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# EVALUATION OF DIFFERENT DECOMPRESSION TABLES BY AGAROSE GEL METHOD

BY

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## ABSTRACT

Nine different decompression tables were evaluated by the method of bubble formation in the agarose gel, the result of which is summarized as follows:

1) The number of bubbles formed in the agarose gel corresponded well with the exposed pressure.

2) The technique of this method was simple and the number of bubbles was accurately counted.

3) This method was considered useful for examining the decompression tables.

4) Using an equation obtained from the experiment with the same agarose gel, the critical number of bubbles at the end of decompression was found to be 6.6.

5) From this point of view, the R.N.P.L. Table of England and Mano's Model I Table were considered to be excellent.

6) The first stop at the deeper level during the ascent resulted in a smaller number of bubbles at the end of decompression, indicating the effectiveness of this procedure for the prevention of decompression sickness.

## INTRODUCTION

In 1908 J. S. Haldane *et al.* [1] presented a theory that a person could quickly and safely come back to the surface of the sea after diving as long as he liked, if he stayed within the depth of 12.5 m. They assumed the critical ratio of decompression as 2:1 ("the Haldane ratio") and published a decompression schedule in order to prevent decompression sickness. This schedule has been modified several times to decrease the incidence of decompression sickness. The U.S. Navy Table [2], the French Navy Table [3] and the Japanese Standard Decompression Schedule No. 2 [4] were designed on the basis of "the Haldane ratio principle" and are now widely used.

Hempleman *et al* [10] pointed out the importance of the $N_2$ gas diffused in the human body. The bubbles in the tissues originate from the pre-existing nuclei, and the gas initially diffuse into the gas nuclei in the tissue and is then frothed out by decompression depending on the difference between the inside tension of the gas nuclei and the surrounding tension of the tissue. According to this theory, a new decompression table was developed by the Royal Naval Physiological Laboratory [5]. The Blackpool Table of England [11] for compressed air work and the Decompression Table by the Ministry of Labor of France [6] were also designed, based on this theory. Previously, K. Yano and Y. Mano [25] evaluated the Japanese Standard Decompression Schedule by the method of bubble formation in the agarose gel, the results of

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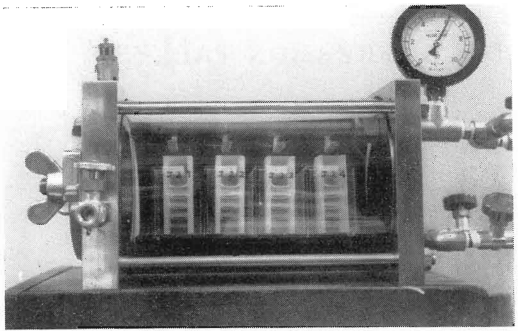

Fig. 1. Apparatus for the experiment.

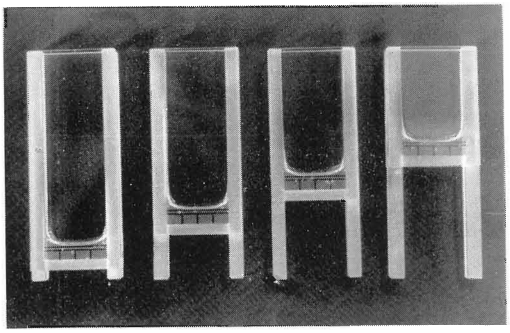

Fig. 2. Counting cells and agarose gel subjected to the decompression schedule.

which were that the number of bubbles increased in proportion to the period of bottom time when staying at the same depth, a deeper first stop resulting in a smaller number of bubbles, and that the coefficient of body pressure was not necessarily correlated with the number of bubbles.

A comparative study on the nine different decompression tables were attempted using this method. The agarose gel cells were exposed to the pressure of 4ATA, the decompression was carried out according to the different schedules of each table and then the number of bubbles formed at each stop and at the end of decompression in the agarose cells was counted.

## MATERIALS AND METHODS

The pressure vessel (Fig. 1) is composed of a plexiglass cylinder with a pressure gauge and an adaptor to the gas cylinder, a safety valve and an air exit for decompression [14]. The glass counting cell (Fig. 2) is rectangular and its inside dimension is 15×6 mm and provided with a plexiglass holder. There are two horizontal red lines on the wall of the cells, each line being 4 and 3 mm from the bottom of each cell. They were filled with an agarose solution to the depth of 4 mm (the upper red line) and the volume amounted to 0.36 m*l*. After gelation, there agarose samples were exposed to a predetermined pressure for a predetermined period of time. As the purpose of this experiment was to evaluate the different decompression tables, the bottom pressure was set at 4ATA and the decompression was carried out according to the tables. The room temperature was kept in the range of 19°C to 22°C throughout the experiment. The bubbles formed 3 mm from the bottom (below the lower red line) were counted, and the total volume of the gel amounted to 0.27 m*l* [8, 14].

A stock solution containing 1.0 mM of Tris [(hydroxymethyl)-aminomethane, $NH_2C(CH_2OH)_3$] buffer was prepared first [8]. The pH was adjusted to 7.4 in each experiment by adding a small quantity of HCl. The buffered solution was heated to 80°C, and thereafter a highly purified agarose powder [by Bio-Rad Lot. No. 16320 (moisture content=4.0%, sulfer content<0.1%)] was added to the solution (0.5% W/W) and agitated carefully for ten minutes. The agarose solution was then poured into the counting cells previously made acid-free and subjected to the experiments.

In this experiment, nine different decompression tables were chosen for the purpose of evaluation. There were six tables for diving—the U.S. Navy Table, the French Navy Table, the Japanese Standard Decompression Schedule No. 2, the R.N.P.L.

Table 1. Bubble formation in different decompression schedules for compressed air work

| Schedule (depth) | Bottom Time | Decompression Time (Bubble Number $\bar{X}$) (k : kg/cm$^2$, p : psi.) | | | | | | | $\bar{X}$ | S.D. | S.E. | Total Decompression Time | Temp. (°C) | Coefficient of Body Pressure |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 28 psi. | 1.8k≒24p | 1.5k≒20p | 1.2k≒16p | 0.9k≒12p | 0.6k≒8p | 0.3k≒4p | 0.0 kg/cm$^2$=0 psi. | | | | | |
| Blackpool (44 psi.) | 60 | | | | | 5 (0.6) | 15 (2.3) | 50 (3.6) | (3.6) | (2.0) | (0.7) | 80′ | 25.6 | |
| | 120 | | | | 10 (2.8) | 30 (5.2) | 50 (5.3) | 60 (5.3) | (5.3) | (1.1) | (0.3) | 160′ | 25.5 | |
| | 240 | | 5 (2.9) | 10 (7.7) | 30 (10.5) | 40 (10.8) | 45 (10.8) | 60 (10.8) | (10.8) | (1.2) | (0.4) | 200′ | 25.5 | |
| | 360 | | 5 (5.2) | 20 (10.8) | 35 (11.0) | 40 (11.0) | 60 (11.0) | 110 (11.0) | (11.0) | (2.7) | (0.7) | 280′ | 25.8 | |
| Washigton (44 psi.) | 60 | 3 (0) → | | | | ~16 (0.3) | | ~ 20 (3.3) | ~ 25 (4.5) | (1.5) | (0.4) | 64′ | 25.8 | |
| | 120 | 3 (0) → | | | | ~16 (6.1) | | ~ 40 (7.1) | ~ 95 (7.5) | (1.3) | (0.5) | 154′ | 25.8 | |
| | 240 | 3 (0.1) → | | | | ~16 (11.2) | | ~ 85 (12.5) | ~130 (12.5) | (2.8) | (0.8) | 234′ | 26.0 | |
| | 360 | 3 (3.7) → | | | | ~16 (14.6) | | ~115 (17.9) | ~130 (18.0) | (1.8) | (0.6) | 264′ | 26.1 | |
| Japan No.1 (3.0 kg/cm$^2$) | 30 | | | | | | | 5 (0.1) | (1.7) | (1.1) | (0.4) | 8′45″ | 26.1 | 1.5 |
| | 60 | | | | | | 13 (1.7) | 20 (3.4) | (4.6) | (0.7) | (0.3) | 36′45″ | 25.5 | 1.9 |
| | 120 | | | | | 13 (5.3) | 30 (8.9) | 45 (8.9) | (8.9) | (2.6) | (0.9) | 91′45″ | 26.5 | 2.1 |
| | 210 | | | | | 26 (12.0) | 40 (13.3) | 75 (13.3) | (13.3) | (3.2) | (1.1) | 144′45″ | 27.6 | 2.2 |

Table 2. Bubble formation in different decompression schedules for diving

| Schedule (depth) | Bottom Time | Decompression Time (Bubble Number $\bar{X}$) | | | | | | $\bar{X}$ | S.D. | S.E. | Total Decompression Time | Temp. (°C) | Coefficient of Body Pressure |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 18m≒60ft | 15m≒50ft | 12m≒40ft | 9m≒30ft | 6m≒20ft | 3m≒10ft | 0m=0ft | | | | | |
| U.S.N. (100 ft) | 25 | | | | | | | (2.7) | (1.0) | (0.3) | 1′40″ | 26.2 | H |
| | 50 | | | | | 2 (0.6) | 24 (2.9) | (4.1) | (1.6) | (0.5) | 27′40″ | 25.5 | H |
| | 80 | | | | | 23 (4.6) | 48 (6.5) | (6.5) | (1.7) | (0.5) | 72′40″ | 25.5 | 0 |
| | 120 | | | | 12 (8.6) | 41 (10.5) | 78 (11.3) | (11.3) | (2.8) | (0.8) | 132′40″ | 27.1 | Z |
| R.N.P.L. (100 ft) | 15 | | | | | | | (0.3) | (0~1) | (0.2) | 1′40″ | 25.5 | |
| | 50 | | | 5 (0) | | 85 (1.1) | | (2.4) | (1.3) | (0.5) | 91′40″ | 25.8 | |
| | 75 | | 5 (0) | | 5 (0.5) | 140 (3.5) | | (3.5) | (1.3) | (0.4) | 151′40″ | 25.6 | |
| | 120 | 5 (0) | | 5 (2.4) | 20 (5.1) | 170 (6.6) | | (6.6) | (1.6) | (0.5) | 201′40″ | 25.8 | |
| Model 1 (100 ft) | 25 | | | | | | 15 (0.1) | (0.7) | (0.5) | (0.2) | 38′50″ | 25.9 | K |
| | 50 | | | | | 9 (0.6) | 28 (2.3) | (3.1) | (2.0) | (0.7) | 60′50″ | 27.0 | N |
| | 80 | | | | 3 (2.1) | 23 (3.4) | 57 (3.9) | (3.9) | (1.0) | (0.3) | 106′50″ | 25.5 | Z |
| | 120 | | | 1 (1.5) | 29 (4.9) | 53 (5.1) | 118 (5.1) | (5.1) | (2.4) | (0.6) | 224′50″ | 26.0 | ** |
| Japan No.2 (30 m) | 25 | | | | | | | (2.2) | (1.1) | (0.4) | 3′ | 26.6 | 1.5 |
| | 50 | | | | | 8 (0.9) | 16 (2.8) | (4.8) | (1.9) | (0.5) | 27′ | 27.6 | 1.8 |
| | 85 | | | | 5 (2.0) | 27 (6.3) | 22 (6.5) | (6.5) | (1.2) | (0.4) | 57′ | 26.0 | 2.2 |
| | 130 | | | | 17 (7.8) | 29 (10.4) | 48 (10.4) | (10.4) | (2.7) | (0.9) | 97′ | 25.5 | 2.2 |
| France N. (30 m) | 30 | | | | | | | (1.6) | (0.9) | (0.3) | 1′40″ | 26.0 | 1.5 |
| | 50 | | | | | | 21 (4.1) | (5.3) | (1.8) | (0.7) | 22′40″ | 27.2 | 1.7 |
| | 60 | | | | | | 37 (5.3) | (6.2) | (1.3) | (0.4) | 38′40″ | 25.5 | 1.8 |
| | 70 | | | | | 5 (1.8) | 47 (6.1) | (6.2) | (1.7) | (0.5) | 53′40″ | 27.0 | 1.8 |
| France Lab. (30 m) | 15 | | | | | | | (0.3) | (0~2) | (0.2) | 1′40″ | 25.5 | |
| | 30 | | | | | | 10 (0.6) | (1.6) | (0.8) | (0.3) | 11′40″ | 26.2 | |
| | 60 | | | | | 15 (1.8) | 30 (3.3) | (4.5) | (0.9) | (0.3) | 46′40″ | 25.7 | |
| | 100 | | | | 12 (4.6) | 31 (7.9) | 44 (8.9) | (8.9) | (2.2) | (0.8) | 88′40″ | 25.6 | |

Table, the Table by the Ministry of Labor of France and the Model I Table by Mano—and three tables for compressed air work—the Washington Table, the Blackpool Table and the Japanese Standard Decompression Schedule No. 1. In order to make the comparison easy, the bottom pressure was set at 4ATA (100 ft ≑ 30 m ≑ 3.0 kg/cm ≑ 44 psi). The bottom time was determined for 15 to 130 minutes for the diving tables and 30 to 360 minutes for the compressed air work tables. Sixteen agarose cells as a unit were pressurized and decompressed simultaneously according to each decompression table. The number of bubbles in each cell was counted at each stop time in the process of decompression and at the end of decompression and then the average number of bubbles and the standard deviation was calculated.

## RESULTS

When drawing the figures representing the relationship between the number of

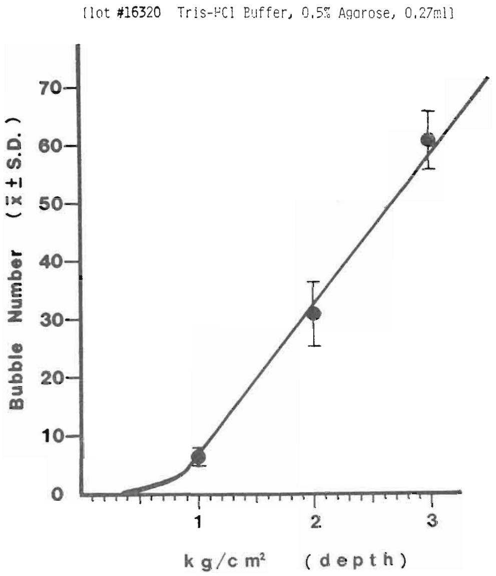

Fig. 3. Bubble formation in saturation dive.

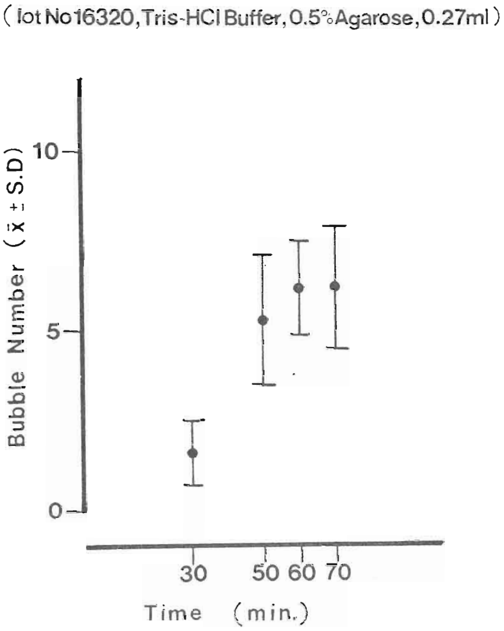

Fig. 5. Bubble formation in France Navy at 30 meters.

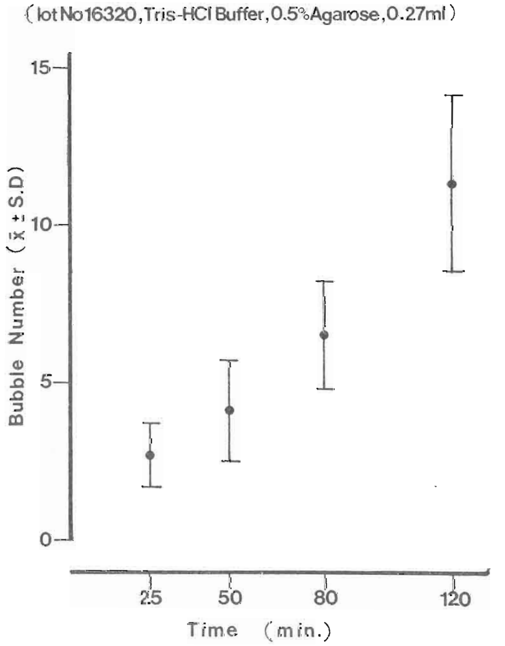

Fig. 4. Bubble formation in U.S. Navy at 100 feet.

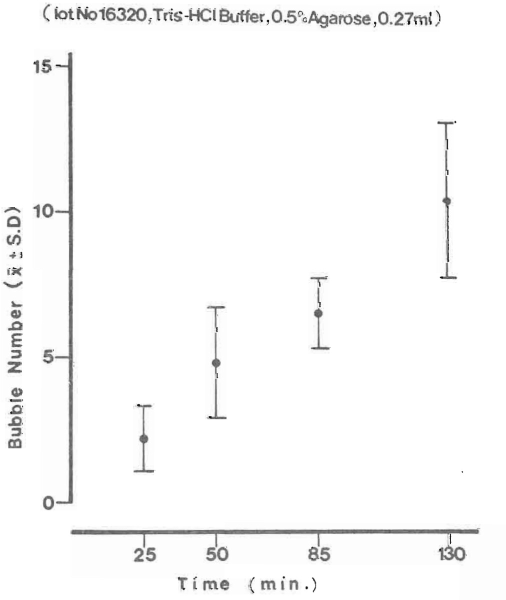

Fig. 6. Bubble formation in Japan No. 2 at 30 meters.

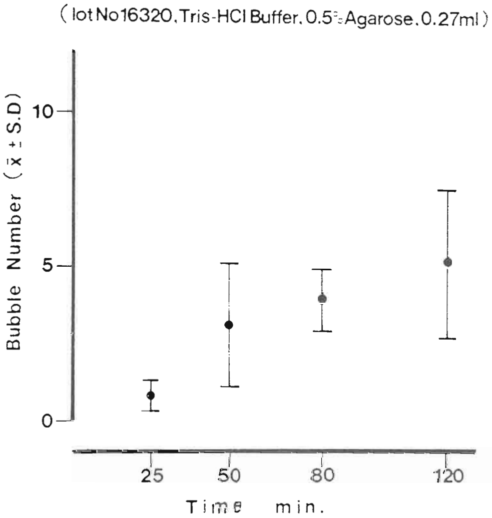

Fig. 7. Bubble formation in R.N.P.L. at 100 feet.

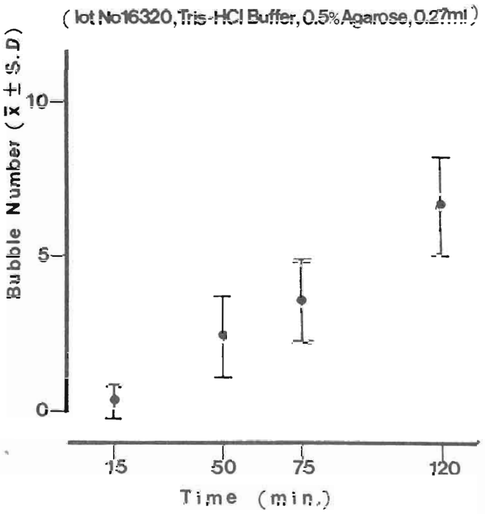

Fig. 9. Bubble formation in Model I at 100 feet.

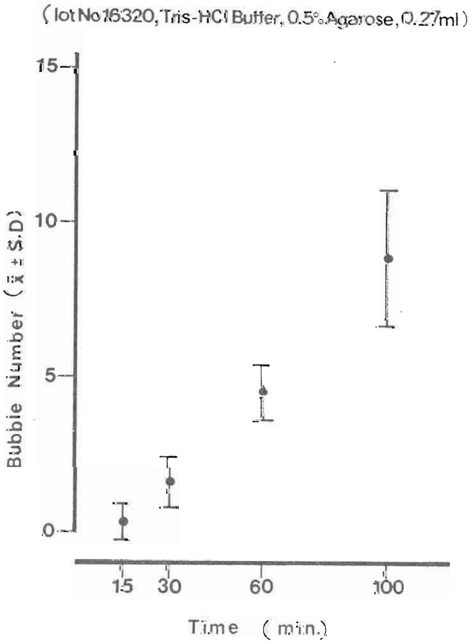

Fig. 8. Bubble formation in France Lab. at 30 meters.

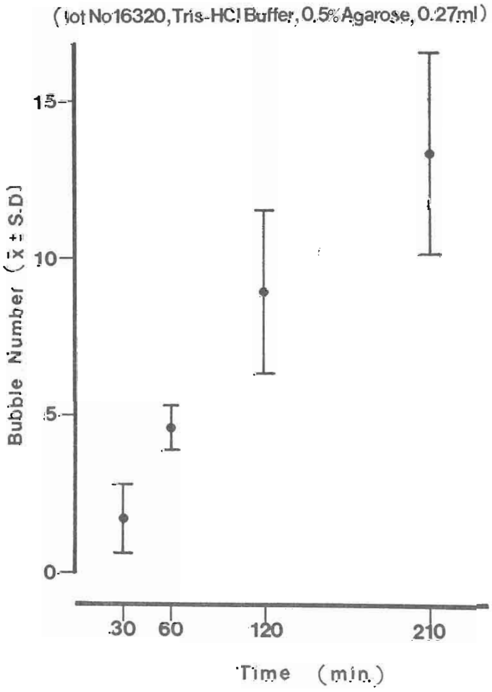

Fig. 10. Bubble formation in Washington at 44 psi.

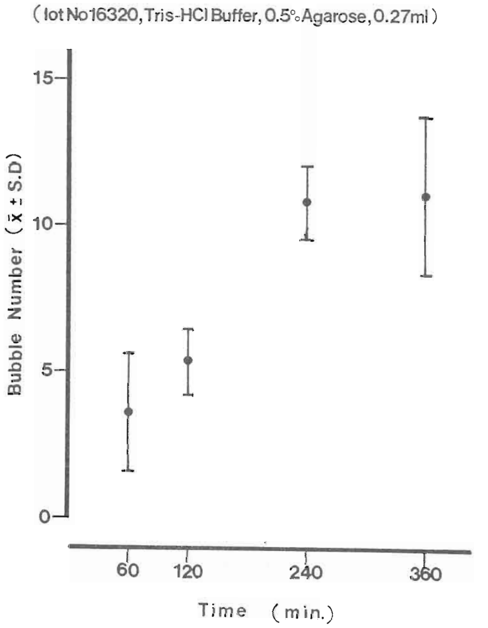

Fig. 11. Bubble formation in Blackpool at 44 psi.

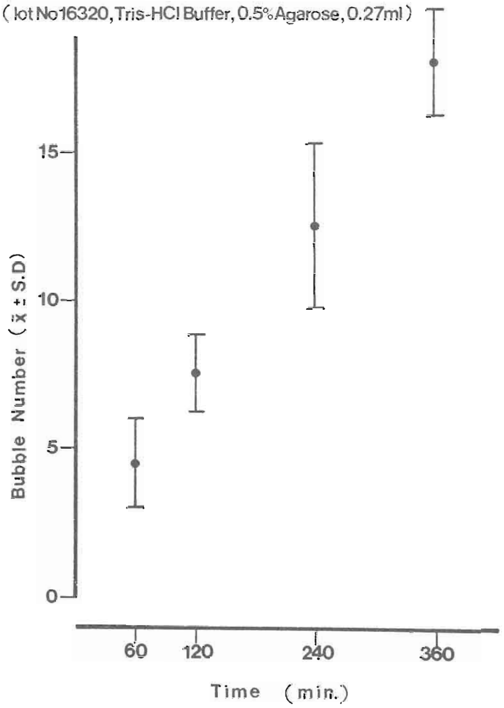

Fig. 12. Bubble formation in Japan No. 1 at 3.0 kg/cm$^2$.

bubbles and the bottom time, attempt was made to unify the bottom time of each decompression table for exact comparison but this was impossible since the range of the bottom time was wide. The maximum period of bottom time which required no decompression after diving was considered as the shortest bottom time of the figures. Namely, decompression is not necessary after diving less than 25 minutes, according to the U.S. Navy Table (see Table 2), and this figure was selected as the minimum bottom time. This figure was 15 minutes in the R.N.P.L. Table and the Table by the Ministry of Labor of France, and was 25 minutes in the U.S. Navy Table, the Japanese Standard Decompression Schedule No. 2 and the Model I Table. In the French Navy Table, it was 30 minutes. Thus the maximum period of bottom time which required no decompression after diving is different at 4ATA dive, depending on each table. The maximum period of bottom time at 4ATA was the shortest in the French Navy Table (70 minutes), but it was relatively long in the U.S. Navy Table (120 minutes), the R.N.P.L. Table (120 minutes) and the Japanese Decompression Schedule No. 2 (103 minutes). These figures were considered as the longest bottom time of the figures. Moreover, two bottom time figures were selected from the former two to make the comparison appropriate (see Fig. 4 to 9).

1) The U.S. Navy Table [2, 15]

Fig. 4 shows the number of bubbles at the end of decompression by the 25, 50, 80 and 120-minute bottom time exposure at 4ATA, being 2.7±1.0, 4.1±1.6, 6.5±1.7 and 11.3±2.8, respectively, which indicated that the increase of the number of bubbles was in proportion to the length of the bottom time. If 11.3±2.8 bubbles formed at the end of decompression by the 120-minute bottom time exposure were the uppermost limit of safety diving, the decompression time by the 25, 50 and 80-minute bottom time exposure could be shortened until the number of bubbles reached 11.3±2.8, and a longer decompression time would be required in the decompression table showing the number of bubbles above that level at the end of decompression. Anyway, if the application of the decompression table is safe for the divers, a shorter total decompression time is more advantageous for them.

2) The French Navy Table [3]

According to Fig. 5, the maximum period of bottom time at 4ATA is the shortest, that is, the limitation is the strictest. But the maximum period of bottom time which needs no decompression after diving is the longest of these six diving tables. In this table, the number of bubbles at the end of decompression was 1.6±0.9 by the 30-minute bottom time exposure, while in the U.S. Navy Table the number of bubbles at the end of decompression was 2.7±1.0 by the 25-minute bottom time exposure. The time required for the ascent was 1 minute 40 seconds in both tables. Although the bottom time was shorter by 5 minutes, the number of bubbles of the latter was a little larger than that of the former, but it seems to be within the range of standard deviation. The number of bubbles at the end of decompression did not increase so much in proportion to the increase of the bottom time, but it might be because the difference in the bottom time was not significant.

3) The Japanese Standard Decompression Schedule No. 2 [4]

The result is shown in Fig. 6. In this table the number of bubbles was almost the same as that in the U.S. Navy Table. The longer the bottom time was, the larger became the number of bubbles. These three tables were designed on the basis of "the Haldane ratio principle" and they resemble each other.

4) The R.N.P.L. (Royal Navy Physiological Laboratory) Table [5]

The result is shown in Fig. 7. The maxi-

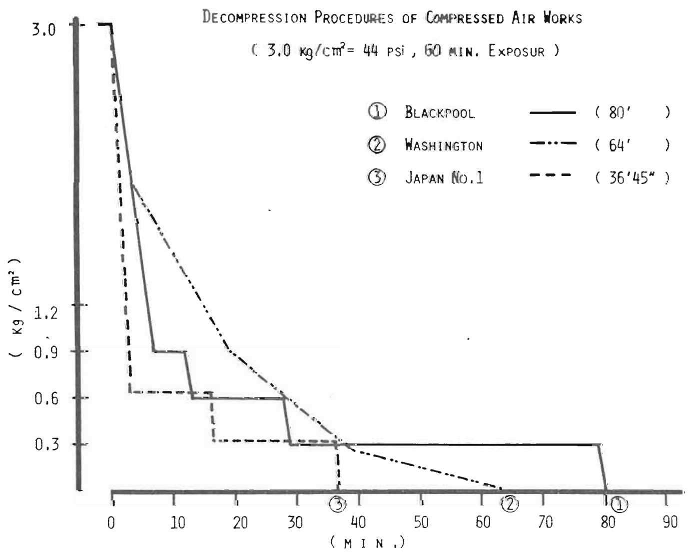

Fig. 13. Procedures of decompression schedules (30 m, 60 min) for compressed air work.

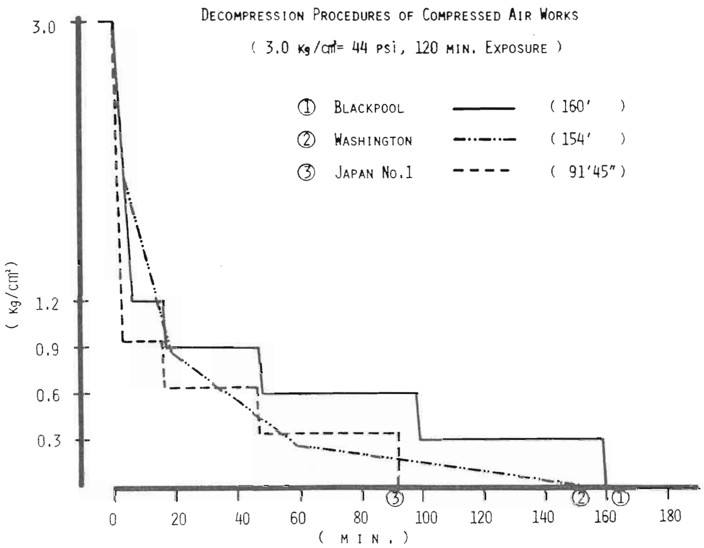

Fig. 14. Procedures of decompression schedules (30 m, 120 min) for compressed air work.

mum bottom time which requires no decompression after diving is 15 minutes and is the shortest among the tables studied. The number of bubbles at the end of decompression was 6.6±1.6 by the 120-minute exposure, which was significantly small compared with 11.3±2.8 in the U.S. Navy Table under the same condition. The first stop during the ascent is generally at the deeper level and the last stop is at the 20-foot depth, while it is set at the 10-foot depth in the former three tables which originated from the "Haldane ratio principle".

5) The Table by the Ministry of Labor of France [6]

As is indicated in Fig. 8, much consideration about safety is paid in this table, as compared with the French Navy Table. The maximum period of bottom time which requires no decompression after diving is one-half as long as that in the French Navy Table, and ten minutes of decompression is obligatory by the 30-minute bottom time exposure, whereas decompression is not required under the same condition according to the French Navy Table. The first stop during the ascent in this table is set at a deeper level, and the total decompression time is also longer than that in the French Navy Table, the reason for which is that this table originated from Hempleman's gas diffusion theory. In this table, the number of bubbles at the end of decompression was 4.5±0.9 by the 60-minute bottom time exposure and was about three-fourths of that in the French Navy Table under the same condition.

6) The Model I Table [8, 13, 16, 17]

This table was published by Y. Mano as a modification of the U.S. Navy Table. The practical application of this schedule in salvage work resulted in a significant reduction of "bends" (0.32%). As is shown in Fig. 9, the number of bubbles at the end of decompression was the smallest among these six tables, including the R.N.P.L. Table. In this table, the number of bubbles at the end of decompression was 3.9±1.0 by the 80-minute bottom time exposure, while in the R.N.P.L. Table, it was 3.5±1.3 by the 75-minute bottom time exposure. In this table, the total decompression time is 106 minutes 50 seconds. It is worth noticing that the number of bubbles at the end of decompression in the two tables was almost the same and that the total decompression time in this table was shorter than that in the R.N.P.L. Table by one-third of the total decompression time, in spite of the fact that the bottom time in this table was longer by 5 minutes than that in the latter.

The following three tables are for compressed air work.

7) The Washington Table [7]

This table was issued by Sealey of the U.S.A. and employs rectilineal decompression, as shown in Fig. 13 and 14. The reason why the number of bubbles was generally large compared with that of the decompression tables for diving is that the period of bottom time was extraordinarily long. As is indicated in Fig. 10, the number of bubbles at the end of decompression was 18.0±1.8 by the 360-minute bottom time exposure, which seemed too large from the point of view of safety against decompression sickness. As a whole, it is doubtful whether it could be an adequate decompression table, since the number of bubbles at the end of decompression increased in proportion to the increase of the bottom time.

8) The Blackpool Table of England [11]

The number of bubbles at the end of decompression was the smallest of the three decompression tables for compressed air

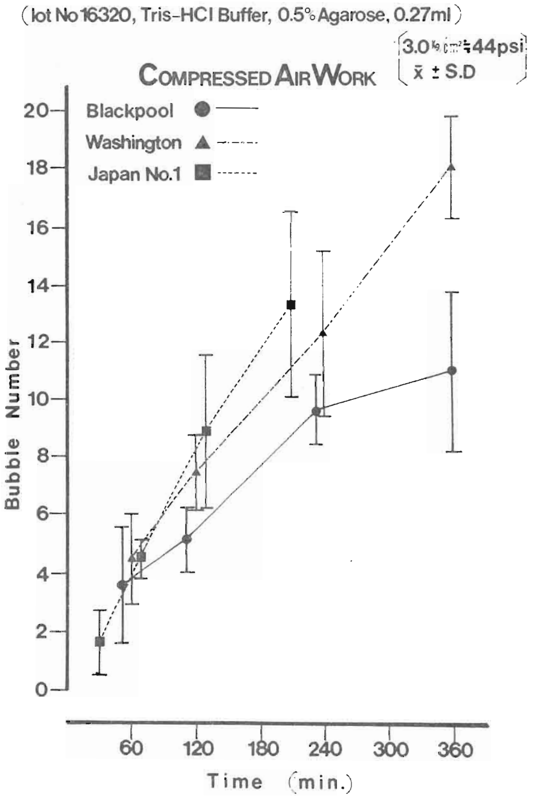

Fig. 15. Bubble formation in different decompression schedules for compressed air work.

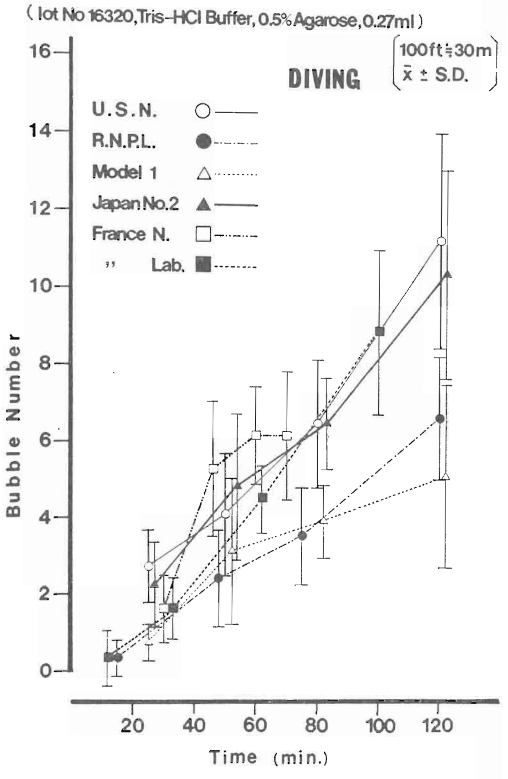

Fig. 16. Bubble formation in different decompression schedules for diving.

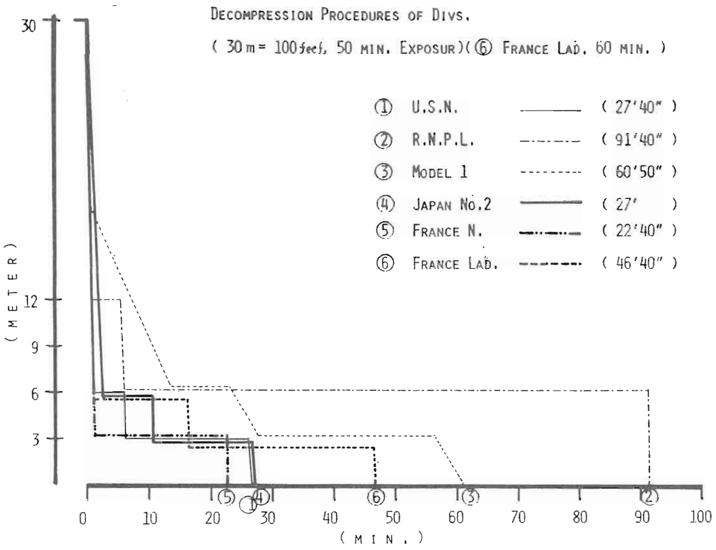

Fig. 17. Procedures of decompression schedules for diving

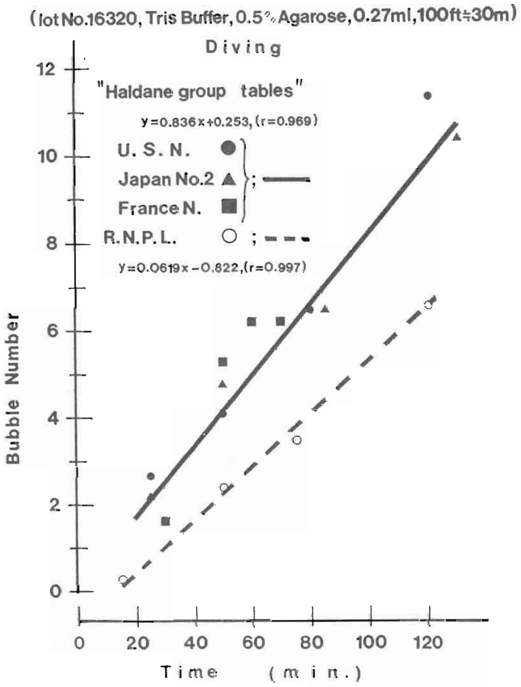

Fig. 18. Regression lines of Haldane group and R.N.P.L.

work (Fig. 11). The bottom time of 360 minutes was selected for comparison with the Washington Table. Originally, the same decompression table was used in the cases of 4 to 8-hour exposure, but the number of bubbles at the end of decompression by the 8-hour bottom time exposure will be larger, since the human body may not be completely saturated by exposure of eight hours or so at this depth.

In this table, however, the number of bubbles at the end of decompression by the 60, 120 and 240-minute bottom time exposure was smaller than that in the Washington Table and the Japanese Standard Decompression Schedule No. 1 under the same condition, and it suggests that the safety of this table was higher than that of the other two.

9) The Japanese Standard Decompression Schedule No. 1 [12]

The Japanese compressed air workers are usually pressurized twice a day by the system called "split shift", while in the U.S.A. and England they are pressurized once a day. It was considered improper to compare this table with the other two, as each bottom time is fairly different. The number of bubbles at the end of decompression

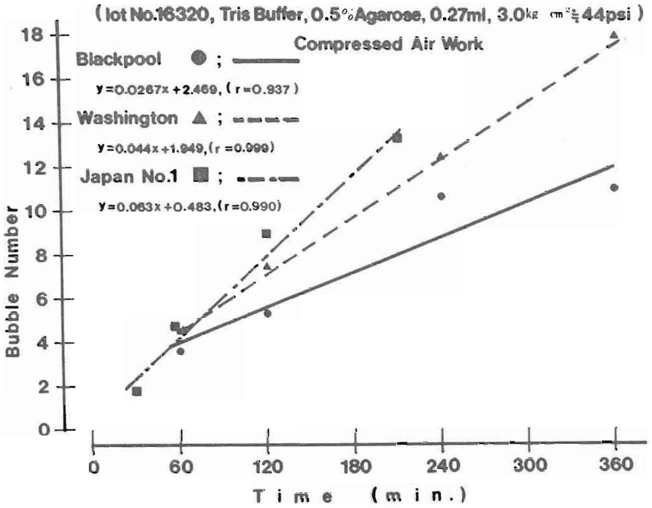

Fig. 19. Regression lines of different decompression schedules for compressed air work.

was generally larger than that in the other two by the 120 to 210-minute bottom time exposure (Fig.12).

## DISCUSSION

Evaluation of the decompression tables, which are now used all over the world, is mainly done by the incidence of decompression sickness. But the incidence varies so much depending on each reporter even if the same decompression table is used. In Japan, the average percentage of contracting "bends", using the Japanese Standard Decompression Schedule No. 1 for compressed air work, is 0.54% (22 bends versus 4,042 trials) [19]. But Mano *et al.* [18] reported it was 1.42% (15 bends versus 1,056 trials) to 3.3% (42 bends versus 1,267 trials). Nashimoto *et al.* [20] reported it was 6.4% and Morita *et al.* [21] 4.5%. Thus, the incidence in Japan ranged from 0.54 to 6.4% and was quite different even if the same decompression table was applied. The difference in these values might be due to the fact that the Japanese workers are likely not to observe the decompression table faithfully. Walder of England [24] said that an incidence of "bends" of about 2% was inevitable. There was a report that the percentage was 0.66%, using the Washington Table [22]. Griffiths reported it was 1.5 to 2.0% [23]. Therefore, it is not recommendable to evaluate different decompression tables depending only on the incidence of the decompression sickness.

As is shown in Table 1 and Fig. 15, the number of bubbles formed at the end of decompression in the Blackpool Table was smaller than that in the Japanese Standard Decompression Schedule No. 1 and the Washington Table. Fig. 14 shows the profiles of decompression by the 100-foot-120-minute bottom time exposure in these three different decompression tables. The total decompression time in the Blackpool Table is the longest, that in the Washington Table is the next longest and that in the Japanese Standard Decompression Schedule No. 1 is the shortest. According to Fig. 14, in the Blackpool Table the first stop is made for 10 minutes at the depth of 1.2 kg/km$^2$, the second for 30 minutes at the depth of

0.9 kg/cm², the third for 50 minutes at the depth of 0.6 kg/cm² and the last for 60 minutes at the depth of 0.3 kg/cm². Namely, a deeper first stop and three more stops are made, requiring a 160-minute total decompression time. In the Washington Table, the decompression is not stepwise, but gradual. It takes 16 minutes to reach the depth of 0.9 kg/cm² from the bottom, 40 minutes to reach the depth of 0.3 kg/cm² and 95 minutes more to reach the surface. So the total decompression time is 154 minutes. In the Japanese Standard Decompression Schedule No. 1, the first stop for 13 minutes is made at the depth of 0.9 kg/cm², the second 30 minutes at the depth of 0.6 kg/cm² and the third 45 minutes at the depth of 0.3 kg/cm². The total decompression time is 91 minutes. As has already mentioned [25], it is recommended to have the decompression time longer, and at the same time a deeper first stop should be made for an ideal decompression.

Table 2 and Fig. 16 show the number of bubbles formed at the end of decompression in the six different decompression tables for diving. The profile of decompression in these tables by the 100-foot depth-50 minute bottom time exposure is shown in Fig. 17. The total decompression time in the R.N.P.L. Table is the longest in these six tables. The relation between the bottom time and the number of bubbles at the end of decompression in the three decompression tables, based on the "Haldane ratio principle", that is the U.S. Navy Table, the Japanese Standard Decompression Schedule No. 2 and the French Navy Table, is expressed by the following equation:

$$y=0.0836\times+0.253$$

$$r=0.969 \text{ (significant, } \alpha=0.01)$$

The line, showing the relation between the bottom time and the number of bubbles at the end of decompression in the R.N.P.L. Table, was clearly located under the straight line which represents the equation above (Fig. 18). Namely, the number of bubbles in the R.N.P.L. Table, based on the gas diffusion theory, was significantly smaller than those in the other decompression tables for diving, except for the Model I Table. As shown in Fig. 17, it is worth noticing that the first stop in the R.N.P.L. Table is at the depth of 40 feet, which is made at a point deeper than that in the three other tables, based on the "Haldane ratio principle". The Model I Table employs the gradual slow ascent from the depth of 70 feet in place of stepwise decompression. There is a tendency that the deeper the first stop is made, the smaller the number of bubbles becomes.

The agarose counting cells of the same kind, as used in the experiment above, were saturated with air at the predetermined pressure, decompressed rapidly and the number of bubbles at the end of each decompression in the samples was counted, the result of which is shown in Fig. 3. The number of bubbles at the end of decompression by the 1.0 kg/cm² (2ATA) 2.0 kg/cm² and 3.0 kg/cm² exposure was 6.6±1.6, 30.8±5.5 and 61.1±4.9, respectively. From these figures the next equation was obtained:

$$\bar{x}=25.725\,Ps-44.85$$

$\bar{x}$; average number of bubbles
Ps; absolute saturation pressure
$Ps\geqq 0.9\ \text{kg/cm}^2=1.9\ \text{ATA}$

According to the "Haldane ratio principle", a person never suffers from decompression sickness by a rapid ascent, if he stays within the depth of 12.5 m as long as he likes. The absolute pressure at the depth of 12.5 m is 2.25 ATA. So when Ps is 2.25, $\bar{x}$ becomes 13.03, which means that a person never suffers from decompression sickness, if the average number of bubbles at the end of decompression in a decompression table is smaller than 13.03. For example, in the U.S. Navy Table, the number of bubbles at the end of decompression is 11.3±2.8 by the 100-foot-120-minute bottom time exposure. It shows that the number 11.3±2.8 is smaller than the limit of safety 13.03 and it proves the reliability of this table under this condition. Taking a wider margin of safety, if the depth of 10 m is taken in the equation above, $\bar{x}$ becomes 6.6. In the R.N.P.L. Table, the number of bubbles at the end of decompression was by chance 6.6±1.6 by the 100-foot-120-minute bottom time exposure. Also in the Model I Table, the number of bubbles under the same condition was smaller than 6.6 With regard to this problem, however, further evaluation is necessary.

## CONCLUSION

1) Evaluation of the decompression table can be done by basing on the incidence of decompression sickness. But it may be inaccurate, since the decompression table is not always followed faithfully by the workers for various reasons.

2) The coefficient of body pressure is used to estimate the residual $N_2$ gas in the human body after decompression. But it is not always accurate.

3) Using the equation ($\bar{x}=25.725\ Ps-44.85$) obtained from one of the experimental research works, the limit of safety in a decompression table can be easily known from the number of bubbles obtained by this method.

4) Different decompression tables can be compared and evaluated with each other, through the number of bubbles at the end of decompression under each condition by diving or by compressed air work (depth, bottom time, profile of decompression and so forth). This fact was found by this study.

5) By using this method, it becomes possible to analyze the unknown patterns of diving or to examine the content of the compressed air work from the point of view of labor hygiene.

6) Six different decompression tables for diving were evaluated by this method and the R.N.P.L. Table was concluded to be the most excellent (except for the Model I Table). Similarly, three other decompression tables for compressed air work were evaluated and the Blackpool Table was estimated to be the best (Fig. 19).

7) The agarose gel method may be useful for the development of a new decompression table to decrease the incidence of decompression sickness including aseptic bone necrosis.

8) When a new decompression table is developed in the near future, the evaluation of the table may be possible by this method. The number of bubbles at the end of decompression increases in proportion to the depth and bottom time in every decompression table now in use, which means that the risk of suffering from decompression sickness increases at the same time. Development of a new decompression table, in which the number of bubbles by this method is kept under the limit of safety, is needed.

9) It is desirable that a new decompression table, in which the number of bubbles in the agarose gel cell at the end of decompression is always kept smaller than 6.6 under any condition of exposure, is needed.

10) For that purpose, the number of bubbles in the agarose gel cell at the first stop during decompression should be as small as possible, and a deeper first stop in the new decompression table is needed than that in the decompression tables used now.

11) Bubble formation in the agarose gel provides a useful tool for evaluating the

different decompression tables. It is also convenient for comparing and examining the difference in the reliability of the ways of decompressing under various conditions (depth, bottom time, decompression profile and so forth) in the decompression table.

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