In 1913 the London diving firm, CE Heinke & Co commissioned construction of a diving chamber for the town of Broome. This was installed in the old hospital, situated on a hill beside the now demolished pearling wharf. Installation of this chamber, together with better understanding of diving physiology and the need for "staging' led to a substantial reduction of deaths for decompression illness. In 1918 there was only one death, and although there were more deaths in later years the mortality remained relatively low. The practices then, however, still seem appalling by today's treatment protocols. The 1918 report of the Master Pearlers Association read as follows: *"this* (one death) *is the lowest on record and it must be ascribed solely to the education of divers by means of the decompressor the generous gift of Messrs CE Heinke and Co with the present day engine boats we are working deeper than ever before* (as deep as 80 m) *and partial paralysis is fairly common, but immediate decompression by returning the diver to the water has almost solved the question. In the majority of cases a few hours "staging" effects a complete cure and the diver is able to carry on his work the next day "*.

Between the wars there was a progressive decline in pearling and the chamber was no longer used. After the second World War the chamber was rescued from the local rubbish tip by Mr Alec Reid, who ran a service station and car sales business in the town. The chamber, together with its motorised compressor now stand in Bedford Park opposite the rebuilt Continental Hotel. Compared with modern chambers, it is primitive in the extreme, barely large enough to accommodate a small Japanese. A normal sized European would have been a very tight fit; there appears to have been no means of communication, no oxygen, and certainly no room for an attendant. The internal diameter is 80 cm, the internal length approximately 6.3 m. It may well have been the fear of being shut in this chamber which persuaded divers to adopt some, be it imperfect, staging procedures!

The chamber now stands in the open, partly filled with rubbish, with the cast iron door unhinged and lying on the ground beside it. Commissioned in 1913, it would seem very likely that this is the first chamber ever operated in Australia. Its present situation is very much better than the town tip, but such a relic, now 74 years old, is probably deserving of even better treatment. The town of Broome has many diving relics; anchors form garden ornaments and the wheels from hand compressors are used as garden edging. The museum, situated in the old Customs House near the now demolished wharf and hospital has a photograph of the chamber as it was in use, as well as many items belonging to divers.

SPUMS has had meetings in many different parts of the Pacific and Indian Oceans. Perhaps we would celebrate the 75th anniversary of the inauguration of Australia's first diving chamber by holding a meeting in Broome.

REFERENCES AND FURTHER READING

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SWISS DECOMPRESSION TABLES

John Lippmann

HISTORICAL BACKGROUND

The laboratory of Hyperbaric Physiology of the Medical Clinic of the University of Zurich was established in 1960. The theme of the research being carried out was that of assessing the well-being and functional ability of the human being in atmospheres of abnormal pressure and composition. The Swiss, lacking a history of decompression research, were free from the shackles of traditional approaches and could begin to introduce new ideas in this area.

The effects of both nitrogen and helium have been considered throughout their decompression research, and the tolerance to nitrogen in decreased ambient pressure has also been investigated, due to the local interest in diving in mountain lakes.

The "Swiss Decompression Theory" is only a method of calculating saturation and desaturation in a way which permits safe decompression. All of the empirical factors that are important for this method were determined experimentally in Zurich.

For decades 240 minutes was considered to be the longest half-time for nitrogen in man, but in the mid-1960s it was shown that complete saturation with nitrogen takes 3-4 days, and hence the longest half-time for nitrogen was calculated to be 8-10 hours. Eventually, after various trials and experiments, sixteen tissue compartments with half-times for nitrogen of 4 to 635 minutes (and for helium of 1 to 240 minutes) were considered for calculating the equalization of the pressure of the inert gas. The sixteen nitrogen (N_2) half-times selected are shown in Table 1 (right). The half times associated with various body organs were identified and some are shown in Table 2.

THE ZH-L_{12} SYSTEM

The Swiss observed that the difference between the pressure of the inert gas in the tissue and the tolerated (ie. asymptomatic) ambient pressure, the "over-pressure" of nitrogen or helium, increases approximately linearly with increasing ambient pressure. Put simply, at depth our tissues can tolerate more excess gas than in the shallows.

It is commonly accepted that tissues with longer half-times (slow tissues) tolerate less excess inert gas than do shorter half-time tissues (fast tissues) at a given ambient pressure. The ambient pressure that can be tolerated (P amb.tol.) when a particular half-time tissue with a calculated inert gas pressure (P i.g.t.) is decompressed is given by:

TABLE 2

N_2 1/2-times associated with various body organs

Organ	**N_2 1/2-time in minutes**
CNS	4.0-27.0
Skin and muscles	38.3-77.0
Inner ear	146.0-239.0
Joints and bones	305.0-635.0

$$\text{P amb.tol.} = (\text{P i.g.t.} - a)b$$

where a and b are coefficients determined experimentally for various tissue types. Twelve pairs of coefficients were determined in order to represent the sixteen tissue half-times. This became known as the ZH-L_{12} system.

Using the ZH-L_{12} system both staged and continuous decompression can be calculated quite easily and a computer can be programmed to carry out the decompression calculations. In fact the "Deco-Brain 2" decompression calculator utilizes this system.

TABLE 1

Sixteen half-time values for N_2 corresponding to various tissue compartments for the ZH-L_{12} system.

Compartment	N_2 1/2 Time
I	4.0
2	8.0
3	12.5
4	18.5
5	27.0
6	38.3
7	54.3
8	77.0
9	109.0
10	146.0
11	187.0
12	239.0
13	305.0
14	390.0
15	498.0
16	635.0

FEATURES OF THE ZH-L12 SYSTEM

The difference between the maximum depth of the dive and the depth of the first decompression stop increases as dive depth increases, and the rate of ascent to the first stop is governed by both the maximum depth and the controlling half-time tissue. *In practice, for SCUBA divers, the maximum ascent rate recommended is 10 metres per minute*, as Swiss experience shows that this is a safe continuous decompression for saturated tissues in order to prevent bubble formation. This ascent rate enhances gas elimination for dives to depths to about 30 metres. However for deep to very deep dives (ie. greater than 30 metres) it is recommended to use ascent rates of 15 to 20 meters per minute below 30 metres and thereafter ascend at 10 metres a minute. This is suggested in order to avoid allowing the "slower tissues" to absorb extra gas during the ascent. Decompression stops are calculated at 0.3 bar (3 msw) intervals.

For short air dives the ZH-L_{12} system gives decompression times comparable to the US Navy and Royal Navy tables, utilising slightly longer stays at the deeper stops and giving an overall decompression time often between those of the US Navy and Royal Navy systems.

DIVING AT ALTITUDE

As previously mentioned, many Swiss have an avid interest in diving in mountain lakes and consequently,

NO-DECOMPRESSION LIMITS AIR DECOMPRESSION TABLE

Depth m	BT min	Stops 6	3	RG
12	125		1	G
15	75		1	G
	90		7	G
18	51		1	F
	70		11	G
21	35		1	E
	50		8	F
	60		16	G
24	25		1	E
	35		4	F
	40		8	F
	50		17	G
	60	4	24	G
27	20		1	E
	30		5	F
	35		10	F
	40	2	13	G
	45	3	18	G
	50	6	22	G
30	17		1	D
	25		5	E
	30	2	7	F
	35	3	14	G
	40	5	17	G
	45	9	23	G

m	min	9	6	3	RG
33	14			1	D
	20			4	E
	25		2	7	F
	30		4	11	G
	35		6	17	G
	40	2	8	23	G
36	12			1	D
	20		2	5	E
	25		4	9	F
	30	2	5	15	G
	35	2	8	23	G
39	10			1	D
	15			4	E
	20		3	7	F
	25	2	4	12	G
	30	3	7	18	G
	35	5	9	28	G
42	9			1	D
	12			4	D
	15		1	5	E
	18		4	6	F
	21	2	4	10	F
	24	3	6	16	G
	27	4	7	19	G

m	min	12	9	6	3	RG
45	12				5	E
	15			3	5	E
	18		2	4	9	F
	21		3	5	13	G
	24		4	6	18	G
48	9				3	E
	12			2	5	E
	15			4	6	F
	18		3	4	10	F
	21		4	6	16	G
51	9				4	E
	12			3	6	E
	15		2	4	8	F
	18		4	5	13	F
	21	3	4	7	18	G
54	9			1	5	E
	12		1	4	6	E
	15		3	4	10	F
	18	1	3	6	17	G
57	9			2	5	E
	12		2	4	8	E
	15	1	4	5	11	F
	18	3	4	7	18	G

Altitude **0–700 m** above sea level

Ascent rate: 10 m/min → Safety stop: 1 min at 3 m

FIGURE 1. Buehlmann no-decompression limits air decompression table for altitudes from 0 to 700 m above sea level.

in 1973, decompression tables for diving at sub-atmospheric pressure were developed. They enabled the calculation of decompression after dives of between the altitudes of 0-3,200 metres above sea-level. These tables were then thoroughly tested by Swiss Army divers and published in 1976. Between 1973 and 1983 no cases of decompression sickness were reported although well over 1,000 real dives were performed, many of these being repetitive dives.

The ZH-L_{12} system suggests somewhat different decompressions to those described in the earlier tables, but provides almost the same nitrogen excess on surfacing. They have been tested by supplementary experiments and found to be acceptable.

For dives above sea-level it is important to consider whether the divers reach the mountain lake quickly and then dive immediately, or whether they have been at altitude for some time prior to the dive, thus commencing diving with a subnormal nitrogen pressure (PN_2) in their tissues. In order to allow greater safety these tables assume that the diver had travelled to altitude very quickly and consequently has not yet adapted to the decreased atmospheric pressure. Adapting to altitude decreases the PN_2 in the tissues and thus provides additional safety. Furthermore the supersaturation factor on surfacing was chosen to allow for a further reduction in pressure, which may occur as a result of travelling by plane or car to a higher place after the dive.

FLYING AFTER DIVING

Experiments were conducted in order to determine the surface intervals required before a diver may be subjected to further decreases in atmospheric pressure. When this reduction of ambient pressure occurred in accordance with the ZH-L12 system, no symptoms of inadequate decompression occurred on testing.

REPETITIVE DIVING

Joints and bones have the least tolerance to an excess of inert gas and release any excess gas only very slowly. The 240 minute tissue half-time, which is the longest utilised in the US Navy tables, has often been found to be inadequate in situations when repetitive dives are undertaken for a number of days in succession (eg. on diving holidays). In these situations, the longer half-times of nitrogen with the lower tolerance towards nitrogen shown by the slower tissues, must be taken into consideration.

NO-DECOMPRESSION LIMITS
AIR DECOMPRESSION TABLE

Depth m	BT min	Stops 6	4	2	RG
9	238			1	G
12	99			1	G
	110			4	G
15	62			1	F
	70			4	G
18	44			1	F
	50			4	F
	60			11	G
21	30			1	E
	35			2	F
	40			5	F
	45			9	G
	50		1	13	G
	55		3	17	G
24	22			1	F
	30			3	F
	35			7	F
	40		2	11	G
	45		4	16	G
27	18			1	D
	20			2	E
	25			4	F
	30		2	7	F
	35		4	11	G
	40	1	6	16	G

m	min	9	6	4	2	RG
30	15				1	D
	20				3	E
	25			2	6	F
	30		1	4	11	G
	35		2	7	15	G
	40	1	5	10	20	G
33	12				1	D
	15				2	E
	20			2	4	F
	25		2	3	9	G
	30	1	3	6	14	G
	35	2	4	9	20	G
36	10				1	D
	15			1	3	E
	20		1	3	6	F
	25	1	3	5	12	G
	30	3	3	8	19	G
39	9				1	D
	12				3	E
	15			2	4	E
	18		2	3	7	F
	21		3	4	10	G
	24	2	3	6	15	G
	27	4	4	8	18	G

m	min	9	6	4	2	RG
42	8				1	D
	12			1	4	E
	15		1	3	5	F
	18		3	4	8	F
	21	3	3	5	13	G
	24	4	4	7	18	G
45	9				3	D
	12			3	3	E
	15		3	3	6	F
	18	2	3	4	11	F
	21	4	4	7	16	G
48	9			1	4	E
	12		1	3	4	F
	15	2	2	4	9	G
	18	4	5	5	14	G
51	6				2	E
	9		1	1	3	F
	12	1	2	3	5	F
	15	3	3	4	11	G
54	6				2	D
	9		1	3	3	F
	12	2	3	3	7	F
	15	4	4	6	13	G

Altitude **701–2500 m** above sea level

Ascent rate: 10 m/min ⟶ Safety stop: 1 min at 2 m

FIGURE 2. Buehlmann no-decompression limits air decompression table for altitudes from 701 to 2,500 m above sea level.

In the Swiss system the inert gas pressure in the tissues with nitrogen half times between 305635 minutes play a leading role during a surface interval and consequently with repetitive dives. This, however, does not mean that the Swiss tables are necessarily more conservative than the US Navy tables when used for repetitive dives. In fact, quite often the converse is true.

THE BUEHLMANN TABLE

The Buehlmann Table, derived using the ZH-L_{12} system, was published in order to provide sports divers with no-decompression limits and decompression stops for both single and repetitive dives.

The following definitions and rules apply to this table:

DEFINITIONS

Depths listed are the maximum depths reached during a dive.

Bottom Time (BT) is the time from leaving the surface until commencing the final ascent to the surface or to any decompression stop/s

Decompression Stop Time (Stops) is the time actually spent at that stop. It does not include the time taken to ascend to it.

Repetitive Group (RG) is a measure of excess nitrogen remaining in the body after a dive.

Surface Interval is the time from surfacing from a dive to commencing the next descent.

Residual Nitrogen Time (RNT) is a measure of the amount of excess nitrogen still in the body at the end of the surface interval. It is the time that the diver must consider that he or she has already spent at the planned depth of the repetitive dive when commencing a repetitive dive.

BUEHLMANN TABLE

REPETITIVE DIVE TIMETABLES 0–2500 m above sea level

Surface Interval Times

RG at start of surface interval							"0"	✈
A							2	2
B						20	2	2
C					10	25	3	3
D				10	15	30	3	3
E			10	15	25	45	4	3
F		20	30	45	75	90	8	4
G	25	45	60	75	100	130	12	5
G	F	E	D	C	B	A	hrs	hrs

RG at end of surface interval

Example:
Previous dive 24 m, 35 min = Repetitive Group (RG) = F
- after 45 min at surface: RG = C
- after 90 min at surface: RG = A (intermediate time: use next shorter interval time)
- after 4 hrs: flying is permitted
- after 8 hrs: RG "0", no more Residual Nitrogen Time (RNT)

RG for No-Decompression Dives and RNT for Repetitive Dives

Repetitive dive depth m (intermediate depths: use next shallower depth)

RG	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57
A	25	19	16	14	12	11	10	9	8	7	7	6	6	6	5	5	5
B	37	25	20	17	15	13	12	11	10	9	8	7	7	6	5	5	5
C	55	37	29	25	22	20	18	16	14	12	11	10	9	8	7	7	6
D	81	57	41	33	28	24	21	19	17	15	14	13	11	10	9	9	8
E	105	82	59	44	37	30	26	23	21	19	17	16	14	13	12	11	10
F	130	111	88	68	53	42	35	30	27	24	21	19	17	16	15	14	13

Example: RG = C at end of surface interval.
Planned depth of repetitive dive = 27 m. RNT = 18 min. *

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* **to be added to the bottom time (BT) of the repetitive dive.**
Note the handwritten correction in line 2 of the RG table.

FIGURE 3. Buehlmann repetitive dive timetables for 0 to 2,500 m altitude above sea level.

RULES

The ascent rate must not exceed 10 metres per minute.

For interim depths use the next greater depth on the table.

For interim times use the next longer time on the table, eg. for a dive to 17 m for 73 minutes look up the decompression for 18 m for 80 min.

For "strenuous" dives use the decompression prescribed for the next longest time increment, eg. for a strenuous dive to 17 m for 73 minutes look up the decompression for 18 m for 90 min.

Repetitive dives require additional time to be added. This time is determined by using the repetitive dive table and is called the residual nitrogen time. The residual nitrogen time is a measure of any excess nitrogen already in a diver's body before a repetitive dive.

If the depth of the repetitive dive is in between two depths then take the shallower figure when calculating the residual nitrogen time. This gives a greater residual nitrogen time and is thus safer.

A safety stop of at least 1 minute at 3 m is required after every no-decompression dive at altitudes up to 700 m and a stop of 1 minute at 2 m is required after dives at higher altitudes.

The following additional rule precedes Professor Dr Buehlmann's publication of his full ZH-L_{12} tables. It reads: "Because of the risk of nitrogen narcosis, diving to more than 40 m may not be undertaken without some security being given from the surface. For diving instructors the limit is increased to 50 m." The Swiss Federal Assurance Court considers that dives deeper than these depths carry "above normal risk" and diving to greater depths may affect a Swiss diver's insurance benefits.

USING THE BUEHLMANN TABLE

A. PLANNING SINGLE DIVES

Enter Table 1 at the exact, or next greater depth box. The lower (and less bold) figure in the first column is the no-decompression limit (NDL) for that depth. If the planned dive exceeds this time, go to the "Bottom Time" (BT) column (column 2), to the exact, or next longer time, then move right to read off the stops and, if required, the repetitive group at the end of the dive.

Example 1

You are planning a single, no-decompression dive to 22 m and wish to know the NDL.

Enter the 24 m box. The NDL is written in bold at the top of the BT column (column 2). It is 25 minutes. Remember that a safety stop of at least 1 minute at 3 m is suggested.

Example 2

What decompression is required for a dive to 36 m for 18 minutes?

Enter the 36 m box and read down the second column until the exact, or next longer time is found, in this case 20 minutes. Moving right, the decompression is found to be 2 minutes at 6 m followed by 5 minutes at 3 m. Remember that the maximum ascent rate must be 10 m/min. The repetitive group after the dive, given in the last column, is E.

Note 1. The time taken ascend from 36 m to the 6 m stop is not included in the 6 m stop time of 2 minutes. It should take 3 minutes to ascend to this first stop.

Note 2. The time taken to ascend from 6 m to 3 m (ie. 20 sec.) and from 3 m to the surface is not included in the 3 m stop time. The diver must spend the entire 5 minutes at 3 m.

Example 3

Calculate the decompression required for a dive to 31 m for 36 minutes.

Enter the 33 m box and move down column 2 until 40 minutes is found. Moving right, the decompression is found to be 2 minutes at 9 m, 8 minutes at 6 m and 23 minutes at 3 m. The repetitive group after the dive is G.

Note: It should take at least 2.2 minutes to ascend from 31 m to the 9 m stop. This is calculated as follows:

Distance to first stop = 31 - 9 = 22 m.

Time taken (at 10 m/min.) =22/10 = 2.2 min.

It is permissible to slow the ascent rate so as to take 3 minutes.

B. PLANNING REPETITIVE DIVES

Example 4.

Calculate any decompression required for the following pair of dives:

25 m for 20 minutes followed 2-1/2 hours later by a dive to 10 m for 50 minutes.

Upon entering the 27 m box the NDL for 25 m is found to be 20 minutes. Hence no decompression is required for the first dive. The repetitive group immediately after the dive is E.

Enter Table 2 from the left at E (the repetitive group) and move right until the 2 1/2 hour surface interval is found. It is between 45 minutes and 4 hours so moving down the repetitive group at the end of the interval is found to be A. Enter Table 3 from the left at A and move right until intersecting the column corresponding to the depth of the repetitive dive, in this case 18 m. The figure 14 which appears, represents the time to be considered already spent at 18 m before the repetitive dive. This 14 minutes must be added to the proposed bottom time in order to compute the correct decompression. Therefore this repetitive dive has an equivalent bottom time of 50 + 14 = 64 min. From Table 1 the decompression required is found to be 11 minutes at 3 m. After the dive the repetitive group is G.

Example 5

You wish to carry out two no-decompression dives, the first to 20 m followed 3 hours later by a dive to 32 m. Calculate the maximum allowable bottom time for each dive.

Enter the 21 m box. The NDL for 21 m is 35 minutes which is the maximum allowable time for the first dive. After this 20 m for 40 minutes dive the repetitive group is E (remember the safety stop time of one minute at 3 m). Entering Table 2 at E, move across to find the surface interval of 3 hours. It lies between 45 minutes and 4 hours so the repetitive group after the surface interval is A. Enter Table 3 from the left at A and move right until the 30 m row (ie. shallower in this case) is intersected. The residual nitrogen time is 9 minutes. Thus your body still has as much extra nitrogen as if you had already spent 9 minutes at 32 m before the dive. Returning to Table 1 and entering the 33 m box, the NDL is found to be 14 minutes You have already used 9 minutes of this (ie. your residual nitrogen time) so you may only dive for 5 minutes for a no-decompression dive. Hence the maximum allowable bottom time for the second dive is 5 minutes. Again do not forget to do the safety stop en route to the surface.

Example 6

You are planning to do two dives. The first is to 34 m for 18 minutes and the second, five hours later, is to be a no-decompression dive to 27 m. Calculate the decompression required for the first dive and the maximum allowable bottom time for the second.

Enter the 36 m box and move down column 2 to 20 minutes. Moving across, the required decompression is 2 minute sat 6 m and 5 minutes at 3 m. The repetitive group is E. Entering Table 2 at E, move across to find the surface interval of 5 hours. This row ends at 4.00 hours which means that, for group E, after 4.00 hours no residual nitrogen needs to be added. In other words, the previous dive can be ignored.

This situation occurs after a surface interval of 2.00 hours for group B, 3.00 hours for group C and up to 12.00 hours for group G. Therefore to find the allowable bottom time for the second dive, return to Table 1, enter the 27 m box and the maximum bottom time is found to be 21 minutes.

Determining the repetitive group after dives with bottom times less than the no-decompression limit is done by referring to the bottom part of Table 2, the repetitive group for no-decompression dives.

Example 7

Find the repetitive group after a dive to 9 m for 30 minutes.

Enter the bottom half of Table 2 at the 9 m column and move downwards to find the 30 minute (or next greater) bottom time. In this case we get 37 minutes and by moving across to the left the repetitive group is found to be group B.

Similarly after a dive to 30 m for 7 minutes (the no-decompression limit is 9 minutes) we are in group A and after a dive to 18 m for 38 minutes (the no-decompression limit is 44 minutes) we are in Group E.

<u>If the bottom time is exactly (or more than) the no-decompression limit the repetitive group must be taken from Table 1</u>. The repetitive groups in Table 1 do not always coincide with those in Table 2.

C. FLYING AFTER DIVING

The surface interval required before flying (or otherwise ascending) to normal commercial cabin altitude (2,400 m) is found in the following manner:

Use the repetitive group after the last dive to enter Table 2. Move across until entering the rightmost column with the picture of the aeroplane. This gives the time required before flying. After this interval it should be safe to fly.

Example 8

After a dive to 27 m for 20 minutes you are in repetitive group E. Entering Table 2 at E and moving across, you will find that after 3 hours it should be safe to fly. If after the dive you were in group F, you would have to wait at least 4 hours before flying.

D. DIVING AT ALTITUDE

Table 1 can be used for diving at altitudes between 0-700 metres. Table 3 is for use for dives at altitudes 701-2,500 m above sea level. This table is governed by the same rules as the 0-700 m tables and utilize the same repetitive dive timetable (Table 2).

NOTE: *This article is taken from the draft of a book relating to decompression and practical diving which is currently being prepared by John Knight and John Lippmann. The author wishes to thank Professor Dr Buehlmann and Beat Mueller for their assistance in the preparation and checking of this draft.*

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<u>PULMONARY OEDEMA FOLLOWING AN IRUKANDJI STING</u>

Ivan Herceg

It appears that stings by the small jellyfish “Irukandji” (Carukia barnesei) are relatively common in northern Queensland, some 61 cases being reported in the 1985-1986 summer season.[1] Although the Irukandji syndrome, as described by Barnes,[2] is extremely unpleasant, no life threatening complications have been described. It is generally believed that with correct supervision Irukandji sting carries no threat to