PEARL DIVERS DIVING SAFETY

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1. SUMMARY

The Western Australian pearling industry obtains its supply of pearl oysters from the wild stocks by means of divers operating in depths from shallow water to about 35 metres. The industry adopted a number of dive profiles, different profiles for different depths, for safe diving. These profiles formed part of the Code of Practice prepared by the Pearl Producers Association.

A three year research program was undertaken, 1991/92 to 1993/94, to test the profiles in a recompression chamber purchased by the pearling industry and donated to the Broome Public Hospital. Volunteer divers from the pearling industry made the testing progam possible.

The seven profiles in the 11 to 23 depth categories have been tested in the recompression chamber, and as a result of those tests each has been modified, some more than once. Only four of the modified profiles have been tested twice. Successful testing means that a profile was tested for eight consecutive days without unaccapteble bubble counts being recorded.

All of the profiles should be tested a number of times to obtain information on the variability of diver "bubbling".

The 19 metre, 21 metre and 23 metre depth catagories require further modification. The first two depth profiles produced high bubble counts in the recompression chamber, and the decompression illness recorded since 1991 came mainly from these depths. The 23 metre profile has still not been tested to a satisfactory result.

The profiles above 23 metres are of a different nature. Two teams of divers operate on a rotaional basis, and there is considerably less botttom time per diver. Most of the diving is undertaken in depths of less than 23 metres.

*This particular research program has not been completed at this stage and will require, at a minimum, another 2 years to allow the complete testing of all the profiles. The research is continueing under another FRDC research program called **"Improved Harvesting Efficiency of Pearl Oysters through Modifications to Dive Profiles" - Project No. 94/098***

2. INTRODUCTION

The Pearl Producers Association profiles were developed over the years by trial and error without any scientific verification. Nevertheless, the PPA claimed that their profiles were safe and worked well for the Industry.

When compared with the conventional decompression tables, the PPA profiles are very economical in terms of Bottom time. Due to the large tidal variations in the Northern part of Australia, diving could only be done during Neap tides. Therefore, the prime aim of the Pearl Divers Dive Profiles is to maximise the in water time during the day light hours of a working day.

Figure 1 shows the comparison of the Canadian Defence & Civil Institute of Environmental Medicine, DCIEM, and the PPA profiles (15m; 21m and 33m) in a 12 hour working day. The areas in the Pie graphs represent the percentage of time spent in various activities - Bottom time, ascent time, decompression time and surface intervals. It can be seen that the PPA profiles allow for much more bottom time in a working day, especially in the shallower depths. Interestingly enough, the PPA Profile at 33 m closely resembles that of the DCIEM Decompression Table.

The PPA profiles are very different from the standard decompression tables in that they contravene the conventional thinking in diving and safe practice; the profiles include repetitive dives (up to 10 a day in shallow depths) and multi-day diving (usually 8 consecutive days during the Neap tides); and diving from shallow water to deep water, which are all recognised as risk factors in causing DCI (Decompression Illness). Therefore, on superficial examination of the profiles, one would expect a high incidence of DCI in the Pearl Divers. This, however, has not been the case, the incidence has been less than 0.01%.

3. OBJECTIVES OF THE STUDY

The objectives set down in the 1991 application were:-

a) To determine whether any significant problem exists with regard to decompression sickness (DCS) arising from diving schedules and practices currently in use by the pearl divers in Broome.

   If such a problem exists, to identify the particular schedules and practices responsible, and to advise on modifications and safe procedures.

b) To document the actual 'dive profile' using a depth-time recorder.

c) To document the 'bubble score' using the Doppler technique in evaluation of the dive profiles.

d) To document the incidence of decompression sickness:-

- *-niggles*

- *-neurological (cerebral, spinal) and*

- *-others (respiratory, inner ear)*

e) To document any long term health effects (as a longer term objective using other funds)".

The original objectives were set down on the basis that a set of dive profiles had been determined by the pearling industry and would be tested over a period of time by the Doppler ultrasonic bubble detection technique. However, data gathered during the course of the study and provided to the pearling industry resulted in all of the profiles being changed so that they were more conservative, ie. safer. Accordingly, the focus of the objective was amended from that of testing one set of dive profiles to that of testing and then revising the profiles so as to establish diving profiles for the pearling industry which passed the test of acceptance within the bubble classification system.

The R&D Corporation approved in 1993 the replacement of the five objectives set out above with the following objective:-

"To evaluate and recommend modifications to dive profiles used in the Western Australian pearling industry so that the profiles are in accord with the Doppler bubble classification system that is now widely accepted as a standard for evaluating dive profiles".
The strategy adopted in relation to this objective was to:-

- Assess the relative safety of the PPA Drift Diving Profiles as set out in the Code of Practice.

- Modify the "stressful profiles" to achieve a higher level of safety.

The safety of a set of profiles depends not only on the incidence of DCI but also on its manisfestations. Whilst musculo-skeletal DCI might be inconvenient and could be accepted as an occupational hazard, neurological DCI on the other hand is not acceptable as it could result in permanent damage.

It is also known that there are some long term health hazards in diving, but this would need to be the subject of another study. Nevertheless, the divers were examined annually for fitness to dive in accordance with the Australian Standard AS 2299 – Occupational Diving 1990.

4. RESEARCH METHOD

The following paragraphs provide a brief outline of the methods and also a brief progress report.

Diving safety can be measured by the incidence of decompression sickness, but this is a gross estimation. The disadvantage of the method is that a dive can be very stressful and a large number of bubbles formed in the blood stream, but without causing clinical symptoms of decompression sickness.

A Doppler ultrasonic monitor and a micro bubble classification system has been developed in the DCIEM as a means of detecting and quantifying intravascular bubbles in divers. This is now the basic research approach for evaluating dive profiles, and it is the approach used in this research project in relation to the dive profiles being used in the W.A. pearling industry.

The bubbles are graded from 0 to IV. Grades I and II are considered as demonstrating low stress and are relatively safe. Grade III and IV are considered to demonstrate stress, and there is a higher likelihood of decompression sickness. Having a high bubble count does not equate to having decompression sickness, but there is a correlation between high bubble counts and decompression sickness.

A dive profile can be modified if the bubble counts are consistently high. The modifications can be a shorter bottom time, longer surface interval, more decompression time, greater use of oxygen, a slower ascent rate or any combination of these.

There were 3 major methods of operation

(i) Doppler monitoring in the Recompression chamber.

(ii) The DCIEM "SAD" - Safe Ascent Depth (that is the depth at which a diver should reach after a certain depth-time dive) was also used to assess the profiles prior to testing. Those with high "SAD" were modified prior to testing. Some of the original profiles had SAD as high as 4 m before modifications;

(iii) Doppler monitoring at sea to test the profiles under field conditions.

5. OUTCOMES OF THE STUDY

5.1. Summary of all Recompression Chamber trials

The profiles range from 11m to 35m with 2m gradations. Table 1 shows the Profiles as stated in the Code of Practice. Table 2 shows the modified profiles (these are not the final profiles, but are currently used at sea).

The original Dive Schedules called for 3 different Depth Zones:-

(i) up to 15m;

(ii) up to 23m;

(iii) Deeper than 23m.

For dives up to 13m, a maximum Bottom time of 500 minutes for the diving day was the aim. Up to 19m, the daily Bottom time was decreased to 400 minutes. It is further reduced to 360 minutes for up to 23m.

Surface interval was fixed at 20 minutes (depths below 11m, Surface interval was 15 minutes).

Schedules deeper than 23m involve 2 teams of divers - the "Rotational Profiles". Surface intervals vary with each dive. The 35m profile has a Bottom time of 25 minutes, with a maximum of 4 dives per day, and Surface intervals vary from 80 minutes after the 1st dive to 100 minutes after the 3rd dive.

The original ascent rate was 5 m/minute for deep water to 21 m. From 21m to the surface, the rate was 3 m/minute. After decompression at 9m, the ascent rate was 2 minutes/metre to 3 minutes/metre depending on depths.

Decompression was not required for the 11m profile. For the 13m profile, decompression was on air at 5 msw. The other profiles called for decompression stops at 9 m on oxygen.

With the modifications of the profiles, all ascent rate was changed to a uniform rate of 3m/minute. Decompression stops were also introduced to all depth profiles.

Below is the list of profiles tested during the RCC trials:-

11m Original Code with modification
other modifications
In current use - tested in RCC twice

13m Original Code
modifications, due to unacceptably high bubble grades
tested in RCC twice, in current use

15m Original Code
modifications
only tested once

17m Original Code
modifications
tested once

19m Original
modifications
tested twice

21m Original Code
modifications
tested once

23m Original Code
1st modification -tested 2x
2nd modification - tested 2x
3rd modification - tested 1x
still high bubble grades - need further refinement

The above mentioned Profiles are "Non-rotational Profiles", that is to say that all the divers dive every dive.

The profiles below are "rotational profiles":-

25m Original; 1 modification, tested once

27m original

29m Original

31m Original

33m original, tested twice

35m original

All the profiles which required modifications were due to unacceptably high bubble grades. In the initial phases, there were 7 incidents of confirmed or suspected musculo-skeletal DCI resulting from the testing of the original profiles from the Code of Practice.

Only 4 of the profiles have been tested twice, that is the profiles were tested for 8 consecutive days without being rejected. All profiles should be tested a number of times to rule out the variability of divers to "bubbling".

5.2. Bubble Grades

This section shows the variations of Bubble grades with Depths; Days of the "Neap"; and at the beginning of each day, that is "Pre-dive" score and finally at the end of each day.

5.2.1. __Bubble Grades from the RCC trials at various depths__ :-

As the depth increases, so does the stress of the dive, if the profile is "stressful", the bubble grade would be expected to be high.

The Bubble Grades in the RCC trials over the years are shown below as an average Grade, these are the Precordial Flex Grades and the Precordial Rest Grades. (The 23m Profile has not yet reached a satisfactory result to be included). It can be seen that all the Bubble Grades are "satisfactory". There were no Grade III bubbles recorded.

	Flex	Rest
11m	I-	0
13m	I+	I
15m	I+	I-
17m	I+	I+
19m	1	I-
21m	II-	I+
23m		
25m	II-	I+
27m	I	I-
29m	I	0
31m	I	I-
33m	II-	I+
35m	I+	I-

5.2.2. *Bubble Grades after each day of the "Neap" :-*

If "acclimatisation" is believed to be a contributing factor, then one could expect the bubble grades to decrease at the end of the "Neap". If on the other hand, Multi-day diving is a high risk factor, then one would expect rising bubble grades towards the end of the "Neap".

The average grade for the Non-rotational profiles over the 8 day "Neap" showed a slight "peak" on day 3, then returned to the Day 1 level on Day 4. The reason for this has not been elucidated. There was no increase in Grades during the last days of the "Neap".

The Rotational Profiles, being deeper profiles showed an average higher Grades. Once again, there was no trend to increase in Grades at the end of the "Neap".

		Non-Rotational	Rotational
Day	1	I+	I+
	2	I+	II-
	3	II-	I+
	4	I+	II-
	5	I	II-
	6	I+	I+
	7	I+	II-
	8	I+	II-

5.2.3. *Bubble Grades for the Pre-dive of each day:-*

Bubbles were recorded at the beginning of each day before diving. The fact that there were bubbles recorded at the beginning of each day indicate that nitrogen elimination is not complete after a 12 hour break - the total time for inert gas elimination is unknown. The French uses 8 hours; USN uses 12 hours for their calculations; DCIEM uses 18 hours. It would appear that 12 hour is inadequate to totally eliminate the Nitrogen load of the "repetitive dives" of the PPA profiles.

The average Pre-dive Flex Grades for the Non-rotational and the Rotational profiles showed very similar results.

		Non-Rotational	Rotational
Day	1	0	0
	2	I+	I-
	3	I-	I-
	4	I+	II-
	5	I-	I+
	6	I+	I+
	7	I+	I+
	8	I+	I

5.2.4. ***Bubble Grades after each dive of the day: -***

As it is believed that more than 3 dives per day constitutes a high risk in DCI, one would expect high bubble grades after dive 3. There is a tendency, however, for the bubble grade to rise towards the end of the day.

The average Precordial Flex Grades after each dive showed a slight rise towards the end of the day for the Non-rotational profiles; whereas the rotational profiles showed a steady rise after dive 3. The rotational profiles are deep profiles, from 25m to 35m, and at the deeper depths, there are only 4 or 5 dives per day. The rise in Bubble grades during the day may indicate cumulative effects of nitrogen load and/or inadequate decompression towards the end of the day. Although the Bubble grades only reached II-, but one could not equate a low bubble grade with no risk in DCI, the low grade does, however, indicate that the risk is low. An attempt should be made to decrease the bubble grade further.

		Non-Rotational		Rotational
Pre-dive		I+		I-
Dive	1	I-		I+
	2	I-		I+
	3	I+		II-
	4	I+		II-
	5	I+	Final	II-
	6	I+		
	7	I+		
	8	I+		
	9	I+		
	10	II-		

5.3. Sea Trials 1992 - 1994

Once the Profiles have been modified in the RCC, they were put to use in the field. It is known that results from the RCC cannot be translated to reflect the results of the actual sea trials - this could be due to a number of factors such as immersion, degree of physical activity and temperature of the water. Hence, "approved profiles" from the RCC must be verified at sea.

1992

The average Precordial flex Grades after each Neap is shown below together with the median depths of the fieldwork recorded:

	Bubble Grades	Median Depth
Neap 1	II+	19.55
2	II-	15.35
3	II-	11.9
4	II+	12.2
5	II+	13.0
6	II+	13.1
7	II+	30.5
8	III-	33.65

Although there appears to be a trend towards higher grades in Neap 8, this was due to the fact that the median depth for Neap 8 was over 33m and was a rotational profile. Whereas, Neap 1, the average depth was 19.55 m. The general observation was that the profiles around 20 m and the deeper rotational profiles tended to give rise to high bubble grades.
(The DCI cases recorded at sea were mainly from the 20m depth).

The average ascent rate recorded in the field on the whole complied with the Code of Practice of 3 m/min., however, during Neap 5, the average ascent rate was recorded as over 9.7 m/min - this was perhaps due to the fact that the dives were shallow and less care was taken by the divers.

1993

	Bubble Grades	Median Depths
Neap 1	II-	14.20
2	I+	10.10
3	II-	10.83
4	I+	10.93
5	II-	12.10

The field work was done at shallow depths in 1993 and the shell quotas were collected in only 5 neaps. Despite the shallow depths, the level of workload was increased in order to fish the quota of shells. The divers were asked to empirically grade the level of workload, eg light work as 1, average as 2 and heavy work as 3. Apart from Neap 2 and 4 where average workload was rated as 1.1, the other neaps indicated workload to be rated as 1.8 on average.

The ascent rate in 1993 had been higher, with average rates over the Neaps recorded as 3.7; 6.3; 4.4; 4.3; 10.2 m/minute. The faster ascent rate could have accounted for the higher bubble grades at these shallow depths.

1994

		Bubble Grades	Median Depths
Neap	1		
	2	II-	11.9
	3	II-	11.5
	4	II-	11.8
	5	II-	12.0
	6	II-	12.3

Workload was rated as 1.4 for Neap 2; the other Neaps were rated as 2.

Due to the shallow depths, with an average Median depth of 12 m, the constancy of the Bubble Grade was not surprising.

5.4. Bubble Grades in RCC Vs Field work

Since the testing of the Profiles in the RCC and their modifications, the bubble grades tended to fall to an average of Grade I. Initially, the Grades at sea appeared to be lower than the RCC, this was due to the fact that in the RCC, the profiles were dived to the maximum depth with maximum bottom time in strict adherence to the Code of Practice, that is they were assumed to be "Square Profiles". However, the fieldwork was different. Depths were variable. With the modifications of the profiles, there was also a trend towards a decrease in Bubble grade. This however did not continue. In 1994, the Bubble Grade at sea tended to rise again. On analysis, this was found to be due to the faster ascent rates the divers have adopted because of the shallower depths dived in 1994.

The recorded ascent rate recorded in 1992 to 1994 were :-

	1992	1993	1994
0 - 3 m/min	34.4%	28.6%	18.6%
<6	45.9	46.6	44.7
<9	8.6	10.6	19.6
>9	11.1	14.3	17.0

This problem could be eliminated if we had a suitable depth-time recorder to monitor the divers. Up to 1994, we only had Suunto Dive computers to record the dives, which unfortunately records at 3 minute intervals, this was inadequate for the purpose of recording the ascent rate. The Joltron Depth-time recorder used in the North Sea is prohibitively expensive for our purpose.

In September 1994, a number of Citizen Hyper Aqualand watches were acquired which could be suitable, as they record depth-time profiles every 5 seconds as well as water temperature at every 5 minute intervals. The data could also be down loaded onto a PC. The trial of this item in the RCC appears to be promising.

The average Doppler Bubble score recorded in the field were:-

	Rest	Flex
1992	II-	II
1993	I+	I+
1994	I+	I+

The lower Bubble Score in 1993 and 1994 could be due to the fact that the Profiles were modified. Or that the dives were mainly shallow.

Every endeavour should be made to record the bubble scores of the deeper dives; however, this might not be easy, as fishing was done in shallower waters in the last 3 years. The diving depths below 13 msw accounted for a large percentage of the total number of dives.

1991	34.8%
1992	46.2%
1993	45.2%
1994	68.3%

However, the abundance of shells at shallow depths could not be relied upon in future years. Fishing might have to be done at deeper depths. The Doppler scores of these deeper depths must be assessed and analysed.

The following table is the breakdown of the frequency of the various depths dived since 1991:-

Depth msw	**1991**	**1992**	**1993**	**1994**
11	17.76%	23.51%	24.51%	42.78%
13	17.07	22.66	20.65	25.57
15	13.20	14.53	11.51	11.13
17	12.82	10.53	8.10	5.28
19	17.65	12.74	12.23	6.46
21	12.11	9.49	10.20	5.93
23	3.25	1.82	2.89	2.62
25	0.12	0.12	0.056	0.23
27	0.03	0.73	0.41	0
29	0.33	0.89	1.47	0
31	1.77	0.39	1.54	0
33	2.83	1.51	3.56	0
35	1.05	1.07	2.80	0

The deeper dives, that is the rotational profiles of 25m or greater accounted for a very small percentage of the total number of dives.

5.5. The Testing Of 2 Ascent Rates In The Rcc

The effect of ascent rate was tested on the same pair of divers in the RCC. The profile used for the tests were:-

(i) 12m with 50 mins Bottom time

(ii) 15m with 45 mins Bottom time

(iii) 17m with 40 mins Bottom time

The 2 ascent rates used were 15 m/min. and 3 m/min.

At depth of 12m, there was little difference in the Bubble Grades, excepting that with the faster ascent rate, the bubbles persisted longer. (The hyperbaric stress at this depth is not as great as that at 17m if one uses Px root t to evaluate the level of stress).

At 15m, the faster ascent rate produced Grade II bubbles, the slow ascent rate produced Grade I bubbles.

At 17m, the difference became more significant. With the fast ascent rate, Grade III- bubbles were observed at 30 minutes, which dropped down to Grade II at 60 minutes. At 3 hours, Bubble grade I was still recorded. Whereas with the slow ascent rate, only Grade II was recorded, which dropped to Grade I in 30 minutes and disappeared within 90 minutes.

The 15 m/min ascent rate (which is slower than the 18m/min of the standard USN or DCIEM Tables) tended to produce higher bubble grades and that the bubbles persisted longer.

5.6. Incidence of DCI from all dives

Figure 2 shows the dives performed by the PPA from 1991 to 1994. The profiles used in 1991 were unmodified. The first modified profiles were used in the 1992 season.

	Number of dives	Number of DCI
1991	30,402	11
1992	30,095	4
1993	21,452	3
1994	20,436	0

The DCI incidence was 0.036% in 1991; 0.013% in 1992; 0.01398% in 1993; 0% in 1994. However, in 1991, there was 1 case of Neurological DCI. Most of the cases of DCI came from diving depths of around 20 msw. These profiles will need to be retested.

It would appear that the PPA Profiles are safe. A survey of currently acceptable risks in DCI (which depends very much on operational requirements) appears to be:-

Space shuttle operations	6%
USN	3 - 4%
Caisson workers	2%
Commercial diving companies	0.1 - 0.5%

6. DISCUSSION

Despite the conventional thinking that Repetitive dives and multi-day diving are Risk Factors in producing serious DCI, the Pearl Divers Profiles in the years 1992 - 1994 appear to be safe.

The safety of the Profiles could be due to :-

(i) slow rate of ascent;

(ii) oxygen decompression;

(iii) suitable depth of decompression;

(iv) suitable interdive interval.

6.1. Ascent Rate

The "Standard ascent rate" of 18m/minute was adopted as a de facto standard from the US Navy's Air Tables of 1958. The previous USN Diving Manual NAVSHIPS 250-880 of 1952 stated an ascent rate of 25 ft/minute - which was also the ascent rate used by Haldane when he released his Decompression Tables in 1908. The tables adopted "Stage Decompression", which was challenged by Sir Leonard Hill (1912) who advocated the slow bleed approach of "Uniform Decompression", a technique used by the Pearl Divers.

There is no scientific basis for an ascent rate of 60 ft/minute. That rate was adopted after an agreement between the Standard Hard Hat Divers who wanted to retain the 25 f/min and CDR D. Fane who wanted his "frogmen" to ascend at 100 ft/minute.

A survey of various dive tables show that the ascent rates vary i.e.
Swiss Tables - 10 msw/minute.
BSAC - 15 msw/minute to 6 msw; then 6 msw/minute to the surface.
Huggins - 40 fsw/minute to 20 fsw; 20 fsw/minute to the surface. A 3 minute stop at 20 fsw is required for dives deeper than 60 fsw.

Zannini reported that the Italian Commercial Divers now routinely use 10 m/minute ascent rate, and recorded no incidence of DCI in over 24,000 dives at depths ranging from 10m to 50 m.

Daniels has calculated that if decompression was slow enough, bubble formation could be avoided. He quoted a 25 times decrease in ascent rate, which is obviously impractical.

Mano using Agar gel experiments demonstrated that as the ascent rate decreases, the number of bubbles also decreases; he further demonstrated that the optimum rate was 9 m/minute.

Koch modified the USN TT6 by slowing the ascent from 18 m to 9 m and reported that was a dramatic reduction of recurrences of symptoms.

Calculations using various Computer models indicated that the slower the rate of ascent the better it is, and that there is no minimum rate of ascent. (Yount; Van Liew)

The 3 metre/minute ascent rate chosen for the Pearling Industry might have been the suitable rate which is manageable for their mode of diving. This slow rate would obviously be difficult for other divers who do not ascend on the shot rope with hand over hand.

6.2. Oxygen Decompression

There are a number of well known decompression tables throughout the world that make use of oxygen, eg DCIEM, COMEX, French Navy, Duke University etc.

There are obvious advantages in the use of oxygen. In the Haldanian model, it was assumed that inert gas was dissolved. It is known that on decompression, bubbles are formed; the faster the rate of ascent, the more bubbles are formed. The elimination of dissolved gas and bubbles have totally different gas kinetics. The half time for the elimination of bubble is far greater than dissolved gas. Oxygen creates a large diffusion gradient for elimination of bubbles. Hence, one could hypothesise that the Pearl Divers "slow rate of ascent" eliminated a large proportion of inert gas and the bubbles which are formed are either removed or reduce in size because of the large diffusion gradient by breathing oxygen.

Oxygen decreases decompression time by 30% to 50% depending on the depths of the dives. The French Navy considers the use of oxygen reduces decompression time by 30% at all depth ranges.

Imbert & Bontoux using the French Air Decompression Tables with in-water oxygen decompression indicated that the incidence of DCI was 2 - 3 times lower than with air decompression for dives of the same depths and bottom time.

Fife et al reported the successful use of oxygen decompression in 7500 dives ranging in depths of 50 - 60 msw in the excavation of a Bronze Age shipwreck. There were 3 cases of DCI reported with no incidence of oxygen toxicity.

Furthermore, oxygen might confer other safety benefits. Dysbaric Osteonecrosis (DON) is a well known occupational hazard for divers and Caisson workers. Since the Germans and the French have introduced the use of oxygen in decompression for the Caisson workers, it was reported by Kindwall that there have not been any cases of DON. It is not known whether oxygen decompression confers the same safety to divers.

There are of course known risks of in-water oxygen decompression. CNS oxygen toxicity leading to convulsion is most hazardous. However, since the introduction of oxygen in decompression in the Pearling Industry, there has not been a single incidence of oxygen toxicity.

Long term use of oxygen also raises doubt of cumulative poisoning. Sterk & Schrier suggested that long term exposure in the order of 400 - 500 UPTD (Units of Pulmonary Dose) each day could be at risk. However, Donald, with his extensive experience with the Royal Navy divers using oxygen considers that cumulative effect as most unlikely.

6.3. Decompression Depth

The choice of decompression depth is obviously important. The study conducted on the Torres Strait diving technique (1965) indicated that the deep stops used by them saved approximately one third of the decompression time used by the US Navy.

Recent trials from the UK indicated that when Decompression stops were done at 6 msw rather than 3 msw, the incidence of DCI dropped by some 40%.

The standard Decompression Tables that make use of shallow stops appear to do no more than slowing the decompression rate of ascent. It appears that deeper in water stops are beneficial for off-gassing. Further, off-gassing is more effective without bubble formation.

Therefore, the depth of 9 msw chosen by the Pearl Divers for their decompression stops might be more beneficial than originally thought. It is proposed to include some deeper air stops at 12 msw for some of the "difficult profiles".

6.4. Surface Interval

Since the time for total elimination of Nitrogen is unknown, the figures have been quoted as 6 hours by Rogers, 8 hours by the French Navy, 12 hours by USN and 18 hours by DCIEM, the calculation for repetitive dives which relies on a knowledge of "tissue half time" for elimination of inert gas is at best based on a premise which needs proof.

It has been suggested by many authors that the longer the Surface interval the better - obviously for the elimination of inert gas. It is further stated by many that from experimental evidence with animals that Repetitive diving was a reliable means of producing spinal DCI in goats (Hills) and dogs (Sykes & Yaffe); also it tends to promote passage of bubbles through the lungs of mice and guinea pigs (Gait et al). It was thought that on decompression, bubbles are trapped in the lungs, and on repetitive dives, the recompression of such bubbles would force them to cross the lungs to the arterial side of the circulation causing severe neurological DCI. However, that has not been the experience with the Pearl Divers.

The success of the Pearl diving could have been due to the slow ascent rate which manages to eliminate most of the dissolved gas; whatever bubbles are formed are largely eliminated by the breathing of oxygen at the decompression stop. On the surface, from the Doppler studies, bubbles tend to peak within 2 hours, and assuming that some of the bubbles formed are recompressed and forced back into solution on repetitive diving (akin to the treatment of DCI by recompression), which could account for the safety.

It has been reported by Brubbak that bubbles were more numerous during the first ascent than the second during saturation dives, it was postulated that this might have been due to micronuclei being used up and insufficient time for them to regenerate. Should that be the case, therefore a suitable Interdive interval might bestow some benefit to repetitive dives by a reduction of bubbles (Daniels).

Ward et al have suggested that activation of the Complement system could lead to DCI and experiments have shown that pharmacologically decomplemented rabbits do not show a tendency to DCI. This aspect of aetiology has not been investigated in the Pearl Divers.

7. COMMUNICATION OF THE OUTCOMES

The PPA established a Diving Committee for the purpose of maintaining industry contact with the research project. The research results have been passed to the Committee as they have become available.

The Diving Committee, in consultaion with Dr Wong, have modified the dive profiles, as required, which have then been adopted by the pearling companies for use by all divers.

The Fisheries Department, the Department of Occupational Health Safety and Welfare, and the Department of Health have been kept informed of progress in the development of dive profiles through meetings of the Pearling Industry Diving Co-ordinating Committee which is chaired by the Western Australian Director of Fisheries.

Dr Wong presented a paper at an international dive symposium held in Queensland from 21 to 23 October 1994. The title of the paper was "Western Australian Pearl Divers Mode of Diving".

8. CONCLUSIONS

The incidence of Decompression Illness in the Drift Diving Pearl Divers has been low, less than 0.01%. The incidence of DCI has been higher in the Pearl Farms where the US Navy Standard Air Tables are followed.

Medical examinations have not revealed any deleterious effects from the use of oxygen; and no evidence of Dysbaric Osteonecrosis has been observed.

In the year 1994, 142 Diving Medical Examinations were conducted at Broome District Hospital in accordance with Australian Standard AS2299 1990 - Occupational Diving. These are all the divers in Broome, both Drift and Farm divers. There were 34 new divers.

All passed the Medical Examinations.

The average age of the divers was 27.7 years. The range was from 18 to 48 years. Both the extreme ages were farm divers.

33% of the divers commenced diving between 1990 - 1993; 24% started in 1994 and 43% commenced prior to 1990.

18% of the current divers had experienced DCI. 34% of divers with 5 or more years experience have experienced DCI. 6% of divers with less than 5 years experience had a history of DCI. Majority of them were treated with in water oxygen recompression emipirically.

None of the current divers have x-ray changes suggestive of Dysbaric Osteonecrosis.

There was no recorded incidence of oxygen toxicity with the use of in-water decompression.

There is however, a band of depths which cause problems. 19m; 21m and 23m. The first 2 depth-profiles produced high bubble counts in the Recompression chamber, and the DCI recorded since 1991 came mainly from these depths. The 23m profile is still to be tested to our satisfaction. It is envisaged that deeper air (eg 12m) decompression stops will need to be added to these profiles for the next series of RCC trials. From the preliminary assessment of these profiles, it appears that using a decompression stop for every second dive is inadequate and accounts for the high bubble grades.

9. ACKNOWLEDGEMENTS

This research could not have been undertaken without the untiring efforts of my Research Assistant - Mr. Beau Bibby, the ready assistance of the PPA especially the pearl divers both in the field and the recompression chamber trials, the PPA Safety & Training Officer - Mr. David Appleby, the PPA Executive Officer - Mr. Michael Buckley and the Project Co-ordinator - Mr. Bernard Bowen.

The Recompression Chamber is situated in the Broome Regional Hospital and many of the staff have provided assistance throughout the time of the research project.

The research would not have taken place without the funding that was made available by the W.A. Fisheries Department, the Fisheries Research & Development Corporation and the Pearl Producers Association (the PPA paid the divers for their chamber time).

TABLE 1
ORIGINAL DIVE PROFILES 1991

PEARL PRODUCERS ASSOCIATION

Maximum Limit Dive Profile

NO ROTATION

DEPTH (Maximum)	BOTTOM TIME (Maximum)	ASCENT RATE	SURFACE INTERVAL	No. of DIVES OR MAX BOTTOM TIME	DECOMPRESSION
0 - 11	90 mins	3 metre/min	Min 15 mins Min Accumulated Surface Intervals 135 mins	Max bottom time for the day 500 mins	Not required
11 - 13	60 mins	3 metre/min	Min 20 mins	Limit of 500 mins	10 mins on Air at 5 metres at end of day. Then 3 min per metre to surface ascending on air.
13 - 15	45 mins	3 metre/min	20 mins	Limit of 400 mins	10 mins on O_2 at 9 metres at end of day. Then 3 metre/minute ascending on O_2.
15 - 17	40 mins	3 metre/min	20 mins	Limit of 400 mins	10 mins on O_2 at 9 metres at end of day. Then 2 mins/metre ascending on O_2 at end of day.

PEARL PRODUCERS ASSOCIATION

Maximum Limit Dive Profile

NO ROTATION — continued

DEPTH (Maximum)	BOTTOM TIME (Maximum)	ASCENT RATE	SURFACE INTERVAL	No. of DIVES OR MAX BOTTOM TIME	DECOMPRESSION
17 - 19	40 mins	3 metre/min	20 mins	Limit of 400 mins	5 mins on O_2 at 9 metres after the 5th drift. 15 mins on O_2 at 9 metres at end of day. Then 2 mins/metre ascending on O_2 at end of day.
19 - 21	40 mins	3 metre/min	20 mins	Limit of 360 mins	5 mins on O_2 at 9 metres after the 5th drift (then ascending at 3 metres/min on O_2) 15 mins on O_2 at 9 metres at the end of the day then ascending on O_2 at 2 mins/metre.
21 - 23	40 mins	3 metre/min	20 mins	Limit of 360 mins	10 mins on O_2 at 9 metres after the 5th drift then ascending at 3 metre/min on O_2. 20 min on O_2 at 9 metre after the last drift ascending on O_2 at 3 minutes/metre.

ROTATING 2 TEAM ROTATING SYSTEM

DEPTH (Maximum)	BOTTOM TIME (Maximum)	ASCENT RATE	SURFACE INTERVAL	No. of DIVES OR MAX BOTTOM TIME	DECOMPRESSION
23 - 25	40 mins	5 metre/ min to 21 metre then 3 metre/ min to stage point at 9 metres.	After D1 = 60 mins D2 = 70 mins D3 = 80 mins D4 = 90 mins	5 per team	D1 = air ascent to surface at 3 metre/min. D2 = 5 min on O_2 D3 = 10 min on O_2 D4 = 15 min on O_2 D5 = 20 min on O_2 (D2 - D5 then ascent on O_2 at 3 metre/min.)
25 - 27	35 mins	5 metre/ min to 21 metre/ min to 9 metre	After D1 = 60 mins D2 = 70 mins D3 = 80 mins D4 = 90 mins	5 per team	D1 = 5 mins on O_2 D2 = 10 min on O_2 D3 = 15 min on O_2 D4 = 20 min on O_2 D5 = 25 min on O_2 (D1 - D5 then ascending at a rate of 3 metre/ minute on O_2.)
27 - 29	30 mins	5 metre/ min to 21 metre 3 metre/ min to 9 metre	D1 = 60 mins D2 = 70 mins D3 = 80 mins D4 = 90 mins	5 max per team	D1 = 5 min on O_2 D2 = 10 min on O_2 D3 = 15 min on O_2 D4 = 20 min on O_2 D5 = 25 min on O_2 (D1 -D5 then O_2 ascending to surface at 3m/min.)

ROTATING 2 TEAM ROTATING SYSTEM (continued)

DEPTH (Maximum)	BOTTOM TIME (Maximum)	ASCENT RATE	SURFACE INTERVAL	No. of DIVES OR MAX BOTTOM TIME	DECOMPRESSION
29 - 31	25 mins	5 metre/ min to 21 metre 3 metre/ min to 9 metre	D1 = 70 mins D2 = 80 mins D3 = 90 mins D4 = 100 mins	5 max per team	D1 = 5 min on O_2 D2 = 10 min on O_2 D3 = 20 min on O_2 D4 = 25 min on O_2 D5 = 30 min on O_2 (D2 - D5 then ascending to surface on O_2 at 3 metre/ min.)
31 - 33	25 mins	5 metre/ min to 21 metre 3 metre/ min to 9 metre	D1 = 70 mins D2 = 80 mins D3 = 90 mins D4 = 100 mins	5 max per team	D1 = 5 min on O_2 D2 = 10 min on O_2 D3 = 20 min on O_2 D4 = 25 min on O_2 D5 = 30 min on O_2 (D1 - D5 then ascending to surface on O_2 at 3m/ min.)
33 - 35	25 mins	5 metre/ min to 21 metre 3 metre/ min to 9 metre	D1 = 80 mins D2 = 90 mins D3 = 100 mins	4 max per team	D1 = 10 min on O_2 D2 = 15 min on O_2 D3 = 20 min on O_2 D4 = 25 min on O_2 (D1 -D4 then ascending to surface on O_2 at 3m/ min.)

ROTATING SYSTEM 4 IN 2 OUT

DEPTH (Maximum)	BOTTOM TIME (Maximum)	ASCENT RATE	SURFACE INTERVAL	No. of DIVES OR MAX BOTTOM TIME	DECOMPRESSION
19 - 21	40 mins	3 metre/min	20 mins Surface/Interval 90 mins S/I Rotating Sequence	8	10 mins on O_2 at 9 metre then ascending with O_2 at 3 metres/minute after the last dive.
21 - 23	40 mins	3 metre/min	20 mins 90 mins Rotating sequence	8	15 min on O_2 at 9 metre then ascending with O_2 at 3 metres/minute after the last dive.

NOTE:

This dive profile is the maximum recommended times with an ascent rate of 3 metres/min from 21 metres. (Below 21 metres ascending at 5 metres/min.) The profile is to be used when conditions are ideal and if necessary the profile associated with the next 2m interval when conditions are less than ideal (for example when considering the fitness of the diver; weather conditions, visibility, prevalence of stingers and the experience of crew).

Three zones have been marked as:-

(1) Deeper than 23m
(2) 15m to 23m
(3) 0 to 15m

If you propose to move from a shallower to a deeper zone you should do the full decompression stop for that day before moving to the deeper zone. Once you have moved to another zone, then you should observe the full decompression stop at the end of the day for whatever zone you have moved into.

If you move from a deeper to a shallower zone, at the end of the day decompression would be that of the deeper zone.

Skippers must allow for tranducer position on ship's hull when determining depth.

TABLE 2
DRIFT DIVE PROFILES 1994 - No Rotation

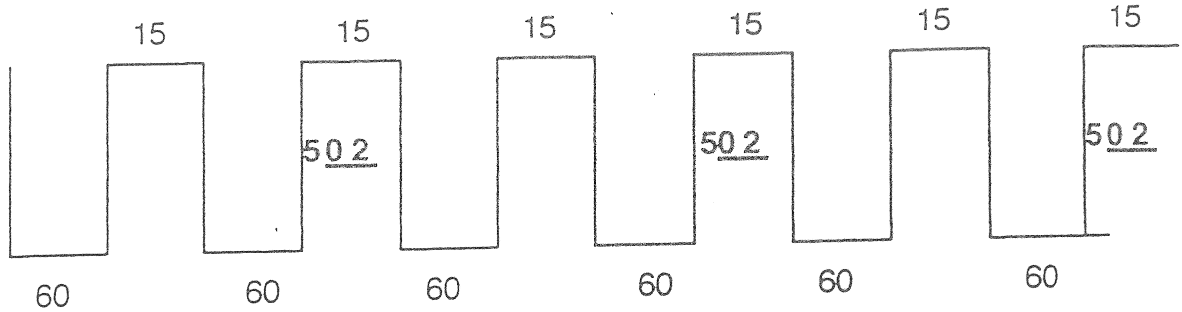
DRIFT DIVE PROFILES 1994 – no rotation.

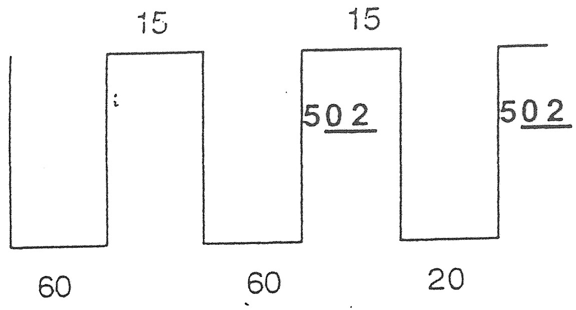
Ascent rates 3m/min. Decompression stops on 02 at 9metres & ascending

02 = oxygen; 5 = 5minutes; 10 = 10minutes etc.

0 - 11metres.

max B.T. 500mins
10 dives max.

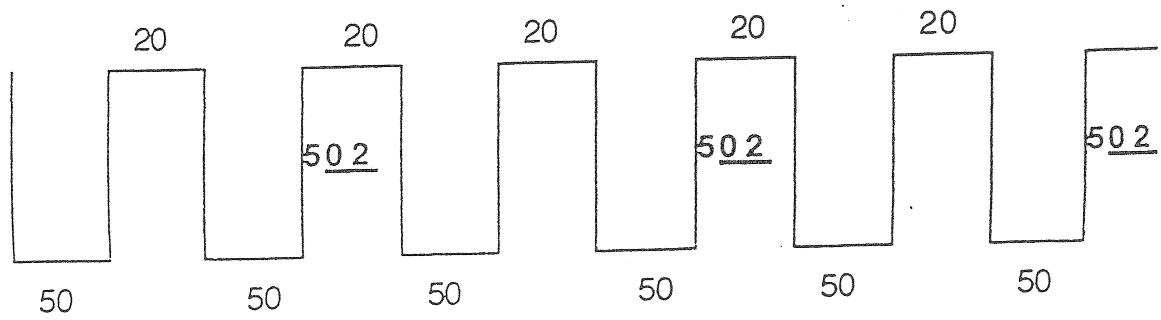


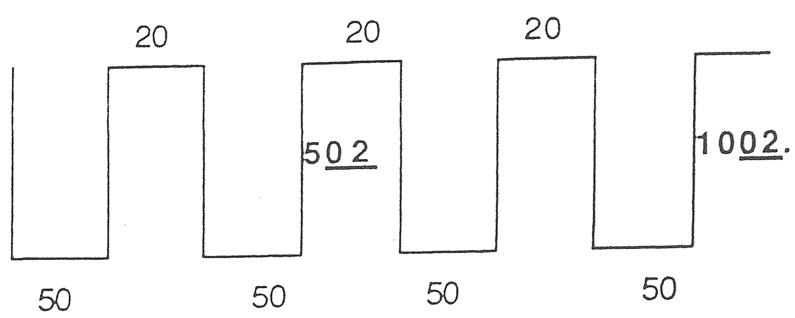


NB: Oxygen staging at this depth increment is to be done at 6 metres.

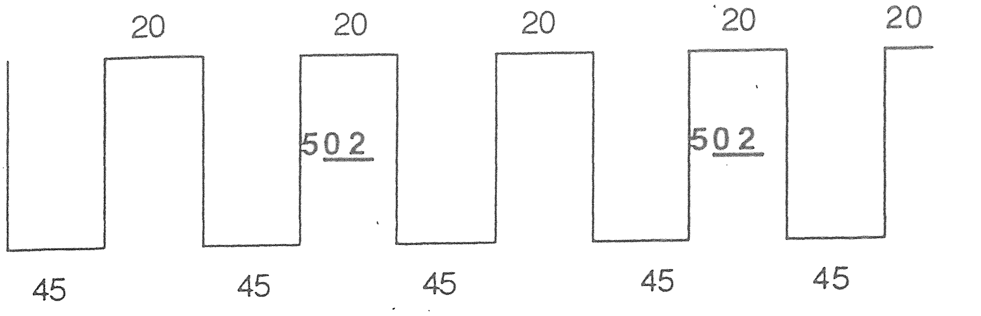
11 - 13 metres

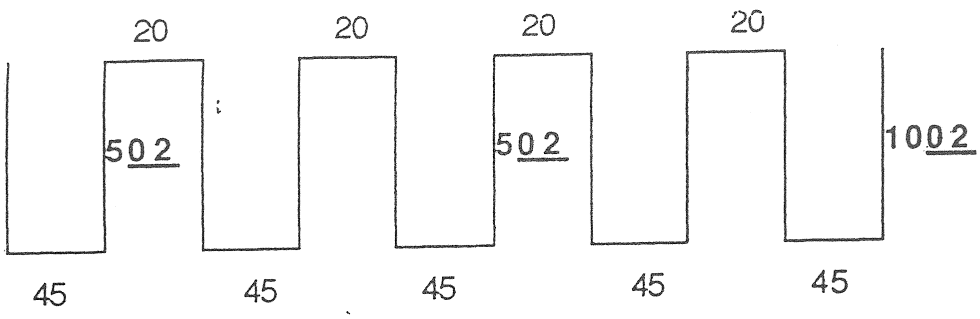
500 mins/day
10 dives max.



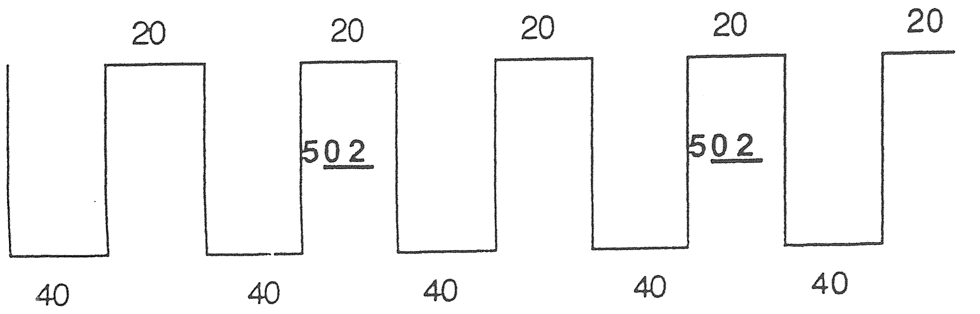


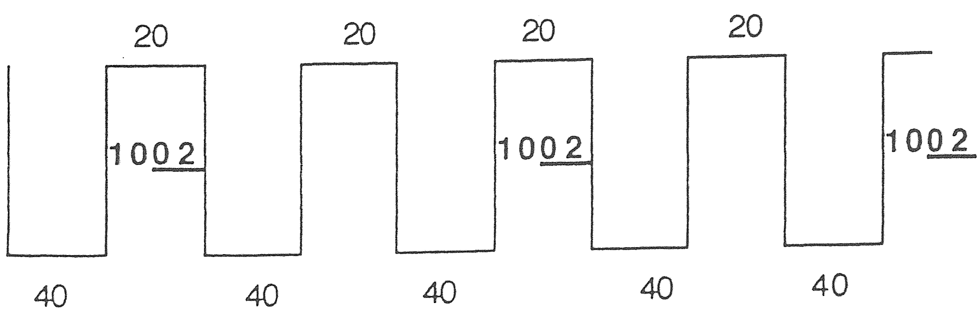
13 - 15 metres
450 mins/day
10 dives max.



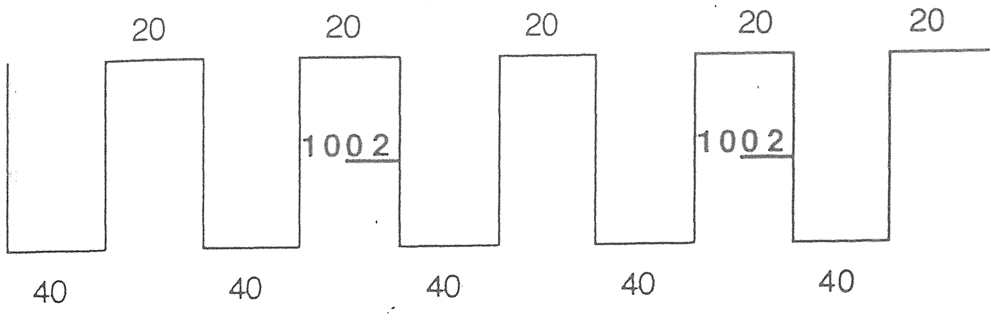


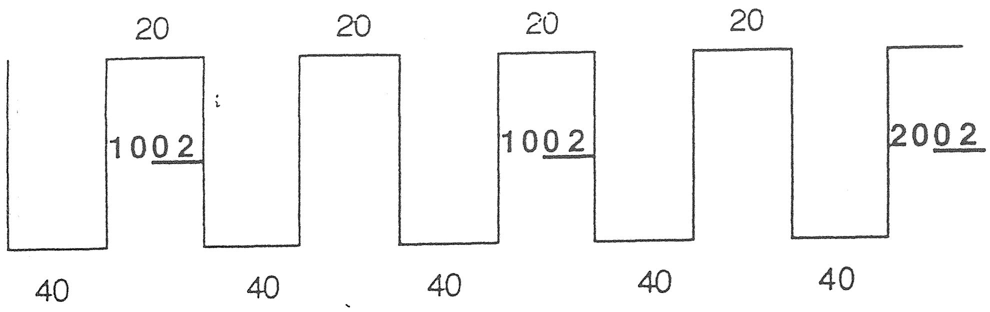
15 - 17 metres
400mins/day
10 dives max.



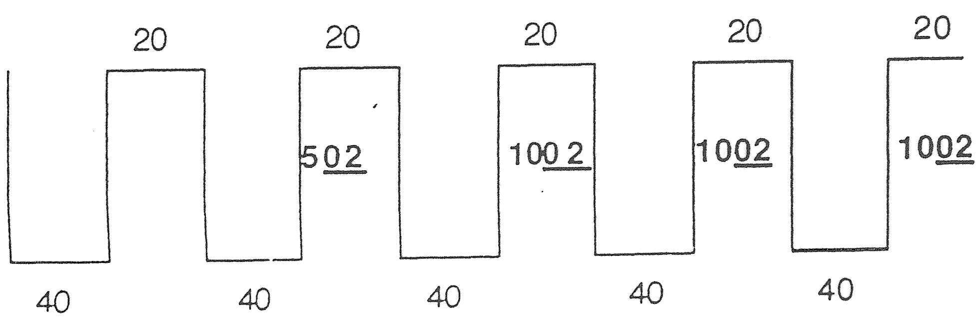


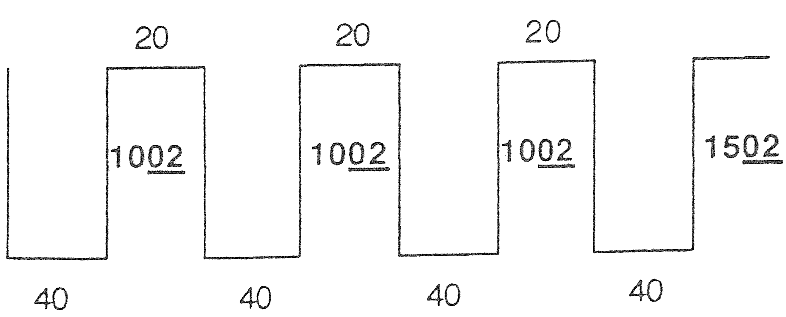
17 - 19 metres
400 mins/day
10 dives max.



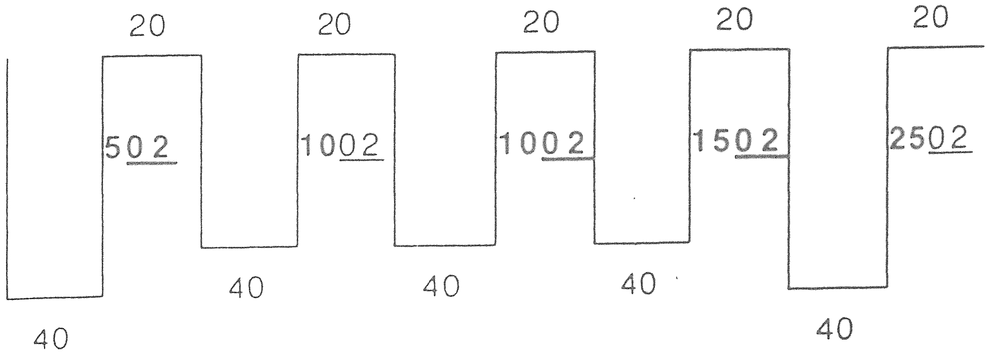


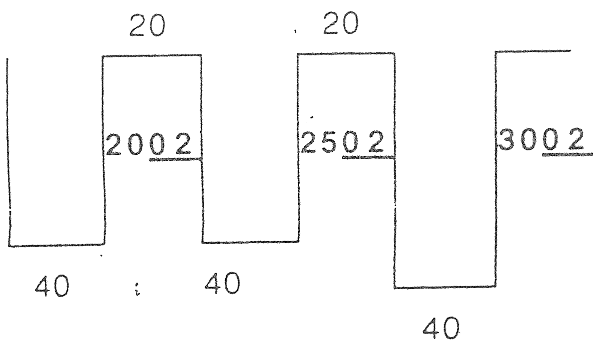
19 - 21 metres
360min/day
9 dives max.





21 - 23 metres.
320mins/day
8 dives max.





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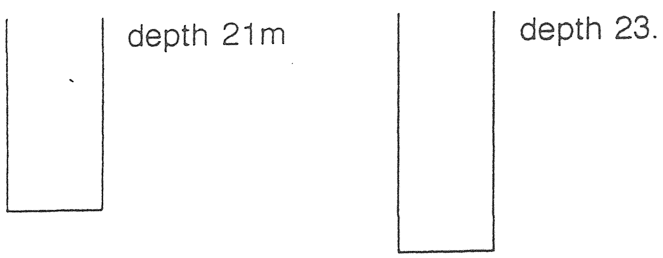


FOOTNOTE: When diving to this profile flexibility to **02** times must be used in relation to tidal variation. ie: The above profile is an example only of how to apply **02** times. If, for example, depths nearing 23 metres are dived at times differing to the above profile, then the greater **02** times will need to follow the greater depths.

NB: Any interruption to the diving day that will preclude the ability to complete decompression procedures will require.-

a) 0 - 13m maximum depths: 30 min. of surface 02.

b) 13 - 23m maximum depths: 60 min. of surface 02.

90 minute turnaround drifts

0 -11 metre depth range.

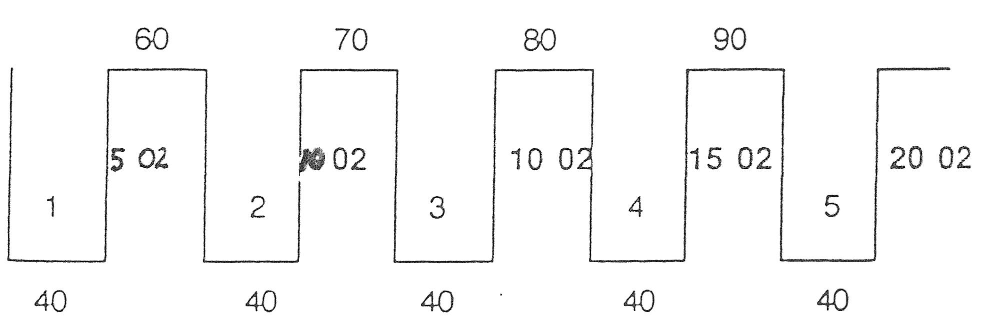
NB: Individual drift times in the 0 - 11 metre depth bracket can be extended to 90minutes provided the following procedures are adhered to.-

a) total daily bottom time does not exceed 500minutes.

b) an additional 10minute oxygen stage at (6 metres) is done at the completion of every 90 minute drift.

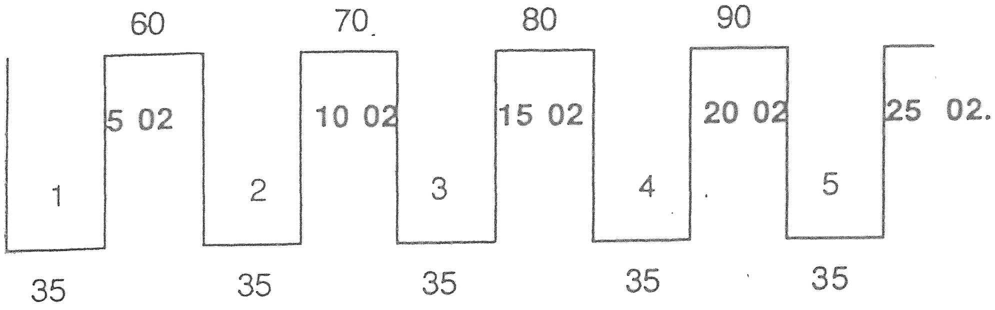
TWO TEAM ROTATING SYSTEM- 23 TO 35 METRES.

23-25 METRES.

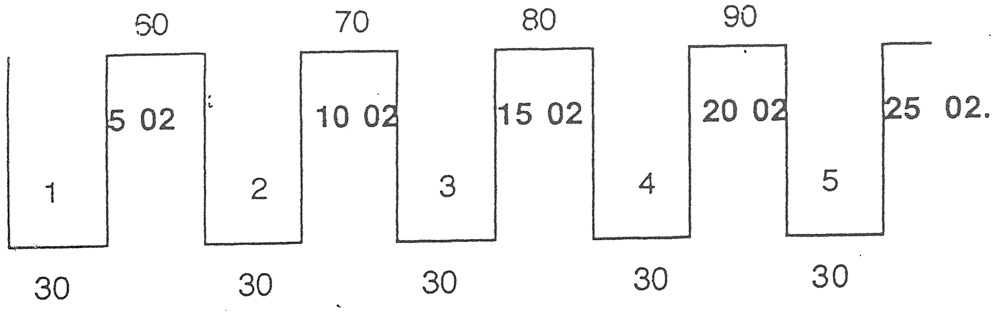


ROTATION.

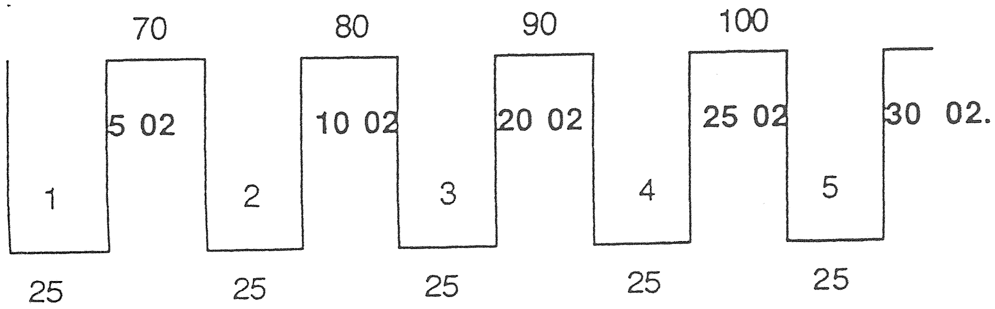
25-27 METRES.



27-29 METRES.

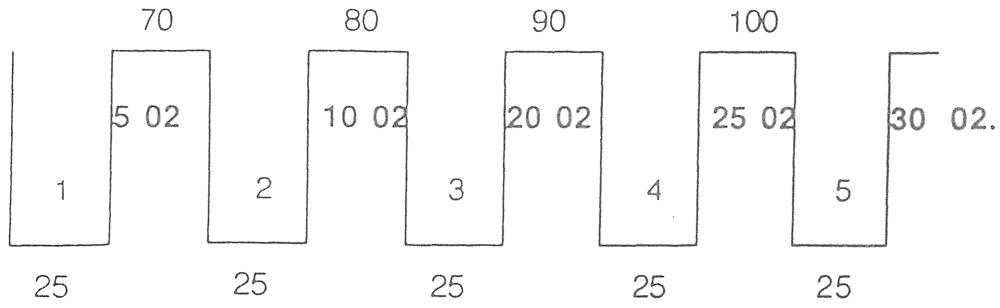


29-31 METRES.

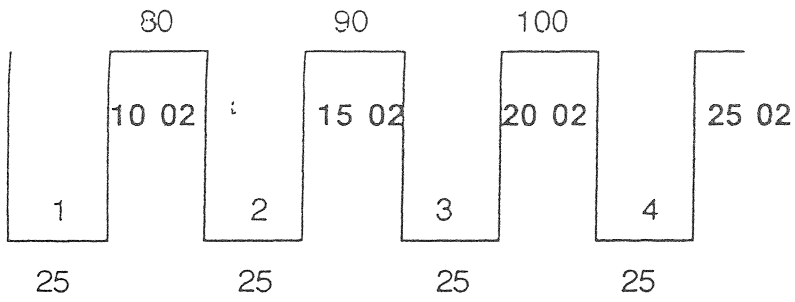


NB: ALL ASCENT RATES ARE 5 METRES/MIN TO 21 METRES AND THREE METRES/MIN TO NINE METRES.

31-33 METRES.



33-35 METRES.



NB: This dive profile is the maximum recommended times with an ascent rate of 3 metres/min from 21 metres (Below 21 metres ascending at 5 metres/min.) The profile is to be used when conditions are ideal and if necessary the profile associated with the next 2M interval when conditions are less than ideal. eg: when considering the fitness of the diver; weather conditions; visibility, prevalence of stingers And the experience of the crew.

Three zones are marked as:-
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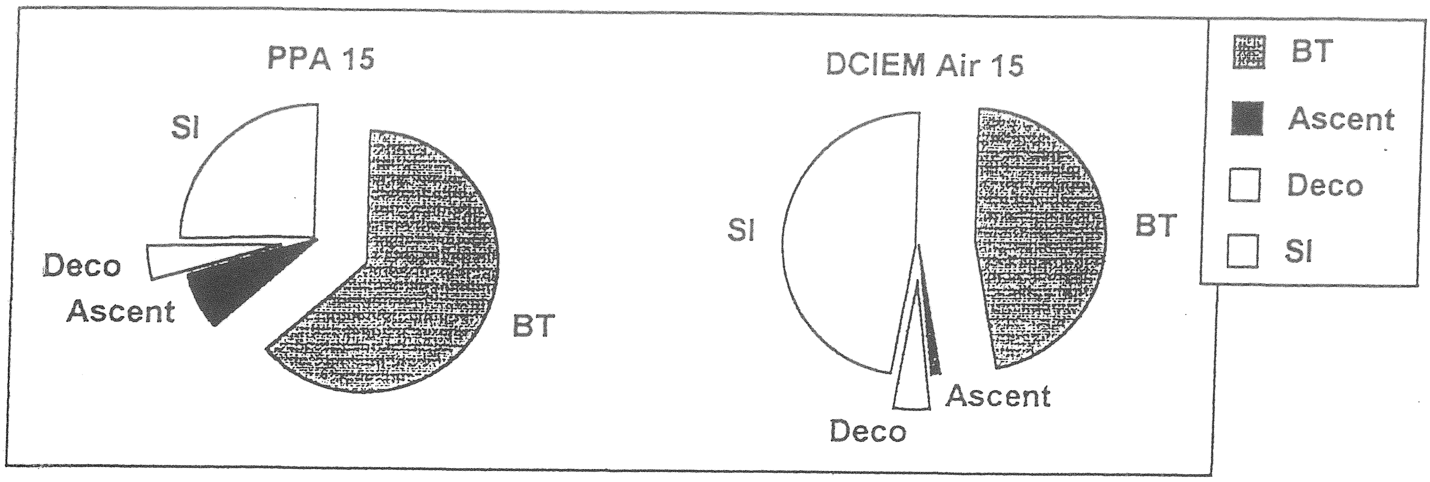
If you move from a deeper zone to a shallower zone, at the end of the day decompression would be that of the deeper zone.

Skippers must allow for transducer position on the ship's hull when determining depth.

FIGURE 1

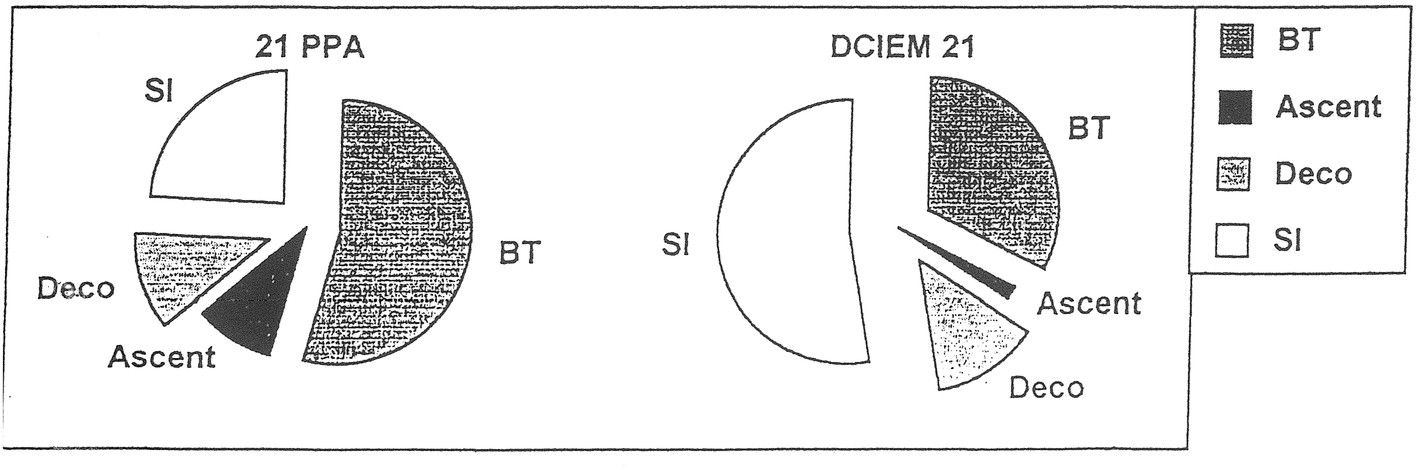
COMPARISON OF PPA AND CANADIAN DEFENCE & CIVIL INSTITUTE OF ENVIRONMENTAL MEDICINE (DCIEM) PROFILES



15 m PPA cf DCIEM Std Air

The Areas in each Pie Graph represent the percentage of the total time

Bottom Time: PPA 450 mins; DCIEM 315 mins
Total Time: PPA 710 mins; DCIEM 672 mins



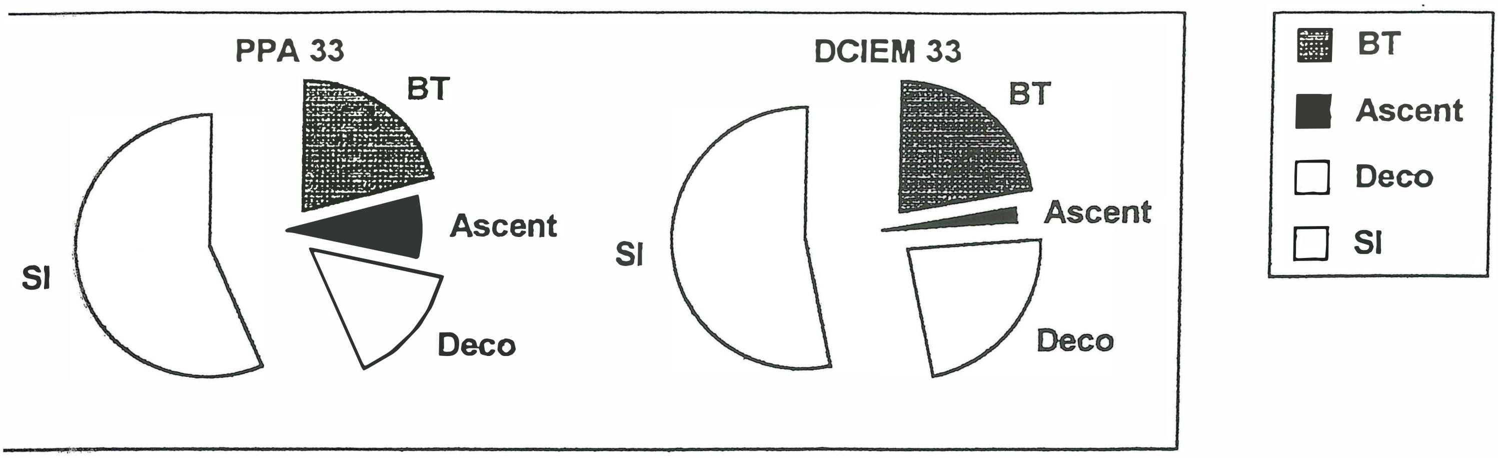
21 msw profiles PPA cf DCIEM Oxygen

Bottom Time: PPA 360 mins: DCIEM 240

Total time: PPA 663 mins
DCIEM 738 mins

FIGURE 1 (Continued)

COMPARISON OF PPA AND CANADIAN DEFENCE & CIVIL INSTITUTE OF ENVIRONMENTAL MEDICINE (DCIEM) PROFILES



33 msw profiles PPA cf DCIEM

Bottom Time - 125 minutes each
Total time: DCIEM 562 minutes
PPA 700 minutes

FIGURE 2

TOTAL NUMBER OF DIVES PER PROFILE FROM 1991 TO 1994

DEPTH	Dives 1991	Dives 1992	Dives 1993	Dives 1994
<11	5400	7075	5269	8742
<13	5189	6821	4429	5226
<15	4013	4373	2470	2274
<17	3898	3168	1738	1080
<19	5366	3835	2624	1320
<21	3682	2856	2189	1212
<23	989	547	621	534
<25	38	35	12	48
<27	8	220	88	0
<29	101	269	316	0
<31	537	118	332	0
<33	861	455	764	0
<35	320	323	600	0

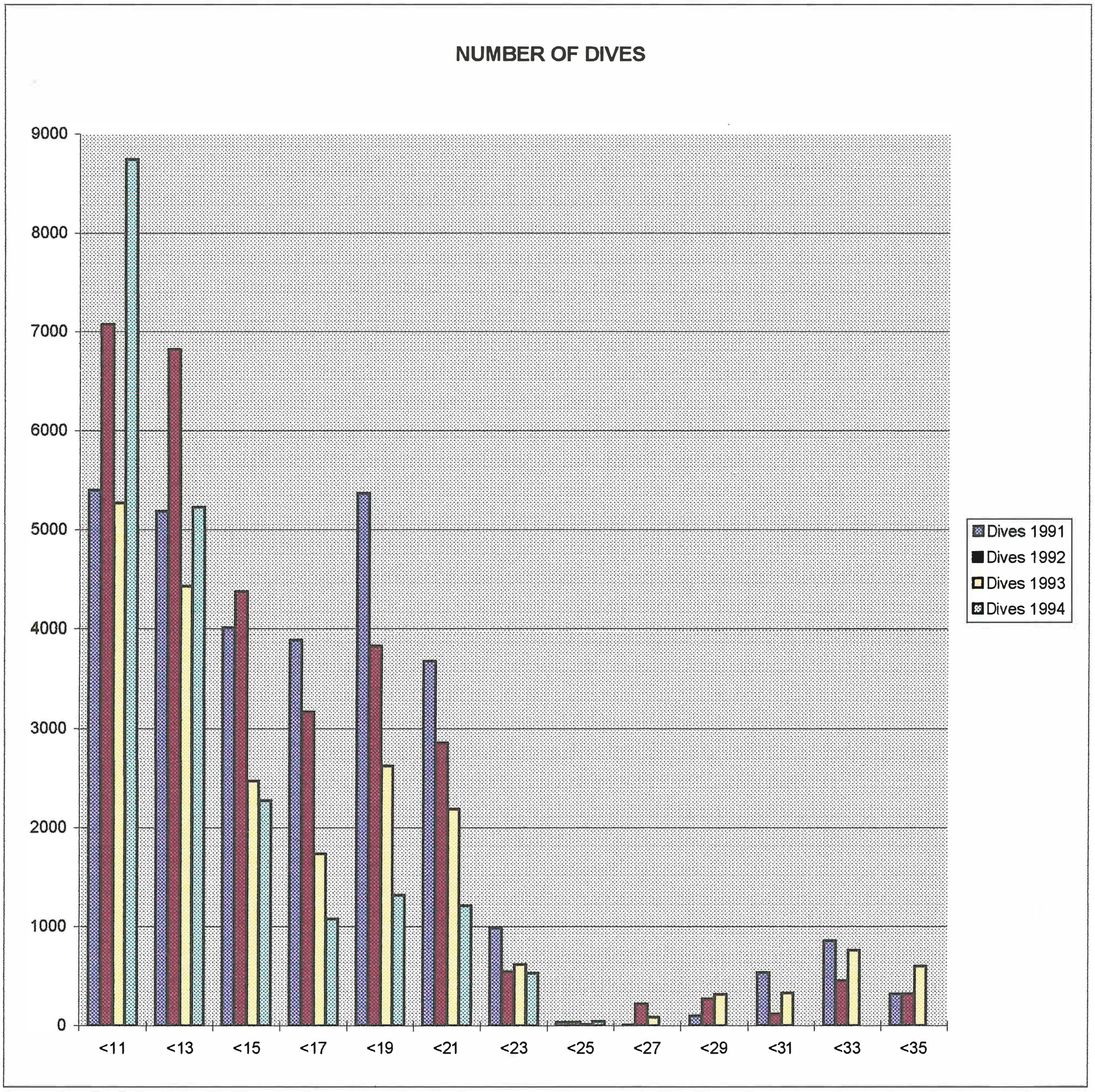


FIGURE 2 (Continued)

TOTAL NUMBER OF DIVES PER DEEP PROFILES (25m to 35m)

DEPTH	Dives 1991	Dives 1992	Dives 1993	Dives 1994
<25	38	35	12	48
<27	8	220	88	0
<29	101	269	316	0
<31	537	118	332	0
<33	861	455	764	0
<35	320	323	600	0