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# DEVELOPMENT OF THE DCIEM 1983 DECOMPRESSION MODEL FOR COMPRESSED AIR DIVIMG


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## ABSTRACT

The Kidd-Stubbs (KS) decompression computer model has been used at DCIEM for a considerable number of years to control experimental, operational, and training dives. Although the KS model has been successful with a low incidence of decompression sickness, several problems exist. These include overly conservative no-decompression limits and conservative decompression times for short exposures. As the bottom times increase, the decompression times become less conservative and the decompression stress increases. A critical study of the model, using the Doppler ultrasonic bubble detector, showed that there was a range of bottom times in which the decompression stress was severe with a high risk of decompression sickness. Beyond this range of bottom times, the KS model once again became excessively conservative. In order to improve the safety of the KS model and to satisfy Canadian Forces requirements for compressed air diving, the Kidd-Stubbs model was modified to increase the no-decompression limit, decrease the decompression requirements for moderate exposures, increase the decompression times for severe exposures and remove the anomaly of the excessively long and unnecessary decompression times caused by the third and fourth compartments of the model.

The modified model, referred to as the DCIEM 1983 Air Decompression Model, has been used to generate standard air decompression tables, in-water oxygen decompression tables, and surface decompression using oxygen tables. Experiments have proven these tables safer than those derived from the Kidd-Stubbs model and they are recommended to become the Standard Canadian Forces Decompression Tables for compressed air diving.

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# INTRODUCTION

Decompression computers (1) have been used for many years at the Defence and Civil Institute of Environmental Medicine (DCIEM) to control compressed air dives. These dives have included experimental, training, and operational dives to depths as great as 100 metres of seawater (msw). Real-time dive control by computer is useful since the diver's actual depth is used to calculate the optimum ascent profile. For repetitive or non-standard dives (where the bottom depth and the descent or ascent rates do not remain constant), decompression computers produce far more efficient ascent profiles than those obtained from dive tables. The DCIEM decompression computer is based on the Kidd-Stubbs (KS) pneumatic analogue decompression computer (PADC) (2,3). The PADC was a pneumatic-mechanical analogue of the human body, in which the gas uptake and elimination were simulated by a series of cavities and flow resistances. The latest DCIEM developed decompression computer is the XDC-2 (1), a digital micro-computer which calculates numerically the gas uptake and elimination from the mathematical model of the PADC (4) which is known as the KS-1971 decompression model (5).

Although the KS-1971 model has been successfully used for many years with a low incidence of decompression sickness (DCS), it has several faults. One of these, the conservative nature of the no-decompression limits, is well known. Others, however, only became evident after a critical study of the model with the XDC-2 computer was undertaken (6,7) using the Doppler ultrasonic bubble detector to assess the severity of the decompression stress. This study revealed that there was a range of bottom times in which the decompression stress was severe enough to present a high risk of DCS. These limitations and other problems of the KS model will be discussed in more detail in the next section.

Because of the problems inherent in the KS-1971 model, it was felt that changes in the model were necessary to improve the safety of Canadian Forces compressed air diving. This report describes the modifications to the KS model and the development of the DCIEM 1983 model.

## BACKGROUND

### 1. History of the DCIEM Decompression Computer

The DCIEM decompression computer is the result of a program started in 1962 by D.J. Kidd and R.A. Stubbs (2-4,8). Their aim was to develop an instrument which would monitor the diver's depth-time history and provide instantaneous decompression information for oxygen-helium diving when complicated dive profiles and wide variations of gas mixtures would make the traditional tabular approach to decompression inadequate. Because excellent data were available for air dives, the concept of computer-controlled decompression was first applied to diving with compressed air.

Initial versions of the computer were pneumatic-mechanical analogue computers. Cavities or volumes into which gas could enter at a controlled rate were used to simulate the different types of tissues in the human body. Early prototypes of the PADC were based on the U.S. Navy Air Tables and consisted of four compartments in parallel. A series of modifications were made to half-times, supersaturation ratios and compartment configurations in order to increase the safety for a wide variety of single and multiple dives.

The diver portable Mark VS PADC, developed in 1965, and the surface-based Mark VIS PADC computers, developed in 1966, were the forerunners of the present day computer. These consisted of four compartments in a series arrangement with the same fixed supersaturation ratio on each compartment.

The operation of the PADC was described by the following set of four nonlinear differential equations (3):

$$dP_1/dt = A((B + P_0 + P_1)(P_0 - P_1) - (B + P_1 + P_2)(P_1 - P_2)) \quad (1)$$
$$dP_2/dt = A((B + P_1 + P_2)(P_1 - P_2) - (B + P_2 + P_3)(P_2 - P_3)) \quad (2)$$
$$dP_3/dt = A((B + P_2 + P_3)(P_2 - P_3) - (B + P_3 + P_4)(P_3 - P_4)) \quad (3)$$
$$dP_4/dt = A(B + P_3 + P_4)(P_3 - P_4) \quad (4)$$

where: $P_i$ = the pressure in compartment i,
$P_0$ = the ambient pressure,
$A$ = 0.0002596, gas flow constant (air, P in msw), and
$B$ = 83.67, gas flow constant (air, P in msw).

The safe ascent depth, SAD, was determined by:

$$SAD = P_t/1.8 - P_{s1}, \quad (5)$$

where $P_t$ is the largest of the four compartments pressures and $P_{s1}$ is the pressure at sea level (10.06 msw). This equation was the same for all four compartments. (All pressures in equations 1-5 are expressed as absolute gas pressures, not inert gas partial pressures).

Equations 1-4 describe the gas flow through pneumatic resistors (consisting of micropores) into and out of the four compartments which make up the PADC. (This gas flow is in the "slip-flow" regime). The flow constant "B" makes the uptake and elimination of gas nonlinear with pressure and introduces an asymmetry between uptake and elimination, with the uptake being more rapid than elimination. Thus, the equations describe the operation of a piece of hardware which is able to predict the safe decompression from a wide variety of dives rather than describing a physiological model for decompression.

However, there was some physiological basis for this nonlinear series model. Kidd and Stubbs (2) felt that, physiologically, the transfer of gas between the lungs and remote tissues could be visualized more as a series or series-parallel system of diffusion gradients rather than the traditional parallel configuration of diffusion compartments. They further argued that the transfer of gas throughout the body's tissues was a linear process only under special conditions (9). The series configuration is, in the limit, an approximation of a distributed system or continuous "slab" of tissue. Hennessy (10) has shown that the equations for the pneumatic computer are essentially an approximation of the bulk-diffusion equation into a slab of material where the diffusion coefficient is a linear function of pressure. In addition, there was physiological evidence from animal experimentation to suggest that the uptake and elimination of inert gas were asymmetrical, with the rate of uptake being faster than elimination (11).

In 1970, it was discovered that hyperbaric chamber operators were not following the computed SAD but were staying deeper by as much as 3 msw because of an inherent distrust in the safety of the PADC for deep dives. This distrust appeared to be justified when dives done in the period June 1970 - February 1971 by following the SAD exactly resulted in a 20% incidence of DCS in the 60 to 91.5 msw depth range. The DCS incidence in the period December 1968 - May 1970 was only 3.6% for the same depth range. An analysis by Stubbs resulted in an equation for the SAD of the form:

$$SAD = P_t/R - OFF - P_{s1} \qquad (6)$$

The two values, R = 1.385 and OFF = 3.018, gave a good fit to the SAD actually being used by the hyperbaric chamber operators.

The effect of the offset constant, OFF, was to make the supersaturation ratio depth-dependent, with the ratio becoming more conservative with increasing depth. The supersaturation ratio, "SR", can be obtained from Equation 6 as:

$$SR = P_t/(SAD + P_{s1}) = R/(1 - (R \times OFF)/P_t). \qquad (7)$$

The surfacing ratio, given by

$$SR_o = P_t/P_{s1} \text{ (i.e., for SAD = 0)}, \qquad (8)$$

was still the same as the original ratio (i.e. 1.8), so that shallow or short dives were not affected greatly. For deeper and longer dives, the depth-dependent ratio had the effect of introducing deeper decompression stops.

Equations 1-4 and 6 define the KS-1971 decompression model. Appendix I gives sample standard air decompression tables calculated from these equations and Figure 1 provides a simple comparison of these tables to the USN Standard Air Tables (12) and RN Tables 11/12 (13).

During the 1970's, a large number of dives was performed using the PADC, primarily on compressed air. (Some dives were also conducted on a 20%-$O_2$/80%-He breathing mixture and, to a limited extent, on a 20%-$O_2$/80%-argon breathing mixture.) These dives included both single and repetitive dives. Both pneumatic-mechanical and pneumatic-electronic versions of the PADC were used. In most dives, the decompression was carried out on a continuous basis with the actual depth being kept the same as the computed SAD until the surface was reached. In practice, however, the actual depth tended to lag behind the SAD by a foot (of seawater) or more, making the actual profile somewhat more conservative than the calculated decompression profile.

In the late 1970's, the PADC was replaced by the microprocessor-controlled XDC-2 digital decompression monitor (1). The advantage of the digital computer was that the extensive calibration and maintenance procedures for each compartment of the PADC were no longer necessary. The only calibration required was for the depth transducer. In addition, the use of digital displays made it possible for the chamber operator to follow the displayed SAD exactly during decompression.

## 2. Limitations of the KS-1971 Model

Although thousands of dives based on the KS decompression model have been conducted successfully, two major problems were apparent. First, the no-decompression limits were extremely conservative. Figure 2 shows a comparison of the KS no-decompression limits with those from the U.S. Navy Standard Air Decompression Table (12) and the Royal Navy Table 11 Air Table (13). Also shown in Figure 2 is a set of three no-decompression isostress curves (curves of constant decompression stress) which define the no-decompression limits for low, moderate, and high decompression stress. These curves were determined using the Doppler ultrasonic bubble detector in a study carried out in 1980 on no-decompression limits (14). No-decompression isostress curve 2 (IS(NoD)-2) represents a good limiting line for hardworking well-acclimatized divers. Young, fit and well acclimatized divers could probably dive to IS(NoD)-3 for light, working dives, although there is some element of risk at the deeper depths. IS(NoD)-1 represents the limit for the "less than average" diver who may not be young or exceptionally fit or well-acclimatized. It can be seen that the KS no-decompression limits are less than IS(NoD)-1.

For some depths, it can be seen that the no-decompression limits are less than half of those specified by the other tables. As a result, there is a range of bottom times in which decompression is required with the computer but not with the other tables. This can be clearly seen in Figure 1 which gives a comparison of the KS decompression times with those of the Royal Navy and US Navy air tables for selected depths.

The second problem was an anomaly introduced by the third and fourth compartments of the KS model. When these became the controlling compartments for determining the safe ascent depth, the decompression times became excessively long. For example, it can be seen in Appendix I that the decompression time required for a 70 min exposure time at 36 msw is over twice that required for a 60 min bottom time at that depth. Figure 1 shows that in all cases, the decompression times become excessively long at long bottom times, and are considerably longer than those for the RN and USN tables.

In 1979, a critical study was undertaken to evaluate the XDC-2 for operational diving. The objectives were to determine if the SAD as displayed could be followed exactly for safe decompression, and to define the operational limits of the model for compressed air diving (6,7). In these dives, the decompression was carried out on a continuous basis by keeping the actual depth equal to the calculated SAD until 3 msw. The depth was held at 3 msw until the computer indicated that it was safe to surface. This procedure was used because it would be impossible to control the depth accurately at shallow depths when diving in the ocean. The Doppler ultrasonic bubble detector was used to assist in the assessment of the decompression stress.

This study resulted in the establishment of another set of three isostress curves (curves of constant decompression stress) (15) which defined regions of "mild to moderate" (isostress curve 1 (IS-1)), "moderate to severe" (IS-2), and "severe" decompression stress (IS-3) for "average" divers decompressed with the KS-1971 model. At IS-3, there was a definite risk of DCS. "Above average" or well-acclimatized divers could expect mild to moderate stress at curve 2 and moderate to severe stress at curve 3. These isostress limits are shown in parentheses in Appendix I besides the appropriate bottom times and in Figure 1.

Many of the dives in the past had been performed for bottom times less than the IS-3 limit where the incidence of bends was low. Some dives, mostly in the 60 to 91.5 msw range had been done for bottom times in which the fourth compartment was controlling and which resulted in long decompression times and generally safe decompressions. Very little diving had been done near the IS-3 limit. The importance of this study was that it identified a range of bottom times, previously unrecognized, in which there was a high risk of DCS and which imposed a limit on operational diving with the computer. Figure 1 shows that in this range of bottom times, the KS decompression times are close to or less than those of the RN or USN tables.

In 1982, decompression procedures for using oxygen in the water (In-water $O_2$) and surface decompression using oxygen (SurD $O_2$) in a recompression chamber (RCC), based on the KS-1971 model, were developed and evaluated (16). These experiments showed that both procedures were very effective in reducing the decompression times and the decompression stress and that the XDC-2 could be used for "real-time" computer control of $O_2$ decompression. However, the inherent problems of the KS-1971 model remained.

3. Objectives for Modifying the KS-1971 Model

To overcome the problems and anomalies in the KS-1971 model, a modification of the model was undertaken using the following criteria:

a. increase the no-decompression limit to approximate those of the Royal Navy Table 11 limits (13);

b. decrease the decompression requirements for moderate exposures (short bottom time dives) where the decompression times are known to be conservative;

c. increase the decompression times for severe exposures in the IS-3 region to reduce the decompression stress; and

d. remove the anomaly of the excessively long and unnecessary decompression times caused by the onset of the third and fourth compartments as controlling compartments.

An additional criterion was to make the modifications simple and not change the KS model too drastically so that the XDC-2 decompression computer could be easily reprogrammed to accommodate these changes. Also, a drastic change in the basic model would invalidate the large data base developed over the years at DCIEM and would require extensive testing which would be prohibitive in terms of time and manpower requirements.

## METHODS

### 1. The Kidd-Stubbs Decompression Model

The KS-1971 model, as defined by equations 1-4 and 6, consists of only four constants which define the entire model - the two gas constants "A" and "B", and the two supersaturation constants "R" and "OFF" (Equation 1-4, 6). These four constants are identical for each compartment. Several approaches can be taken to modify the model in order to meet the five main criteria described previously.

One approach is to change all or some of the four constants. These four constants could also be made different for each compartment, thus giving 16 variable parameters. However, it is not necessary, or desirable, to go to this complexity. For example, Kidd, Stubbs and Weaver (9) have shown that it is possible to obtain a close match to the Workman M-value system (17) (which uses 27 parameters) with only 5 parameters.

The relationship between "A" and "B" can be seen from the half-time equation for a single compartment:

$$T(1/2) = (\ln ( 2 - \Delta P/(B + P_i + P_f)))/(A(B + 2P_f)), \qquad (9)$$

where:

$P_i$ is the initial pressure,
$P_f$ is the final pressure, and
$\Delta P = P_f - P_i$.

The constant "B" controls the nonlinearity of the gas uptake and elimination. The half-time is dependent on the pressure interval $\Delta P$ over which the measurement is made. Therefore, for gas uptake, $P_f > P_i$, the half-time is shorter than for gas elimination, $P_i > P_f$ (i.e. uptake is faster than elimination). Increasing "B" will reduce the nonlinearity and reduce the asymmetry between the uptake and elimination. To keep the half-time of the system similar to that of the KS model, "A" will then have to be made smaller. Note that if $B >> P_i + P_f$, the half-time equation becomes the same as that for linear uptake and elimination, i.e.:

$$T(1/2) = (\ln 2)/k, \qquad (10)$$

where k is a constant.

Any changes, however, even to only one compartment, affect the behaviour of all the compartments and will require changes to "R" and "OFF" to obtain the required behaviour. The problem with this approach is that it is difficult to make the required changes and still retain the desirable features of the KS model without a great deal of trial and error effort.

A simpler and more direct approach is to change only the two constants "R" and "OFF". For example, to increase the no-decompression limits and reduce the decompression times for short exposures, the first compartment supersaturation ratio needs to be made less conservative. To increase the decompression times for longer exposures, the ratios for the second to fourth compartments can be made more conservative. There is still a "downstream" effect with any first compartment changes affecting what happens to the second, third, and fourth compartments. However, the reverse is not true. Changes in the second or higher compartment will not affect the properties of the first compartment. Thus, the interaction problem between compartments is easier to deal with. This was the approach finally selected to meet the first three criteria for the new model.

To meet the fourth criterion for reducing the long decompression times when the third and fourth compartments become the controlling compartments, it is necessary to understand the reason for the long decompression times. The long decompression times for extended bottom times are a result of the model being limited to four compartments. Hennessy (10) has estimated that at least 8 compartments should be used to obtain an accurate fit to the bulk diffusion equation. For the long bottom time dives, the fourth compartment saturates faster than in a model in which there are more compartments. Hence, during decompression, more gas has to be eliminated, thus resulting in the "long tail" to the decompression. As a first step, it is therefore necessary to investigate the behaviour with more than four compartments.

## 2. Approach to Changing the KS-1971 Model

An analysis of the KS-1971 model showed that the first compartment controlled the decompression for all bottom times up to IS-2. Compartment 2 then controlled the decompression from IS-2 to bottom times about 20% greater than those at IS-3. The third compartment controlled for only a short time before the fourth compartment took over, thus resulting in the long "tail".

Between the no-decompression limits and IS-1, which defines the region of "mild to moderate" decompression stress, the decompression requirements had to be reduced by increasing the supersaturation ratio for the first compartment only. Between IS-1 and IS-2, the decompression stress increases from "mild to moderate" to "moderate to severe". In this region, the decompression requirements had to be increased slightly to keep the stress at IS-2 "moderate". Between IS-2 and IS-3, where the second compartment is dominant, the decompression stress becomes severe. Hence, the supersaturation ratio for the second compartment had to be reduced to give slightly longer decompression times. Reducing the supersaturation ratio for the second compartment would also shift where the second compartment is controlling towards IS-1, thus, increasing the decompression requirements below IS-2.

Based on the above considerations, the modifications to meet the criteria for the new decompression model could be achieved in three stages:

a. First Compartment

Increase no-decompression limits and reduce decompression requirements for short exposures (up to approximately IS-1);

b. Second Compartment

Increase the safety for moderate and long exposures (from between IS-1 and IS-2 to beyond IS-3); and

c. Third/Fourth Compartments

Eliminate the long "tail" in the decompression.

## RESULTS

### 1. The DCIEM 1983 Model

#### a. First Compartment

The no-decompression limits are determined by the surfacing ratio of the first compartment only. For the first compartment, the surfacing supersaturation ratio was increased from 1.8 in the KS model to 1.92. This value increased the no-decompression limits slightly. Figure 3 shows the no-decompression limits for the final surfacing ratio, with the US Navy and Royal Navy limits and the three no-decompression isostress (IS(NoD)) limits for comparison. The DCIEM 1983 no-decompression limits are not as great as the targeted Royal Navy limits for depths greater than 15 msw. At 12 msw, the DCIEM 1983 no-decompression limit exceeds that of the Royal Navy but is less than that of the US Navy. Deeper than 18 msw, the DCIEM 1983 no-decompression limits are still slightly less than the IS(NoD)-1 limits.

Although higher surfacing ratios give a better match to the Royal Navy limits, the limits at the shallower depths become too large because of the nonlinearity of the KS series model. In addition, the higher ratios tend to make the decompression times too short at 18 and 21 msw, compared to those from the RN Tables (13) or US Navy Standard Air Decompression Tables (12), for bottom times greater than IS(NoD)-1. To get a better fit to the RN no-decompression limits, the nonlinearity of the model would have to be altered by changing the "A" and "B" constants. This would have required a drastic change in the model.

The higher surfacing ratio decreases the decompression times for all bottom times controlled by the first compartment. For diver safety, however, it was felt necessary to retain the deep stops of the basic KS model. An analysis showed that the dives where additional decompression was required could be specified as all dives in which the first decompression stop was 15 msw or deeper. Therefore, the constants "R" and "OFF" were determined by the surfacing ratio of 1.92 (for SAD = 0) and by the supersaturation ratio from the KS model at SAD = 15 msw. The values of R = 1.3 and OFF = 4.8 were found to satisfy the constraints at SAD = 15 msw and at SAD = 0.

The no-decompression limits resulting from the new model (shown in Figure 3) are rather conservative - especially between 15 and 24 msw. They are, however, considerably less restrictive than the KS-1971 limits shown in Figure 2. It is suggested that this extra margin of safety for short, shallow dives is beneficial since it is in this region that the majority of diving by "novice" and "infrequent" divers is done.

b. Second Compartment

For the second compartment, the surfacing ratio was made more conservative, from 1.8 in the KS model to 1.73. This resulted in about a 10 minute increase in decompression time at IS-3, and shifted the point where the second compartment became controlling down to approximately IS-1. To determine "R" and "OFF", the second constraint on the supersaturation ratio was the value on the surface (P = 10.06 msw) which determined the maximum safe altitude for flying. The target was to make this value as close to 2 as possible, thus, giving 0.5 atm (18000 ft altitude) which is normally accepted as being the threshold for altitude "bends" (18). The KS model gives a ratio of 2.37 (just over 22000 ft altitude) which was felt to be too high. The final values selected were R = 1.385 and OFF = 2.5. These gave a reasonable match to the constraints for surfacing and for altitude. The supersaturation ratio at the surface was found to be 2.11, which gave an altitude of just over 19000 ft, not too different from the normally accepted value of 18000 ft. A lower ratio was found to increase the decompression times too much.

c. Third/Fourth Compartments

The problem of removing the anomaly of the excessively long decompression times when the third and fourth compartments became the controlling compartments was solved by monitoring only the first two compartments (although all four compartments are used for calculating the compartment pressures). The decision to use this solution was based on an examination of the behaviour of the model when the number of compartments was made larger than four.

Figure 4 shows what happens when more than four compartments are used in the model. The figure shows the decompression times for the four compartment model with only two being monitored (indicated as DCIEM) with the decompression times for 4, 5, 6, and 8 compartments with all compartments being monitored. Also shown for comparison are the Royal Navy and US Navy decompression tables for air. The effect of adding more compartments is to reduce the decompression times for the longer bottom times since the "end" effect is reduced. For example, with 5 compartments, the pressure in the fourth compartment is reduced since the gas can escape into the fifth compartment. The "end" effect is still present but at a much greater bottom time. Similarily, by adding more compartments, the "end" effect can be pushed farther to the right (longer bottom times). However, the reduction in decompression time is serious since the decompression times become shorter than those of the Royal Navy and US Navy at extended bottom times and are considered insufficient.

On the other hand, monitoring only two compartments of a four-compartment model gives decompression times at extended bottom times which are more conservative than those of the other two tables and those generated for 5 or more compartments.

d. Summary

The final DCIEM 1983 model is thus derived from the KS-1971 four-compartment series model defined at the beginning of this paper with the following changes:

| | | | |
|---|---|---|---|
| (1) | First Compartment: | R = 1.3, | OFF = 4.8 |
| (2) | Second Compartment: | R = 1.385, | OFF = 2.5 |
| (3) | Third/Fourth Compartments: | 1/R = 0.0, | OFF = 0.0 |

Figure 5 graphically compares the KS-1971 and the DCIEM 1983 models. It is readily seen that the objectives of increasing the no-decompression limits, decreasing the decompression for moderate exposures, increasing the decompression in the KS IS-3 region and reducing the "tail" for extended bottom times has been achieved.

The DCIEM 1983 model has been programmed into the XDC-2 computers and real-time computer control (with printed tables for backup) has been used throughout the model validation process. Over 500 experimental man-dives with full ultrasonic Doppler monitoring have been done by this method to date.

For operational simplicity, "staged" decompression rather than "continuous ascent" is now used at DCIEM with the XDC-2. Decompression is carried out with stops at intervals of 3 msw (10 fsw). The diver stays at the 3 msw multiple (10 fsw multiple) deeper than the indicated "Safe Ascent Depth" (SAD) until the computer shows that he can ascend to the next stop.

2. Standard Air Decompression

Appendix II contains sample Standard Air decompression tables derived from the DCIEM 1983 model. Figure 6 compares total decompression times from these tables with those of the equivalent RN and USN tables. The DCIEM procedure is:

a. descend at 18 msw/min (60 fsw/min) or slower; and

b. ascend at 18 msw/min to the indicated stops and remain at each stop for the tabulated time. The stop time at each stop includes the ascent time to that stop.

The procedure for real-time computer control (with the XDC-2) is:

a. descend at 18 msw/min (60 fsw/min) or slower;

b. ascend at 18 msw/min or slower to the closest multiple of 3 msw (10 fsw) which is deeper than the indicated Safe Ascent Depth (SAD);

c. remain at that stop until the SAD has decreased to the next shallower 3 msw multiple and then ascend to this next stop, and so on; and

d. ascend to the surface when the SAD = "0".

The DCIEM tables are divided into two sections for each depth increment. The section above the line defines the "normal" air diving range and provides "Repetitive Dive Groups" for each profile. Profiles below the line are designated "exceptional exposures" and no repetitive diving is permitted following an "exceptional exposure" dive.

Although the DCIEM decompression times at extended bottom times are more conservative than those of the other published tables, experiments have shown that this conservatism is well justified. The US Navy Diving Manual (12) states that "if the diver was exceptionally cold during the dive, or if his work load was relatively strenuous, the next longer decompression schedule than the one he would normally follow should be selected". Canadian Forces experience has shown that the "next longer plus next deeper" is often required for adequate decompression after long hard dives in cold water. The DCIEM 1983 tables are designed for hard work in cold water and if the decompression times are compared to those of the US Navy for the next longer bottom times (USN +1), the results are quite similar. This can be seen in Figure 7.

3. <u>In-Water Oxygen Decompression</u>

Surface decompression with $O_2$ is well known and widely used. However, in military diving, it is not always possible to have a recompression chamber (RCC) on-site, yet it is possible to supply the diver with $O_2$. Therefore, it was decided to apply $O_2$ in the water - albeit at a conservative depth. Appendix III shows sample "In-Water $O_2$" decompression tables. The DCIEM "In-Water $O_2$" procedure is:

a. do normal staged ascent as for Standard Air to 9 msw (30 fsw);

b. switch diver's gas to $O_2$. The diver remains on $O_2$ at 9 msw for the tabulated stop time; and

c. ascend to surface on $O_2$ in one minute.

For real-time computer control, the procedure is:

a. do a normal computer-controlled ascent to 9 msw at 18 msw/min or slower;

b. switch diver's gas and computer to $O_2$. The diver remains on $O_2$ at 9 msw until the indicated SAD = "0"; and

c. ascend to surface on $O_2$ in one minute.

Figure 8 compares this method to RN Table 13. The total decompression times with this procedure are reduced by 35-40% over Standard Air decompression. Figure 9 presents a graphic comparison of in-water decompression times between DCIEM 1983 Standard Air, In-Water $O_2$ and USN Standard Air Decompression.

4. Surface Decompression with $O_2$

Appendix IV shows sample "SurD $O_2$" tables generated by the DCIEM 1983 model. Experimentation has shown that a diver could be safely surfaced for recompression in a chamber after he has completed the 9 msw (30 fsw) in-water stop, i.e., when the computer SAD reads 6 msw. The DCIEM "SurD $O_2$" procedure is:

a. do a normal staged ascent as for Standard Air to 9 msw (30 fsw) or surface (if no in-water stop is shown);

b. remain at the 9 msw stop for the tabulated stop time (stop time includes ascent time to 9 msw stop at 18 msw/min);

c. ascend to surface in 1 minute (9 msw/min) and recompress on $O_2$ to 12 msw (40 fsw) in the RCC. The "Surface Interval" (SI), which is the time from leaving the 9 msw water stop (or the bottom, if no in-water stop is required) to reaching the 12 msw RCC stop must not exceed 7 minutes (Note 1);

d. remain on $O_2$ at 12 msw for the tabulated stop time with 5 min air breaks after every 30 minutes on $O_2$ (Note 2); and

e. ascend to surface on $O_2$ in 2 min (6 msw/min).

For real-time computer control, the procedure is:

a. do a normal computer-controlled ascent to 9 msw. (If, on reaching 9 msw, the indicated SAD is 6 msw or shallower, ascend directly to the surface);

b. remain at 9 msw until the SAD indicates 6 msw, then ascend to surface at 9 msw/min and recompress on $O_2$ to 12 msw in the RCC. (The computer is switched to $O_2$ when the diver starts breathing $O_2$. The SI must not exceed 7 minutes.);

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NOTE 1: A maximum SI of 7 minutes was chosen to enhance the "operability" of the procedure and to reduce the chances for "omitted decompression" during operations. Extensive experimentation using the full 7 minute SI has proven this approach safe.

2: The 5 minute air breaks after 30 minutes on $O_2$ were included in calculating the 12 msw $O_2$ stop times. The tabulated 12 msw stop times are "$O_2$ times" only, while the "Total Decompression Time" includes the airbreaks.

c. remain on $O_2$ at 12 msw with 5 minute air breaks after every 30 minutes on $O_2$ (the computer is switched to "Air" during air breaks); and

d. ascend to surface on $O_2$ in 2 minutes (6 msw/min) when the SAD = "-1 msw" ("-3 fsw"). (Note 3).

The SurD $O_2$ method originally examined with the XDC-2 (16) was a combination of In-Water $O_2$ at 9 msw and $O_2$ in the RCC at 12 msw. Although this approach reduced the in-water decompression times somewhat, it was decided to adhere to the traditional method for general SurD $O_2$. If however, minimum water exposure and extended surface intervals are the prime criteria, (as may be the case in special military diving scenarios) the combination of In-Water $O_2$ with SurD $O_2$ provides an attractive alternate.

## 5. Repetitive Diving

The repetitive diving procedures developed for the DCIEM 1983 model are similar to those developed earlier for the KS-1971 model (5) but considerably simpler in operation. These procedures take into account the depths and bottom times of both the first and second dives and the surface interval between the dives. With a computer like the XDC-2, any combination of first dives, surface intervals, and subsequent dives is possible. With tables, however, compromises have to be made since it is impossible to take into account all possible repetitive dive combinations.

Each dive in the "normal" air diving range was classified into a repetitive dive group (Appendix II, III, IV) from A to O. For each repetitive dive group, a correction factor was calculated for a number of surface intervals following the first dive and the resulting table is shown in Appendix V. The actual bottom time of the second dive is multiplied by this correction factor to determine the Effective Bottom Time which would give the required decompression. The correction factors depend on the depth and bottom times of the second dive, particularly for short surface intervals - with the values being higher for shallow and short second dives. This dependency on the bottom time and the depth of the second dive becomes less as the surface interval becomes greater. For the values shown in Appendix V, the worst case situation has been taken, so that the correction to be made for the second dive may result in considerably more conservative decompression than actually required in some cases. (This is true of all procedures used for calculating repetitive dives.) In order to obtain the optimum decompression for the second dive, it is necessary to use a real-time on-line decompression computer such as the XDC-2.

============

NOTE 3: The diver remains at 12 msw in the RCC until the computer SAD = "-1 msw" to provide a "compensatory" decompression benefit for the time that he was in violation of the model during the surface interval. This benefit is therefore always proportional to the severity of the dive and is included in the tabulated RCC $O_2$ stop times.

The repetitive dive group correction factors shown in Appendix V can also be used for in-water $O_2$ decompression and surface decompression with $O_2$. However, it should be noted that the repetitive dive groups may not be the same as those for standard air because the use of $O_2$ changes the distribution of pressures in the four compartments. In fact, since the $O_2$ decompression procedures are more "efficient", the repetitive dive groups will normally be lower (never higher) than for straight air decompression.

The repetitive factors in Appendix V have been cut off arbitrarily at 2.0. It is felt that after a strenuous first dive, the minimum surface interval should be sufficient to reduce the residual nitrogen level of the diver to that degree. This approach brings the maximum "Effective Bottom Time" of a second dive within the range of the exceptional exposure tables. In effect, this defines the limits of the printed DCIEM 1983 tables.

## 6. Diving at Altitude

Appendix VI gives the depth corrections required for calculating the decompression times for dives done at different altitudes. The depth correction given in the table is added to the actual depth at altitude to obtain the decompression schedule from the sea level table. The reduced atmospheric pressure at altitude makes the actual dive equivalent to a much deeper dive at sea level. Corrections for the difference between sea water and fresh water have not been included since the difference is less than 3%.

The depth corrections were determined by comparing dives at different altitudes and selecting those depths which gave similar total decompression times to similar dives at sea level. The actual decompressions for these equivalent dives may have different stop depths and times even though the total decompression times are similar. In general, when differences exist, the equivalent sea level dive has either a deeper first stop depth or a longer first stop time which is compensated by slightly shorter stop times for the shallow decompression stops.

Appendix VI also gives the corrections which have to be made to the stop depths at altitude. Corrections for the rate of dive can also be made. However, the dive calculations at altitude were based on actual 18msw/min descent and ascent rates.

The corrections for altitude shown in Appendix VI only apply for divers who have been acclimatized at that altitude, i.e., for those who have spent at least 12 to 24 hrs at the altitude of the dive site. Corrections to the depth would have to be greater for those who have not been acclimatized. Although the depth corrections presented here have never been experimentally validated, they are similar to those derived from the Cross Method (19) which is widely used for sports diving.

## DISCUSSION

The approach taken in defining the DCIEM 1983 model has been purely empirical, starting from the existing KS-1971 model. This approach was taken since a considerable amount of data existed which defined the safety and limitations of the KS model. The final solution involved only changes to the surfacing ratios and the supersaturation ratios rather than changes to the actual gas uptake and elimination parameters. In effect, the solution was more a fine tuning of the KS model rather than a derivation of a new model.

The KS model, it must be realized, is a decompression calculation method rather than a decompression model, with the equations defining the model being derived from the operation of the pneumatic analogue decompression computer rather than from the physiology of decompression. Hills (20) makes the distinction clear between decompression calculation methods and decompression models. In a decompression calculation method, the equations and constants have been selected to fit the data. If the equations or constants prove inadequate, then other equations or constants are introduced until a good fit is achieved. Moreover, calculation methods are restricted to a limited range of conditions. It should be noted that most methods used for deriving decompression tables are calculation methods instead of mathematical models of decompression. These include the modified "Haldane" models which has been widely used for developing tables.

Hempleman (11) has indicated that a precise knowledge of the aetiology of decompression sickness is not a necessary prerequisite for successful decompression table calculations. Hence, it is not necessary to have a "physiological" model to calculate decompression tables. The important factor is that the model or method is based on actual diving data and predicts safe decompression. Selected profiles from DCIEM 1983 have been extensively tested for bottom times where the decompression requirements were reduced and for bottom times where the decompression requirements were extended in comparison to the KS-1971 model. The results showed that the DCIEM 1983 tables are as safe as the KS-1971 tables for short, moderate dives and much safer for dives in the KS IS 2/3 region. At extended bottom times where the 'tail' of the KS-1971 model has been reduced, the DCIEM 1983 model also gave excellent results.

As described previously, there is some physiological basis for the Kidd-Stubbs nonlinear series model. Hennessy, who has shown that the equations for the pneumatic computer are essentially an approximation of the bulk-diffusion equation into a slab of material where the diffusion coefficient is a linear function of pressure, found that the diffusion time scale is longer than that of straightforward diffusion models, and approaches current values only at the greater depth zones (10). He attributes the success of the computer to its inherent asymmetry. However, he does not believe that pneumatic flow through micropores or bulk diffusion with a diffusion coefficient which is a linear function of pressure are representative of the true physiological situation at low pressures. Ordinary linear diffusion with bubble growth during decompression is believed to be the main cause of the observed gas uptake-elimination asymmetry. However, as described above, it is not necessary for the model to be representative of the true physiological situation. Even if bubble growth during decompression is the cause of the asymmetry, the nonlinear series model can be used to predict this asymmetry.

The nonlinearity of the KS model does pose some problems, probably due to the diffusion time scales not being exactly correct as found by Hennessy. This is manifested in the difficulty in obtaining a good match to other no-decompression limits such as those of the RN. The two constants, "A" and "B", in the KS model should ideally be changed, and perhaps, the values should be different for each compartment in order to retain the same behaviour for dives requiring decompression.

Although Hennessy (10) has estimated that at least 8 compartments should be used for a bulk diffusion model, analysis showed that the use of more than 4 compartments reduced the decompression times excessively for long bottom times. This reduction in decompression times could be eliminated by using different gas exchange parameters "A" and "B" and the supersaturation constants "R" and "OFF" for each compartment. However, introducing too many constants destroys the simplicity of the series model. The choice of monitoring only two compartments while still calculating gas uptake and elimination for four compartments retains some of the simplicity of the original KS model. An additional two parameters have been introduced in DCIEM 1983 since the supersaturation constants are different for the first and second compartments.

In a series model, all compartments are related and an unique half-time cannot be ascribed to each individual compartment. In addition, because of the nonlinear nature of the gas uptake and elimination, the half-times are time and pressure-dependent.

The main difference between the KS model and DCIEM 1983 is in the surfacing and supersaturation ratios. Hennessy and Hempleman (21) have shown that the critical pressure formula is not a simple pressure ratio but is of the form:

$$P_1 = aP_2 + b,$$

where $P_1$ corresponds to $P_t$ in the SAD equation, $P_2$ corresponds to SAD + $P_{s1}$, and "a" and "b" are constants. The constant "a" depends on the solubility of the gas in the tissue. The formula which they derived for fatty tissue from experimental dive data,

$$P_1 = 1.361P_2 + 3.4 \quad \text{(msw)}$$

is remarkably similar to that originally derived empirically by Stubbs, which when converted to the same form, gives

$$P_1 = 1.385P_2 + 4.2.$$

The formula for DCIEM 1983 is even closer to that derived by Hennessy and Hempleman:

$$P_1 = 1.385P_2 + 3.46.$$

This formula holds only for the second compartment which is the limiting compartment for this model.

It is also interesting to look at the direct or no-stop decompression from air saturation for DCIEM 1983. With the Royal Navy or US Navy tables, there is no limit for depths to 9 msw. The limit for the KS-1971 model was 8 msw. With the new model, based on the constants "R" and "OFF" for the second compartment, the no-stop limit is 7.3 msw. Although this value seems low, there is recent evidence to suggest that the actual no-stop limit is lower than previously thought. Tests at the US Navy Submarine Medical Research Laboratory, Groton, Connecticutt (22) suggest that the limit is close to 7.8 msw. Hennessy and Hempleman's estimate is even lower than the DCIEM value, at 7.0 msw.

The DCIEM 1983 decompression model has been evaluated for selected dive profiles - including repetitive dive combinations - with the Doppler ultrasonic bubble detector. The results show that the basic conservatism of the model is justified and necessary. The use of oxygen with this model was found to be effective in increasing the safety of the decompression and in reducing the in-water decompression times. The evaluations, which included Standard Air, In-Water $O_2$ and SurD $O_2$ decompression will be reported separately.

**SUMMARY**

The development of the DCIEM 1983 decompression model was undertaken to overcome the problems and limitations of the KS-1971 model. The objectives - to provide increased no-decompression limits, shorter decompression requirements for moderate dives, longer decompression times for more severe exposures, and to remove the anomaly of the excessively long decompression times for extended exposures - were achieved without significantly changing the basic philosophy of the Kidd-Stubbs approach. Thus, the definition of the DCIEM 1983 model is based on the large data base of dives performed on the Kidd-Stubbs model (over 5000 man-dives) as well as some 500 model validation dives using the Doppler ultrasonic bubble monitor. The results of these evaluation experiments have proven that the DCIEM 1983 model is safer than the Kidd-Stubbs model.

The new model has been used to produce "Standard Air", "In-Water $O_2$" and "Surface Decompression with $O_2$" tables. Repetitive diving procedures have also been developed. The DCIEM 1983 tables are more conservative than the equivalent USN and RN tables and this conservatism increases at extended bottom times. If, however, the "one bottom time longer" rule is applied to the USN tables (USN+1) for hard working dives - as is often done by experienced divers - the resulting decompression times are remarkably similar (Figure 7). When the USN tables are modified by the "one deeper plus one longer" philosophy for extended bottom times, the results again coincide well with the DCIEM model.

The evaluation of the DCIEM 1983 model with the Doppler ultrasonic bubble detector has shown that the basic conservatism is indeed justified and necessary. The use of oxygen with this model enhances the safety and time-effectiveness of the decompression considerably.

In summary, it is submitted that the DCIEM 1983 model can satisfy all the decompression requirements for safe compressed air diving. The decompression tables and procedures based on this model will be recommended for adoption by the Canadian Armed Forces.

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## LIST OF FIGURES

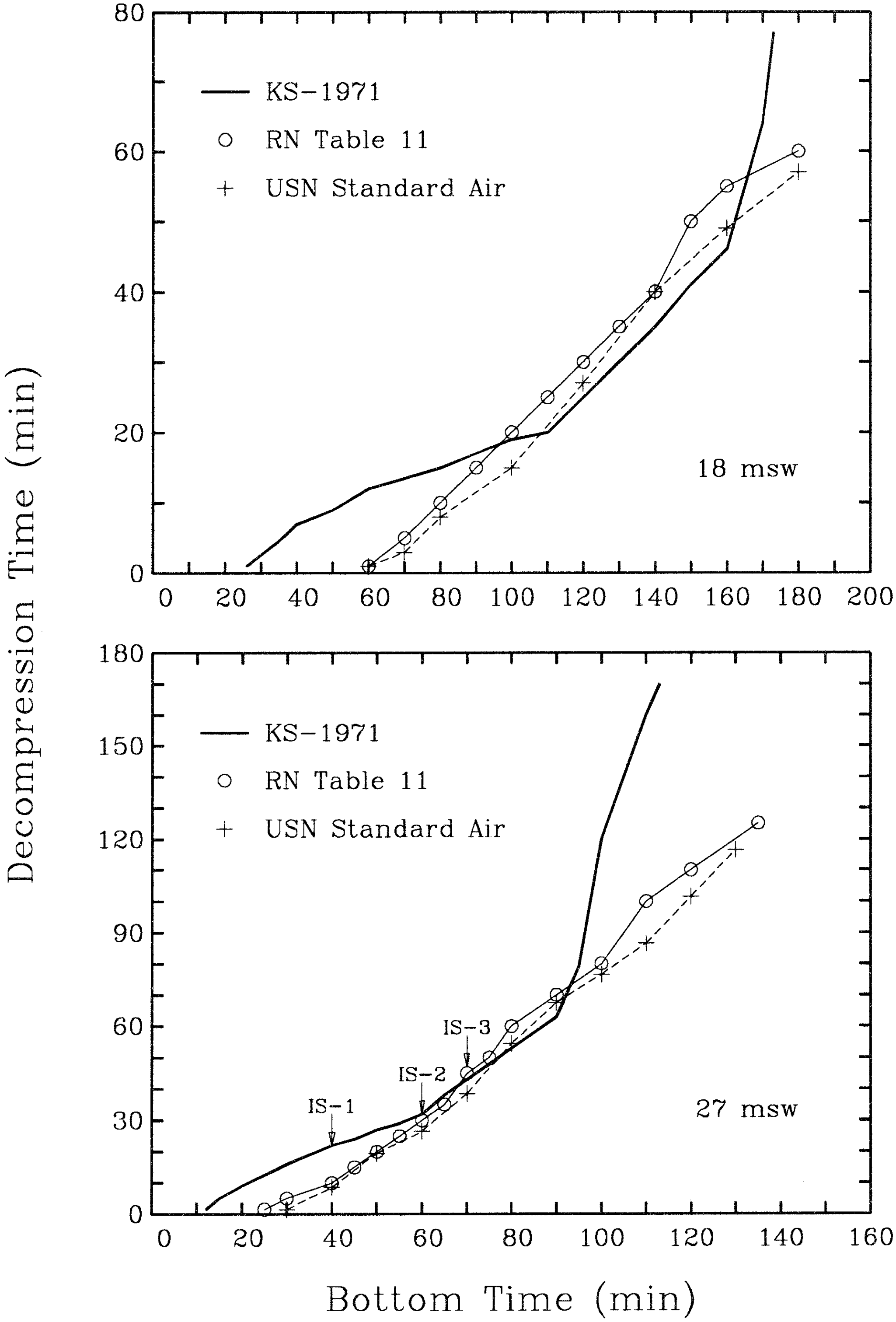



Fig. 1a. Comparison of the KS-1971 total decompression times for standard air dives (showing the Isostress Limits) for 18 and 27 msw with those of the Royal Navy and US Navy air tables.

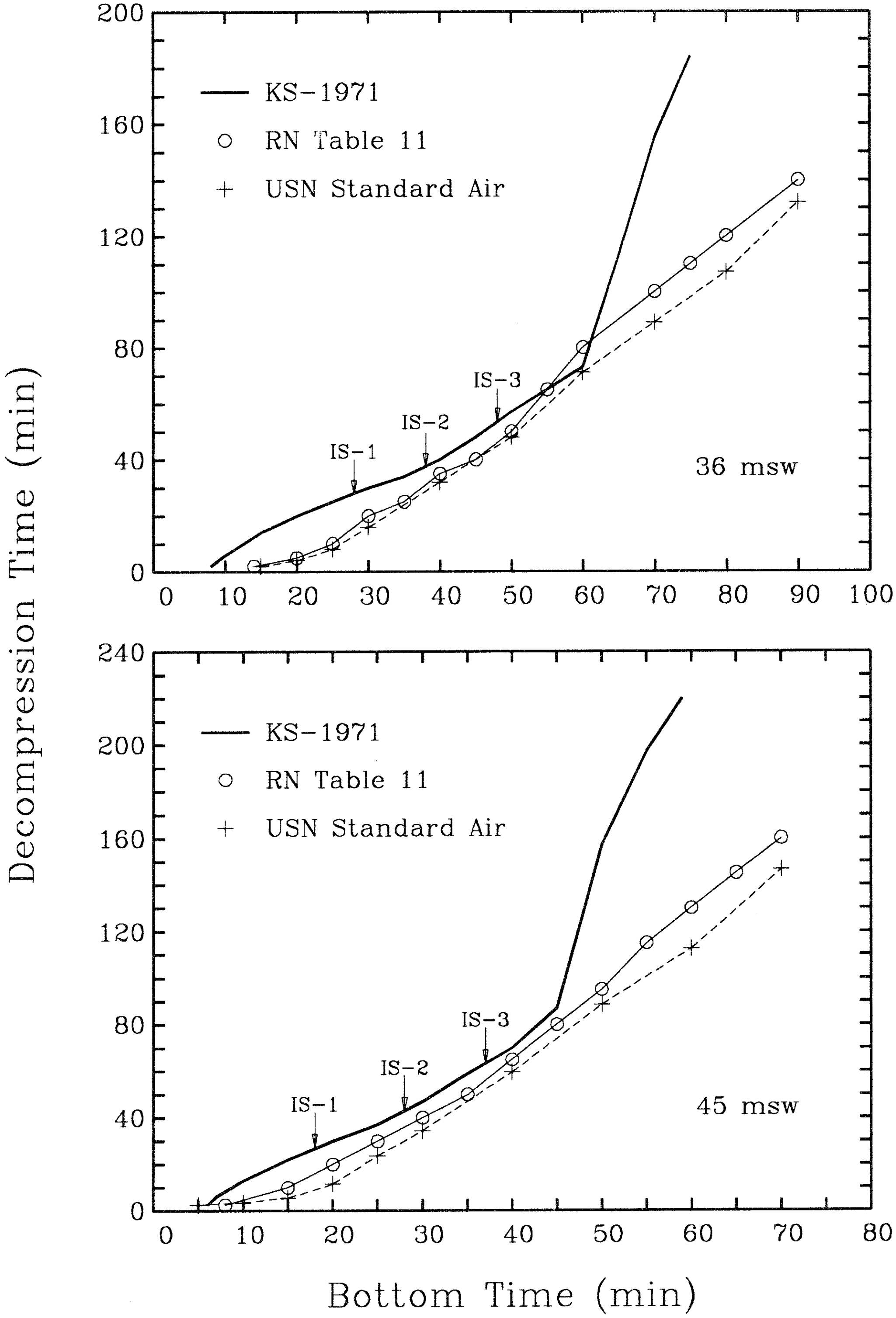



Fig. 1b. Comparison of the KS-1971 total decompression times for standard air dives (showing the Isostress Limits) for 36 and 45 msw with those of the Royal Navy and US Navy air tables.

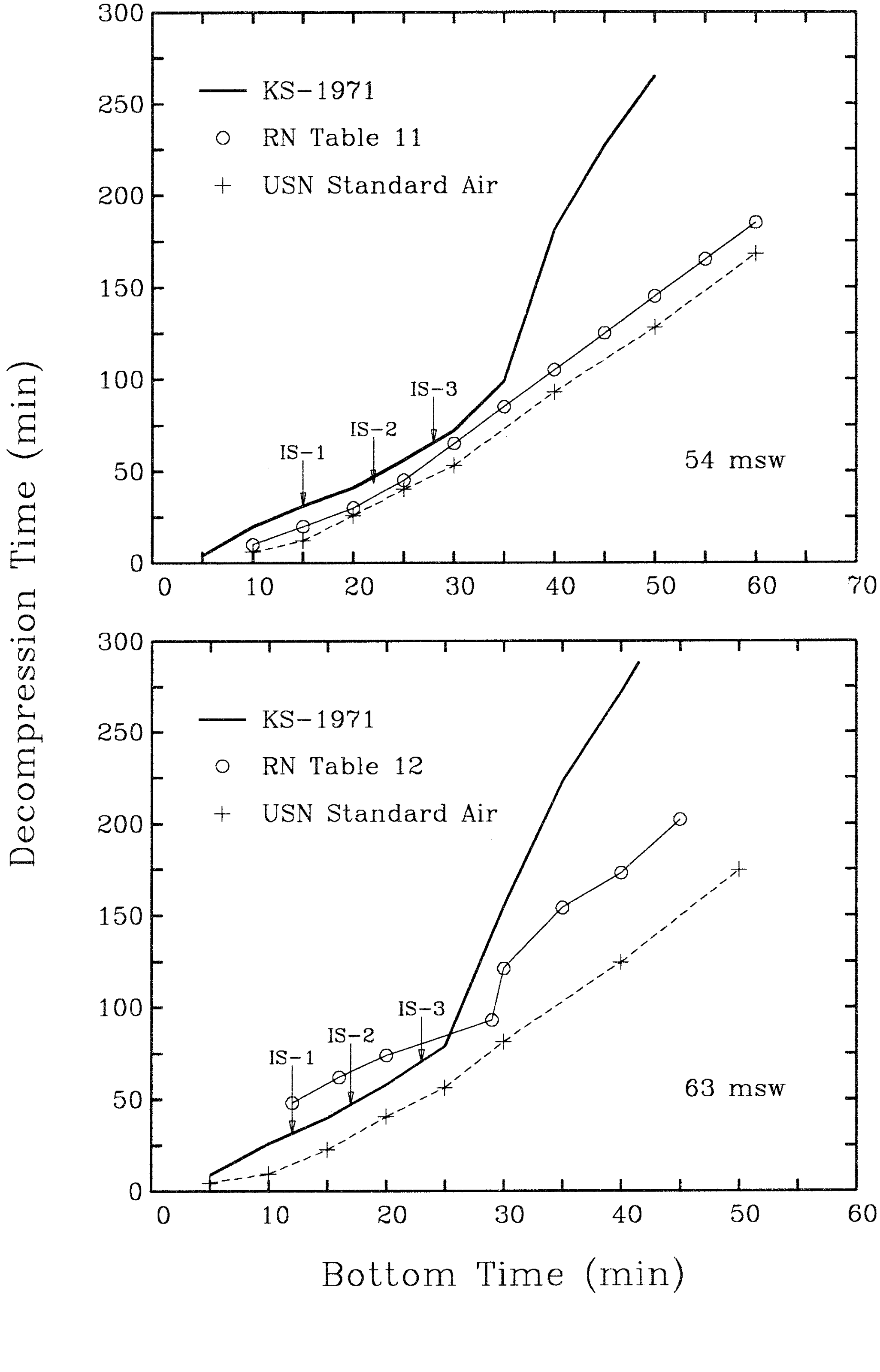



Fig. 1c. Comparison of the KS-1971 total decompression times for standard air dives (showing the Isostress Limits) for 54 and 63 msw with those of the Royal Navy and US Navy air tables.

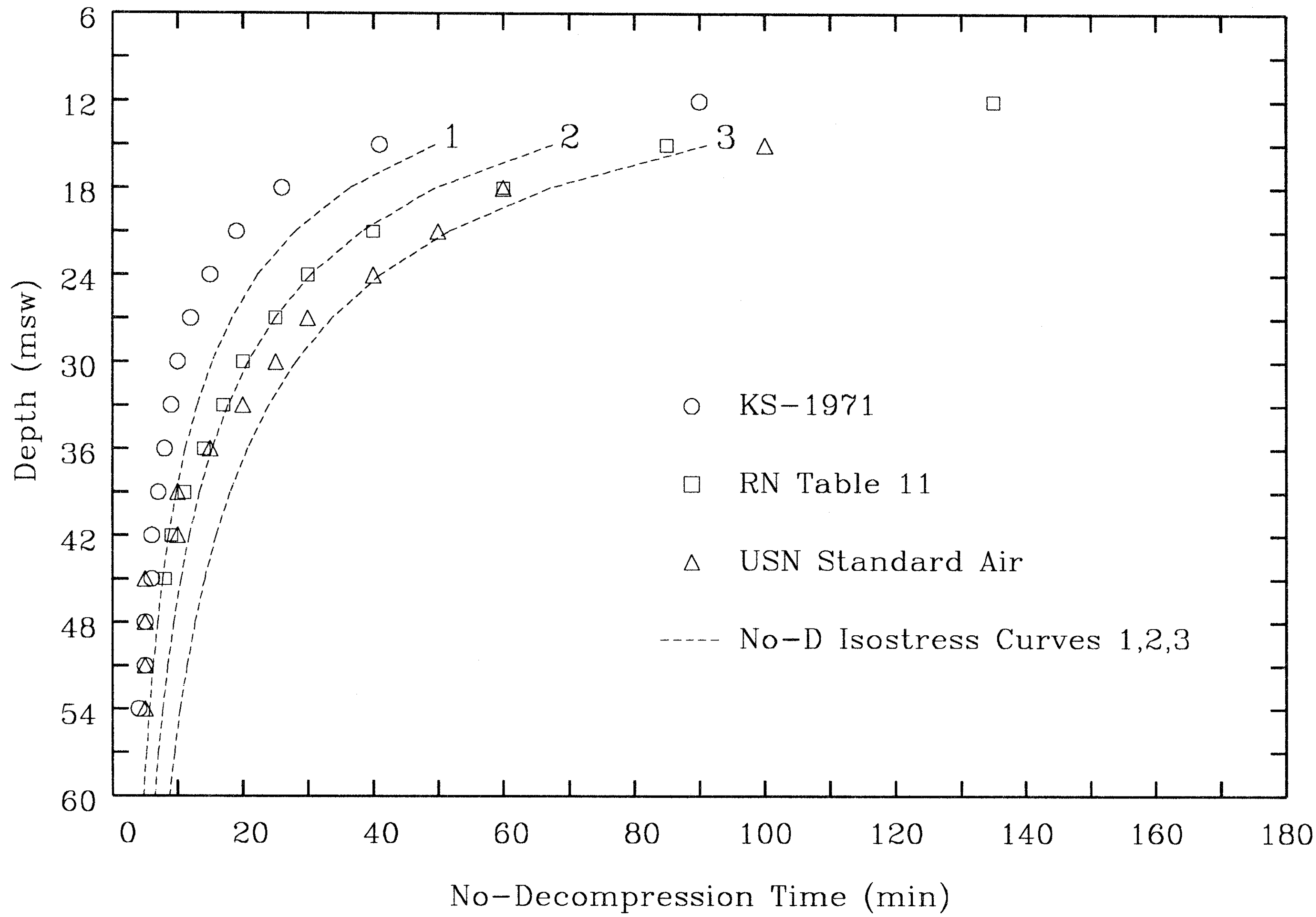



Fig. 2. Comparison of the KS-1971 no-decompression limits with those of the Royal Navy, US Navy, and the DCIEM no-decompression isostress curves.

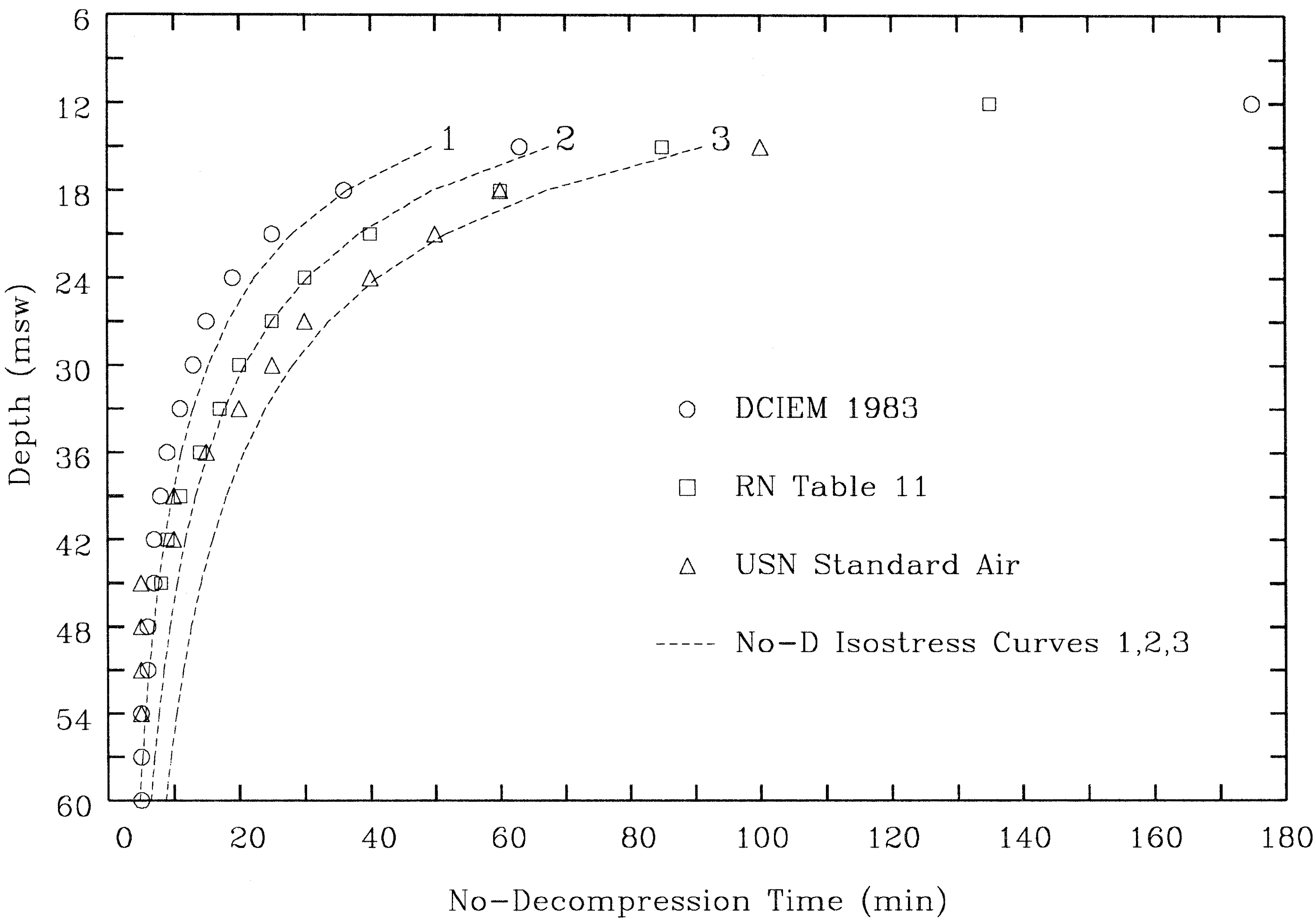



Fig. 3. Comparison of the DCIEM 1983 no-decompression limits with those of the Royal Navy, US Navy, and the DCIEM no-decompression isostress curves.

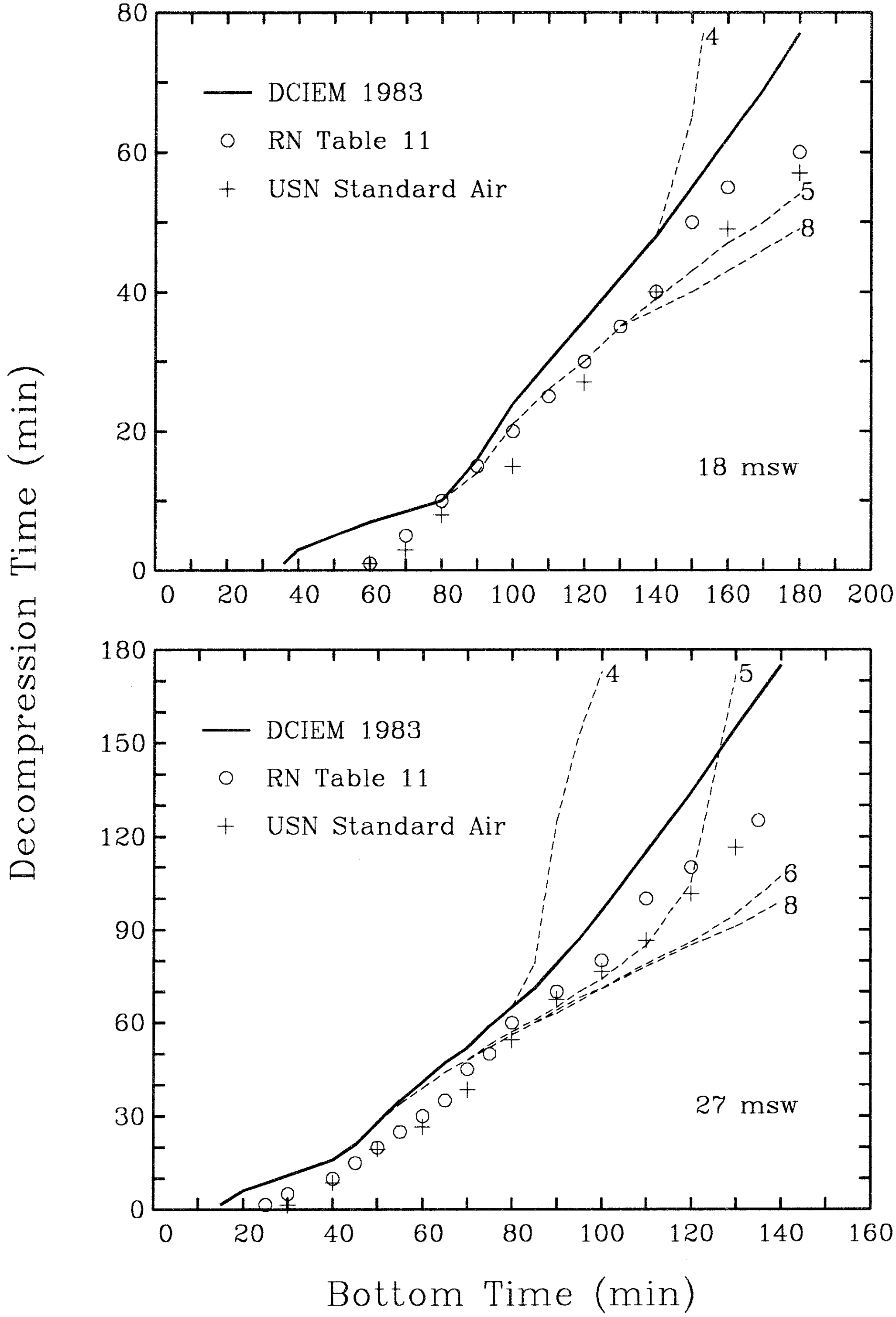



Fig. 4a. Total decompression times at 18 and 27 msw (standard air) for 4, 5, 6, and 8 compartments (indicated by the numbers to the right of the dashed lines) showing the effect of adding more compartments to the DCIEM 1983 nonlinear series model, with comparison to the final DCIEM 1983 model (4 compartments, first 2 monitored only), the Royal Navy and US Navy air tables.

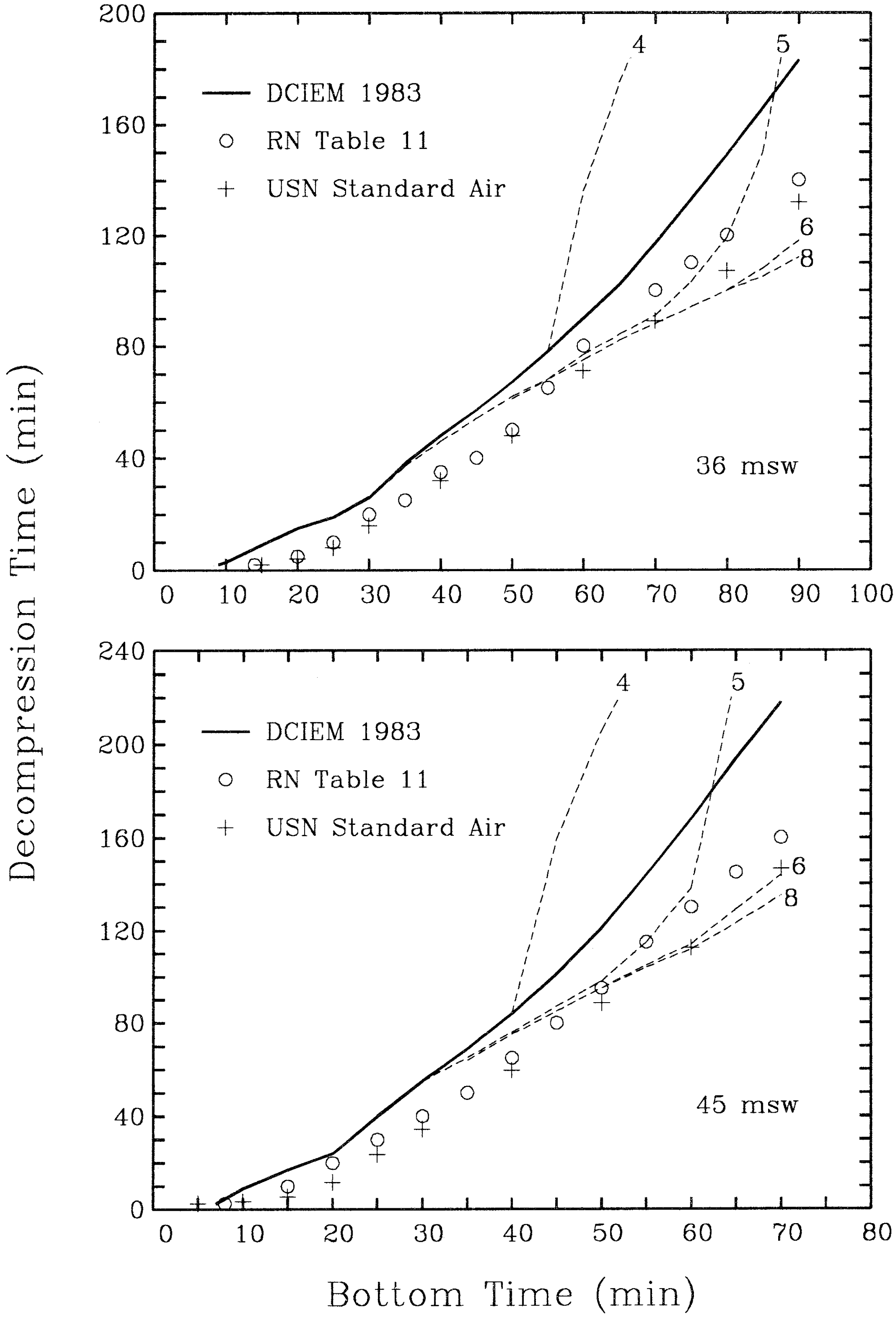



Fig. 4b. Total decompression times at 36 and 45 msw (standard air) for 4, 5, 6, and 8 compartments (indicated by the numbers to the right of the dashed lines) showing the effect of adding more compartments to the DCIEM 1983 nonlinear series model, with comparison to the final DCIEM 1983 model (4 compartments, first 2 monitored only), the Royal Navy and US Navy air tables.

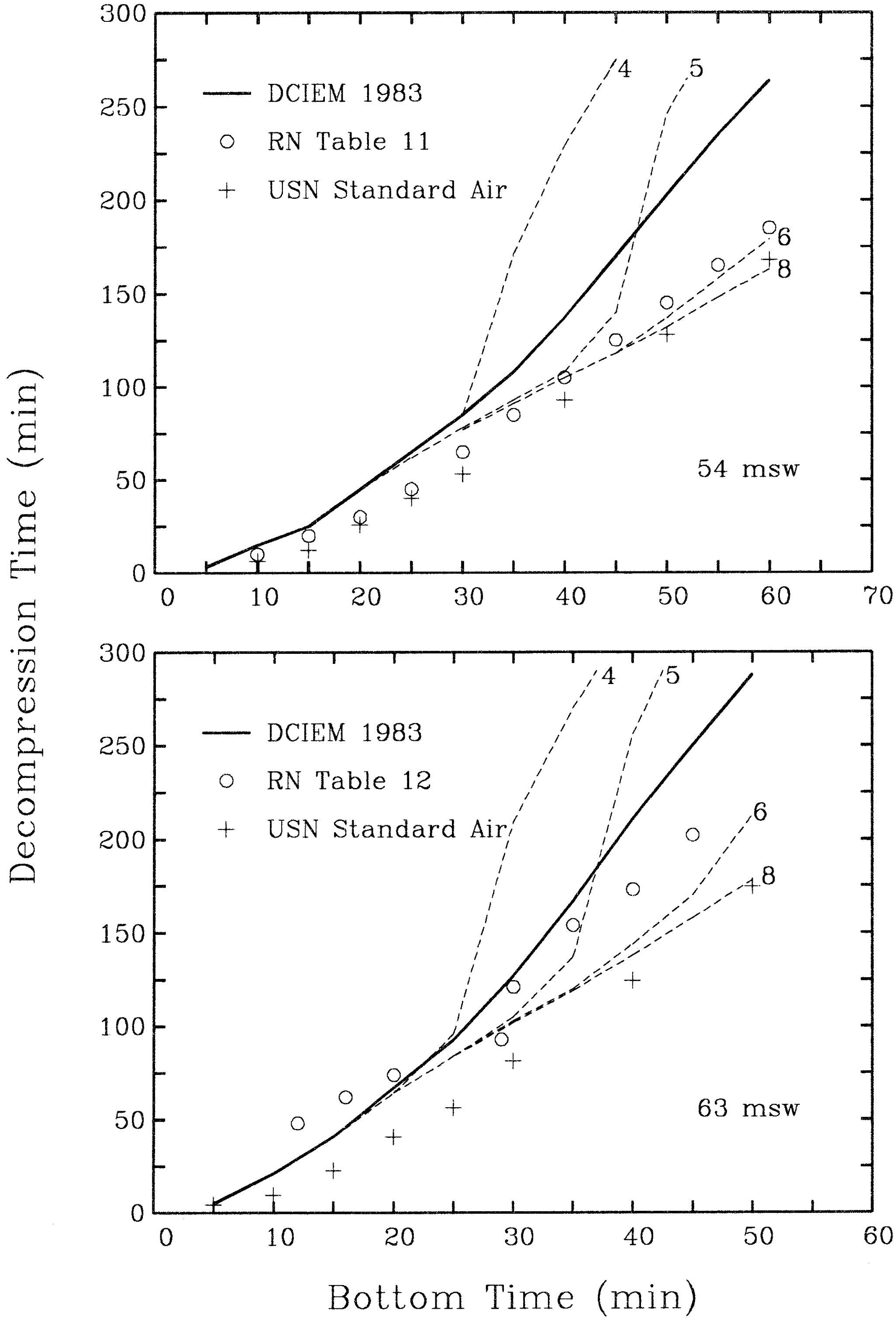



Fig. 4c. Total decompression times at 54 and 63 msw (standard air) for 4, 5, 6, and 8 compartments (indicated by the numbers to the right of the dashed lines) showing the effect of adding more compartments to the DCIEM 1983 nonlinear series model, with comparison to the final DCIEM 1983 model (4 compartments, first 2 monitored only), the Royal Navy and US Navy air tables.

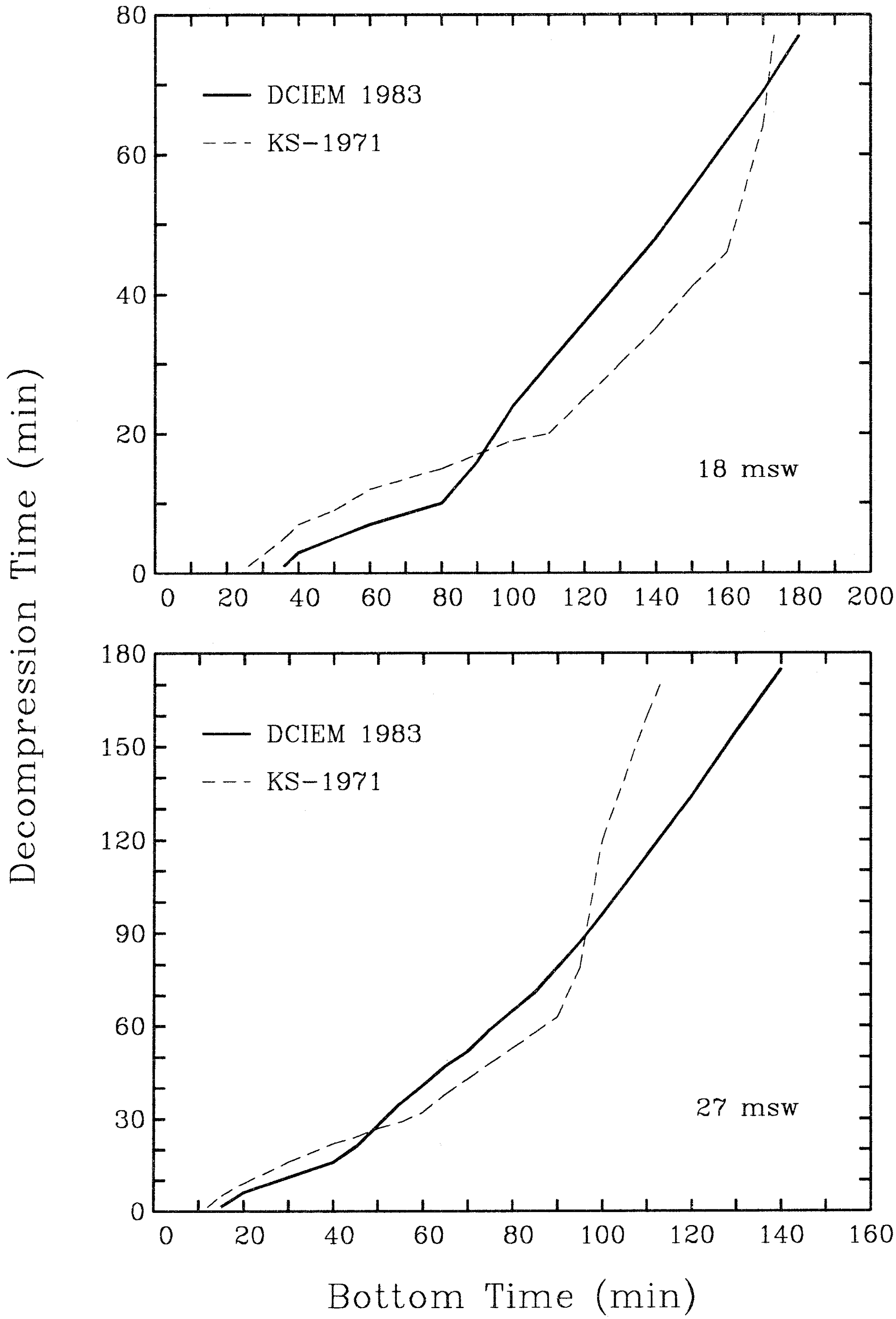



Fig. 5a. Comparison of DCIEM 1983 total decompression times for standard air dives with those of the Kidd-Stubbs (KS) 1971 model for 18 and 27 msw.

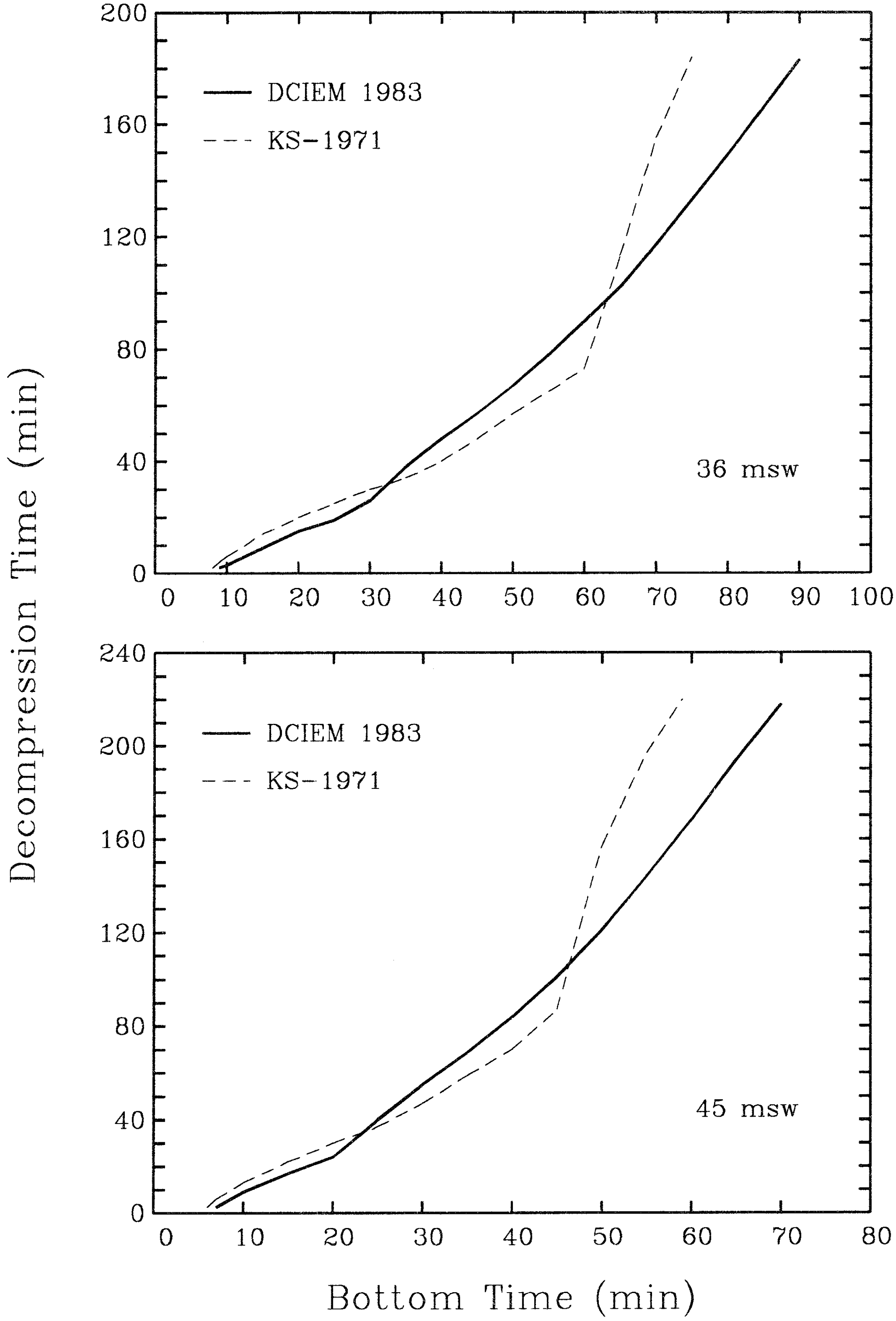



Fig. 5b. Comparison of DCIEM 1983 total decompression times for standard air dives with those of the Kidd-Stubbs (KS) 1971 model for 36 and 45 msw.

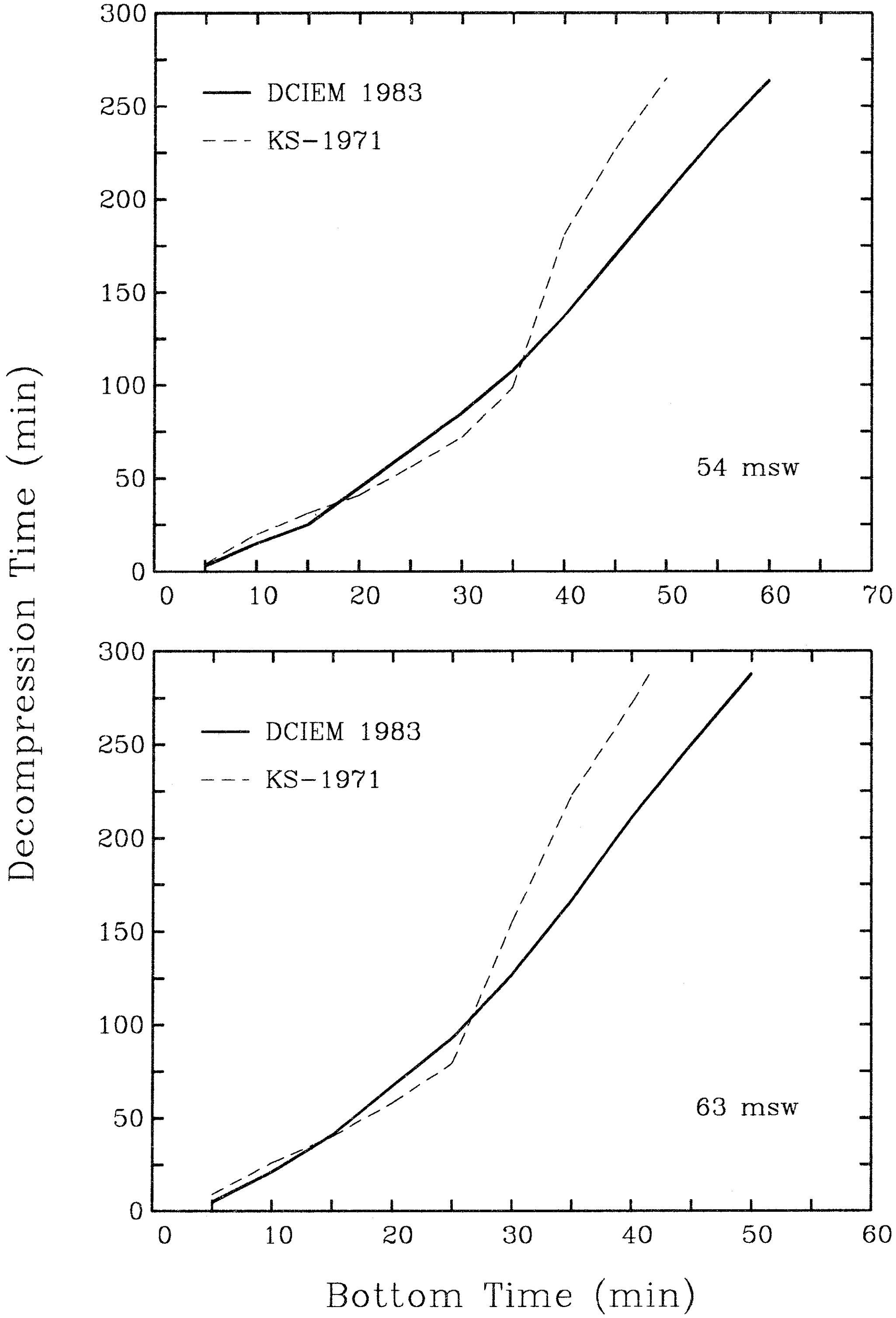



Fig. 5c. Comparison of DCIEM 1983 total decompression times for standard air dives with those of the Kidd-Stubbs (KS) 1971 model for 54 and 63 msw.

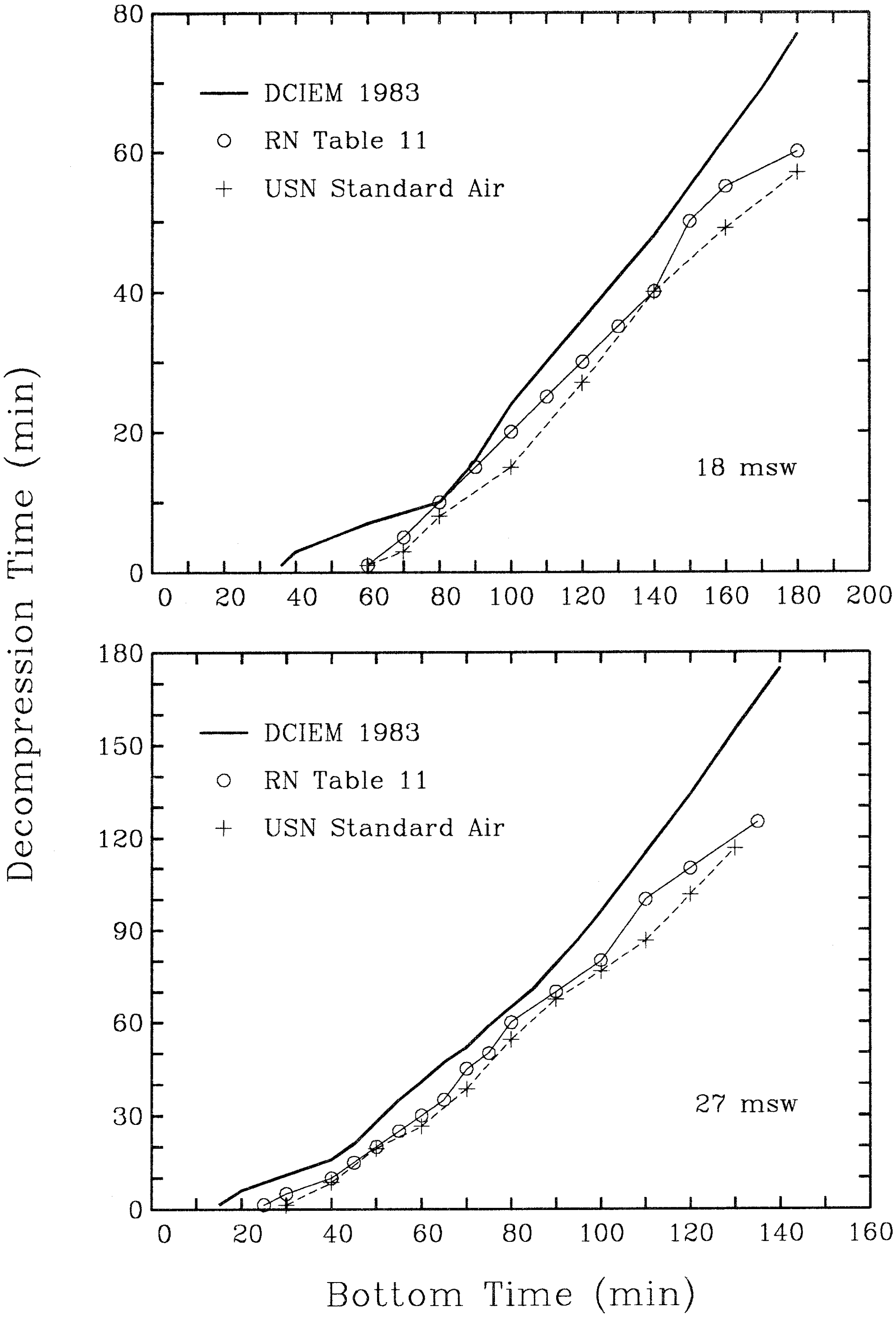



Fig. 6a. Comparison of DCIEM 1983 total decompression times for standard air dives with those of the Royal Navy and the US Navy air tables for 18 and 27 msw.

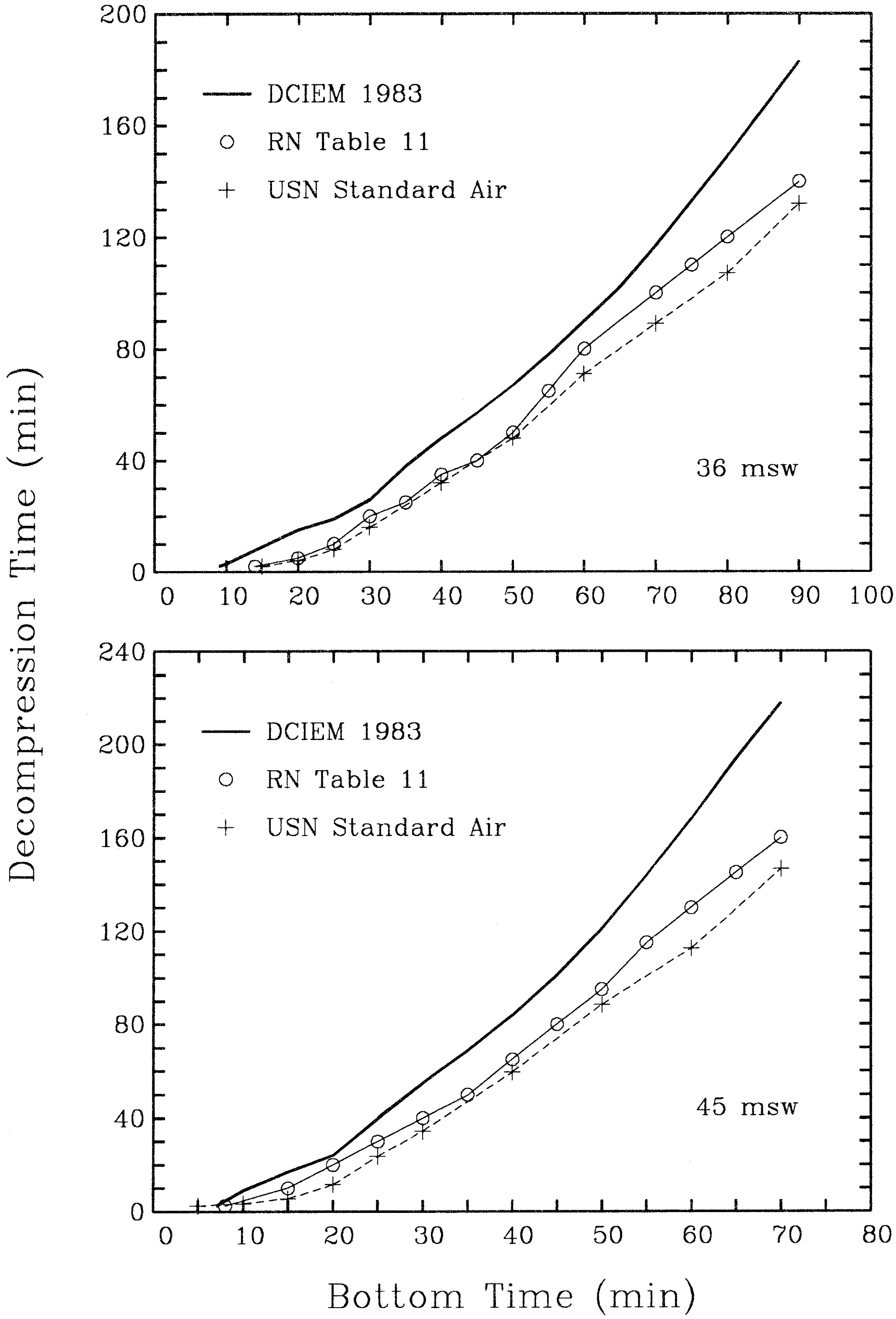



Fig. 6b. Comparison of DCIEM 1983 total decompression times for standard air dives with those of the Royal Navy and the US Navy air tables for 36 and 45 msw.

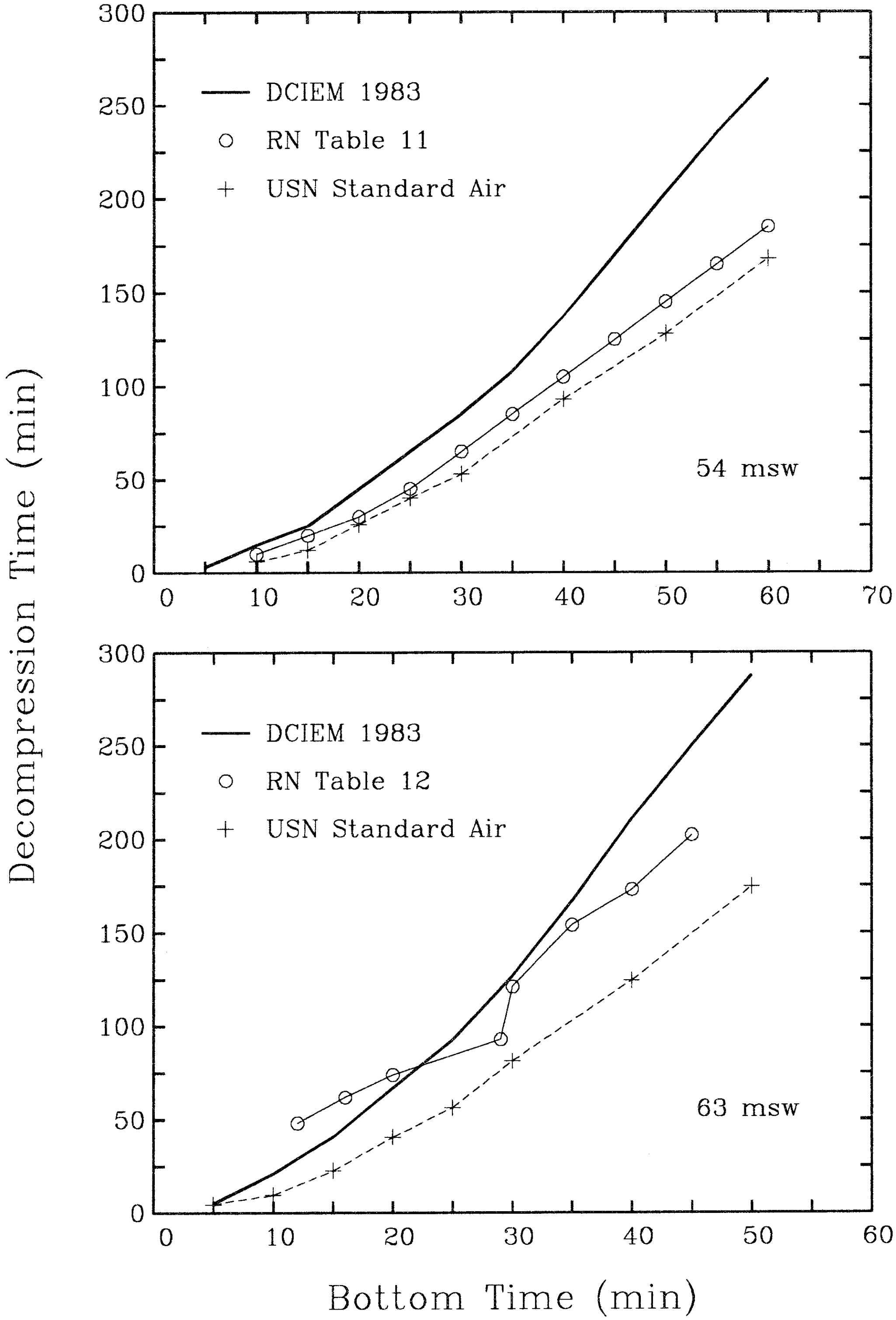



Fig. 6c. Comparison of DCIEM 1983 total decompression times for standard air dives with those of the Royal Navy and the US Navy air tables for 54 and 63 msw.

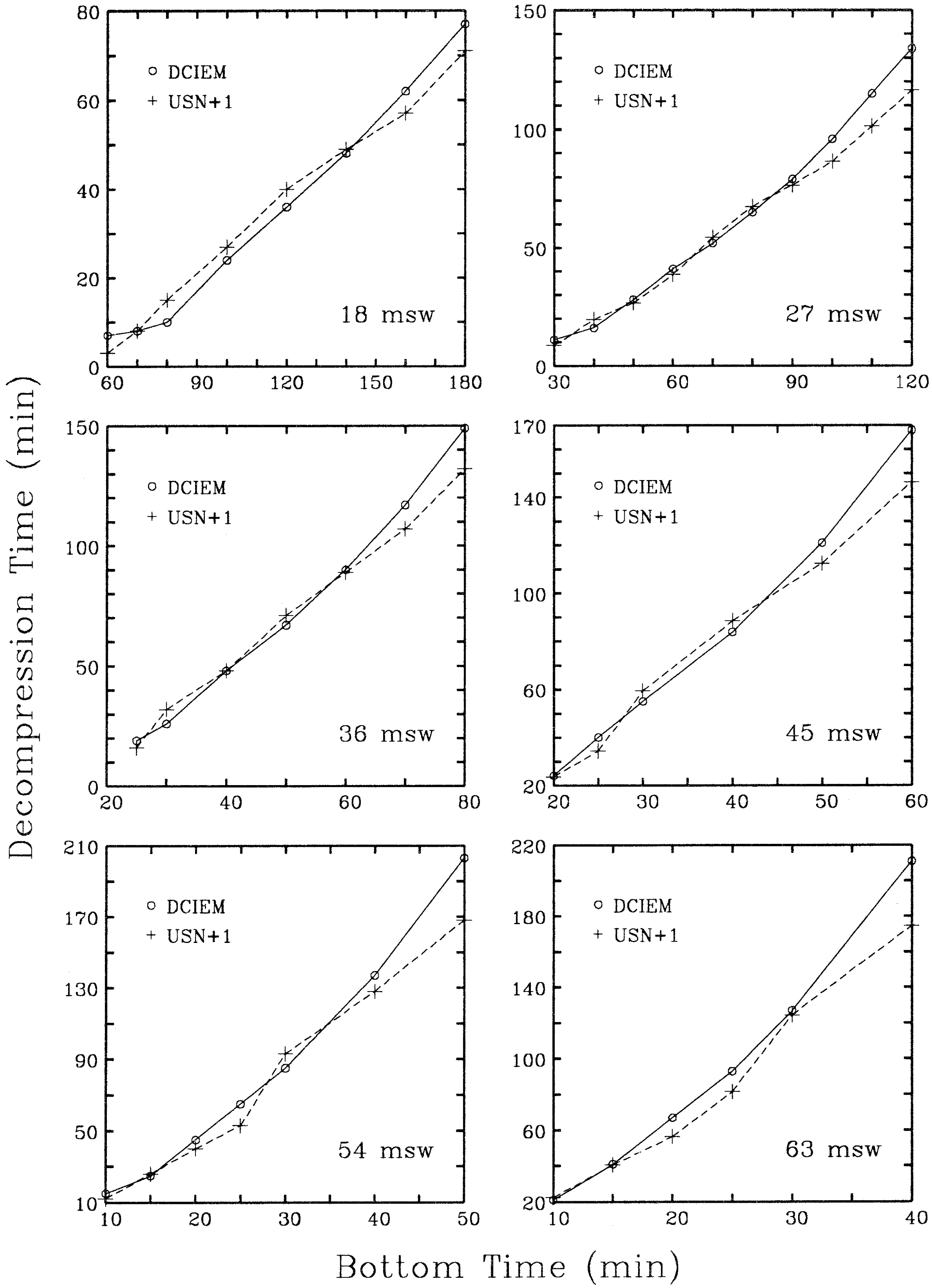
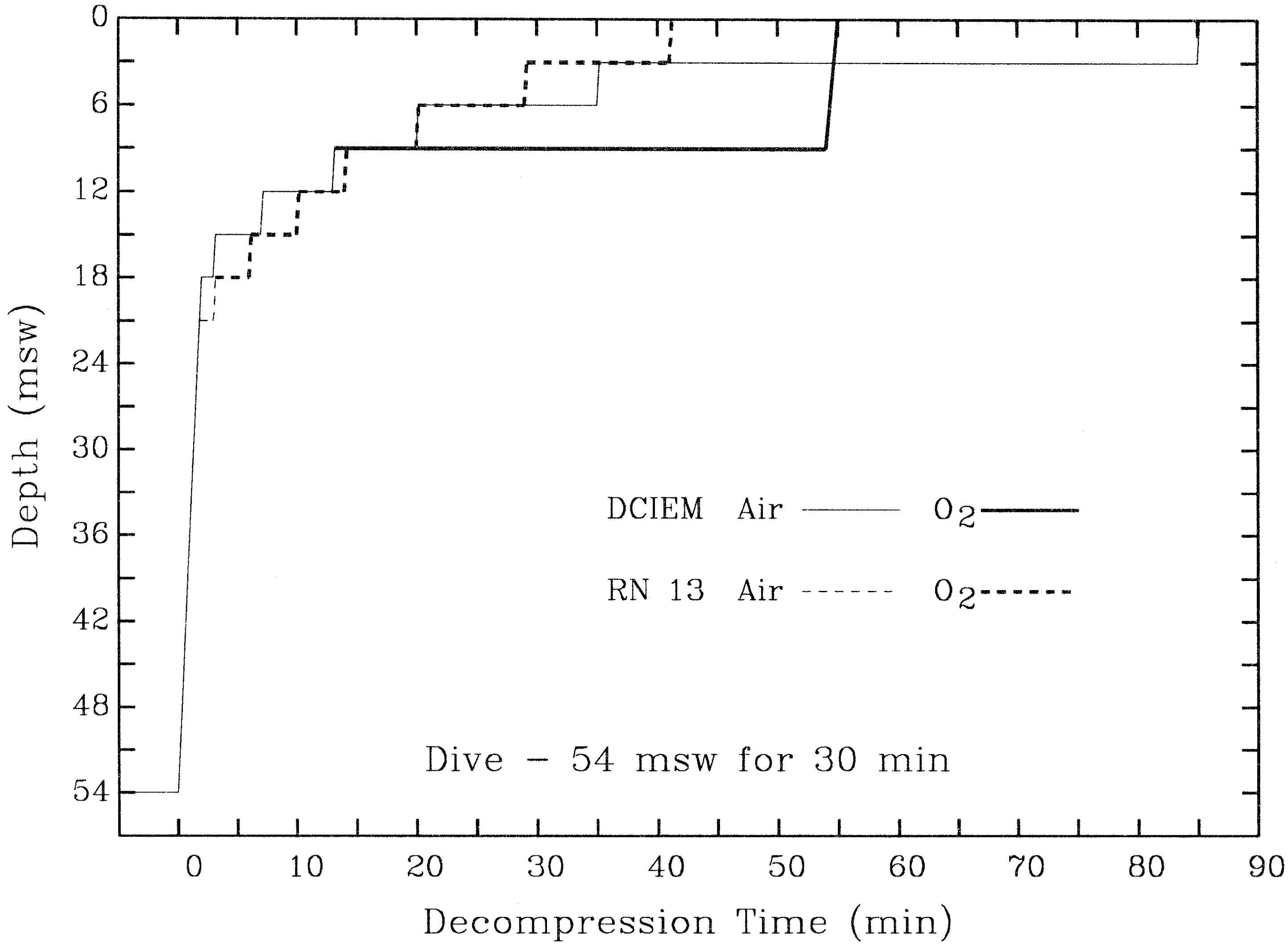



Fig. 7. Comparison of the DCIEM 1983 total decompression times for standard air with those for the next bottom time from US Navy Standard Air Table (USN+1).

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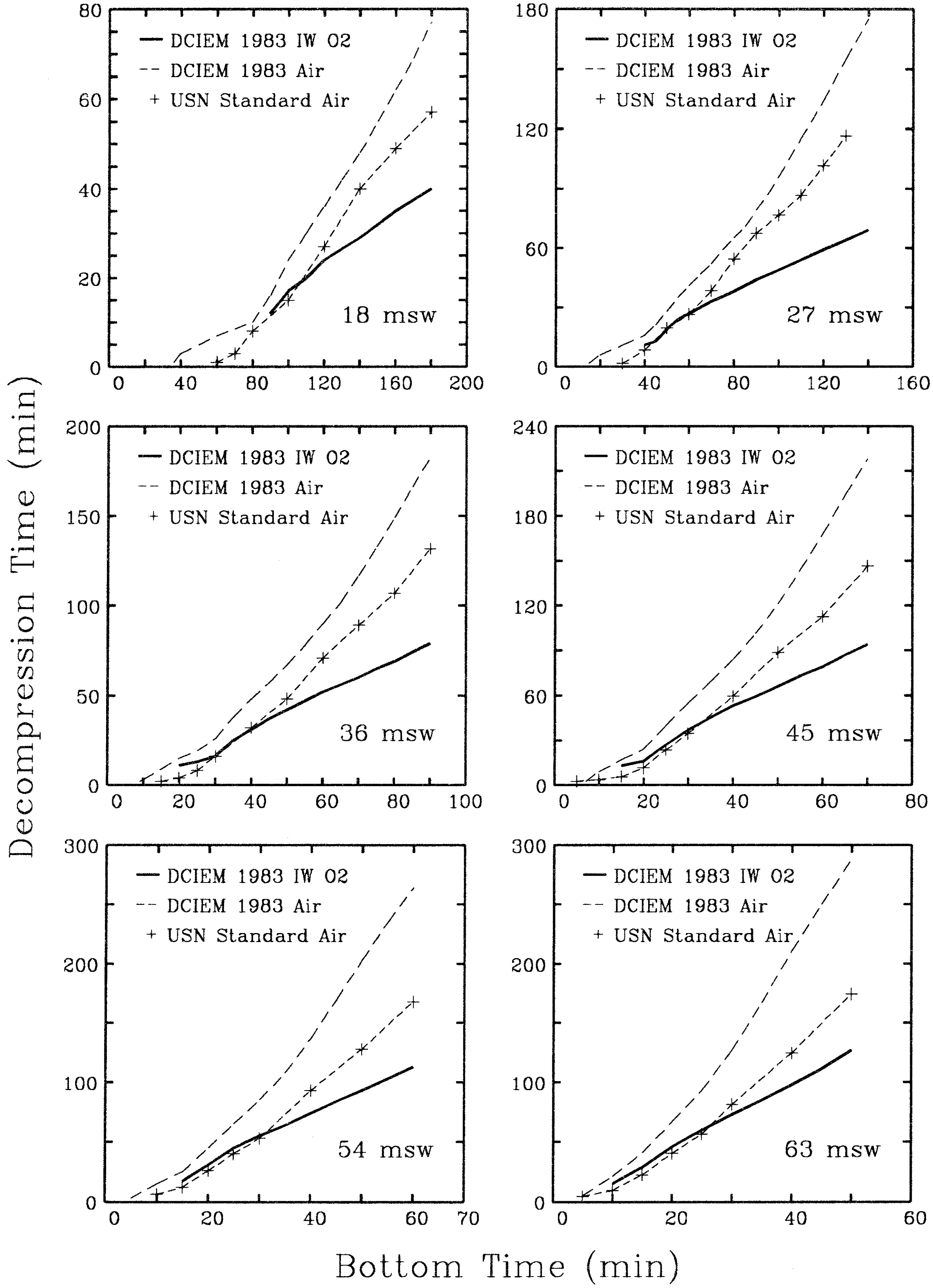


Fig. 9. Comparison of the DCIEM 1983 total decompression times for in-water oxygen decompression dives with those from the DCIEM 1983 and US Navy Standard Air Tables.

# APPENDICES

## SAMPLE DECOMPRESSION TABLES

I. Kidd-Stubbs 1971 Standard Air Table

II. DCIEM 1983 Standard Air Table

III. DCIEM 1983 In-Water Oxygen Table

IV. DCIEM 1983 Surface Decompression using Oxygen Table

V. DCIEM 1983 Repetitive Factors Table

VI. DCIEM Altitude Diving Corrections

# APPENDIX I
# KIDD-STUBBS 1971 AIR DIVING TABLE 1 (METRES)
# STANDARD AIR

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | | Decom. Time (min) |
|---|---|---|---|---|---|---|---|---|---|
| | | 21 | 18 | 15 | 12 | 9 | 6 | 3 | |
| **18** | 26 | - | - | - | - | - | - | - | - |
| | 30 | - | - | - | - | - | - | 3 | 3 |
| | 40 | - | - | - | - | - | - | 7 | 7 |
| | 60 | - | - | - | - | - | - | 12 | 12 |
| | 80(1) | - | - | - | - | - | - | 15 | 15 |
| | 100 | - | - | - | - | - | 3 | 16 | 19 |
| | 120 | - | - | - | - | - | 4 | 21 | 25 |
| | 130 | - | - | - | - | - | 5 | 25 | 30 |
| | 140 | - | - | - | - | - | 5 | 30 | 35 |
| | 150 | - | - | - | - | - | 6 | 35 | 41 |
| | 160 | - | - | - | - | - | 7 | 39 | 46 |
| | 170 | - | - | - | - | - | 7 | 57 | 64 |
| | 180 | - | - | - | - | - | 8 | 98 | 106 |
| **27** | 12 | - | - | - | - | - | - | - | - |
| | 15 | - | - | - | - | - | - | 5 | 5 |
| | 20 | - | - | - | - | - | - | 9 | 9 |
| | 30 | - | - | - | - | - | 4 | 12 | 16 |
| | 40(1) | - | - | - | - | - | 8 | 14 | 22 |
| | 50 | - | - | - | - | - | 11 | 16 | 27 |
| | 60(2) | - | - | - | - | 3 | 11 | 18 | 32 |
| | 70(3) | - | - | - | - | 5 | 11 | 27 | 43 |
| | 80 | - | - | - | - | 6 | 12 | 35 | 53 |
| | 90 | - | - | - | - | 7 | 13 | 43 | 63 |
| | 95 | - | - | - | - | 8 | 13 | 58 | 79 |
| | 100 | - | - | - | - | 8 | 14 | 98 | 120 |
| | 110 | - | - | - | - | 9 | 16 | 135 | 160 |
| | 120 | - | - | - | - | 10 | 21 | 159 | 190 |
| **36** | 8 | - | - | - | - | - | - | - | - |
| | 10 | - | - | - | - | - | - | 6 | 6 |
| | 15 | - | - | - | - | - | 3 | 11 | 14 |
| | 20 | - | - | - | - | - | 8 | 12 | 20 |
| | 25 | - | - | - | - | 3 | 8 | 14 | 25 |
| | 28(1) | - | - | - | - | 5 | 8 | 15 | 28 |
| | 30 | - | - | - | - | 5 | 9 | 16 | 30 |
| | 35 | - | - | - | - | 7 | 10 | 17 | 34 |
| | 38(2) | - | - | - | - | 9 | 10 | 17 | 36 |
| | 40 | - | - | - | 2 | 7 | 11 | 20 | 40 |
| | 45 | - | - | - | 4 | 7 | 11 | 26 | 48 |
| | 48(3) | - | - | - | 4 | 8 | 12 | 29 | 53 |
| | 50 | - | - | - | 5 | 8 | 12 | 32 | 57 |
| | 55 | - | - | - | 6 | 8 | 13 | 38 | 65 |
| | 60 | - | - | - | 6 | 9 | 14 | 44 | 73 |

## APPENDIX I (continued)
## KIDD-STUBBS 1971 AIR DIVING TABLE 1 (METRES)
## STANDARD AIR

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | | | Decom. Time (min) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 24 | 21 | 18 | 15 | 12 | 9 | 6 | 3 | |
| **36** | 65 | - | - | - | - | 7 | 9 | 14 | 83 | 113 |
| | 70 | - | - | - | - | 8 | 9 | 18 | 120 | 155 |
| | 80 | - | - | - | 3 | 7 | 10 | 25 | 162 | 207 |
| | 90 | - | - | - | 3 | 8 | 11 | 33 | 191 | 246 |
| **45** | 6 | - | - | - | - | - | - | - | - | - |
| | 10 | - | - | - | - | - | - | - | 13 | 13 |
| | 15 | - | - | - | - | - | - | 10 | 12 | 22 |
| | 20(1) | - | - | - | - | - | 7 | 9 | 14 | 30 |
| | 25 | - | - | - | - | 4 | 7 | 10 | 16 | 37 |
| | 28(2) | - | - | - | - | 6 | 7 | 10 | 18 | 41 |
| | 30 | - | - | - | - | 7 | 7 | 11 | 22 | 47 |
| | 35 | - | - | - | 3 | 6 | 8 | 12 | 30 | 59 |
| | 37(3) | - | - | - | 4 | 5 | 9 | 12 | 34 | 64 |
| | 40 | - | - | - | 4 | 6 | 9 | 13 | 38 | 70 |
| | 45 | - | - | - | 6 | 6 | 9 | 14 | 52 | 87 |
| | 50 | - | - | - | 7 | 7 | 10 | 18 | 115 | 157 |
| | 55 | - | - | 3 | 5 | 7 | 11 | 23 | 148 | 197 |
| | 60 | - | - | 3 | 6 | 7 | 11 | 29 | 172 | 228 |
| **54** | 5 | - | - | - | - | - | - | - | 4 | 4 |
| | 10 | - | - | - | - | - | - | 8 | 12 | 20 |
| | 15(1) | - | - | - | - | - | 8 | 9 | 14 | 31 |
| | 20 | - | - | - | - | 7 | 7 | 10 | 17 | 41 |
| | 22(2) | - | - | - | 4 | 5 | 7 | 11 | 19 | 46 |
| | 25 | - | - | - | 5 | 6 | 7 | 12 | 26 | 56 |
| | 28(3) | - | - | - | 7 | 5 | 9 | 12 | 33 | 66 |
| | 30 | - | - | 3 | 5 | 6 | 8 | 13 | 37 | 72 |
| | 35 | - | - | 5 | 5 | 6 | 10 | 15 | 58 | 99 |
| | 40 | - | - | 6 | 5 | 7 | 11 | 21 | 131 | 181 |
| | 45 | - | 3 | 4 | 6 | 8 | 11 | 28 | 167 | 227 |
| | 50 | - | 4 | 5 | 6 | 8 | 12 | 36 | 194 | 265 |
| **63** | 5 | - | - | - | - | - | - | - | 9 | 9 |
| | 10 | - | - | - | - | - | 6 | 8 | 12 | 26 |
| | 12(1) | - | - | - | - | 4 | 6 | 8 | 14 | 32 |
| | 15 | - | - | - | - | 8 | 6 | 10 | 16 | 40 |
| | 17(2) | - | - | - | 5 | 5 | 7 | 10 | 18 | 45 |
| | 20 | - | - | - | 7 | 6 | 7 | 12 | 26 | 58 |
| | 23(3) | - | - | 5 | 4 | 6 | 9 | 13 | 34 | 71 |
| | 25 | - | - | 6 | 5 | 6 | 9 | 13 | 40 | 79 |
| | 30 | - | 4 | 4 | 5 | 7 | 10 | 19 | 106 | 155 |
| | 35 | - | 6 | 4 | 6 | 8 | 11 | 27 | 161 | 223 |
| | 40 | 4 | 4 | 4 | 6 | 9 | 13 | 36 | 196 | 272 |

# APPENDIX II
# DCIEM 1983 AIR DIVING TABLE 1 (METRES)
# STANDARD AIR

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | | Decom. Time (min) | Repet. Dive Group |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 21 | 18 | 15 | 12 | 9 | 6 | 3 | | |
| **18** | 10 | - | - | - | - | - | - | - | - | A |
| | 20 | - | - | - | - | - | - | - | - | B |
| | 30 | - | - | - | - | - | - | - | - | D |
| | 36 | - | - | - | - | - | - | - | - | D |
| | 40 | - | - | - | - | - | - | 3 | 3 | E |
| | 50 | - | - | - | - | - | - | 5 | 5 | F |
| | 60 | - | - | - | - | - | - | 7 | 7 | G |
| | 80 | - | - | - | - | - | - | 10 | 10 | I |
| | 90 | - | - | - | - | - | - | 16 | 16 | J |
| | 100 | - | - | - | - | - | - | 24 | 24 | K |
| | 110 | - | - | - | - | - | - | 30 | 30 | L |
| | 120 | - | - | - | - | - | - | 36 | 36 | M |
| | 130 | - | - | - | - | - | 2 | 40 | 42 | |
| | 140 | - | - | - | - | - | 2 | 46 | 48 | |
| | 150 | - | - | - | - | - | 3 | 52 | 55 | |
| | 160 | - | - | - | - | - | 3 | 59 | 62 | |
| | 170 | - | - | - | - | - | 4 | 65 | 69 | |
| | 180 | - | - | - | - | - | 4 | 73 | 77 | |
| | 190 | - | - | - | - | - | 5 | 80 | 85 | |
| | 200 | - | - | - | - | - | 7 | 87 | 94 | |
| | 210 | - | - | - | - | - | 13 | 91 | 104 | |
| | 220 | - | - | - | - | - | 17 | 97 | 114 | |
| | 230 | - | - | - | - | - | 21 | 103 | 124 | |
| | 240 | - | - | - | - | - | 24 | 109 | 133 | |
| **27** | 10 | - | - | - | - | - | - | - | - | A |
| | 15 | - | - | - | - | - | - | - | - | C |
| | 20 | - | - | - | - | - | - | 6 | 6 | D |
| | 30 | - | - | - | - | - | 2 | 9 | 11 | F |
| | 40 | - | - | - | - | - | 6 | 10 | 16 | H |
| | 45 | - | - | - | - | - | 7 | 14 | 21 | I |
| | 50 | - | - | - | - | - | 8 | 20 | 28 | J |
| | 55 | - | - | - | - | - | 9 | 26 | 35 | K |
| | 60 | - | - | - | - | 2 | 8 | 31 | 41 | L |
| | 65 | - | - | - | - | 3 | 8 | 36 | 47 | |
| | 70 | - | - | - | - | 3 | 9 | 40 | 52 | |
| | 75 | - | - | - | - | 4 | 9 | 46 | 59 | |
| | 80 | - | - | - | - | 4 | 10 | 51 | 65 | |
| | 85 | - | - | - | - | 5 | 10 | 56 | 71 | |
| | 90 | - | - | - | - | 5 | 14 | 60 | 79 | |
| | 95 | - | - | - | - | 6 | 17 | 64 | 87 | |
| | 100 | - | - | - | - | 6 | 20 | 70 | 96 | |
| | 110 | - | - | - | - | 7 | 26 | 82 | 115 | |
| | 120 | - | - | - | - | 8 | 31 | 95 | 134 | |

## APPENDIX II (continued)
## DCIEM 1983 AIR DIVING TABLE 1 (METRES)
## STANDARD AIR

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | | Decom. Time (min) | Repet. Dive Group |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 21 | 18 | 15 | 12 | 9 | 6 | 3 | | |
| **36** | 5 | - | - | - | - | - | - | - | - | A |
| | 9 | - | - | - | - | - | - | - | - | B |
| | 10 | - | - | - | - | - | - | 3 | 3 | C |
| | 15 | - | - | - | - | - | - | 9 | 9 | D |
| | 20 | - | - | - | - | - | 6 | 9 | 15 | F |
| | 25 | - | - | - | - | - | 9 | 10 | 19 | G |
| | 30 | - | - | - | - | 4 | 8 | 14 | 26 | I |
| | 35 | - | - | - | - | 6 | 8 | 24 | 38 | J |
| | 40 | - | - | - | - | 8 | 8 | 32 | 48 | K |
| | 45 | - | - | - | 3 | 6 | 10 | 38 | 57 | M |
| | 50 | - | - | - | 4 | 7 | 10 | 46 | 67 | N |
| | 55 | - | - | - | 5 | 7 | 13 | 53 | 78 | |
| | 60 | - | - | - | 6 | 7 | 18 | 59 | 90 | |
| | 65 | - | - | - | 6 | 8 | 22 | 66 | 102 | |
| | 70 | - | - | - | 7 | 8 | 27 | 75 | 117 | |
| | 75 | - | - | - | 8 | 8 | 31 | 86 | 133 | |
| | 80 | - | - | 2 | 6 | 9 | 35 | 97 | 149 | |
| | 85 | - | - | 3 | 6 | 10 | 40 | 107 | 166 | |
| | 90 | - | - | 3 | 7 | 13 | 42 | 118 | 183 | |
| | 95 | - | - | 4 | 6 | 16 | 46 | 128 | 200 | |
| | 100 | - | - | 4 | 7 | 19 | 50 | 136 | 216 | |
| **45** | 7 | - | - | - | - | - | - | - | - | B |
| | 10 | - | - | - | - | - | - | 9 | 9 | D |
| | 15 | - | - | - | - | - | 8 | 9 | 17 | F |
| | 20 | - | - | - | - | 6 | 7 | 11 | 24 | H |
| | 25 | - | - | - | 4 | 5 | 8 | 23 | 40 | J |
| | 30 | - | - | - | 6 | 6 | 9 | 34 | 55 | K |
| | 35 | - | - | 3 | 5 | 7 | 10 | 44 | 69 | M |
| | 40 | - | - | 4 | 6 | 7 | 15 | 52 | 84 | O |
| | 45 | - | - | 5 | 6 | 8 | 21 | 61 | 101 | |
| | 50 | - | - | 6 | 7 | 8 | 27 | 73 | 121 | |
| | 55 | - | 3 | 5 | 6 | 9 | 33 | 88 | 144 | |
| | 60 | - | 3 | 5 | 7 | 12 | 38 | 103 | 168 | |
| | 65 | - | 4 | 5 | 8 | 16 | 42 | 119 | 194 | |
| | 70 | - | 5 | 5 | 8 | 20 | 48 | 132 | 218 | |
| | 75 | - | 5 | 6 | 8 | 24 | 55 | 142 | 240 | |
| | 80 | - | 6 | 6 | 8 | 28 | 63 | 150 | 261 | |

## APPENDIX II (continued)
## DCIEM 1983 AIR DIVING TABLE 1 (METRES)
## STANDARD AIR

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | | | | Decom. Time (min) | Repet. Dive Group |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 27 | 24 | 21 | 18 | 15 | 12 | 9 | 6 | 3 | | |
| **54** | 5 | - | - | - | - | - | - | - | - | - | - | B |
| | 10 | - | - | - | - | - | - | - | 6 | 9 | 15 | E |
| | 15 | - | - | - | - | - | - | 7 | 7 | 11 | 25 | H |
| | 20 | - | - | - | - | - | 6 | 6 | 8 | 25 | 45 | J |
| | 25 | - | - | - | - | 5 | 5 | 7 | 9 | 39 | 65 | M |
| | 30 | - | - | - | 3 | 4 | 6 | 7 | 15 | 50 | 85 | O |
| | 35 | - | - | - | 5 | 4 | 6 | 8 | 23 | 62 | 108 | |
| | 40 | - | - | - | 6 | 5 | 7 | 9 | 30 | 80 | 137 | |
| | 45 | - | - | 4 | 4 | 5 | 7 | 13 | 36 | 101 | 170 | |
| | 50 | - | - | 4 | 5 | 5 | 8 | 18 | 42 | 121 | 203 | |
| | 55 | - | - | 5 | 5 | 6 | 8 | 23 | 51 | 137 | 235 | |
| | 60 | - | - | 6 | 5 | 6 | 9 | 28 | 61 | 149 | 264 | |
| **63** | 5 | - | - | - | - | - | - | - | - | 5 | 5 | |
| | 10 | - | - | - | - | - | - | 5 | 6 | 10 | 21 | |
| | 15 | - | - | - | - | - | 7 | 6 | 8 | 20 | 41 | |
| | 20 | - | - | - | - | 7 | 5 | 7 | 9 | 39 | 67 | |
| | 25 | - | - | - | 6 | 4 | 6 | 8 | 17 | 52 | 93 | |
| | 30 | - | - | 5 | 4 | 4 | 7 | 8 | 28 | 71 | 127 | |
| | 35 | - | 3 | 3 | 4 | 6 | 7 | 12 | 35 | 97 | 167 | |
| | 40 | - | 4 | 4 | 4 | 6 | 8 | 19 | 43 | 123 | 211 | |
| | 45 | - | 5 | 4 | 5 | 6 | 9 | 25 | 54 | 142 | 250 | |
| | 50 | 3 | 3 | 4 | 6 | 6 | 13 | 29 | 70 | 154 | 288 | |

# APPENDIX III
# DCIEM 1983 AIR DIVING TABLE 2 (METRES)
# IN-WATER OXYGEN

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | Decom. Time (min) | Repet. Dive Group |
|---|---|---|---|---|---|---|---|---|---|
| | | Air | | | | | $O_2$ | | |
| | | 24 | 21 | 18 | 15 | 12 | 9 | | |
| **18** | 90 | - | - | - | - | - | 11 | 12 | J |
| | 100 | - | - | - | - | - | 16 | 17 | J |
| | 110 | - | - | - | - | - | 19 | 20 | K |
| | 120 | - | - | - | - | - | 23 | 24 | K |
| | 140 | - | - | - | - | - | 28 | 29 | |
| | 160 | - | - | - | - | - | 34 | 35 | |
| | 180 | - | - | - | - | - | 39 | 40 | |
| | 200 | - | - | - | - | - | 44 | 45 | |
| | 220 | - | - | - | - | - | 49 | 50 | |
| | 240 | - | - | - | - | - | 53 | 54 | |
| **27** | 40 | - | - | - | - | - | 10 | 11 | G |
| | 45 | - | - | - | - | - | 12 | 13 | H |
| | 50 | - | - | - | - | - | 18 | 19 | H |
| | 55 | - | - | - | - | - | 23 | 24 | I |
| | 60 | - | - | - | - | - | 26 | 27 | J |
| | 70 | - | - | - | - | - | 32 | 33 | |
| | 80 | - | - | - | - | - | 37 | 38 | |
| | 90 | - | - | - | - | - | 43 | 44 | |
| | 100 | - | - | - | - | - | 48 | 49 | |
| | 110 | - | - | - | - | - | 53 | 54 | |
| | 120 | - | - | - | - | - | 58 | 59 | |
| **36** | 20 | - | - | - | - | - | 10 | 11 | F |
| | 25 | - | - | - | - | - | 12 | 13 | G |
| | 30 | - | - | - | - | - | 15 | 16 | H |
| | 35 | - | - | - | - | - | 24 | 25 | H |
| | 40 | - | - | - | - | - | 30 | 31 | I |
| | 45 | - | - | - | - | 3 | 33 | 37 | J |
| | 50 | - | - | - | - | 4 | 37 | 42 | K |
| | 55 | - | - | - | - | 5 | 41 | 47 | |
| | 60 | - | - | - | - | 6 | 45 | 52 | |
| | 65 | - | - | - | - | 6 | 49 | 56 | |
| | 70 | - | - | - | - | 7 | 52 | 60 | |
| | 75 | - | - | - | - | 8 | 56 | 65 | |
| | 80 | - | - | - | 2 | 6 | 60 | 69 | |
| | 85 | - | - | - | 3 | 6 | 64 | 74 | |
| | 90 | - | - | - | 3 | 7 | 68 | 79 | |
| | 95 | - | - | - | 4 | 6 | 72 | 83 | |
| | 100 | - | - | - | 4 | 7 | 76 | 88 | |

## APPENDIX III (continued)
## DCIEM 1983 AIR DIVING TABLE 2 (METRES)
## IN-WATER OXYGEN

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | | Decom. Time (min) | Repet. Dive Group |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Air | | | | | | $O_2$ | | |
| | | 27 | 24 | 21 | 18 | 15 | 12 | 9 | | |
| **45** | 15 | - | - | - | - | - | - | 12 | 13 | F |
| | 20 | - | - | - | - | - | - | 15 | 16 | G |
| | 25 | - | - | - | - | - | 4 | 22 | 27 | H |
| | 30 | - | - | - | - | - | 6 | 30 | 37 | I |
| | 35 | - | - | - | - | 3 | 5 | 36 | 45 | K |
| | 40 | - | - | - | - | 4 | 6 | 42 | 53 | M |
| | 45 | - | - | - | - | 5 | 6 | 47 | 59 | |
| | 50 | - | - | - | - | 6 | 7 | 52 | 66 | |
| | 55 | - | - | - | 3 | 5 | 6 | 58 | 73 | |
| | 60 | - | - | - | 3 | 5 | 7 | 63 | 79 | |
| | 65 | - | - | - | 4 | 5 | 8 | 69 | 87 | |
| | 70 | - | - | - | 5 | 5 | 8 | 75 | 94 | |
| | 75 | - | - | - | 5 | 6 | 8 | 81 | 101 | |
| | 80 | - | - | - | 6 | 6 | 8 | 87 | 108 | |
| **54** | 15 | - | - | - | - | - | - | 16 | 17 | G |
| | 20 | - | - | - | - | - | 6 | 24 | 31 | H |
| | 25 | - | - | - | - | 5 | 5 | 34 | 45 | J |
| | 30 | - | - | - | 3 | 4 | 6 | 41 | 55 | M |
| | 35 | - | - | - | 5 | 4 | 6 | 48 | 64 | |
| | 40 | - | - | - | 6 | 5 | 7 | 55 | 74 | |
| | 45 | - | - | 4 | 4 | 5 | 7 | 63 | 84 | |
| | 50 | - | - | 4 | 5 | 5 | 8 | 70 | 93 | |
| | 55 | - | - | 5 | 5 | 6 | 8 | 78 | 103 | |
| | 60 | - | - | 6 | 5 | 6 | 9 | 86 | 113 | |
| **63** | 10 | - | - | - | - | - | - | 14 | 15 | |
| | 15 | - | - | - | - | - | 7 | 21 | 29 | |
| | 20 | - | - | - | - | 7 | 5 | 33 | 46 | |
| | 25 | - | - | - | 6 | 4 | 6 | 43 | 60 | |
| | 30 | - | - | 5 | 4 | 4 | 7 | 52 | 73 | |
| | 35 | - | 3 | 3 | 4 | 6 | 7 | 61 | 85 | |
| | 40 | - | 4 | 4 | 4 | 6 | 8 | 71 | 98 | |
| | 45 | - | 5 | 4 | 5 | 6 | 9 | 81 | 111 | |
| | 50 | 3 | 3 | 4 | 6 | 6 | 13 | 91 | 127 | |

## APPENDIX IV
## DCIEM 1983 AIR DIVING TABLE 3 (METRES)
## SURFACE DECOMPRESSION WITH OXYGEN

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | | | Decom. Time (min) | Repet. Dive Group |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | In-Water Stops Air | | | | | | Surface Interval | Chamber $O_2$ | | |
| | | 24 | 21 | 18 | 15 | 12 | 9 | | 12 | | |
| **18** | 80 | - | - | - | - | - | - | Time from leaving the 9 msw stop (or the bottom, if no in-water stop is required) to reaching the 12 msw Chamber stop must not exceed **7 minutes**. | 16 | 25 | H |
| | 90 | - | - | - | - | - | - | | 20 | 29 | I |
| | 100 | - | - | - | - | - | - | | 24 | 33 | J |
| | 110 | - | - | - | - | - | - | | 28 | 37 | K |
| | 120 | - | - | - | - | - | - | | 30 | 39 | K |
| | 130 | - | - | - | - | - | - | | 32* | 46 | |
| | 140 | - | - | - | - | - | - | | 38* | 52 | |
| | 150 | - | - | - | - | - | - | | 42* | 56 | |
| | 160 | - | - | - | - | - | - | | 46* | 60 | |
| | 170 | - | - | - | - | - | - | | 50* | 64 | |
| | 180 | - | - | - | - | - | - | | 54* | 68 | |
| | 190 | - | - | - | - | - | - | | 57* | 71 | |
| | 200 | - | - | - | - | - | - | | 60* | 74 | |
| | 210 | - | - | - | - | - | - | | 63** | 82 | |
| | 220 | - | - | - | - | - | - | | 69** | 88 | |
| | 230 | - | - | - | - | - | - | | 73** | 92 | |
| | 240 | - | - | - | - | - | - | | 77** | 96 | |
| **27** | 40 | - | - | - | - | - | - | | 16 | 25 | G |
| | 45 | - | - | - | - | - | - | | 21 | 30 | H |
| | 50 | - | - | - | - | - | - | | 25 | 34 | H |
| | 55 | - | - | - | - | - | 1 | | 28 | 38 | I |
| | 60 | - | - | - | - | - | 2 | | 30* | 46 | J |
| | 70 | - | - | - | - | - | 3 | | 37* | 54 | |
| | 80 | - | - | - | - | - | 4 | | 45* | 63 | |
| | 90 | - | - | - | - | - | 5 | | 52* | 71 | |
| | 100 | - | - | - | - | - | 6 | | 58* | 78 | |
| | 110 | - | - | - | - | - | 7 | | 65** | 91 | |
| | 120 | - | - | - | - | - | 8 | | 74** | 101 | |
| **36** | 25 | - | - | - | - | - | 2 | | 13 | 24 | G |
| | 30 | - | - | - | - | - | 4 | | 21 | 34 | G |
| | 35 | - | - | - | - | - | 6 | | 27 | 42 | H |
| | 40 | - | - | - | - | - | 8 | | 30* | 52 | I |
| | 45 | - | - | - | - | 3 | 6 | | 36* | 59 | J |
| | 50 | - | - | - | - | 4 | 7 | | 42* | 67 | K |
| | 55 | - | - | - | - | 5 | 7 | | 48* | 74 | |
| | 60 | - | - | - | - | 6 | 7 | | 53* | 80 | |
| | 65 | - | - | - | - | 6 | 8 | | 58* | 86 | |

Note: asterisk (*) indicates number of 5 min air breaks required

## APPENDIX IV (continued)
## DCIEM 1983 AIR DIVING TABLE 3 (METRES)
## SURFACE DECOMPRESSION WITH OXYGEN

| Depth (msw) | Bottom Time (min) | Stop Times (min) at Different Depths (msw) | | | | | | | | | Decom. Time (min) | Repet. Dive Group |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | In-Water Stops | | | | | | | Surface | Chamber | | |
| | | Air | | | | | | | Interval | $O_2$ | | |
| | | 27 | 24 | 21 | 18 | 15 | 12 | 9 | | 12 | | |
| **36** | 70 | - | - | - | - | - | 7 | 8 | Time from leaving the 9 msw stop (or the bottom, if no in-water stop is required) to reaching the 12 msw Chamber stop must not exceed **7 minutes**. | 60** | 94 | |
| | 75 | - | - | - | - | - | 8 | 8 | | 70** | 105 | |
| | 80 | - | - | - | - | 2 | 6 | 9 | | 76** | 112 | |
| | 85 | - | - | - | - | 3 | 6 | 10 | | 82** | 120 | |
| | 90 | - | - | - | - | 3 | 7 | 13 | | 87** | 129 | |
| | 95 | - | - | - | - | 4 | 6 | 16 | | 90** | 135 | |
| | 100 | - | - | - | - | 4 | 7 | 19 | | 100*** | 154 | |
| **45** | 20 | - | - | - | - | - | - | 6 | | 17 | 32 | G |
| | 25 | - | - | - | - | - | 4 | 5 | | 27 | 45 | H |
| | 30 | - | - | - | - | - | 6 | 6 | | 30* | 56 | I |
| | 35 | - | - | - | - | 3 | 5 | 7 | | 40* | 69 | K |
| | 40 | - | - | - | - | 4 | 6 | 7 | | 48* | 79 | M |
| | 45 | - | - | - | - | 5 | 6 | 8 | | 55* | 88 | |
| | 50 | - | - | - | - | 6 | 7 | 8 | | 60** | 100 | |
| | 55 | - | - | - | 3 | 5 | 6 | 9 | | 72** | 114 | |
| | 60 | - | - | - | 3 | 5 | 7 | 12 | | 80** | 126 | |
| | 65 | - | - | - | 4 | 5 | 8 | 16 | | 87** | 139 | |
| | 75 | - | - | - | 5 | 6 | 8 | 24 | | 105*** | 172 | |
| | 80 | - | - | - | 6 | 6 | 8 | 28 | | 111*** | 183 | |
| **54** | 15 | - | - | - | - | - | - | 7 | | 15 | 31 | G |
| | 20 | - | - | - | - | - | 6 | 6 | | 28 | 49 | H |
| | 25 | - | - | - | - | 5 | 5 | 7 | | 36* | 67 | J |
| | 30 | - | - | - | 3 | 4 | 6 | 7 | | 47* | 81 | M |
| | 35 | - | - | - | 5 | 4 | 6 | 8 | | 56* | 93 | |
| | 40 | - | - | - | 6 | 5 | 7 | 9 | | 66** | 112 | |
| | 45 | - | - | 4 | 4 | 5 | 7 | 13 | | 78** | 130 | |
| | 50 | - | - | 4 | 5 | 5 | 8 | 18 | | 88** | 147 | |
| | 55 | - | - | 5 | 5 | 6 | 8 | 23 | | 101*** | 172 | |
| | 60 | - | - | 6 | 5 | 6 | 9 | 28 | | 110*** | 188 | |
| **63** | 15 | - | - | - | - | - | 7 | 6 | | 25 | 47 | |
| | 20 | - | - | - | - | 7 | 5 | 7 | | 36* | 69 | |
| | 25 | - | - | - | 6 | 4 | 6 | 8 | | 49* | 87 | |
| | 30 | - | - | 5 | 4 | 4 | 7 | 8 | | 60* | 102 | |
| | 35 | - | 3 | 3 | 4 | 6 | 7 | 12 | | 76** | 130 | |
| | 40 | - | 4 | 4 | 4 | 6 | 8 | 19 | | 88** | 152 | |
| | 45 | - | 5 | 4 | 5 | 6 | 9 | 25 | | 105*** | 183 | |
| | 50 | 3 | 3 | 4 | 6 | 6 | 13 | 29 | | 116*** | 204 | |

Note: asterisk (*) indicates number of 5 min air breaks required

# APPENDIX V
# DCIEM 1983 AIR DIVING TABLE 4
# REPETITIVE DIVE FACTORS

| Repetitive Dive Group First Dive | Surface Intervals (hr:min) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0:30 →0:59 | 1:00 →1:29 | 1:30 →1:59 | 2:00 →2:59 | 3:00 →3:59 | 4:00 →5:59 | 6:00 →8:59 | 9:00 →11:59 | 12:00 →18:00 |
| **A** | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 |
| **B** | 1.3 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 |
| **C** | 1.4 | 1.3 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.1 | 1.0 |
| **D** | 1.5 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 |
| **E** | 1.6 | 1.5 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 |
| **F** | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.3 | 1.2 | 1.1 | 1.1 |
| **G** | 1.9 | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.2 | 1.1 | 1.1 |
| **H** | - | 1.9 | 1.7 | 1.6 | 1.5 | 1.4 | 1.3 | 1.1 | 1.1 |
| **I** | - | 2.0 | 1.8 | 1.7 | 1.5 | 1.4 | 1.3 | 1.1 | 1.1 |
| **J** | - | - | 1.9 | 1.8 | 1.6 | 1.5 | 1.3 | 1.2 | 1.1 |
| **K** | - | - | 2.0 | 1.9 | 1.7 | 1.5 | 1.3 | 1.2 | 1.1 |
| **L** | - | - | - | 2.0 | 1.7 | 1.6 | 1.4 | 1.2 | 1.1 |
| **M** | - | - | - | - | 1.8 | 1.6 | 1.4 | 1.2 | 1.1 |
| **N** | - | - | - | - | 1.9 | 1.7 | 1.4 | 1.2 | 1.1 |
| **O** | - | - | - | - | 2.0 | 1.7 | 1.4 | 1.2 | 1.1 |

## INSTRUCTIONS

1. Determine the **First Dive** Group from the table used.
2. Find the **Repetitive Factor (RF)** from this table under the appropriate **Surface Interval.**
3. Multiply the **Bottom Time** of the **Second Dive** by this **RF** to obtain the **Effective Bottom Time (EBT).**
4. Decompress for the **Depth** and **EBT** of the **Second Dive.**

# APPENDIX VI
# DCIEM 1983 AIR DIVING TABLE 5 (METRES)
# DEPTH CORRECTION FOR DIVING AT ALTITUDE

| Actual Depth (msw) | Depth Correction (msw) at Altitude (metres) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 100 →300 | 300 →600 | 600 →900 | 900 →1200 | 1200 →1500 | 1500 →1800 | 1800 →2100 | 2100 →2400 | 2400 →3000 |
| 9 | +0 | +3 | +3 | +3 | +3 | +3 | +3 | +6 | +6 |
| 12 | +0 | +3 | +3 | +3 | +3 | +3 | +6 | +6 | +6 |
| 15 | +0 | +3 | +3 | +3 | +3 | +6 | +6 | +6 | +6 |
| 18 | +0 | +3 | +3 | +3 | +6 | +6 | +6 | +6 | +9 |
| 21 | +0 | +3 | +3 | +3 | +6 | +6 | +6 | +9 | +9 |
| 24 | +0 | +3 | +3 | +6 | +6 | +6 | +9 | +9 | +12 |
| 27 | +0 | +3 | +3 | +6 | +6 | +6 | +9 | +9 | +12 |
| 30 | +0 | +3 | +3 | +6 | +6 | +9 | +9 | +9 | +12 |
| 33 | +0 | +3 | +6 | +6 | +6 | +9 | +9 | +12 | +15 |
| 36 | +0 | +3 | +6 | +6 | +6 | +9 | +9 | +12 | +15 |
| 39 | +0 | +3 | +6 | +6 | +9 | +9 | +12 | +12 | +15 |
| 42 | +0 | +3 | +6 | +6 | +9 | +9 | +12 | +12 | +18 |
| 45 | +3 | +3 | +6 | +6 | +9 | +9 | +12 | +15 | +18 |
| 48 | +3 | +6 | +6 | +9 | +9 | +12 | +12 | +15 | +18 |
| 51 | +3 | +6 | +6 | +9 | +9 | +12 | +15 | +15 | +21 |
| 54 | +3 | +6 | +6 | +9 | +9 | +12 | +15 | +15 | |
| 57 | +3 | +6 | +6 | +9 | +12 | +12 | +15 | | |
| 60 | +3 | +6 | +6 | +9 | +12 | +12 | | | |
| 63 | +3 | +6 | +6 | +9 | | | | | |
| 66 | +3 | +6 | | | | | | | |
| 69 | +3 | | | | | | | | |

| Sea Level Stop Depth (msw) | Actual Stop Depth (msw) at Altitude (metres) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 100 →300 | 300 →600 | 600 →900 | 900 →1200 | 1200 →1500 | 1500 →1800 | 1800 →2100 | 2100 →2400 | 2400 →3000 |
| 3 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 2.5 | 2.5 | 2.5 | 2.5 |
| 6 | 6.0 | 6.0 | 6.0 | 5.5 | 5.5 | 5.0 | 5.0 | 5.0 | 4.5 |
| 9 | 9.0 | 9.0 | 8.5 | 8.5 | 8.0 | 7.5 | 7.5 | 7.0 | 7.0 |
| 12 | 12.0 | 12.0 | 11.5 | 11.0 | 10.5 | 10.0 | 10.0 | 9.5 | 9.0 |
| 15 | 15.0 | 14.5 | 14.0 | 13.5 | 13.0 | 12.5 | 12.0 | 12.0 | 11.5 |
| 18 | 18.0 | 17.5 | 17.0 | 16.5 | 16.0 | 15.0 | 14.5 | 14.0 | 13.5 |
| 21 | 21.0 | 20.5 | 20.0 | 19.0 | 18.5 | 17.5 | 17.0 | 16.5 | 16.0 |