27 Kalina M and Pease DC. The preservation of ultrastructure saturated in phosphatidyl cholines by tannic acid in model systems and Type II pneumocytes. *J Cell Biol* 1977; 74: 726-741.
28 Ueda S, Kawamura K and Ishii N et al. Ultrastructural studies on surface lining layer of the lungs Part IV. Resected human lung. *J Jap Med Soc Biol Interface* 1985; 16: 34-60.
29 Stratton CJ. Morphology of surfactant-producing cells and of the alveolar lining layer. In Roberston B and Van Golde LMG Eds. *Pulmonary surfactant*. Amsterdam: Elsevier, 1984:68-118.
30 Peters A, Palay SL and Webster Hde F. *The fine structure of the nervous system*. New York: Harper and Row, 1970: 28-29.
31 Morley CJ, Bangham AD, Johnson P, Thorburn GD and Jenkins G. Physical and physiological properties of dry lung surfactant. *Nature* 1978; 271: 1620163.
32 Tierney DF and Johnson RP. Altered surface tension of lung extracts and lung mechanics. *J Appl Physiol* 1965; 20: 1253-1260.
33 Barrow RE and Hills BA. A critical assessment of the Wilhelmy method in studying lung surfactant. *J Physiol* 1979; 295: 217-227.
34 Hills BA. Alveolar liquid lining. Langmuir method used to measure surface tension in bovine and canine lung extracts. *J Physiol* 1985; 359: 65-79.
35 Gersh I, Hawkinson GE and Jenney Eh. Comparison of vascular and extravascular bubbles following decompression from high-pressure atmospheres of oxygen, helium-oxygen, argon-oxygen and air. *J Cell Comp Physiol* 1945; 26: 63-74.
36 Hills BA. Alternating bubble approach to decompression: sequential vs random patency in human skin. In James PB and Elliott DH Eds. *Proc 7th Ann Congr Europ Undersea Biomed Soc* Great Yarmouth, UK: North Sea Medical Centre, 1981: 310-318.
37 Hills BA. Decompression sickness: a fundamental study of "surface excursion" diving and the selection of limb bends versus c.n.s. symptoms. *Aerospace Med* 1971; 42: 833-836.
38 Wilson PD, Lieberman GE and Peters TJ. Ultrastructural localization of adenosine diphosphatase activity in cultured aortic endothelial cells. *Histochem J* 1982; 14: 215-219.
39 Hills BA. A novel approach to hypertension. *Med Hypoth* 1991, (in press).

Professor Brian Hills' address is Department of Physiology, University of New England, Armidale, New South Wales, 2351, Australia.

COMPUTER RECREATION

David Brookman

All diving computers continually sample pressure and time, either using an algorithm, or a look-up table, to determine approximate nitrogen saturation from a theoretical model of the human body. Dissolved nitrogen is estimated in a series of tissue compartments ranging from one to many (there is an infinite continuum in which nitrogen may dissolve) which for mathematical simplicity are usually limited to about 6 to 12.[1,2] The concept of tissue compartments and the mathematical model of nitrogen uptake and elimination were derived by J.S.Haldane.[3] Some dive computers provides a record of the diver's depth-time profile and this can later be used to review the dive profile, and for comparatively accurate estimations of air consumption. These results in turn allow detailed dive planning.

Computer models of breathing gas usage and nitrogen gradients are a useful means of presenting graphically what may happen during a dive. They are idealised and hence cannot be used as an accurate representation of physiological reality.

This paper grew from electronic doodling using a spreadsheet (Microsoft Works) with an accompanying charting program. It is easy to calculate variations associated with nitrogen uptake and air consumption. I have used an IBM compatible with only 1 megabyte of random access memory, so my models have been limited to 5 tissue compartments with half-times of 2.5, 5, 10, 20 and 40 minutes, but these are the ones relevant to sports dives of less than 60 minutes duration and not suitable for repetitive dive calculations.

Using a computer to estimate air consumption

Obviously air consumption is dependent on the amount of physical work the diver does and his or her breathing rate. The latter is dependant on the pH of the CSF (which depends on blood CO_2 levels), the partial pressure of oxygen in the arterial blood (both are affected by exercise) and the psychological state. Lippmann[4] gives a method of calculating air consumption in his book that is limited in accuracy by the approximation to a trapezoidal dive profile.

Using a computer that replays a depth-time profile will give 3 minute samples of depth that allows the derivation of a weighted average of the depth (or an estimate of the integral of the depth/time curve). Table 1 provides such a profile.

In this table the respiratory minute volume (RMV) has been calculated (it is directly reproduced from the spreadsheet). The method of calculation is:

TABLE 1

Dive time		44 minutes
Fill pressure	280 bar	276.41 atm
End of dive pressure	70 bar	69.10 atm
Air cylinder water capacity		10 l

Depth (MSW)	Time (minutes)	Pressure (atm)
15.0	3	2.58
23.4	6	3.32
31.2	9	4.10
32.7	12	4.24
32.4	15	4.21
30.9	18	4.07
22.5	21	3.23
16.2	24	2.61
14.7	27	2.46
10.5	30	2.04
8.4	33	1.83
7.8	36	1.77
9.9	39	1.98
7.2	42	1.71
0	45	0.00
0	48	0.00
0	51	0.00
0	54	0.00
0	57	0.00
0	60	0.00

Sum of pressure * time	120.48 atm.min
Average pressure	2.74 atm
RMV	17.21 L/min at 1 atm

TABLE 2

Dive time		61 minutes
Fill pressure	210 bar	207.31 atm
End of dive pressure	50 bar	49.36 atm
Air cylinder water capacity		11.4 l

Depth (MSW)	Time (Min)	Pressure (atm)
11.4	3	2.13
11.1	6	2.10
8.4	9	1.83
5.7	12	1.57
5.1	15	1.51
7.5	18	1.74
9.6	21	1.95
9.3	24	1.92
9.3	27	1.92
8.7	30	1.86
7.5	33	1.74
6.9	36	1.68
11.1	39	2.10
10.8	42	2.07
9.6	45	1.95
11.4	48	2.13
10.8	51	2.07
9.3	54	1.92
8.1	57	1.80
4.8	60	1.48

Sum pressure * time	112.50 atm.min
Average pressure	1.84 atm
RMV=	16.01 L/min at 1 atm

For each depth:

Pressure = (depth/10.8)+1 (atm)

For the whole dive (where T = duration of dive)

Mean pressure = (1/T) *sum(pressures *3) (atm)
(the 3 is the three minute sampling intervals)

and finally where Pe = tank pressure at end (bar)

Pf = tank filling pressure (bar)
C= water capacity of tank (litres)

RMV = (Pf-Pe) * C/ (T * P) litres/min (at 1 atm)

Greater accuracy could be obtained if the times of variations of the diver's physical activity and the tank pressure at the time are recorded. RMV's can then be calculated for each phase of the dive. It is doubtful that such accuracy is valid or desirable as it represents a sampling variation of the experimental result, and intrudes into the enjoyment of diving.

Table 2 demonstrates the same calculation for a shallower but longer dive.

Estimating nitrogen gradients

Haldane proposed a limit to the rate of ascent of a maximum ratio of nitrogen partial pressure to ambient pressure of 1.58. As nitrogen is the dominant inert gas involved (CO_2 and O_2 being chemically interactive are not usually included in the determination of partial pressure) this equates to a ratio of 2:1 of nitrogen partial pressure to ambient pressure.

Using the Haldane model with tissue compartments with half times of 2.5, 5, 10, 20 and 40 minutes it is possible to graph the changing nitrogen partial pressures (which equate to tissue saturation) for each dive. Figure 1 represents the dive of Table 1 showing the nitrogen partial pressures in each compartment, and Figure 2 shows the dive of Table 2.

The U.S. Navy tables have been derived using the Haldane model. Data from experimental dives suggest that the Haldane model is too restrictive where fast tissues are involved, and may not be adequate where slow tissues are considered. Slow tissues affect the repetitive dive estimations of residual nitrogen which are not the subject of this

Fig 1

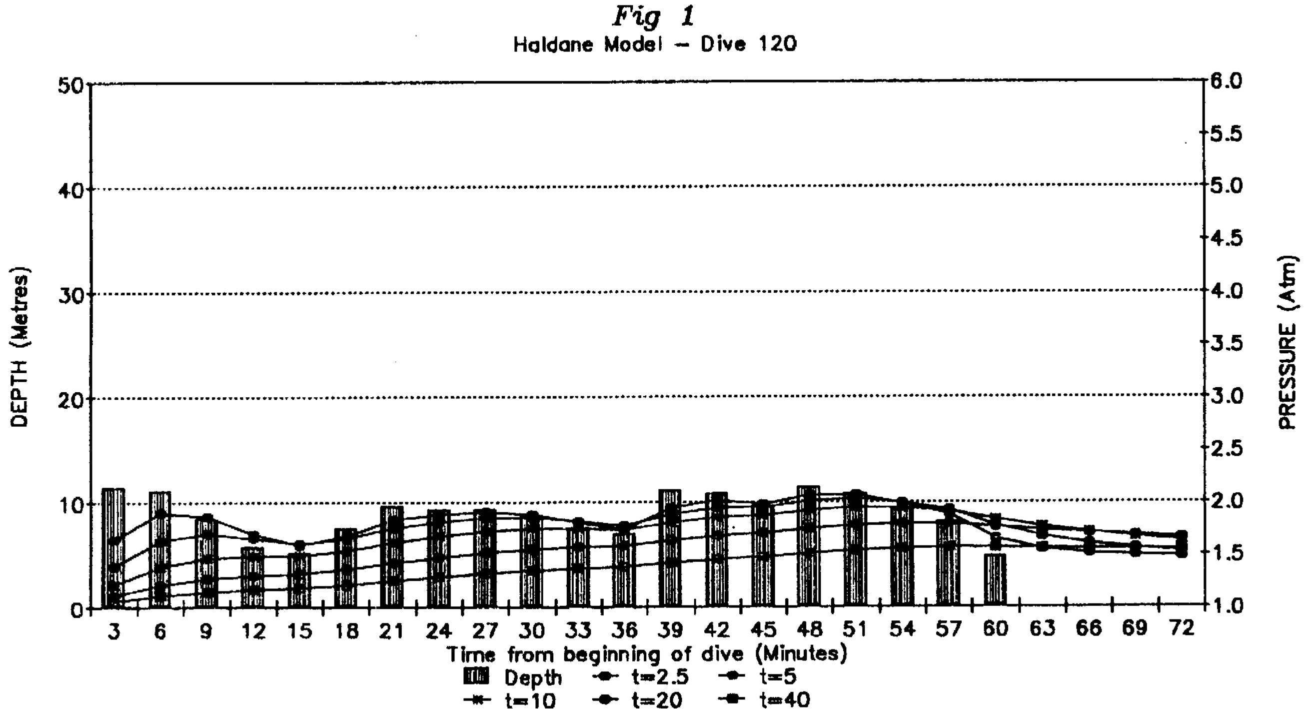
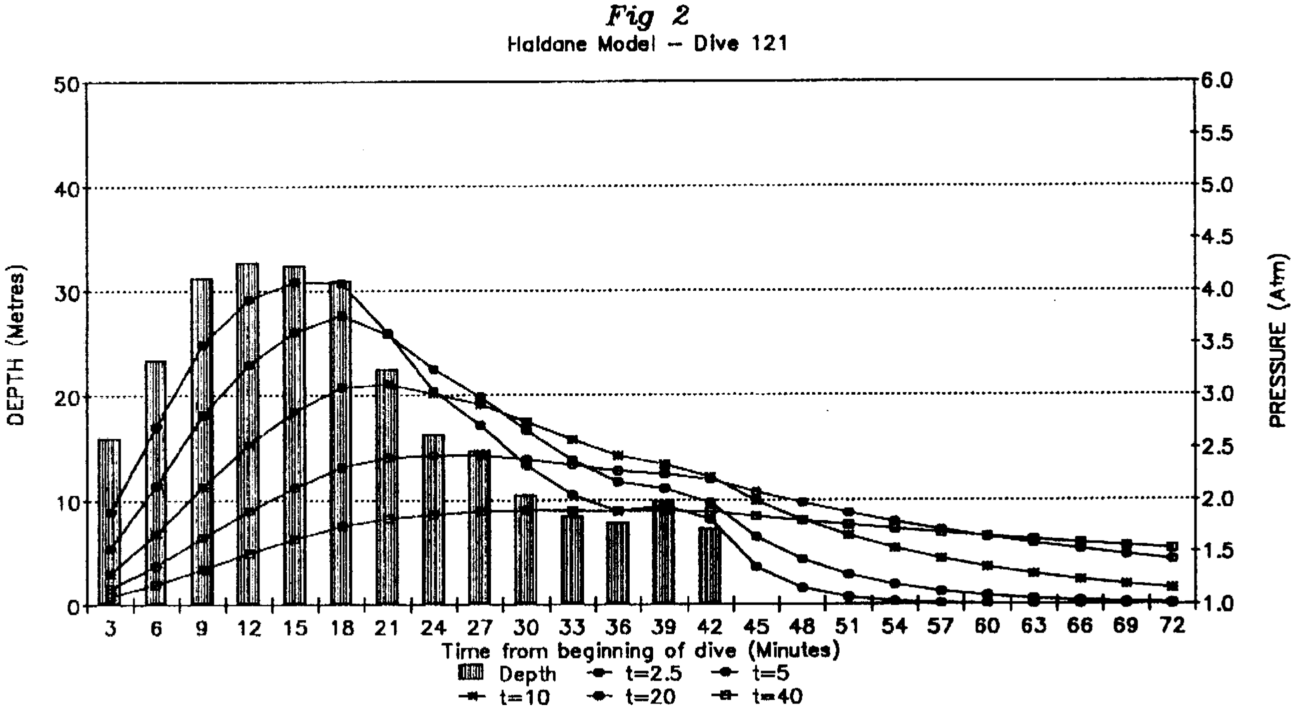


Fig 2



paper. The nitrogen gradient can be used to demonstrate the desirability of slow ascents from deep dives and the effect of staging and decompression stops. Readers who are interested can readily analyse individual dives (if they are wearing the appropriate dive computer) as a teaching exercise. It may also be useful to those divers who are not fit, lean, males aged between 20 and 30 years of age who wish to modify their dive profiles to minimise their nitrogen gradients.

Table 3 shows an nitrogen gradient calculation for a comparatively deep dive.

TABLE 3

Depth (MSW)	Time (minutes)	Relative Ambient (atm)	Nitrogen Pressure Gradient	Nitrogen Gradient Ratio
35.7	3	3.54	1.54	3.54
37.2	6	3.69	0.74	0.64
36.6	9	3.63	0.29	0.85
36	12	3.57	0.10	0.95
37.2	15	3.69	0.1	0.95
36.9	18	3.66	0.03	0.99
21.6	21	2.14	-0.79	-1.47
12	24	1.19	-1.15	-1.80
8.4	27	0.83	-1.16	-1.82
4.8	30	0.48	-1.23	-2.03
4	33	0.40	-1.07	-1.94
4	36	0.40	-0.88	-1.76
0	39	0	-1.15	-2.28
0	42	0	-1.04	-2.15
0	45	0	-0.94	-2.04
0	48	0	-0.84	-1.94
0	54	0	-0.69	-1.76
0	57	0	-0.65	-1.69
0	60	0	-0.62	-1.65
0	63	0	-0.59	-1.62
0	66	0	-0.56	-1.59

These calculations can be reproduced graphically (the dark bars represent the gradient ratio, the light the actual estimated pressure). Figure 3 shows the dive of Table 3, and Figure 4 shows another better executed dive with a slower ascent time and longer staging but of similar depth and more suited to those not fulfilling the physical criteria of the U.S. Navy's divers.

Dive planning

Data derived from the above dive analysis can be used to plan new dives in greater detail. It is a moot point whether this is desirable as it may encourage some to push their air supply to its limits and thereby create "out of air" crises and hence subject themselves to the risk of decompression illness. Therefore I would not envisage this as being useful for any but the most experienced divers who are planning exceptional dives and for those involved in teaching. The rule of thumb recommended by most of the training agencies of one third out, one third back, one third reserve should be maintained. Where this planning function may be useful is pre-dive estimation of the nitrogen gradient (particularly for those at greater risk of DCS), and for demonstrating to students the change in the tank pressures that can be expected throughout the dive.

Table 4 gives a projected dive which would exceed the expected safety limits and hence should not be con-

Fig 3

Nitrogen gradient (Haldane Model) — Di

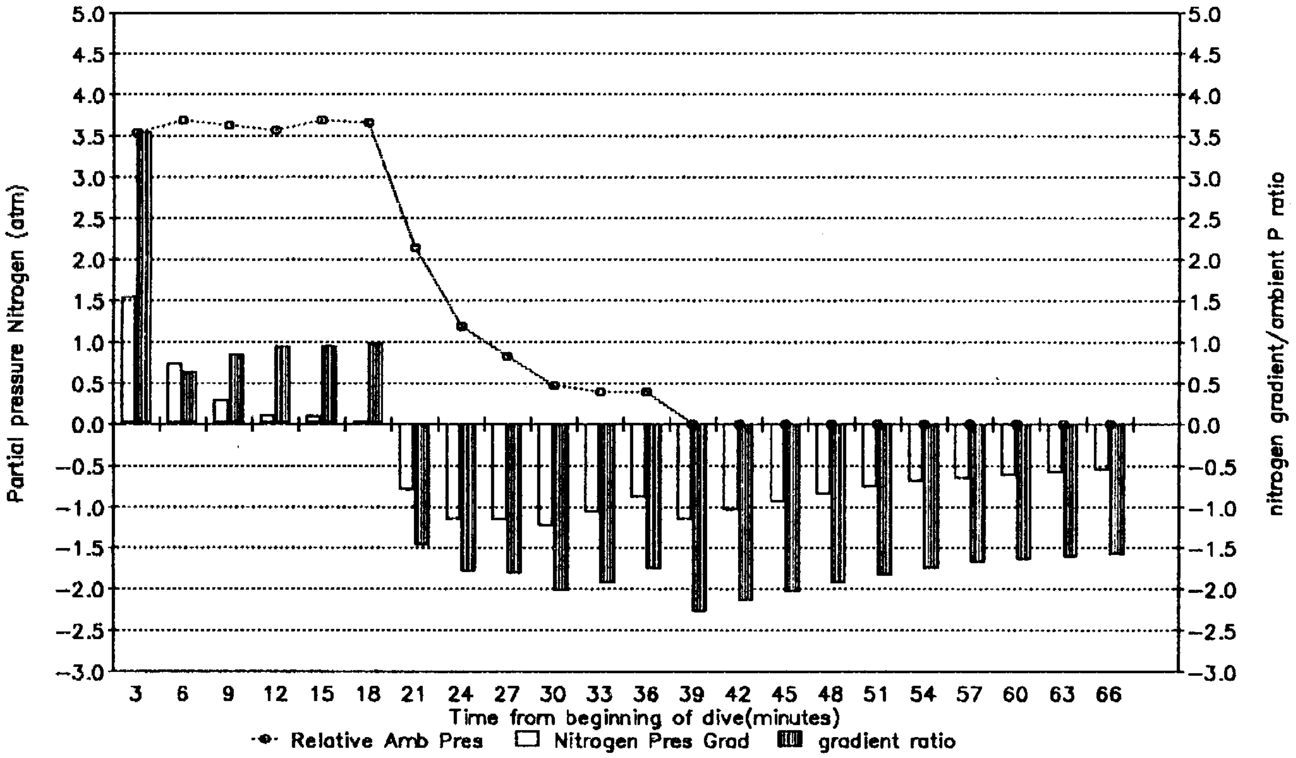


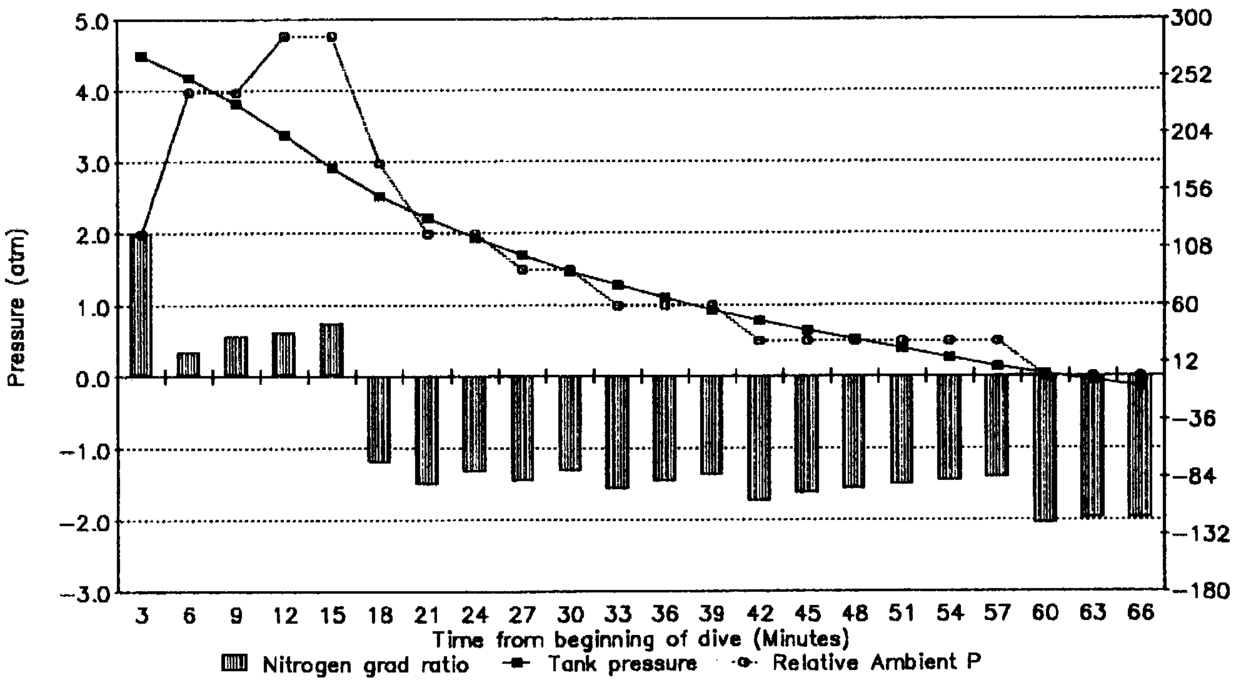
TABLE 4

Depth (MSW)	Time (minutes)	Relative Ambient Pressure (atm)	Nitrogen Pressure Gradient (atm)	Nitrogen Pressure Ratio (atm)	Tank Pressure (bar)
20	3	1.98	1.31	1.98	269
40	6	3.97	2.17	0.34	251
40	9	3.97	1.43	0.56	228
48	12	4.76	1.47	0.61	202
48	15	4.76	0.97	0.74	174
30	18	2.98	-0.54	-1.21	151
20	21	1.98	-1.01	-1.51	132
20	24	1.98	-0.67	-1.34	116
15	27	1.49	-0.80	-1.47	101
15	30	1.49	-0.65	-1.38	88
10	33	0.99	-0.93	-1.58	77
10	36	0.99	-0.76	-1.47	66
10	39	0.99	-0.62	-1.38	56
5	42	0.50	-0.94	-1.74	47
5	45	0.50	-0.85	-1.63	39
5	48	0.50	-0.77	-1.57	31
5	51	0.50	-0.69	-1.51	23
5	54	0.50	-0.62	-1.49	16
5	57	0.50	0.56	-1.42	8
0	60	0	-0.98	-2.06	2
0	63	0	-0.98	-1.98	2
0	66	0	-0.98	-1.98	2

Cylinder fill pressure = 280 Bar   Cylinder water capacity = 101 litres   Respiratory minute volume = 16.8 L/min

Fig 4

Dive Planner



ducted.

The dive is demonstrated graphically in Figure 4. The failure in this dive is the inevitable out-of-air risk though the decompression stops are quite conservative. A diver with this profile would need to resort to extra air (a spare tank hanging at the 5 m decompression stop) even assuming that the Respiratory Minute Volume did not change from the diver's average (i.e. exceptional physical activity was not required and no anxiety was aroused) and such an assumption cannot be the basis for a safe deep dive.

Obviously greater sophistication of the computer model could be achieved if RMV's for differing levels of activity were included. Such a step is not desirable given the use to which this model should be put.

There have been articles criticizing the use of dive computers because they lack the inherent safety margin imposed by the maximum square profile resulting from the use of the tables. It is postulated this prompts divers to push their dive to the limits of the computer. Others have lauded computers as they reduce the risk of miscalculation by the narcosed diver! Both are probably correct. Dive computers are merely tools. Their use is another art that must be acquired by divers to minimise their risk of decompression illness. Computers that record the dive profile allow the analysis of divers' profiles and can show if they are misusing the computer. They also provide a useful record should the diver be unfortunate enough to suffer a decompression illness. Analysis of the dive profile could allow some judgement to be made of where the dive went wrong, rather than relying upon the diver's imperfect memory.

References

1 Edmonds C, Lowry C and Pennefather J. *Diving and subaquatic medicine.* 2nd edition. Sydney: Diving Medical Centre, 1983; chapter 7

2 Lippmann J. *Deeper into diving*. Melbourne: JL Publications, 1990; chapter 12 et seq

3 Lippmann J. *Deeper into diving*. Melbourne: JL Publications, 1990; 177-181

4 Lippmann J. *Deeper into diving*. Melbourne: JL Publications, 1990; chapter 29

5 Lippmann J. *Deeper into diving*. Melbourne: JL Publications, 1990; 177-184

6 Edmonds C, Lowry C and Pennefather J. *Diving and subaquatic medicine*. 2nd edition. Sydney: Diving Medical Centre, 1983; 145-146

Dr David Brookman's address is 57 Kensington Road, Bolwarra, New South Wales 2320, Australia.

SPUMS NOTICES

SPUMS ANNUAL SCIENTIFIC MEETING 1993

This will be held at the Pan-Pacific Hotel in Palau in May or early June 1993. The exact date is still to be fixed.

The guest speaker will be Professor David Elliott, co-author with Dr Peter Bennett of The Physiology and Medicine of Diving. He is an excellent teacher and an entertaining speaker.

As there has been much interest in this venue from members and associates the Committee considers that those who usually leave their decision to the last minute (and there are many) are likely to miss out because the hotel will have sold the rooms not booked by SPUMS to others.

To make certain of being able to accommodate all those who wish to attend it has been decided that there will be a cut off date, the **14th of December 1992**, when hotel bookings will be made, and rooms guaranteed, for all those who have applied to Allways Travel enclosing a deposit of $Aust 600 per person.

Every attempt will be made to provide accommodation for those who decide, after the cut off date, to attend but they may be disappointed. The message is book early and be certain of attending.