support to the multiple tissue theory of calculation developed by Haldane by demonstrating the variation in distribution of blood flow in relation to the distribution of nitrogen in the body.

2.5.4 The present U.S. Navy Standard Air Decompression Table was calculated by using the 20, 40 and 75 minute tissues (2, 9). The tissue ratios for the 5 and 10 minute tissues appeared to be so high that they were not normally brought into control. The pattern of reduction used in the ratios was somewhat irregular, but the following values were applied to fit empirical results:

20 minute tissue	2.45:1 to 2.8:1
40 minute tissue	1.75:1 to 2:1
75 minute tissue	1.75:1 to 2:1

Tests of schedules calculated by the three tissue method indicated that the ratios had to be reduced to the lower values after prolonged exposures at greater depths.

2.5.5 Van Der Aue et al (10) did extensive testing of these decompression tables in carrying out tests of surface decompression using air. They reported that 24 percent of 81 subjects developed "bends" or "mild bends" when standard decompression was used for working dives of long duration.

2.5.6 They further analyzed available data to find logical values for tissue ratios. As a result of calculation and extensive testing of a series of surface decompression schedules using oxygen (11), they found:

(1) that tissue ratios must be reduced considerable for all components in longer deeper dives

(2) that the fast tissues sometimes control deep stops even with high tissue ratios

(3) that the surfacing ratios could be increased to the following values:

5 minute tissue	3.8:1
10 minute tissue	3.4:1
20 minute tissue	2.8:1
40 minute tissue	2.27:1
75 minute tissue	2.06:1
120 minute tissue	2.00:1

2.5.7 Reduction of tissue ratios with depth appears to be essential for calculation of safe decompression tables by the Haldane method (11, 15). There are several mathematical-physical evaluations to support this concept. Bateman (12) derived a mathematical relationship between "decompression ratio for symptom threshold" and "body saturation with air before decompression". Basically it results in a smooth reduction of tissue ratio with increasing pressure. Piccard (13) discussed the mathematical probability of a reduction in allowable supersaturation as the total mass of dissolved gas increases with increasing pressure. Calculation of decompression tables using a tenth-power relationship between tissue ratio and tissue pressure, with the surfacing ratios indicated by Van Der Aue (11) was described in EDU Research Report 1-57 (14).

2.5.8 Testing and revision of these tables in terms of the experimental results is reported in EDU Research Report 5-57 (3). The allowable surfacing ratios required modification as follows:

5 minute tissue	4:1
10 minute tissue	3.4:1
20 minute tissue	2.8:1
40 minute tissue	2.4:1
80 minute tissue	2.0:1
120 minute tissue	1.94:1

The projected depth ratios were acceptable as far as they were able to be tested, but for the slower tissues testing was possible only to the depths of the following stops:

40 minute tissue	40 foot stop
80 minute tissue	10 foot stop
120 minute tissue	surfacing

Therefore, the present series of tests of longer exposures will determine the adequacy of these projected allowable tissue tensions at stops as deep as 70 feet for the 120 minute half-time tissue.

3. PROCEDURE

3.1 Initial calculation and testing of decompression tables

3.1.1 Decompression tables were calculated for a depth of 140 feet for exposure times of 90, 120, 180, and 240 minutes by the method described in EDU Research Report 5-57 (Fig. 1, Table 1A).

3.1.2 The validity of these tables was tested by exposing a series of 6 subjects, 2 on each test, in the recompression chamber. The subjects were decompressed in accordance with the calculated schedules. Only two subjects were exposed to the calculated table for 240 minutes exposure, as symptoms requiring recompression occurred in both subjects following decompression in accordance with this table.

3.2 <u>Further calculation and testing of decompression tables</u>

3.2.1 Evaluation of the calculations for the 240 minute exposure indicated that further reduction of the allowable tissue tensions at the stops was in order. This table was recalculated with the allowable tissue tensions at the stops based on the pressure-diameter relationship of decreasing bubble diameter with increased ambient pressure, proposed by Duffner (25) (Fig. 2, Table 1B). This table added 68 minutes decompression time to the previous table tested, and decreased the allowable tissue tensions at each stop for the various half-time tissues. Four dives were made on this table.

3.2.2 As the pressure-diameter controls did not prove safe, further evaluation as to the defect in the controls was necessary. A review of these two tables showed the 120 minute tissue to be controlling for four and six stops, respectively. The possibility of control passing to a slower half-time tissue, as 160 and 240 minutes half-time, presented itself. The 160 and 240 minute tissues would require 16 and 24 hours, respectively, to desaturate to atmospheric pressure.

3.2.3 A table was calculated for 140 feet for 180 minutes on the basis of the pressure-diameter control with the 160 minute tissue allowed to surface with 66 feet absolute tension of nitrogen. (Fig. 2, Table 13). Six dives were made with decompression according to this table. Based on the results of these dives, it was felt the 160 minute tissue was still surfacing with too great an excess tissue tension of nitrogen. This was reduced to 64 feet allowable inert gas tissue tension.

3.2.4 While the pressure-diameter controls were considered to be conservative compared to the J controls tested initially, it was possible that loss of efficiency in desaturation would occur due to a reduction of the maximum allowable differential acting at each stop. Thus a control was determined as a mean between the J and pressure-diameter controls for each half-time tissue. (Fig. 3, Table 10). It did not exceed the maximum safe tissue tensions at any stop for safe dives. A 240 minute dive was calculated and tested with this control.

3.2.5 As this dive did not prove safe, it was decided to recalculate it using the more conservative pressure-diameter controls with the 160 minute tissue surfacing at 64 feet absolute. This table added 68 minutes decompression time to the previous table calculated on the pressure-diameter control for 240 minutes exposure. This table did not prove safe when tested for two dives.

3.3 <u>Further evaluation of safe surfacing tissue tensions</u>

3.3.1 In order to gain any further information on the safe surfacing tissue tensions of inert gas for the longer half-time tissues, a search of the files at EDU revealed records of a number of long dives made between 1937-1945 which had not been previously reported. Many of these dives were made at depths between 30 to 99 feet for exposures up to 36 hours. Unfortunately, the number of dives at each depth and time of exposure was not considered sufficient to give valid data. There is obviously a wide individual variation in susceptibility to decompression sickness from long exposures as evidenced in these dives. The 160 minute tissue surfaced safely with 69.3 feet absolute of nitrogen tension, the 120 minute tissue with 70.4 feet, and the 240 minute tissue with 69.9 feet in some of these dives. Yet there were dives which caused symptoms requiring treatment with much lower values than these. It does not appear that 66 feet absolute is safe for surfacing the 120, 160 and 240 minute tissues. No evidence of symptoms was found for dives in which the 120 minute tissue surfaced at 65 feet absolute. Likewise the 160 minute tissue appears to surface safely with 64 feet absolute. However, there were a number of dives which were safe in which the 120 and 160 minute tissues were below these levels, and the 240 minute tissue was from 66 to 70 feet absolute. While there appears to be some variation in the safe values for the 120 and 160 minute tissues, the range of safe variation for the 240 minute tissue seems wide indeed. One must question the existence of tissues requiring control slower than the 240 minute tissue in many subjects, as it would be safe to surface these with much greater values than allowable for the 120 and 160 minute tissues. The 240 minute tissues were calculated for the 240 minute exposures in this series and found to surface from 71.3, 74.4, 69 and 69.5 feet respectively. (Table 3E).

3.3.2 Since the third and fourth dives for 240 minutes still caused symptoms, it was decided to control the 240 minute tissue at 64 feet as well. The 120 minute exposure which caused no symptoms requiring treatment surfaced with the 240 minute tissue at 63.3 feet absolute. A review of the records of long dives showed no evidence of symptoms with the 240 minute tissue at 64 feet, the 120 minute tissue at 65 feet and the 160 minute tissue at 64 feet.

3.3.3 The maximum tissue tensions at the stops for the various half-time tissues were determined for dives in this series which were free of symptoms. A regular decrease of change (S) between the tissue tensions at successively deeper stops appeared for each half-time tissue. A graphical representation of this data aided in projecting the allowable tissue tensions at the deeper stops (Fig. 5, Table 1D). A table was calculated on the basis of these controls for 240 minutes exposure, and six dives made to test it.

3.3.4 To determine if the allowable tissue tensions at the various stops related to density increase as a function of increasing ambient pressure, known safe tissue tensions at 33 feet were chosen. The allowable tissue tensions at the deeper stops were then projected using a pressure-volume reduction of change (S) allowable at 33 feet, considering this to be 0.5 of the change occurring in 10 atmospheres increased pressure. Change (S) at 66 feet would be 0.333 and at 99 feet, 0.25. These points were plotted to determine the tissue tensions allowable at each stop for each half-time tissue. (Fig. 6, 8; Table 1E). These values related well to the empirical values used for the shallower stops, and projected the allowable tissue tensions for the deeper stops as a function of change (S) at 2 atmospheres absolute and ambient pressure. This is an attempt to maintain constant the density of inert gas in terms of known safe differential pressure. A dive for 360 minutes exposure at 140 feet was calculated on the basis of these controls for testing. No attempt was made to control a 320 minute tissue, as it was considered that longer half-time tissues than 240 minutes do no exist to require control in many subjects. It was calculated to surface at 69 feet absolute on this dive with the 240 minute tissue surfacing at 64 feet absolute. This would require 108 minutes additional time at the 10 foot stop to reduce it from 69 to 64 feet absolute. Six dives were made to test this schedule.

3.3.5 Further graphical study of the relationship of change (S), differential (E), and allowable tissue tension at the stops was carried out for the pressure-volume controls. (Fig. 6, 7). It was determined that for deeper stops, the increments of change (S) decreased markedly. This resulted in a negative curve of differential (E) for the deeper stops. (Fig.7). Since an increasing differential is allowable as deep as the 80 foot stop for the 240 minute tissue, and the 110 foot stop for the 40 minute tissue, it is logical to assume that the curve of allowable change (S) will at least become asymptomatic at 11. (Fig. 9). This would allow for some increasing increment of allowable differential (E) in determining allowable tissue tension at the various stops. (Fig. 10). As the rate of change in density of inert gas in the tissues decreases markedly after the first 2 atmospheres of increased pressure (Boyle's law), it is logical to assume that allowable differential should at least have a slight positive rate of change in its curve as it relates to the depth of stops. (Fig. 10). A curve of change (S) becoming asymptomatic at 11 for each half-time tissue insures this. (Fig. 9).

3.3.6 A graphical solution for maximum allowable tissue pressure at the various stops for each half-time tissue was made on the basis of the curves of change (S) and differential (E) allowable for these stops. (Fig. 11). The resulting table of maximum allowable tissue pressures appears in table 1F. As this solution affects only the deeper stops at which no symptoms have appeared during the last two series of dives for 240 and 360 minutes, it is felt that this projection of the curves for these stops is logical and safe. It will increase the efficiency of decompression in the unnecessarily deep stops are avoided, which would increase the decompression time required to desaturate slow tissues exposed to higher pressures for longer times than necessary.

3.4 Calculation of final decompression tables

3.4.1 Calculation of the final decompression tables was carried out by the same method and controls projected in 3.3.6. A graphical solution was made of time in full minutes required to reduce each tissue tension to that allowable at each stop. This was prepared in tabular form for the 40, 80, 120, 160 and 240 minute tissues to facilitate the calculation of the large number of decompression tables required.

3.4.2 Decompression tables calculated were as follows:

40 feet	360, 480, 720 minutes
60 feet	240, 360, 480, 720 minutes
80 feet	180, 240, 360, 480, 720 minutes
100 feet	180, 240, 360, 480, 720 minutes
120 feet	120, 130, 240, 360, 480, 720 minutes
140 feet	90, 120, 180, 240, 360, 480, 720 minutes
170 feet	90, 120, 180, 240, 360, 480 minutes
200 feet	90, 120, 180, 240, 360 minutes
250 feet	60, 90, 120, 180, 240 minutes
300 feet	60, 90, 120, 180 minutes

4. RESULTS

4.1 General

4.1.1 The results obtained from a total of 46 long exposure dives performed in the conduct of this project are recorded in detail in tables 2 and 4. These results will be discussed in order of sequence according to the various controls of allowable tissue tensions used.

4.2 Testing of computed tables

4.2.1 J controls (Dwyer) (14)

(1) Of six subjects exposed for 90 minutes, two of the three subjects in the first set had pruritis (itching of skin) during decompression. One of these had marked rash over the thorax. Jackets were worn by the divers during ascent after this, to avoid skin cooling with the drop in chamber temperature. None of the three subjects in the second set experienced pruritis, rash or other symptoms.

(2) Five of six subjects exposed for 120 minutes were symptom-free. One subject had pruritis during decompression and 4½ hours later experienced dull pain in his left knee lasting several hours. This subsided without recompression.

(3) Four of six subjects exposed for 180 minutes had no complaints. Two subjects had pruritis during decompression. One complained of pain in an ankle 1½ hours after surfacing, which subsided without treatment. The other subject with pruritis had onset of knee pain 6 hours after surfacing. Treatment was carried out on treatment table two (4) without recurrence or residual symptoms.

(4) Both subjects exposed for 240 minutes presented symptoms within 20 minutes after surfacing which required treatment on treatment table three (4). Both subjects had knee pain. One also complained of dizziness, and presented limitation of visual fields and nystagmus.

The other subject presented decreased muscle strength in both legs. There were no residual symptoms or recurrence after treatment.

4.2.2 Pressure-diameter controls

(1) Four subjects made dives on the second trial of the 240 minute exposure. The first two subjects had onset of transient dull leg pain several hours after surfacing, which subsided spontaneously without treatment. After the next exposure on this table one subject complained of ankle and knee pain; the other, upper abdominal pain. The onset of symptoms was within 10 minutes after surfacing. Both subjects were treated on treatment table two. The subject with ankle and knee pain had a recurrence of these symptoms four hours later. Treatment of this recurrence was carried out on treatment table three with freedom from residual symptoms and further recurrence. The subject who complained of abdominal pain presented generalized muscle tenderness and epigastric tenderness 6 to 8 hours after treatment, but this cleared without further recompression.

(2) Six dives were made as a second trial of 180 minutes exposure with the 160 minute tissue permitted to surface with a computed tension of 66 feet absolute of inert gas. One subject complained of knee pain four hours after surfacing. Treatment was carried out on treatment table two with no residual symptoms or recurrence. Three other subjects complained of mild knee pain which subsided spontaneously.

4.2.3 Mean between J and pressure-diameter controls

(1) Two dives were made as a third trial of a 240 minute exposure with the 160 minute tissue surfacing with a computed tension of 64 feet absolute. One diver developed mottled rash over the abdomen on coming to the 30 foot stop. This disappeared during the stop, but recurred on coming to the 20 and 10 foot stops. Upon reaching the 10 foot stop, he complained of severe pain in his right hip and knee. The other subject was locked into the igloo to finish decompression as he was symptom-free.

(2) The subject with symptoms was treated on treatment table three and was symptom-free on surfacing. However, he again complained of pain in his right knee 18 hours after surfacing from treatment. He was recompressed and retreated on treatment table three, but had no relief after 30 minutes at 165 feet. He had persistence of pain until finishing 30 minutes of oxygen breathing at 60 and 50 feet, respectively. The pain was completely relieved after finishing an additional 30 minutes of oxygen breathing at 40 feet. He had no residual symptoms.

(3) The other subject complained of pain in both knees and lower back ten hours after surfacing from the dive. He was recompressed slowly to 165 feet with no improvement of symptoms. In fact he noted onset and progressive increase of pain in his right mid-thigh during recompression. He had no complaint of pain in this area before recompression. It was necessary to give him 100 mgm of Demerol for relief of this severe pain, even though pressure had been decreased to 60 feet without improvement in an attempt to decrease a possible tissue squeeze around the bubble (15). It was then possible to recompress him very slowly to 165 feet and carry out treatment on treatment table three. He noted residual pain in his right thigh, but had no recurrence of symptoms.

4.2.4 Pressure-diameter control

(1) Two dives were made for a fourth trial of a 240 minute exposure with the 160 minute tissue surfacing with a computed tension of 64 feet absolute. One subject complained of dull pain in his left knee, thigh and foot 20 minutes after surfacing. He was treated on treatment table three in view of the recurrences of symptoms previously encountered in treating decompression sickness occurring from these long exposures less than 4 to 6 hours after surfacing. He had no residual symptoms or recurrence after treatment.

(2) The second subject remained symptom-free for 11 hours after surfacing, then complained of dull pain in his left shoulder. He was treated on treatment table two but had little relief of the dull pain until he had finished 30 minutes of oxygen breathing at 60 and

50 feet, respectively. He was given oxygen for 2 hours at 30 feet, and 1 hour at 20 feet and at 10 feet in addition to insure complete resolution of his symptoms.

4.2.5 Regular decrease of change (S) based on known safe tissue tensions.

(1) Six dives were made on a control based on a graphical analysis of allowable increments of change (S) between stops with both the 160 and 240 minute tissues surfacing with a computed tension of 64 feet absolute. This was the fifth trial for a 240 minute exposure.

(2) No subjects complained of symptoms after the first two dives. One of these subjects had symptoms requiring treatment after the second trial of 180 minutes exposure.

(3) The second dive produced knee and hip pain in one subject two hours after surfacing. He was treated uneventfully on treatment table three. This subject complained transient knee pain after the 120 minute dive which produced no symptoms in other subjects. The other subject on this dive was free of symptoms. He experienced symptoms requiring treatment after the first trial on the 180 minute dive.

(4) The third dive in this series produced knee pain in one subject about 20 minutes after surfacing. He was treated uneventfully on treatment table three. This subject had knee pain requiring treatment after the first and third trials on the 240 minute dive. The other subject who was symptom-free following this dive, had symptoms requiring treatment coming on 10 hours after surfacing from the 4th trial of the 240 minute dive.

(5) The two subjects experiencing symptoms during this series of dives apparently have body components requiring control slower than the 240 minute tissue. The 320 minute tissue on this dive surfaced with a computed tension of 65.6 feet absolute. It wo ld require 33 more minutes at the 10 foot stop to reduce this to 64 feet absolute. There is a possibility that even slower tissues might need to be considered for subjects particularly susceptible to symptoms after long exposures. This would require much longer decompression then is needed for the average subject. Thus to have an efficient decompression table for long exposures it may be necessary to accept the possibility of symptoms occurring in a few susceptible subjects.

4.2.6 Pressure-volume reduction of change (S) based on know safe tissue tensions at 33 feet. Six dives were made to test a 360 minute exposure calculated on these controls. Four subjects were asymptomatic following these dives. One subject complained of dull pain in one knee which lasted several hours, but subsided without treatment. Another subject experienced pain in his right knee and left ankle, 6 hours after surfacing from the dive. He was treated on treatment table three with no residual symptoms or recurrence. Another subject who was symptom-free on the fifth trial of the 240 minute exposure was also asymptomatic on this dive. None of the subjects had any symptoms during the decompression phase of this dive.

4.3 Results of long bone x-rays

4.3.1 Antero-posterior and lateral x-rays of long bones of the legs of all subjects making dives in this series were made at the start, upon completion of the dives, and after a 2 month interval. This was done to rule out the possibility of aseptic bone necrosis developing as a result of prolonged exposures to increased pressure or inadequate decompression (15, 16, 17, 18, 19). No evidence of aseptic bone necrosis or other bony pathology appeared on these films. This is in accord with the report of Behnke and Welham (15) who found no characteristic lesions in roentgenologic study of divers at different periods following bends arising from experimental dives.

5. DISCUSSION

5.1 Results of test dives

5.1.1 In the course of carrying out the test dives for long exposures in this project, it became apparent that consideration of slower half-time tissues was required than is necessary for dives of depths and exposure times usually encountered in air diving. Until this requirement was fully appreciated, further reduction of allowable tissue tensions at the decompression stops was of no avail in preventing symptoms of decompression sickness.

5.1.2 Interpretation of the results of these experimental dives was further complicated by considerable individual variation in susceptibility to decompression sickness among the subjects exposed to identical decompression schedules. The only subject to have minor symptoms, of six subjects exposed on the 120 minute schedule, had made 31 dives without symptoms during the conduct of the experimental dives for the revised standard air decompression tables. He also had symptoms requiring treatment after the fifth trial of the 240 minute exposure. The only other subject having symptoms after this fifth trial, developed symptoms during the decompression period on the third trial at 240 minutes exposure. The other subject who required treatment after the third trial did not develop symptoms until 10 hours after surfacing. It is remarkable that of two subjects requiring treatment after the first and second trials of the 180 minute exposure each made the other trial without symptoms requiring treatment.

5.1.3 A further implication of the wide range of individual variation to symptoms following long exposures is that to privide reasonably efficient decompression for such dives, it may be necessary to accept the possibility of symptoms occurring in the more susceptible subjects. If a 320 minute tissue were to be controlled on these dives, it would add many hours of decompression time to that which is already very long. This may very well be decompression not required by most of the divers. In view of recurrence of symptoms when shorter treatment tables were used with less than 6 hours interval after surfacing, at least treatment table three with use of oxygen will be required to treat symptoms occurring after decompression from long exposures (20).

5.1.4 Several attempts were made to relate the allowable tissue tensions at the decompression stops to ambient pressure. The validity of the final controls rests on the fact that symptoms did not occur during the decompression stops. Due to the length of these stops and further reduction of pressure, it is believed that symptoms will occur before surfacing if the controls upon which they are based are unsafe. It remains to be proven that more liberal controls than those presently used are permissible. The present controls used for calculation of the final tables are based on known safe tissue tensions at 66 feet absolute, and upon surfacing. The curve of change (S) (Fig. 9) becomes asymptotic at 11 for each half-time tissue, thus permitting a positive rate of change of differential pressure at the various stops. (Fig. 10). This results in a rapid decrease of allowable tissue tension with the greatest increase in density of gas in the first 2 atmosphere increased pressure (Fig. 11), and a less rapid decrease with smaller increases in density with further pressure increase (13, 15). While decrease of allowable tissue tension in this manner is quite conservative, it is desirable to avoid the possibility of onset of symptoms at any of the water stops after long exposures. It remains to be proven, however, that a constant rate of increase of differential resulting from constant ratios of tissue tension to ambient pressure are unsafe.

5.1.5 Van Der Aue (21) studied exposures of 12 hours at 99 feet with immediate ascent to 33 feet where 12 to 24 hours were spent in decompression before surfacing. Upon reaching 33 feet, a 2:1 ratio resulted in all tissues through the 120 minute tissue, with a 1.97:1 ratio occurring in the 160 and 240 minute tissue. No symptoms other than mild itching occurred at the 33 foot stop, but decompression sickness did occur upon surfacing in several subjects. This would indicate that no reduction of ratio at the stops is required for the slow tissues, but that surfacing with a 2:1 ratio for them is unsafe. (Fig. 12). Dives studied in EDU Report 5-57 were asymptomatic with the 10 minute tissue at 2.8:1 and the 20 minute tissue at 2.4:1 at the 60 foot stop. Therefore the evidence for reduction of tissue ratios at the deeper stops is not altogether convincing.

5.1.6 For routine air dives, reduction of tissue ratios from those allowed for surfacing does not result in excessive decompression time requirements. However, it is apparent that maximum differential pressure (E) is not utilized in keeping with efficient decompression methods.

Decompression time required is much greater for long exposures when depth ratios are reduced. Thus if Van Der Aue's work can be validated for deeper dives it would result in great saving in decompression time for long exposures. This will remain to be proven in future projects.

5.1.7 It is now apparent that previous failure to provide adequate decompression for the longer, deeper exposures, even with marked reduction of the slowest tissues controlled (75 minute half-time), was due to failure to consider the 120, 160 and 240 minute half-time tissues in decompression calculations. Computation of decompression with a ratio as conservative as 1.75:1 for the 40 and 75 minute tissues (1, 2, 7, 10) did not result in safe decompression for longer exposures, as control of the 120, 160 and 240 minute tissues at 1.94 (64 feet absolute) is even more conservative.

5.1.8 Piccard's mathematical-physical evaluation of bubble formation (13) suggests marked reduction of allowable tissue tension at each deeper stop to maintain a constant differential pressure acting upon tissues at any depth. This results in a pressure-volume-density control of allowable tissue tension by Boyle's law to maintain the probability of bubble formation constant. Control curves of tissue tensions at the various stops calculated on this basis appear to be vastly more conservative than empirical controls based on known safe tissue tensions derived from experimental dives.

5.1.9 The constant differential control used by Rashbass (22) with saturation-desaturation calculated by Hill's solution of Fick's equation (23) has not resulted in tables which are considered adequate in the usual range of depths and exposure times used in air diving. Saturation by the equation used is considered to be 98.5 percent at 6 hours for the whole body. As desaturation would also be 98.5 percent in 6 hours for the whole body with the same differential, longer dives requiring control by the 120, 160 and 240 minute tissues will not be safe with this method. Inert gas uptake is also considerably less by Fick's equation than for the 5, 10, 20 and 40 minute tissues for exposures from 20 to 480 minutes. Dives calculated by the present U.S. Navy modification of the Haldane method (3, 24) using the decompression tables derived by Rashbass (22) reveal surfacing tissue tensions which are considered in excess of safe values. This is even more apparent for the longer exposures.

6. CONCLUSIONS

6.1 Conclusions

6.1.1 On the basis of the results of 46 long exposure dives it was determined that control of slower half-time tissues as the 160 and 240 minute tissues was required to provide reasonably safe decompression. It was found that the 120 minute tissue could surface safely with 65 feet absolute inert gas tension and the 160 and 240 minute tissues could surface safely with 64 feet absolute.

6.1.2 The control of the allowable tissue tensions at the decompression stops was determined on the basis of the relation of change (S) and differential (E) to known safe tissue tensions at 66 feet and 33 feet absolute for the various half-time tissues.

6.1.3 Tables calculated on the basis of these controls agree well with those dives in this series which caused symptoms in only a few relatively susceptible subjects. It is believed that decompression tables to be safe for all subjects on long exposures would be unnecessarily long, compared to the decompression requirements of the greatest number of subjects.

6.1.4 The increments of depth and exposure time provided in these decompression tables will provide safer, more efficient decompression than the present tables in use today.

6.2 Recommendations

6.2.1 That the decompression tables presented be accepted for use in emergency decompression for longer and deeper exposures than provided for by the revised standard air decompression tables presented in EDU Research Report 5-57.

6.2.2 The feasibility of use of the submarine rescue chamber be tested for decompression of the diver requiring long water stops. This is to be used as an emergency measure to prevent loss of body heat of the diver during his decompression in the water. If this proves practicable, the possibility of use of oxygen decompression to decrease the length of the shallower decompression stops should be tested by using a demand-supply mask with oxygen cylinders in the rescue chamber. Oxygen decompression stops can be calculated and tested for use with these tables.

6.2.3 The relative susceptibility of divers to altitude decompression sickness should be tested by using the subjects of this experiment for altitude exposures. If there is a good correlation between susceptibility to decompression sickness after long exposures at increased pressure and altitude decompression, a safe, practical susceptibility test would be provided for evaluation of the basic susceptibility of divers to decompression sickness. This would prove a valuable aid in evaluation of subject susceptibility for decompression table testing.

6.2.4 Test both short and long exposures for subjects using decompression tables based on a constant ratio for each half-time tissue as tried by Van Der Aue (21). This would determine if reduction of tissue ratios is required with increased ambient pressure. If this reduction is not require, decompression time could be markedly decreased for the longer exposures.

7. FIGURES

7.1 Figures

(1) Figure 1 - Maximum allowable final tissue pressures determined by tenth-power relationship (J factor) between tissue ratio and tissue pressure.

(2) Figure 2 - Maximum allowable final tissue pressures determined by a pressure-diameter relationship to ambient pressure absolute.

(3) Figure 3 - Maximum allowable final tissue pressures derived as a mean between J and pressure-diameter controls.

(4) Figure 4 - Decrease of change (S) in regular increments based on known safe tissue pressures at shallower decompression stops.

(5) Figure 5 - Maximum allowable final tissue pressures based on regular increments of decrease in change (S) for known safe tissue pressures at shallower decompression stops.

(6) Figure 6 - Pressure-volume relation to change (S) based on maximum safe tissue pressures at 33 foot stop used to determine allowable final tissue pressures.

(7) Figure 7 - Maximum allowable final tissue pressures based on pressure-volume relation to change (S) allowable at 66 feet (abs) - comparison of allowable differential (E).

(8) Figure 8 - Maximum allowable final tissue pressures determined by pressure-volume relation to change (S) based on maximum safe tissue pressures at 66 feet (abs).

(9) Figure 9 - Decrease of change (S) on basis of S/E relationship and allowable differential with change (S) becoming asymptotic at 11.

(10) Figure 10 - Maximum allowable final tissue pressures based on allowable differential (E), S/E relations ip with change (S) asymptotic at 11.

(11) Figure 11 - Maximum allowable final tissue pressures based on allowable differential (E), S/E relationship with change (S) asymptotic at 11.

(12) Figure 12 - Maximum allowable final tissue pressures based on allowable differential (E)-40 and 240 minute tissues related to 2.00:1 ratio of tissue pressure absolute to ambient pressure absolute.

8. TABLES

8.1 Table 1 - Allowable final tissue pressures at stops for each half-time tissue for test dives in this series.

(1) Table 1A - J control of final tissue pressure

(2) Table 1B - Pressure-diameter control of final tissue pressure

(3) Table 1C - Mean between J and pressure-diameter curves for control of final tissue pressures.

(4) Table 1D - Final tissue pressures based on regular increments of decrease in change (S) for known safe tissue pressures at shallower stops.

(5) Table 1E - Pressure-volume relation to change (S) based on maximum safe tissue pressures at 33 feet (guage).

(6) Table 1F - Final tissue pressures determined on basis of S/E relationship, with S becoming asymptotic at 11.

(7) Table 2 - Exposure time and decompression time at stops for the various test dives in this series.

Table 3 - Final tissue pressure in feet of nitrogen (absolute) for each half-time tissue for the various dives in this series.

(8) Table 3A - Forty minute half-time tissue

(9) Table 3B - Eighty minute half-time tissue

(10) Table 3C - One hundred twenty half-time tissue

(11) Table 3D - One hundred sixty half-time tissue

(12) Table 3E - Two hundred forty half-time tissue

(13) Table 4 - Summary of results obtained from long exposures at 140 feet.

(14) Table 5 - Table of time functions for determination of tissue pressure in 160 and 240 minute tissues during exposures up to 150 minutes.

(15) Table 6 - Navy standard air decompression table - second half.

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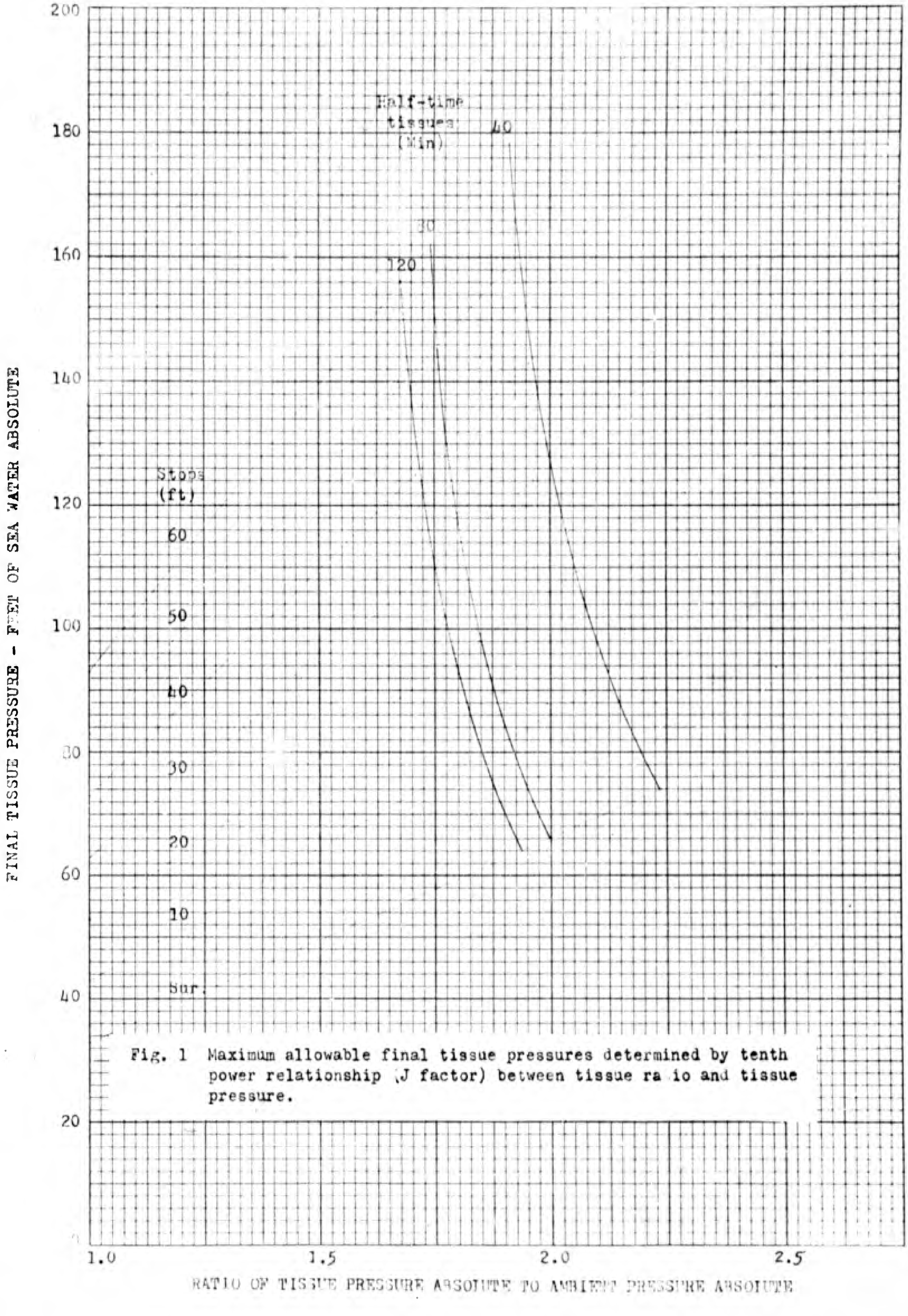

Fig. 1 Maximum allowable final tissue pressures determined by tenth power relationship (J factor) between tissue ra io and tissue pressure.

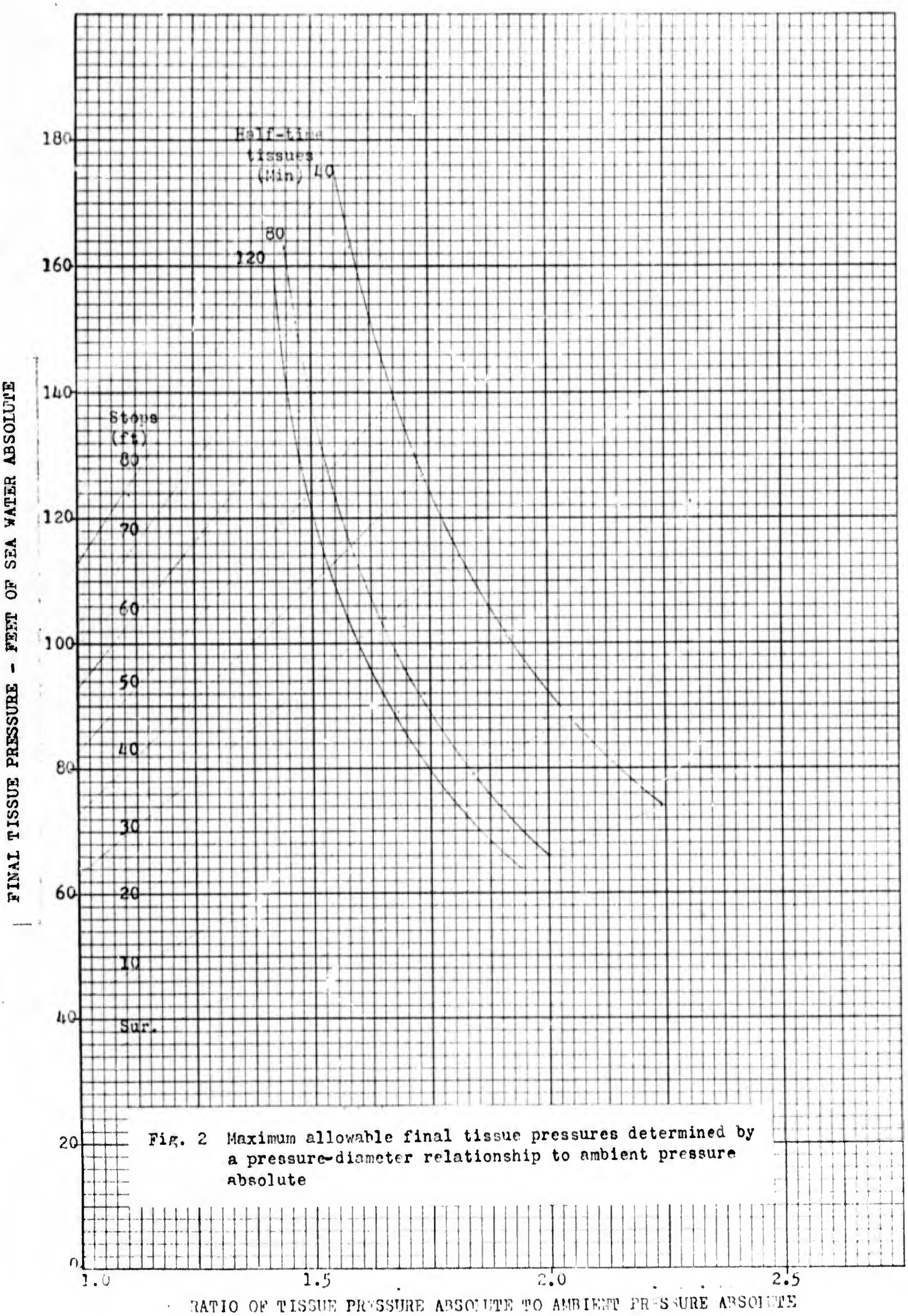

Fig. 2 Maximum allowable final tissue pressures determined by a pressure-diameter relationship to ambient pressure absolute

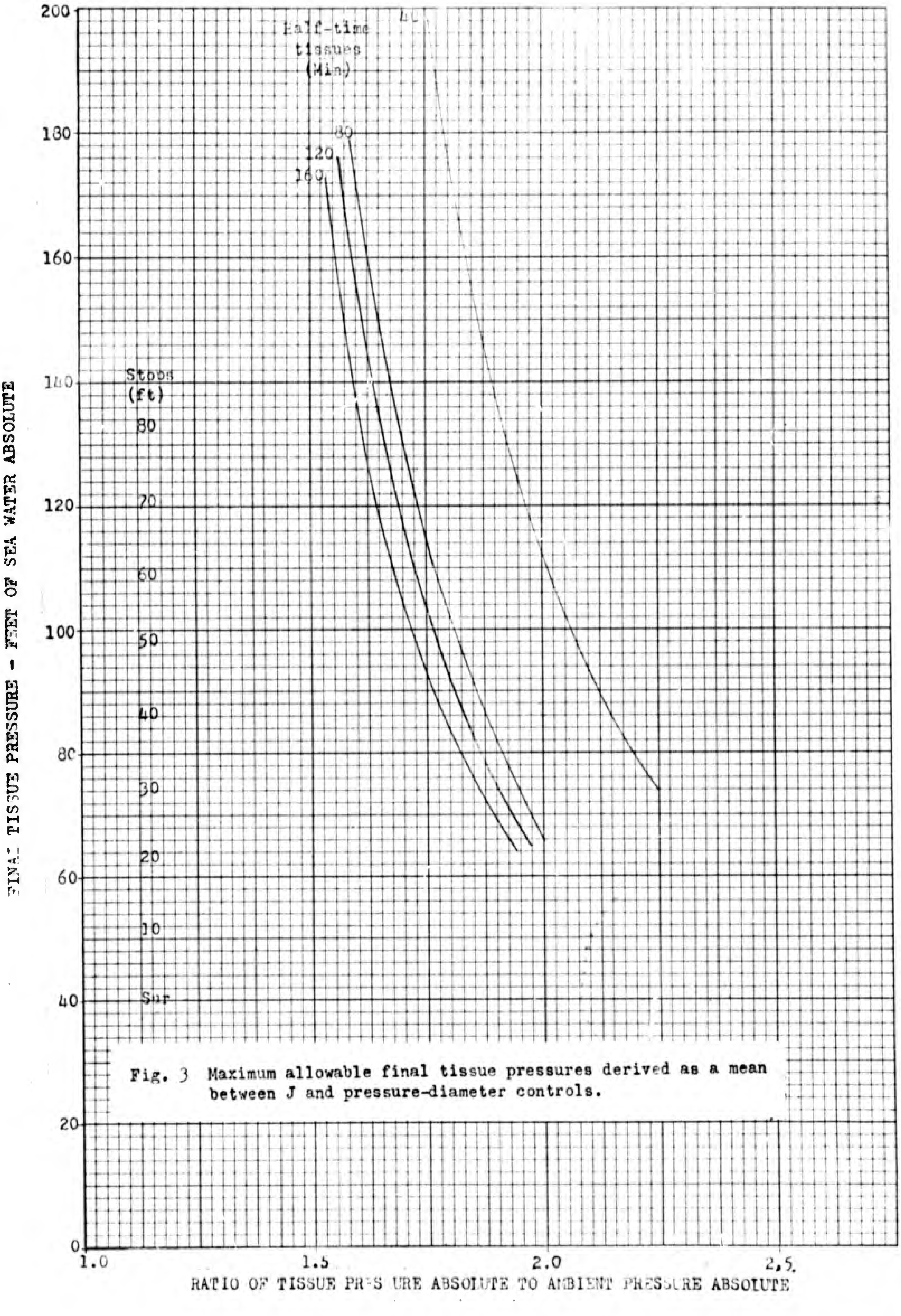

Fig. 3 Maximum allowable final tissue pressures derived as a mean between J and pressure-diameter controls.

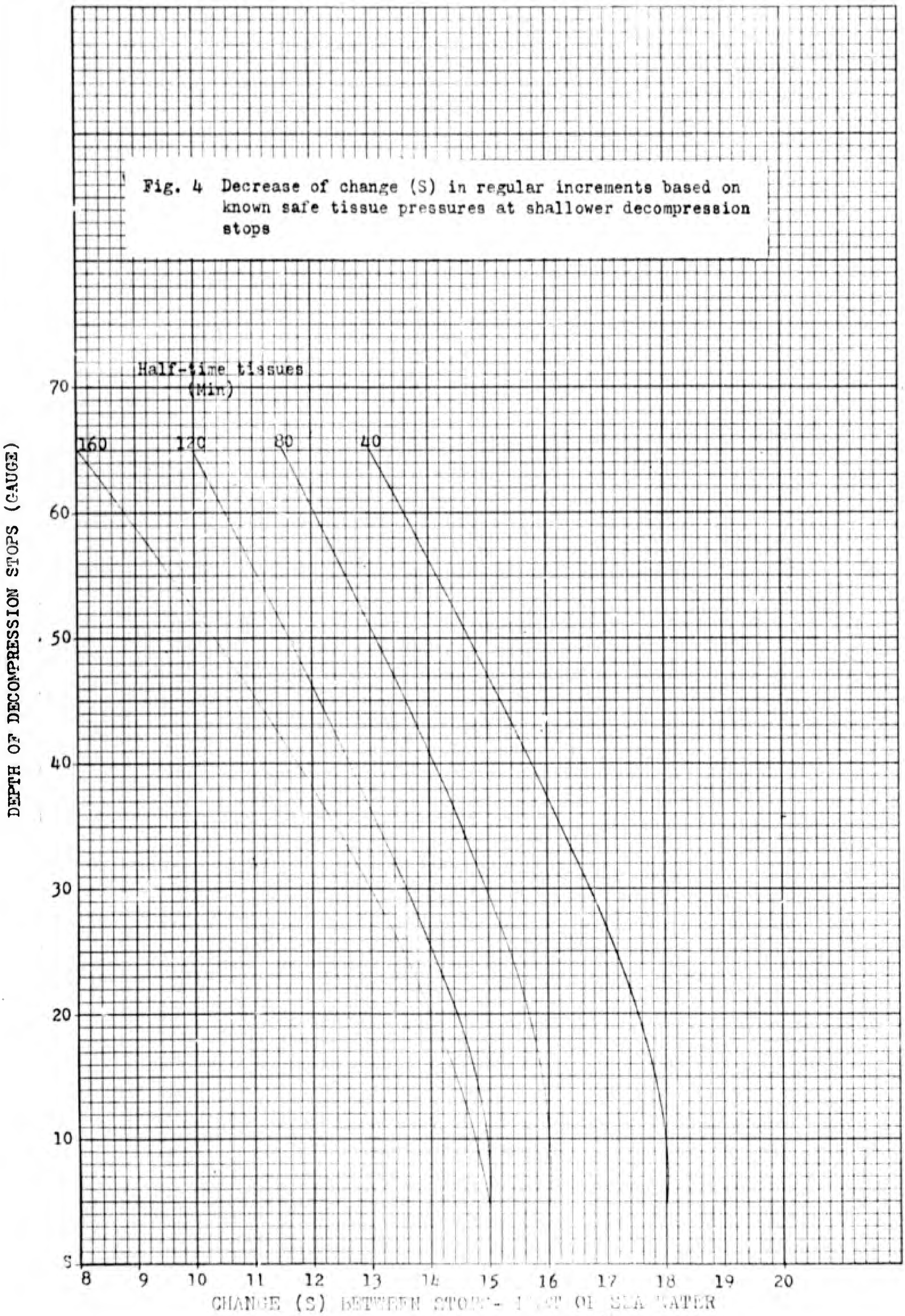

Fig. 4 Decrease of change (S) in regular increments based on known safe tissue pressures at shallower decompression stops

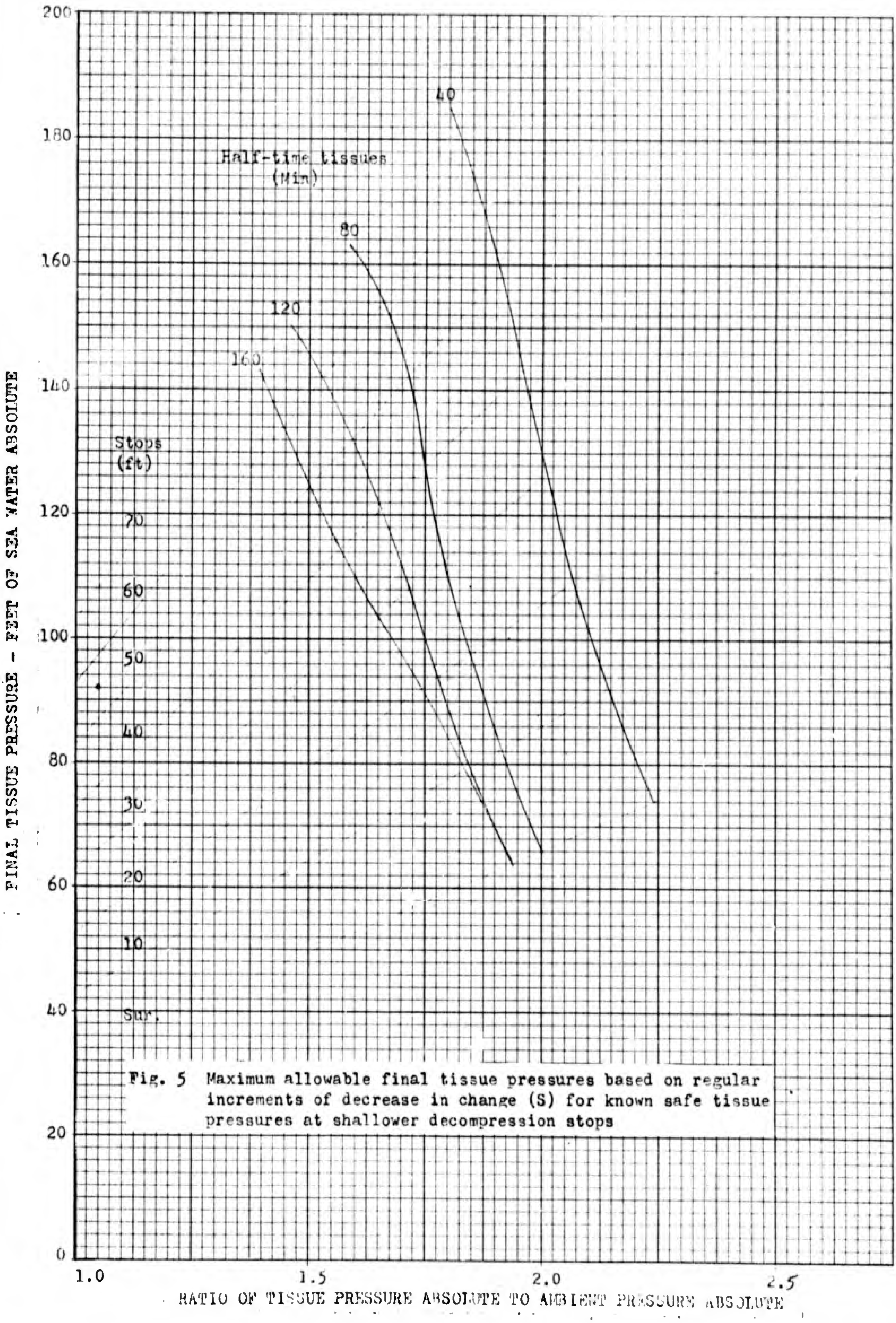

Fig. 5 Maximum allowable final tissue pressures based on regular increments of decrease in change (S) for known safe tissue pressures at shallower decompression stops

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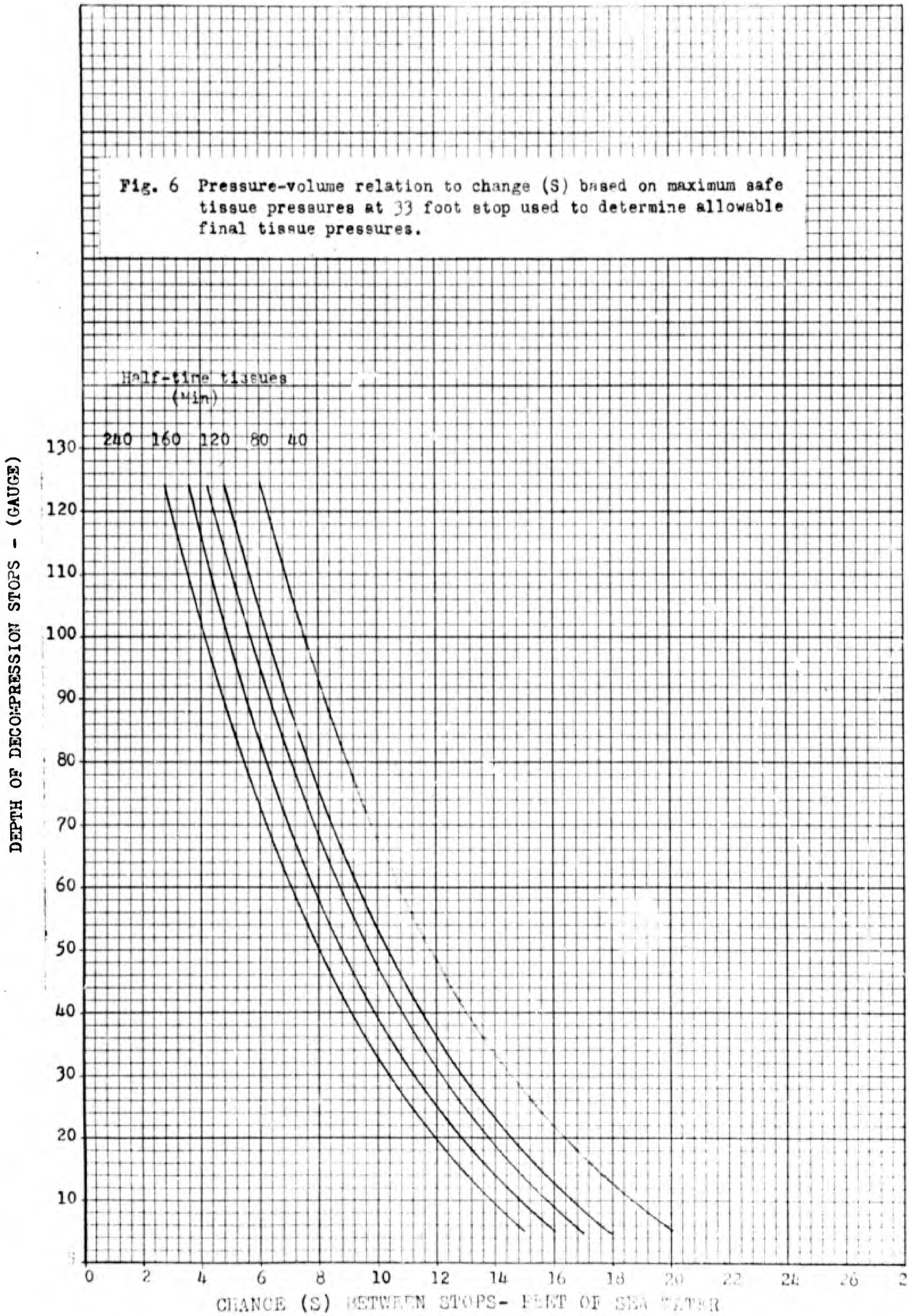
Fig. 6 Pressure-volume relation to change (S) based on maximum safe tissue pressures at 33 foot stop used to determine allowable final tissue pressures.



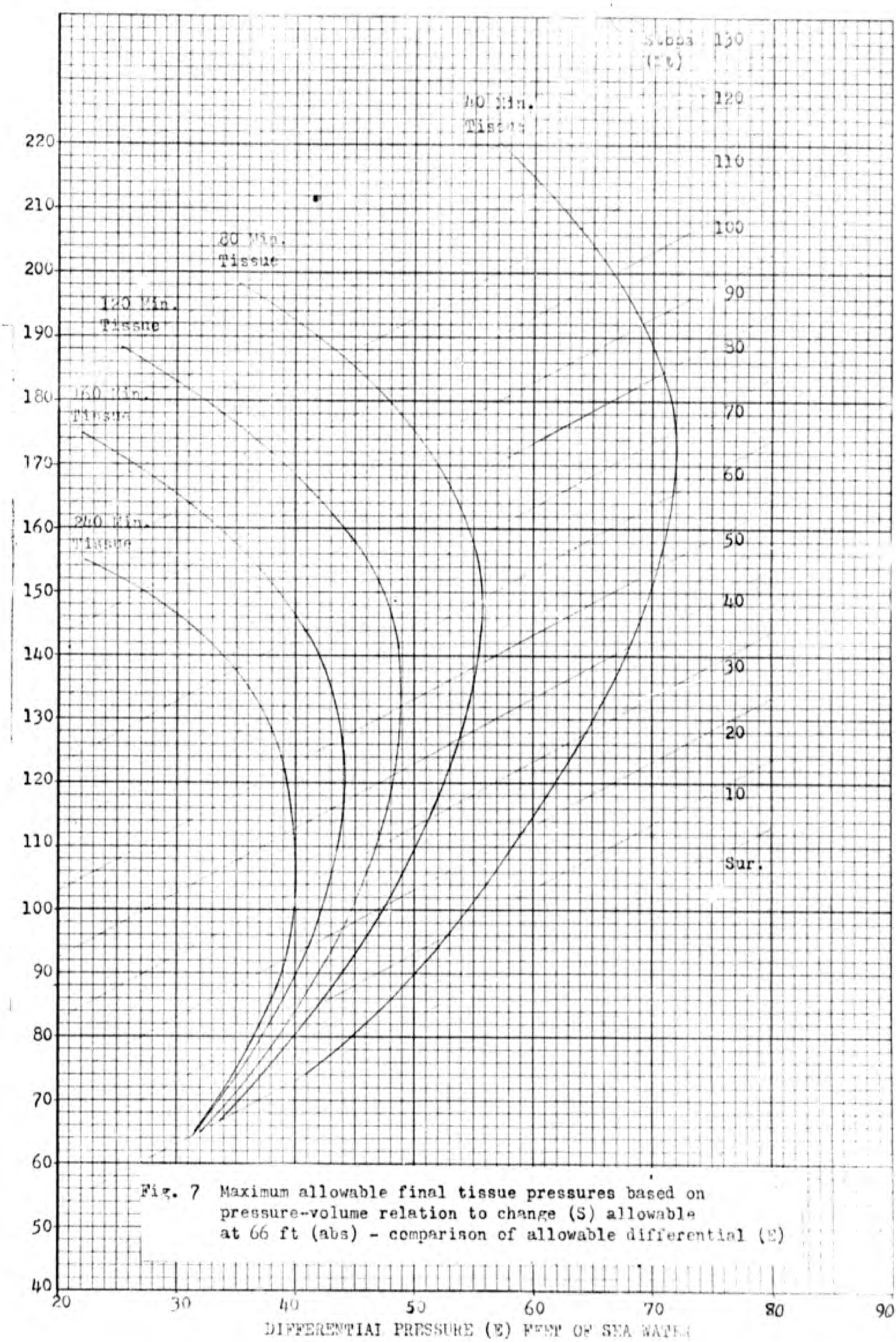


Fig. 7 Maximum allowable final tissue pressures based on pressure-volume relation to change (S) allowable at 66 ft (abs) - comparison of allowable differential (E)

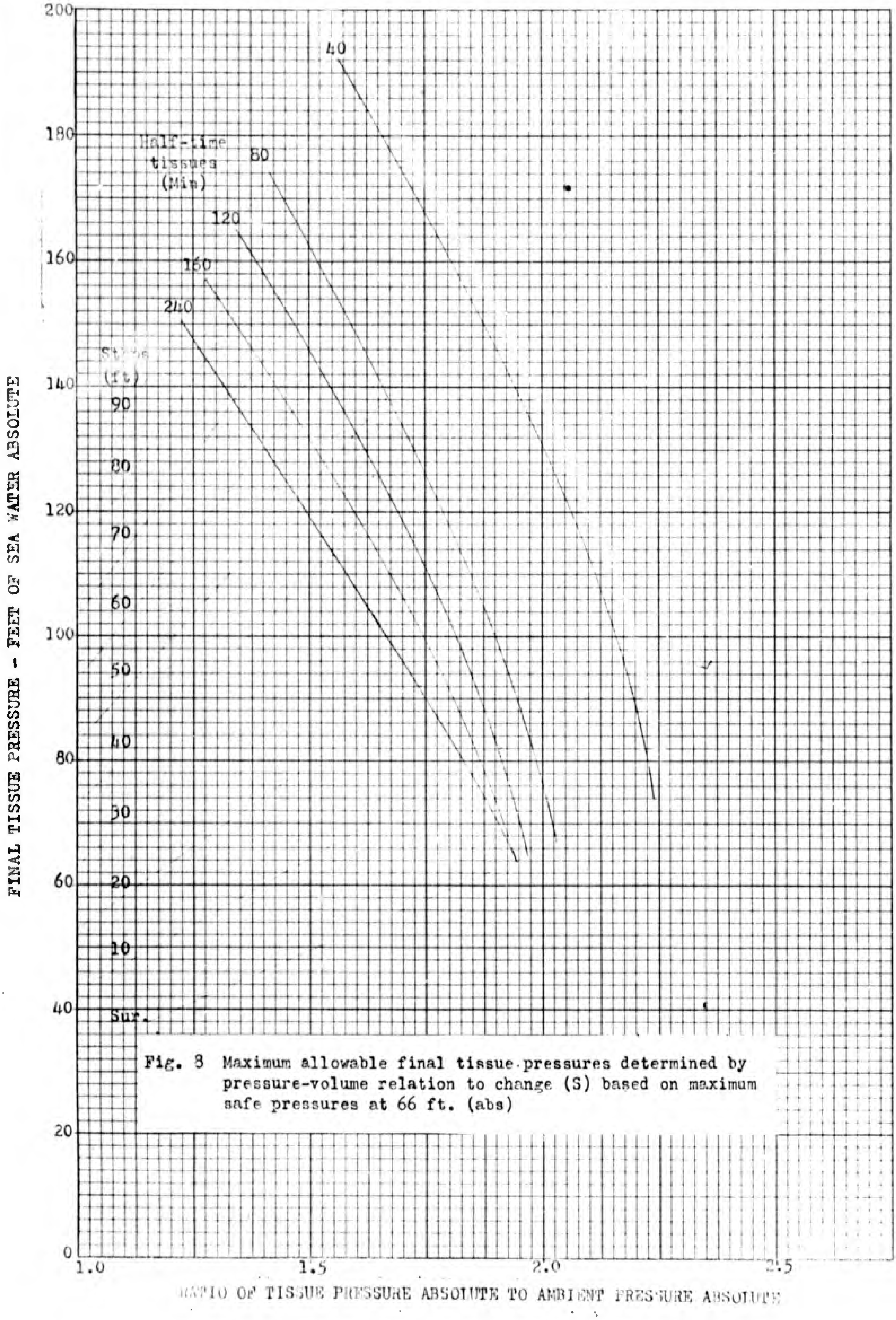


Fig. 8 Maximum allowable final tissue pressures determined by pressure-volume relation to change (S) based on maximum safe pressures at 66 ft. (abs)

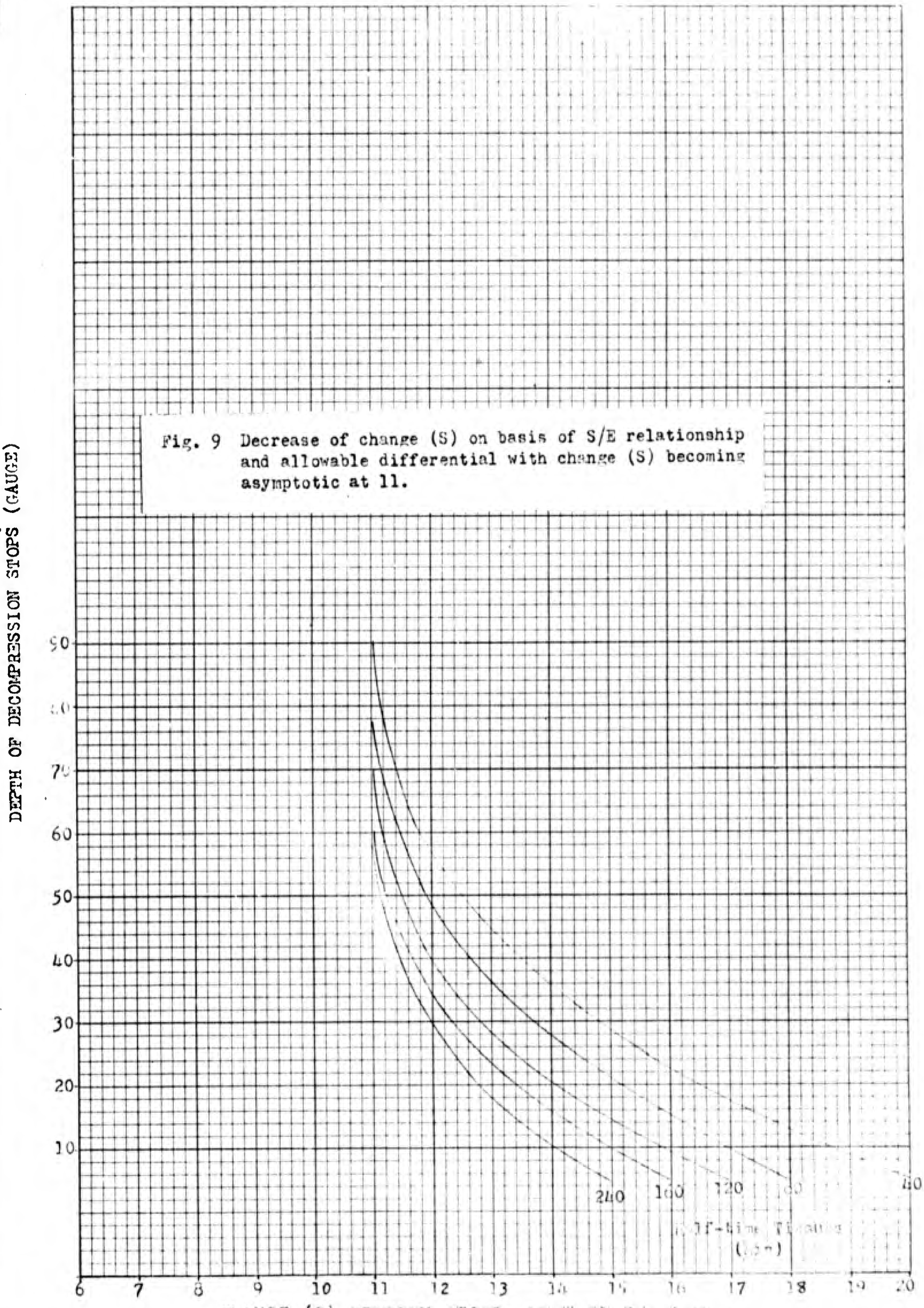


Fig. 9 Decrease of change (S) on basis of S/E relationship and allowable differential with change (S) becoming asymptotic at 11.

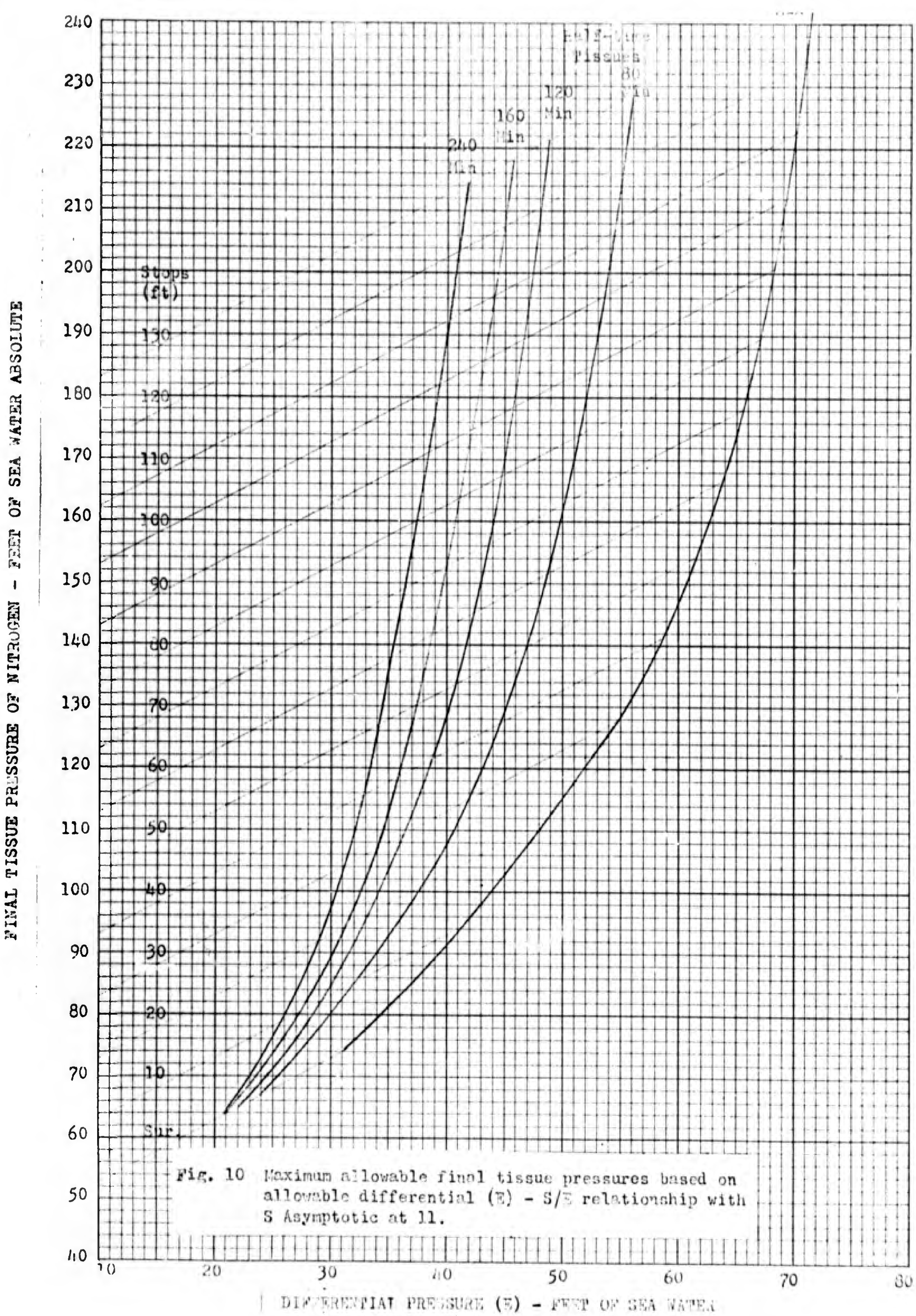


Fig. 10 Maximum allowable final tissue pressures based on allowable differential (E) - S/E relationship with S Asymptotic at 11.

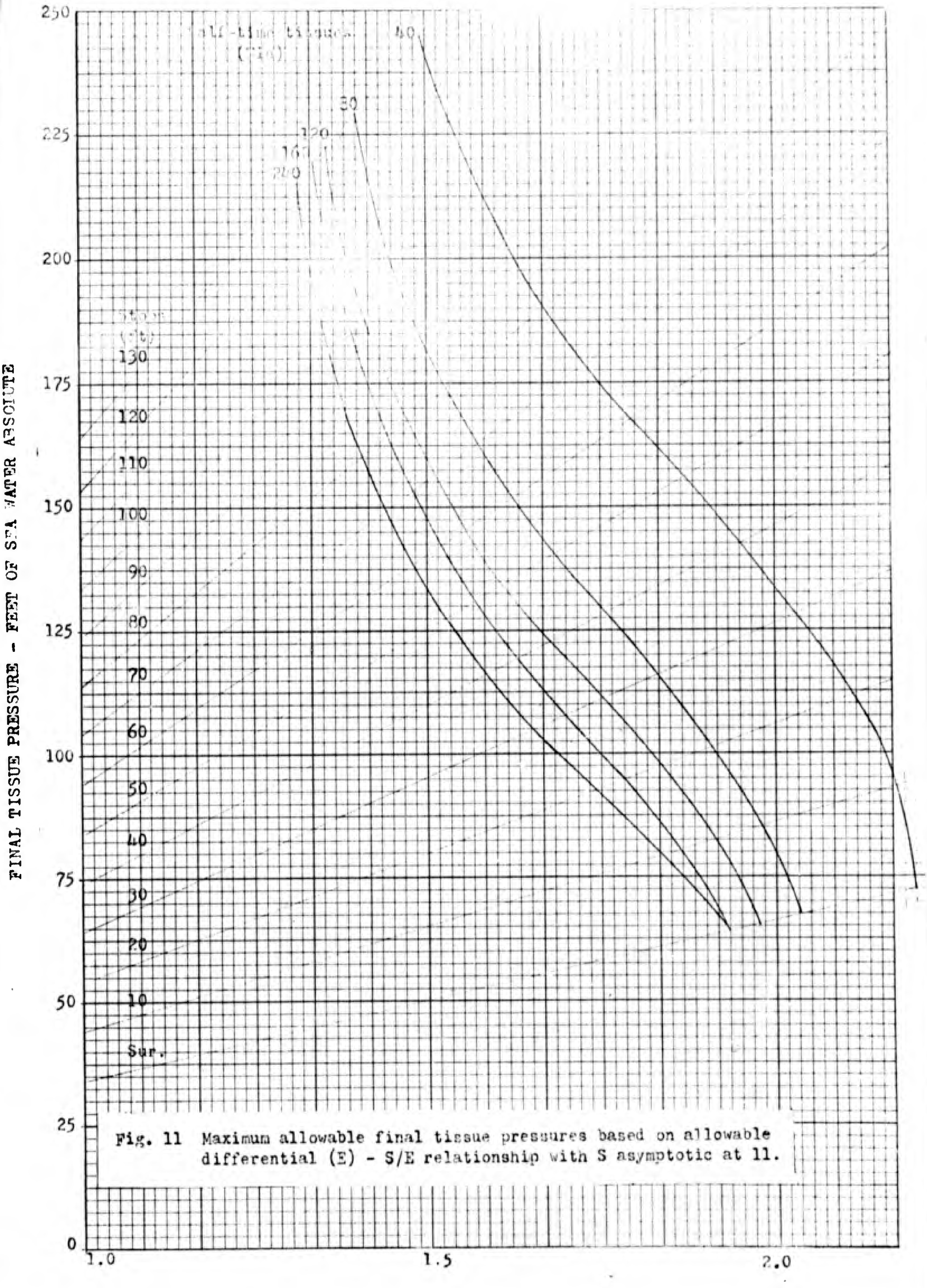


Fig. 11 Maximum allowable final tissue pressures based on allowable differential (E) - S/E relationship with S asymptotic at 11.

Fig. 12 Maximum allowable final tissue pressure based on allowable differential (E) - 40 and 240 minute tissues related to 2.00:1 ratio of tissue pressure absolute to ambient pressure absolute

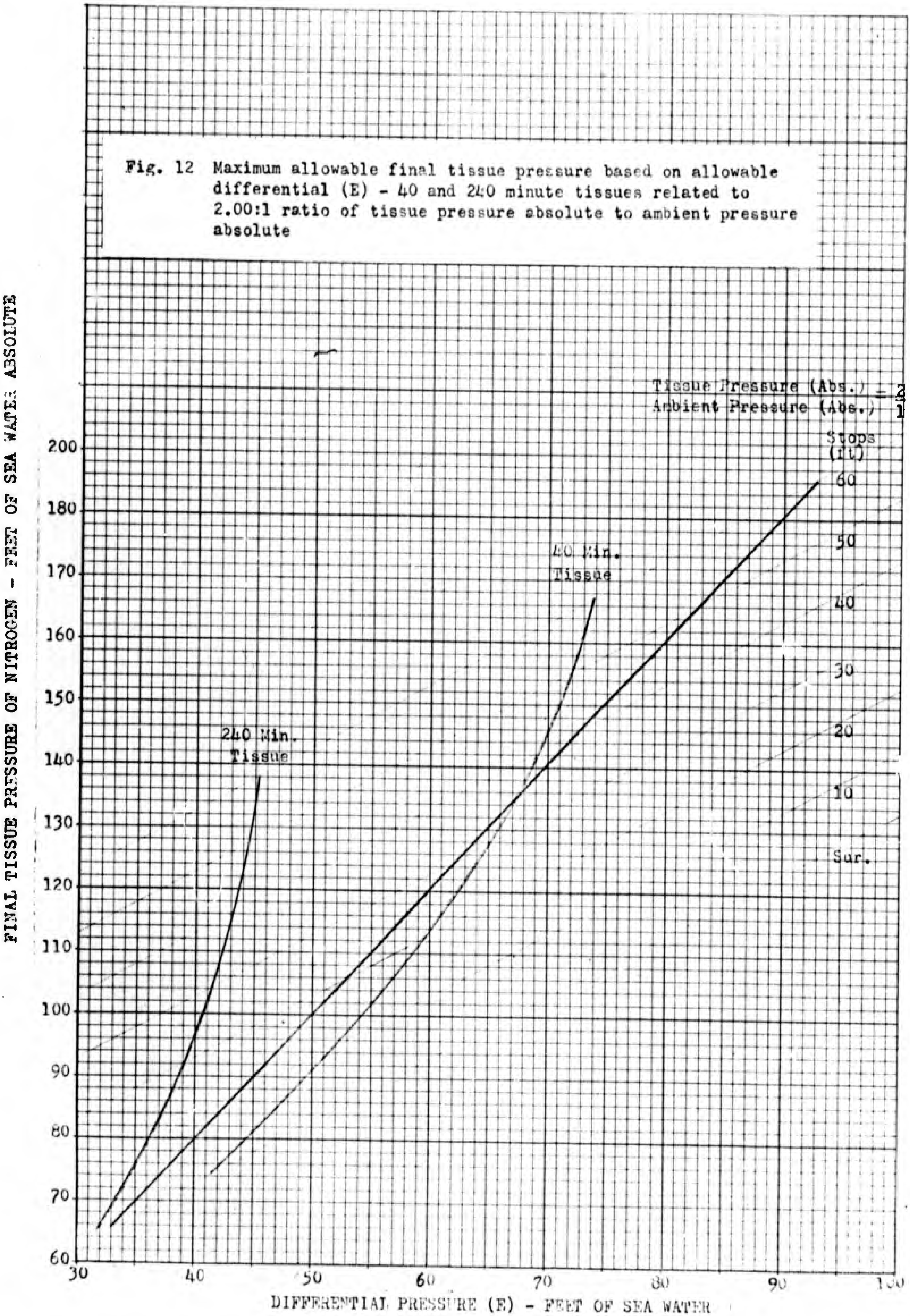


TABLE 1- Allowable final tissue pressure at decompression stops for each half-time tissue for test dives in this series

TABLE 1A- J Control of final tissue pressure *

STOPS (feet)	TISSUE HALF-TIME		
	40 Min.	80 Min.	120 Min.
70	179	162	156
60	161	146	141.5
50	143	130	125
40	126	114	111
30	110	98	95.3
20	92	82	79.5
10	74	66	64

* $Q = 33 \left[(J) + r - 1 \right]$ $J = \left(\frac{S}{r}\right) 10$

Q = Final Tissue Pressure
J = Tissue Pressure Factor
r = Depth Tissue Ratio
S = Surface Tissue Ratio

TABLE 1B- PRESSURE-DIAMETER REDUCTION OF FINAL TISSUE PRESSURE *

STOPS (feet)	TISSUE HALF-TIME			
	40 Min.	80 Min.	120 Min.	160 Min.
90	175	163	160	160
80	163	151	148	148
70	151	140	137	137
60	139	128	123	123
50	127	116	113	113
40	114	104	101	101
30	101	92	89	89
20	88	79	76	76
10	74	66	64	64

* $Qd = Es \sqrt[3]{.03 X Ad} + Ad$

Qd = Final Tissue Pressure at Decompression Stop
Es = Differential Pressure Allowable upon Surfacing
Ad = Ambient Pressure Absolute at Decompression Stop

TABLE 1C- MEAN BETWEEN J and PRESSURE-DIAMETER CURVES FOR CONTROL OF FINAL TISSUE PRESSURES

STOPS (feet)	TISSUE HALF-TIME			
	40 Min.	80 Min.	120 Min.	160 Min.
90	198	179	176	172
80	183	166	162	159
70	168	153	149	146
60	154	138	136	133
50	138	125	122	120
40	123	111	109	107
30	107	97	95	93
20	91	82	80	79
10	74	66	65	64

TABLE 1D- FINAL TISSUE PRESSURE BASED ON REGULAR INNCREMENTS OF DECREASE IN CHANGE (S) FOR KNOWN SAFE TISSUE PRESSURES AT SHALLOWER STOPS

STOPS (feet)	TISSUE HALF-TIME				
	40 Min.	80 Min.	120 Min.	160 Min.	240 Min.
80	185	164	154	143	143
70	172	153	144	134	134
60	158	141	133	124	124
50	143	127	121	114	114
40	127	113	108	104	104
30	110	98	94	92	92
20	92	82	79	79	79
10	74	66	64	64	64

Table 1 E - PRESSURE-VOLUME RELATION TO CHANGE (S) BASED ON MAXIMUM SAFE TISSUE PRESSURE AT 33 FEET (GAUGE)

STOPS (feet)	TISSUE HALF-TIME				
	40 min.	80 min.	120 min.	160 min.	240 min.
100	192	174	165	157	150
90	184	166	158	151	144
80	175	158	150	144	138
70	164	149	142	136	130
60	153	138	132	127	122
50	141	127	121	117	113
40	127	114	110	106	103
30	112	101	97	94	92
20	94	85	82	80	79
10	74	67	65	64	64

TABLE 1F- FINAL TISSUE PRESSURE DETERMINED ON BASIS OF S/E RELATIONSHIP WITH S BECOMING ASYMPTOTIC AT 11*

STOPS (feet)	TISSUE HALF-TIME				
	40 Min.	80 Min.	120 Min.	160 Min.	240 Min.
140	245	229	222	219	215
130	234	218	211	208	204
120	223	207	200	197	193
110	212	196	189	186	182
100	201	185	178	175	171
90	190	174	167	164	160
80	179	163	156	153	149
70	167	152	145	142	138
60	155	140	134	131	127
50	142	128	122	119	116
40	128	115	110	107	104
30	112	101	97	94	92
20	94	85	82	80	79
10	74	67	65	64	64

* See Figs. 9,10 and 11.

TABLE 2- Exposure time and decompression time at stops for the various test dives in this series

Depth (feet)	140	140	(1st) 140	(2nd) 140	(1st) 140	(2nd) 140	(3rd) 140	(4th) 140	(5th) 140	140
Exposure (Min)	90	120	180	180	240	240	240	240	240	360
Ascent	1.5	1.5	1.3	1.0	1.3	1.0	1.2	1.0	1.2	1.0
90										3
80				5		13		13		25
70				13		30	6	30	6	32
60			5	20	21	42	33	34	19	53
50	1	10	25	33	32	49	33	36	46	60
40	15	17	38	39	53	62	54	77	64	85
30	19	43	60	55	69	66	87	88	80	112
20	51	65	80	94	80	78	100	104	113	141
10	86	96	96	103	96	79	125	105	187	187
Total Decompression Time (Min)	174.5	232.5	305.3	363	352.3	420	439.2	488	516.2	699
Final tissue Pressure Control	J	J	J	PD	J	PD	PD-J	PD	Decrease of S	PD of S
Surfacing Control (Feet Abs)	64	64	64	66	64	64	64	64	64	64
Tissue Controlling On surfacing	120 Min	120 Min	120 Min	160 Min	120 Min	120 Min	160 Min	160 Min	240 Min	240 Min
Safe	6	6	5	5	0	2	0	0	4	5
Bends	0	0	1	1	2	2	2	2	2	1

Table 3B - Eighty minute half-time tissue

Dive	140/90	140/120	(1st) 140/180	(2nd) 140/180	(1st) 140/240	(2nd) 140/240	(3rd) 140/240	(4th) 140/240	(5th) 140/240	140/360
Exposure	108.6	123.5	143.5	143.5	155.5	155.5	155.5	155.5	155.5	167
Ascent	108.9	123.6	143.4	143.5	155.2	155.4	155.3	155.4	155.3	166.8
90										165.7
80				142.2		150.9		150.9		155.3
70				138		140	152.7	140	152.7	142.7
60			141.1	130.9	144.9	125.8	137.9	128	143.7	122.5
50	108.7	120.2	129.9	119	129.9	111	124.3	116	123.7	106.1
40	104.1	113.8	114	105.8	108.9	95.3	105.2	95.1	102.1	88.9
30	97.9	98	93.4	89.6	88.3	81.3	82.9	78	82.6	72.8
20	81.9	78.6	73.2	69.2	70.9	67.5	65.6	63.2	63.9	58.9
10	61.5	58.5	56.1	53.7	55.1	55.4	50.6	51.2	47	46.2

Table 3 - Final tissue pressure in feet of nitrogen (absolute) for each half-time tissue for the various test dives in this series.

Table 3A - Forty minute half-time tissue

DIVE	140/90	140/120	(1st) 140/180	(2nd) 140/180	(1st) 140/240	(2nd) 140/240	(3rd) 140/240	(4th) 140/240	(5th) 140/240	140/360
Exposure	144	155	167	167	170.9	170.9	170.9	170.9	170.9	173
Ascent	143.6	154	166.3	166.6	170.1	170.4	170.2	170.3	170.2	172.6
90										170.1
80				162.2		158.9		158.8		150.1
70				150.3		136.3	164.3	136.3	163.6	130
60			160.2	133.6	146.7	114	133.3	117.1	143.8	107.8
50	142.6	142.8	133.1	111.6	119.6	94.6	109.4	101.3	110.4	91.5
40	125.8	125.1	104.1	92.7	91.6	80.5	87.3	80.5	85.6	77
30	108.2	92.5	77.6	74.5	71.6	68.6	68.4	66.9	68.4	65
20	75.9	65.9	59.1	57.2	57.5	57.1	55.7	55.3	55.5	54
10	50.4	47.4	46	45.4	45.8	46.6	43.8	45	43	43.5

Table 3D - One hundred sixty minute half-time tissue

DIVE	140/90	140/120	(1st) 140/180	(2nd) 140/180	(1st) 140/240	(2nd) 140/240	(3rd) 140/240	(4th) 140/240	(5th) 140/240	140/360
Exposure	78.2	89.7	109	109	123.4	123.4	123.4	123.4	123.4	144
Ascent	78.5	89.9	109.2	109.2	123.5	123.5	123.5	123.5	123.5	144
90										143.7
80				109.3		122.9		123		140.6
70				109		120.5	123	120.6	123	135.8
60			108.9	107.7	120.9	116	119.1	116.9	120.7	127
50	78.5	89.6	106.3	104.5	116	109.7	115.4	112	113.9	117
40	78.2	88.4	101.3	99.7	107.2	101	106.6	101	104	103.5
30	77	84.1	92.6	92	95.8	91.6	93	89	92	88
20	72.3	76.5	81.3	79	83.3	80.7	79	76	77	72
10	63.2	65.2	68.3	66	69.6	69.7	64	64	58.1	55.9

Table 3 C - One hundred twenty minute half-time tissue

DIVE	140/90	140/120	(1st) 140/180	(2nd) 140/180	(1st) 140/240	(2nd) 140/240	(3rd) 140/240	(4th) 140/240	(5th) 140/240	140/360
Exposure	89.6	103	123.4	123.4	138	138	138	138	138	156
Ascent	90	103.2	123.5	123.5	138	138	138	138	138	156
90										155.5
80				123.2		136.2		136.2		149.9
70				121.8		131	137.8	131	136.8	142
60			122.7	118.7	132.9	122.9	130.1	124.3	132.3	127.6
50	90	102.1	117.4	112.5	124.5	113	122	116.6	120.8	114.3
40	88.5	99.4	108.7	104.7	110.9	101	108.9	101	106	98.3
30	85.9	91.5	95.3	93.3	95.2	89	90.7	85.9	90	81.5
20	77.5	79.5	79.5	76.5	79.4	76	74.5	71.1	72.3	65.7
10	64	64	64	61.7	63.9	63.9	58.6	58.3	52.9	50.7

TABLE 4 - SUMMARY OF RESULTS OBTAINED FROM LONG EXPOSURES AT 140 FEET

DEPTH (FT)	EXPOSURE TIME (MIN)	TRIAL NO.	HAYES	SUGLIA	PEIFER	COGGESHALL	WILEY	WILLOUGHBY	ADAMS	FISCHER	KOHL	DIMMICK	JENSEN	KIRK	DES GRANGES	TRIPP	HANGER	NORMAL O	MILD BENDS M	BENDS B
140	90	1	0	0	M	0	0	0										5	1	0
140	120	1	0	0		0	0			M	0							5	1	0
140	180	1			0			0	0			M	B	0				4	1	1
140	180	2			0			0	B				M		M	M		2	3	1
140	240	1	B				B											0	0	2
140	240	2		M		M				B	B							0	2	2
140	240	3	B				B											0	0	2
140	240	4										B					B	0	0	2
140	240	5			0		B			0	B			0			0	4	0	2
140	360	1		0		0		0					0			M	B	4	1	1
TOTAL DIVES			4	4	4	4	5	4	3	3	2	2	4	1	1	2	3	24	9	13

Table 3E - Two hundred forty minute half-time tissue

DIVE	140/90	140/120	(1st) 140/180	(2nd) 140/180	(1st) 140/240	(2nd) 140/240	(3rd) 140/240	(4th) 140/240	(5th) 140/240	140/360
Exposure	64.9	74	89.7	89.7	103	103	103	103	103	123.4
Ascent	65.1	74.2	89.8	89.8	103.1	103.1	103.1	103.1	103.1	123.5
90										123.5
80				90.1		103.4		103.4		122.1
70				90.5		103.4	103.1	103.4	103.1	120.5
60			89.8	90.6	102.5	102.2	102.2	102.5	102.6	116.6
50	65.1	74.4	89.4	89.9	100.8	99.7	100.5	100.6	100.2	111.3
40	65.5	74.4	87.7	88.1	96.9	95.4	96.6	95.1	95.7	103
30	65.4	73.1	83.8	84.5	87.4	89.8	89.2	87.9	89	92
20	62	69.7	77.5	77.1	80.3	82.4	80.2	78.9	79	79
10	57.6	63.3	69.2	68.4	71.3	74.4	69	69.5	64	64

TIME FUNCTIONS

(PERCENTAGE DECIMAL)

FOR DETERMINATION OF TISSUE PRESSURE IN 160 AND 240 MINUTE TISSUES DURING EXPOSURES UP TO 150 MINUTES

EXPOSURE TIME MINUTES	160	240		EXPOSURE TIME MINUTES	160	240
1	.004	.002		81	.296	.208
2	.009	.004		82	.299	.210
3	.013	.009		83	.302	.212
4	.017	.011		84	.305	.215
5	.022	.014		85	.308	.217
6	.025	.017		86	.310	.219
7	.030	.020		87	.313	.222
8	.034	.022		88	.317	.224
9	.037	.025		89	.319	.226
10	.042	.028		90	.323	.228
11	.045	.031		91	.325	.231
12	.050	.034		92	.328	.233
13	.055	.036		93	.332	.235
14	.059	.039		94	.334	.237
15	.063	.042		95	.337	.239
16	.067	.045		96	.340	.242
17	.071	.047		97	.342	.245
18	.074	.050		98	.346	.248
19	.078	.053		99	.348	.249
20	.084	.055		100	.352	.250
21	.087	.059		101	.355	.253
22	.090	.061		102	.357	.255
23	.094	.064		103	.359	.257
24	.099	.066		104	.363	.259
25	.102	.069		105	.365	.262
26	.107	.072		106	.368	.264
27	.110	.075		107	.371	.266
28	.114	.078		108	.374	.268
29	.118	.081		109	.377	.270
30	.122	.083		110	.379	.272
31	.125	.085		111	.381	.274
32	.129	.088		112	.384	.277
33	.132	.090		113	.386	.279
34	.137	.093		114	.390	.281
35	.141	.095		115	.392	.283
36	.144	.098		116	.395	.285
37	.148	.101		117	.398	.287
38	.151	.103		118	.400	.289
39	.154	.106		119	.403	.291
40	.159	.108		120	.405	.293
41	.162	.111		121	.407	.295
42	.166	.114		122	.411	.297
43	.169	.116		123	.413	.299
44	.173	.119		124	.416	.300
45	.177	.121		125	.418	.302
46	.180	.124		126	.421	.304
47	.184	.126		127	.424	.306
48	.188	.129		128	.426	.309
49	.192	.131		129	.428	.311
50	.195	.134		130	.431	.313
51	.198	.137		131	.433	.315
52	.201	.139		132	.436	.317
53	.205	.141		133	.438	.319
54	.208	.143		134	.440	.321
55	.211	.146		135	.443	.323
56	.215	.149		136	.445	.324
57	.218	.151		137	.447	.326
58	.222	.154		138	.450	.328
59	.226	.156		139	.452	.330
60	.229	.156		140	.455	.332
61	.233	.160		141	.457	.334
62	.235	.162		142	.459	.336
63	.238	.165		143	.462	.338
64	.242	.168		144	.464	.340
65	.244	.171		145	.466	.341
66	.248	.173		146	.469	.342
67	.251	.175		147	.471	.345
68	.255	.178		148	.474	.347
69	.259	.180		149	.476	.349
70	.262	.183		150	.478	.352
71	.264	.185				
72	.268	.187				
73	.271	.190				
74	.274	.192				
75	.276	.194				
76	.280	.197				
77	.284	.199				
78	.287	.201				
79	.289	.203				
80	.293	.206				

NAVY STANDARD AIR DECOMPRESSION TABLE
SECOND HALF

Depth (ft)	Bottom Time (min)	Time to First Stop	130	120	110	100	90	80	70	60	50	40	30	20	10	Total Ascent Time
			Decompression Stops													
40	360	0.5													23	24
	480	0.5													41	42
	720	0.5													69	70
60	240	0.7												2	79	82
	360	0.7												20	119	140
	480	0.7												44	148	193
	720	0.7												78	187	266
80	180	1.0												35	85	121
	240	0.8											6	52	120	179
	360	0.8											29	90	160	280
	480	0.8											59	107	187	354
	720	0.7										17	108	142	187	455
100	180	1.0										1	29	53	118	202
	240	1.0										14	42	84	142	283
	360	0.8									2	42	73	111	187	416
	480	0.8									21	61	91	142	187	502
	720	0.8									55	106	122	142	187	613
120	120	1.3										10	19	47	98	176
	180	1.2									5	27	37	76	137	283
	240	1.2									23	35	60	97	179	395
	360	1.0								18	45	64	93	142	187	550
	480	0.8							3	41	64	93	122	142	187	653
	720	0.8							32	74	100	114	122	142	187	772
140	90	1.5									2	14	18	42	88	166
	120	1.5									12	14	36	56	120	240
	180	1.3								10	26	32	54	94	168	386
	240	1.2							8	28	34	50	78	124	187	511
	360	1.0						9	32	42	64	84	122	142	187	683
	480	1.0						31	44	59	100	114	122	142	187	800
	720	0.8					16	56	88	97	100	114	122	142	187	923
170	90	1.6								12	12	14	34	52	120	232
	120	1.5						2	10	12	18	32	42	82	156	356
	180	1.3					4	10	22	28	34	50	78	120	187	535
	240	1.3					18	24	30	42	50	70	116	142	187	681
	360	1.2				22	34	40	52	60	98	114	122	142	187	873
	480	1.0			14	40	42	56	91	97	100	114	127	142	187	1006
200	5	3.2													1	5
	10	3.0												1	4	8
	15	2.8											1	4	10	18
	20	2.8											3	7	27	40
	25	2.8											7	14	25	49
	30	2.7										2	9	22	37	73
	40	2.5									2	8	17	23	59	112
	50	2.5									6	16	22	39	75	161
	60	2.3								2	13	17	24	51	89	199
	90	1.8					1	10	10	12	12	30	38	74	134	323
	120	1.7				6	10	10	10	24	28	40	64	98	180	472
	180	1.3		1	10	10	18	24	24	42	48	70	106	142	187	684
	240	1.3		6	20	24	24	36	42	54	68	114	122	142	187	841
	360	1.2	12	22	36	40	44	56	82	98	100	114	122	142	187	1057
210	5	3.3													1	5
	10	3.2												2	7	10
	15	3.0											1	5	13	22
	20	3.0											4	10	23	40
	25	2.8										2	7	17	27	56
	30	2.8										4	9	24	41	81
	40	2.7									4	9	19	26	63	124
	50	2.5								1	9	17	19	45	80	174
220	5	3.5													2	6
	10	3.3												2	5	11
	15	3.2											2	5	16	27
	20	3.0										1	3	11	24	43
	25	3.0										3	8	19	33	66
	30	2.8									1	7	10	23	47	91
	40	2.8									6	12	22	29	68	140
	50	2.7								3	12	17	18	51	86	190

Depth (ft)	Bottom Time (min)	Decompression Stops 160	150	140
250	120*			5
	180*	4	8	8
	240*	9	14	21

* ADDITIONAL DECOMPRESSION STOPS

Depth (ft)	Bottom Time (min)	Time to First Stop	130	120	110	100	90	80	70	60	50	40	30	20	10	Total Ascent Time
			Decompression Stops													
230	5	3.7													2	6
	10	3.3											1	2	6	13
	15	3.3											3	6	18	31
	20	3.2										2	5	12	26	49
	25	3.2										4	8	22	37	75
	30	3.0									2	8	12	23	51	99
	40	2.8								1	7	15	22	34	74	156
	50	2.8								5	14	16	24	51	69	202
240	5	3.8													2	6
	10	3.5											1	3	6	14
	15	3.5											4	6	21	35
	20	3.3										3	6	15	25	53
	25	3.2									1	4	9	24	40	82
	30	3.2									4	8	15	22	56	109
	40	3.0								3	7	17	22	39	75	166
	50	2.8							1	8	15	16	29	51	94	217
250	5	3.8												1	2	7
	10	3.7											1	4	7	16
	15	3.5										1	4	7	22	38
	20	3.5										4	7	17	27	59
	25	3.3									2	7	10	24	45	92
	30	3.3									6	7	17	23	59	116
	40	3.2								5	9	17	19	45	79	178
	60	2.7					4	10	10	10	12	22	36	64	126	297
	90	2.2		8	10	10	10	10	10	28	28	44	68	98	166	[illegible]
	120*	1.8	10	10	10	10	16	24	24	36	48	64	94	142	187	682
	180*	1.5	10	22	24	24	32	42	44	60	54	114	122	142	157	929
	240*	1.5	22	22	40	40	42	56	76	98	100	114	122	142	187	1107
260	5	4.0												1	2	7
	10	3.8											2	4	9	19
	15	3.7										2	4	10	22	42
	20	3.5									1	4	7	20	31	67
	25	3.5									3	8	11	23	50	99
	30	3.3								2	6	8	19	26	61	125
	40	3.2							1	6	11	16	19	49	84	190
270	5	4.2												1	3	9
	10	4.0											2	5	11	22
	15	3.8										3	4	11	24	46
	20	3.7									2	3	9	21	35	74
	25	3.5								2	3	8	13	23	53	106
	30	3.5								3	6	12	22	27	64	138
	40	3.3							5	6	11	17	22	51	88	204
280	5	4.3												2	2	9
	10	4.0										1	2	5	13	25
	15	3.8									1	3	4	11	26	49
	20	3.8									3	4	8	23	39	81
	25	3.7								2	5	7	16	23	56	113
	30	3.5							1	3	7	13	22	30	70	150
	40	3.3						1	6	6	13	17	27	51	93	218
290	5	4.5												2	3	10
	10	4.2										1	3	5	16	30
	15	4.0									1	3	6	12	26	52
	20	4.0									3	7	9	23	43	89
	25	3.8								3	5	8	17	23	60	120
	30	3.7							1	5	6	16	22	36	72	162
	40	3.5						3	5	7	15	16	32	51	95	264
300	5	4.7												3	3	11
	10	4.3										1	3	6	17	32
	15	4.2									2	3	6	15	26	56
	20	4.0								2	3	7	10	23	47	104
	25	3.8							1	3	6	8	19	26	61	126
	30	3.8							2	5	7	17	22	39	75	171
	40	2.7						4	6	9	15	17	34	51	90	234
	60	3.0		4	10	10	10	10	10	14	28	32	50	90	187	458
	90*	2.3	10	10	10	10	16	24	24	34	48	64	90	142	187	691
	120*	2.0	10	14	24	24	24	34	42	58	66	102	122	142	187	887
	180*	1.7	21	28	40	40	48	56	82	98	100	114	122	142	187	1165

Depth (ft)	Bottom Time (min)	Decompression Stops 200	190	180	170	160	150	140
300	90*					3	8	8
	120*			4	8	8	8	8
	180*	6	8	8	8	14	20	21

* ADDITIONAL DECOMPRESSION STOPS

Table 6