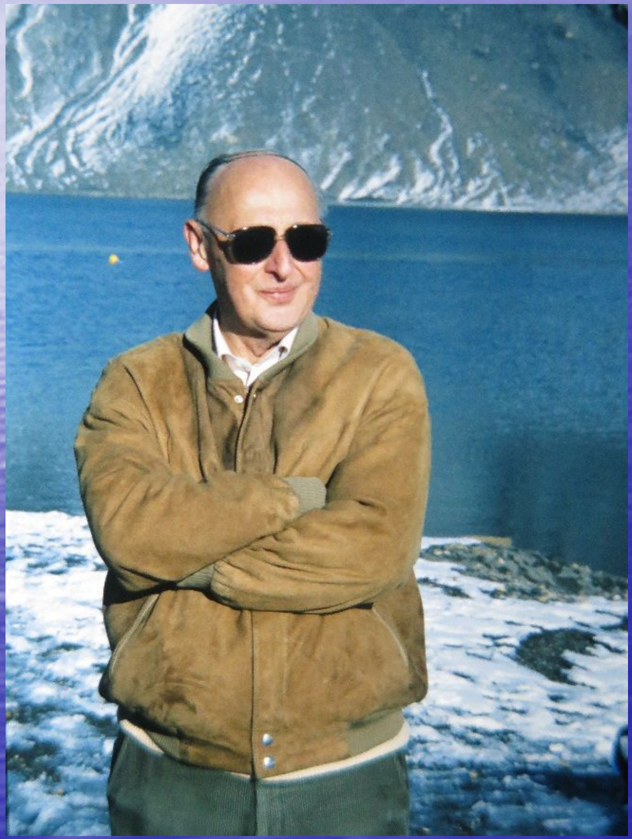
Bühlmann Memorial Symposium 2019

High Altitude Decompression Research and Diving Tables

by Beat A. Mueller, MSc. Mech. Eng. ETH

Bühlmann Memorial Symposium 2019



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Bühlmann Memorial Symposium 2019

VEREIN
HISTORISCHES DRUCKKAMMERLABOR
UNIVERSITÄTSSPITAL ZÜRICH (DKL-USZ)

Pressemitteilung

Horgen, 12.01.2017

Bühlmann's Forschungsdruckkammer vom Untergang bedroht.

Beschäftigt man sich mit der Anschaffung eines Tauchcomputers, stösst man praktisch automatisch auf das „Bühlmann-Modell". Die Druckkammer, in dem diese Dekompressionsalgorithmen entwickelt wurden, ist akut von der Verschrottung bedroht.
Ein Grossteil der heute verkauften Tauchcomputer arbeitet mit Dekompressionsalgorithmen, die auf dem Bühlmann-Modell basieren. Prof. Albert Bühlmann verfügte ab 1974 über eine Forschungsdruckkammer am Universitätsspital Zürich (USZ), in der er seine Berechnungen bis auf Tiefen von über 500m überprüfen konnte. Der Tauchpionier Hannes Keller, der als erster Mensch im Freiwasser die 300m Grenze mit Heliox überschritt, gab den Anstoss zur tauchmedizinischen Forschung in der Schweiz. Für die Ölindustrie war diese Tiefe notwendig um am Rand der Kontinentalschelfe nach Öl bohren zu können. Deswegen finanzierte sie den Bau des Druckkammlaboratoriums grösstenteils. Der Aviatik-Ingenieur Benno Schenk konstruierte eine Druckkammer die aus einem zylindrischen Teil mit Vorkammer und zwei Kugeln bestand, von denen eine mit Wasser gefüllt war, um „nasse" Tauchgänge zu ermöglichen. Sie wurde komplett in der Schweiz hergestellt und konnte sowohl Druckverhältnisse herstellen, wie sie in 1000 Meter Wassertiefe herrschen, als auch solche in 10'000 Meter Höhe über dem Meeresspiegel, was das Laboratorium für die Erforschung höhenmedizinischer Fragestellungen ebenso nutzbar machte. Nachdem in diesem Laboratorium und im Freiwasser international bedeutende Erkenntnisse gewonnen wurden, die teilweise bis heute Gültigkeit besitzen, führten Sparzwänge am USZ letztlich dazu, dass die Kammer im Jahr 2005 geschlossen werden musste. Die Druckkammer existiert zwar noch, ist aber inzwischen nicht mehr betriebsfähig. Im Zuge der umfangreichen Baumassnahmen am USZ wird das Gebäude in dem sich das ehemalige Labor befindet in einigen Jahren abgerissen und die eindrucksvollen Reste dieser Experimental-Druckkammer sollen verschrottet werden. Eine Gruppe aus ehemaligen Mitarbeitern, Probanden der Tieftauchversuche, Tauchern und Tauchmedizinern versucht die Kammer vor dem Schmelzofen zu bewahren und sie als Hauptexponat für eine Museumsabteilung über die Dekompressionsforschung „made in Switzerland" zu erhalten. Unter der URL www.druckkammer.ch gibt es weitere Infos inklusive Fotogalerie und geschichtlichem Überblick.

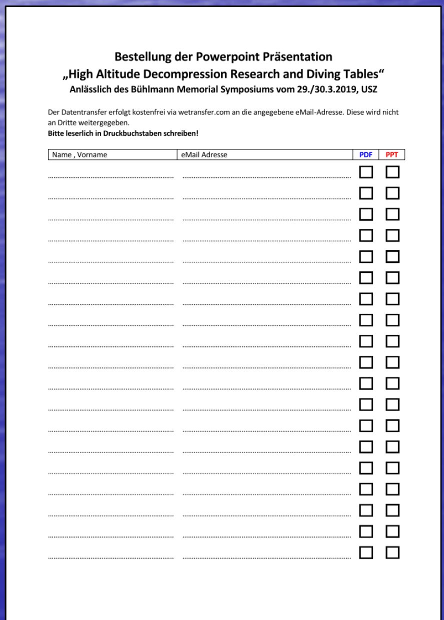
Ansprechpartner:
Christian Wölfel
Mättenbergstrasse 6A
3367 Thörigen
T +41 78 849 41 07
F +41 62 916 37 91
christian.woelfel@bluewin.ch
http://www.druckkammer.ch

Don't let the DKL die, don't leave it to the cutting torches!

You can change it!

Questions ?

Due to our tight schedule, please ask me during the breaks or the socializing part of this event.



Bestellung der Powerpoint Präsentation
„High Altitude Decompression Research and Diving Tables“
Anlässlich des Bühlmann Memorial Symposiums vom 29./30.3.2019, USZ

Der Datentransfer erfolgt kostenfrei via wetransfer.com an die angegebene eMail-Adresse. Diese wird nicht an Dritte weitergegeben.
Bitte leserlich in Druckbuchstaben schreiben!

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You want a copy of the complete presentation in ppt- OR in pdf-format? Leave me your email address and you‘ll get one!

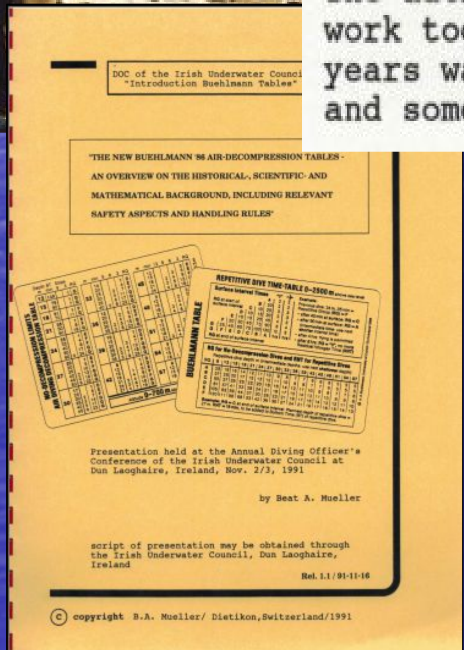
Bühlmann Memorial Symposium 2019

A tribute to
Prof. A.A. Bühlmann

Bühlmann Memorial Symposium 2019

A tribute to Prof. Dr. A.A. Bühlmann

Muttsee high altitude trials, 1988



DOC of the Irish Underwater Counci[l]
"Introduction Buehlmann Tables"

"THE NEW BUEHLMANN '86 AIR-DECOMPRESSION TABLES - AN OVERVIEW ON THE HISTORICAL-, SCIENTIFIC- AND MATHEMATICAL BACKGROUND, INCLUDING RELEVANT SAFETY ASPECTS AND HANDLING RULES"

Presentation held at the Annual Diving Officer's Conference of the Irish Underwater Council at Dun Laoghaire, Ireland, Nov. 2/3, 1991

by Beat A. Mueller

script of presentation may be obtained through the Irish Underwater Council, Dun Laoghaire, Ireland

Rel. 1.1 / 91-11-16

In the person of Prof. Dr. Buehlmann, Switzerland as a country with no access to any sea, is lucky enough to have an expert of worldwide reputation, accepted as a leading scientist in the field of hyperbaric research not only by the vaste diving community and scientific organisations, but also by many governmental bodies such as the US-NAVY, the German Navy and the American NASA. The author therefor still feels that the opportunity to work together with Prof.Buehlmann during more than 5 years was a unique chance, a lifelong lasting experience and some kind of undeserved luck.

Statement made at the Diving Officers Conference of the Irish Underwater Council November 1991, Dun Loaghaire, Ireland

…and it still holds true!

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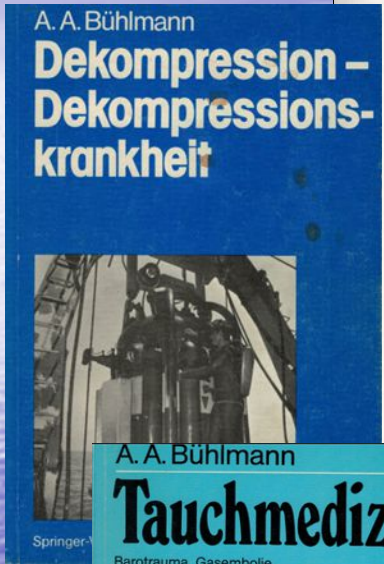
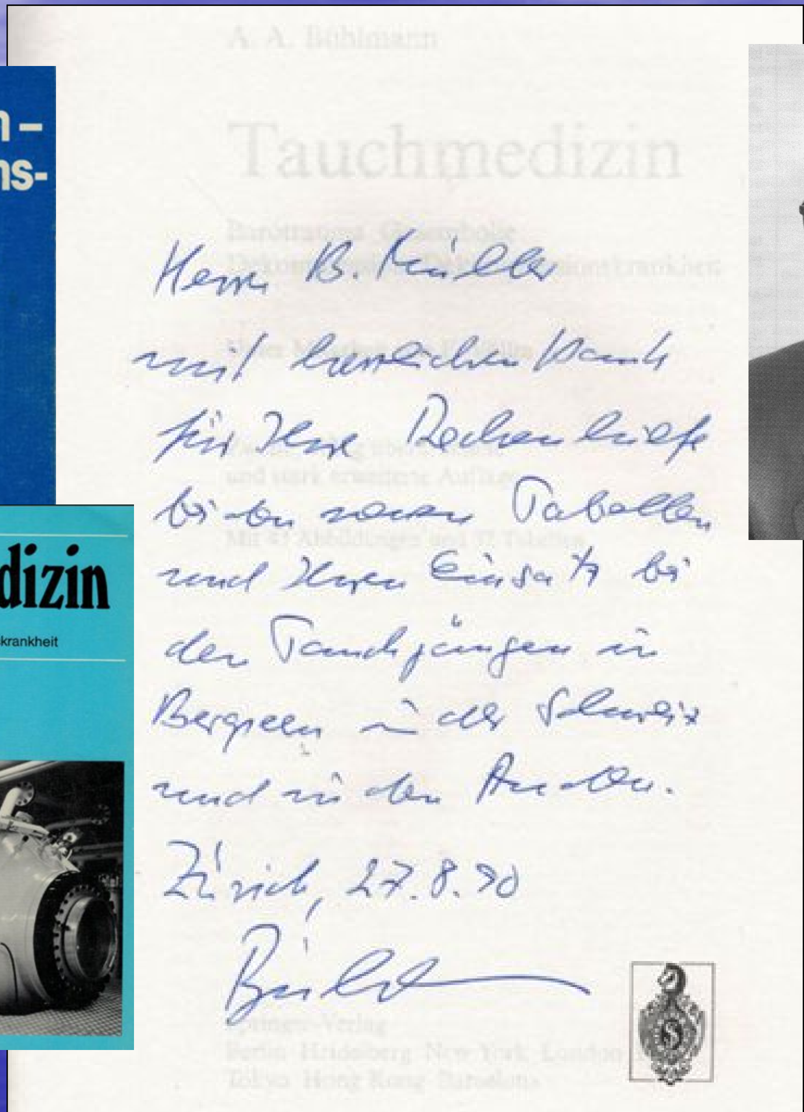
Personal Contributions





About the Model behind

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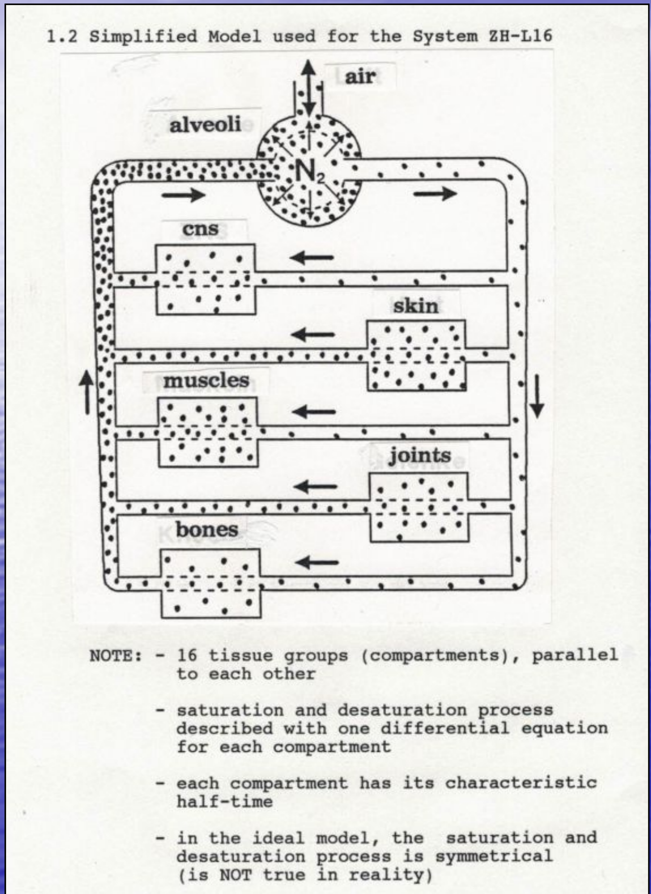
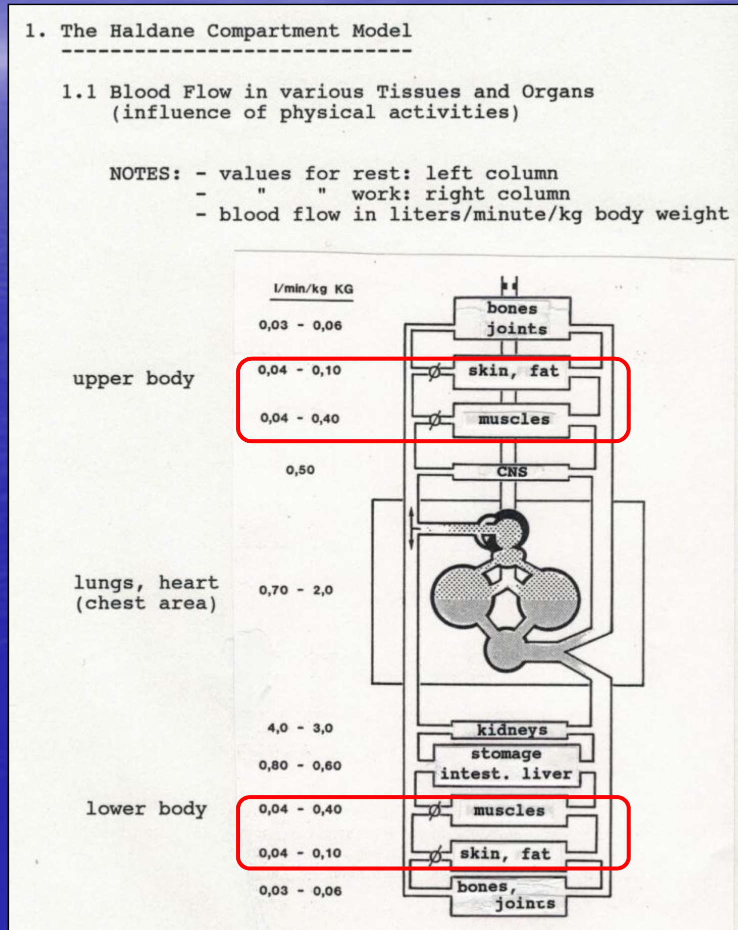
About the modell behind(1)


1.2 Simplified Model used for the System ZH-L16

NOTE: - 16 tissue groups (compartments), parallel to each other

- saturation and desaturation process described with one differential equation for each compartment
- each compartment has its characteristic half-time
- in the ideal model, the saturation and desaturation process is symmetrical (is NOT true in reality)

ZH: Zuerich
L: linear
16: tissue groups


1. The Haldane Compartment Model

1.1 Blood Flow in various Tissues and Organs (influence of physical activities)

NOTES: - values for rest: left column
- " " work: right column
- blood flow in liters/minute/kg body weight

ZHL-16 is a „simple“ *perfusion, dissolved phase model* that does not account for diffusion effects and bubble mechanics…but it works quite well!

Further concepts: → Appendices

About the modell behind(2)

Calculation „path“ of the inert gas (e.g. nitrogen) transport to the different tissue groupes, charac-terized by their half-times.

Each compartment has identical inert gas pressure level as „input“, inpendent of the state of adjecent tissues

1.3 The Nitrogen Transport in the Model

$$p\_insp.N2 = \alpha\_N2 * (p\_amb. - p\_H2O)$$

inert gas pressure in breathing gas

with respiratory coefficient Rc:

$$p\_alv.N2 = \alpha\_N2 * \left[p\_amb. - p\_H2O + \frac{(1 - Rc)}{Rc} * p\_CO2 \right]$$

alveolar inert gas pressure

normally Rc = 0.8 - 0.9
(for explanations, ref. to PART III / appendix F)

```
+------------------------+
| barometric pressure    |
| at surface  p_amb.surf.|
+------------------------+
            |
            V
+----------------------------+
| ambient pressure at depth  |   --> environ-
|   p_amb.(t,depth)          |       ment
+----------------------------+
            |
            V
+---------------------+
| N2-partial pressure |
| p_N2(p_amb.,α_N2)   |
+---------------------+
            |
            V
arterial side     lungs                 venous side
             alveolar N2 pressure
                p_alv.N2(t)

left heart                              right heart

              Compart-
     ------>  ment #1  ------>
p_alv.N2(t)   p_TN2(t)       p_TN2(t)
```

About the modell behind(3)

- One differential equation (and a solution) for each compartment (tisssue-group)
- All compartments act independently of their neighbour compartments
- „inbound“ inert gas partial pressure is identical for all compartments (all compartments parallel)
- Saturation and desaturation is mirror-like inverse to each other (not exactly true in reality due to shunt effects etc.)

simplified;
for rectangular ambient pressure change

```
2. The Saturation and Desaturation Process
   ---------------------------------------

   2.1 The Mathematical Approach (1 tissue)

                .  arterial       .Compartment C.   venous       .
                .  side           .             .   side         .
                .                                                .
                .blood input flow | volume V    |blood ouput flow
p_alv.N2        .    b   ==>      pressure diff. dp_C    b   ==>  .
                .                  (complete                      .
                .                   mixture)                      .
blood flow      .                                                 .
per unit        .                 .             .                 .
of time Δt.         b             .      b      .        b        .
                .                 .             .                 .
blood vol.  .      Δt * b         .   Δt * b    .     Δt * b      .
                .                 .             .                 .
N2-solub.   .                     .             .                 .
coeff.      .       α_b           .      α      .       α_b       .
                .                 .             .                 .
N2-tissue   .                     .             .                 .
part. press.    p_alv.N2          .    pC_N2    .      pC_N2      .
                .                 .             .                 .
N2-gas-     .                     .             .                 .
volume      .  Δt*b*α_b*p_alv.N2. V*α*dp_C   . Δt*b*α_b*pC_N2.
---------------------------------------------------------------------
                                  V

      input gas    -   output gas    =   remaining gas
      volume           volume            volume

                                  V

   p_TN2(t1) = p_TN2(t0) + [ p_alv.N2(t1) - p_TN2(t0) ]
               * [ 1 - exp(-k * Δt) ]

   (for rectangular ambient pressure change only)

   Δt = t1 - t0    p_TN2: tissue pressure    t_h: tissue half-
                                                       time
        b * α_b    ln(2)
   k = -------- = ----- (tissue constant)
        V * α      t_h
```

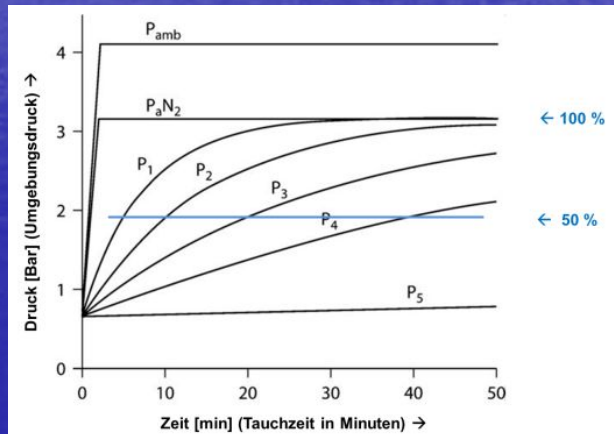
About the modell behind(4)

$$dP_t(t)/dt = k[P_{alv}(t) - P_t(t)]$$

LDE: linear differential equation

$$P_t(t) = P_{alv0} + [P_{t0}-P_{alv0}]\, e^{-kt}$$

Solution for ΔP = const.: Haldane equation

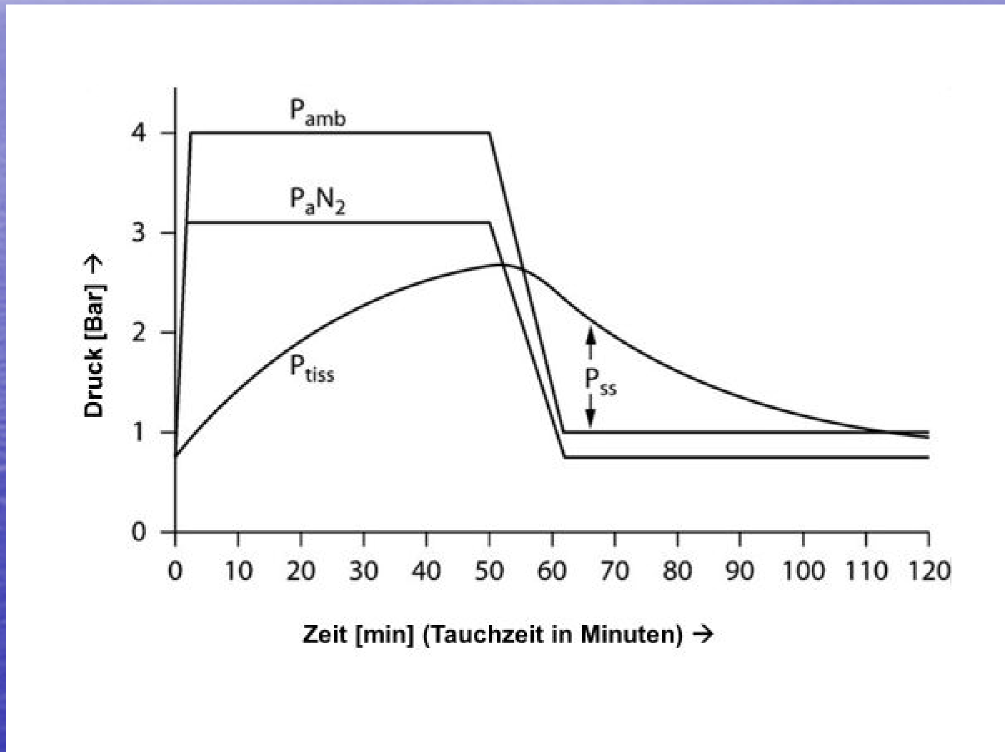


$$P_t(t) = P_{alv0} + R\,[t - 1/k] - [P_{alv0} - P_{t0} - R/k]\, e^{-kt}$$

Solution for ΔP / Δ t = const.: Schreiner equation

source: A. Salm (www.divetable.info)

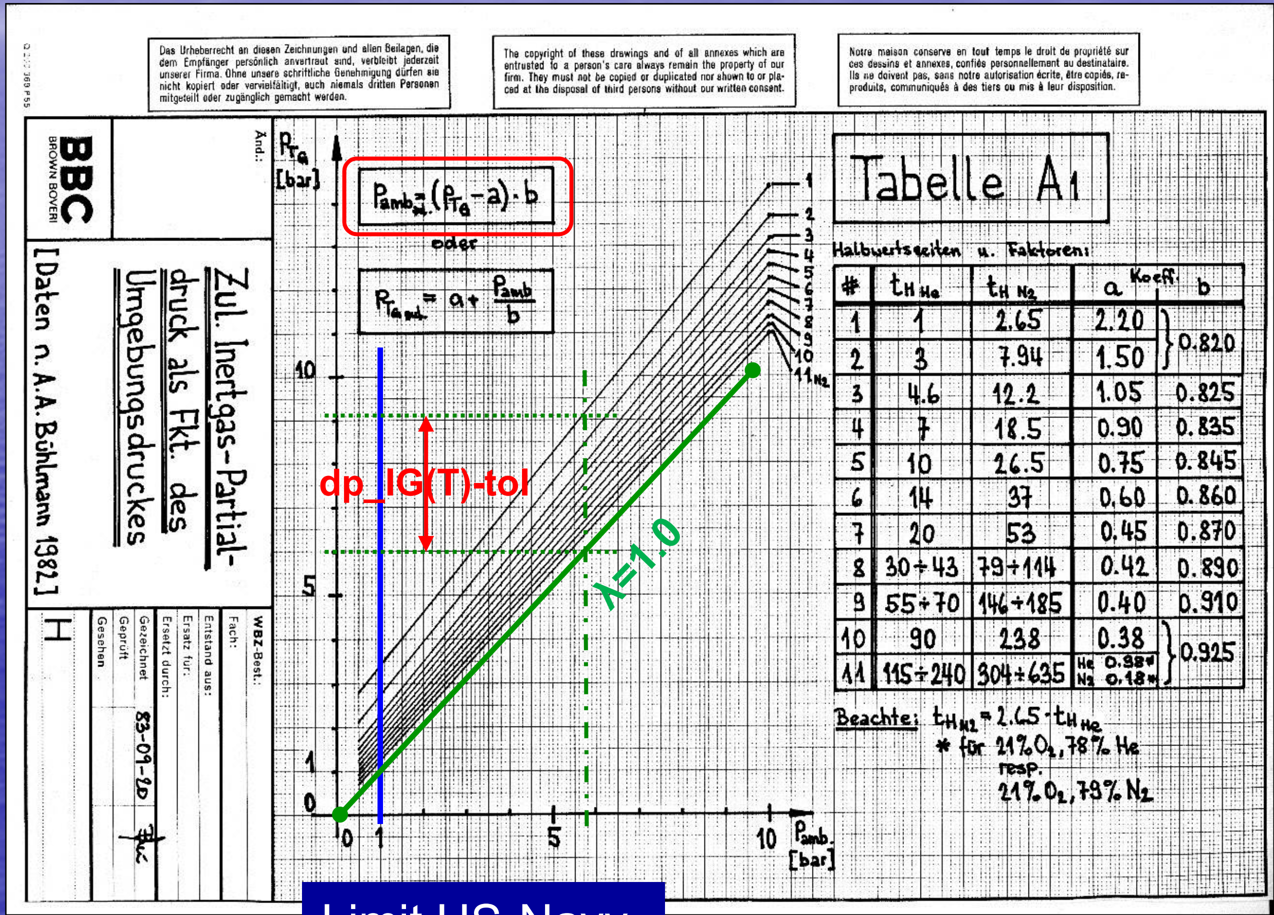
About the modell behind(5)



Courtesy of Dr. David A. Doolette, USN NEDU:
Doolette, D. J. and Mitchell, S. J. 2010. Hyperbaric Conditions. Comprehensive Physiology. 1:163–201.

About the modell behind (6a)

Tissue half-times, coefficients a, b to determine the ratio between ambient pressure and max. inert gas tissue pressure (similar to M-values of US-Navy tables)

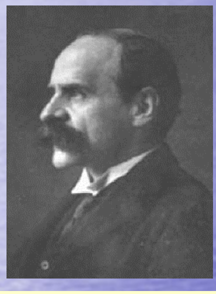


#	$t_{H\,He}$	$t_{H\,N_2}$	Koeff. a	Koeff. b
1	1	2.65	2.20	0.820
2	3	7.94	1.50	
3	4.6	12.2	1.05	0.825
4	7	18.5	0.90	0.835
5	10	26.5	0.75	0.845
6	14	37	0.60	0.860
7	20	53	0.45	0.870
8	30÷43	79÷114	0.42	0.890
9	55÷70	146÷185	0.40	0.910
10	90	238	0.38	0.925
11	115÷240	304÷635	He 0.38* N2 0.18*	

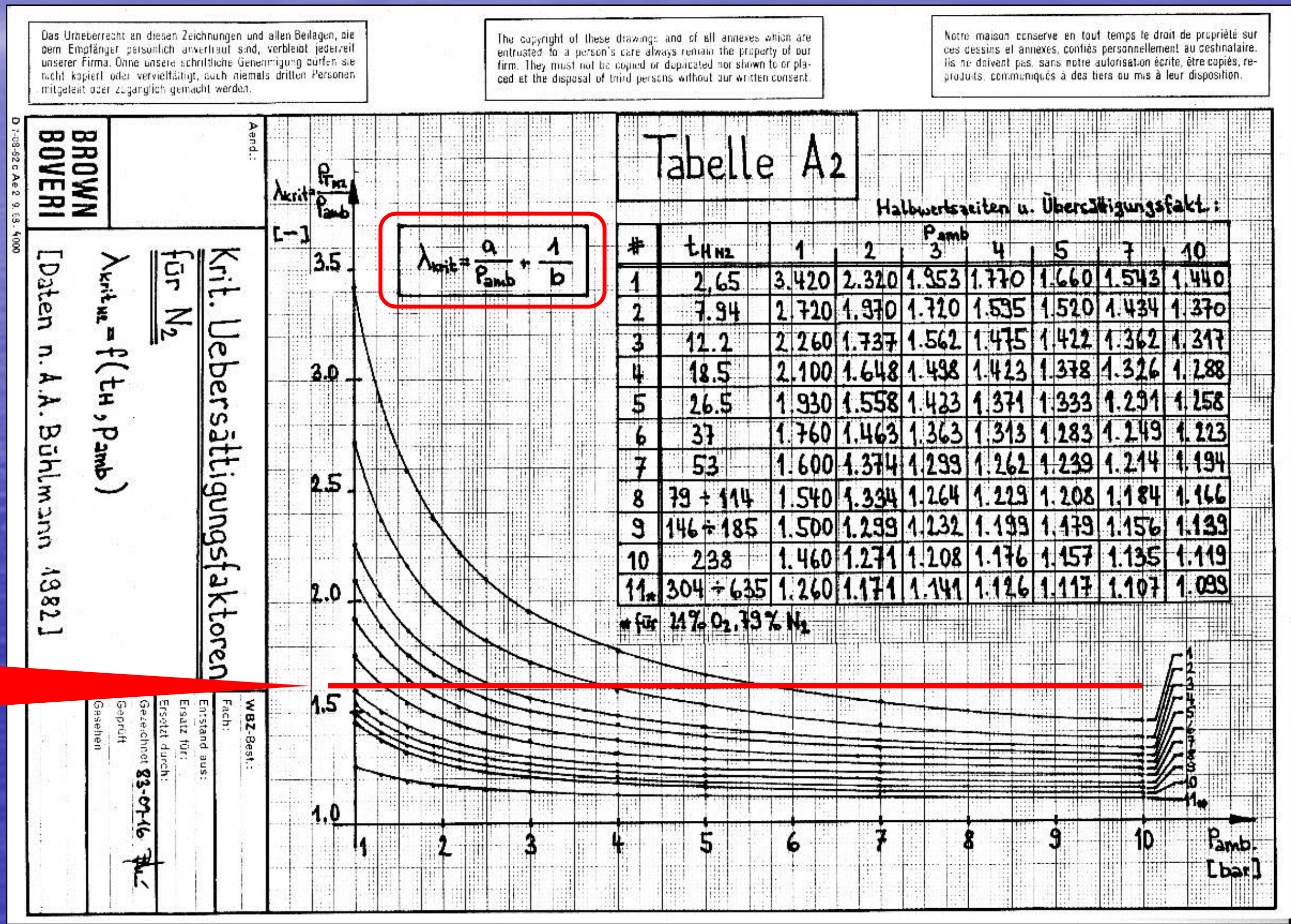
Limit US-Navy (sea level)

→ ref. to Appendices

About the modell behind (6b)



Haldane:
Factor = 1.58
(2 x 0.79) for all tissues; overly conservative for shorter halftimes, critical for longer ones



#	$t_{H N2}$	P_{amb} 1	2	3	4	5	7	10
1	2,65	3.420	2.320	1.953	1.770	1.660	1.543	1.440
2	7.94	2.720	1.970	1.720	1.595	1.520	1.434	1.370
3	12.2	2.260	1.737	1.562	1.475	1.422	1.362	1.317
4	18.5	2.100	1.648	1.498	1.423	1.378	1.326	1.288
5	26.5	1.930	1.558	1.423	1.371	1.333	1.291	1.258
6	37	1.760	1.463	1.363	1.313	1.283	1.249	1.223
7	53	1.600	1.374	1.299	1.262	1.239	1.214	1.194
8	79 ÷ 114	1.540	1.334	1.264	1.229	1.208	1.184	1.166
9	146 ÷ 185	1.500	1.299	1.232	1.199	1.179	1.156	1.139
10	238	1.460	1.271	1.208	1.176	1.157	1.135	1.119
11*	304 ÷ 635	1.260	1.171	1.141	1.126	1.117	1.107	1.099

* für 21% O_2, 79% N_2

Tissue half-times, critical over-saturation ratios

→ ref. to Appendices

High Altitude Diving Trials of the Swiss Army (1969)

High Altitude Diving Trials of the Swiss Army (1)

Lake Silvaplana, 1800 m a.s.l.

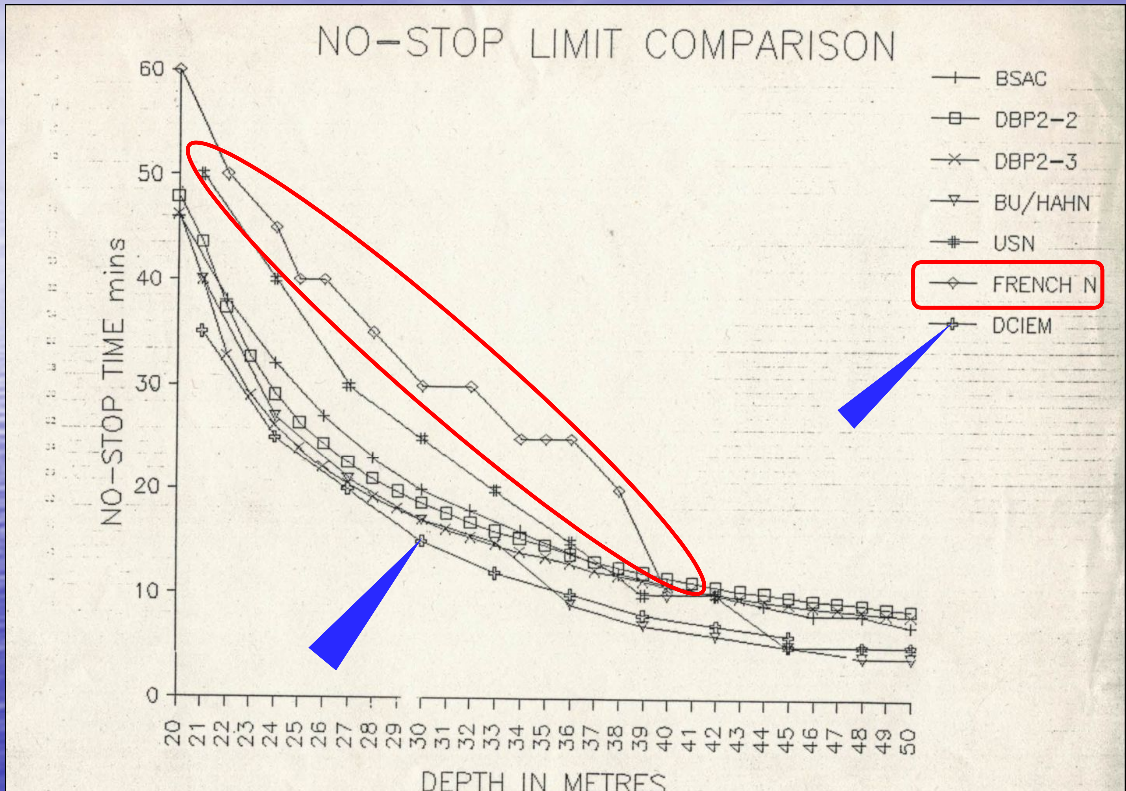
….using the French G.E.R.S. tables and with **disastrous** results….

(2 out of 8 divers suffered from severe DCS)

It is not known whether the sea-level GERS tables have been modified (adapted to altitude) or not.

→ Appendices: References

High Altitude Diving Trials of the Swiss Army (2)

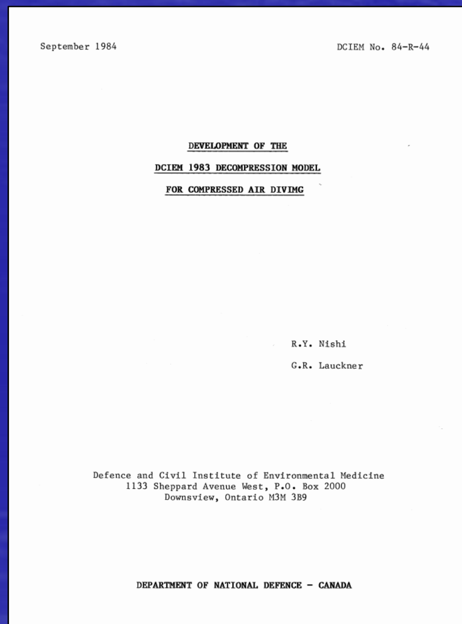


DEPTH I	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
BSAC	46.00		38.00		32.00		27.00		23.00		20.00		18.00		16.00	
DBP2-2	47.90	43.60	37.30	32.60	29.10	26.40	24.40	22.60	21.00	19.80	18.70	17.70	16.80	16.00	15.30	14.70
DBP2-3	46.20	40.00	32.70	29.00	26.10	23.90	22.10	20.50	19.20	18.10	17.00	16.10	15.40	14.70	14.00	13.50
BU/HAHN		40.00			27.00			21.00			17.00			15.00		
USN		50.00			40.00			30.00			25.00			20.00		
FRENCH	60.00		50.00		45.00	40.00	40.00		35.00		30.00		30.00		25.00	25.00
DCIEM		35.00			25.00			[illegible]			[illegible]					

DEPTH I	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
BSAC	14.00		12.00		11.00		10.00		9.00		8.00		8.00		7.00
DBP2-2	13.80	13.10	12.60	12.10	11.60	11.20	10.80	10.40	10.20	9.80	9.50	9.30	9.10	8.90	8.60
DBP2-3	12.90	12.20	11.80	11.30	10.80	10.50	10.10	9.70	9.40	9.10	8.80	8.60	8.40	8.10	8.00
BU/HAHN	9.00			7.00			6.00			5.00			4.00		4.00
USN	15.00			10.00			10.00			5.00			5.00		5.00
FRENCH	25.00		20.00		10.00		10.00			5.00			5.00		5.00
DCIEM															

data as of 1986/87

In hindsight, it is obvious that the GERS table imust have some inconsistencies with no link to physiological reasons! Also interesting: Canadian DCIEM uses a SERIAL compartment model and is very close to Bühlmann.


September 1984 DCIEM No. 84-R-44

DEVELOPMENT OF THE
DCIEM 1983 DECOMPRESSION MODEL
FOR COMPRESSED AIR DIVING

R.Y. Nishi
G.R. Lauckner

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, P.O. Box 2000
Downsview, Ontario M3M 3B9

DEPARTMENT OF NATIONAL DEFENCE - CANADA

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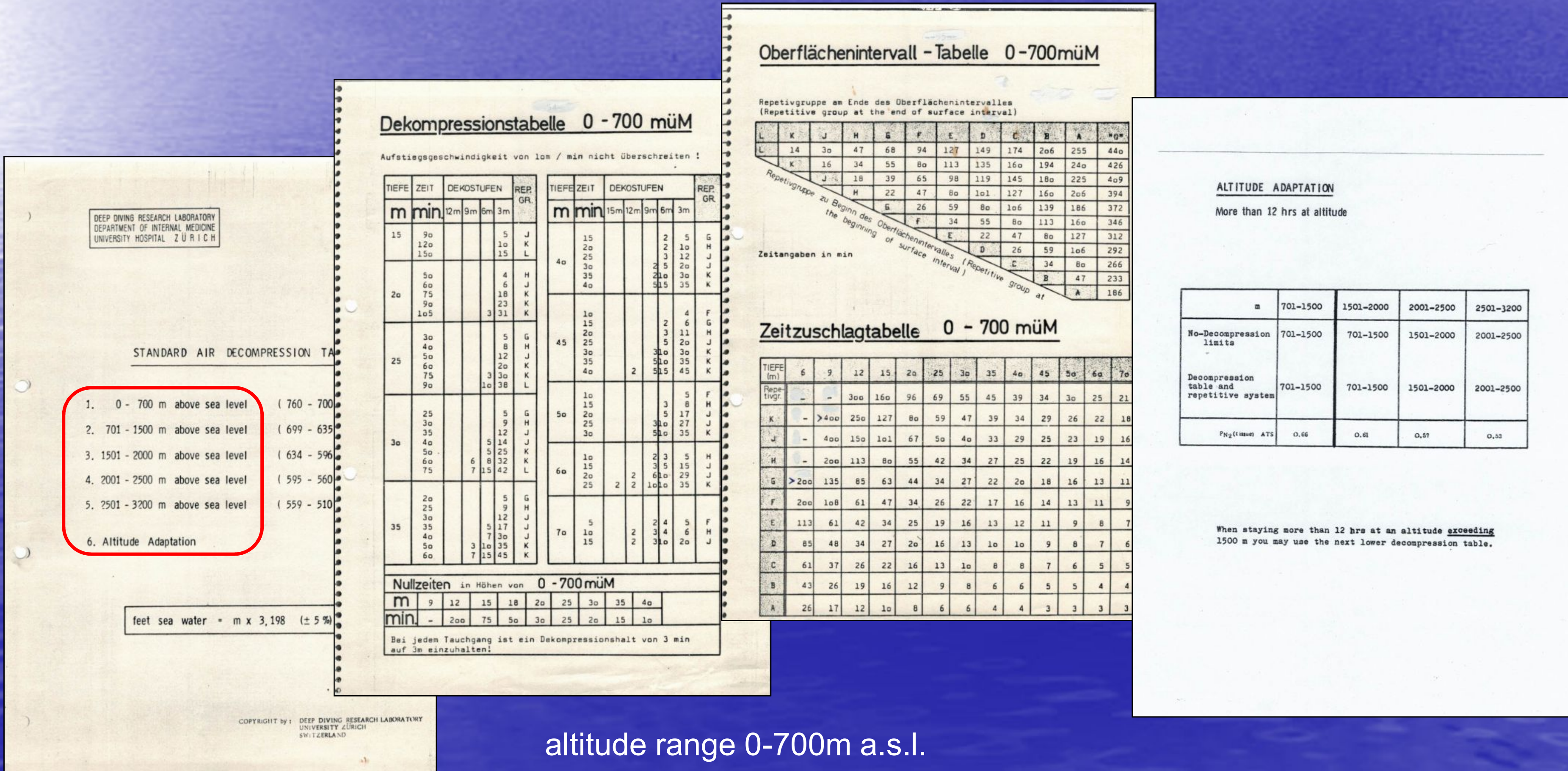
High Altitude Diving Trials of the Swiss Army (3)

As a result of the follow-up research, the air diving tables of 1976 were created



altitude range 0-700m a.s.l.

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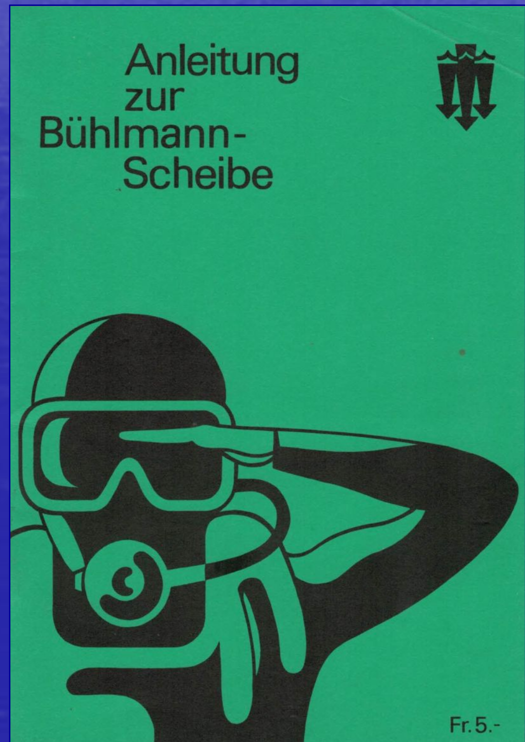
High Altitude Diving Trials of the Swiss Army (4)

The famous `76 disk



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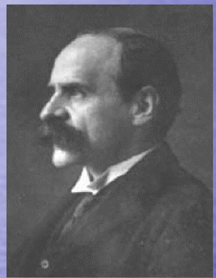
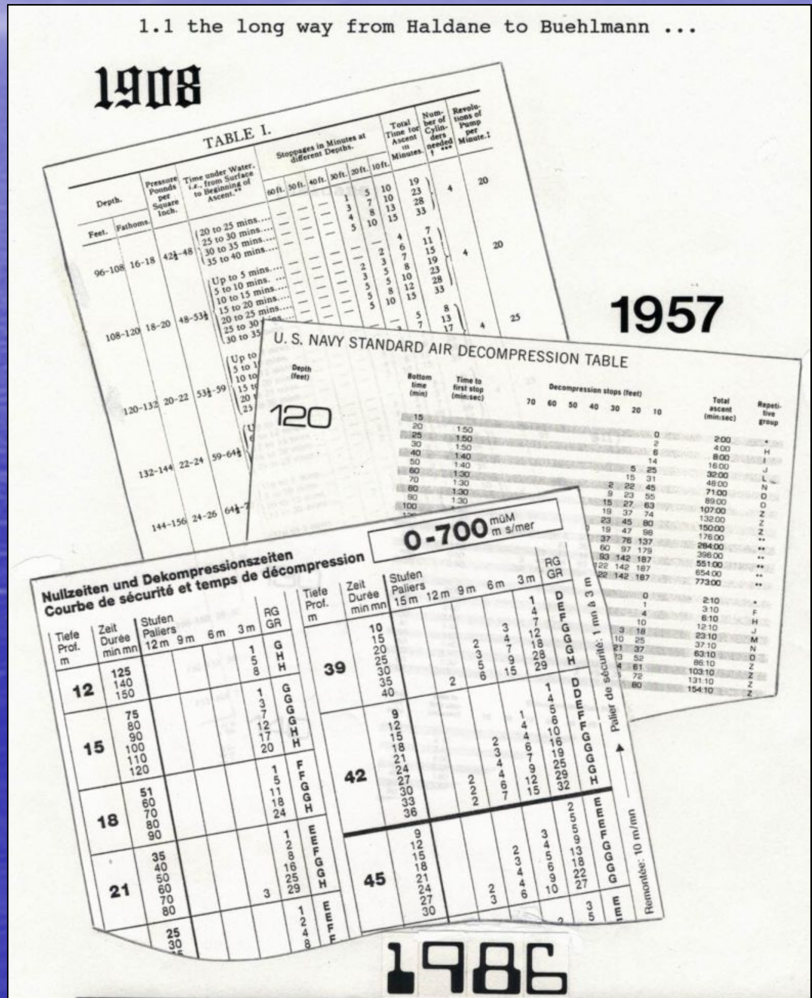
The `86 Air Diving Tables

Bühlmann Memorial Symposium 2019

The `86 Air Diving Tables: Historical Development (1)



Bühlmann air diving tables `76 not shown here…



(<< DCIEM Air Decompression Tables 1983)

(<< intermediate version „tables `83 with ZHL-12)

(<< with ZHL-16)

The `86 Air Diving Tables: Historical Development (2)

Situation as of october 1991….

1. Historical Background and Table-Development

1.1 Overview on "Popular" Dive Tables

a) "old" tables:

* US-NAVY, 1937, 1957 (sea level) incl. derivatives used by NAUI,PADI, metric versions, partly modified
* GERS, 1965
* diff. tables issued by ministry of health and labour (France,Germany)
* modified tables from SEEMANN, DRAEGER (no background information)

b) tables of the seventies:

* Buehlmann '76, (first tables for altitude, multi-tissue-model) plus some obscure, non-authorised "modifications"
* RNPL (Royal Navy), 1972 (one-tissue mod.,sea level)

In the meantime (2019), many organisations have published many tables, many of them with a undisclosed or fishy background.
Some of them obviously „created" with a total lack of physiological competence and ruled by the fear of law-suits!

c) newest generation tables:

Canadian Dept. of National Defense/ DCIEM, 1983/85 (multi-tissue, altitude)
Huggins, USA, 1981 (sea level, no-decompression dives only, modified Navy-model)

Buehlmann, Switzerland, 1986/87 (ZHL-L12/16 system, high altitudes, flying)

PADI, USA, 1987 (sea level, no-decompression dives only)
BSAC, GB, 1988 (sea level, no info on model and safety factors, fixed surface intervals)
NAUI, USA, 1989 (sea level, no-decompression dives only, modified Navy-model)
COMEX PRO, France, 1991 (sea level, no info on model or safety factors, fixed surface intervals)

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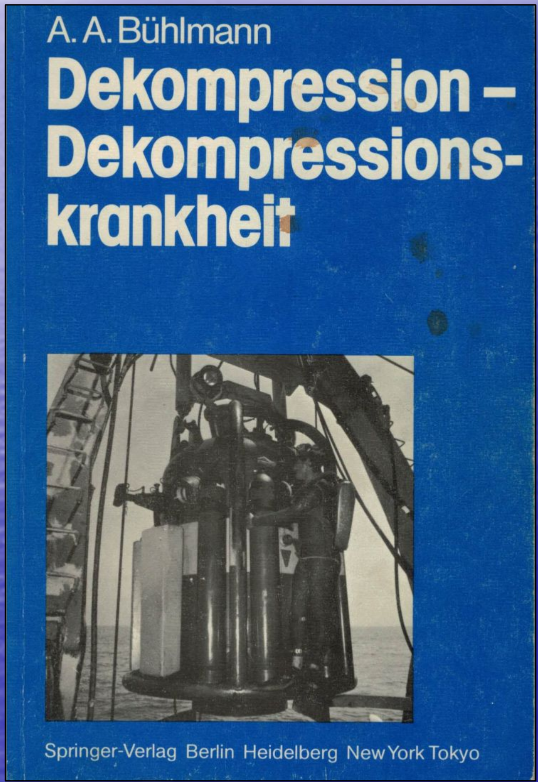
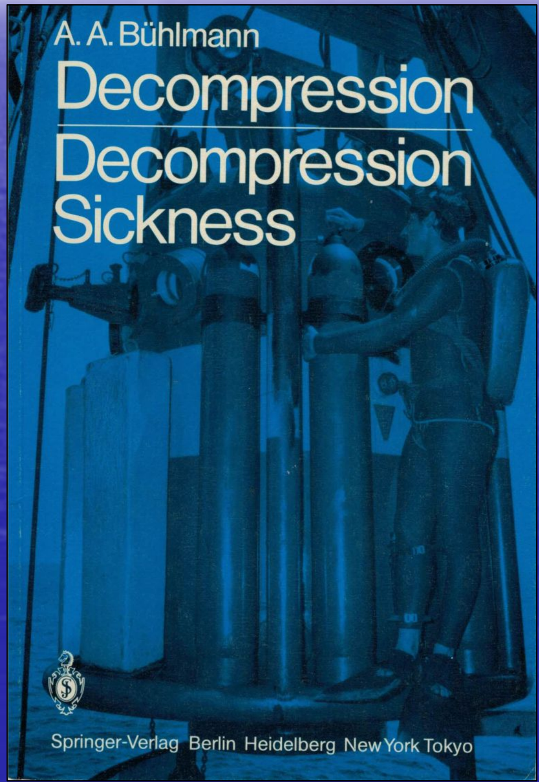
The `86 Air Diving Tables: The Trigger





Publication of the „new" Air Diving Tables of 1983, based on the compartment modell ZHL-12 with 16 compartments and 12 different pairs of coefficients.

Bühlmann Memorial Symposium 2019

The `86 Air Diving Tables: Initialization

Zürich, den 17. Juni 1986

geht an: - alle Teilnehmer
- Herrn H. Binkert, Reg. Chef DRS
- Herrn H.R. Elsener, Chef TK

z.K : - Chefinstruktor SUSV
- Med. Kommission
- Mitglieder des Instruktorenausschusses

Besprechungsprotokoll

Ort : Medizin. Universitätsklinik Zürich / Prof. A.A. Bühlmann

Datum : 08.05.1986 von 9.00 Uhr bis 12.15 Uhr

Teilnehmer: Prof. Dr. A.A. Bühlmann, Medizin. Leiter des DKL
Dr. M. Hahn (M***VDST, Leiter Fachreferat Tauchwissenschaften)
Herr G. Götte, Instruktor SUSV, Sachbearbeiter in der Angelegenheit "Einführung von neuen Tabellen" und Gesprächsleiter
Herr D. Gehlhaar, Instruktor SUSV, Mitglied des Instruktorenausschusses.
Herr B. Müller, M** SUSV, in beratender Funktion und Protokollführer

Gegenstand des Treffens: s. Schreiben (Einladung) von G. Götte vom 06.05.1986
Pflichtenheft für die neuen Tauchtabellen

Inhalt des Protokolls: 1. Zusammenfassung
2. Ausgangslage
3. Pflichtenheft der neuen Tabellen (Grundlagen und Design)
4. weiteres Vorgehen
5. Schluss

**Kick-off Meeting: defined and detailed specifications for the new tables to be created and ….
to be adopted by the Swiss Underwater Sports Federation**

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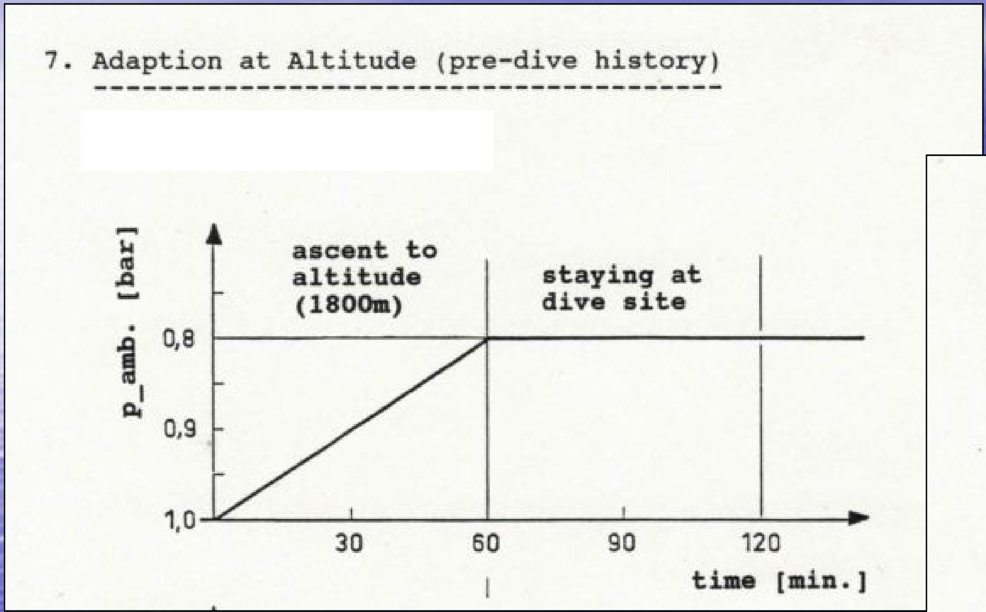
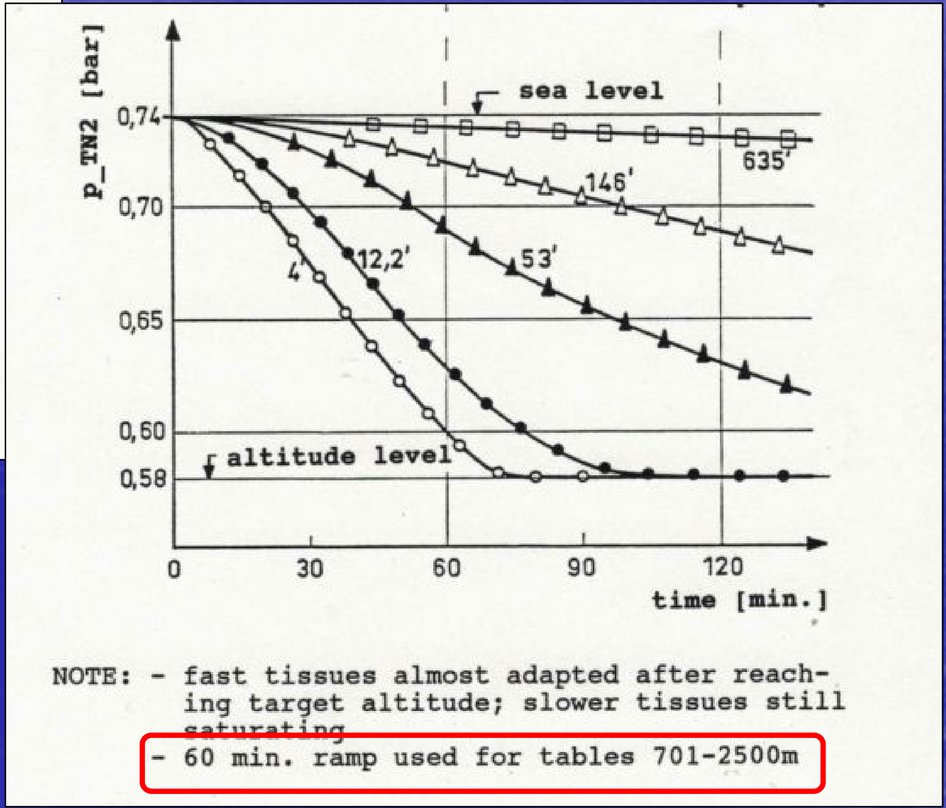
The `86 Air Diving Tables: The Ascent Ramp (1)





Start at 0m asl. with all compartments fully adapted; immediate dive at altitude upon arrival.

For the 86 table, a ramp of 1hr from 700m to 2500m a.s.l. was assumed. Desaturation was calculated with strict solution of differential equation.

Diagrams courtesy of Dr. K. Meier-Ewert

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The `86 Air Diving Tables: The Ascent Ramp (2a)

Aufstiegszeit zur Zielhöhe	60	min
dH/dt	29.98	m/min
dp_N2alv/dt	-0.00238151	bar/min

Start-Höhe 0	701	m
pamb	0.931	bar
f_N2	0.790	---
pN2-insp	0.736	bar
pN2-alv	0.678	bar

Ziel-Höhe H1	2500	m
pamb	0.750	bar
f_N2	0.790	---
pN2-insp	0.593	bar
pN2-alv	0.535	bar

ZHL-16B	tH	RG	a	b	k	p_TN2tol-Hoehe 0	p_TN2init-Hoehe 0	SAT (H0)	p_TN2tol-Hoehe 1	p_TN2arrival-Höhe 1	SAT (H1)
#	[min]	Code	[bar]	[---]	[1/min]	[bar]	[bar]	[%]	[bar]	[bar]	[%]
1	4	A	1.2599	0.5050	0.17329	3.104	0.678	21.83%	2.746	0.548	19.97%
2	8	B	1.0000	0.6514	0.08664	2.430	0.678	27.89%	2.152	0.562	26.12%
3	12.5	C	0.8618	0.7222	0.05545	2.151	0.678	31.49%	1.901	0.576	30.31%
4	18.5	D	0.7562	0.7825	0.03747	1.946	0.678	34.81%	1.715	0.591	34.49%
5	27	E	0.6667	0.8126	0.02567	1.813	0.678	37.38%	1.590	0.608	38.21%
6	38.3	F	0.5600	0.8434	0.01810	1.664	0.678	40.71%	1.450	0.622	42.89%
7	54.3	G	0.4947	0.8693	0.01277	1.566	0.678	43.27%	1.358	0.634	46.72%
8	77	H	0.4500	0.8910	0.00900	1.495	0.678	45.31%	1.292	0.645	49.92%
9	109	I	0.4187	0.9092	0.00636	1.443	0.678	46.95%	1.244	0.653	52.53%
10	146	J	0.3798	0.9222	0.00475	1.390	0.678	48.76%	1.193	0.659	55.22%
11	187	K	0.3497	0.9319	0.00371	1.349	0.678	50.23%	1.155	0.663	57.39%
12	239	L	0.3223	0.9403	0.00290	1.313	0.678	51.62%	1.120	0.666	59.43%
13	305	M	0.2850	0.9477	0.00227	1.268	0.678	53.45%	1.077	0.668	62.06%
14	390	N	0.2737	0.9544	0.00178	1.249	0.678	54.23%	1.060	0.670	63.23%
15	498	O	0.2523	0.9602	0.00139	1.222	0.678	55.44%	1.034	0.672	64.98%
16	635	P	0.2327	0.9653	0.00109	1.197	0.678	56.58%	1.010	0.673	66.63%

Effect of Ascent Ramp 701->2500m a.s.l. in 60min
- Relative saturation increases significantly
- Longer –half-times do not react significantly
- Tolerated tissue pressure decreases significantly!

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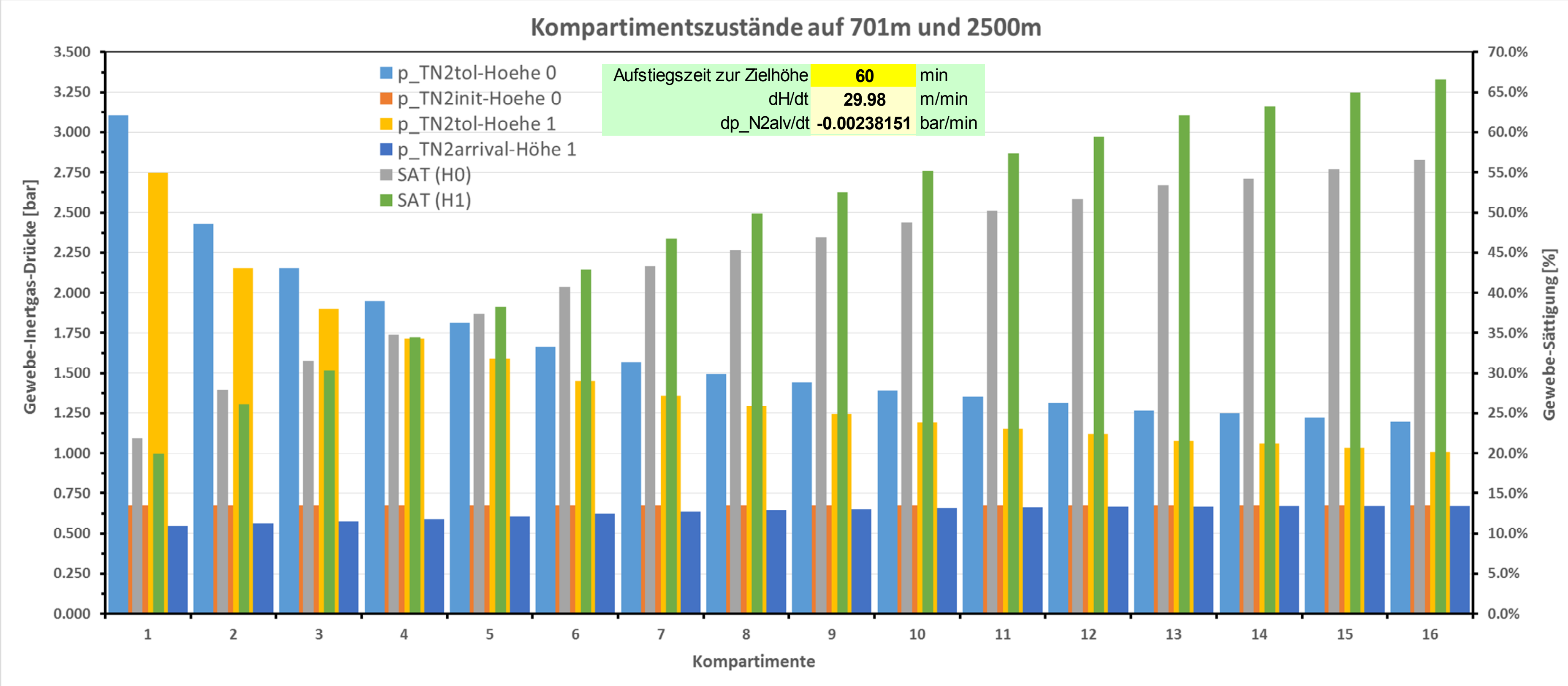
The `86 Air Diving Tables: The Ascent Ramp (2b)



Effect of Ascent Ramp 701->2500m a.s.l. in 60min

- Relativ saturation increases significantly
- Longer –half-times do not react significantly
- Tolerated tissue pressure decreases significantly!

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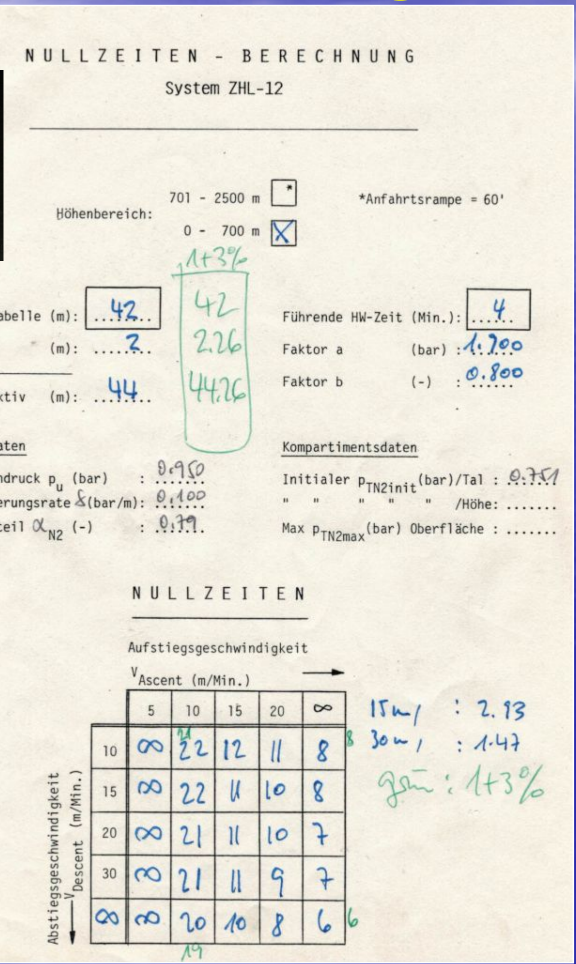
The `86 Air Diving Tables: No Decompression Limits (1)



NULLZEITEN - BERECHNUNG

System ZHL-12

Höhenbereich: 701 - 2500 m ☐ 0 - 700 m ☒

*Anfahrtsrampe = 60'

Tiefe n. Tabelle (m): 42

+ Zuschlag (m): 2

Tiefe effektiv (m): 44

1+3%
42
2.26
44.26

Führende HW-Zeit (Min.): 4

Faktor a (bar): 1.700

Faktor b (-): 0.800

Umgebungsdaten

Oberflächendruck p_u (bar): 0.950

Drucksteigerungsrate δ (bar/m): 0.100

Inertgasanteil α_{N2} (-): 0.79

Kompartimentsdaten

Initialer $p_{TN2init}$ (bar)/Tal: 0.751

" " " " /Höhe: ....

Max p_{TN2max} (bar) Oberfläche: ....

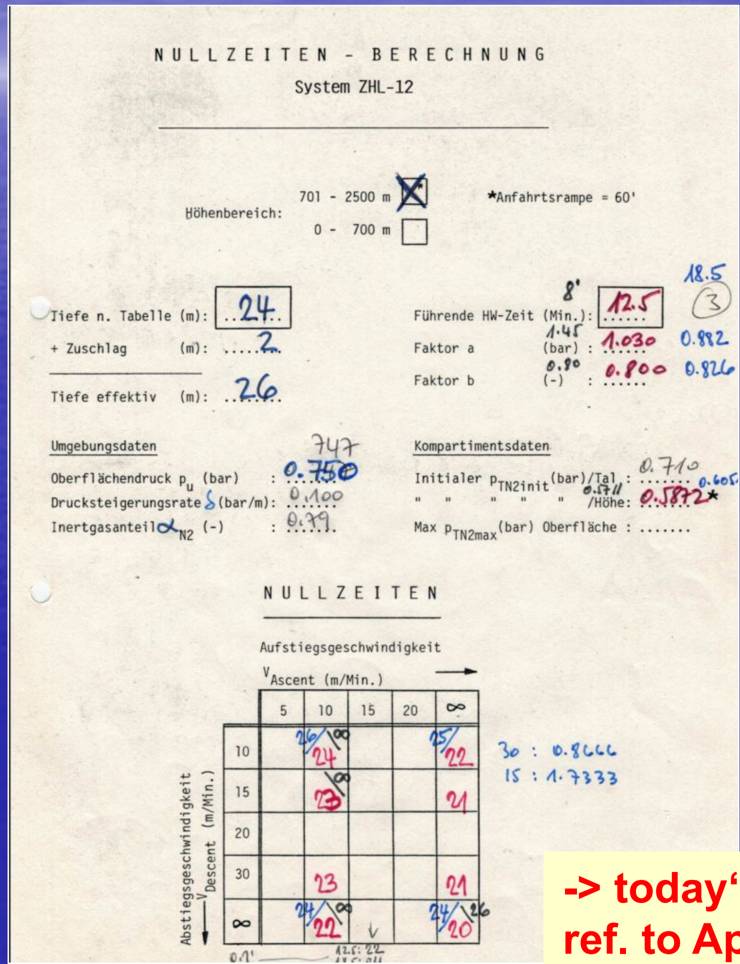
NULLZEITEN

Aufstiegsgeschwindigkeit V_{Ascent} (m/Min.)

Abstiegsgeschwindigkeit $V_{Descent}$ (m/Min.)

	5	10	15	20	∞
10	∞	22	12	11	8
15	∞	22	11	10	8
20	∞	21	11	10	7
30	∞	21	11	9	7
∞	∞	20	10	8	6

15 m/ : 2.93
30 m/ : 1.47
grün: 1+3%



NULLZEITEN - BERECHNUNG

System ZHL-12

Höhenbereich: 701 - 2500 m ☒ 0 - 700 m ☐

*Anfahrtsrampe = 60'

Tiefe n. Tabelle (m): 24

+ Zuschlag (m): 2

Tiefe effektiv (m): 26

Führende HW-Zeit (Min.): 8' 12.5 18.5 (3)

Faktor a (bar): 1.45 1.030 0.882

Faktor b (-): 0.80 0.800 0.826

Umgebungsdaten

Oberflächendruck p_u (bar): 747 0.750

Drucksteigerungsrate δ (bar/m): 0.100

Inertgasanteil α_{N2} (-): 0.79

Kompartimentsdaten

Initialer $p_{TN2init}$ (bar)/Tal: 0.710 0.605

" " " " /Höhe: 0.5711 0.5872*

Max p_{TN2max} (bar) Oberfläche: ....

NULLZEITEN

Aufstiegsgeschwindigkeit V_{Ascent} (m/Min.)

Abstiegsgeschwindigkeit $V_{Descent}$ (m/Min.)

	5	10	15	20	∞
10		26/24 ∞			25/22
15		23 ∞			21
20					
30		23			21
∞		24/22 ∞			24/20 26

30 : 0.8666
15 : 1.7333

-> today's methods: ref. to Appendices!

All combinations of descent and ascent rates checked with fixed and variable safety margins for depth and for the relevant compartment half-times

The `86 Air Diving Tables: No Decompression Limits (2)

A) NULLZEITEN

Tabelle

Tiefe [m]	US-Navy 1957 Meer	GERS 1965 Meer	RNPL 1972 Meer	Bue76 1973 0-700	DCIEM 1983 Meer	Bue86 1987 0-700	PADI 1988 Meer	BSAC 1988 0-250 6m-St.
9	--	--	--	--	380	335	>205	243
12	200	--	137	200	175	125	140	122
15	100	>120		75	75	75	80	74
18	60	75	57	50	50	51	55	51
21	50				35	35	40	37
24	40	45	32		25	25	30	30
27	30				20	20	25	24
30	25	30	20	20	15	17	20	20
36	15	25	14		10	12	13	14
42	10	10	10		7	9	8	12

New No-decompression limits; more conservative than other contemporary tables.
Most other tables NOT suitable above sea level.

GERS tables definitely off-limits.

Compare DCIEM NDL, almost identical from 15m on; DCIEM model is a serial compartment model with asymmetrical saturation / desaturation.

file: TABBUEH 0-2 datum:89-11-27/1 Seite 1/12

NULLZEITEN-UND DEKOMPRES-
SIONSTABELLEN FUER LUFT
(Erweiterung fuer lange Expositionszeiten zum
neuen Buch von Prof. A.A. Buehlmann)

neue Tabellen Release 1.0 / 89-11-27

Later addendum of 1989 for long exposition times

The `86 Air Diving Tables: No Decompression Limits (3a)

Values and comparison of today‘s calculations (1)

Values attained by using ZHL-12 and ZHL-16B

		NDL times in [min]				
Altitude range [m a.s.l.]		**0-0**	**0-700**	**701-2500**	**2501-4500**	**4400-4800**
Altitude of adaption [m a.s.l.]		0	0	701	4500	4400
Altitude of calculated dive [m a.s.l.]		0	700	2500	4500	4800
Ramp to upper range limit [hr]		no	no	1	no	6
Surface Interval at dive site before dive [hr]		>24	0	0	>24	3
Depth [m]	6	1473	1110	714	663	667
	9	475	349	**238**	**204**	167
	12	139	**125**	**99**	**88**	86
	15	81	**75**	**62**	**50**	56
	18	55	**51**	**44**	**32**	39
	21	40	**35**	**30**	**22**	27
	24	28	**25**	**22**	**16**	20
	27	22	**20**	**18**	**14**	16
	30	18	**17**	**15**	**11**	14
	33	15	**14**	**12**	**9**	12
	36	13	**12**	**10**	**8**	10
	39	11	**10**	**9**	**7**	9
	42	10	**9**	**8**	**7**	8
	45	9	8	7	**6**	7
	48	8	7	6	**6**	6
	51	7	6	6	**5**	5
	54	6	6	5	5	5
	57	5	5	4	4	4
	60	5	4	4	4	3

Descent rate:
timeless, rectangular
Ascent rate:
10m/min; constant

bold values: as published on tables
blue values: added by calculation

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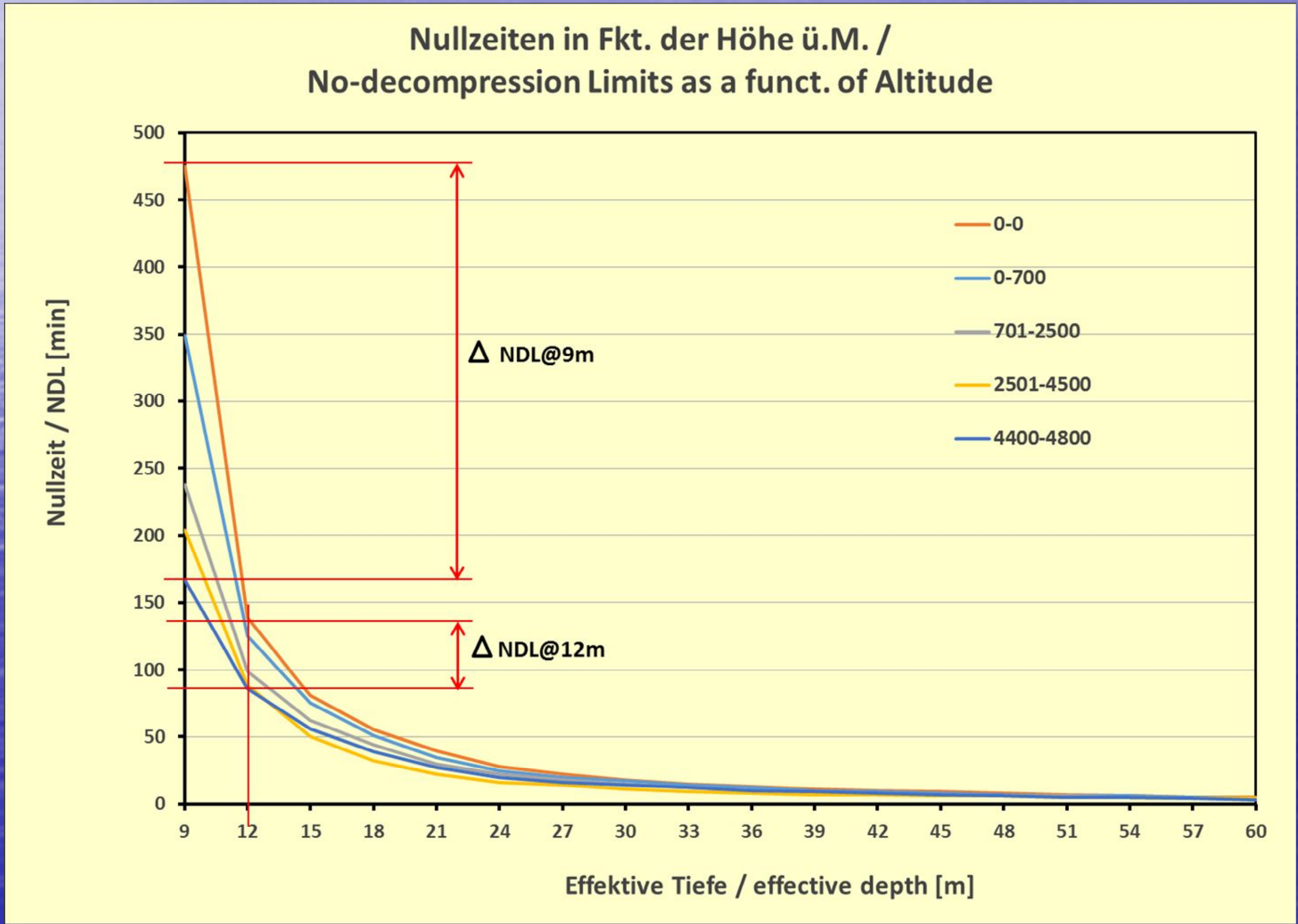
The `86 Air Diving Tables: No Decompression Limits (3b)

Values and comparison of today‘s calculations (2)



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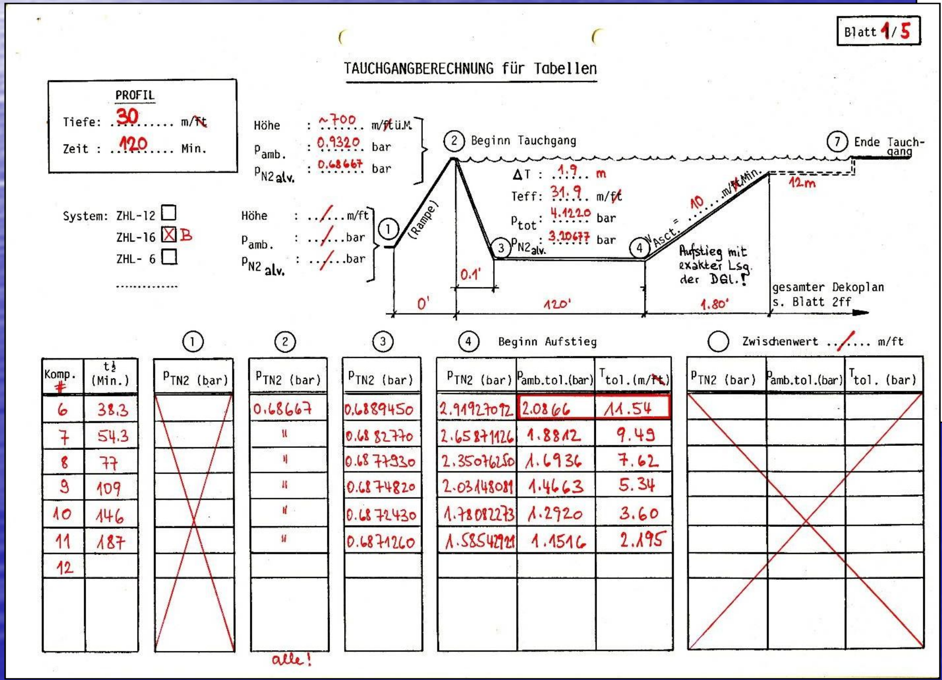
The `86 Air Diving Tables: all other profiles (1)

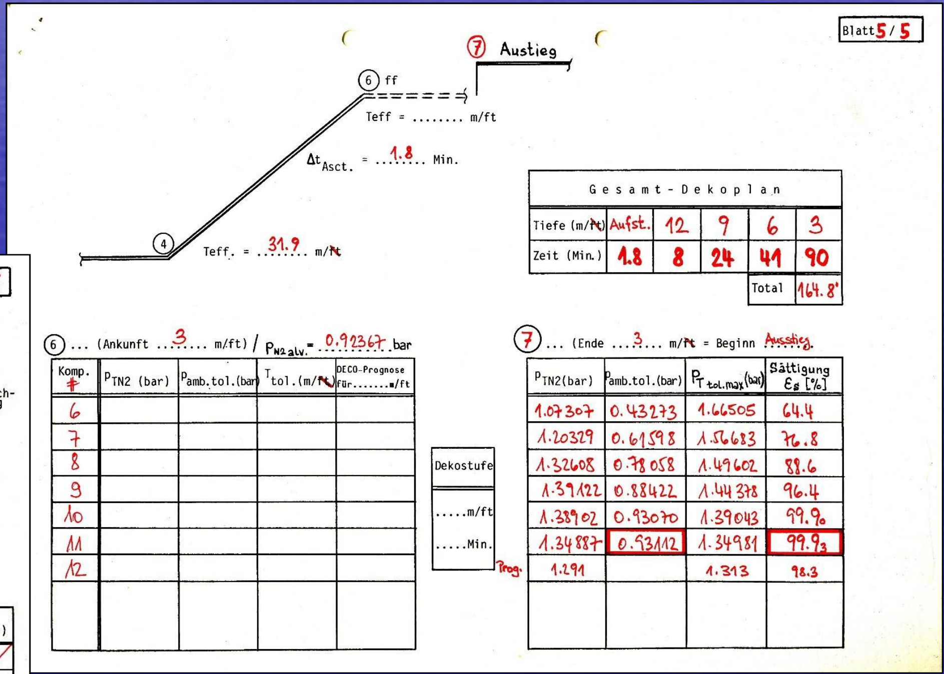
Step by step / way-point by way-point / tissue by tissue calculation for all depth time combinations



1 | 2 | 3 | 4 Beginn Aufstieg | ○ Zwischenwert ../... m/ft

Komp. #	$t_{1/2}$ (Min.)	① p_{TN2} (bar)	② p_{TN2} (bar)	③ p_{TN2} (bar)	④ p_{TN2} (bar)	④ $p_{amb.tol.}$ (bar)	④ $T_{tol.}$ (m/ft)	○ p_{TN2} (bar)	○ $p_{amb.tol.}$ (bar)	○ $T_{tol.}$ (bar)
6	38.3		0.68667	0.6889450	2.91927092	2.0866	11.54			
7	54.3		"	0.6882770	2.65871126	1.8812	9.49			
8	77		"	0.6877930	2.35076250	1.6936	7.62			
9	109		"	0.6874820	2.03148081	1.4663	5.34			
10	146		"	0.6872430	1.78082273	1.2920	3.60			
11	187		"	0.6871260	1.58542921	1.1516	2.195			
12										

alle!



Gesamt-Dekoplan					
Tiefe (m/ft)	Aufst.	12	9	6	3
Zeit (Min.)	1.8	8	24	41	90
				Total	164.8'

6 ... (Ankunft 3 m/ft) / $p_{N2\,alv.}$ = 0.92367 bar

Komp. #	p_{TN2} (bar)	$p_{amb.tol.}$ (bar)	$T_{tol.}$ (m/ft)	DECO-Prognose für.......m/ft
6				
7				
8				
9				
10				
11				
12				

Dekostufe
.....m/ft
.....Min.

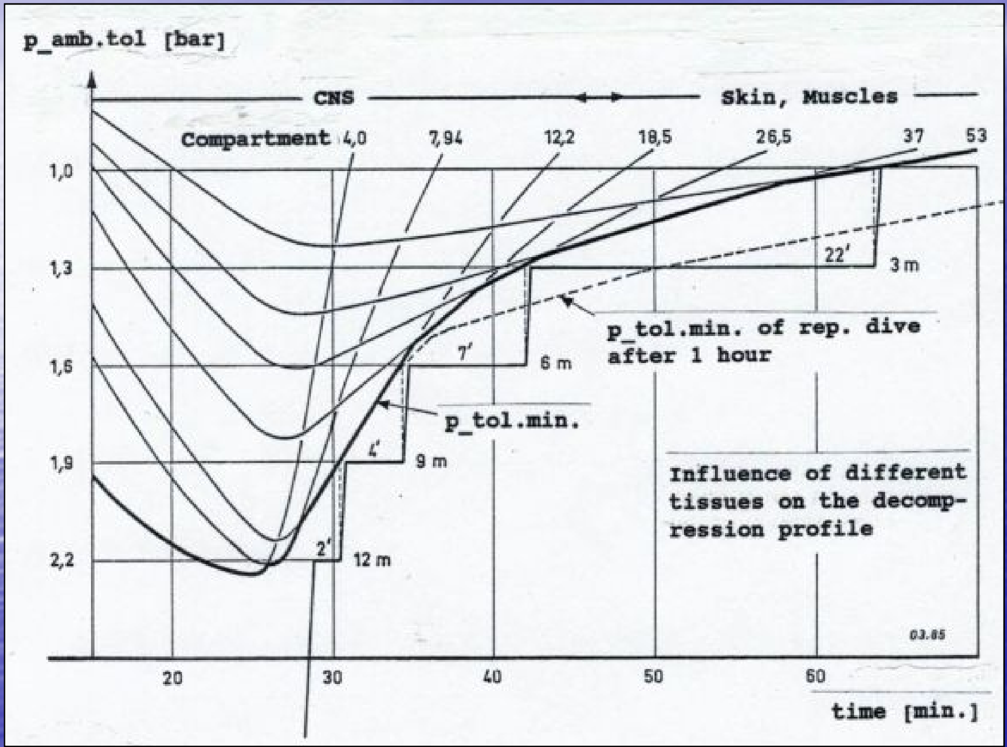
7 ... (Ende 3 m/ft = Beginn Ausstieg

p_{TN2} (bar)	$p_{amb.tol.}$ (bar)	$P_{T\,tol.max}$ (bar)	Sättigung ε_s [%]
1.07307	0.43273	1.66505	64.4
1.20329	0.61598	1.56683	76.8
1.32608	0.78058	1.49602	88.6
1.39122	0.88422	1.44378	96.4
1.38902	0.93070	1.39043	99.9₀
1.34887	0.93112	1.34981	99.9₃
1.291		1.313	98.3

Prog.

Note the change from one leading tissue to the next or overnext one during ascent and deco stops!

The `86 Air Diving Tables: all other profiles (2)



6. "Leading Tissues" during the Desaturation Phase

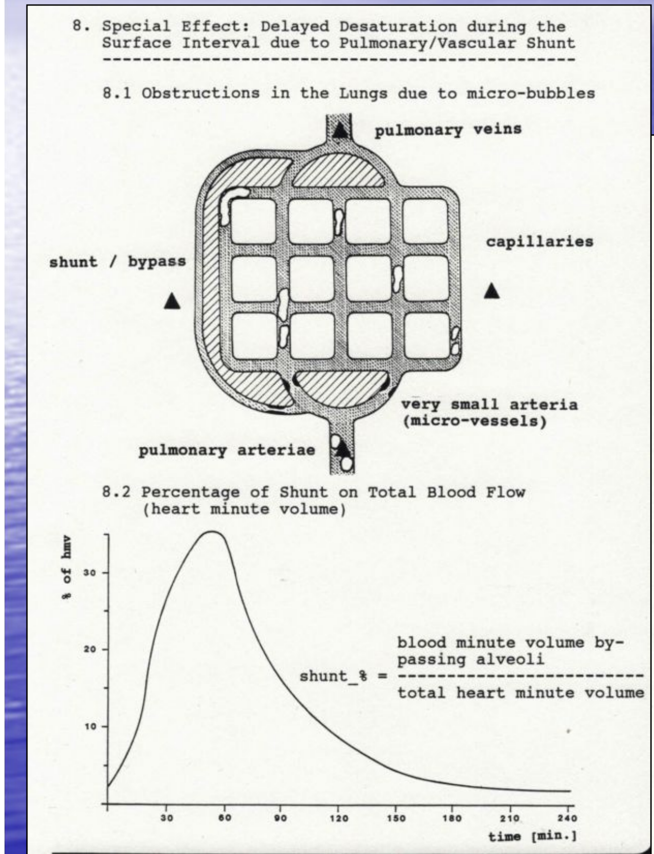
NOTE: a leading tissue is the tissue requesting for the highest (tolerated) ambient pressure, therefor determining the ceiling (shallowest depth not to be surpassed) and the corresponding decompression stage depth.

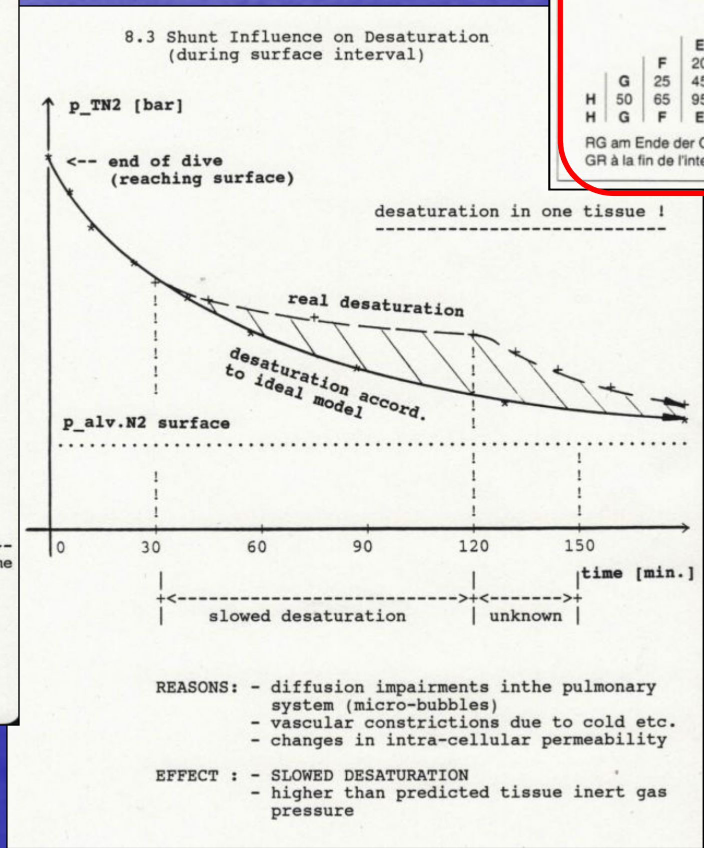
NOTE: - tissues with short half-times (CNS etc.) are governing the deeper stops, tissues with longer half-times the shallower ones !
- p_tol.min. = the MAXIMUM of all tissue-related p_amb.tol -> the permitted MINIMUM depth !)

RG at end of dive = letter code of leading tissue when surfacing. When next following tissue was also saturated to 95%+, then that letter code was taken for end-of-dive RG.

Diagram courtesy of Dr. K. Meier-Ewert

The `86 Air Diving Tables: Surface Interval (SI) table





Oberflächenpause
Intervalle de surface

RG nach Ende des Tauchganges
GR à la fin de la plongée

								"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
H	50	65	95	130	180	240	340	24	7
H	G	F	E	D	C	B	A	Std/h	Std/h

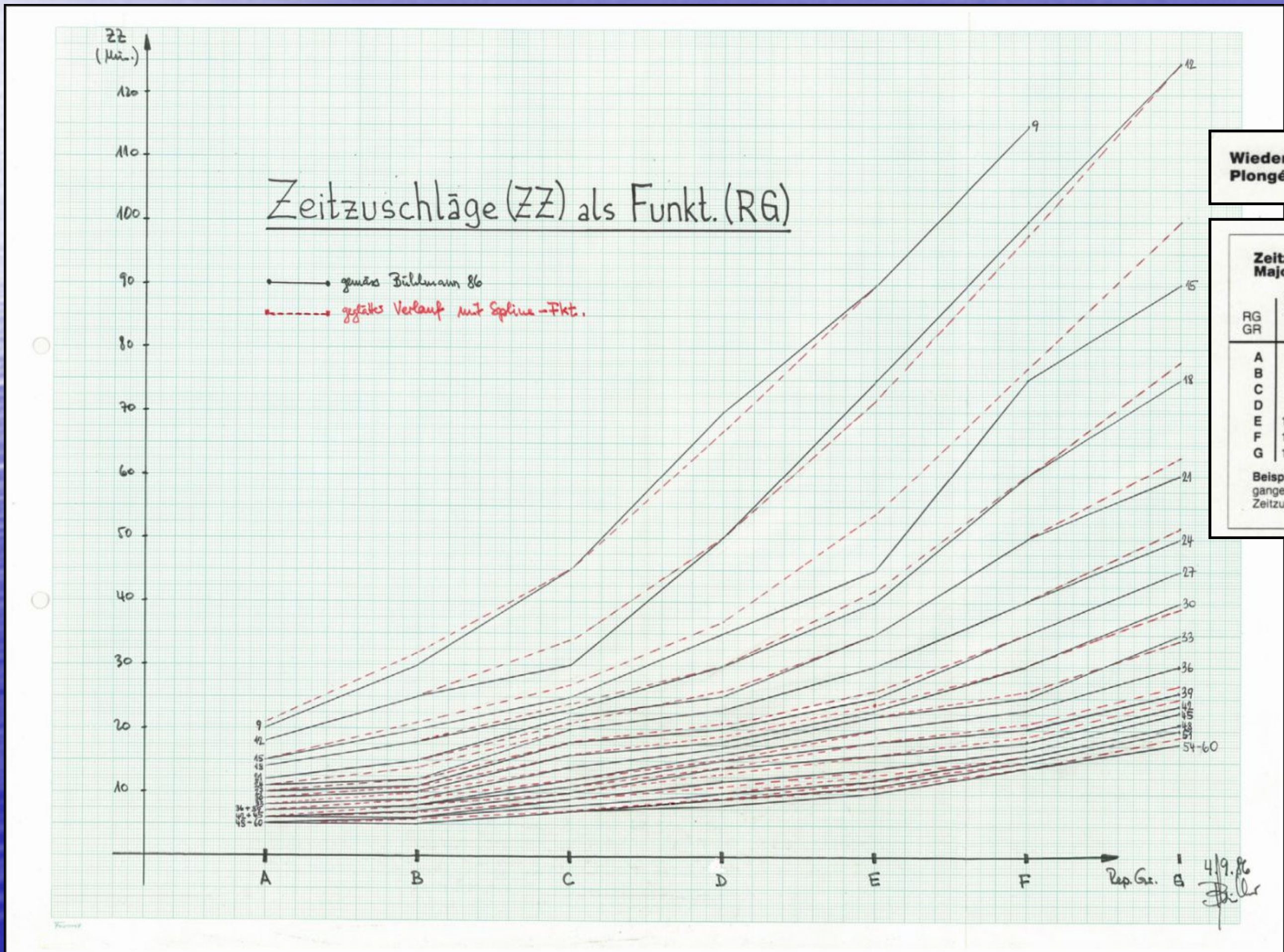
RG am Ende der Oberflächenpause
GR à la fin de l'intervalle de surface

Beispiel: Wiederholungsgruppe RG **F** nach Ende des Tauchganges
- nach 45 Minuten ist RG **C,** nach 90 Minuten **A** erreicht (Zwischenwerte abrunden)
- nach 8 Stunden kann ohne Zeitzuschlag getaucht werden
- 4 Stunden Wartezeit bis Flug

Exemple: Groupe répétitif GR **F** à la fin de la plongée
- après 45 minutes **F** devient **C,** après 90 minutes **F** devient **A** (prendre pour les valeurs intermédiaires celle immédiatement inférieure
- après 8 heures on peut replonger sans ajouter de majoration
- temps d'attente avant l'envol: 4 heures

Due to lack of scientific data at that time (!), no shunt effect included. Effect is masked and compensated by safety margins and rounding rules.

The `86 Air Diving Tables: „Smoothing“ of Residual Nitrogen Time table RNT (1)



Wiederholungstauchgänge 0–2500 müM
Plongées successives de 0–2500 m s/mer

0–2500 müM m s/mer

Zeitzuschläge für Wiederholungstauchgänge
Majorations aux plongées successives

(Zwischenwerte abrunden)
(prendre pour les valeurs intermédiaires celle immédiatement inférieure)

Vorgesehene Tauchtiefe in Meter
Profondeur en mètres de la plongée envisagée

RG GR	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
G	154	137	115	91	72	57	47	40	35	31	27	25	23	21	20	19	18

Beispiel: RG **C** zu Beginn des Wiederholungstauchganges. Vorgesehene Tiefe 27 Meter = 18 Minuten Zeitzuschlag zur Grundzeit des Tauchganges

Exemple: GR **C** au départ de la plongée successive. Profondeur envisagée 27 mètres = 18 minutes de majoration à rajouter au temps de séjour au fond

Splines: mostly sequential representation of real function by polynominals 3rd ordre.
At the interfaces of the segments, the functions must be twice continuously differentiable.

The `86 Air Diving Tables: „Smoothing“ of Residual Nitrogen Time table RNT (2)

Zeitzuschlagstabelle

A) Bühlmann bisher (nicht geglättet)

	9m	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
A	20	18	15	14	12	11	10	9	8	7	7	6	6	5	5	5	5	5
B	30	25	20	18	15	12	11	10	9	8	8	7	6	6	5	5	5	5
C	45	30	25	23	22	20	18	16	14	12	11	10	9	8	7	7	7	7
D	70	50	35	30	25	23	20	18	17	16	15	14	12	10	9	8	8	8
E	90	75	45	40	35	30	25	23	22	20	18	16	14	12	11	10	10	10
F	115	100	75	60	50	40	35	30	25	23	20	18	17	16	15	14	14	14
G	145	125	90	75	60	50	45	40	35	30	26	24	23	21	20	18	18	18

B) Hahn (geglättet) (bleibt unverändert)

	9m	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
A	25	19	16	14	12	11	10	9	8	7	7	6	6	6	5	5	5	4
B	56	24	19	17	15	13	12	10	9	8	8	7	6	6	5	5	5	4
C	75	33	28	25	23	20	18	16	14	13	11	10	9	8	7	7	6	6
D	116	57	42	34	28	24	21	19	17	15	14	12	11	11	10	9	9	8
E	211	81	61	44	37	30	26	22	20	18	16	15	14	13	12	11	10	10
F	305	111	88	69	54	44	37	31	27	24	21	19	18	16	15	14	13	12
G																		

?

C) Bühlmann NEU (geglättet)

	9m	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
A	25	19	16	14	12	11	10	9	8	7	7	6	6	6	5	5	5	4
B	37	25	20	17	15	13	12	11	10	9	8	7	7	6	5	5	5	4
C	55	37	29	25	22	20	18	16	14	12	11	10	9	8	7	7	6	6
D	81	57	41	33	28	24	21	19	17	15	14	13	11	10	9	9	8	8
E	105	82	59	44	37	30	26	23	21	19	17	16	14	13	12	11	10	10
F	130	111	88	68	53	42	35	30	27	24	21	19	17	16	15	14	13	13
G	154	137	115	91	72	57	47	40	35	31	27	25	23	21	20	19	18	18

25.10.86

Wiederholungstauchgänge 0–2500 müM
Plongées successives de 0–2500 m s/mer

0–2500 müM m s/mer

Zeitzuschläge für Wiederholungstauchgänge
Majorations aux plongées successives

(Zwischenwerte abrunden)
(prendre pour les valeurs intermédiaires celle immédiatement inférieure)

Vorgesehene Tauchtiefe in Meter
Profondeur en mètres de la plongée envisagée

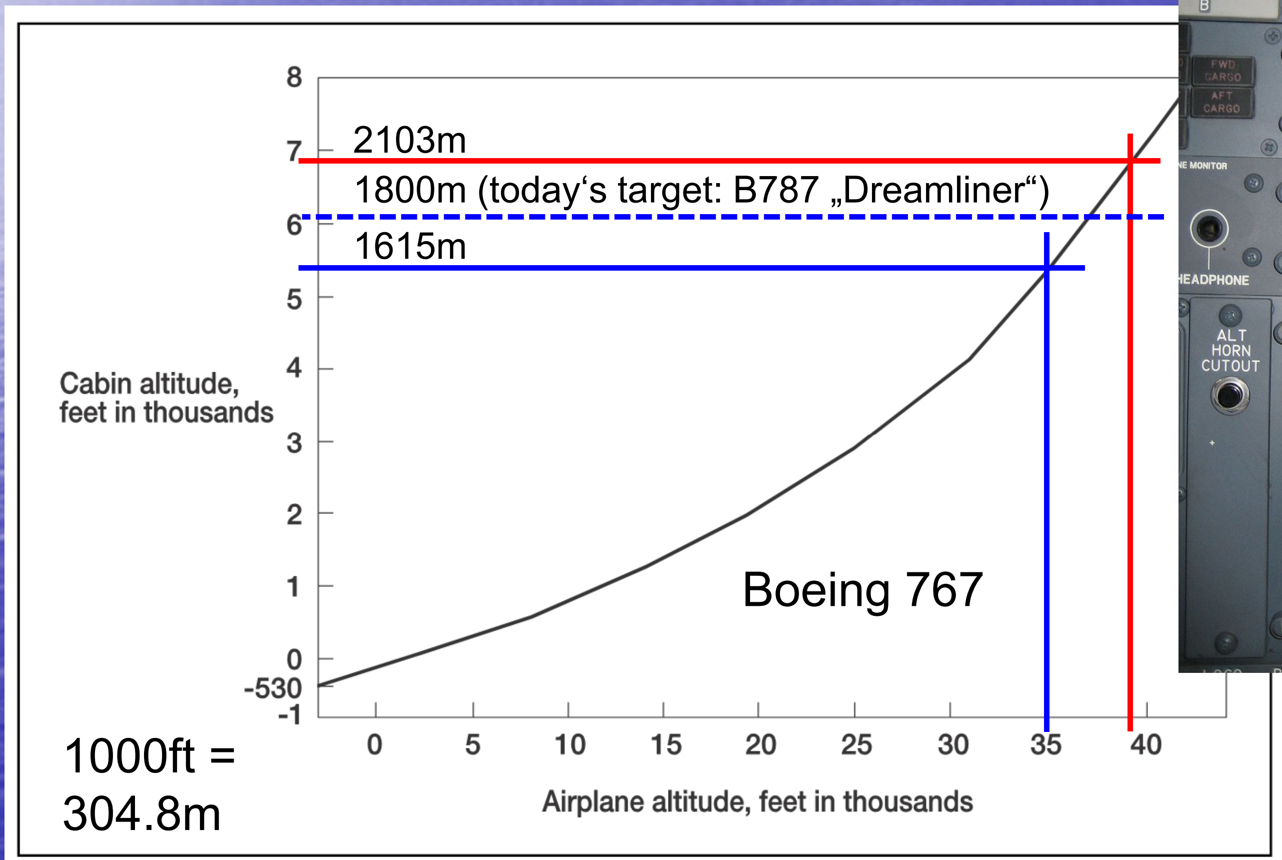
RG GR	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57
A	25	19	16	14	12	11	10	9	8	7	7	6	6	6	5	5	5
B	37	25	20	17	15	13	12	11	10	9	8	7	7	6	5	5	5
C	55	37	29	25	22	20	18	16	14	12	11	10	9	8	7	7	6
D	81	57	41	33	28	24	21	19	17	15	14	13	11	10	9	9	8
E	105	82	59	44	37	30	26	23	21	19	17	16	14	13	12	11	10
F	130	111	88	68	53	42	35	30	27	24	21	19	17	16	15	14	13
G	154	137	115	91	72	57	47	40	35	31	27	25	23	21	20	19	18

Beispiel: RG **C** zu Beginn des Wiederholungstauchganges. Vorgesehene Tiefe 27 Meter = 18 Minuten Zeitzuschlag zur Grundzeit des Tauchganges

Exemple: GR **C** au départ de la plongée successive. Profondeur envisagée 27 mètres = 18 minutes de majoration à rajouter au temps de séjour au fond

The `86 Air Diving Tables: Flying after Diving (1)

„Cabin altitude“ vs. cruising altitude



control panel of older aircraft

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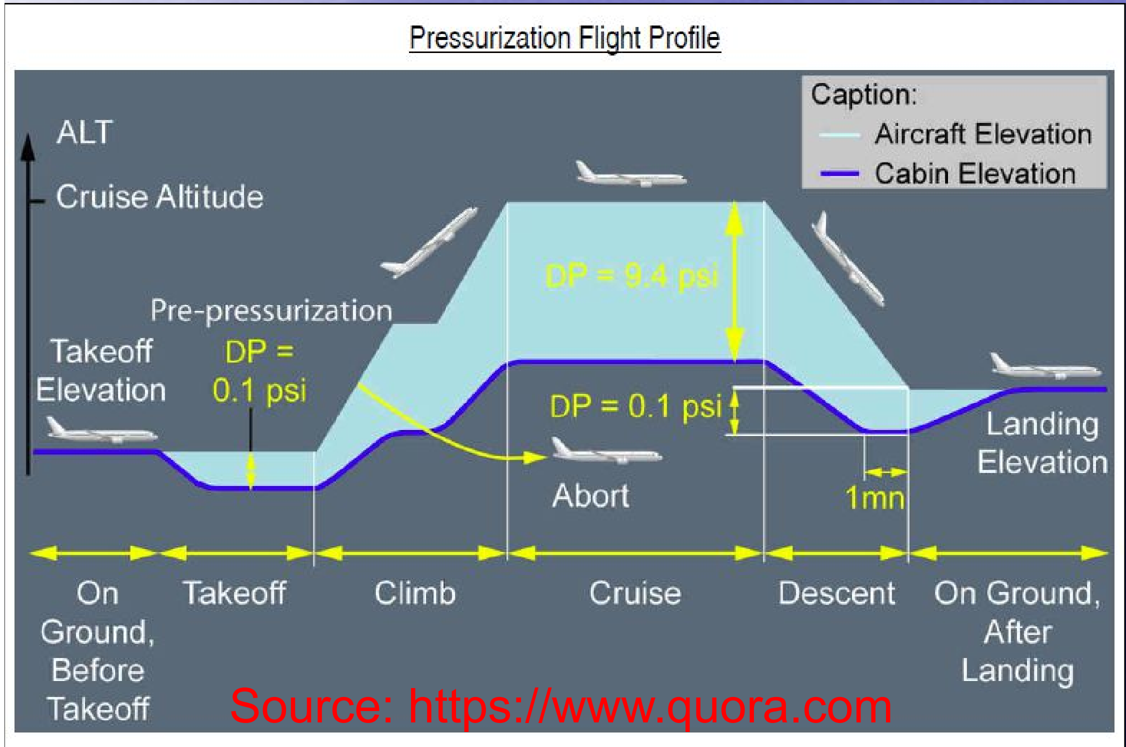
The `86 Air Diving Tables: Flying after Diving (2a)

„Cabin altitude“ vs. cruising altitude



Source: https://www.quora.com

Note how on the takeoff roll, the airplane starts to pressurize to 0.1 PSI differential pressure.

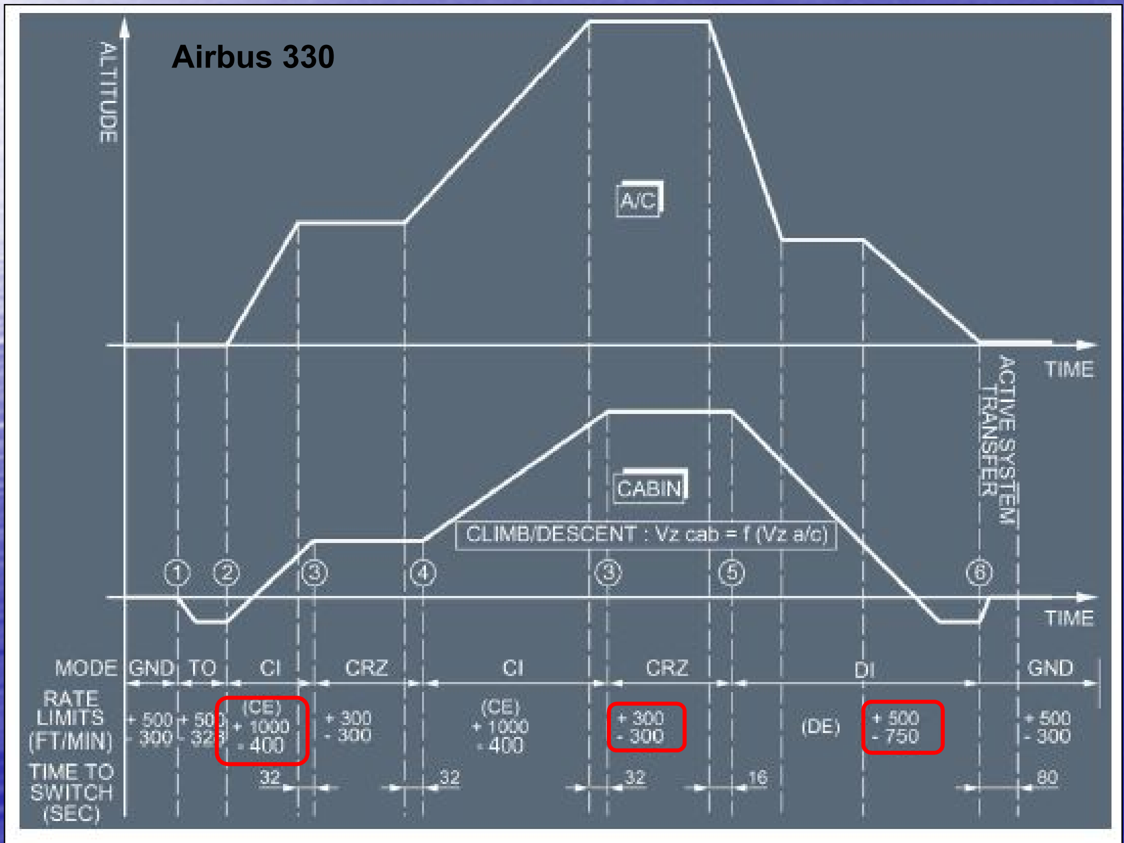
That means that in fact your pressure altitude inside the cabin will be above the pressure altitude of the airstrip. This guarantees a smooth transition into the climb.

This additional amount of pressure mustn't compromise the ability to quickly open the doors in case of emergency, so pressure differential is limited. On a B737-NG, the differential is 0.125 PSI (9 hPa). This is equivalent to an altitude 236 ft below the runway.

In the climb the cabin altitude increases with the airplane's altitude, though at a lower rate, meaning the cabin climbs slower, smoother and to a lower max level.

The `86 Air Diving Tables: Flying after Diving (2b)

„cabin altitude“ vs. aircraft cruising altitude



Source: https://www.quora.com

On this example of an Airbus A330 you can see the rate limits at the bottom of the graph. Notice how the cabin altitude will be limited to + 1,000 feet per minute in the climb and to - 750 feet per minute in descend. In cruise, any adjustments will be less than +/- 300 feet per minute.

Normal passenger aircraft climbing rates:
(between 10‘000 and 30‘000 ft)

A320: 2000-2200 ft/min const.
A319: from 3000 to 1500 ft/min
A321: from 1400 to 500 ft/min

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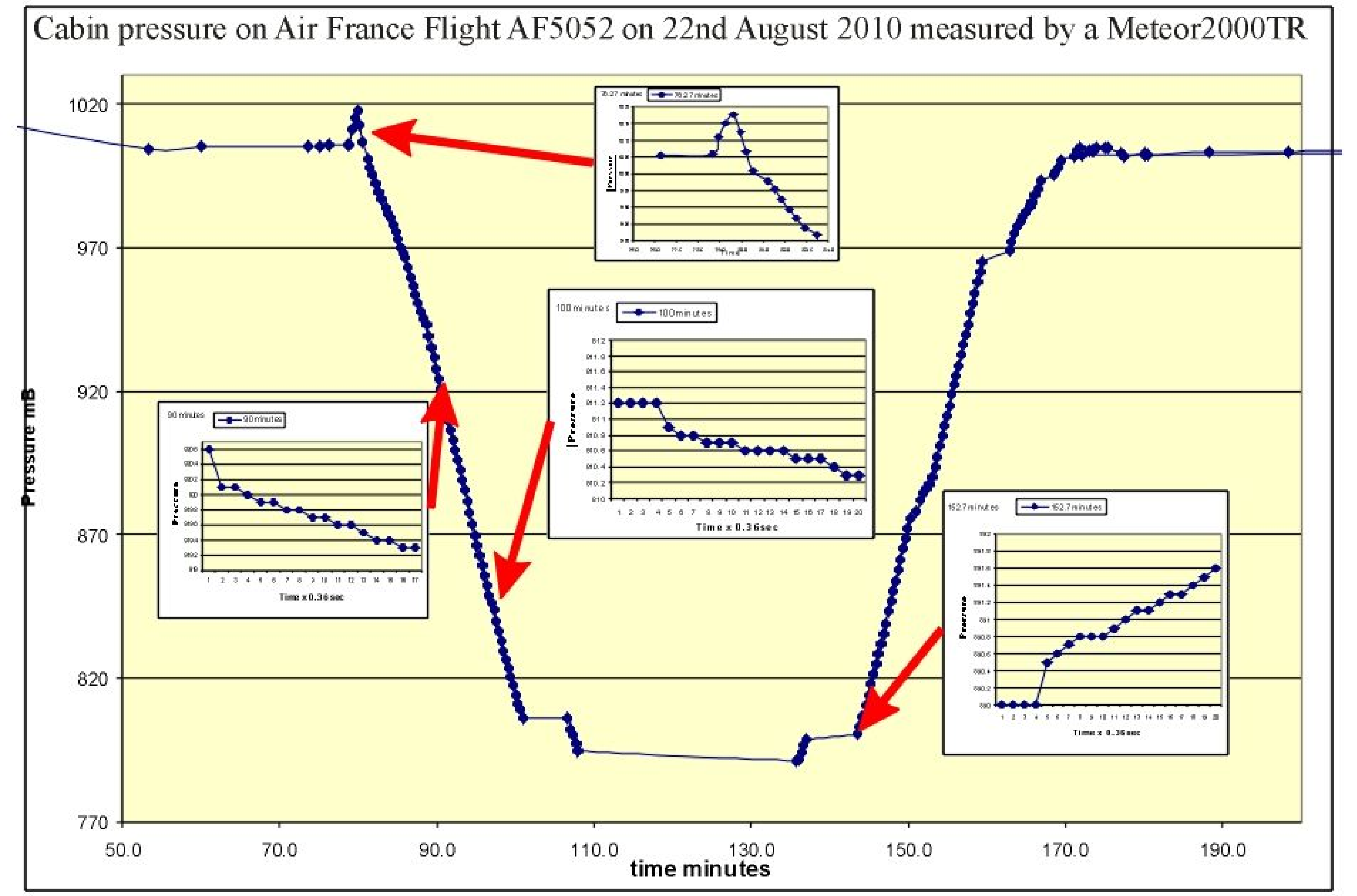
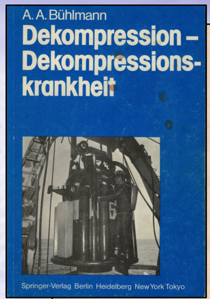
The `86 Air Diving Tables: Flying after Diving (2c)



Source: https://aviation.stackexchange.com

The `86 Air Diving Tables: Flying after Diving (3)



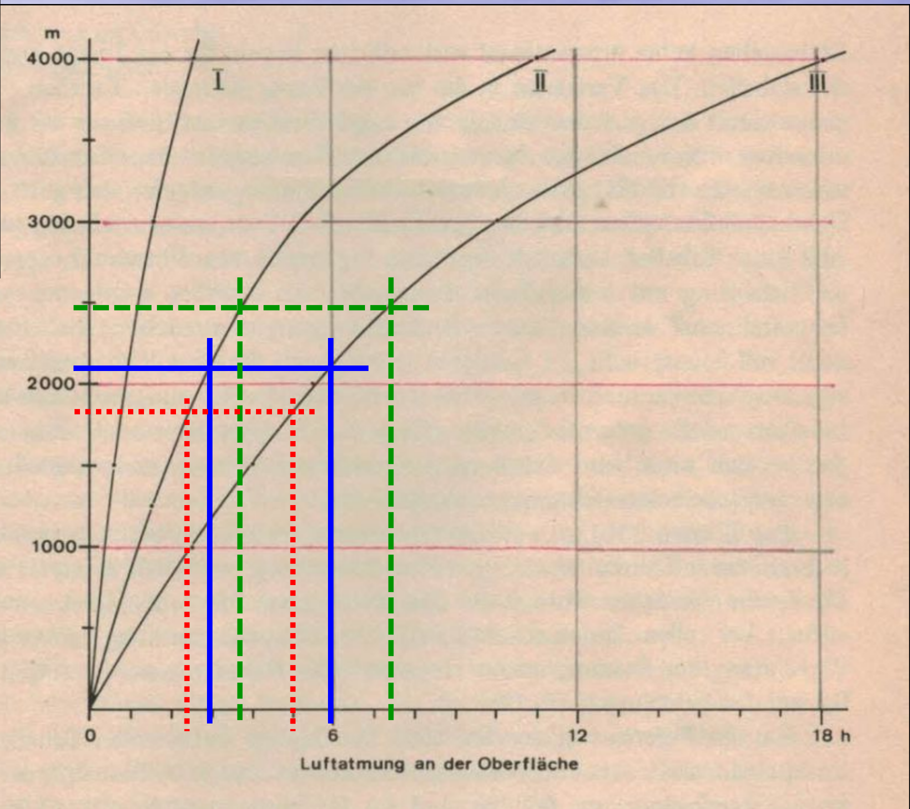


Abb. 17. *Fliegen nach Tauchgängen für Sporttaucher.* I = Einmalige Tauchgänge *ohne* Dekompression aber tiefer als 12 m in 0–700 m ü.M. oder tiefer als 9 m in der Höhe. II = Einmalige Tauchgänge *ohne* Dekompression bis 12 m (0–700 m ü.M.) oder bis 9 m (in der Höhe) sowie einmalige Tauchgänge *mit* Dekompression bis zu einer Tauchzeit von 120 min. III = Tauchzeiten länger als 120 min, repetierte Tauchgänge, „Tauchferien"

Höhe ü.M. [m]	Höhe ü.M. [ft]	pamb-surf [bar]	pO2 Luft [bar]
0	0	1.013	0.211
250	820	0.983	0.204
500	1'640	0.954	0.198
750	2'461	0.926	0.193
1'000	3'281	0.898	0.187
1'250	4'101	0.872	0.181
1'500	4'921	0.846	0.176
1'750	5'741	0.821	0.171
2'000	6'562	0.797	0.166
2'250	7'382	0.773	0.161
2'500	8'202	0.750	0.156
2'750	9'022	0.728	0.151
3'000	9'843	0.707	0.147
3'250	10'663	0.686	0.143
3'500	11'483	0.665	0.138
3'750	12'303	0.646	0.134
4'000	13'123	0.627	0.130
4'250	13'944	0.608	0.127
4'500	14'764	0.590	0.123
4'750	15'584	0.573	0.119
5'000	16'404	0.556	0.116

as of 1983

The `86 Air Diving Tables: Flying after Diving (4a)

Situation	cabin pressure	equivalent cabine altitude	equivalent cabine altitude
	(bar)	(m a.s.l.	(ft a.s.l.)
normal flight	0.77	2'300	7'546
max. tolerated technical deviation	0.60	4'250	13'944
max. single failure	0.55	4'800	15'748
triggering of masks	0.54	5'000	16'404
Asumption for table calculations	0.58-0.60	4'400	14'436

(data as of 1986 by Lufthansa)

For the table calculation a cabin pressure of 0.58 bar (corresp. to approx. 4600m) was assumed. This pressure is a trifle lower than the lowest possible pressure according to IATA rules (0.60bar), which is classified as a „tolerated technical deviation".

„normal" are approx. 0.77-0.8bar (approx. 2300-2000m on 35'000 to 39'000ft).


venting valve

Data of 2018

Typical values for A330:
Short flights <2.5Std.: 7460ft
Long flights: 8000ft:

Typical values for A350:
All flights: 6000ft

Typical values for B747-400:
10 hrs flight
Altitude 34'00ft/10300m: 0.843bar
Altitude 40'000ft / 12'200m: 0.792bar

The `86 Air Diving Tables: Flying after Diving (4aa)

modern (B757, 767)
control panel

If the masks drop down, you should not care too much about DCS….

but having you credit card ready for paying the extra oxygen!

Jet Airways, B737, real incident in Mumbai

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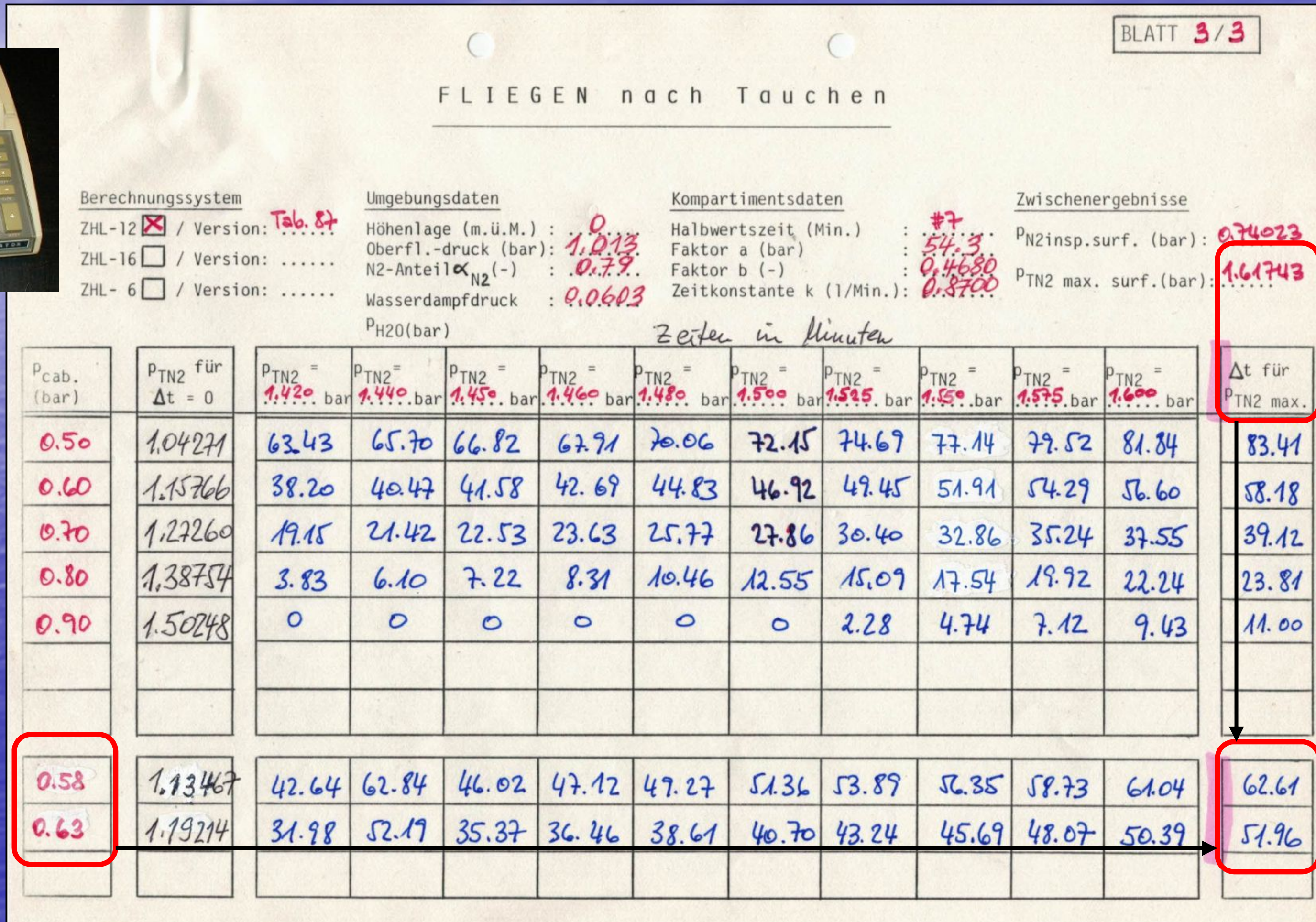
The `86 Air Diving Tables: Flying after Diving (4b)



BLATT 3/3

FLIEGEN nach Tauchen

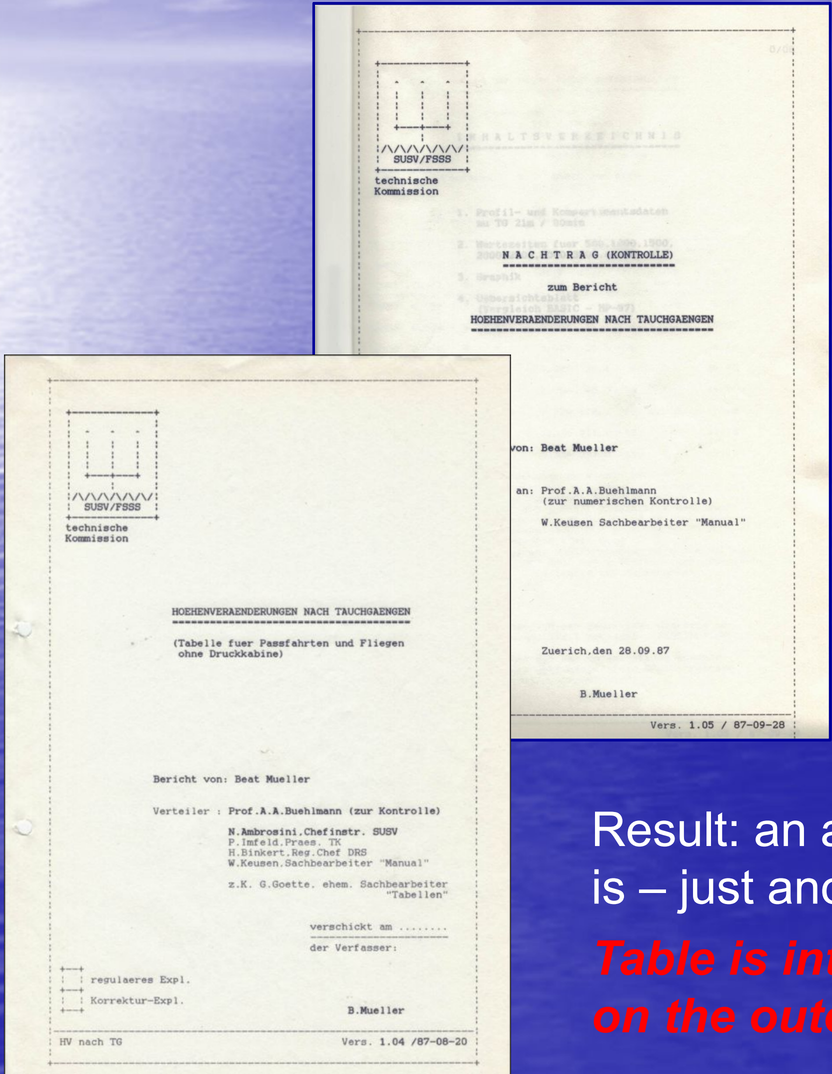
Berechnungssystem	Umgebungsdaten	Kompartimentsdaten	Zwischenergebnisse
ZHL-12 ☒ / Version: Tab. 87	Höhenlage (m.ü.M.) : 0	Halbwertszeit (Min.) : #7	$p_{N2insp.surf.}$ (bar): 0.74023
ZHL-16 ☐ / Version:	Oberfl.-druck (bar): 1.013	Faktor a (bar) : 54.3	$p_{TN2\ max.\ surf.}$ (bar): 1.61743
ZHL- 6 ☐ / Version:	N2-Anteil α_{N2} (-) : 0.79	Faktor b (-) : 0.4680	
	Wasserdampfdruck p_{H2O} (bar) : 0.0603	Zeitkonstante k (1/Min.): 0.8700	

Zeiten in Minuten

$p_{cab.}$ (bar)	p_{TN2} für $\Delta t = 0$	p_{TN2} = 1.420 bar	p_{TN2} = 1.440 bar	p_{TN2} = 1.450 bar	p_{TN2} = 1.460 bar	p_{TN2} = 1.480 bar	p_{TN2} = 1.500 bar	p_{TN2} = 1.525 bar	p_{TN2} = 1.550 bar	p_{TN2} = 1.575 bar	p_{TN2} = 1.600 bar	Δt für $p_{TN2\ max.}$
0.50	1.04271	63.43	65.70	66.82	67.91	70.06	72.15	74.69	77.14	79.52	81.84	83.41
0.60	1.15766	38.20	40.47	41.58	42.69	44.83	46.92	49.45	51.91	54.29	56.60	58.18
0.70	1.27260	19.15	21.42	22.53	23.63	25.77	27.86	30.40	32.86	35.24	37.55	39.12
0.80	1.38754	3.83	6.10	7.22	8.31	10.46	12.55	15.09	17.54	19.92	22.24	23.81
0.90	1.50248	0	0	0	0	0	0	2.28	4.74	7.12	9.43	11.00
0.58	1.13467	42.64	62.84	46.02	47.12	49.27	51.36	53.89	56.35	58.73	61.04	62.61
0.63	1.19214	31.98	52.19	35.37	36.46	38.61	40.70	43.24	45.69	48.07	50.39	51.96

Parametric calculation for each tissue with varying cabin pressures

The `86 Air Diving Tables: Flying after Diving (5a)


SUSV/FSSS
technische Kommission

N A C H T R A G (KONTROLLE)

zum Bericht

HOEHENVERAENDERUNGEN NACH TAUCHGAENGEN

von: Beat Mueller

an: Prof.A.A.Buehlmann (zur numerischen Kontrolle)

W.Keusen Sachbearbeiter "Manual"

Zuerich.den 28.09.87

B.Mueller

Vers. 1.05 / 87-09-28

SUSV/FSSS
technische Kommission

HOEHENVERAENDERUNGEN NACH TAUCHGAENGEN

(Tabelle fuer Passfahrten und Fliegen ohne Druckkabine)

Bericht von: Beat Mueller

Verteiler : Prof.A.A.Buehlmann (zur Kontrolle)

N.Ambrosini.Chefinstr. SUSV
P.Imfeld.Praes. TK
H.Binkert.Reg.Chef DRS
W.Keusen.Sachbearbeiter "Manual"

z.K. G.Goette. ehem. Sachbearbeiter "Tabellen"

verschickt am ....

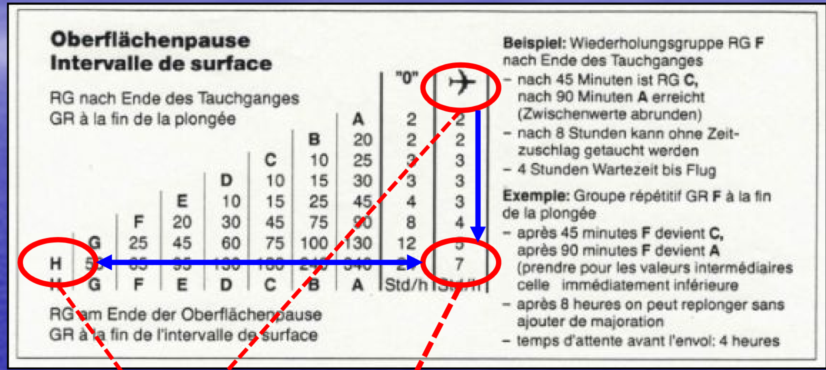
der Verfasser:

regulaeres Expl.
Korrektur-Expl.

B.Mueller

HV nach TG

Vers. 1.04 /87-08-20


Oberflächenpause
Intervalle de surface

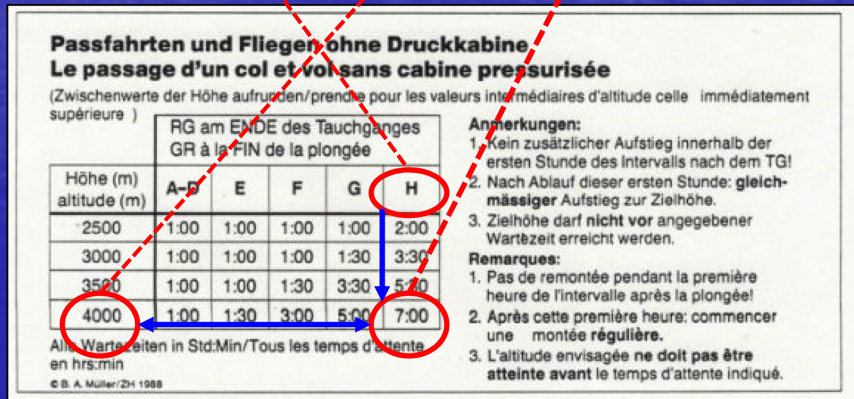
RG nach Ende des Tauchganges
GR à la fin de la plongée

	H	G	F	E	D	C	B	A	"0" Std/h	✈ Std/h
A								A	2	2
B							B	20	2	2
C						C	10	25	2	3
D					D	10	15	30	3	3
E				E	10	15	25	45	4	3
F			F	20	30	45	75	90	8	4
G		G	25	45	60	75	100	130	12	5
H	H	55	65	95	130	180	240	340	[illegible]	7

RG am Ende der Oberflächenpause
GR à la fin de l'intervalle de surface

Beispiel: Wiederholungsgruppe RG **F** nach Ende des Tauchganges
- nach 45 Minuten ist RG **C**, nach 90 Minuten **A** erreicht (Zwischenwerte abrunden)
- nach 8 Stunden kann ohne Zeitzuschlag getaucht werden
- 4 Stunden Wartezeit bis Flug

Exemple: Groupe répétitif GR **F** à la fin de la plongée
- après 45 minutes **F** devient **C**, après 90 minutes **F** devient **A** (prendre pour les valeurs intermédiaires celle immédiatement inférieure
- après 8 heures on peut replonger sans ajouter de majoration
- temps d'attente avant l'envol: 4 heures


Passfahrten und Fliegen ohne Druckkabine
Le passage d'un col et vol sans cabine pressurisée

(Zwischenwerte der Höhe aufrunden/prendre pour les valeurs intermédiaires d'altitude celle immédiatement supérieure)

Höhe (m) altitude (m)	RG am ENDE des Tauchganges GR à la FIN de la plongée A–D	E	F	G	H
2500	1:00	1:00	1:00	1:00	2:00
3000	1:00	1:00	1:00	1:30	3:30
3500	1:00	1:00	1:30	3:30	5:30
4000	1:00	1:30	3:00	5:00	7:00

Alle Wartezeiten in Std:Min/Tous les temps d'attente en hrs:min

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Anmerkungen:
1. Kein zusätzlicher Aufstieg innerhalb der ersten Stunde des Intervalls nach dem TG!
2. Nach Ablauf dieser ersten Stunde: **gleichmässiger** Aufstieg zur Zielhöhe.
3. Zielhöhe darf **nicht vor** angegebener Wartezeit erreicht werden.

Remarques:
1. Pas de remontée pendant la première heure de l'intervalle après la plongée!
2. Après cette première heure: commencer une montée **régulière.**
3. L'altitude envisagée **ne doit pas être atteinte avant** le temps d'attente indiqué.

Result: an adequat consistent and coherent system which is – just another benefit – easy to use.

Table is intentionally limited to RG=H, because this is on the outer edge of recreational sports diving.

The `86 Air Diving Tables: Flying after Diving (5b)

F l i e g e n   n a c h   T a u c h e n

(Entsättigungszeiten, Wartezeiten bis Flug)

1. System ZHL-12, Koeffizienten wie P2-2
2. Oberflächendruck p_v = 0.95 bar
3. alle Gewebe zu Beginn mit p_{N2} = 0.751 bar initialisiert
4. Abstiegsgeschwindigkeit 30m/Min.
5. Aufstiegsgeschwindigkeit bis 1. Dekostufe 10m/Min.
6. Kabinendruck 0.58 bar
7. Die Tabelle gilt ausschliesslich nur für Erst-Tauchgänge!

Tiefe (m)	Grundzeit (Min.)	Dekostufen 3m	6m	9m	Entsättigungszeit (Std.)	Wartezeit bis Flug (Std.)
9 NZ=607'	300	-	-	-	26.5	6.3
12 NZ=140.4'	120	-	-	-	18.3	3.0
	180	8	-	-	24.1	5.5
15	75	-	-	-	14.9	1.6
	120	18	-	-	21.9	4.6
NZ= 78.9'	180	40	-	-	27.5	7.0
18	60	4	-	-	14.5	1.4
	90	22	-	-	20.6	4.1
NZ= 55.2'	120	36	2	-	24.8	5.8
21	35	-	-	-	9.8	0.6
	50	7	-	-	14.2	1.3
NZ= 41.6'	70	23	-	-	19.3	3.5
24 NZ= 27.9'	25	-	-	-	7.9	0.4
	40	6	-	-	12.9	0.9
	60	25	2	-	19.2	3.5
27 NZ= 21.8'	22	1	-	-	7.8	0.4
	30	4	-	-	10.9	0.7
	40	14	1	-	14.8	1.6
30	20	2	-	-	7.9	0.4
	30	7	1	-	12.2	0.9
NZ= 18.1'	40	18	4	-	16.6	2.4
33	17	2	-	-	7.4	0.3
	25	5	2	-	11.2	0.7
NZ= 13.7'	30	12	3	-	13.7	1.0
36	15	2	-	-	7.1	0.3
	20	4	1	-	9.6	0.6
NZ= 13.5'	30	15	5	1	15.2	1.7
39 NZ= 11.8'	12	1	-	-	6.0	0.1
	20	2	1	-	10.5	0.4
	25	11	5	1	13.6	1.0
42	10	-	-	-	5.3	0.1
	15	4	1	-	8.3	0.5
NZ= 10.6'	20	5	4	1	11.6	0.8

Passfahrten und Fliegen ohne Druckkabine
Le passage d'un col et vol sans cabine pressurisée

(Zwischenwerte der Höhe aufrunden/prendre pour les valeurs intermédiaires d'altitude celle immédiatement supérieure)

Höhe (m) altitude (m)	RG am ENDE des Tauchganges GR à la FIN de la plongée A–D	E	F	G	H
2500	1:00	1:00	1:00	1:00	2:00
3000	1:00	1:00	1:00	1:30	3:30
3500	1:00	1:00	1:30	3:30	5:30
4000	1:00	1:30	3:00	5:00	7:00

Alle Wartezeiten in Std:Min/Tous les temps d'attente en hrs:min

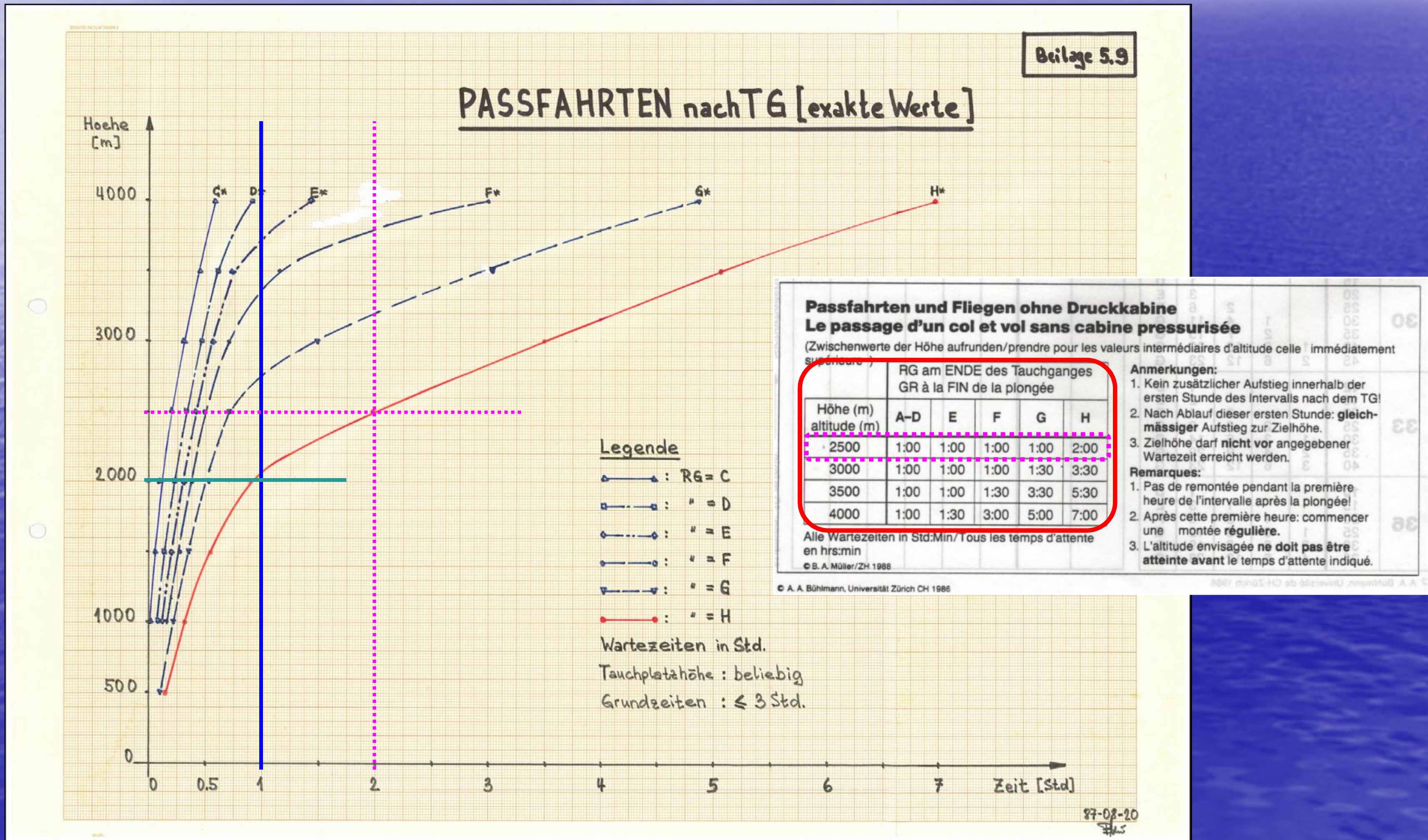
Anmerkungen:
1. Kein zusätzlicher Aufstieg innerhalb der ersten Stunde des Intervalls nach dem TG!
2. Nach Ablauf dieser ersten Stunde: **gleichmässiger** Aufstieg zur Zielhöhe.
3. Zielhöhe darf **nicht vor** angegebener Wartezeit erreicht werden.

Remarques:
1. Pas de remontée pendant la première heure de l'intervalle après la plongée!
2. Après cette première heure: commencer une montée **régulière**.
3. L'altitude envisagée **ne doit pas être atteinte avant** le temps d'attente indiqué.

It was shown that especially longer dives at shallow depths led to longer desaturation times and waiting times for flying.
Obvious reason: for these profiles, the leading compartments are those with longer halftimes which
a) have lower inert gas tissue limits and
b) require more time to desaturate.

Table is limited to RG=H, because this is on the outer edge of recreational sports diving.

The `86 Air Diving Tables: Crossing a Pass and Flying in non-pressurized Aircrafts



Passfahrten und Fliegen ohne Druckkabine
Le passage d'un col et vol sans cabine pressurisée

(Zwischenwerte der Höhe aufrunden/prendre pour les valeurs intermédiaires d'altitude celle immédiatement supérieure)

Höhe (m) altitude (m)	RG am ENDE des Tauchganges GR à la FIN de la plongée				
	A–D	E	F	G	H
2500	1:00	1:00	1:00	1:00	2:00
3000	1:00	1:00	1:00	1:30	3:30
3500	1:00	1:00	1:30	3:30	5:30
4000	1:00	1:30	3:00	5:00	7:00

Alle Wartezeiten in Std:Min/Tous les temps d'attente en hrs:min

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Anmerkungen:
1. Kein zusätzlicher Aufstieg innerhalb der ersten Stunde des Intervalls nach dem TG!
2. Nach Ablauf dieser ersten Stunde: **gleichmässiger** Aufstieg zur Zielhöhe.
3. Zielhöhe darf **nicht vor** angegebener Wartezeit erreicht werden.

Remarques:
1. Pas de remontée pendant la première heure de l'intervalle après la plongée!
2. Après cette première heure: commencer une montée **régulière.**
3. L'altitude envisagée **ne doit pas être atteinte avant** le temps d'attente indiqué.

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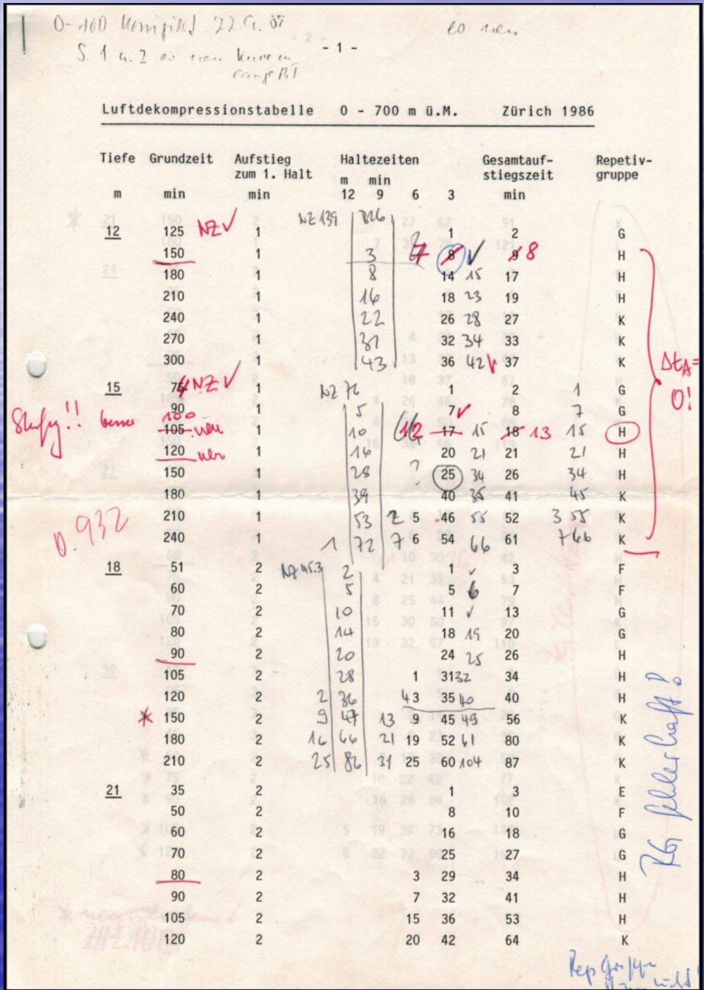
The `86 Air Diving Tables: Number crunching behind…

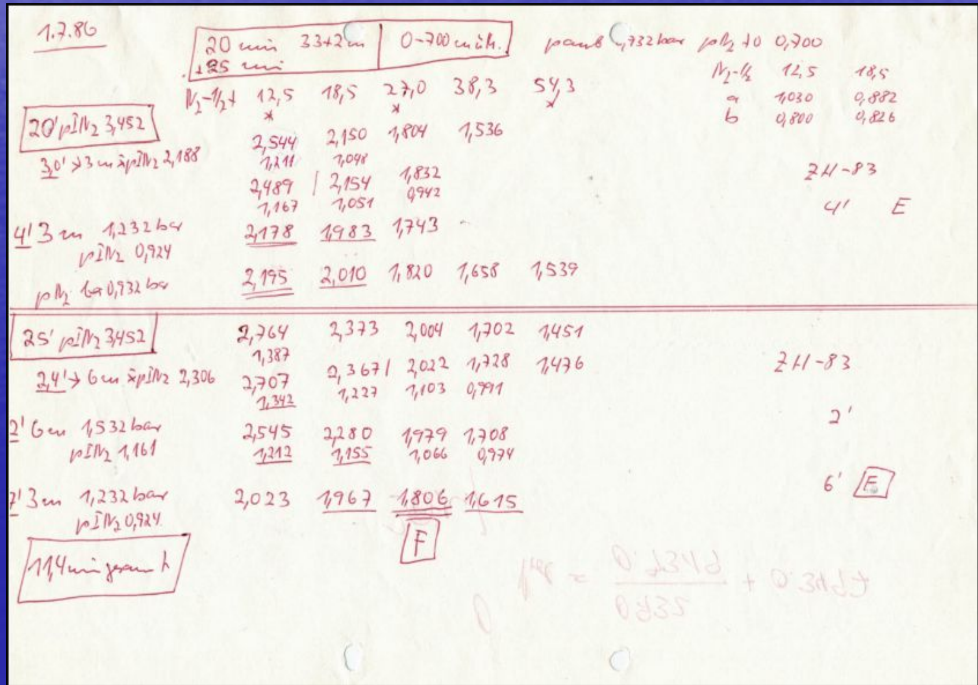


- 1 -

Luftdekompressionstabelle 0 - 700 m ü.M. Zürich 1986

Tiefe m	Grundzeit min	Aufstieg zum 1. Halt min	Haltezeiten m min 12	9	6	3	Gesamtaufstiegszeit min	Repetivgruppe
12	125	1				1	2	G
	150	1				8	9	H
	180	1				14	17	H
	210	1				18	19	H
	240	1				26	27	K
	270	1				32	33	K
	300	1				36	37	K
15	75	1				1	2	G
	90	1				7	8	G
	105	1				17	18	H
	120	1				20	21	H
	150	1				25	26	H
	180	1				40	41	K
	210	1			5	46	52	K
	240	1			6	54	61	K
18	51	2				1	3	F
	60	2				5	7	F
	70	2				11	13	G
	80	2				18	20	G
	90	2				24	26	H
	105	2			1	31	34	H
	120	2			3	35	40	H
	150	2			9	45	56	K
	180	2			19	52	80	K
	210	2			25	60	87	K
21	35	2				1	3	E
	50	2				8	10	F
	60	2				16	18	G
	70	2				25	27	G
	80	2			3	29	34	H
	90	2			7	32	41	H
	105	2			15	36	53	H
	120	2			20	42	64	K

Professor Bühlmann as a numerical wizard…..



repeated iterations of corrections and refinements…..

Bühlmann Memorial Symposium 2019

The `86 Air Diving Tables: Decision for Introduction

Secrétariat permanent
1000 Lausanne 9
Case postale 183
CCP/PC 10-6169

SUSV·FSSS

Fédération Suisse de Sports Subaquatiques
Schweizer Unterwasser-Sport-Verband
Federazione Svizzera di Sports Subacquei

Membre fondateur de la Confédération Mondiale des Activités Subaquatiques (CMAS) Membre de l'Association Suisse du Sport (ASS/SLS) Membre de l'Interassociation du Sauvetage (IAS/IVR) et de la Société Suisse de Sauvetage (SSS/SLRG)

Copia

Ing. Nicolao AMBROSINI
CAPO-ISTRUTTORE FSSS-SUSV
Via Migiome 61
6616 LOSONE

AN DIE MITGLIEDER DES ZV

AI MEMBRI DEL COMITATO DIRETTIVO

AUX MEMBRES DU BD

Notre référence: / Unser Zeichen:

Votre référence: / Ihr Zeichen:

Date: / Datum: 23 luglio 1986
11 agosto 1986

INCARICO DEL BD DEL 21 6 86 ALLA COMM. AD HOC : INTRODUZIONE NUOVE TABELLE .	AUFTRAG DES ZV VOM 21 6 1986 AN DIE AD HOC KOM.: EINFÜHRUNG DER NEUEN TABELLEN .	Demande du BD du 21 06 1986 à la commission ad hoc pour l'introduction des nouvelles tables.
La commissione, preso atto della documentazione esistente ed esperiti i necessari accertamenti, ha deciso all'unanimita quanto segue : 1.-Il Comitato Centrale FSSS é invitato a voler decidere l'introduzione presso la Federazione delle nuove tabelle Bühlmann 83/FSSS . 2.- Ne viene parimenti proposta l'entrata in vigore per l'1 1 87.	Die Kommission hat, nach Kenntnisnahme der bestehenden Unterlagen und den nötigen Ueberprüfungen, folgendes einstimmig beschlossen : 1.- Der Zentralvorstand des SUSV wird ersucht, die neuen Bühlmann Tabellen 83/SUSV in den Verband einzuführen. 2.- Gleichzeitig wird vorgeschlagen, sie mit dem 1. Januar 1987 in Kraft zu setzen.	La commission a décidé à l'unanimité, après avoir pris connaissance de la documentation existante et fait les vérifications nécessaires, de : 1. inviter le BD d'accepter les tables Bühlmann 83/FSSS, 2. de les faire entrer en vigueur dans toute la Fédération à partir du 1er janvier 1987.

Ambrosini Nicolao	Badoux Maurice	Bianda Patrizio	Galfetti Americo	Müller Beat
Ambrosini	Badoux		Galfetti	

Sucessful Termination

Bühlmann Memorial Symposium 2019

The `86 Air Diving Tables: Final report to the Instructor in Chief

Dietikon,den 12.10.87

Beat Mueller
Muehlehaldenstr.3
8953 Dietikon

Hrn.Nicolao Ambrosini
Chefinstruktor SUSV
Via Migiome 61
6616 Losone

Betrifft: **Passfahrtentabelle,Hoehenveraenderungen nach Tauchgaengen**

Lieber Nico,

ich habe zwischenzeitlich meinen Bericht mit Prof.Buehlmann durchgesehen und wertemaessig ueberprueft. Auf seinen Wunsch hin habe ich fuer ein zusaetzliches,spezielles Tauchgangprofil (21m/80') die verlangten Wartezeiten fuer alle Hoehen sowohl mit dem BASIC-Programm, wie auch auf dem HP-97 durchgerechnet. Die Werte der beiden Programme stimmen einmal gegenseitig , aber auch mit den durch Handrechnungen von Prof. Buehlmann ermittelten Werten voellig ueberein.

Im weiteren Verlauf der Diskussion ging Prof.Buehlmann noch einmal auf das Phaenomen der verzoegerten Gaselimination im Bereich der Haut und Muskulatur waehrend des Oberflaechenintervalles ein.

Um dieses Problem auch noch in den Griff zu bekommen,macht Prof.Buehlmann folgenden Vorschlag:

1. als **minimale Wartezeit** an der Oberflaeche sollte ein Intervall von **1 Stunde** nicht unterschritten werden.
2. die **Rundung** der exakten Werte sollte auf **HALBE Stunden** erfolgen (meine Variante "B").

Damit ergibt sich folgendes Tabellenbild:

zul. Hoehe [m]	Rep.Gruppen A	B	C	D	E	F	G	H
500	1:00	1:00	1:00	1:00	1:00	1:00	1:00	1:00
1500	1:00	1:00	1:00	1:00	1:00	1:00	1:00	1:00
2000	1:00	1:00	1:00	1:00	1:00	1:00	1:00	1:00
2500	1:00	1:00	1:00	1:00	1:00	1:00	1:00	2:00
3000	1:00	1:00	1:00	1:00	1:00	1:00	1:30	3:30
3500	1:00	1:00	1:00	1:00	1:00	1:30	3:30	5:30
4000	1:00	1:00	1:00	1:00	1:30	3:00	5:00	7:00

- 2 -

Dies kann noch stark vereinfacht werden (mit der Anmerkung!):

zul. Hoehe [m]	Rep.Gruppen E	F	G	H
2500	1:00	1:00	1:00	2:00
3000	1:00	1:00	1:30	3:30
3500	1:00	1:30	3:30	5:30
4000	1:30	3:00	5:00	7:00

Anmerkung: im Verlauf der ersten Stunde nach einem TG kann in den RG "A" bis "D" stetig bis 4000m, in den uebrigen RG's bis 2000m aufgestiegen werden!

Ferner kann festgehalten werden:

Die **Sicherheit** der vorliegenden Tabelle fuer Hoehenveraenderungen nach Tauchgaengen basiert auf folgenden Punkten:

1. experimentell durch Kammerversuche und Freiwassertauchgaenge breit abgestuetzte Koeffizienten des Systems ZHL-12
2. das dem vorangegangen TG zugrundegelegte Rechteckprofil (ergibt hoeheren Inertgasdruck im Kompartiment)
3. der diesem TG zugrundegelegte Tiefenzuschlag
4. die Annahme der Ausgangshoehe (Tauchplatz) mit 0 m , d.h. Meereshoehe
5. die Annahme eines zeitlosen Aufstiegs auf die Zielhoehe
6. die Bestimmung der maximalen Wartezeit an der moeglichst exakt ermittelten Grenze von einer RG zur naechsten
7. die ausschliessliche Beruecksichtigung des Maximalwertes aller TG innerhalb einer Rep.Gruppe
8. die Vorschrift einer minimalen Wartezeit von 1 Stunde
9. die Aufrundung der exakten Werte auf die naechste halbe Stunde

Damit ich rechtzeitig die entsprechende Publikation mit Erklaerungen und ev. Beispielen fuer den NEREUS vorbereiten kann, darf ich Dich bitten, mir moeglichst RASCH (spaetestens bis 21.10.87) eine verbindliche Stellungsnahme zukommen zu lassen.
Falls gewuenscht, bin ich auch bereit, anlaesslich der TK-Sitzung am 19.10.87 in Zuerich und/oder am Zentralkurs eine Praesentation zu diesem Thema zu geben.
Auf Grund der umfangreichen Dokumentation die Euch (TK,IA) vorliegt, sowie des Vertrauens, das wir alle in die Arbeit von Prof.Buehlmann setzen, sollte die Meinungsbildung eigentlich eine kurze Sache sein.

In Erwartung Deiner Antwort verbleibe ich

mit kollegialen Gruessen

Beat

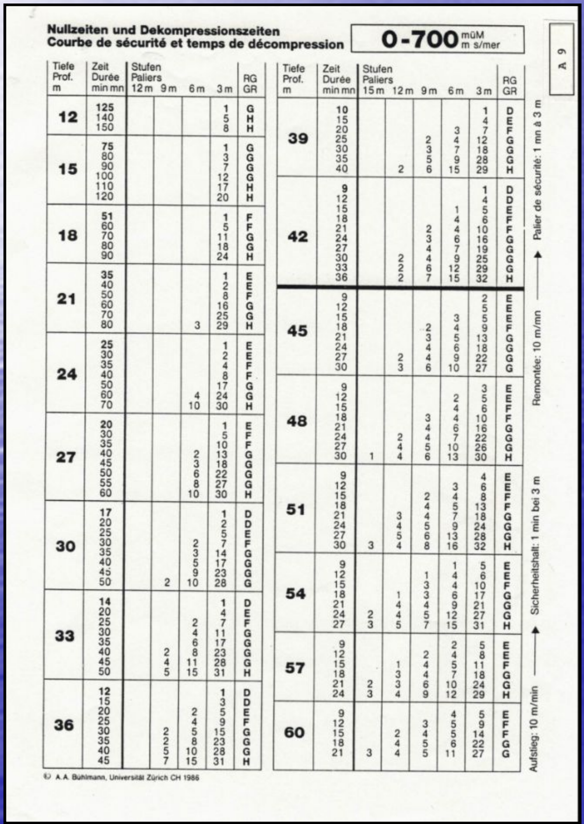
The `86 Air Diving Tables: Presentation to the Public

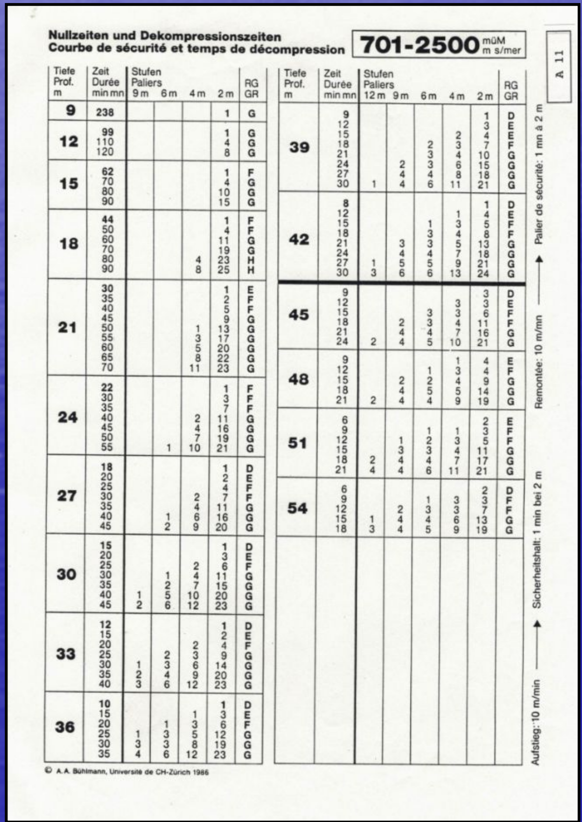
The final „product“: the air diving tables of `86 (1)

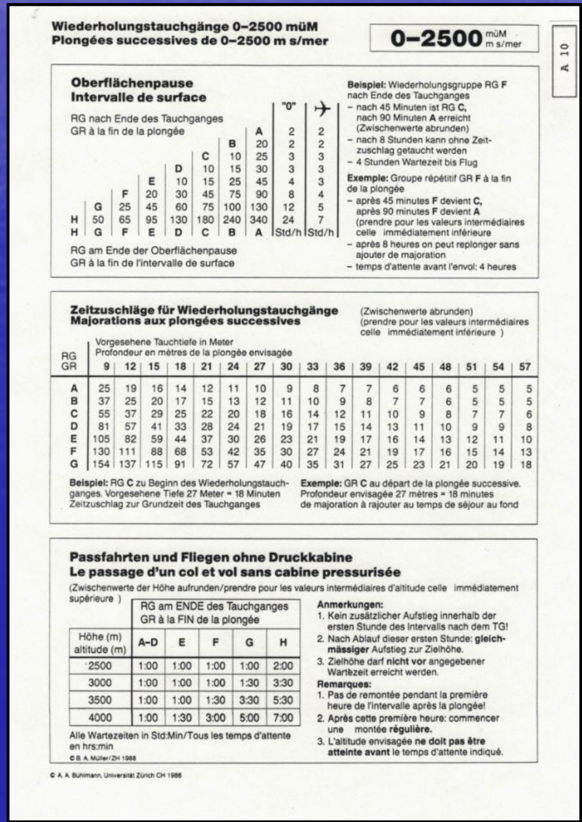
- 2 forms for usage:
  - paper print
  - plastified version
- 2 sets of diving tables for different altitude ranges
  - 0 – 700m a.s.l. (complete adaption at sea level, immediate dive at 700m)
  - 701 – 2500m a.s.l. (complete adaption at 700m, drive to 2500m in 1 hr, immediate dive)
- 1 Surface Intervall Table (SIT) for 0-2500m a.s.l. including
  - Time for almost complete desaturation for each RG at end of dive
  - Waiting Time for Flying after diving in pressurized aircrafts
- 1 Residual Nitrogen Table (RNT) for 0-2500m a.s.l.
- 1 Table for Waiting Times for Flying after diving in non-pressurized aircrafts and for crossing a pass (up to 4000m a.s.l.)
- Handling rules for all tables

The `86 Air Diving Tables: Printed version of tables

The final „product“: the air diving tables of `86 (2)



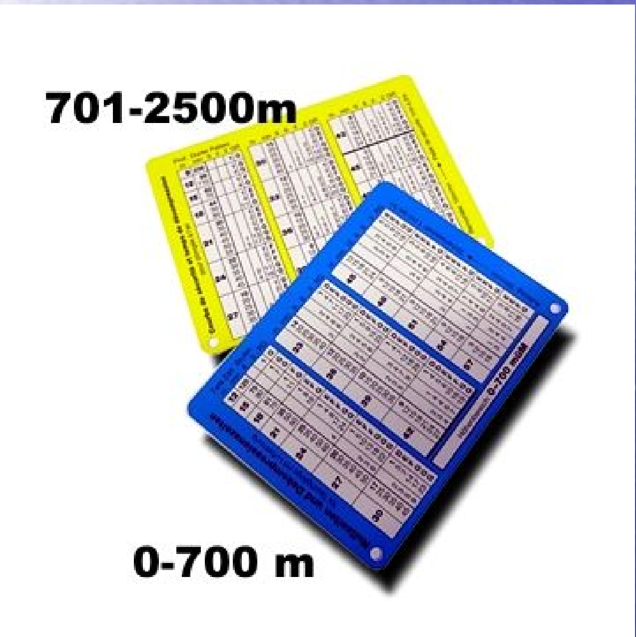


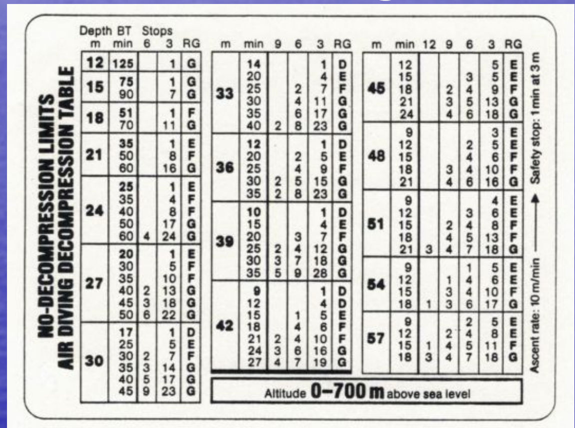


Printed paper version; it is agreed that diving beyond 40m (absolute) is regarded in most jurisdictions as an voluntary risk, which may have legal consequences.

The `86 Air Diving Tables: Plastified version of tables

The final „product“: the air diving tables of `86 (3)





NO-DECOMPRESSION LIMITS AIR DIVING DECOMPRESSION TABLE

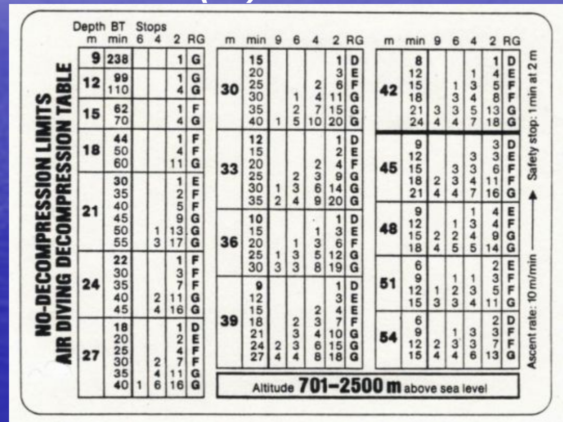
Depth m	BT min	Stops 6	3	RG
12	125		1	G
15	75		1	G
	90		7	G
18	51		1	F
	70		11	G
21	35		1	E
	50		8	F
	60		16	G
24	25		1	E
	35		4	F
	40		8	F
	50		17	G
	60	4	24	G
27	20		1	E
	30		5	F
	35		10	F
	40	2	13	G
	45	3	18	G
	50	6	22	G
30	17		1	D
	25		5	E
	30	2	7	F
	35	3	14	G
	40	5	17	G
	45	9	23	G

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



NO-DECOMPRESSION LIMITS AIR DIVING DECOMPRESSION TABLE

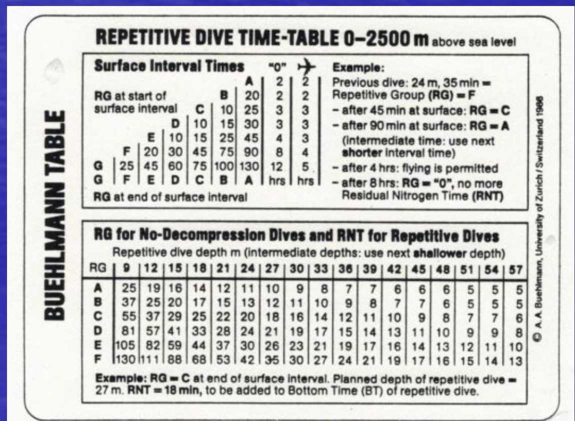
Depth m	BT min	Stops 6	4	2	RG
9	238			1	G
12	99			1	G
	110			4	G
15	62			1	F
	70			4	G
18	44			1	F
	50			4	F
	60			11	G
21	30			1	E
	35			2	F
	40			5	F
	45			9	G
	50		1	13	G
	55		3	17	G
24	22			1	F
	30			3	F
	35			7	F
	40		2	11	G
	45		4	16	G
27	18			1	D
	20			2	E
	25			4	F
	30		2	7	F
	35		4	11	G
	40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



BUEHLMANN TABLE

REPETITIVE DIVE TIME-TABLE 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
RG at end of surface interval	G	F	E	D	C	B	A	hrs	hrs

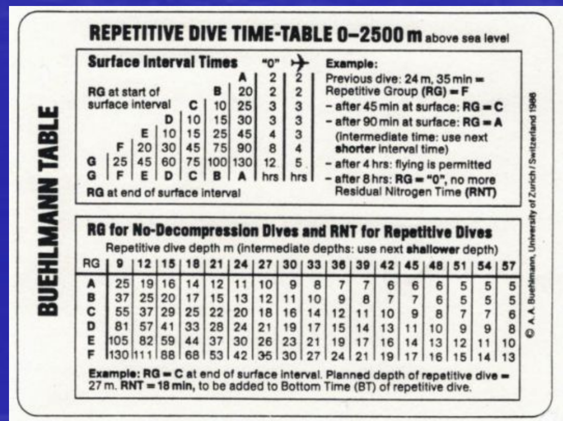
Example:
Previous dive: 24 m, 35 min = Repetitive Group **(RG) = F**
- after 45 min at surface: **RG = C**
- after 90 min at surface: **RG = A** (intermediate time: use next **shorter** interval time)
- after 4 hrs: flying is permitted
- after 8 hrs: **RG = "0"**, no more Residual Nitrogen Time **(RNT)**

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,** to be added to Bottom Time (BT) of repetitive dive.



BUEHLMANN TABLE

REPETITIVE DIVE TIME-TABLE 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
RG at end of surface interval	G	F	E	D	C	B	A	hrs	hrs

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,** to be added to Bottom Time (BT) of repetitive dive.

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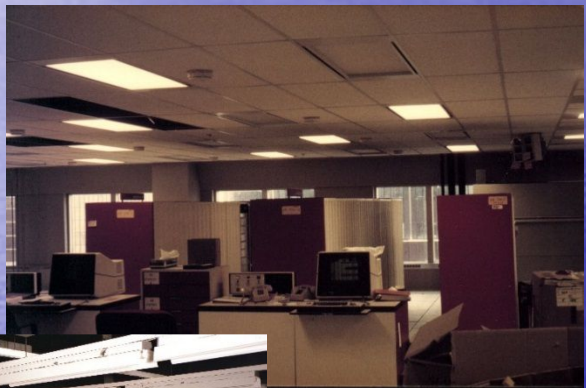
Set of plastified carry-on uw tables (in German, French, English) for both altitude ranges. Slightly reduced number of depth-bottom time combinations compared to printed paper version.

Tools and Technical Support behind

Bühlmann Memorial Symposium 2019

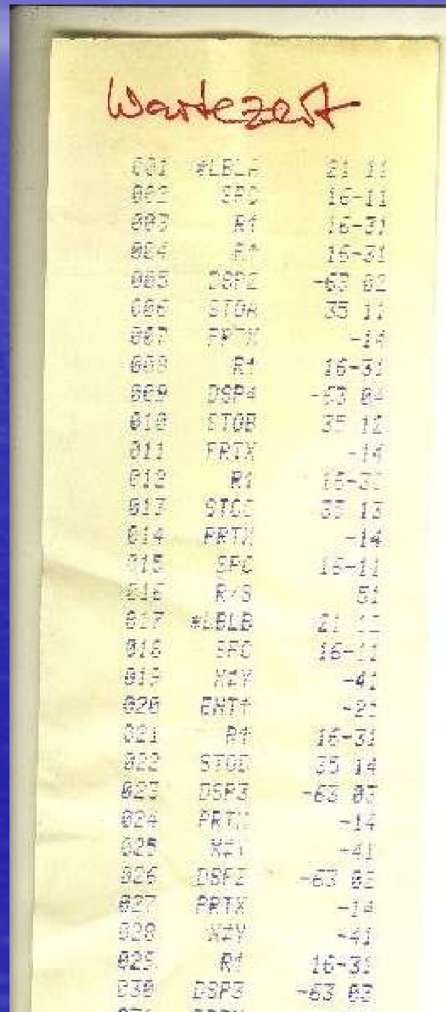
Tools and Technical Support behind (1)



parallel…
(IBM 3033 and 3081;
Fortran Program)

First try… (HP97; 224 programmable steps; reverse Polish notation)

2nd try: Compaq portable III;
Turbo Basic



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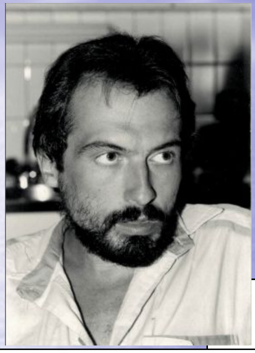
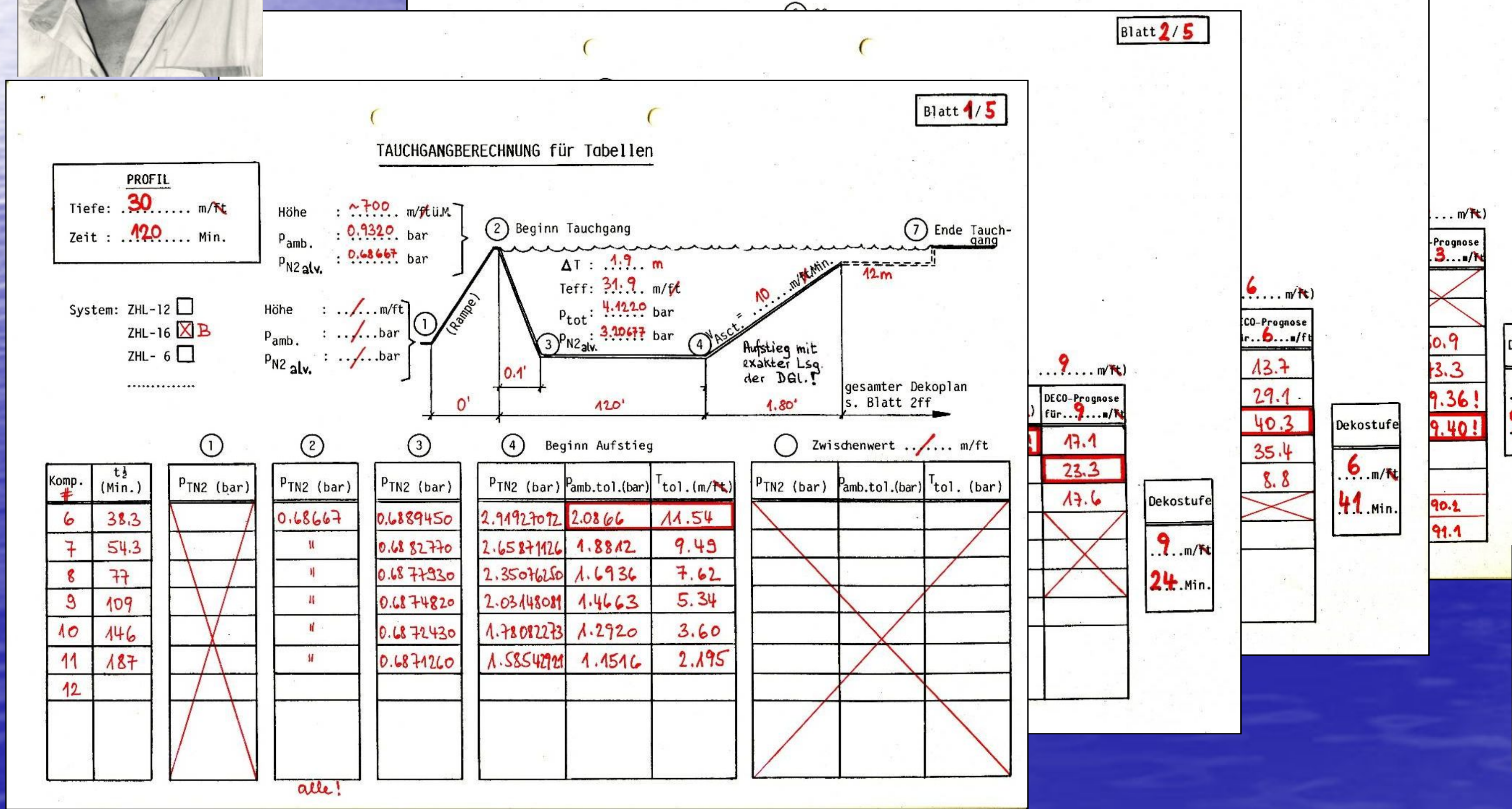
Tools and Technical Support behind (2)





TAUCHGANGBERECHNUNG für Tabellen

PROFIL
Tiefe: 30 m/ft
Zeit: 120 Min.

Höhe: ~700 m/ft ü.M.
$p_{amb.}$: 0.9320 bar
$p_{N2\,alv.}$: 0.68667 bar

System: ZHL-12 ☐ ZHL-16 ☒ B ZHL-6 ☐

Höhe: ../... m/ft
$p_{amb.}$: ../... bar
$p_{N2\,alv.}$: ../... bar

1 (Rampe) 2 Beginn Tauchgang 3 4 7 Ende Tauchgang

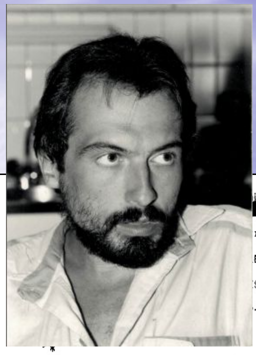
ΔT: 1.9 m
Teff: 31.9 m/ft
p_{tot}: 4.1220 bar
$p_{N2\,alv.}$: 3.20677 bar

$v_{Asct.}$ = 10 m/ft/Min.
12 m
Aufstieg mit exakter Lsg. der DGl.!
0' 0.1' 120' 1.80'
gesamter Dekoplan s. Blatt 2ff

Komp. #	$t_{1/2}$ (Min.)	① p_{TN2} (bar)	② p_{TN2} (bar)	③ p_{TN2} (bar)	④ Beginn Aufstieg p_{TN2} (bar)	$p_{amb.tol.}$ (bar)	$T_{tol.}$ (m/ft)	Zwischenwert ../... m/ft p_{TN2} (bar)	$p_{amb.tol.}$ (bar)	$T_{tol.}$ (bar)
6	38.3		0.68667	0.6889450	2.91927092	2.0866	11.54			
7	54.3		"	0.6882770	2.65871126	1.8812	9.49			
8	77		"	0.6877930	2.35076250	1.6936	7.62			
9	109		"	0.6874820	2.03148081	1.4663	5.34			
10	146		"	0.6872430	1.78082273	1.2920	3.60			
11	187		"	0.6871260	1.58542921	1.1516	2.195			
12										

alle!

Tools and Technical Support behind (3)



```
LT(1),PIGNEU(1),DELTAT )
**********************80*
*************************************
ER KOMPARTIMENTSDRUECKE DES MODELLS
SULTAT AUF DASSELBE 2-DIM. ARRAY.
-08-03 / #62
'*****************************************************
LOCAL       ITYP(),  DPDT()
DIM DYNAMIC ITYP(2), DPDT(2)
'
'ERROR - HANDLING
'------------------
'
ON ERROR GOTO ERRPTIGA
'
'
'
'CHECK AUF NEGATIVE WERTE / EXIT FUER DELTAT=0
'----------------------------------------------
'
FOR I = 0 TO NTISS-1
  FOR J = 1 TO NGAMAX
    IF PTISS[J,I] <0.0  THEN PTISS[J,I] = 0.0
  NEXT J
NEXT I
'
IF DELTAT = 0.0  THEN ENDPTIGA
'
'FESTSTELLUNG DER BERECHNUNGSART
'-------------------------------
'
FOR J = 1 TO NGAMAX
  ITYP[J] = 2
  DPDT[J] = (PIGNEU[J] - PIGALT[J]) / DELTAT
  IF DPDT[J] = 0.0  THEN ITYP[J] = 1
NEXT J
'
'NACHFUEHREN KOMPARTIMENTSDRUECKE
'--------------------------------
'
STRPTGA:
    FOR I = 0 TO NTISS-1
      IF ITEXCL[I] = 1  THEN ENDPTGA
        FOR J = NGAMI TO NGAMA
          IF DELTAT >= NT2AMAX*T2[J,I]_
          THEN PTISS[J,I] = PIGNEU[J]: GOTO CHECKA
            EXPO = EXP(-FK[J,I]*DELTAT)
            ON ITYP[J] GOTO ITYP1A, ITYP2A
ITYP1A:
    'a) mit einfacher Lsg. der DGL
            PTISS[J,I] = PIGNEU[J] - ( PIGNEU[J]-PTISS[J,I] )*EXPO
            GOTO CHECKA
ITYP2A:
    'b) mit strenger Lsg. der DGL
            PTISS[J,I] = PIGNEU[J]-DPDT[J]/FK[J,I]_
                       - (PIGALT[J]-PTISS[J,I]-DPDT[J]/FK[J,I])*EXPO
CHECKA:
          IF PTISS[J,I] <0.0  THEN PTISS[J,I] = 0.0
        NEXT J
```

```
Programm     : CAP GEMINI (SUISSE) AG
               SOFTWARE DEPARTEMENT

Programmer   : B.Mueller
Eingabe (#1): KOEFF.TB6
Eingabe (#2): DTABMUTT.INP
Ausgabe (#3): t0825r15.#h3
Datum        : 88-08-28

1a.Hoehenlage (Hoehe 1)  m u.M.   =  2500 m
2a.Oberfl.-Luftdruck Hoehe 1      =  0.741 bar
3a.alv. N2-Druck (Oberfl.Hoehe 1)=  0.537 bar
4a.alv. HE-Druck (Oberfl.Hoehe 1)=  0.000 bar
1b.Hoehenlage (Hoehe 0)  m u.M.   =   800 m
2b.Oberfl.-Luftdruck Hoehe 0      =  0.917 bar
3b.alv. N2-Druck (Oberfl.Hoehe 0)=  0.675 bar
4b.alv. HE-Druck (Oberfl.Hoehe 0)=  0.000 bar
5. Anfahrtszeit Hoehe0->Hoehe1    =    15 min
6. Aufenthaltsdauer auf Hoehe1    =   180 min
7a.konst. N2-Anteil Oberflaeche   = 79.0 %
7b.konst. HE-Anteil Oberflaeche   =  0.0 %
8a.konst. N2-Anteil waehrend TG   = 79.0 %
8b.konst. HE-Anteil waehrend TG   =  0.0 %
9. konst. Wasserdampfdruck        =  0.062 bar
10. konst. CO2-Partialdruck       =  0.053 bar
11. Respirationskoeffizient       = 1.000
12a.Drucksteigerungsfaktor        = 0.961 bar/10
12b.entsprech. Wasserdichte       = 0.980 kg/liter
13. konst. TIEFEN-Zuschlag        = 0.00 m
14. multipl. TIEFEN-Zuschlag      = 0.00 %
15. zus.Dekostufen-Sicherheit     = 0.00 m
16. konst. Tiefenzuschl. DEKO     = 0.00 m
17. multipl.Tiefenzuschl.DEKO     = 0.00 %
18. Abtauchzeit a. Tiefe (fix)    =   3.0 min
19. Auftauchgeschwindigkeit       =  10.0 m/min
21. Spezif.Luftverbr.(Oberfl.)    = 20.0 L/min./a
22a.Kabinendruck f. Wartezeit     = 0.696 bar
22b.Flughoehe n. Kabinendruck     =  3000 m
23a.Kabinen-N2-Partialdruck       = 0.501 bar
23b.Kabinen-HE-Partialdruck       = 0.000 bar
23c.Zeitloser Aufstieg bis Flughoehe (TAFLG=0.0 min)
24. Entsaettigung bis PIGSRF1 * 1.050
25. Grundzeit = Abtauchzeit + Zeit auf Tiefe
26. Aufstieg ZWISCHEN Dekostufen NICHT beruecksichtigt.
27. alle Dekozeiten auf GANZE Minuten aufgerundet.
28. Hainwertszeiten,Koeffizienten, tol. Oberfl.,Komp.-druecke,K'-I
```

Note: as long as you don‘t know all this governing parameters, any discussion on a table is useless!

```
KOMMENTARE: mutisee 800/15/2500/180/t86

NULLZEITEN und DEKOMPRESSIONSTABELLE
fuer  L U F T

HOEHENBEREICH:  800 - 2500 m u.M.

30   NULLZEIT=  20.4 min (inkl. Abstiegszeit= 3.00 min) / Kompartiment= 3,PTIG[ 3] = 1.957 bar

  12:     | 3 1.23|0.00/ 1 2.091|25.3/16 0.677|              | 3/1.557  4/1.317/ 74
  15:     | 3 1.53|0.00/ 1 2.181|26.0/16 0.684|              | 3/1.722  4/1.463/ 82
          | 3 1.82|0.00/ 1 2.235|26.7/16 0.691|              | 3/1.862  4/1.594/ 90
       1: 4 2.14|0.01/ 3 1.925|27.4/16 0.698|           3/3 | 3/1.925  4/1.681/ 94
       2: 5 2.46|0.01/ 3 1.949|28.0/16 0.705|           3/3 | 3/1.949  4/1.742/ 98
       4: 7 2.80|0.01/ 4 1.747|28.7/16 0.712|           3/4 | 4/1.747  5/1.546/ 97
     1 5: 9 3.15|0.03/ 5 1.581|29.2/16 0.719|     3/3   3/5 | 5/1.581  6/1.396/ 97
min (inkl. Abstiegszeit= 3.00 min) / Kompartiment= 3,PTIG[ 3] = 1.957 bar
        | 3 1.35|0.00/ 1 2.213|25.7/16 0.681|              | 3/1.660  4/1.399/ 79
        | 3 1.66|0.00/ 1 2.308|26.5/16 0.688|              | 3/1.839  4/1.558/ 88
       1: 4 2.01|0.01/ 3 1.934|27.2/16 0.696|           3/3 | 3/1.934  4/1.671/ 94
       3: 6 2.37|0.00/ 3 1.913|27.9/16 0.704|           3/3 | 3/1.913  4/1.714/ 96
     1 4: 8 2.75|0.01/ 4 1.747|28.6/16 0.711|     3/3   3/4 | 4/1.747  5/1.544/ 97
     2 5: 10 3.12|0.03/ 5 1.586|29.3/16 0.719|    3/3   3/5 | 5/1.586  6/1.399/ 97
min (inkl. Abstiegszeit= 3.00 min) / Kompartiment= 3,PTIG[ 3] = 1.957 bar
        | 4 1.46|0.00/ 1 2.331|26.0/16 0.684|              | 3/1.763  4/1.482/ 83
        | 4 1.80|0.01/ 3 1.955|26.9/16 0.693|              | 3/1.955  4/1.653/ 93
       3: 7 2.22|0.00/                                 3/3 | 3/1.912  4/1.695/ 95
  21:  2 3: 9 2.62|0.01/                         3/3   3/3 | 4/1.754  5/1.539/ 97
  24:  3 4: 11 3.01|0.03/                        3/3   3/5 | 5/1.594  6/1.400/ 97
```

Later program version in Turbo Basic on a carry-on Compac PC

Tools and Technical Support behind (4)

Kind support of Dr. Klaus Meier-Ewert, Germany, Physicist, Diving Instructor and Computer Expert

Cross-Checks done on IBM-mainframe

(†1989)

27+1+3% Tiefe Grundzeit

WOHNORT (BAR): .93 — 0,932
TAUCHGEB.(BAR): .75 — 0.747
AUFENTHALT (H): 999.00

KOMPRESSION-DEKOMPRESSIONS-PROFIL

TI/ZT 27/55 — SEITE 1

	1	2	3	4	5	6	7
AUSGANGSTIEFE (M)	0.00	0.00		1.85	0.00		28.81
N2-PARTIALDRUCK (BAR)	.69	.69		.69	.54		2.82
ZIEL-TIEFE GELOTET (M)	1.85	1.85	1.85	0.00	28.81	28.81	9.00
N2-PARTIALDRUCK (BAR)	.54	.69	.69	.54	2.82	2.82	1.25
AUF/AB-GESCHW. (M/MIN)		999.00		- .03	288.10		-10.00
ZEIT FUER AUF/AB (MIN)	~~74836.47~~	.00		60.00	.10		1.98
VERWEILZEIT (MIN)			99999.00			$\boxed{55.00}$ Grundzeit	
BELASTUNGSFAKTOR							
TEMPERATURFAKTOR							
LUFTVERBR.(L) 20 L/MIN	neg. wird ∅		39952	40496	3	3994	4066
SPEZ.DICHTE 1.02		ABSTIEG	AUFENTHALT	AUFSTIEG	ABSTIEG	AUFENTHALT	AUFSTIEG

GEWEBE-ART		HS-ZEIT	1 GPN2	1 PTOL	2 GPN2	2 PTOL	3 GPN2	3 PTOL	4 GPN2	4 PTOL	5 GPN2	5 PTOL	6 GPN2	6 PTOL	7 GPN2	7 PTOL
GEHIRN-	1	4.00	.540	.000	.551	.000	.687	.000	.555	.000	.574	.000	2.817	.733	2.576	.541
RUECKENMARK	2	8.00	.540	.000	.524	.000	.687	.000	.568	.000	.578	.000	2.798	1.078	2.674	.979
	3	12.5	.540	.000	.517	.000	.687	.000	.583	.000	.589	.000	2.711	1.345	2.640	1.288
	4	18.5	.540	.000	.561	.000	.687	.000	.599	.000	.603	.000	2.535	1.365	2.498	1.335
	5	27.0	.540	.000	.503	.000	.687	.000	.615	.000	.618	.000	2.281	1.322	2.269	1.311
HAUT-	6	38.3	.540	.000	.426	.000	.687	.096	.630	.047	.632	.049	2.009	1.233	2.010	1.234
MUSKULATUR	7	54.3	.540	.063	.687	.190	.687	.190	.643	.152	.644	.153	1.740	1.107	1.747	1.113
	8	77	.540	.090	.687	.222	.687	.222	.653	.192	.654	.193	1.499	.955	1.508	.964
	9	109	.540	.114	.687	.247	.687	.247	.662	.224	.663	.225	1.299	.802	1.308	.811
INNENOHR	10	146	.540	.117	.687	.254	.687	.254	.668	.236	.668	.237	1.162	.701	1.170	.708
	11	187	.540	.162	.687	.301	.687	.301	.672	.286	.672	.286	1.067	.661	1.074	.667
	12	239	.540	.162	.687	.301	.687	.301	.675	.289	.675	.289	.991	.588	.997	.594
GELENKE-	13	305	.540	.275	.687	.415	.687	.415	.677	.406	.678	.407	.929	.648	.934	.653
KNOCHEN	14	390	.540	.275	.687	.415	.687	.415	.679	.408	.679	.408	.878	.599	.882	.603
	15	498	.540	.275	.687	.415	.687	.415	.681	.410	.681	.410	.838	.561	.842	.564
	16	635	.540	.275	.687	.415	.687	.415	.682	.411	.682	.411	.807	.531	.809	.533

DEKOZEITEN FUER (MIN)	1	2	3	4	5	6	7
2M 4M	Sättigungszust. auf 2500 m ≙ 0.747 bar	∞-langer TG auf 1.85 m ≙ 0.932 − 0.747	Sätt. zustand bei 700 m	Rampe		24 13	24 14
6M 9M						7 1	7
12M 15M						Ende Grundzeit	
18M 21M							
24M 27M							
	.00	.00	9999.00	60.00	.10	55.10	57.08

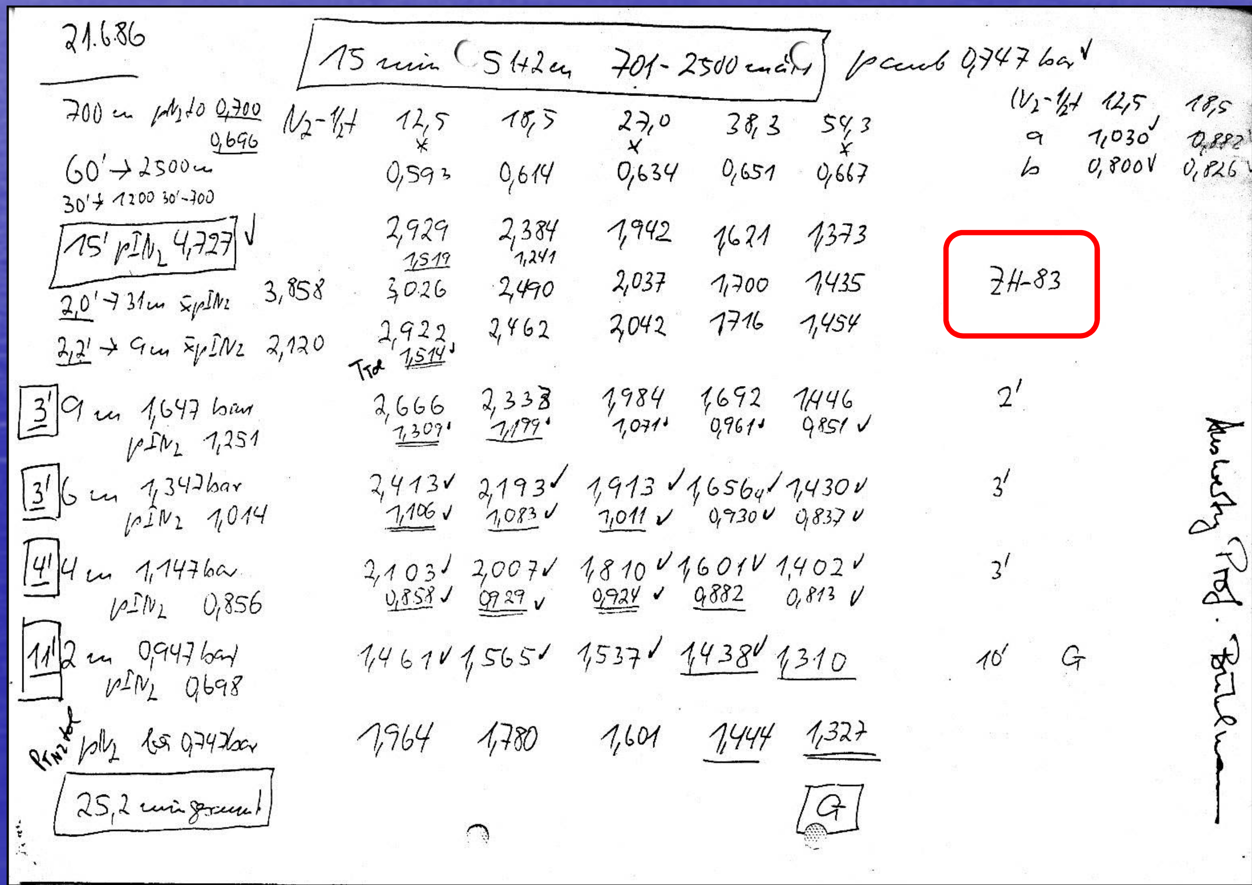
ME/24.10.86

Zeitachse

Bühlmann Memorial Symposium 2019

Tools and Technical Support behind (5)

Another personal check in Prof. Bühlmann‘s own handwriting; as already mentioned he did all calculations with a small hand-held „calculator“

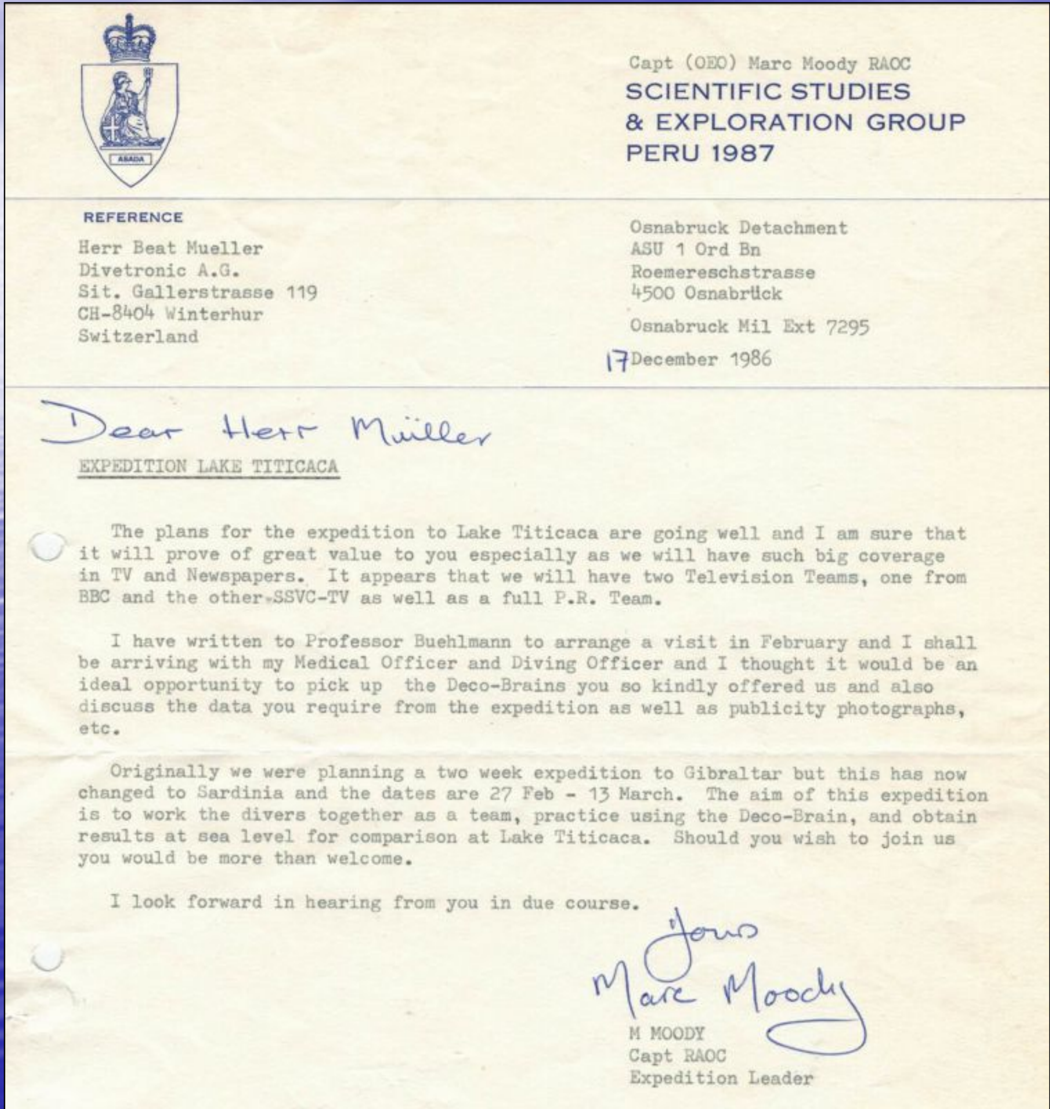


Bühlmann Memorial Symposium 2019

Lake Titicaca Trials (1987)

Bühlmann Memorial Symposium 2019

Lake Titicaca Trials; Bolivia, 3800m a.s.l. (1)



Capt (OEO) Marc Moody RAOC
SCIENTIFIC STUDIES
& EXPLORATION GROUP
PERU 1987

REFERENCE

Herr Beat Mueller
Divetronic A.G.
Sit. Gallerstrasse 119
CH-8404 Winterhur
Switzerland

Osnabruck Detachment
ASU 1 Ord Bn
Roemereschstrasse
4500 Osnabrück

Osnabruck Mil Ext 7295

17 December 1986

Dear Herr Müller

EXPEDITION LAKE TITICACA

The plans for the expedition to Lake Titicaca are going well and I am sure that it will prove of great value to you especially as we will have such big coverage in TV and Newspapers. It appears that we will have two Television Teams, one from BBC and the other SSVC-TV as well as a full P.R. Team.

I have written to Professor Buehlmann to arrange a visit in February and I shall be arriving with my Medical Officer and Diving Officer and I thought it would be an ideal opportunity to pick up the Deco-Brains you so kindly offered us and also discuss the data you require from the expedition as well as publicity photographs, etc.

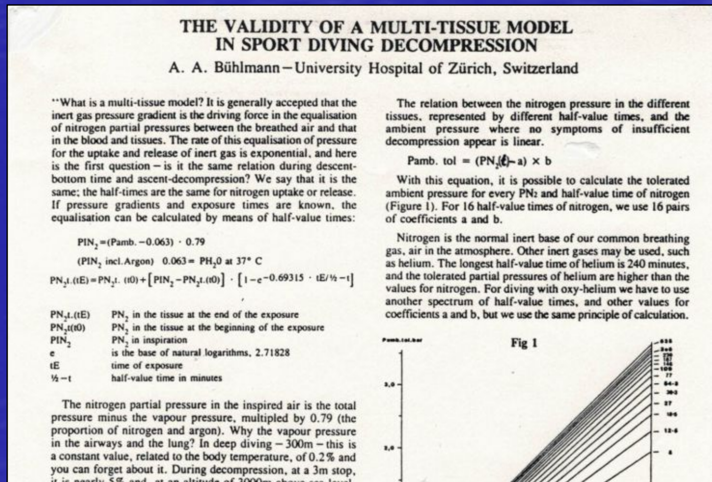
Originally we were planning a two week expedition to Gibraltar but this has now changed to Sardinia and the dates are 27 Feb - 13 March. The aim of this expedition is to work the divers together as a team, practice using the Deco-Brain, and obtain results at sea level for comparison at Lake Titicaca. Should you wish to join us you would be more than welcome.

I look forward in hearing from you in due course.

Yours
Marc Moody

M MOODY
Capt RAOC
Expedition Leader

BSAC Diving Officer's Conference, London, Nov. 1986



THE VALIDITY OF A MULTI-TISSUE MODEL IN SPORT DIVING DECOMPRESSION

A. A. Bühlmann – University Hospital of Zürich, Switzerland

"What is a multi-tissue model? It is generally accepted that the inert gas pressure gradient is the driving force in the equalisation of nitrogen partial pressures between the breathed air and that in the blood and tissues. The rate of this equalisation of pressure for the uptake and release of inert gas is exponential, and here is the first question – is it the same relation during descent-bottom time and ascent-decompression? We say that it is the same; the half-times are the same for nitrogen uptake or release. If pressure gradients and exposure times are known, the equalisation can be calculated by means of half-value times:

$$PIN_2 = (Pamb. - 0.063) \cdot 0.79$$

$(PIN_2$ incl. Argon$)$ $0.063 = PH_2O$ at 37° C

$$PN_2t.(tE) = PN_2t.(t0) + \left[PIN_2 - PN_2t.(t0)\right] \cdot \left[1 - e^{-0.69315 \cdot tE/½-t}\right]$$

$PN_2t.(tE)$	PN_2 in the tissue at the end of the exposure
$PN_2t(t0)$	PN_2 in the tissue at the beginning of the exposure
PIN_2	PN_2 in inspiration
e	is the base of natural logarithms, 2.71828
tE	time of exposure
½−t	half-value time in minutes

The nitrogen partial pressure in the inspired air is the total pressure minus the vapour pressure, multipled by 0.79 (the proportion of nitrogen and argon). Why the vapour pressure in the airways and the lung? In deep diving – 300m – this is a constant value, related to the body temperature, of 0.2% and you can forget about it. During decompression, at a 3m stop,

The relation between the nitrogen pressure in the different tissues, represented by different half-value times, and the ambient pressure where no symptoms of insufficient decompression appear is linear.

$$Pamb.\ tol = (PN_2(t) - a) \times b$$

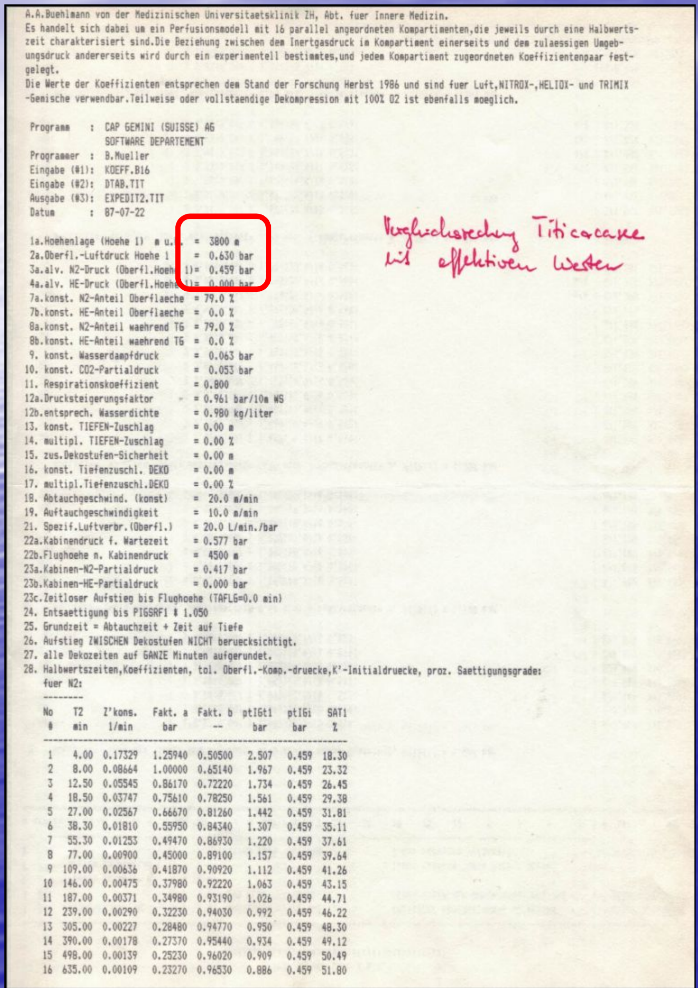
With this equation, it is possible to calculate the tolerated ambient pressure for every PN_2 and half-value time of nitrogen (Figure 1). For 16 half-value times of nitrogen, we use 16 pairs of coefficients a and b.

Nitrogen is the normal inert base of our common breathing gas, air in the atmosphere. Other inert gases may be used, such as helium. The longest half-value time of helium is 240 minutes, and the tolerated partial pressures of helium are higher than the values for nitrogen. For diving with oxy-helium we have to use another spectrum of half-value times, and other values for coefficients a and b, but we use the same principle of calculation.

Fig 1

Bühlmann Memorial Symposium 2019

Lake Titicaca Trials; Bolivia, 3800m a.s.l. (2)



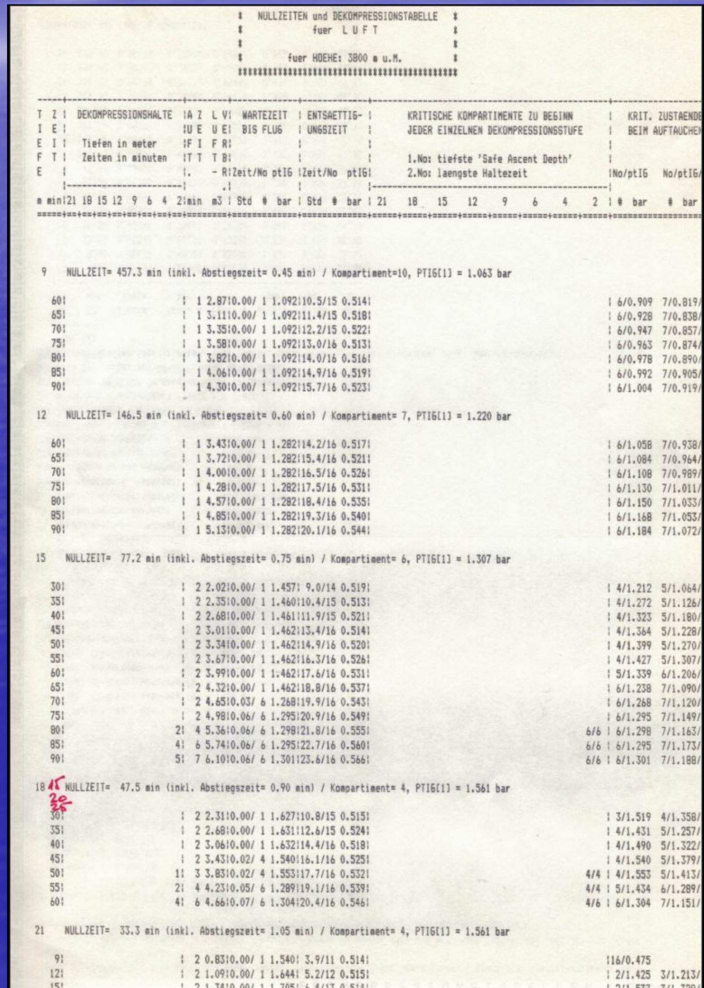
A.A.Buehlmann von der Medizinischen Universitaetsklinik ZH, Abt. fuer Innere Medizin.
Es handelt sich dabei um ein Perfusionsmodell mit 16 parallel angeordneten Kompartimenten,die jeweils durch eine Halbwertszeit charakterisiert sind.Die Beziehung zwischen dem Inertgasdruck im Kompartiment einerseits und dem zulaessigen Umgebungsdruck andererseits wird durch ein experimentell bestimmtes,und jedem Kompartiment zugeordneten Koeffizientenpaar festgelegt.
Die Werte der Koeffizienten entsprechen dem Stand der Forschung Herbst 1986 und sind fuer Luft,NITROX-,HELIOX- und TRIMIX-Gemische verwendbar.Teilweise oder vollstaendige Dekompression mit 100% O2 ist ebenfalls moeglich.

Programm : CAP GEMINI (SUISSE) AG
SOFTWARE DEPARTEMENT
Programmer : B.Mueller
Eingabe (#1): KOEFF.B16
Eingabe (#2): DTAB.TIT
Ausgabe (#3): EXPEDIT2.TIT
Datum : 87-07-22

Vergleichsrechnung Titicacasee mit effektiven Werten

1a.Hoehenlage (Hoehe 1) m u.M. = 3800 m
2a.Oberfl.-Luftdruck Hoehe 1 = 0.630 bar
3a.alv. N2-Druck (Oberfl.Hoehe 1)= 0.459 bar
4a.alv. HE-Druck (Oberfl.Hoehe 1)= 0.000 bar
7a.konst. N2-Anteil Oberflaeche = 79.0 %
7b.konst. HE-Anteil Oberflaeche = 0.0 %
8a.konst. N2-Anteil waehrend TG = 79.0 %
8b.konst. HE-Anteil waehrend TG = 0.0 %
9. konst. Wasserdampfdruck = 0.063 bar
10. konst. CO2-Partialdruck = 0.053 bar
11. Respirationskoeffizient = 0.800
12a.Drucksteigerungsfaktor = 0.961 bar/10m WS
12b.entsprech. Wasserdichte = 0.980 kg/liter
13. konst. TIEFEN-Zuschlag = 0.00 m
14. multipl. TIEFEN-Zuschlag = 0.00 %
15. zus.Dekostufen-Sicherheit = 0.00 m
16. konst. Tiefenzuschl. DEKO = 0.00 m
17. multipl.Tiefenzuschl.DEKO = 0.00 %
18. Abtauchgeschwind. (konst) = 20.0 m/min
19. Auftauchgeschwindigkeit = 10.0 m/min
21. Spezif.Luftverbr.(Oberfl.) = 20.0 L/min./bar
22a.Kabinendruck f. Wartezeit = 0.577 bar
22b.Flughoehe n. Kabinendruck = 4500 m
23a.Kabinen-N2-Partialdruck = 0.417 bar
23b.Kabinen-HE-Partialdruck = 0.000 bar
23c.Zeitloser Aufstieg bis Flughoehe (TAFLG=0.0 min)
24. Entsaettigung bis PIGSRF1 # 1.050
25. Grundzeit = Abtauchzeit + Zeit auf Tiefe
26. Aufstieg ZWISCHEN Dekostufen NICHT beruecksichtigt.
27. alle Dekozeiten auf GANZE Minuten aufgerundet.
28. Halbwertszeiten,Koeffizienten, tol. Oberfl.-Komp.-druecke,K'-Initialdruecke, proz. Saettigungsgrade:
fuer N2:

No #	T2 min	Z'kons. 1/min	Fakt. a bar	Fakt. b --	ptIGt1 bar	ptIGi bar	SAT1 %
1	4.00	0.17329	1.25940	0.50500	2.507	0.459	18.30
2	8.00	0.08664	1.00000	0.65140	1.967	0.459	23.32
3	12.50	0.05545	0.86170	0.72220	1.734	0.459	26.45
4	18.50	0.03747	0.75610	0.78250	1.561	0.459	29.38
5	27.00	0.02567	0.66670	0.81260	1.442	0.459	31.81
6	38.30	0.01810	0.55950	0.84340	1.307	0.459	35.11
7	55.30	0.01253	0.49470	0.86930	1.220	0.459	37.61
8	77.00	0.00900	0.45000	0.89100	1.157	0.459	39.64
9	109.00	0.00636	0.41870	0.90920	1.112	0.459	41.26
10	146.00	0.00475	0.37980	0.92220	1.063	0.459	43.15
11	187.00	0.00371	0.34980	0.93190	1.026	0.459	44.71
12	239.00	0.00290	0.32230	0.94030	0.992	0.459	46.22
13	305.00	0.00227	0.28480	0.94770	0.950	0.459	48.30
14	390.00	0.00178	0.27370	0.95440	0.934	0.459	49.12
15	498.00	0.00139	0.25230	0.96020	0.909	0.459	50.49
16	635.00	0.00109	0.23270	0.96530	0.886	0.459	51.80



```
* NULLZEITEN und DEKOMPRESSIONSTABELLE *
*            fuer  L U F T             *
*                                      *
*       fuer HOEHE: 3800 m u.M.        *
****************************************

T Z | DEKOMPRESSIONSHALTE |A Z L V| WARTEZEIT | ENTSAETTIG- | KRITISCHE KOMPARTIMENTE ZU BEGINN   | KRIT. ZUSTAENDE
I E |                     |U E U E| BIS FLUG  | UNGSZEIT    | JEDER EINZELNEN DEKOMPRESSIONSSTUFE | BEIM AUFTAUCHEN
E I | Tiefen in meter     |F I F R|           |             |                                     |
F T | Zeiten in minuten   |T T T B|           |             | 1.No: tiefste 'Safe Ascent Depth'   |
E   |                     |.  - R|Zeit/No ptIG|Zeit/No ptIG| 2.No: laengste Haltezeit            |No/ptIG  No/ptIG/
m min|21 18 15 12 9 6 4 2|min m3 | Std # bar | Std # bar | 21 18 15 12 9 6 4 2 | # bar  # bar

9   NULLZEIT= 457.3 min (inkl. Abstiegszeit= 0.45 min) / Kompartiment=10, PTIG[1] = 1.063 bar

 60|  | 1 2.87|0.00/ 1 1.092|10.5/15 0.514|  | 6/0.909 7/0.819/
 65|  | 1 3.11|0.00/ 1 1.092|11.4/15 0.518|  | 6/0.928 7/0.838/
 70|  | 1 3.35|0.00/ 1 1.092|12.2/15 0.522|  | 6/0.947 7/0.857/
 75|  | 1 3.58|0.00/ 1 1.092|13.0/16 0.513|  | 6/0.963 7/0.874/
 80|  | 1 3.82|0.00/ 1 1.092|14.0/16 0.516|  | 6/0.978 7/0.890/
 85|  | 1 4.06|0.00/ 1 1.092|14.9/16 0.519|  | 6/0.992 7/0.905/
 90|  | 1 4.30|0.00/ 1 1.092|15.7/16 0.523|  | 6/1.004 7/0.919/

12  NULLZEIT= 146.5 min (inkl. Abstiegszeit= 0.60 min) / Kompartiment= 7, PTIG[1] = 1.220 bar

 60|  | 1 3.43|0.00/ 1 1.282|14.2/16 0.517|  | 6/1.058 7/0.938/
 65|  | 1 3.72|0.00/ 1 1.282|15.4/16 0.521|  | 6/1.084 7/0.964/
 70|  | 1 4.00|0.00/ 1 1.282|16.5/16 0.526|  | 6/1.108 7/0.989/
 75|  | 1 4.28|0.00/ 1 1.282|17.5/16 0.531|  | 6/1.130 7/1.011/
 80|  | 1 4.57|0.00/ 1 1.282|18.4/16 0.535|  | 6/1.150 7/1.033/
 85|  | 1 4.85|0.00/ 1 1.282|19.3/16 0.540|  | 6/1.168 7/1.053/
 90|  | 1 5.13|0.00/ 1 1.282|20.1/16 0.544|  | 6/1.184 7/1.072/

15  NULLZEIT=  77.2 min (inkl. Abstiegszeit= 0.75 min) / Kompartiment= 6, PTIG[1] = 1.307 bar

 30|  | 2 2.02|0.00/ 1 1.457| 9.0/14 0.519|      | 4/1.212 5/1.064/
 35|  | 2 2.35|0.00/ 1 1.460|10.4/15 0.513|      | 4/1.272 5/1.126/
 40|  | 2 2.68|0.00/ 1 1.461|11.9/15 0.521|      | 4/1.323 5/1.180/
 45|  | 2 3.01|0.00/ 1 1.462|13.4/16 0.514|      | 4/1.364 5/1.228/
 50|  | 2 3.34|0.00/ 1 1.462|14.9/16 0.520|      | 4/1.399 5/1.270/
 55|  | 2 3.67|0.00/ 1 1.462|16.3/16 0.526|      | 4/1.427 5/1.307/
 60|  | 2 3.99|0.00/ 1 1.462|17.6/16 0.531|      | 5/1.339 6/1.206/
 65|  | 2 4.32|0.00/ 1 1.462|18.8/16 0.537|      | 6/1.238 7/1.090/
 70|  | 2 4.65|0.03/ 6 1.268|19.9/16 0.543|      | 6/1.268 7/1.120/
 75|  | 2 4.98|0.06/ 6 1.295|20.9/16 0.549|      | 6/1.295 7/1.149/
 80| 2| 4 5.36|0.06/ 6 1.298|21.8/16 0.555|  6/6 | 6/1.298 7/1.163/
 85| 4| 6 5.74|0.06/ 6 1.295|22.7/16 0.560|  6/6 | 6/1.295 7/1.173/
 90| 5| 7 6.10|0.06/ 6 1.301|23.6/16 0.566|  6/6 | 6/1.301 7/1.188/

18 15 NULLZEIT=  47.5 min (inkl. Abstiegszeit= 0.90 min) / Kompartiment= 4, PTIG[1] = 1.561 bar
   20
   25
 30|  | 2 2.31|0.00/ 1 1.627|10.8/15 0.515|      | 3/1.519 4/1.358/
 35|  | 2 2.68|0.00/ 1 1.631|12.6/15 0.524|      | 4/1.431 5/1.257/
 40|  | 2 3.06|0.00/ 1 1.632|14.4/16 0.518|      | 4/1.490 5/1.322/
 45|  | 2 3.43|0.02/ 4 1.540|16.1/16 0.525|      | 4/1.540 5/1.379/
 50| 1| 3 3.83|0.02/ 4 1.553|17.7/16 0.532|  4/4 | 4/1.553 5/1.413/
 55| 2| 4 4.23|0.05/ 6 1.289|19.1/16 0.539|  4/4 | 5/1.434 6/1.289/
 60| 4| 6 4.66|0.07/ 6 1.304|20.4/16 0.546|  4/6 | 6/1.304 7/1.151/

21  NULLZEIT=  33.3 min (inkl. Abstiegszeit= 1.05 min) / Kompartiment= 4, PTIG[1] = 1.561 bar

  9|  | 2 0.83|0.00/ 1 1.540| 3.9/11 0.514|  |16/0.475
 12|  | 2 1.09|0.00/ 1 1.644| 5.2/12 0.515|  | 2/1.425 3/1.213/
```

First version of table; calculated for exact altitude (3800m); fully adapted; without safety margins for depth

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Lake Titicaca Trials; Bolivia, 3800m a.s.l. (3)

No-decompression limits

UEBERSICHTSTABELLE ZU DEN NULLZEITEN / STATISTIK

TIEFE [m]	SICHERHEIT [m]	TOTAL-DRUCK [bar]	ALVEOL. N2-DRUCK [bar]	ALVEOL. HE-DRUCK [min]	ABSTIEG ZEIT [min]	EXAKT. NULLZEIT [min]	ABGER. NULLZEIT [min]	KOMP. INDEX [-]	ANZAHL PROFILE [-]
9	0.00	1.495	1.142	0.000	0.45	457.3	457	10	7
12	0.00	1.784	1.370	0.000	0.60	146.5	146	7	7
15	0.00	2.072	1.598	0.000	0.75	77.2	77	6	13
18	0.00	2.361	1.826	0.000	0.90	47.5	47	4	7
21	0.00	2.649	2.054	0.000	1.05	33.3	33	4	18
24	0.00	2.937	2.282	0.000	1.20	24.2	24	3	18
27	0.00	3.226	2.509	0.000	1.35	19.3	19	3	13
30	0.00	3.514	2.737	0.000	1.50	15.3	15	2	14
33	0.00	3.803	2.965	0.000	1.65	12.7	12	2	14
36	0.00	4.091	3.193	0.000	1.80	10.9	10	2	14
39	0.00	4.380	3.421	0.000	1.95	9.6	9	2	9
42	0.00	4.668	3.649	0.000	2.10	8.5	8	2	10
45	0.00	4.956	3.876	0.000	2.25	7.6	7	2	10

First version of NDL-table; calculated for exact altitude (3800m); fully adapted; without safety margins for depth; v_Dsct=20m/min

Lake Titicaca Trials; Bolivia, 3800m a.s.l. (4)

16.1.87 Dekompressionstabellen 2501 - 4500 müM. ZH-L_{16} Version B Berechnungen von "Hand", ergänzt mit dem Computer, B. Müller.
P amb. 0.577 bar, PIN_2 0.406 bar, PN_2 t. t0 0.416 bar (adaptiert).

Tiefe m	Zeit min	12	9	6	4	2	RG
9	204					1	G
12	88					1	G
	100					5	G
	110					9	G
	120					13	G
15	50					1	E
	60					2	F
	70					8	G
	80					14	G
	90					20	G
18	32					1	D
	40					3	F
	50					7	F
	60				1	13	G
	70				3	17	G
21	22					1	D
	30					3	E
	35					6	F
	40				1	7	F
	45				3	10	F
	50				4	13	G
	55				6	15	G
	60				8	18	G
24	16					1	D
	25					4	E
	30				1	6	F
	35				3	8	F
	40				5	12	F
	45			1	6	15	F
	50			3	7	18	G
27	14					1	D
	20					4	E
	25				2	6	E
	30				5	7	F
	35			2	5	12	F
	40			4	6	15	G
30	11					1	D
	15					3	D
	20				2	5	E
	25			1	4	7	F
	30			3	5	11	F
	35		1	4	7	15	G
33	9					1	D
	12					2	D
	15				1	4	E
	18				3	5	F
	21			1	4	6	F
	24			3	5	7	F
	27		1	3	6	11	G

Tiefe m	Zeit min	12	9	6	4	2	RG
36	8					1	D
	12				1	3	D
	15				3	4	E
	18			1	4	6	F
	21			3	5	7	F
	24		1	4	6	11	F
	27		3	4	7	14	G
39	7					1	D
	12				2	4	E
	15			1	4	5	E
	18		1	2	5	6	F
	21		2	3	6	10	F
	24		3	5	6	14	G
42	7					1	D
	9				1	3	E
	12			1	3	4	E
	15		1	2	4	6	F
	18		2	3	5	9	F
	21		4	4	6	13	F
	24	1	5	5	8	16	G
45	6					1	C
	9				2	3	E
	12			2	3	5	F
	15		2	3	4	7	F
	18		3	4	6	11	F
	21	1	5	5	7	15	G
48	6					1	C
	9			1	2	4	E
	12		1	2	4	6	F
	15		3	3	5	9	F
	18	1	4	5	6	14	G
51	5					1	C
	9			2	2	5	E
	12		2	3	4	6	F
	15	1	3	4	6	11	F
	18	2	5	5	7	16	G
54	6				1	2	E
	9		1	2	3	5	F
	12		3	3	5	7	F
	15	2	4	5	6	13	G

A.A. Bühlmann

Final table, calculated for up to 4500m (reason was also a probable evacuation flight with helicopter).

Parameters:
- ZHL-16B
- Fully adapted
- Upper altitude limit: 4500m a.s.l.
- Added safety margins for depth
- descent rate of 20m/min
- ascent rate of 10m/min

Lake Titicaca; Bolivia, 3800m a.s.l. (5)

Statement of the then British Ambassador in Bolivia at the arrival at La Paz airport:

„Gentlemen, whatever happens, stay British!“

To save the honor of Switzerland, it must be said that the Swiss Embassador also gave a farewell party to the expedition team.

Lake Titicaca; Bolivia, 3800m a.s.l. (6a)

EX PADDINGTON DIAMOND
TEAM MEMBERS

A Goodwin *Boats* — M V Ince *Asst Admin* — M Strickland *Diving Officer* — F Walker *Trg Officer*

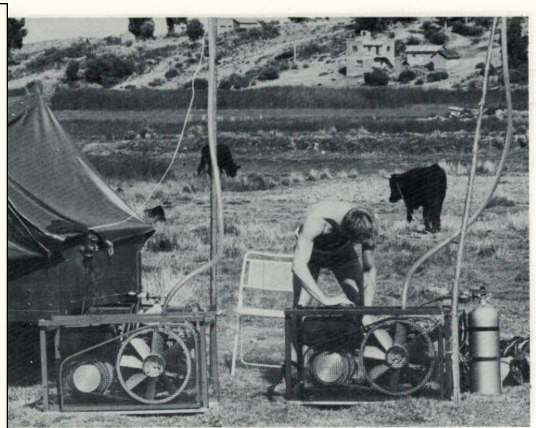
M Moody *Expedition Leader* — J Beatty *Equipments* — D Laut *PR* — R Wilde *Catering* — D Morgan - Jones *Medical Officer* — M Duffin *Stores*

P Rheiner *Medical Advisor* — W Keusen *Tech Advisor* — R Dally *Asst Eqpts* — A Hayes *Admin Officer*

Final comparison prior to the dive.

Local ladies

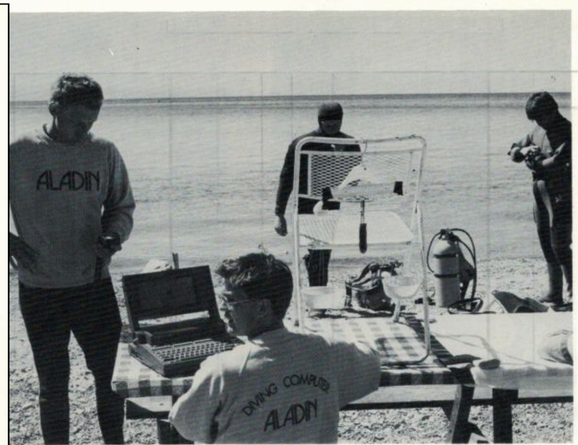
40



ompressor maintenance was a continuous operation, starting first thing in the morning was ometimes difficult.

Capt Strickland and Cpl Beatty our two mechanics

44



All the information was input into the latest desktop computer kindly loaned by 'WANG'.

Routine blood pressure tests.

45

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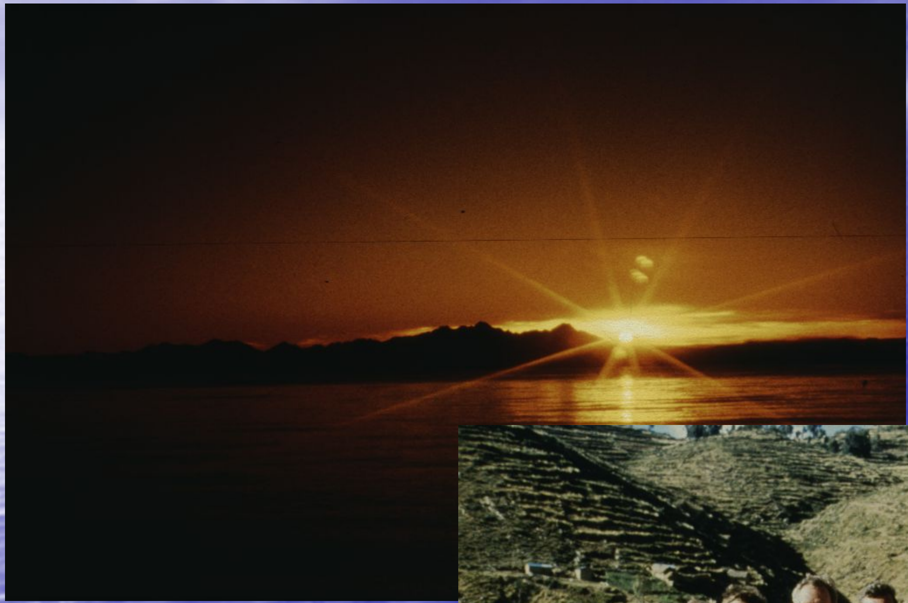
Lake Titicaca; Bolivia, 3800m a.s.l. (6b)



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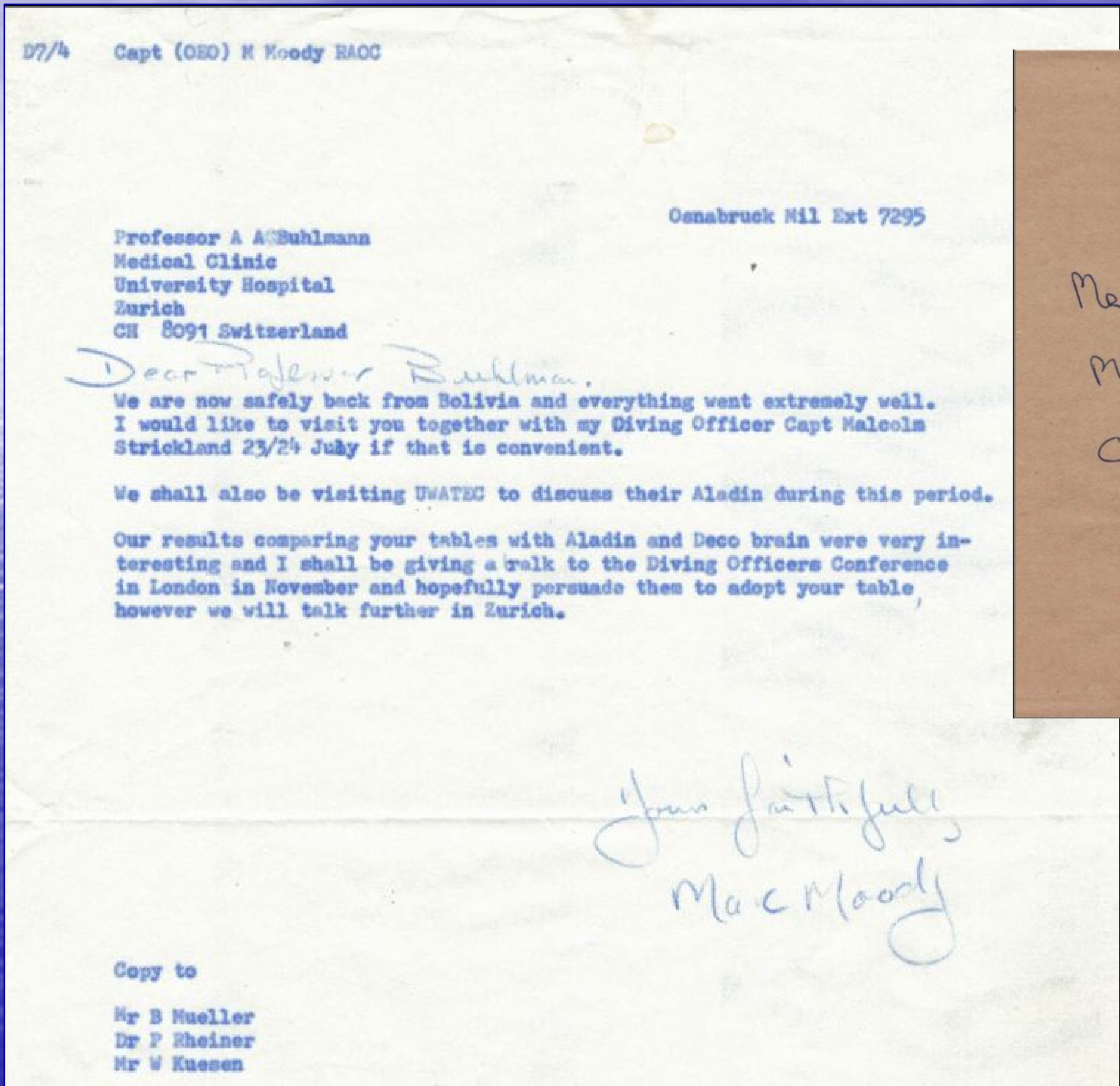
Lake Titicaca; Bolivia, 3800m a.s.l. (7)



D7/4 Capt (OEO) M Moody RAOC

Osnabruck Mil Ext 7295

Professor A A Buhlmann
Medical Clinic
University Hospital
Zurich
CH 8091 Switzerland

Dear Professor Buhlmann,

We are now safely back from Bolivia and everything went extremely well. I would like to visit you together with my Diving Officer Capt Malcolm Strickland 23/24 July if that is convenient.

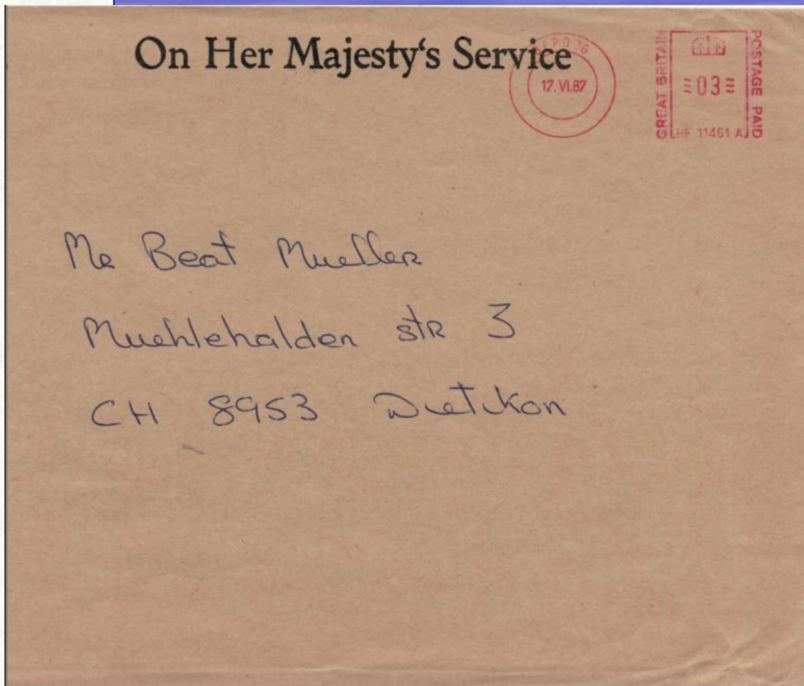
We shall also be visiting UWATEC to discuss their Aladin during this period.

Our results comparing your tables with Aladin and Deco brain were very interesting and I shall be giving a talk to the Diving Officers Conference in London in November and hopefully persuade them to adopt your table, however we will talk further in Zurich.

Yours faithfully
Mac Moody

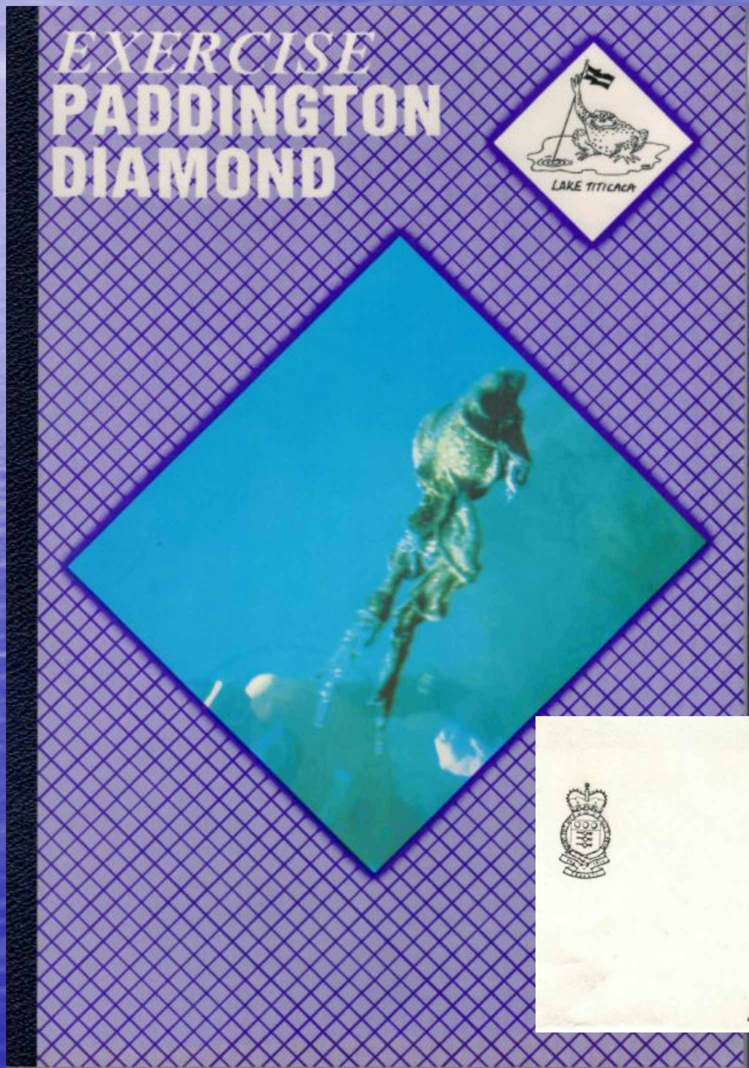
Copy to

Mr B Mueller
Dr P Rheiner
Mr W Kuesen

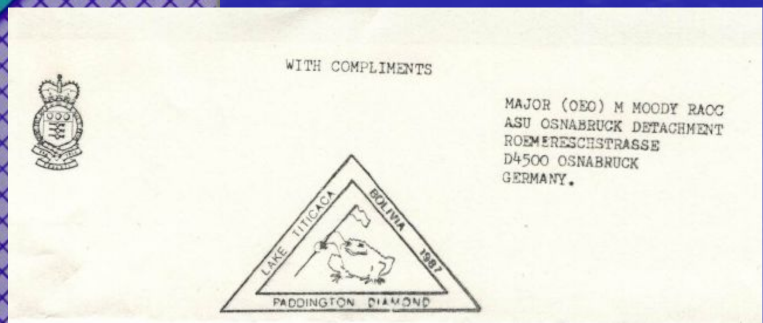


Safely back home!

Lake Titicaca; Bolivia, 3800m a.s.l. (8)



Report: 78 pages,
3 weeks, 17 divers, 290 dives,
5-39m, BT=11-52min



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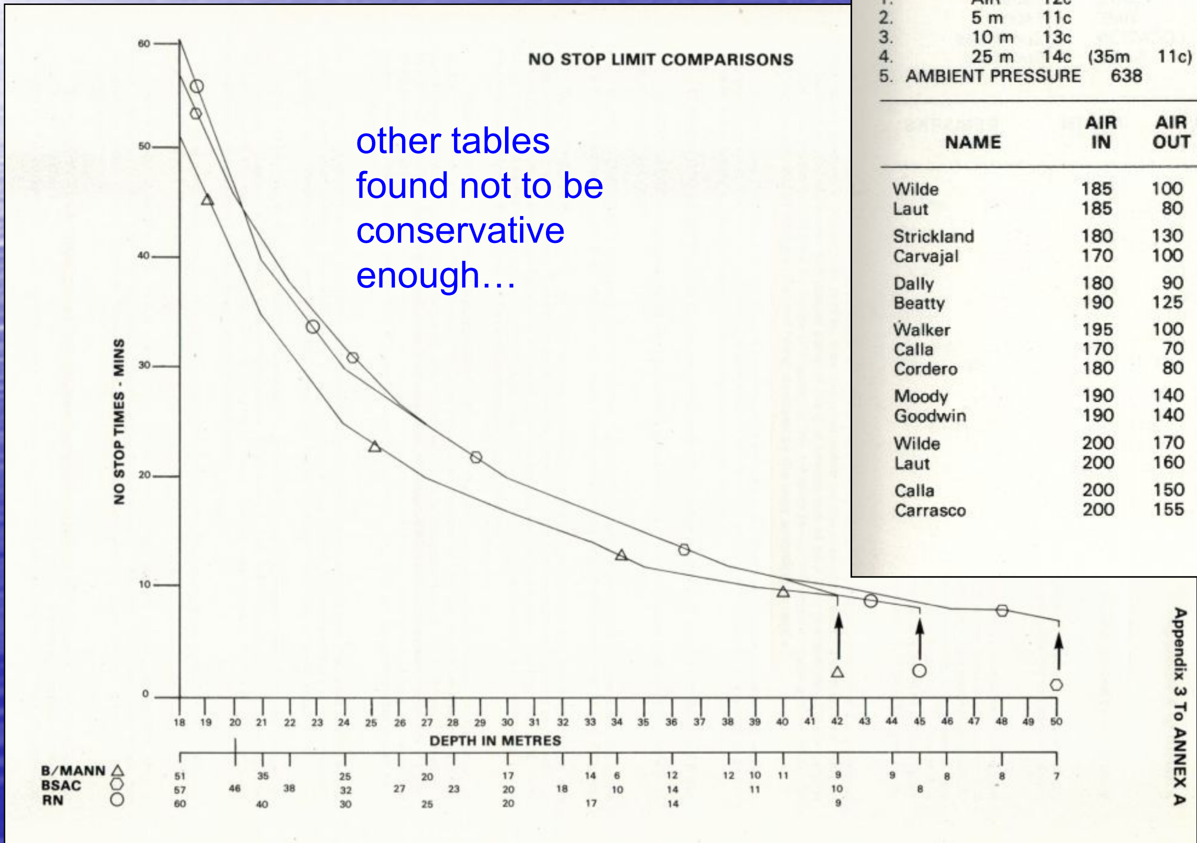
Lake Titicaca; Bolivia, 3800m a.s.l. (9)



other tables found not to be conservative enough…

SHEET No. 20

SCIENTIFIC STUDIES & EXPLORATION GROUP 1987

REFERENCE **EXERCISE PADDINGTON DIAMOND**

TEMPERATURE

1. AIR 12c
2. 5 m 11c
3. 10 m 13c
4. 25 m 14c (35m 11c)
5. AMBIENT PRESSURE 638

DATE. 250587
TIME. 0900
LOCATION. Camp Bay
SADS. Strickland

NAME	AIR IN	AIR OUT	TIME IN	TIME OUT	TOTAL TIME	DEPTH	REMARKS
Wilde	185	100	0912	0926	14	35.3	Deco 9.38
Laut	185	80					Sur 82mins
Strickland	180	130	0928	0943	15	35.7	Deco 8.18
Carvajal	170	100					Sur 63mins
Dally	180	90	0952	1004	12	36.7	Deco 8.10
Beatty	190	125					Sur 63mins
Walker	195	100	1009	1021	12	36	Deco 8.47
Calla	170	70					Sur 77mins
Cordero	180	80					
Moody	190	140	1013	1037	24	4.3	Filming
Goodwin	190	140					
Wilde	200	170	1200	1210	10	4	Frog hunting
Laut	200	160					
Calla	200	150	1200	1210	10	4	Frog hunting
Carrasco	200	155					

could that be a secret tactic of the British army?

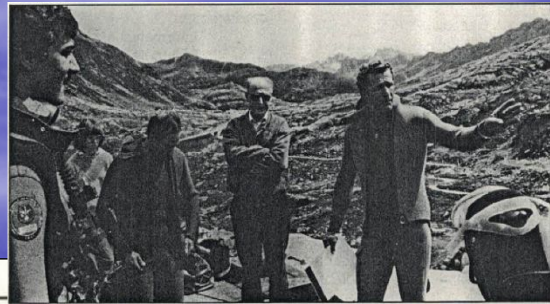
→ results further down

Lago di Lucendro Trials (1984-88)

Lago di Lucendro Trials (1)

Lago di Lucendro; Gotthard, 2134m a.s.l.; 23.8.1986 (1)

Lago di Lucendro Trials (2)



Gruppe Groupe	Name Nom	Vorname Prénom	Jahrgang Année	Tauchtiefe Profondeur	descent Abstieg	G'zeit Temps de séjour *	Zeitzuschlag Adjonction de temps	actually performed Dekompression Décompression (durchgeführt) 6 m	4 m	2 m	Bü Tab 83 (intermediate) 6 m	4 m	2 m	Bü Tab 76 (old) 10 m	7 m	4 m	2 m
1	Stettler	Roger	1946	30 m	4'	16'	–	4'	5'	9'			4'		3'	7'	10'
	Looser	Heinz	1950	29 m	4'	16'	–	4'	5'	9'			4'		3'	7'	10'
	Ziegler	Jürg	1950	29 m	4'	16'	–	4'	5'	9'			4'		3'	7'	10'
2	Ronzani	Aldo	1965	33 m	2'	18'	–			1'		2'	5'	2'	6'	7'	15'
	Pollini	Mauro	1954	33 m	2'	18'	–			1'		2'	5'	2'	6'	7'	15'
	Karlen	Silvio	1954	33 m	2'	18'	–			–		2'	5'	2'	6'	7'	15'
3	Looser	Vinka	1952	36 m	3'	16'	–			2'		4'	6'	4'	7'	8'	17'
	Bühler	Armin	1956	36 m	3'	16'	–			2'		4'	6'	4'	7'	8'	17'
	Keller	Peter	1944	36 m	3'	16'	–			4'		4'	6'	4'	7'	8'	17'
4	Hüsler	Gerda	1953	37 m	3'	15'	–			4'		2'	4'	3'	5'	6'	13'
	Götte	Georg	1950	36 m	2'	15'	–			4'			4'	3'	5'	6'	13'
	Baer	Marcel	1943	35 m	3'	15'	–			5'			4'		4'	5'	13'
5	Weber	Christoph	1968	32 m	3'	15'	–			1'			3'		4'	5'	13'
	Wohlgemuth	Hans-Jörg	1952	32 m	3'	15'	–			1'			3'		4'	5'	13'
Intervalltauchgang: Oberflächenpause 60 min. / **Plongée successive:** intervalle de surface 60 min.																	
6	Weber	Christoph		32 m	2'	15'	9'/9'			1'	1'	4'	9'	3'	8'	9'	24'
	Wohlgemuth	Hans-Jörg		32 m	2'	15'	9'			1'	1'	4'	9'	3'	8'	9'	24'

* Grundzeit **inkl.** Abstiegszeit, d. h. die Gruppe 1 tauchte in 4 min auf 29–30 m ab und blieb dort 12 min. Die Gruppen 2 bis 5 orientieren sich am Decobrain oder an der provisorischen neuen Tabelle 701–2500 m ü. M.

2 days, 14 divers, 16 dives, 29-37m, BT=15-18min
(from 1984-88: 50-60 divers, 55-60 dives)

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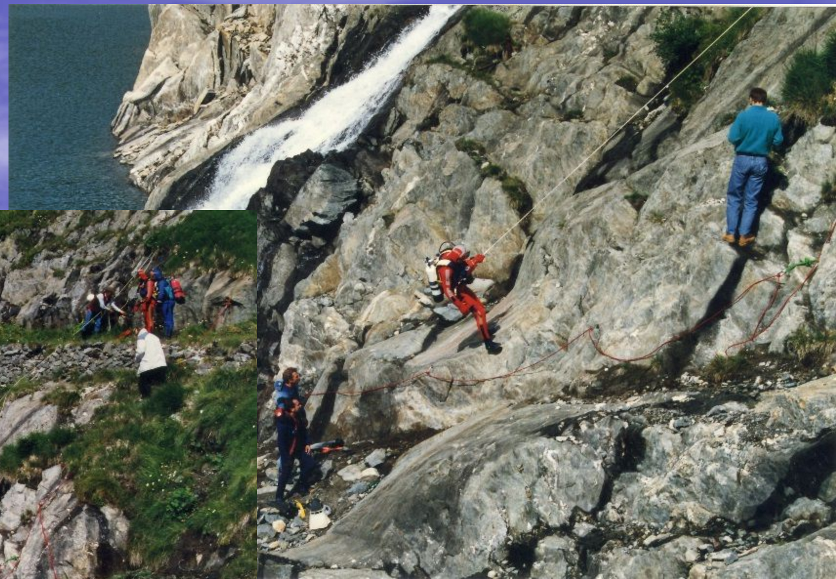
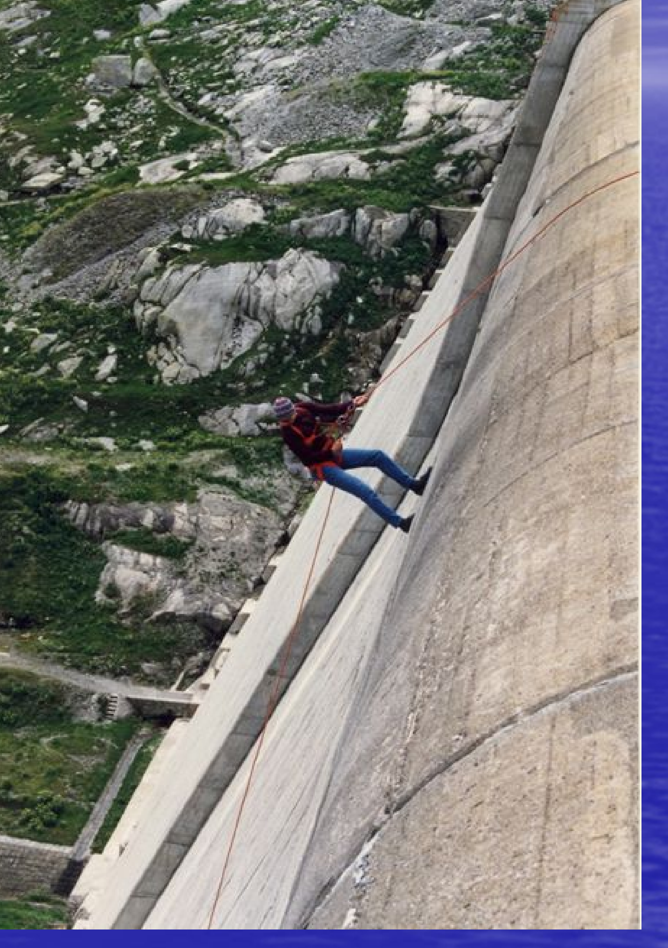
Lago di Lucendro Trials (3a)



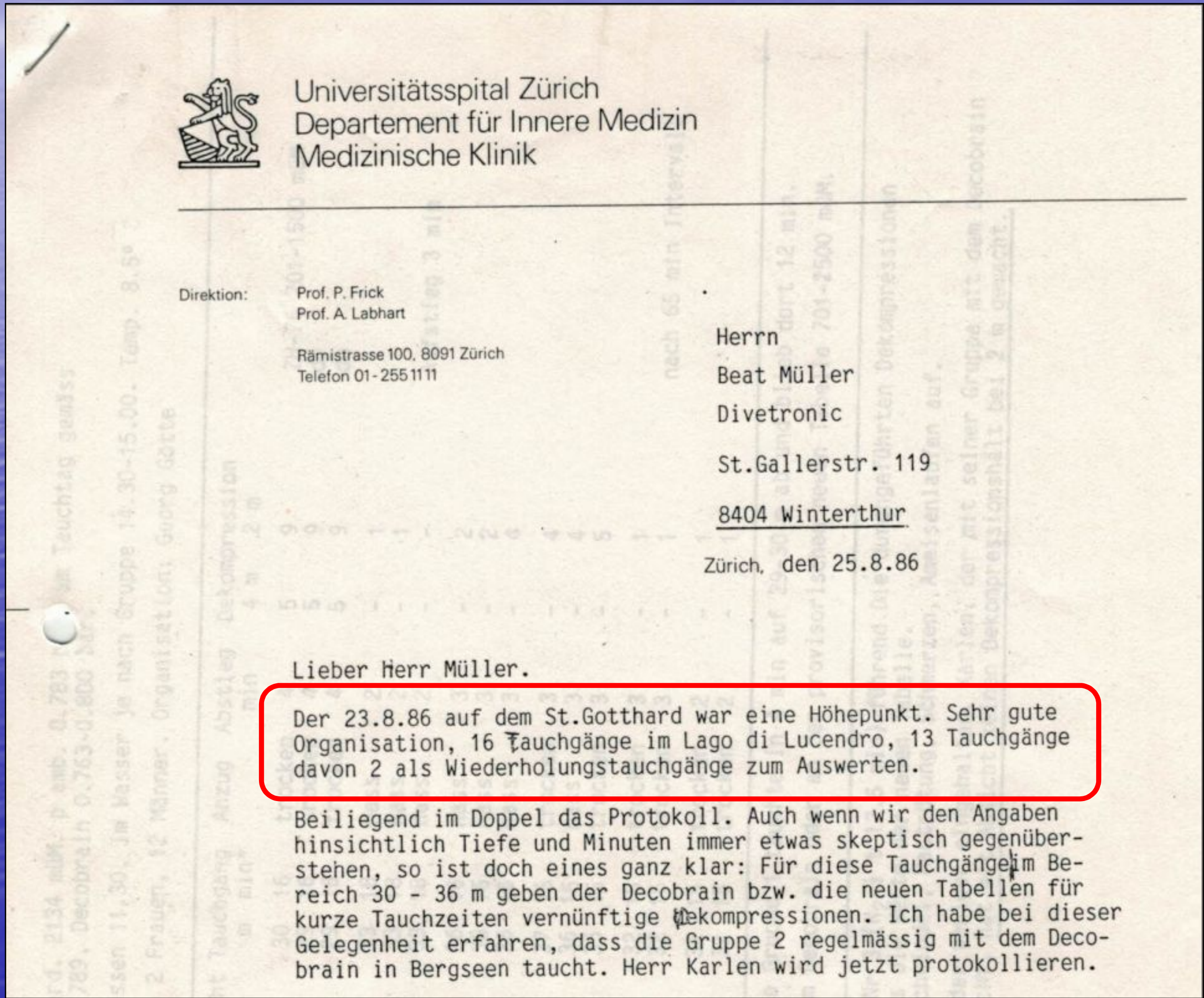
…a bit of adventure….

Lago di Lucendro Trials (3b)



The very best always comes at the end!

Lago di Lucendro Trials (4)



Universitätsspital Zürich
Departement für Innere Medizin
Medizinische Klinik

Direktion: Prof. P. Frick
Prof. A. Labhart

Rämistrasse 100, 8091 Zürich
Telefon 01-255 11 11

Herrn
Beat Müller
Divetronic
St.Gallerstr. 119
8404 Winterthur

Zürich, den 25.8.86

Lieber Herr Müller.

Der 23.8.86 auf dem St.Gotthard war eine Höhepunkt. Sehr gute Organisation, 16 Tauchgänge im Lago di Lucendro, 13 Tauchgänge davon 2 als Wiederholungstauchgänge zum Auswerten.

Beiliegend im Doppel das Protokoll. Auch wenn wir den Angaben hinsichtlich Tiefe und Minuten immer etwas skeptisch gegenüberstehen, so ist doch eines ganz klar: Für diese Tauchgänge im Bereich 30 - 36 m geben der Decobrain bzw. die neuen Tabellen für kurze Tauchzeiten vernünftige Dekompressionen. Ich habe bei dieser Gelegenheit erfahren, dass die Gruppe 2 regelmässig mit dem Decobrain in Bergseen taucht. Herr Karlen wird jetzt protokollieren.

Muttsee Trials (1988)

Muttsee Trials (1)

First reconnoiter dives (August); 2500m a.s.l.; 1988

…still the highest dives ever made in the Alpes!

(left to right: E. Völlm, B. Müller, E. Lochbronner at preliminary dives Muttsee, 1988)

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Muttsee Trials (2)

KURZBERICHT ZUM

R E K O G N O S Z I E R U N G S - TG

I M M U T T S E E (2500m) V O M 27.8.88

VERTEILER: - Prof.Dr.A.A.Buehlmann
- alle Teilnehmer
- G.Goette (Mitorganisator)

4. Verwendete Tabellen u. Computer

- mehrere Saetze von speziellen Tauchtabellen, mit folgenden Merkmalen:
  * Beruecksichtigung der Anflugsrampe
  * Beruecksichtigung verschieden langer Adaptionszeiten
  * Beruecksichtigung des Oberfl.-Luftdrucks gem. ISO
  * Einbezug einer Abstiegsrampe von 10m/min. beim TG
  * Einbezug einer Aufstiegsrampe von 10m/min. beim TG
  * hydrostat. Wasserdruck von Suesswasser
  * KEIN Tiefenzuschlag
  * Koeffizientensaetze ZHL-12 und ZHL-16; die jeweils "kuerzeren" Tabellen wurden effektiv eingesetzt
- Tauchcomputer Deko-Brain, Prog. P2-2
- Tauchcomputer ALADIN PRO, ZHL-6 (Versuchsmodelle)
- Tauchtabellen '86, 701-2500m (zur Kontr.)

6. Uebersicht der Tauchgaenge

Adapt.	Rep.TG?	Int'v.	Pers.	Profil	eff.Deko
0:45'	Nein	--	2	39m / 15'	4m/2.5' + 2m/5.5'
1:06'	Nein	--	1	39m / 21'	4m/2' + 2m/4'
4:50'	Ja	3:35'	2	33m / 18'	4m/2' + 2m/4'
4:50'	Ja	3:12'	1	33m / 18'	----- 2m/2'

Die exakten Profildaten, sowie weiteren wichtigen Randbedingungen, wie Luft- und Wassertemperaturen, verwendete Anzuege, Anfahrtsrampen, Luftdruecke etc., sind den TG-Protokollen zu entnehmen.

Wie erwartet, traten bei keinem der Taucher irgendwelche Symptome einer inadequaten Dekompression auf.

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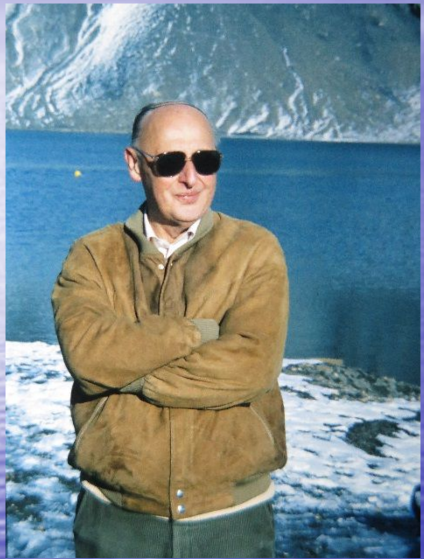
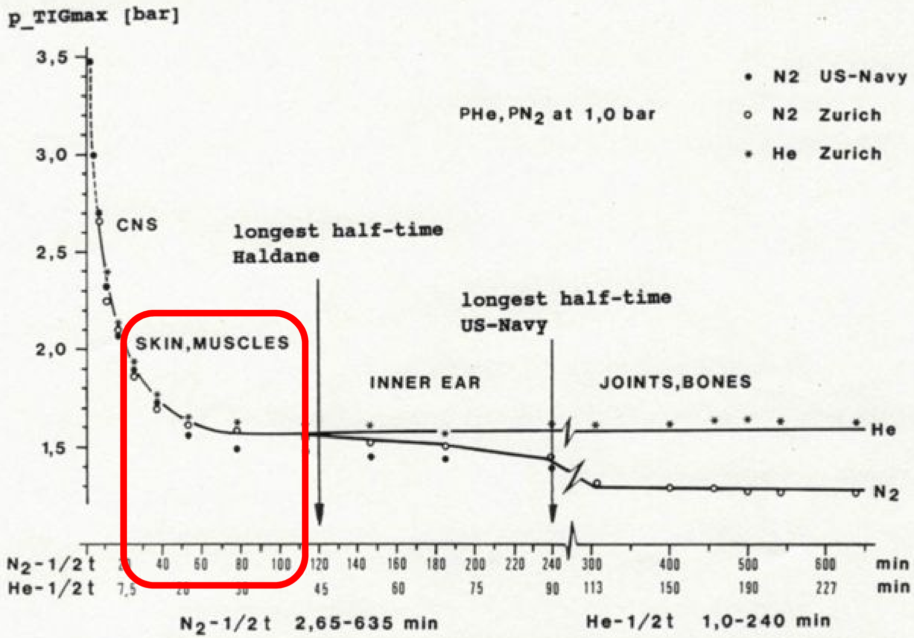
Muttsee Trials (3)



3.3 Tissue Tolerances (max. tissue pressures) at fixed ambient pressure

$$p\_TN2max = \frac{p\_amb.}{b} + a$$



Tolerated pressure of inert gas at an ambient pressure of 1.0 bar as a function of the half-value times for nitrogen and helium. •PN_2 calculated in correspondence with the tables of the US Navy; °PN_2 and *PHe determined experimentally in Zurich.

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Muttsee Trials (4)

Administrative / Logistics documentation

MUTTSEE-TAUCHEN VOM 21.-23.10.88

(Zuordnung d. Profilkombinationen)

TG1 (Erst.-Tauchgänge)				Intervall	TG2 (Rep.-Tauchgänge)					
#	Anz.	Profil (Tiefe/Zeit)	Namen d. Taucher		#	Anz	ZZ#	EFFEK. GZ	Profil (Tiefe/Zeit)	Namen d. Taucher
1a	1	33/21	Zanker	254	19	1	5	13	45/18	Zanker
1b	2	33/21	Wirth♀/Götte	239	20	2	5	13	45/18	♀Wirth/Götte
2.	2	39/18	♀Unold/Brügger	246	17	2	5	10	42/15	♀Unold/Brügger
3	2	42/18	Müller/Müller ♀	246	21	2	5	10	48/15	Müller/Müller♀
4	1	45/12	Denoth	—	—	—	—	—	—	—
5	2	45/15	Schifferle/Dürst	246	15	2	6	12	39/18	Schifferle/Dürst
6	2	45/15	♀Unold/Brügger	213	16	2	6	12	39/18	♀Unold/Brügger
7	2	45/18	Holliger/Flury	277	18	2	5	13	42/18	Holliger/Flury
8	2	45/18	♀Wirth/Götte	—	—	—	—	—	—	—
9	2	51/15	Müller/Müller♀	202	22	2	4	8	57/12	Müller/Müller♀
10	2	57/12	Rauber/Caprez	210	24	2	4	11	60/15	Rauber/Caprez
11	2	60/15	Rauber/Caprez	180	23	2	4	8	60/12	Rauber/Caprez
12*	2	39/25*	Denoth/Zanker	103	25*	1	[1]	25	33/[26]*	Denoth
13*	2	39/25*	Schifferle/Dürst	117	26*	2	[1]	25	33/[26]*	Schifferle/Dürst
14*	2	39/25*	Holliger/Flury	99	27*	2	[1]	25	33/[26]*	Holliger/Flury

Total: 28

* mit ZHL-16A berechnet
(Rest: ZHL-12 / T86 Spez.)

Total: 24

zu #25-27: Deko war direkt vorberechnet
(entspricht ~ 33m/27'
" ~ 33m/26')

gem. Tab.'86

Bergseetauchen "Muttsee"
vom 21.10.88 bis 23.10.88

Notfalldispositiv	Blatt 1

1) Was tun?

1. Sofortige Bergung aus dem Wasser
2. LESOMA unter Verwendung der Notfall-Koffern, O_2
3. bei Verdacht auf arterielle Gasembolie:
   telefonische Verständigung REGA von der Muttseehütte aus (2 Meldeläufer) und falls Funkgerät vorhanden: Hüttenwart zusätzlich anfunken (HECTOR UNO)
4. Lagerung des Verunfallten, Witterungsschutz
5. Landestelle Helikopter (ø 30m) räumen von ALLEM Material

2) Standort Notfallkoffer:

a) während Tauchen: bei Kompressoren am See
b) sonst : Muttseehütte, Aufenthaltsraum
c) währendHeli-Flug: No 1 im Helikopter
(2.Tag) " 2 am See

Telefonnummern:

- REGA 01/ 47 47 47
- Heli-Linth/ Mollis 058/ 34 30 85
- Druckkammer-labor/ZH 01/255 20 36
- Kraftwerke Linth-Limmern/ Tierfehd 058/ 84 31 67 (Hr.O. Bächtiger, H. Müller, H. Zweifel)

Standort Funkgeräte

a) während Tauchen: in der Hütte: HECTOR UNO
am See : HECTOR DUE
b) sonst : Muttseehütte, Aufenthaltsraum
c) während Heliflug: 1 bei übrigen Teilnehmern: HECTOR UNO
(2.Tag) 1 im Heli : HECTOR DUE

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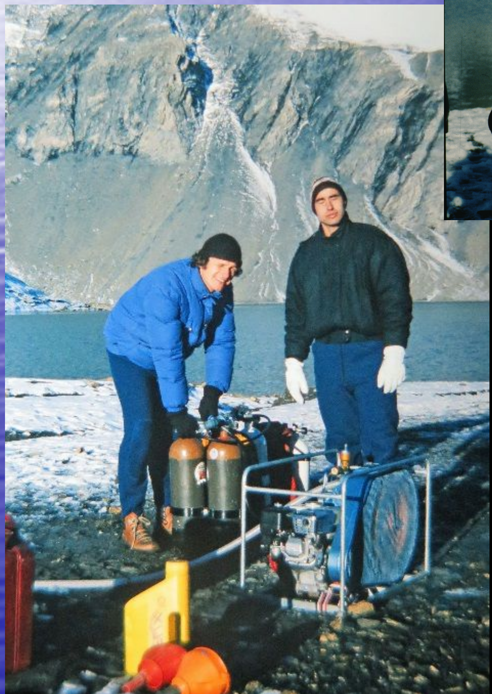
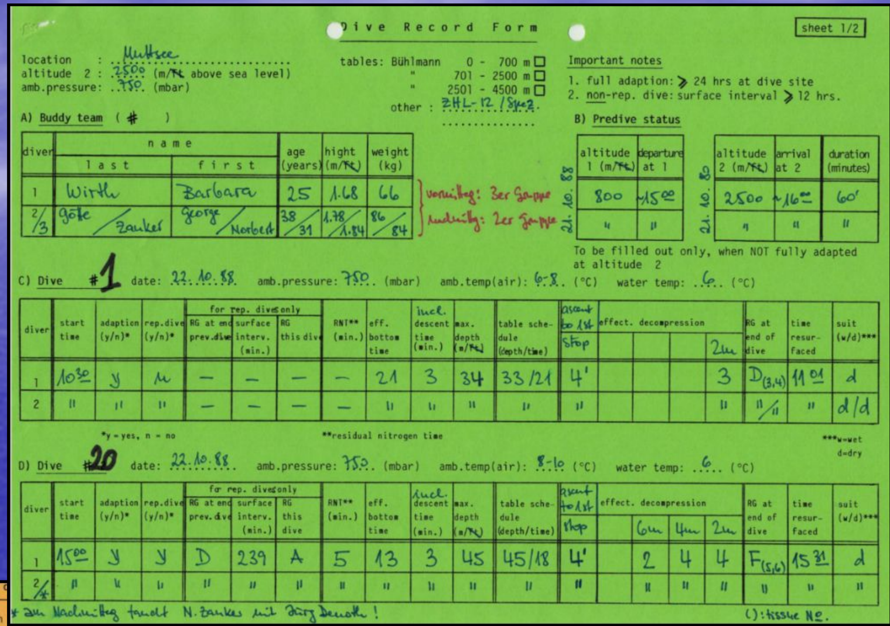
Muttsee Trials (5)

Dive Logs




Dive Record Form — sheet 1/2

location : Muttsee
altitude 2 : 2500 (m/ft above sea level)
amb.pressure: 750 (mbar)

tables: Bühlmann 0 - 700 m / 701 - 2500 m / 2501 - 4500 m / other : ZHL-12 / Sp.2

Important notes
1. full adaption: > 24 hrs at dive site
2. non-rep. dive: surface interval > 12 hrs.

A) Buddy team (#)

diver	last	first	age (years)	hight (m/ft)	weight (kg)
1	Wirth	Barbara	25	1.68	66
2/3	Göte / Zauker	George / Norbert	38 / 31	1.78 / 1.84	86 / 84

B) Predive status

	altitude 1 (m/ft)	departure at 1	altitude 2 (m/ft)	arrival at 2	duration (minutes)
21.10.88	800	15⁰⁰	2500	16⁰⁰	60'
	"	"	"	"	"

To be filled out only, when NOT fully adapted at altitude 2

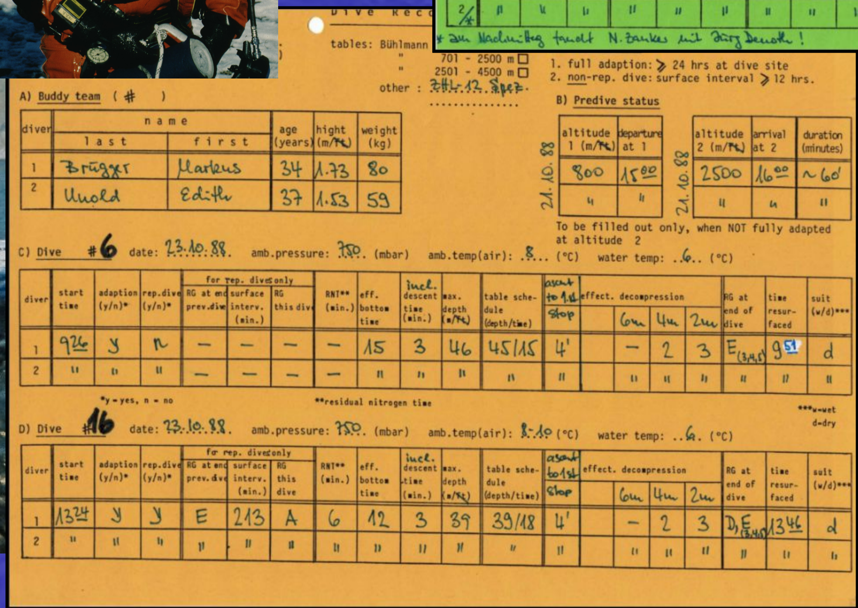
C) Dive #1 date: 22.10.88 amb.pressure: 750 (mbar) amb.temp(air): 6-8 (°C) water temp: 6 (°C)

diver	start time	adaption (y/n)*	rep.dive (y/n)*	RG at end prev.dive	surface interv. (min.)	RG this dive	RNT** (min.)	eff. bottom time	incl. descent time (min.)	max. depth (m/ft)	table schedule (depth/time)	ascent to 1st stop	6m	4m	2m	RG at end of dive	time resurfaced	suit (w/d)***
1	10³⁰	y	n	—	—	—	—	21	3	34	33/21	4'			3	D	11⁰¹	d
2	"	"	"	—	—	—	—	"	"	"	"	"			"	"	"	d/d

*y=yes, n=no **residual nitrogen time ***w=wet d=dry

D) Dive #20 date: 22.10.88 amb.pressure: 750 (mbar) amb.temp(air): 8-10 (°C) water temp: 6 (°C)

diver	start time	adaption (y/n)*	rep.dive (y/n)*	RG at end prev.dive	surface interv. (min.)	RG this dive	RNT** (min.)	eff. bottom time	incl. descent time (min.)	max. depth (m/ft)	table schedule (depth/time)	ascent to 1st stop	6m	4m	2m	RG at end of dive	time resurfaced	suit (w/d)***
1	15⁰⁰	y	y	D	239	A	5	13	3	45	45/18	4'	2	4	4	F	15³¹	d
2/3	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"


Dive Record Form

tables: Bühlmann 701 - 2500 m / 2501 - 4500 m / other : ZHL-12 Sp.2

1. full adaption: > 24 hrs at dive site
2. non-rep. dive: surface interval > 12 hrs.

A) Buddy team (#)

diver	last	first	age (years)	hight (m/ft)	weight (kg)
1	Brügger	Markus	34	1.73	80
2	Unold	Edith	37	1.53	59

B) Predive status

	altitude 1 (m/ft)	departure at 1	altitude 2 (m/ft)	arrival at 2	duration (minutes)
21.10.88	800	15⁰⁰	2500	16⁰⁰	~60'
	"	"	"	"	"

To be filled out only, when NOT fully adapted at altitude 2

C) Dive #6 date: 23.10.88 amb.pressure: 750 (mbar) amb.temp(air): 8 (°C) water temp: 6 (°C)

diver	start time	adaption (y/n)*	rep.dive (y/n)*	RG at end prev.dive	surface interv. (min.)	RG this dive	RNT** (min.)	eff. bottom time	incl. descent time (min.)	max. depth (m/ft)	table schedule (depth/time)	ascent to 1st stop	6m	4m	2m	RG at end of dive	time resurfaced	suit (w/d)***
1	9²⁶	y	n	—	—	—	—	15	3	46	45/15	4'	—	2	3	E	9⁵¹	d
2	"	"	"	—	—	—	—	"	"	"	"	"	"	"	"	"	"	"

*y=yes, n=no **residual nitrogen time ***w=wet d=dry

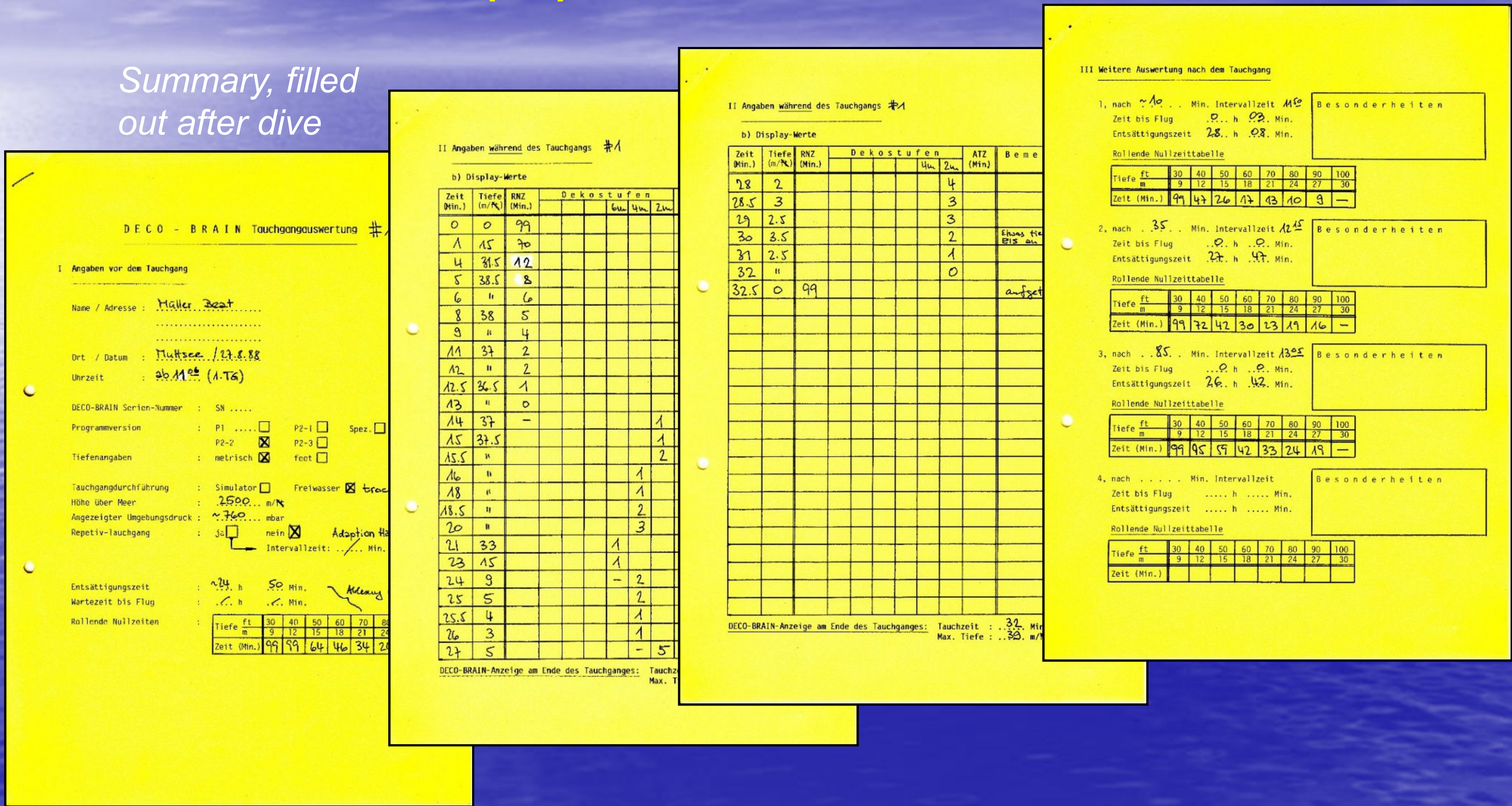
D) Dive #16 date: 23.10.88 amb.pressure: 750 (mbar) amb.temp(air): 8-10 (°C) water temp: 6 (°C)

diver	start time	adaption (y/n)*	rep.dive (y/n)*	RG at end prev.dive	surface interv. (min.)	RG this dive	RNT** (min.)	eff. bottom time	incl. descent time (min.)	max. depth (m/ft)	table schedule (depth/time)	ascent to 1st stop	6m	4m	2m	RG at end of dive	time resurfaced	suit (w/d)***
1	13²⁴	y	y	E	213	A	6	12	3	39	39/18	4'	—	2	3	D	13⁴⁶	d
2	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"

2 days
15 divers
52 (56 dives)
28 first dives
24 repet. dives
depths= 24-58m
BT=12-25min
4 symptoms

Muttsee Trials (6a)

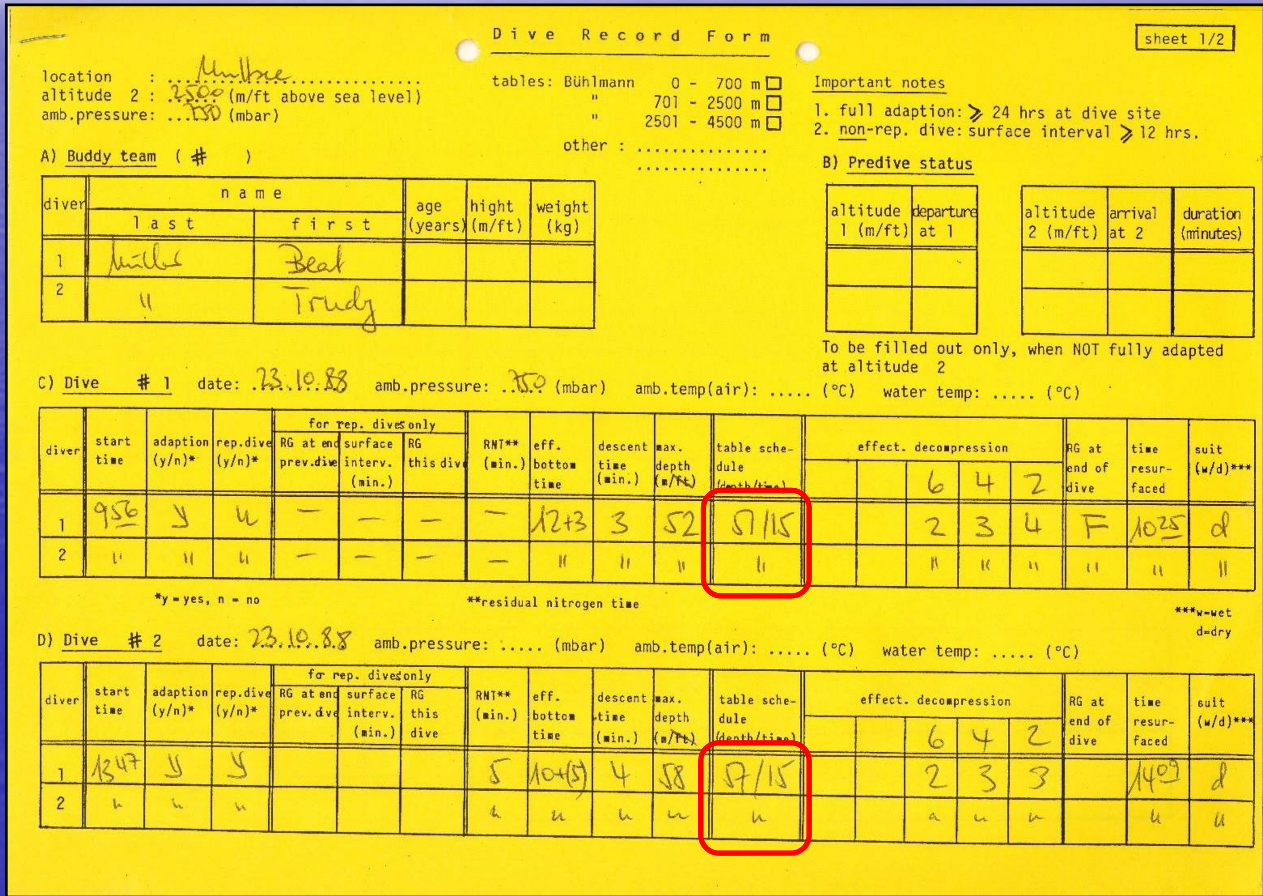
Summary, filled out after dive



Protocol data, recorded every 1-2minutes and written on a wrist-slate

Muttsee Trials (6b)

Summary, filed out after dive



Dive Record Form

sheet 1/2

location : Muttsee
altitude 2 : 2500 (m/ft above sea level)
amb.pressure: 750 (mbar)

tables: Bühlmann 0 - 700 m ☐
" 701 - 2500 m ☐
" 2501 - 4500 m ☐
other : ....

Important notes
1. full adaption: ≥ 24 hrs at dive site
2. non-rep. dive: surface interval ≥ 12 hrs.

A) Buddy team (#)

diver	name: last	name: first	age (years)	hight (m/ft)	weight (kg)
1	Müller	Beat			
2	"	Trudy			

B) Predive status

altitude 1 (m/ft)	departure at 1

altitude 2 (m/ft)	arrival at 2	duration (minutes)

To be filled out only, when NOT fully adapted at altitude 2

C) Dive # 1 date: 23.10.88 amb.pressure: 750 (mbar) amb.temp(air): ..... (°C) water temp: ..... (°C)

diver	start time	adaption (y/n)*	rep.dive (y/n)*	for rep. dives only: RG at end prev.dive	for rep. dives only: surface interv. (min.)	for rep. dives only: RG this dive	RNT** (min.)	eff. bottom time	descent time (min.)	max. depth (m/ft)	table schedule (depth/time)	effect. decompression					RG at end of dive	time resurfaced	suit (w/d)***
														6	4	2			
1	956	y	n	—	—	—	—	12+3	3	52	57/15			2	3	4	F	1025	d
2	"	"	"	—	—	—	—	"	"	"	"			"	"	"	"	"	"

*y = yes, n = no **residual nitrogen time ***w=wet d=dry

D) Dive # 2 date: 23.10.88 amb.pressure: ..... (mbar) amb.temp(air): ..... (°C) water temp: ..... (°C)

diver	start time	adaption (y/n)*	rep.dive (y/n)*	for rep. dives only: RG at end prev.dive	for rep. dives only: surface interv. (min.)	for rep. dives only: RG this dive	RNT** (min.)	eff. bottom time	descent time (min.)	max. depth (m/ft)	table schedule (depth/time)	effect. decompression					RG at end of dive	time resurfaced	suit (w/d)***
														6	4	2			
1	1347	y	y				5	10+(5)	4	58	57/15			2	3	3		1409	d
2	"	"	"				"	"	"	"	"			"	"	"		"	"

Protocol data transferred from wrist slate notices, filled out during the dive; Deco Brain readings (here: P2-2).

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Muttsee Trials (7)

G. Götte

2 days, 15 divers,
56 dives, 24-58m

Analysis of Open Water Dives at Altitude 1988

C) experimental dive weekend of october / ZHL-16 schedules

(23.10.88 only)

NOTE: 1) ascent from 800m to 2500m was done by helicopter in 10 minutes two days before (21.10.88)

date	dive	-altitude -max.depth -deco-stop -(interv.)	-adapt.time -bottom time -stop time -interv.time	gas " " "	n-dives	n-DCS	symptoms
23.10.	#12	2500 39 6 4 2 0	~ 39 hrs 25* 3 5 7 103	air " " " " "	2	0	---
	#25	33 4 2	25* 3 5	" " "	1	1	muscles, skin
23.10.	#13	2500 39 6 4 2 0	~ 39 hrs 25 * 3 5 7 117	air " " " " "	2	0	---
	#26	33 4 2	25 * 3 5	" " "	2	2	muscles, skin
23.10.	#14	2500 39 6 4 2 0	~ 39 hrs 25 * 3 5 7 99	air " " " " "	2	0	---
	#27	33 4 2	25 * 3 5	" " "	2	1	muscles, skin
				total	11	4	

* calculated with ZHL-16A

RG:
F (38.3'),
G (54.3')

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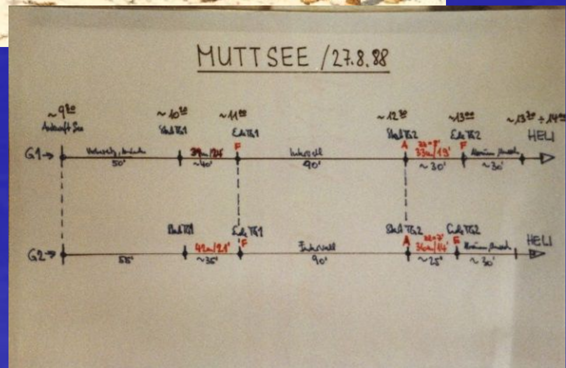
Muttsee Trials (8)



→ results further down

Dives at Mount Kenia (1988)

Dives at Mount Kenia 1988

- „private expedition of 2 Swiss individuals (M. Weber, W. Keusen)
- at that time M. Weber was living in Kenia at approx. 1800m
- W. Keusen came directly from Switzerland
- both used special designed Aladins
- breathing gas was air only
- all dives with dry suits
- on ascent an intermediate stop was done at approx. 3500m
- overall duration 8-10 days
- in total 18 dives between approx. 4400m and 4780m
- depths in the range of 10m-15m, bottom times 20-30min
- No DCS symptoms of any kind but exhaustion due to lack of enough oxygen

(data obtained from private communication with Mr. Weber)

Results and Consequences

→ For more details ref. to Appendices

Results and Consequences (1)

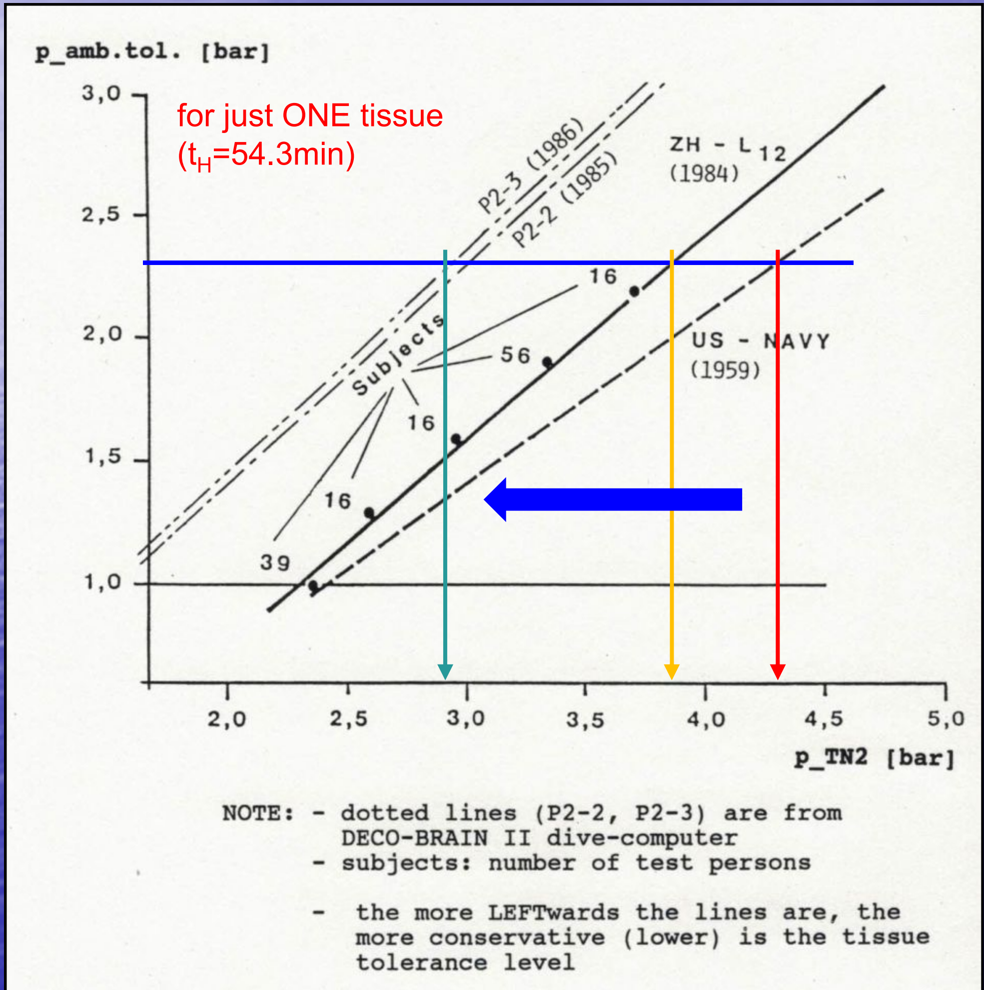
(all data from the period of 1981-1991)

The testing and operational „envelope“:

- Extremely broad range of diving candidates
- Altitudes from 0 to 4780m asl (chamber: 4200m asl)
- Single and repetitive dives (up to 3 consecutives); surface intervals from 10-120min
- Tests done with drastically reduced stop times
- Chamber and real dives
- Depths down to 500m and even 575m (chamber)
- Bounce dives and saturation dives (30m – 220m)
- Recreational dives and hyperbaric work, from minutes to hours
- Tables and computer with several 100‘000 real dives
- Air, nitrox, heliox, other mixed-gases, O2 decompression
- Extremely reliable for multi-gas diving and adaption
- **In short: one of the best tested and proofed systems ever!**

→ **For more details ref. to Appendices**

Results and Consequences (2)



Careful analysis of hundred of dive profiles executed with dive computers led to a refinement of the underlying set of coefficients towards higher tolerated ambient pressures (reduced gradients) for a given tissue inert gas pressure.

It also shows the dramatic change compared to US-Navy and the original ZHL-12 limits.

Results and Consequences (3)

Comparison of NDL (1)

Values attained by using ZHL-12 and ZHL-16B

	NDL times in [min]				
Altitude range [m a.s.l.]	**0-0**	**0-700**	**701-2500**	**2501-4500**	**4400-4800**
Altitude of adaption [m a.s.l.]	0	0	701	4500	4400
Altitude of calculated dive [m a.s.l.]	0	700	2500	4500	4800
Ramp to upper range limit [hr]	no	no	1	no	6
Surface Interval at dive site before dive [hr]	>24	0	0	>24	3

Depth [m]					
6					
9	475	349	**238**	**204**	167
12	139	**125**	**99**	**88**	86
15	81	**75**	**62**	**50**	56
18	55	**51**	**44**	**32**	39
21	40	**35**	**30**	**22**	27
24	28	**25**	**22**	**16**	20
27	22	**20**	**18**	**14**	16
30	18	**17**	**15**	**11**	14
33	15	**14**	**12**	**9**	12
36	13	**12**	**10**	**8**	10
39	11	**10**	**9**	**7**	9
42	10	**9**	**8**	**7**	8
45	9	8	7	**6**	7
48	8	7	6	**6**	6
51	7	6	6	**5**	5
54	6	6	5	5	5
57	5	5	4	4	4
60	5	4	4	4	3

bold values: as published on tables
blue values: added by calculation

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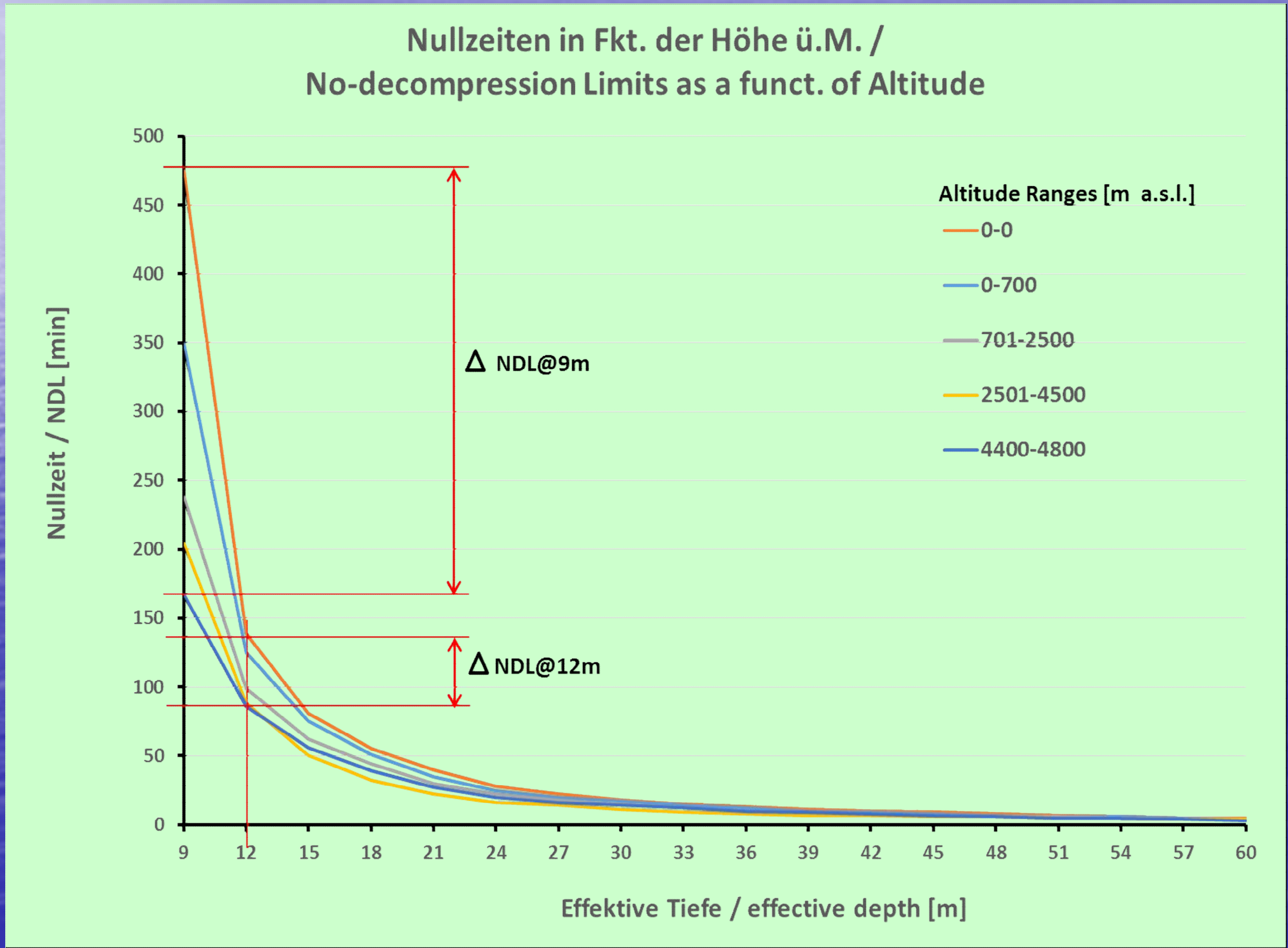
Results and Consequences (4)

Comparison of NDL (2)



Results and Consequences (5)

The final System ZHL-16 (as published)

compart-ment #	half-time [min]	ZH-L16A (theoretical) b [-]	ZH-L16A (theoretical) a [bar]	ZH-L16B table a [bar]	ZH-L16C computer a [bar]
1	4,0	0,5050	1,2599	1,2599	1,2599
2	8,0	0,6514	1,0000	1,0000	1,0000
3	12,5	0,7222	0,8618	0,8618	0,8618
4	18,5	0,7825	0,7562	0,7562	0,7562
5	27,0	0,8126	0,6667	0,6667	0,6200
6	38,3	0,8434	0,5933	0,5600	0,5043
7	54,3	0,8693	0,5282	0,4947	0,4410
8	77,0	0,8910	0,4701	0,4500	0,4000
9	109,0	0,9092	0,4187	0,4187	0,3750
10	146,0	0,9222	0,3798	0,3798	0,3500
11	187,0	0,9319	0,3497	0,3497	0,3295
12	239,0	0,9403	0,3223	0,3223	0,3065
13	305,0	0,9477	0,2971	0,2850	0,2835
14	390,0	0,9544	0,2737	0,2737	0,2610
15	498,0	0,9602	0,2523	0,2523	0,2480
16	635,0	0,9653	0,2327	0,2327	0,2327

- *A verified set of 16 tissue group halftimes and their coefficients a,b for air with adaption to table- and computer use.*
- *A similar set exists for Helium.*
- *With more than 1 inert gas breathed, resulting factors a, b are calculated on the basis of their momentary tissue pressures.*

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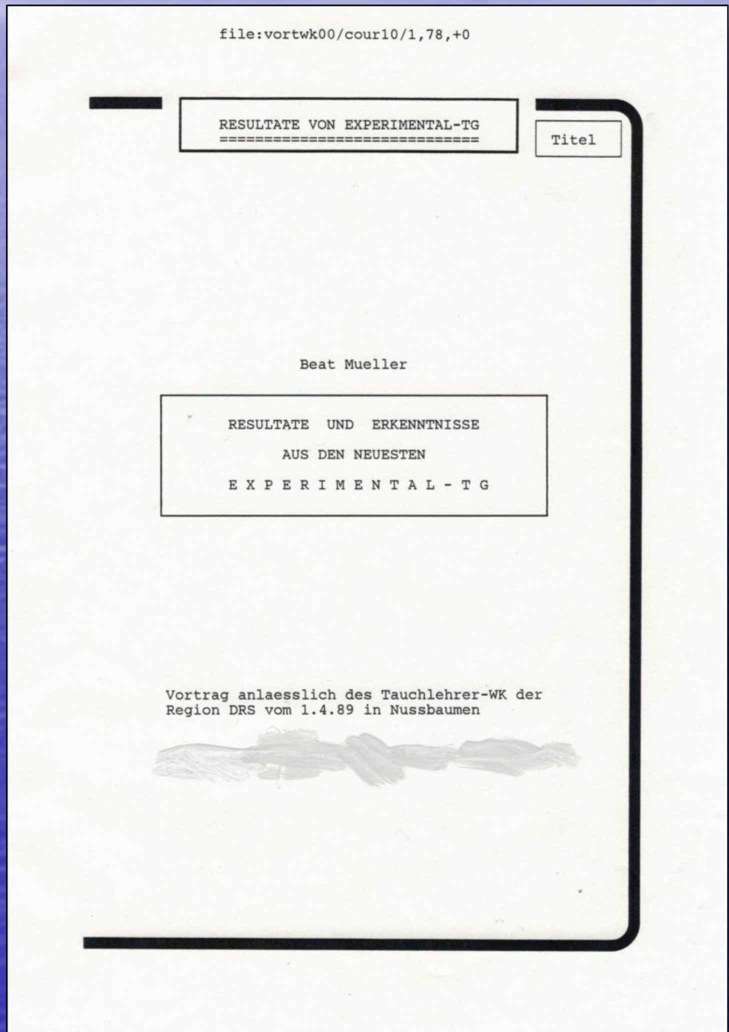
Results and Consequences (6)


file:vortwk00/courl0/1,78,+0

RESULTATE VON EXPERIMENTAL-TG
=============================

Titel

Beat Mueller

RESULTATE UND ERKENNTNISSE
AUS DEN NEUESTEN
E X P E R I M E N T A L - T G

Vortrag anlaesslich des Tauchlehrer-WK der Region DRS vom 1.4.89 in Nussbaumen

Termination of project:
Report at the Annual Instructor Meeting 1989 (summary of all high altitudes test dives from 1984 to 1988)

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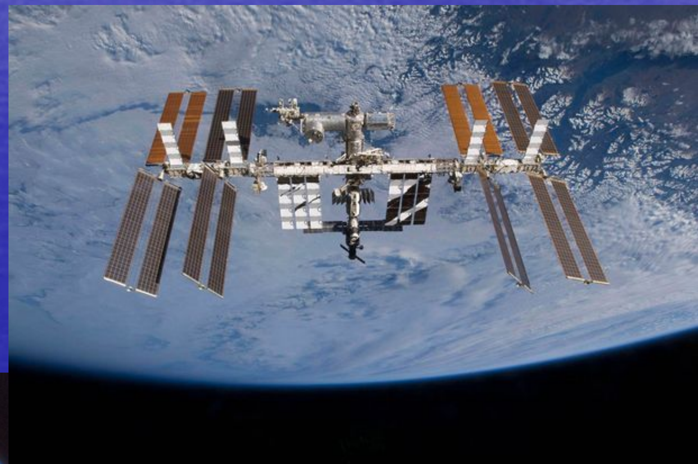
Practical Applications and Special Environments

Bühlmann Memorial Symposium 2019

Practical Applications and Special Environments: Space (1)

Excursion: Decompression in Space (Bühlmann‘s involvement with NASA)



Ambient pressure in space craft: 5 ->10.2 -> 14.7 psi
O_2-content: 100% O_2 -> 26.5% -> 21% (today)

Ambient pressure in EVA suit: 3.75-5.8 psi
O_2-content: 100% O_2

pN_2-SC / ptot-EVA (max) = 14.7*0.79/:4 = **2.9 (too high!)**
take longest half-time -> max. pN_2-ratio = **1.27**
EVA O_2 pre-breathe time: approx. **30min**

EVA: extra-vehicular activity

→ ref. to Appencies

Practical Applications and Special Environments: Space (2)

Historical Data on Cabin Atmospheres

Program	Cabin Pressure, kPa (psia)	Cabin Oxygen Concentration, volume %	EVA Suit Pressure,[1] kPa (psia)	EVA O_2 Pre-breathe Time, minutes	EVA Prebreathe Conditions
Mercury	34.5 (5)	100	-	-	-
Gemini/Apollo	34.5 (5)	100	25.8 (3.75)	0	-
Skylab	34.5 (5)	70	25.8 (3.75)	0	-
Shuttle	70.3 (10.2)	26.5	29.6 (4.3)	40	In-suit (after 36 hours at 70.3 kPa)
	101.3 (14.7)	21	29.6 (4.3)	240[3]	In-suit
ISS/US	101.3 (14.7)	21	29.6 (4.3)	120-140	Mask and in-suit; staged w/exercise
				240[3]	In-suit
Salyut, Mir, ISS/Russian	101.3 (14.7)	21	40.0 (5.8)[2]	30	In-suit

References: Carson, et al. (1975), McBarron, et al. (1993), Waligora, et al. (1993), NASA (2002), NASA (2003).
(1) 100% oxygen.
(2) In earlier versions of the Orlan suit, the pressure could be reduced to 26.5 kPa (3.8 psia) for short-duration work regime.
(3) Under emergency conditions, a minimum of 150 minutes of unbroken prebreathe is recommended.

from Scheuring et. al., "Risk Assessment of Physiological Effects of Atmospheric Composition and Pressure in Constellation Vehicles" 16th Annual Humans in Space, Beijing, China, May 2007

Practical Applications and Special Environments: Space (3)

Ich bin seit 5.30 Uhr „auf den Beinen". Ich lege eine Windel an und darüber flüssigkeitsgekühlte Unterwäsche. Nach dem Frühstück mache ich mich auf den Weg zur Luftschleuse. Kjell und ich atmen eine Stunde lang reinen Sauerstoff, um den Stickstoffgehalt im Blut zu senken und uns so vor der Dekompressionskrankheit zu schützen.

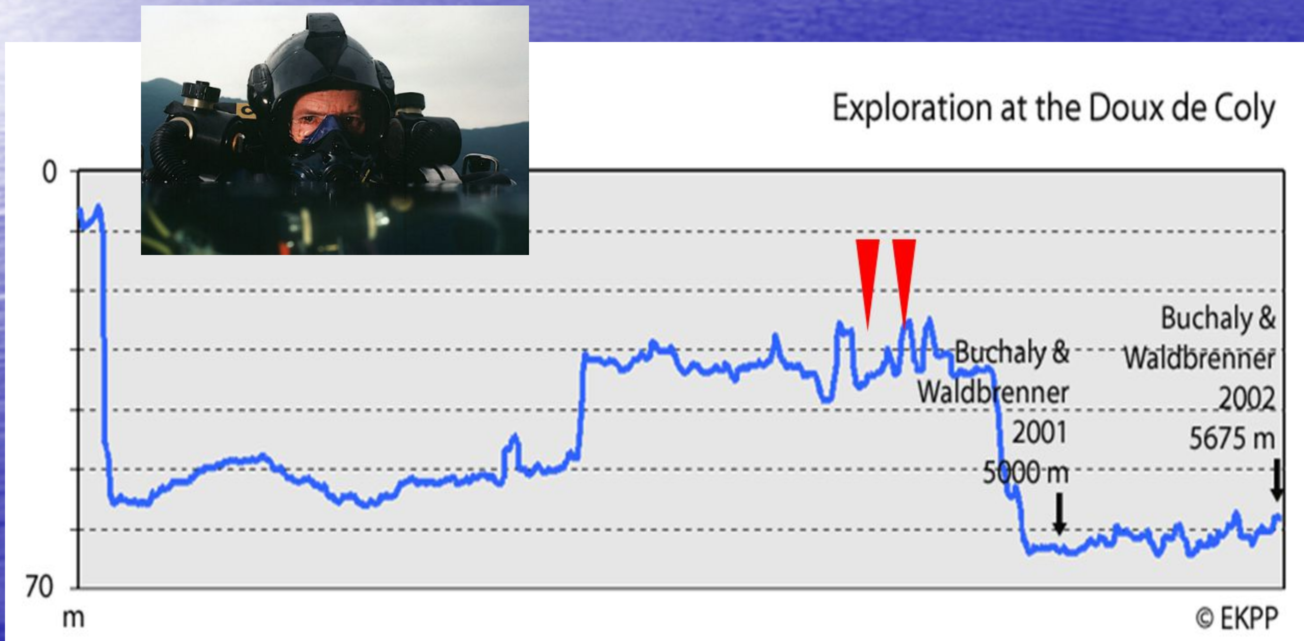
Bühlmann Memorial Symposium 2019

Practical Applications and Special Environments: Cave Diving (1)

*Calculation of special tables for Olivier Isler's Doux de Coly Expedition and his push dives with **OC systems** (1989)*

Practical Applications and Special Environments: Cave Diving (2)

*Calculation of special tables for Olivier Isler's Doux de Coly Expedition and his push dives in 1989 with **OC systems**.*



Two years later, in 1991, Isler reached 4'055 meters (13'303 feet) in Doux de Coly with his self-developed RI-2000 double-rebreather. In 1998, Isler arrives at 4'250m at a depth of -35m.

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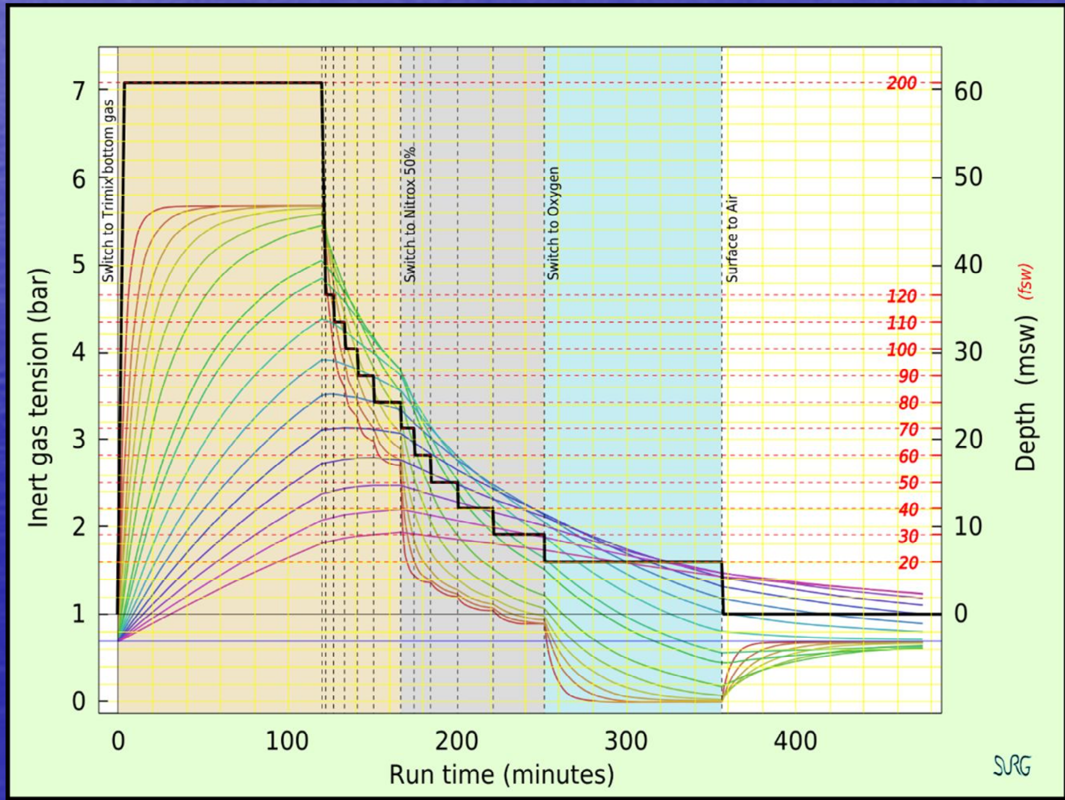
Practical Applications and Special Environments: Multi-Gas Technical Diving

ZHL-16x used as a basis for calculation algorithms in various decompression computers AND simulation software.
It has been further refined by the ***Gradient Factor Method****, popular with technical divers.*



Calculated inert gas uptake and elimination with gas switches for decompression (Tmx, EAN50; O2, air)

Practical Applications and Special Environments: Diving Computers

Models: Bühlmann, RGBM, VPM, combined; gas- or non gas-integrated; storage of up to 10 different gases

→ results from Deco Brain Trials in Appendices

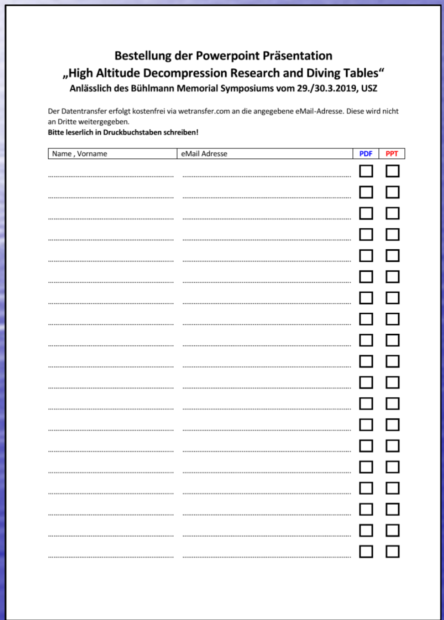
…and many, many more…

Bühlmann Memorial Symposium 2019

Thank you for your attendance!

…and don‘t let the DKL die!

Contact the author:


Bestellung der Powerpoint Präsentation
„High Altitude Decompression Research and Diving Tables“
Anlässlich des Bühlmann Memorial Symposiums vom 29./30.3.2019, USZ

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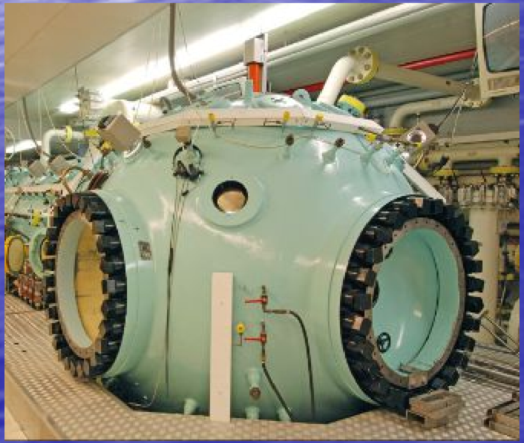
Beat Müller
Grossmattstr. 8
CH-8964 Rudolfstetten
+41 56 631 25 25
btmueller@bluewin.ch

Request for ppt-presentation: use order form or send request to *btmueller@bluewin.ch*

Appendices

(not shown during presentation)

Appendices (not shown)



- Program and Faculty Members of the Symposium 2019 (4 frames)
- References (4 frames)
- Further Publications (3 frames)
- The Deep Diving Research Laboratory of the University Hospital of Zurich (DKL) (15 frames)
- Early Deep Diving Trials (6 frames)
- Perfusion- and Diffusion based models (6 frames)
- The Linear Perfusion Models ZHL-12/16 (8 frames)
- Parametric NDL calculations today (6 frames)
- Parameters for Bühlmann `86 Air Diving Tables and later developments (3 frames)
- Results and consequences (details) (9 frames)
- Barometric Pressure as a function of Altitude (2 frames)
- Seawater Density (2 frames)
- Deco Brain Trials (9 frames)
- Decompression Problems in Space (6 frames)
- About the Author (3 frames)

Program and Faculty Members of the Symposium 2019

Bühlmann Memorial Symposium 2019

Program of the Symposium 2019 (1)

Seminargebühren/Frais d'enregistrement/ Registration fees

Freitag/Vendredi/Friday
Taucher/plongeur/diver CHF 20.–
Arzt/médecin/doctor CHF 50.–

Samstag/Samedi/Saturday
Taucher/plongeur/diver CHF 50.–
Arzt/médecin/doctor CHF 200.–

Besichtigung Druckkammer frei
Visite gratuite du laboratoire hyperbare
Free visit of the decompretion chambre

Bitte Teilnahmegebühr VOR DEM ANLASS auf das Konto einzahlen:

Veuillez verser les frais de participation AVANT LE SYMPOSIUM sur le compte SUHMS suivant:

Please pay the registration fees BEFOR THE EVENT to the SUHMS account as follows:

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SUHMS
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Lerchenweg 9
2543 Lengnau
Tel. 032 653 85 46
www.suhms.org / suhms@datacomm.ch

Referenten:

Dr. med. Daniel Blickenstorfer, Tauchmedizin SUHMS
Dr. iur. Thomas A. Bühlmann, Rechtsanwalt
Dr. med. Frank Hartig, Tauchmedizin
Dr. med. Francis Héritier, Tauchmedizin
Dr. med. Peter Knessl, Tauchmedizin, SUHMS
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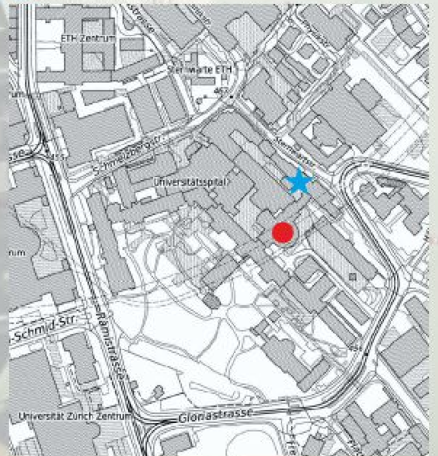

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SUHMS

Verein Historisches Druckkammerlabor Universitätsspital Zürich

Bühlmann Symposium

Freitag/Vendredi/Friday
29.03.2019
16.00-20.00 Uhr/heure/hours

Samstag/Samedi/Saturday
30.03.2019
08.30-19.00 Uhr/heure/hours

Universitätsspital Zürich
Kleiner Hörsaal OST
Druckkammerlabor

Bühlmann Memorial Symposium 2019

Program of the Symposium 2019 (2)

Im März 2019 jährt sich A. A. Bühlmanns Todestag zum 25. Mal. Die Schweizerische Gesellschaft für Unterwasser- und Hyperbarmedizin und der Verein Historisches Druckkammerlabor Universitätsspital Zürich organisieren deshalb ein Symposium mit vielen spannenden Themen und Referenten. U.a. wird Thomas Bühlmann, Sohn des Entwicklers des berühmten Dekompressionsmodelles, über die tauchmedizinische Forschung in Zürich von 1959 bis 1994 aus historischer Sicht berichten. Zudem stehen die Räumlichkeiten des seit 2005 stillgelegten Druckkammerlabors zur Besichtigung offen.

Mars 2019 marque le 25e anniversaire de la mort de A. A. Bühlmann. A cette occasion, la Société Suisse de Médecine Subaquatique et Hyperbare et l'Association du Laboratoire Hyperbare Historique de l'Hôpital Universitaire de Zurich organisent un symposium avec de nombreux sujets et intervenants passionnants. Entre autres Thomas Bühlmann, fils du développeur du fameux modèle de décompression, présentera un compte-rendu historique sur la recherche en médecine de plongée effectuée à Zurich de 1959 à 1994. De plus, les locaux du laboratoire hyperbare désaffectés depuis 2005 pourront être visités. Nous nous réjouissons de vous accueillir sur l'ancien lieu de travail du prof. Bühlmann.

25 years ago A.A. Bühlman passed away. For this reason the Swiss Underwater and Hyperbaric Medical Society (SUHMS) and the Historical Hyperbaric Chamber Zurich Association (DKL-USZ) are offering an extraordinary memorial symposium to all interested divers and physicians with a series of interesting lectures. Among others, Thomas Bühlmann, A.A. Bühlmann's son, who is engaged in historical research about his father's diving medical work from 1959 to 1994, will present a report about this period. In addition, there will be a unique opportunity to visit the remains of the former Hyperbaric Chamber Laboratory with a guided tour. We are looking forward to welcome you at A. A. Bühlmanns former work-place.

Freitag/Vendredi/Friday
29.03.2019

- 15:15 Registration
- 15:45 Opening
- 16:00 Current Diving and Hyperbaric Medical Research in Switzerland
- 16:30 Rapture of the deep, new insights and questions
- 17:20 Bühlmann and funnel chest? What is the link?
- 17:35 Decompression Models: «de-mystified»
- 18:40 General assembly «Historical Hyperbaric Chamber Laboratory Zurich Association»
- 19:10 General assembly «Swiss Underwater and Hyperbaric Medical Society»
- 19:40 Welcome Drink

Fotos
private archive Bühlmann

Samstag/Samedi/Saturday
30.03.2019

- 08:15 Opening and Registration
- 08:30 Diving Medical Research in Zurich 1959 to 1994
- 09:10 A. A. Bühlmann - Beyond Diving Medicine
- 09:50 Coffee Break
- 10:10 History and Development of Decompression Algorithms
- 11:00 Milestones of the Deep Diving Research Laboratory Zurich
- 11:35 500 m Chamber Dive
- 11:55 Interview: Being Guinea Pig at 500 Meters
- 12:15 Lunch Break
- 13:00 Bühlmann's Saturation Diving Algorithm, deep mixed gas tables and how they changed practice in occupational diving
- 13:35 Tables for Mountain Lake Diving
- 14:25 Bühlmann-Algorithms for Dive Computers
- 15:00 The use of the Zurich Hyperbaric Chamber Laboratory during the late period 1994 until today
- 15:25 Coffee Break
- 15:45 Is diving a stress for pulmonary capillaries?
- 16:35 The DAN Europe Diving Data Base: Diving Modalities, Habits, Echogra-phic & Doppler Bubble Monitoring, Risk Factors, Incidents & Accidents
- 17:25 Extreme Recreational Diving
- 18:15 Farewell

Präsentationsfolien auf englisch, Referate in einer der drei Amtssprachen (D/F/I).

Diapositives en anglais, présentations en allmand, français ou italien.

Slides allways in English, talks in German, French or Italian.

Bühlmann Memorial Symposium 2019

The Faculty Members of the Symposium 2019

Dr. jur. T. Bühlmann
(son)

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34) Personal communication with Dr. Max Hahn (analysis, calculations)
35) Personal communication with Dr. phys. Klaus Meier-Ewert (calculation programming, cross-checks)
36) Personal communication with Mr. George Götte (Lago di Lucendro and Muttsee)
37) Personal communication with Mr. Martin Weber (Mount Kenia dives)

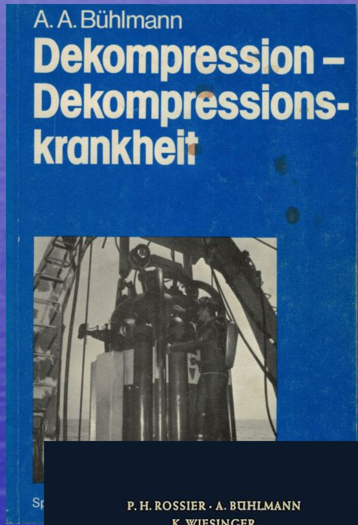
Further Publications

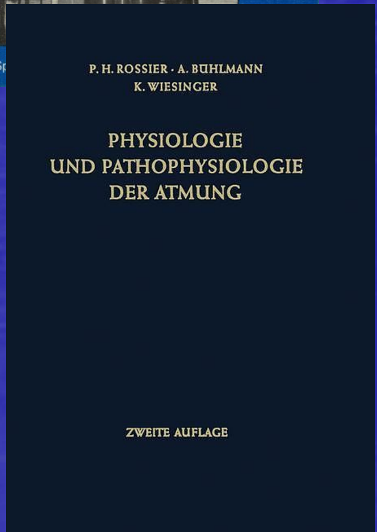
Bühlmann Memorial Symposium 2019

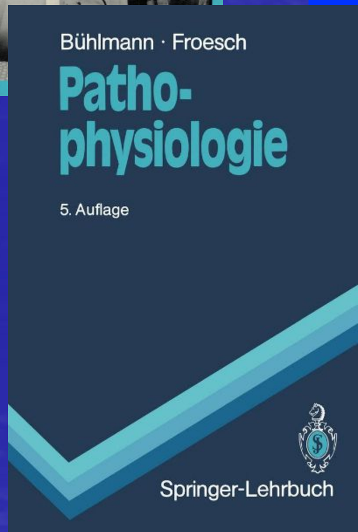
Further Publications (1)

Some of his publications

1961 (#1 to #5)
„The way into depth“







1st ed. 1952
2nd ed. 1958

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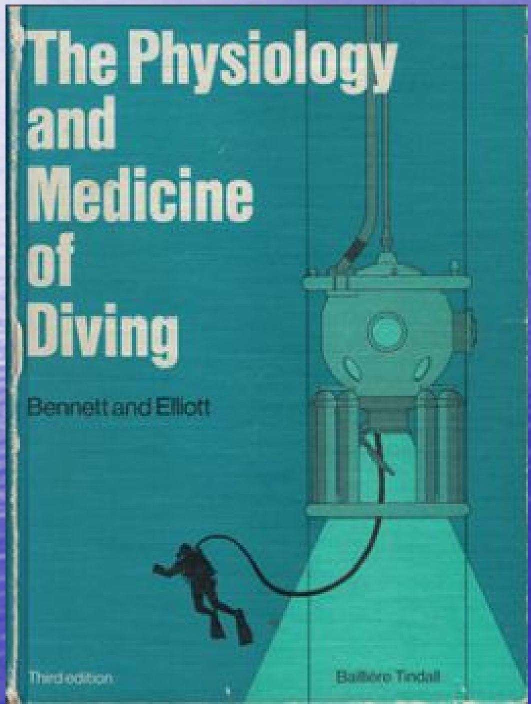
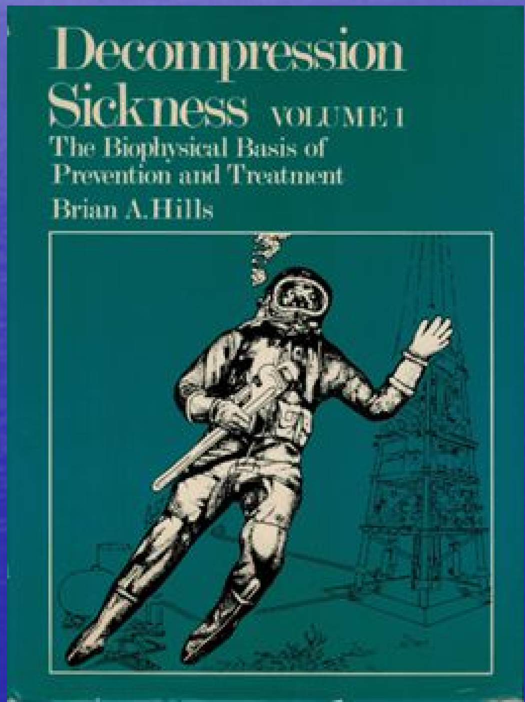
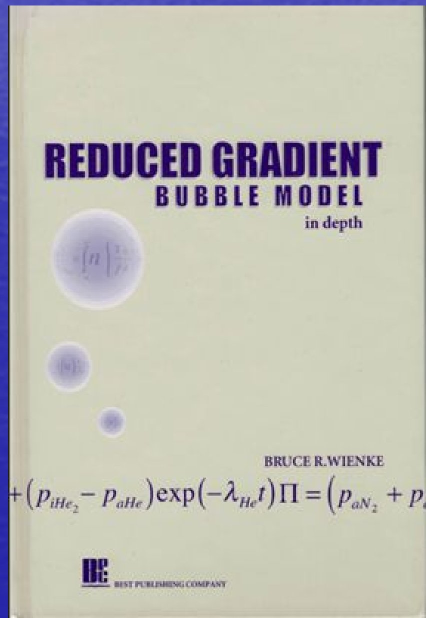
Further Publications (2)



Different models, basic physiology of gas transport, DCS



Different models, „thermodynamic decompression“ (diffusion, bubble model), DCS



Gas transport, phase models, bubble-model

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The Deep Diving Research Laboratory of the University Hospital of Zurich (DKL)

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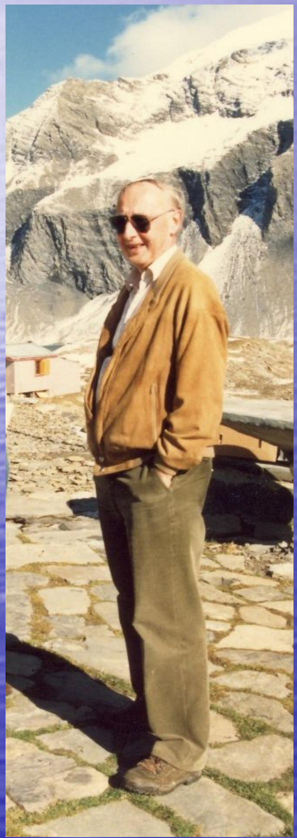
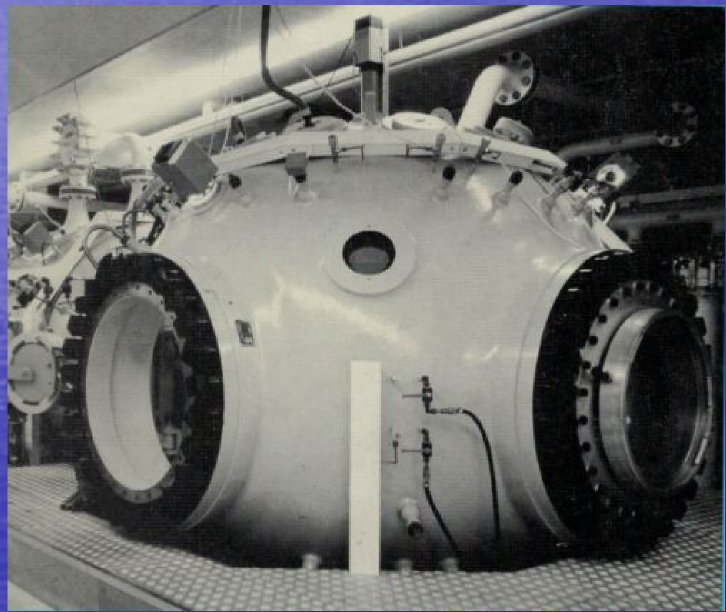
The „Lab“ and the men behind (1)



16.5.1923 –
16.3.1994



Chamber at University Hospital Zurich; water tank module

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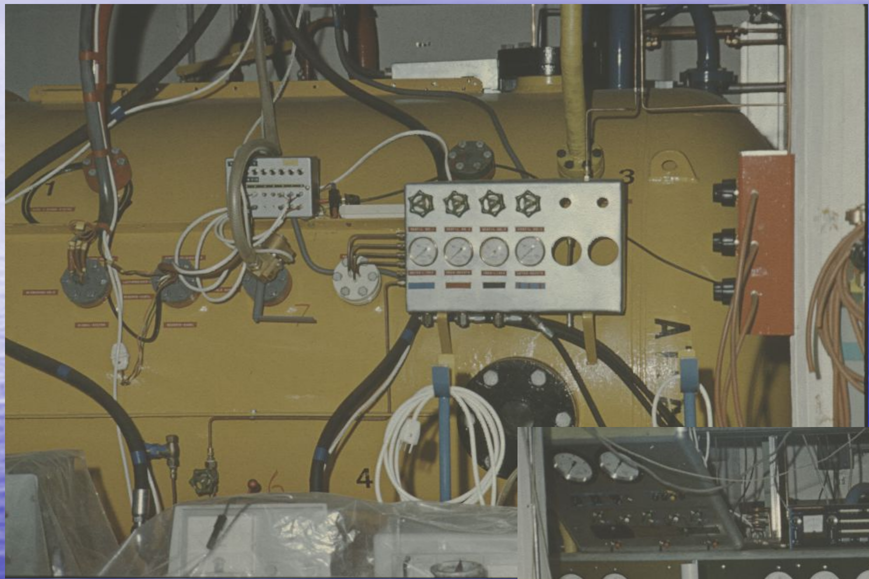
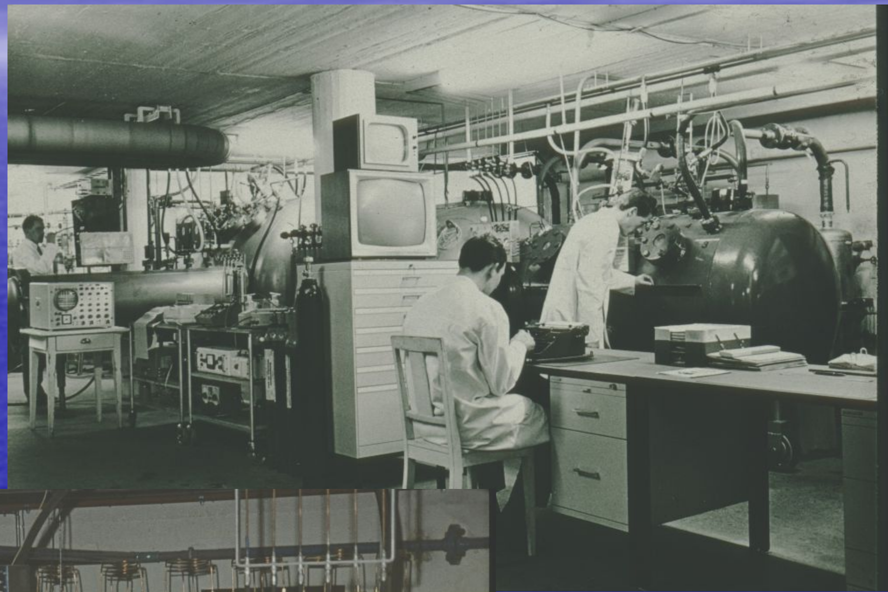
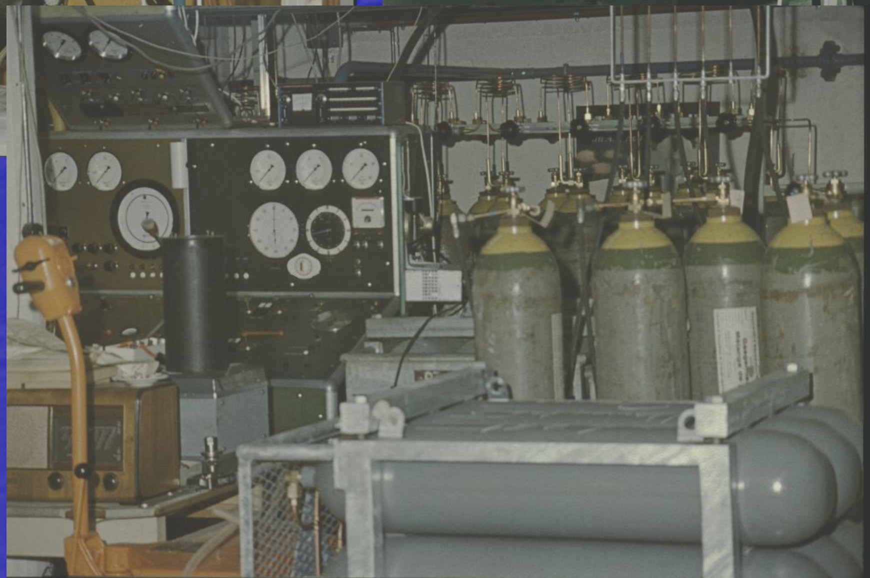
The „Lab“ and the men behind (2)

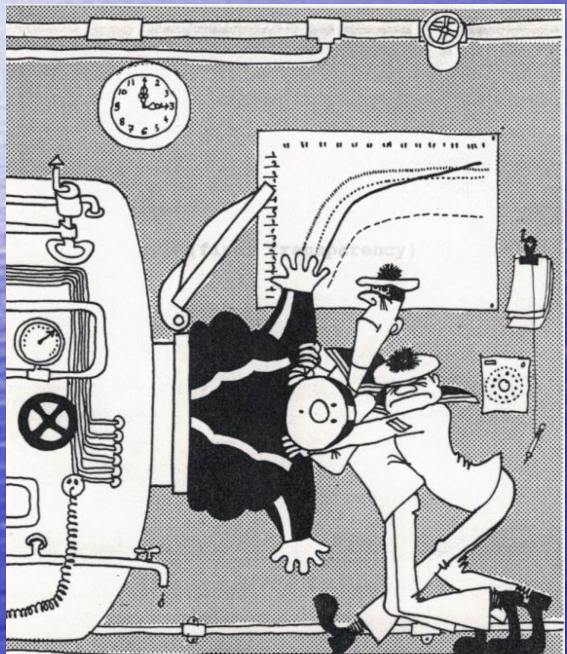
The old chamber installation







The „Lab“ and the men behind (3)



Location: Zürich, Switzerland

Operator: University Hospital, Zürich

Manufacturer: Pressure vessels by Gebrüder Sulzer, Winterthur, Switzerland

Completion: 1975

Technical details:

Operating pressure	0.5–101 bar			
Dimensions of chamber	1	2	3	4
Diameter (mm)	2500	2000	2000	3500
Internal length (mm)	—	3200	1600	—
Hatch diameter (mm)	800	800	800	1300
Volume (m^3)	8	10	6.5	22

Filled with air, heliox or pure oxygen; chamber 4 only water.

Purpose:

Development of practicable diving procedures for off-shore exploration (field oriented)

Solutions for special problems of deep diving down to 1000 m in form of basic research

Development of decompression and treatment tables

Development of decompression tables for high altitudes (mountain lakes)

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The „Lab“ and the men behind (4)

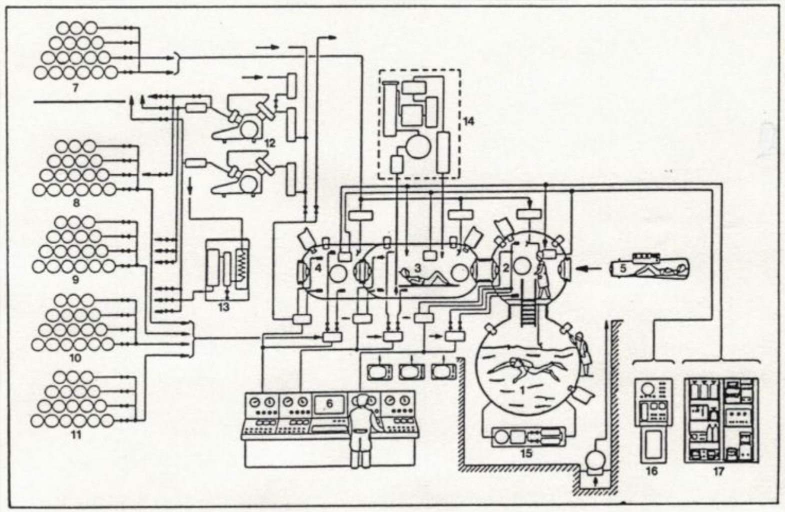


Fig. 2.15: schematic diagram of monitory-, supply-, and life-supporting systems and peripherals

1: wet chamber
2: high pressure sphere
3: decompression chamber
4: pre-chamber/ lock
5: one-man transport chamber
6: control-/monitoring centre
7: storage breathing gases
8: oxygen
9: spec. gas mixtures
10: air
11: helium
12: compressors
13: helium recovery unit
14: chamber: air conditioning/treatment unit
15: water treatment unit
16: medical surveillance
17: gas analyzing system

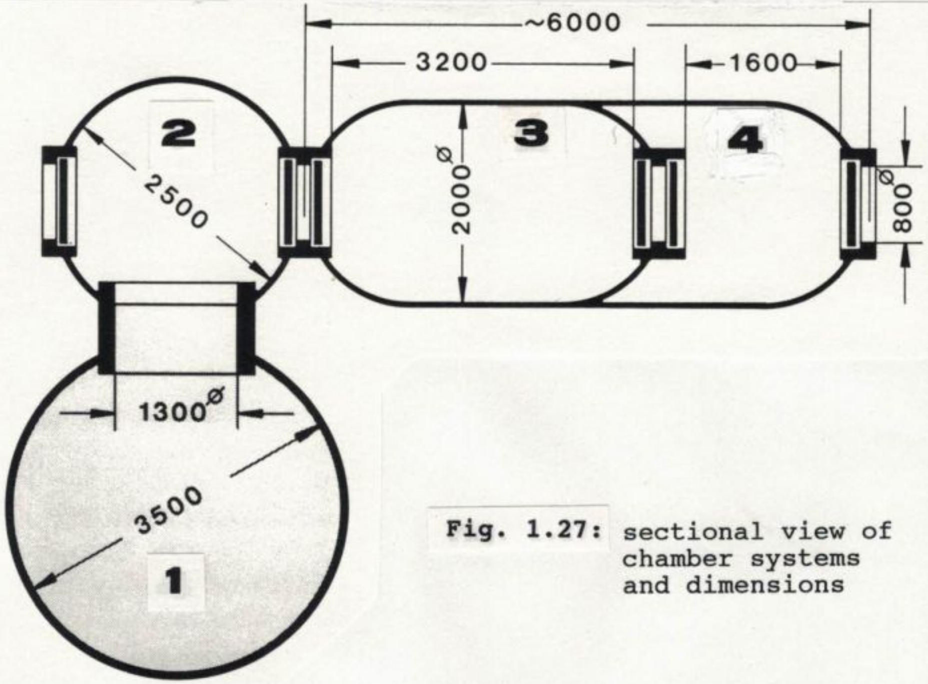
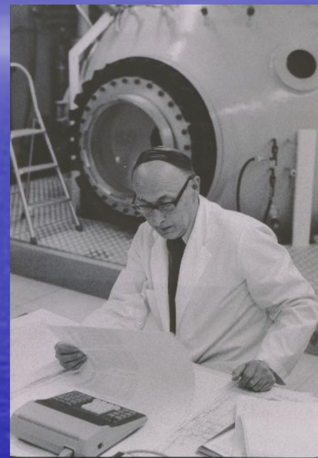


Fig. 1.27: sectional view of chamber systems and dimensions

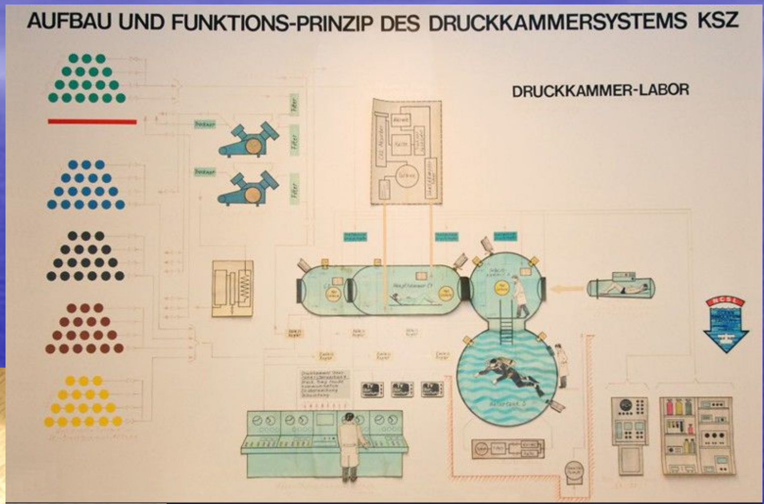
1: wet chamber
2: high pressure sphere
3: decompression chamber
4: pre-chamber (transfer)

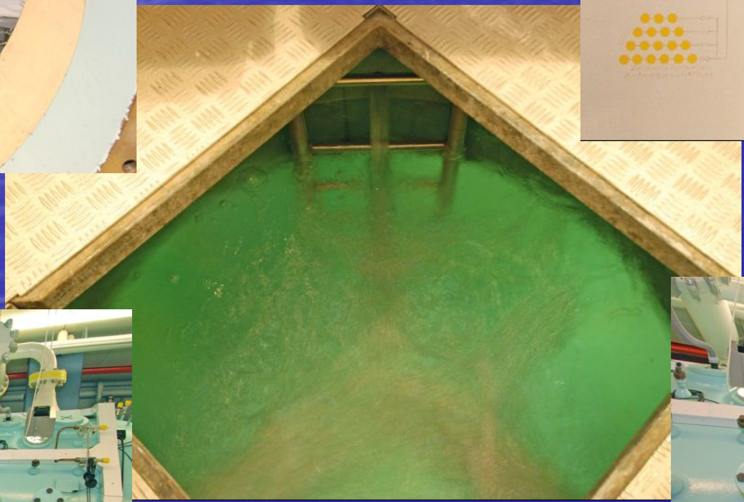
The „Lab“ and the men behind (5)



Link to Photo Galery: http://www.swiss-cave-diving.ch/gallery/DKL-Zuerich/DKL-ZH.html

The „Lab“ and the men behind (6)





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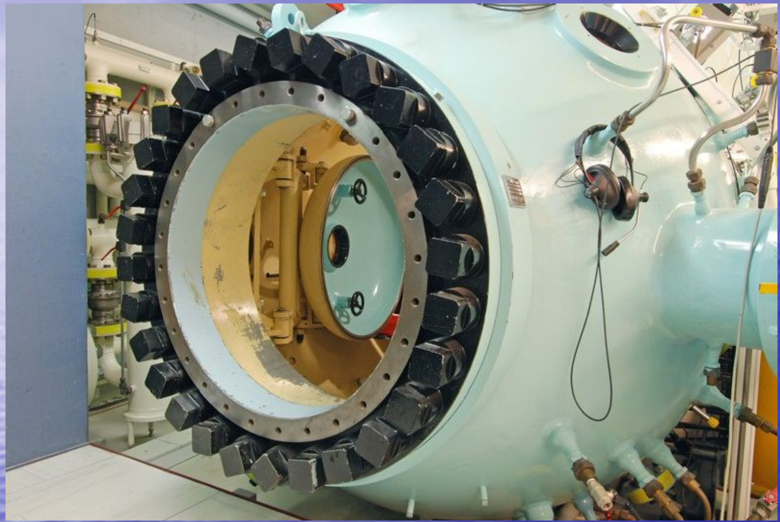
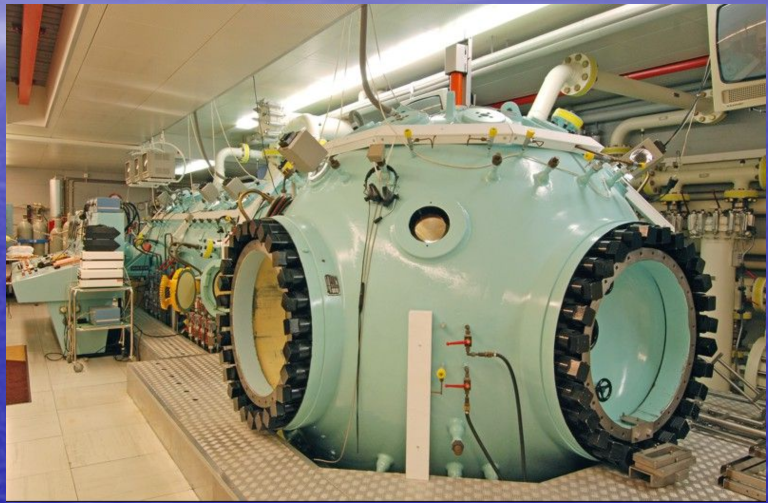
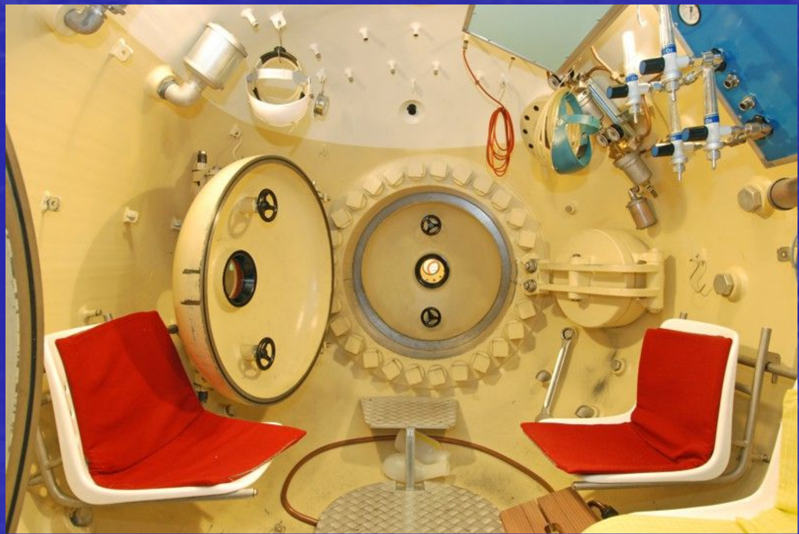
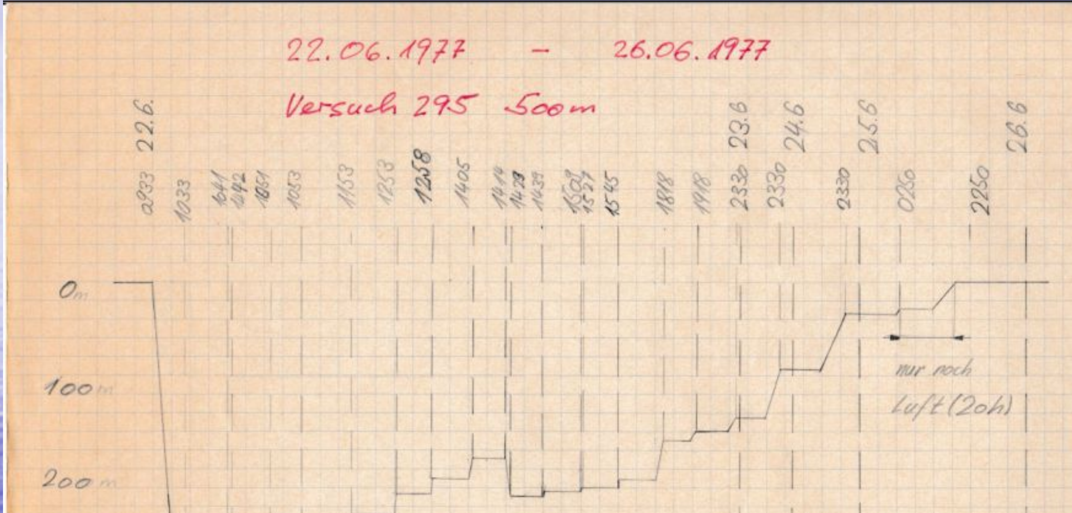
The „Lab“ and the men behind (7)







The „Lab“ and the men behind (8)



Erstmals in der Schweiz: 500-Meter-Tauchgang

jhm. Im neuen Tauchsimulator des Kantonsspitals Zürich haben vergangene Woche die drei Versuchtaucher *Peter Ita, Miroslav Korienek* und *Livio De Toffel* die schweizerische Rekordtiefe von 500 Metern erreicht. Der Experimentaltauchgang begann am Mittwoch, 22. Juni, um 9 Uhr morgens. Innerhalb von 50 Minuten wurde die Maximaltiefe erreicht, auf der die Taucher insgesamt 8 Minuten verweilten. Der anschliessende Wiederaufstieg beziehungsweise die Rückkehr zum Normaldruck nahm über dreieinhalb Tage in Anspruch. In der Nacht vom Samstag auf den Sonntag verliessen die Taucher die Ueberdruckkammer bei guter Gesundheit. Der im Jahr 1975 in Betrieb genommene neueentwickelte Tauchsimulator lieferte im Rahmen dieses Experiments den Beweis einwandfreier Funktion sämtlicher Systeme unter hoher Belastung. Konstruktiv ist er für Tauchtiefen bis 1000 Meter ausgelegt.

Livio de Toffol
ca. 1977

Livio de Toffol
2018

The „Lab“ and the men behind (9)

…after a successful trial (chamber dive)

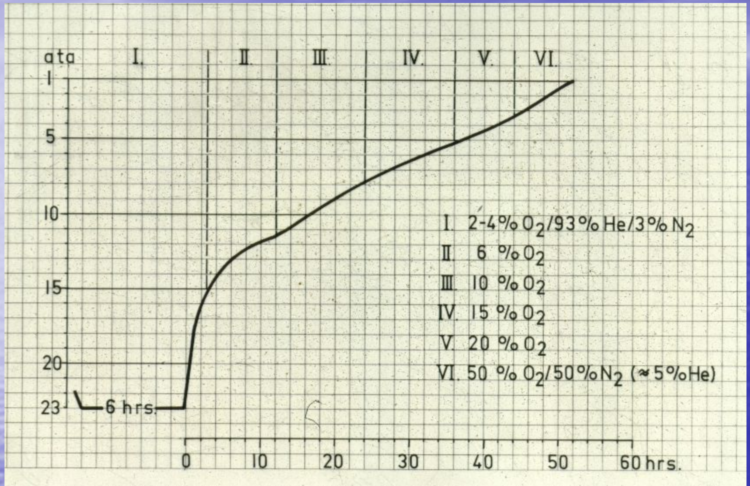
Mr. de Toffol

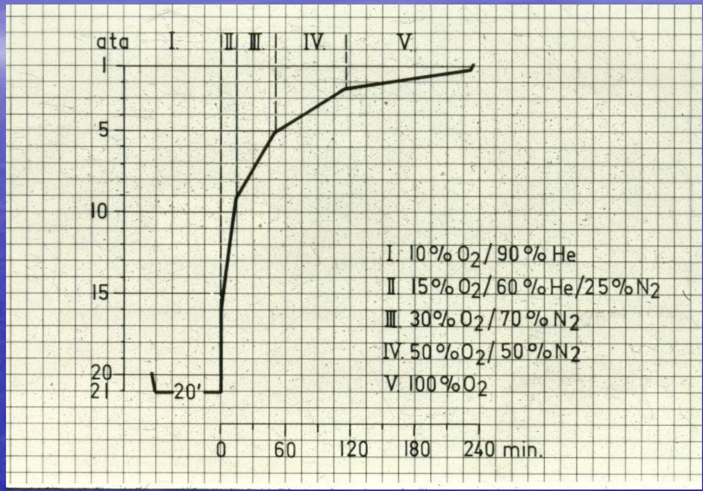
Prof. A.A. Bühlmann

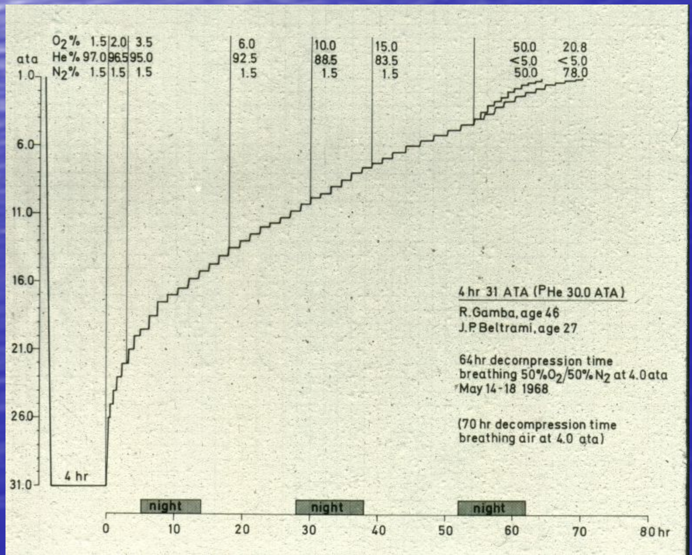
Mr. B. Schenk, former Technical Director of the DKL

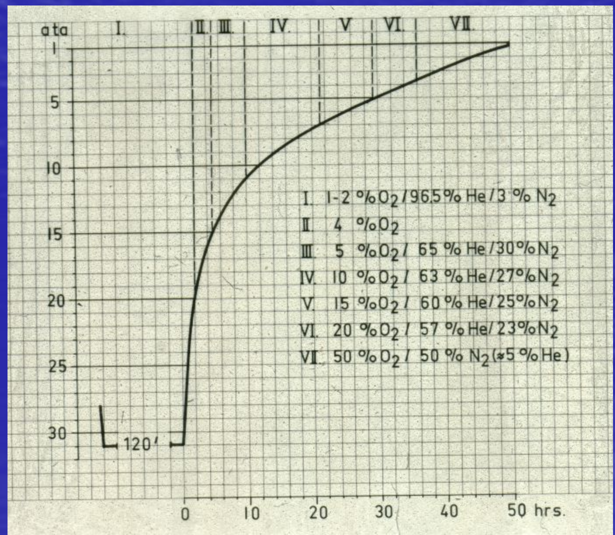
Bühlmann Memorial Symposium 2019

The „Lab“ and the men behind (10a)









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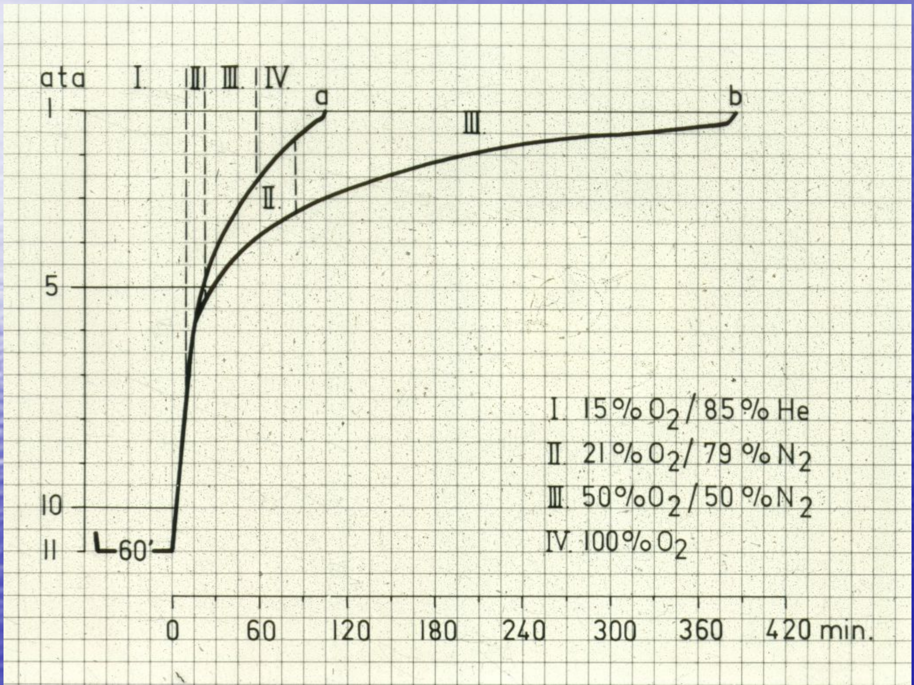
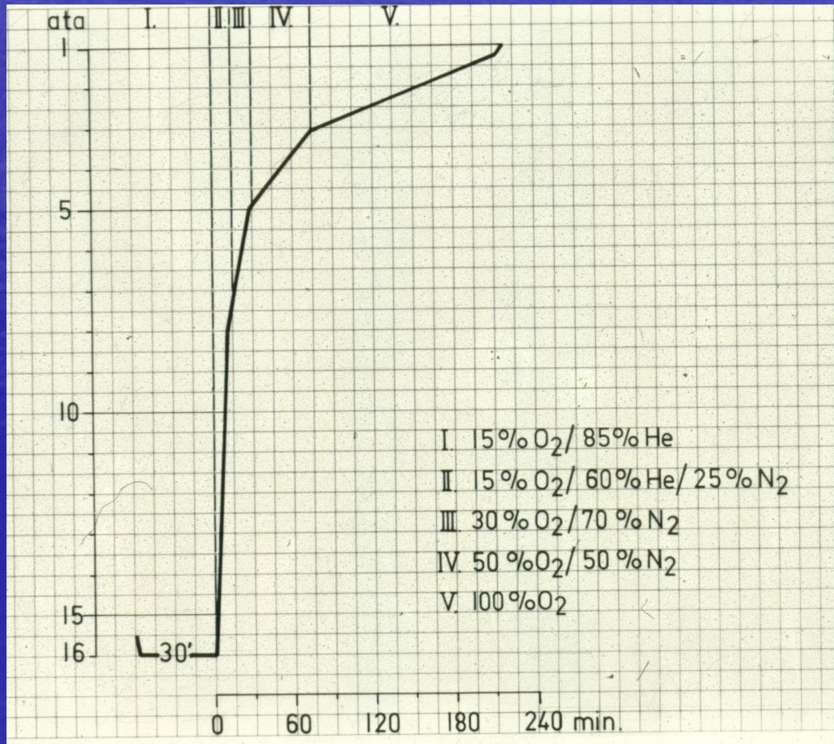
The „Lab“ and the men behind (10b)





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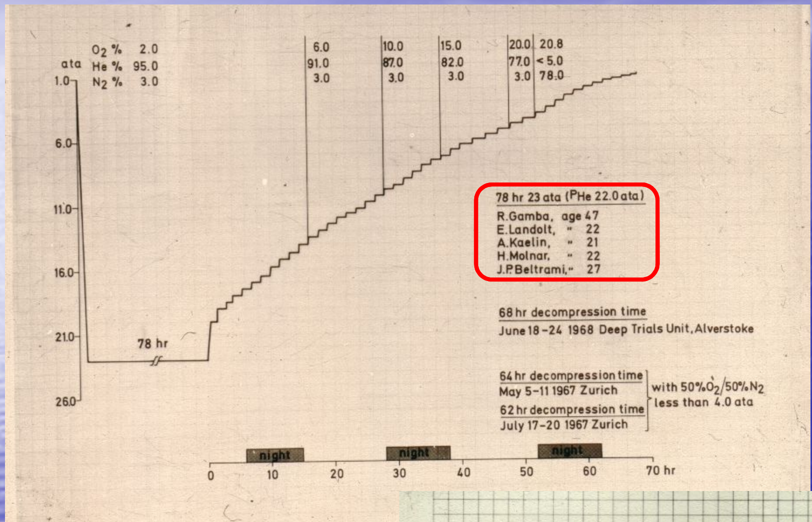
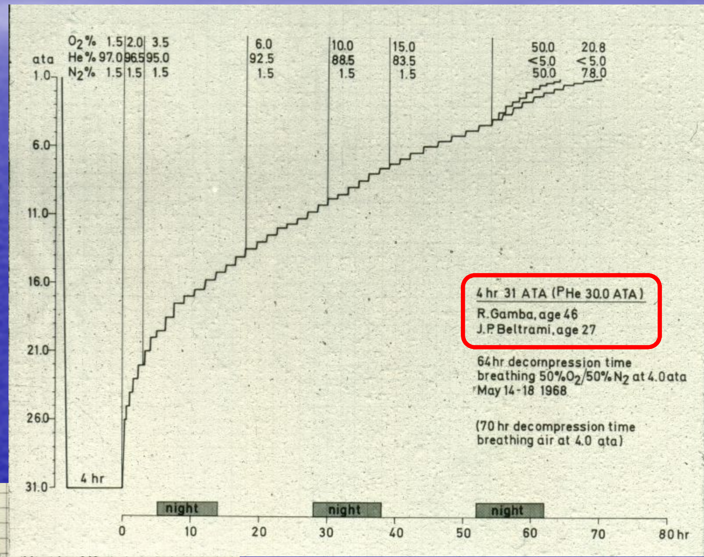
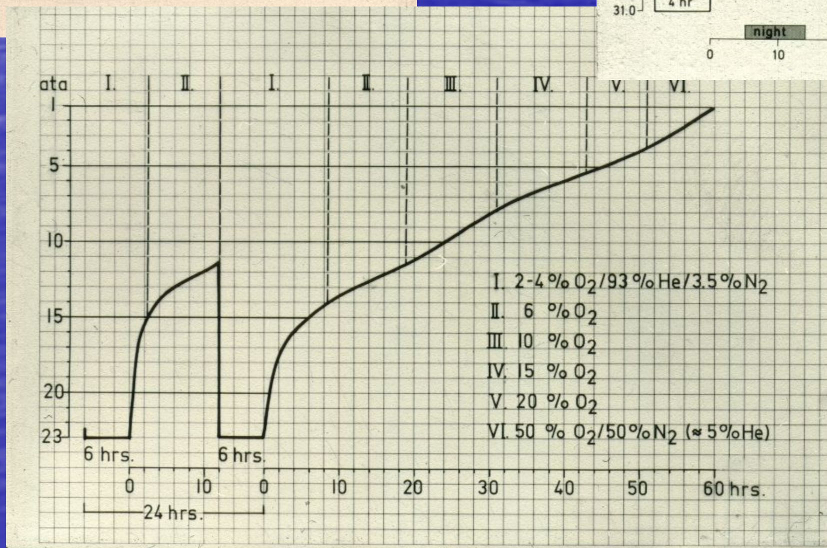
The „Lab“ and the men behind (10c)







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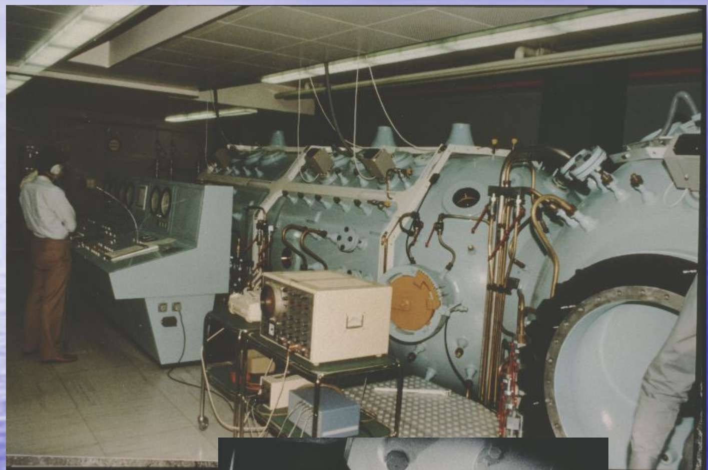
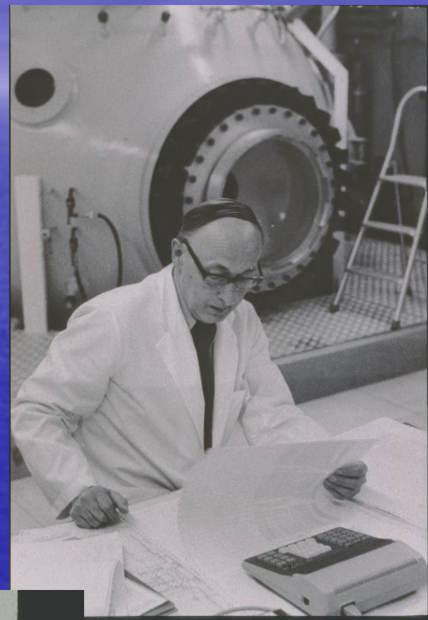
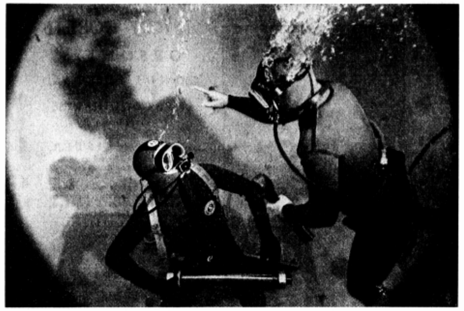
The „Lab“ and the men behind (11)





Bühlmann Memorial Symposium 2019

The „Lab“ and the men behind (12)



Beim Einsatz unter Wasser im Tauchtank lässt sich auch die Funktion von Atemgeräten und anderen Ausrüstungsteilen untersuchen. Ein raffiniertes Kommunikationssystem ermöglicht es dem Kontrollpersonal, sich mit unter Wasser schwimmenden Tauchern zu verständigen. Das Wasser im Tauchtank kann geheizt, gekühlt sowie laufend gereinigt werden. Ueber Unterwasserlautsprecher lassen sich in den Tauchtank Hintergrundgeräusche einspielen, wie sie für eine untermeerische Erdölbohrstelle kennzeichnend sind.

Tauchen im Tank

Von Kay Lommer (Text) und Heinz Baumann (Aufnahmen

Die Ozeane bedecken mehr als zwei Drittel der Oberfläche unseres Planeten. Noch sind sie weitgehend unerforscht, doch man weiss, dass sie die letzten unerschlossenen Schatzkammern der Menschheit sind. Auf dem Grund der Ozeane warten Rohstoffe in nach heutiger Auffassung nahezu unerschöpflichen Mengen auf ihre Ausbeutung. Und bei vernünftiger Bewirtschaftung kann das Meer auch eine überreiche Nahrungsquelle bleiben.

Die Geheimnisse der Tiefe haben Menschen schon vor Jahrtausenden unter Wasser gelockt. Bereits Aristoteles berichtet von Tauchern, die sich eines Atemschlauches oder kleiner Taucherglocken bedienten. Das Problem des Ueberlebens unter Wasser wurde ursprünglich als eine reine Frage der Beschaffung von Atemluft angesehen. Doch bei Verwendung einer einfachen Schlauchverbindung zur Oberfläche wird schon in geringer Tiefe der Druck des Wassers auf den Brustkorb spürbar, der das Heben der Rippen und damit die Atembewegung verunmöglicht.

Dieses Hindernis kann überwunden werden, indem man dem Taucher Luft unter Druck zuführt. Das Prinzip ist dasselbe, und zwar sowohl beim Helmtaucher wie beim mit Pressluftflaschen tauchenden Froschmann. Der Druck der Atemluft muss dabei dem in der entsprechenden Tauchtiefe herrschenden Ueberdruck angepasst werden. Dieser nimmt pro zehn Meter Wassertiefe um jeweils eine Atmosphäre zu. In 100 Metern Tiefe lastet auf dem Taucher somit ein Ueberdruck von 10 Atmosphären, in 200 Metern Tiefe von 20 Atmosphären und so weiter.

So enorm dieser Druck erscheint, er wird vom Körper ohne weiteres vertragen. Doch das Einatmen von Pressluft hat eine andere, folgenschwere Wirkung auf den Organismus: Je tiefer man taucht, je höher also der Druck der Atemluft ist, desto mehr *Stickstoff* löst sich im Blut, in den Muskeln, im Bindegewebe, im Fett und in den Knorpeln auf. Das Gas, aus dem vier Fünftel unserer Atemluft bestehen, ist dann im Organismus gelöst wie die Kohlensäure im Mineralwasser. Kehrt der Taucher nun zu schnell an die Oberfläche zurück, das heisst reduziert er den auf ihm lastenden Druck zu schnell, passiert dasselbe wie beim Oeffnen einer Mineralwasserflasche: Sein Blut schäumt auf, Gasbläschen in allen Geweben und im Gehirn führen zu raschem Tod. Kommt der Taucher mit dem Leben davon, können irreversible Schädigungen unterschiedlicher Schwere die Folge sein.

Indessen zeigt der Stickstoff auch noch eine andere Wirkung: Unterhalb einer gewissen Tiefe, also bei ausreichender Lösungskonzentration im Körper, beginnt er *narkotisch* zu wirken. Dies äussert sich zunächst im sogenannten Tiefenrausch, vergleichbar der Trunkenheit durch Alkohol. In grösseren Tiefen stellt sich rasch Bewusstlosigkeit ein. Schon leichter Tiefenrausch jedoch kann den Taucher zu falschem Verhalten verleiten. Unter Wasser bedeutet das sehr leicht den Tod.

Der Tiefenbereich, bis zu welchem ein Taucher mit stickstoffhaltiger Pressluft ungefährdet tauchen kann, wird in der Regel mit 30 bis 50 Metern angegeben. Risikofreudige, «abgehärtete» Taucher stiessen auch immer wieder weiter vor, doch Tauchtiefen von 80 oder gar 100 Metern galten noch vor etwa 15 Jahren als heroische Leistung. Heute wird – vor allem auf unterseeischen Erdölbohrstellen – routinemässig in Tiefen über 200, ja gegen 300 Meter getaucht. Dies wurde nur möglich durch die Entwicklung neuartiger Tauchmethoden und -verfahren. Nicht nur in Ländern, die an Ozeane grenzen – wie etwa in Frankreich, in den USA, in England oder Russland –, machten sich Wissenschafter an die schwierige Aufgabe, dem Menschen den Weg in die Tiefe zu erschliessen. Die wesentlichen Impulse kamen aus dem Binnenland Schweiz, und unser Land steht heute in diesem Forschungszweig international mit an vorderster Front.

Genau genommen begann die Entwicklung im Jahre 1959 mit dem Besuch eines Studenten beim damaligen Spezialisten für Lungenfunktion und heute international bekannten Zürcher Tauchmediziner Prof. Albert A. Bühlmann. Der junge Mann trug dem Wissenschafter seine Pläne vor, die durch die Stickstoffnarkose gegebene Tiefengrenze zu überwinden. Er stellte sich als Versuchstaucher zur Verfügung und wurde innert kurzem weltberühmt: Am 21. November 1959 machte Hannes Keller durch einen ersten sensationellen Tieftauchversuch im Zürichsee auf 120 Meter Schlagzeilen, ein Jahr später erreichte er im Tauchsimulator der französischen Marine in Toulon 250 Meter und 1962 vor der Küste Kaliforniens 300 Meter.

So grosses Aufsehen diese Rekordtauchgänge auch erregten – von ihrer wissenschaftlichen Bedeutung abgesehen waren sie von keinem praktischen Wert. Die Aufenthaltszeit in der grössten Tiefe betrug jeweils nur Sekunden beziehungsweise wenige Minuten. Der Taucher musste rasch wieder zur Oberfläche zurückkehren, da die Anreicherung der Atemgase in seinem Körper ein noch weitgehend ungelöstes Problem darstellte.

Die Leiter des Zürcher Druckkammerlaboratoriums, Prof. Dr. med. Albert A. Bühlmann und Ing. Benno Schenk, am Kommandopult des neuen Tauchsimulators.

Prof. Albert A. Bühlmann überprüft den Gesundheitszustand eines Tauchers nach Abschluss eines Ueberdrucktests.

Die Rekordtauchgänge erbrachten indessen den Beweis, dass der Mensch grundsätzlich unter dem Druck auch grosser Tiefen existieren kann. Nun begann Prof. Bühlmann in einem am Kantonsspital Zürich eingerichteten Druckkammerlaboratorium systematisch die physiologischen Gegebenheiten zu untersuchen, die bei einem *langen* Unterwasseraufenthalt des Menschen zu berücksichtigen sind. Im Vergleich zu den Forschungsstätten der nun ihre Anstrengungen ebenfalls verstärkenden Amerikaner, Franzosen, Engländer und Russen war das Zürcher Druckkammerlaboratorium bescheiden eingerichtet. Dennoch schaffte es Bühlmann, der internationalen Konkurrenz stets einige Nasenlängen voraus zu sein, und er verblüffte die Fachwelt immer wieder durch aufsehenerregende wissenschaftliche Leistungen. Eine der bemerkenswertesten war ein Rekordtauchgang im Jahre 1969 mit mehreren Versuchspersonen, die während mehr als dreier Tage unter Verhältnissen entsprechend einer Tiefe von 300 Metern lebten und zudem drei Arbeitstauchgänge von jeweils 1 bis 2 Stunden in 350 Metern Tiefe ausführten.

Dieser Rekordtauchgang fand in einem Tauchsimulator der Royal Navy in Südengland statt, da in Zürich damals noch keine Druckkammer entsprechender Grösse und mit einem Wassertank zur Verfügung stand. Experimente solcher Art werden nicht im Meer durchgeführt. Der technische Aufwand wäre enorm, das Risiko gross, die Verhältnisse unübersichtlich.

Man kann die physiologischen Verhältnisse, wie sie in der Meerestiefe herrschen, absolut naturgetreu simulieren, indem man Taucher in druckfeste Stahltanks setzt und diese mit dem entsprechenden Ueberdruck «aufpumpt». In einer solchen Druckkammer verhält sich der Körper genauso, als befände er sich in der entsprechenden Wassertiefe. Die Simulation wird noch echter, wenn ein Druckkammersystem mit einem wassergefüllten Abteil versehen wird, in dem Taucher mit Atemgeräten herumschwimmen und den Organismus belastende Arbeiten ausführen können.

Die dargelegte Problematik um den Tiefenrausch macht deutlich, dass der Taucher in den sicheren Tod schwimmen würde, wenn er mit stickstoffhaltiger Pressluft 100, 200 Meter oder gar noch tiefer tauchte. Er muss in solchen Fällen ein anderes Atemgasgemisch benützen, in dem der gefährliche Stickstoff durch das Edelgas Helium ersetzt wurde. Auch Helium führt zur Bläschenbildung im Organismus, wenn der Taucher zu schnell aufsteigt. Es entfaltet jedoch selbst in mehreren hundert Metern Tiefe noch keine narkotische Wirkung.

Wie tief kann ein Taucher mit einem Helium-Sauerstoff-Gemisch tauchen? Wie lange braucht er zum sicheren Auftauchen, wenn er kurze oder längere Zeit in einer bestimmten Tiefe zugebracht hat? Dies sind zwei im Vordergrund stehende Fragen, die die Tauchforscher mit Hilfe von Druckkammerexperimenten beantworten wollen. Im Druckkammerlaboratorium Zürich wurde Mitte letzten Jahres einer der modernsten heute existierenden Tauchsimulatoren in Betrieb genommen. Dieser

Mit dem Fahrrad-Ergometer wird das Verhalten des Organismus bei körperlicher Arbeit unter Ueberdruck getestet.

Neue Zürcher Zeitung vom 06.02.1977

environment has been questioned in the past. Trials conducted led to a revision of practices and changes were made to guard book procedures. The SURVIVEX provided the opportunity to verify the guard book in a realistic situation.

The ELSS capability had not yet been conclusively demonstrated. Pods which weigh approximately 100 kg when fully laden with life support stores, food, water, medications etc. can be posted by ROV into the escape tower, providing extra time for the rescue forces to prepare. Difficulties have been noted when trialling the pods and a formal evaluation of the pod posting according to guard book procedures occurred during BLACK CARILLON 98.

Monitoring System

How does the RAN manage such a process? The RAN has implemented an internal 2 stage certification process addressing the material, engineering and operational aspects of the SERS with an additional annual audit of the system addressing these issues. The Remora is certified by the classification authority, Det Norske Veritas (DNV) for material safety with the recompression chamber suite currently undergoing this certification process.

The SUBSAFE Board Submarine Escape and Rescue Subgroup (comprising operational, medical and engineering representatives) is responsible for ensuring no hazard items represent an unacceptable risk prior to the conduct of these trials and in future operations.

Australian Defence Medical Ethics committee approval has been sought and granted for each phase of the exercises.

Summary

The RAN has developed and implemented a sophisticated escape and rescue organisation, the concept of which is being adopted by other major submarine nations around the world. The organisation includes not only the material hardware but a framework for review, accountability and progress. The Black Carillon exercise series will be followed by future exercises planned to maintain the momentum and in-house expertise in submarine escape and rescue.

LCDR Robyn Walker, MBBS, Dip DHM, is Officer in Charge, Royal Australian Navy Submarine and Underwater Medicine Unit, HMAS PENGUIN, Middle Head Road, Mosman, New South Wales 2088, Australia. Phone +61-(0)2-9960-0333. Fax +61-(0)2-9960-4435. E-mail Robyn.Walker.150150@navy.gov.au .

MILESTONES OF THE DEEP DIVING RESEARCH LABORATORY ZURICH

J Wendling, P Nussberger and B Schenk

Key Words

Decompression, deep diving, history, hyperbaric facilities, hyperbaric research, mixed gases, research, tables.

Abstract

Between 1959 and 1963 the deep diving pioneer Hannes Keller performed a series of depth records using heliox. He was assisted by the lung physiologist Professor A A Bühlmann of Zurich University. In 1961 application of a modified multi-tissue, perfusion limited, decompression algorithm for nitrogen and helium enabled an open sea dive to 305 m at Santa Catalina Island off California. However the price was a fatality. This dive was a break through for commercial diving, proving the feasibility of deep diving with helium.

A research contract with Shell, to develop decompression tables for offshore work, allowed the restructured research team at Zurich to construct a 100 ATA hyper- and hypobaric, multichamber, research and treatment facility, planned and directed by one of the authors (BS), an engineer. Experimental dives were continued down to 220 and 350 m at Alverstoke, UK, in 1969, and to 575 m in Zurich in 1981. The original decompression tables were empirically modified and became widely used. The problems of calculated tables and true reality will be discussed.

Altitude dive tables for scuba bounce diving were produced to meet the needs of military and police divers in Switzerland. Dive tables using the same algorithms as used for the deep dive experiments were calculated and tested for different altitude ranges. Bühlmann postulated a linear relationship of his supersaturation tolerance coefficients to the external pressure. In 1972 the first altitude table was produced using a 12-tissue model and in 1986 the actual set of tables was produced based on 16 tissues.

In a period of general rejection of any diving practices using computers as on-line dive planners, Bühlmann supported the adaptation of the Zurich tables for diving computers. The 1986 model has been further adapted to take into account workload, temperature, respiratory rate and inadequate decompression procedures specially considering the bubbles load of the lungs during certain phases.

The actual activities of the hyperbaric facility can be divided into the development of deep dive breathing apparatus and research into clinical hyperbaric oxygen (HBO) therapy.

Early Deep Diving Trials

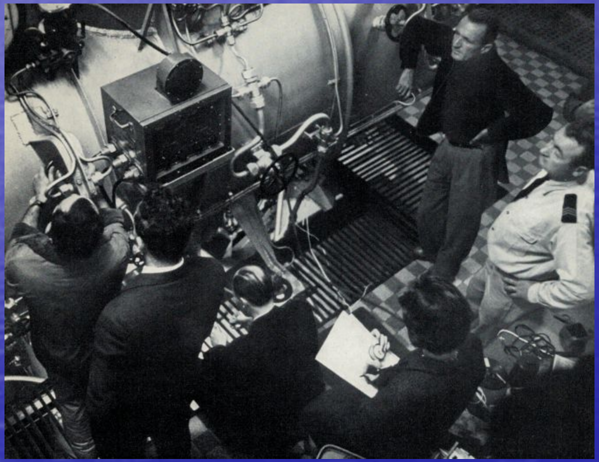
Bühlmann Memorial Symposium 2019

Early Deep Diving Trials (1)

Birth of a new model: Early deep dives with Hannes Keller (1)

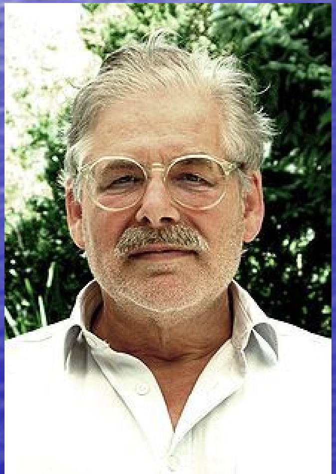
Toulon, French Navy, 25. April 1961

300m and 220m Heliox dives



H. Keller & A.A. Bühlmann

Trials with French Navy 1961; 300m



H. Keller ca. 2005

Capt Stover USN….
Cmdr de Croulard, GERS

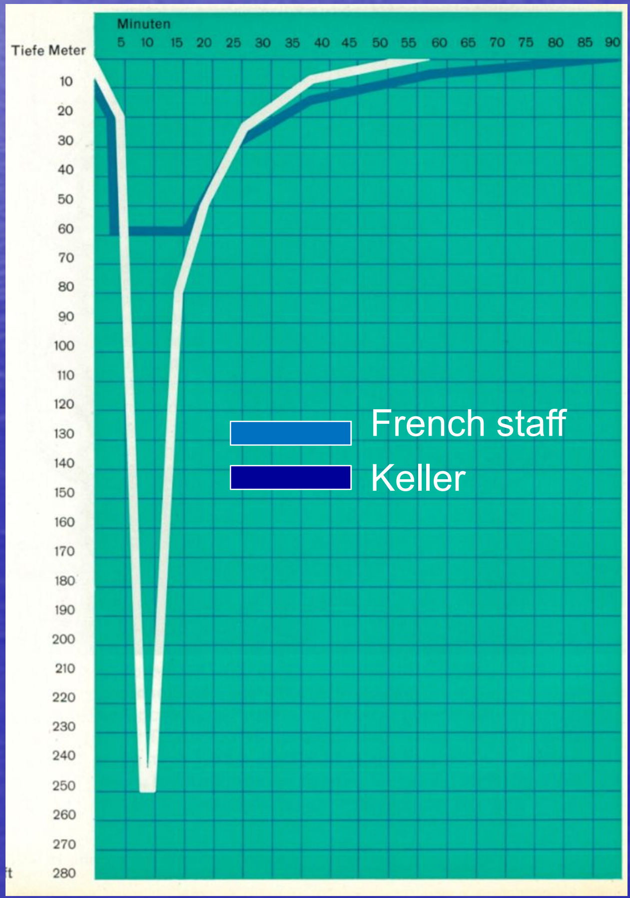
Early Deep Diving Trials (2)

Birth of a new model: Early deep dives with Hannes Keller (2a)

Toulon, French Navy, 4 November 1960

Early trials to 60m and 250m

Bottom time: 15 and 10min



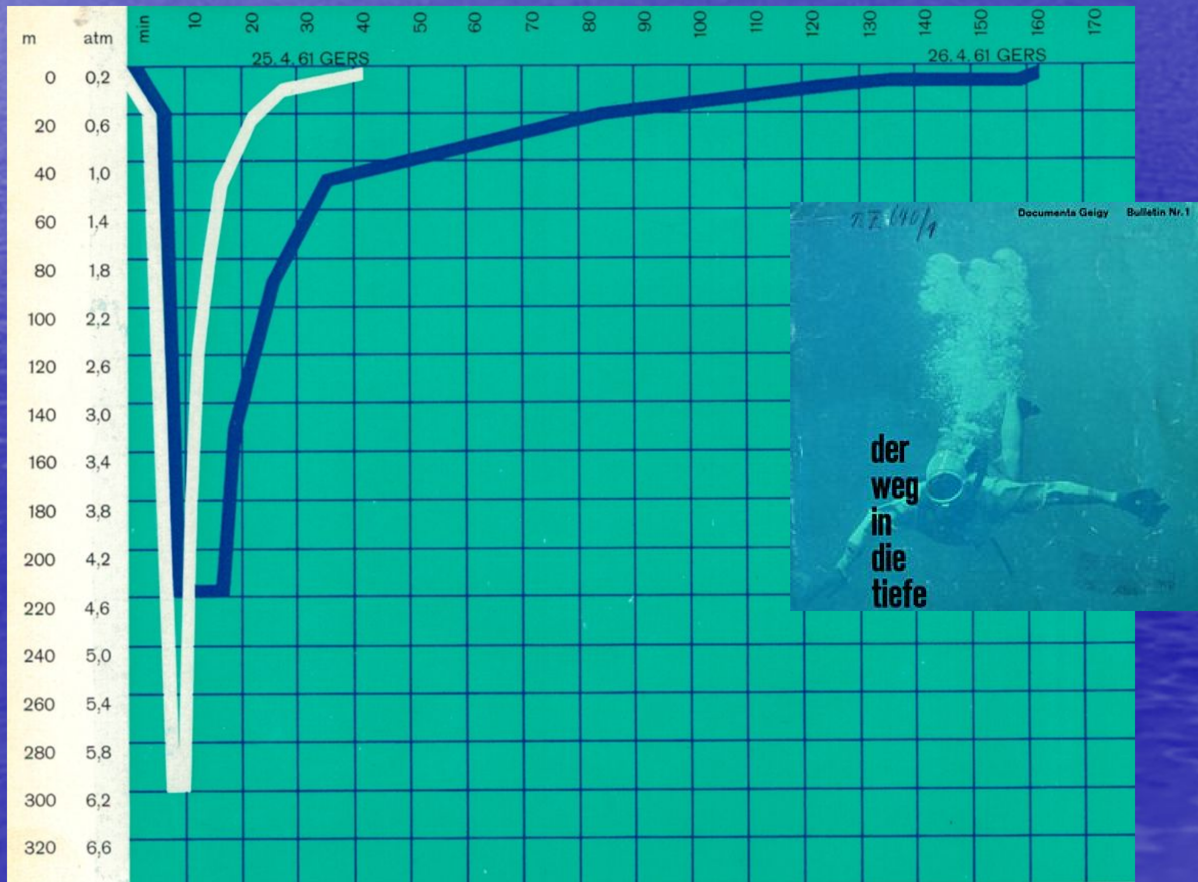
Early Deep Diving Trials (3)

Birth of a new model: Early deep dives with Hannes Keller (2b)

Toulon, French Navy, 25. April 1961

300m and 220m dives within 2 days!

Bottom time: 10 and 18min



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Early Deep Diving Trials (4a)

Birth of a new model: Early deep dives with Hannes Keller (3)

San Diego, off
Catalina Island,
US Navy,
December 3, 1962

First 1020ft dive
ever made by
humans

Peter Small, who died of annoxia shortly afterwards

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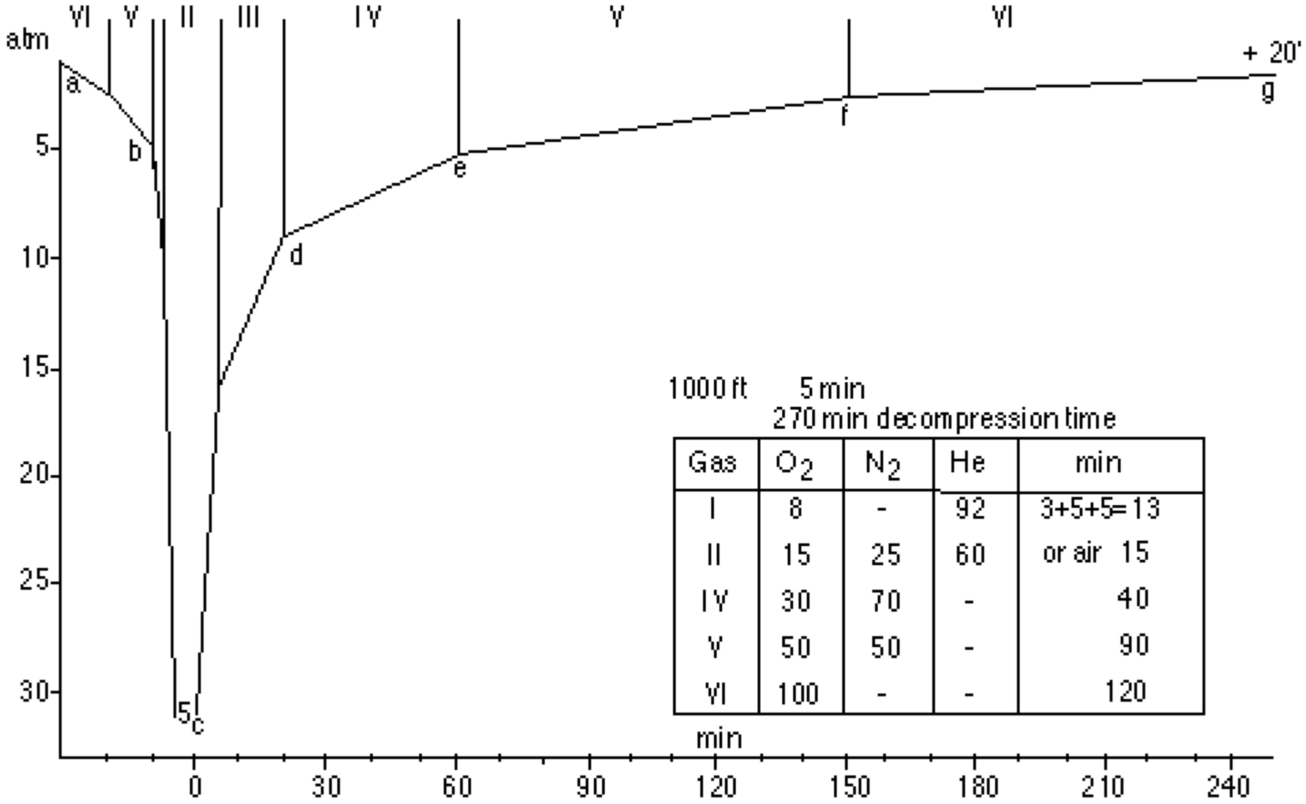
Early Deep Diving Trials (4b)

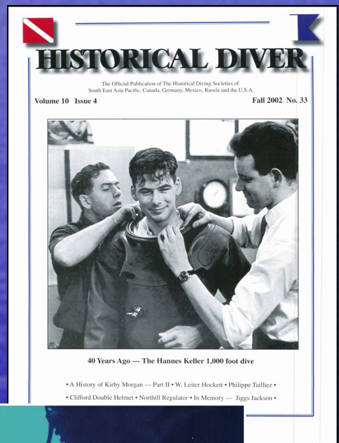


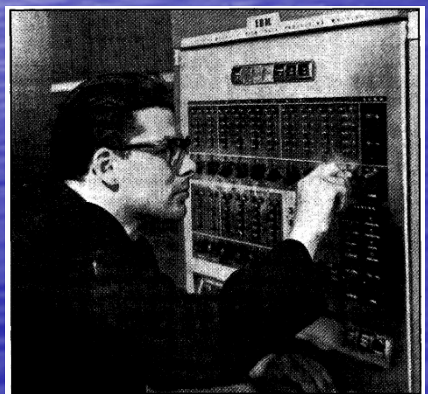
Gas	O_2	N_2	He	min
I	8	-	92	3+5+5=13
II	15	25	60	or air 15
IV	30	70	-	40
V	50	50	-	90
VI	100	-	-	120

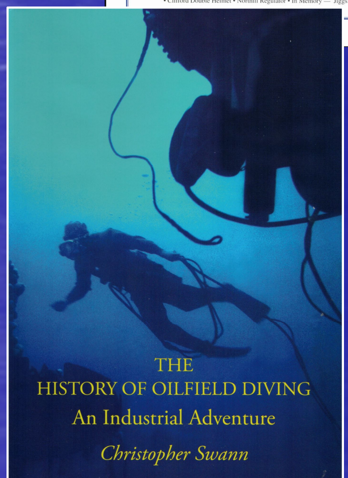
Figure 3. Compression and decompression profiles and gases used for a dive to 300 m (1,000 ft) for 5 minutes bottom time, two subjects. (Figure 6 in Keller and Bühlmann[1]).

Early Deep Diving Trials (5)

Birth of a new model: Early deep dives with Hannes Keller (4)




Keller with IBM data processing equipment working on his decompression tables.



Triumph and Tragedy at once

Gas mixtures breathed through mask:

Bottom: 8% O_2 / 92% He

500ft: 15% O_2 / 60% He / 25% N_2

165ft: 30% O_2 / 70% N_2

133ft: 50% O_2 / 50% N_2

50ft: 100% O_2

(the bell was filled with air. So after cut of external mixture supply from outside tanks at bottom, Keller was forced to breathe air on 300m / 30bar!)

Perfusion- and Diffusion based models

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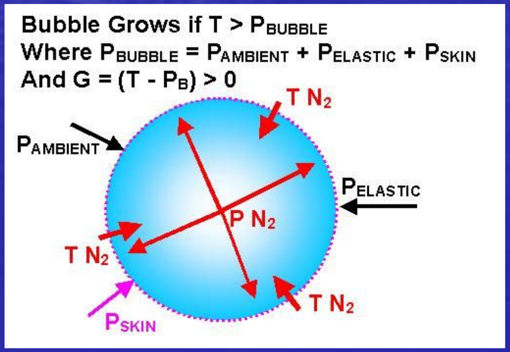
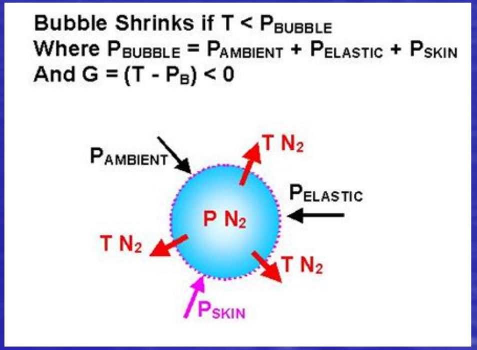
Perfusion- and Diffusion based models (1)

General overview on models: concepts (1)

Two rather different concepts have been used for decompression modelling:

- The first assumes that dissolved gas is eliminated while in the ***dissolved phase***, and that bubbles are not formed during asymptomatic decompression.
- The second, which is supported by experimental observation, assumes that bubbles are formed during most asymptomatic decompressions, and that gas elimination must consider both ***dissolved gas*** - and ***bubble phases***.



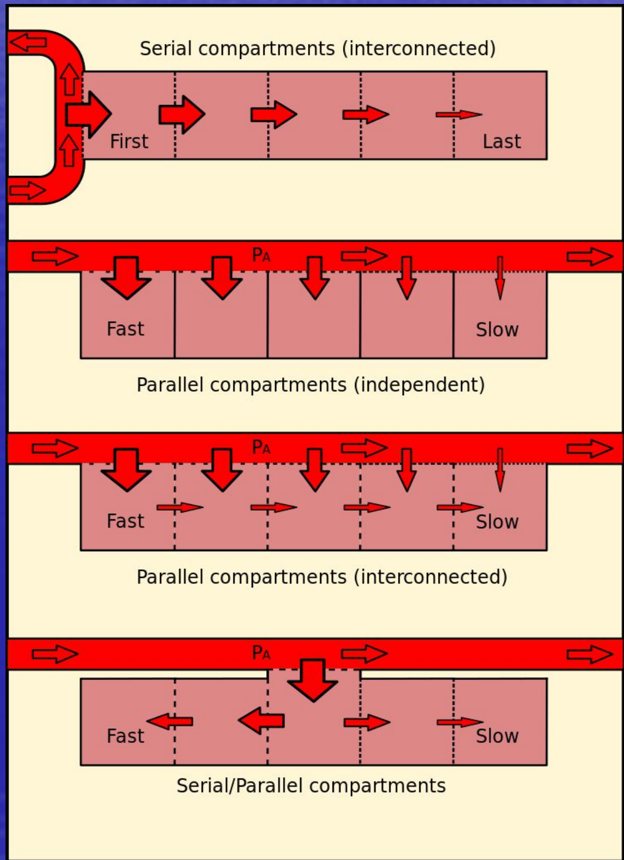


Perfusion- and Diffusion based models (2)

General overview on models: dissolved phase types (2)

Early decompression models tended to use the dissolved phase models, and adjusted them by more or less arbitrary factors to reduce the risk of symptomatic bubble formation. ***Dissolved phase models*** are of two main groups:

- Parallel compartment models, where several compartments with varying rates of gas absorption (half time), are considered to exist independently of each other, and the limiting condition is controlled by the compartment which shows the worst case for a specific exposure profile. These compartments represent conceptual tissues and are not intended to represent specific organic tissues, merely to represent the range of possibilities for the organic tissues.
- The second group uses serial compartments, where gas is assumed to diffuse through one compartment before it reaches the next.
- A recent variation on the serial compartment model is the Goldman interconnected compartment model (ICM).



Different types of dissolved gas models

Perfusion- and Diffusion based models (3)

General overview on models: outgassing mechanics (3)

The critical supersaturation approach

J.S. Haldane first used a (fixed) critical pressure ratio between the sum of the inert gas in each tissue and the surrounding ambient pressure. Further research by Workmann, Bühlmann et al. suggested that the criterion was not the ratio of pressures, but the actual pressure differentials.

At a given ambient pressure, the M-value is the maximum value of absolute inert gas pressure that a tissue compartment can take without symptoms of DCS. M-values are limits for the tolerated gradient between inert gas pressure and ambient pressure in each compartment

The no-supersaturation approach

According to the thermodynamic model of Hugh LeMessurier and Brian A. Hills, this condition of optimum driving force for outgassing is satisfied when the ambient pressure is just sufficient to prevent phase separation (bubble formation).

The model assumes that the natural unsaturation in the tissues due to metabolic reduction in oxygen partial pressure provides the buffer against bubble formation, and that the tissue may be safely decompressed provided that the reduction in ambient pressure does not exceed this unsaturation value. The natural unsaturation increases with depth.

The critical volume approach

The critical-volume criterion assumes that whenever the total volume of gas phase accumulated in the tissues exceeds a critical value, signs or symptoms of DCS will appear. This assumption is supported by doppler bubble detection surveys. The consequences of this approach depend strongly on the bubble formation and growth model used, primarily whether bubble formation is practicably avoidable during decompression.

Perfusion- and Diffusion based models (4)

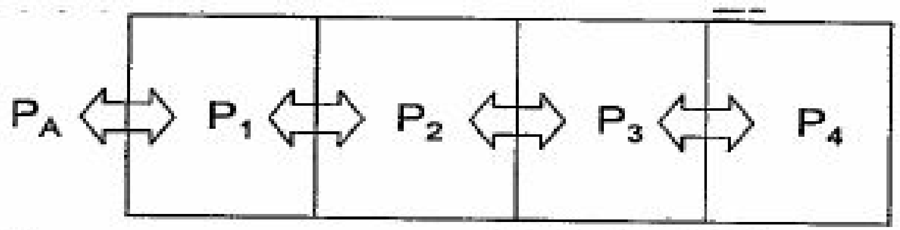
General overview on models: general remarks/conclusions (4)

- More recent models attempt to model bubble dynamics, also by simplified models, to facilitate the computation of tables, and later to allow real time predictions during a dive.
  The models used to *approximate bubble dynamics* are varied, and range from those which are not much more complex that the *dissolved phase* models, to those which require considerably greater computational power.

- *None of the decompression models can be shown to be an accurate representation of the physiological processes, although interpretations of the mathematical models have been proposed which correspond with various hypotheses.*
  They are all approximations which predict reality to a greater or lesser extent, and are acceptably reliable only within the bounds of calibration against collected experimental data.

Perfusion- and Diffusion based models (5)

DCIEM (Canada) serial 4 compartment model



$$\frac{dP_n}{dt} = A\left[(B + P_{n-1} + P_n)(P_{n-1} - P_n) - (B + P_n + P_{n+1})(P_n - P_{n+1})\right]$$

where $P_0 = P_A$ and $P_5 = 0$

Fig. 6. Serial compartments decompression model - Kidd-Stubbs Model (Canadian/ DCIEM).

(Source: DEVELOPMENT OF THE DCIEM 1983 DECOMPRESSION MODEL FOR COMPRESSED AIR DIVING, September 1984, DCIEM No. 84-R-44, R.Y. Nishi, G.R. Lauckner. Defence and Civil Institute of Environmental Medicine, Ontario, Canada)

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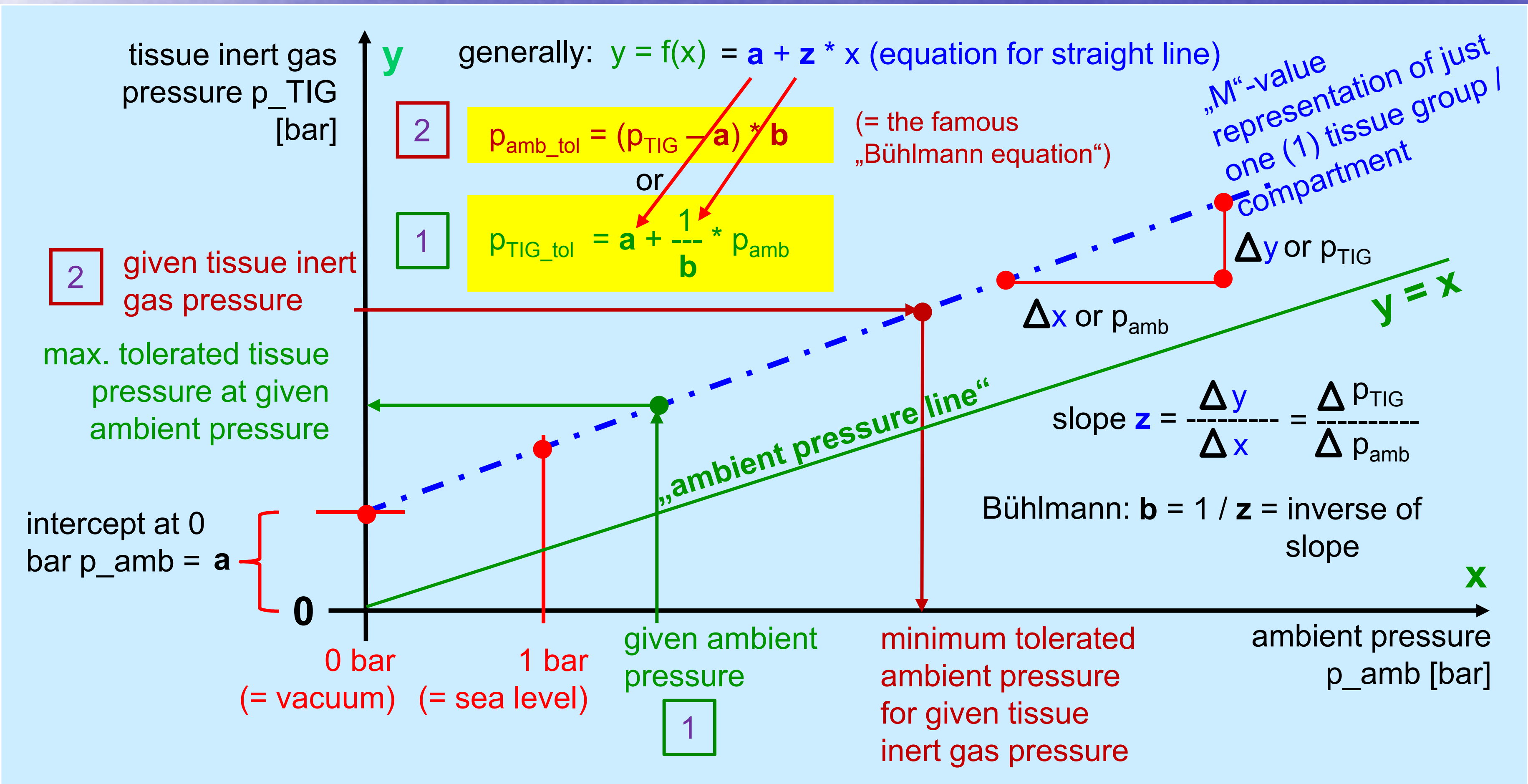
The Linear Perfusion Models ZHL-12/16

The Linear Perfusion Models ZHL12/16 (1)

What do the factors **a, b** represent?



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The Linear Perfusion Models ZHL12/16 (2a)

The former System ZHL-12 (1983, already modified)

BBC BROWN BOVERI

Zul. Inertgas-Partialdruck als Fkt. des Umgebungsdruckes

[Daten n. A.A. Bühlmann 1982]

Änd.:

WBZ-Best.:
Fach:
Entstand aus:
Ersatz für:
Ersetzt durch:
Gezeichnet 83-09-26
Geprüft
Gesehen

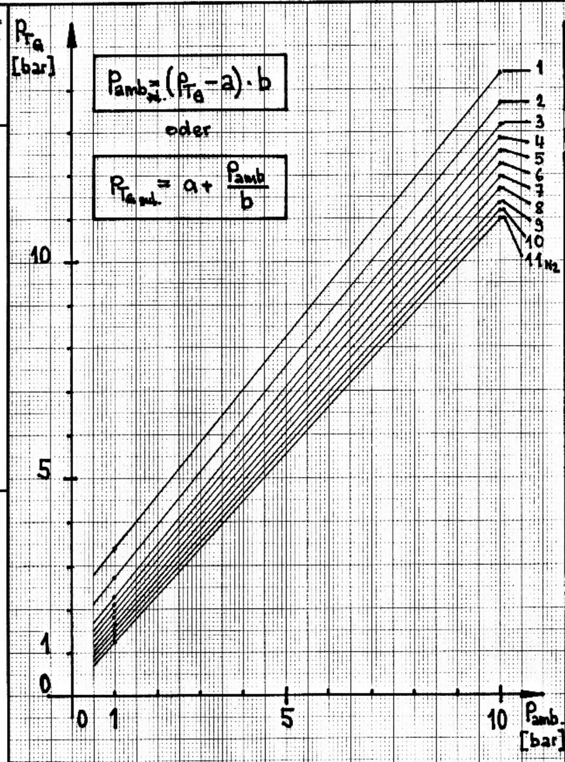

Tabelle A1

Halbwertszeiten u. Faktoren:

#	$t_{H\,He}$	$t_{H\,N_2}$	Koeff. a	Koeff. b
1	1	2.65	2.20	0.820
2	3	7.94	1.50	
3	4.6	12.2	1.05	0.825
4	7	18.5	0.90	0.835
5	10	26.5	0.75	0.845
6	14	37	0.60	0.860
7	20	53	0.45	0.870
8	30÷43	79÷114	0.42	0.890
9	55÷70	146÷185	0.40	0.910
10	90	238	0.38	0.925
11	115÷240	304÷635	He 0.38* N2 0.18*	

Beachte: $t_{H\,N_2} = 2.65 \cdot t_{H\,He}$

* für 21% O_2, 78% He resp. 21% O_2, 79% N_2

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The Linear Perfusion Models ZHL12/16 (2b)

The former System ZHL-12 (1983, already modified)

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Krit. Uebersättigungsfaktoren für N_2

$\lambda_{krit_{N2}} = f(t_H, P_{amb})$

[Daten n. A.A. Bühlmann 1982]

Gezeichnet 83-07-16

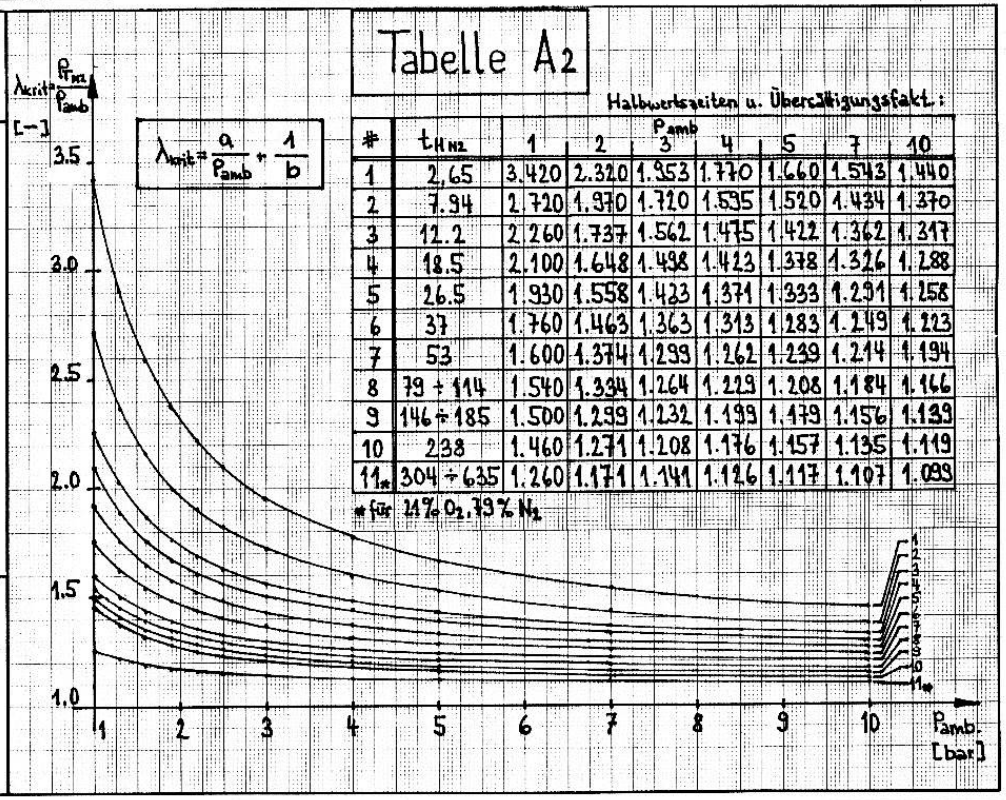
Tabelle A2

Halbwertszeiten u. Übersättigungsfakt.:

#	$t_{H\,N2}$	P_{amb} 1	2	3	4	5	7	10
1	2,65	3.420	2.320	1.953	1.770	1.660	1.543	1.440
2	7.94	2.720	1.970	1.720	1.595	1.520	1.434	1.370
3	12.2	2.260	1.737	1.562	1.475	1.422	1.362	1.317
4	18.5	2.100	1.648	1.498	1.423	1.378	1.326	1.288
5	26.5	1.930	1.558	1.423	1.371	1.333	1.291	1.258
6	37	1.760	1.463	1.363	1.313	1.283	1.249	1.223
7	53	1.600	1.374	1.299	1.262	1.239	1.214	1.194
8	79 ÷ 114	1.540	1.334	1.264	1.229	1.208	1.184	1.166
9	146 ÷ 185	1.500	1.299	1.232	1.199	1.179	1.156	1.139
10	238	1.460	1.271	1.208	1.176	1.157	1.135	1.119
11*	304 ÷ 635	1.260	1.171	1.141	1.126	1.117	1.107	1.099

* für 21% O_2, 79% N_2

$$\lambda_{krit} = \frac{a}{P_{amb}} + \frac{1}{b}$$



The Linear Perfusion Models ZHL12/16 (2c)

Die Koeffizienten des Systems ZHL-12

Version : Bühlmann, 28.05.1986 (Aenderungen Nr. 1÷4)
verwendet: neue Tabelle 0-700 m und 701-2500 m des SUSV/VDST

$$P_{amb.tol} = (P_{TIG} - a) \cdot b \quad (bar)$$

$P_{amb.tol}$: tolerierter Umgebungsdruck

P_{TIG} : N_2-Lösungsdruck im Gewebe

a,b : ZHL-12 Koeffizienten

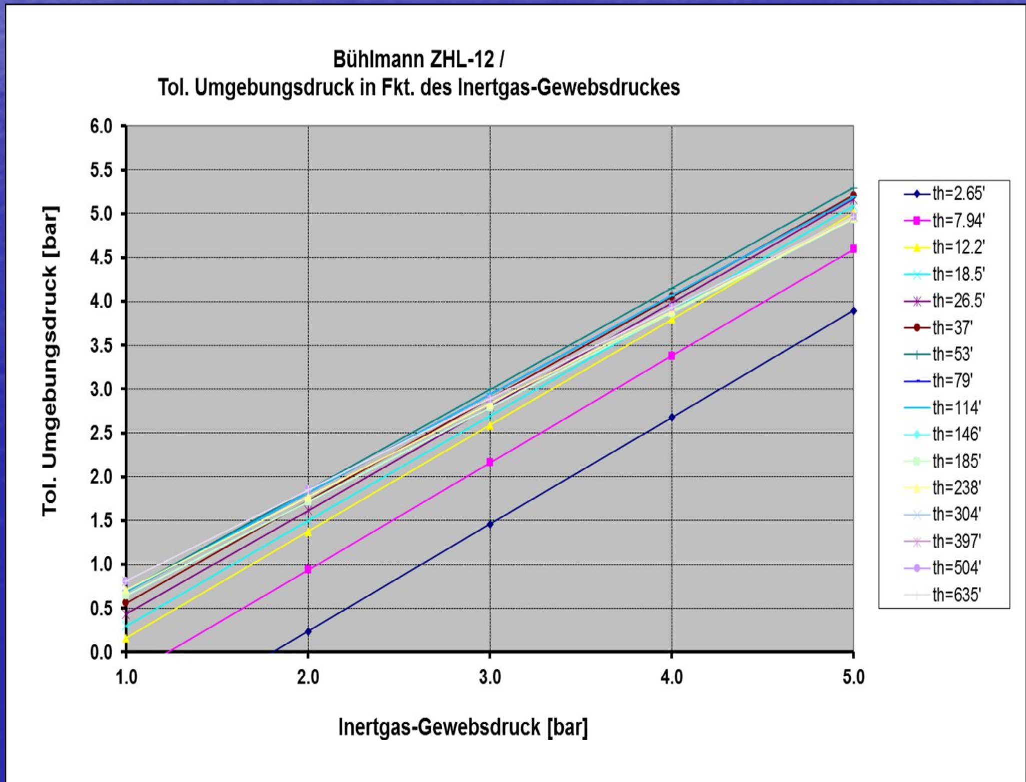
Gewebe	Komp. Nr.	$t_{½}$ (min)	Koeff.a (bar)	Koeff.b (-)
Gehirn, Rückenmark	1	4.0	1.906	0.810
	2	8.0	1.450	0.810
	3	12.5	1.040	0.810
	4	18.5	0.880	0.830
	5	27.0	0.717	0.845
Haut, Muskulatur	6	38.3	0.575	0.860
	7	54.3	0.468	0.870
	8	77.0	0.441	0.903
	9	109.0	0.415	0.908
Innenohr	10	146.0	0.416	0.939
	11	187.0	0.369	0.946
	12	239.0	0.369	0.946
	13	305.0	0.255	0.962
Gelenke, Knochen	14	390.0	0.255	0.962
	15	498.0	0.255	0.962
	16	635.0	0.255	0.962

As originally planned for SUSV / VDST tables.
Some minor adaptins were later made towards ZHL-16B.

The Linear Perfusion Models ZHL12/16 (2d)

The former System ZHL-12 (as published)

#	HWZ (tH) [min]	Letter Code	a [bar]	b [---]
1	th=2.65'	A	2.2000	0.8200
2	th=7.94'	B	1.5000	0.8200
3	th=12.2'	C	1.0500	0.8250
4	th=18.5'	D	0.9000	0.8350
5	th=26.5'	E	0.7500	0.8450
6	th=37'	F	0.6000	0.8600
7	th=53'	G	0.4500	0.8700
8	th=79'	H	0.4300	0.8900
9	th=114'	I	0.4300	0.8900
10	th=146'	J	0.4300	0.9310
11	th=185'	K	0.4300	0.9310
12	th=238'	L	0.3500	0.9430
13	th=304'	M	0.2300	0.9620
14	th=397'	N	0.2300	0.9620
15	th=504'	O	0.2300	0.9620
16	th=635'	P	0.2300	0.9620



From: Decompression – Decompression Sicknes, 1983

The Linear Perfusion Models ZHL12/16 (3a)

The new System ZHL-16 (as published)

compartment #	half-time [min]	ZH-L16A (theoretical) b [-]	ZH-L16A (theoretical) a [bar]	ZH-L16B table a [bar]	ZH-L16C computer a [bar]
1	4,0	0,5050	1,2599	1,2599	1,2599
2	8,0	0,6514	1,0000	1,0000	1,0000
3	12,5	0,7222	0,8618	0,8618	0,8618
4	18,5	0,7825	0,7562	0,7562	0,7562
5	27,0	0,8126	0,6667	0,6667	0,6200
6	38,3	0,8434	0,5933	0,5600	0,5043
7	54,3	0,8693	0,5282	0,4947	0,4410
8	77,0	0,8910	0,4701	0,4500	0,4000
9	109,0	0,9092	0,4187	0,4187	0,3750
10	146,0	0,9222	0,3798	0,3798	0,3500
11	187,0	0,9319	0,3497	0,3497	0,3295
12	239,0	0,9403	0,3223	0,3223	0,3065
13	305,0	0,9477	0,2971	0,2850	0,2835
14	390,0	0,9544	0,2737	0,2737	0,2610
15	498,0	0,9602	0,2523	0,2523	0,2480
16	635,0	0,9653	0,2327	0,2327	0,2327

- *A verified set of 16 tissue group halftimes and their factors a,b for air with adaption to table- and computer use.*
- *A similar set exists for Helium.*
- *With more than 1 inert gas breathed, resulting factors a, b are calculated on the base of their momentary tissue pressures.*

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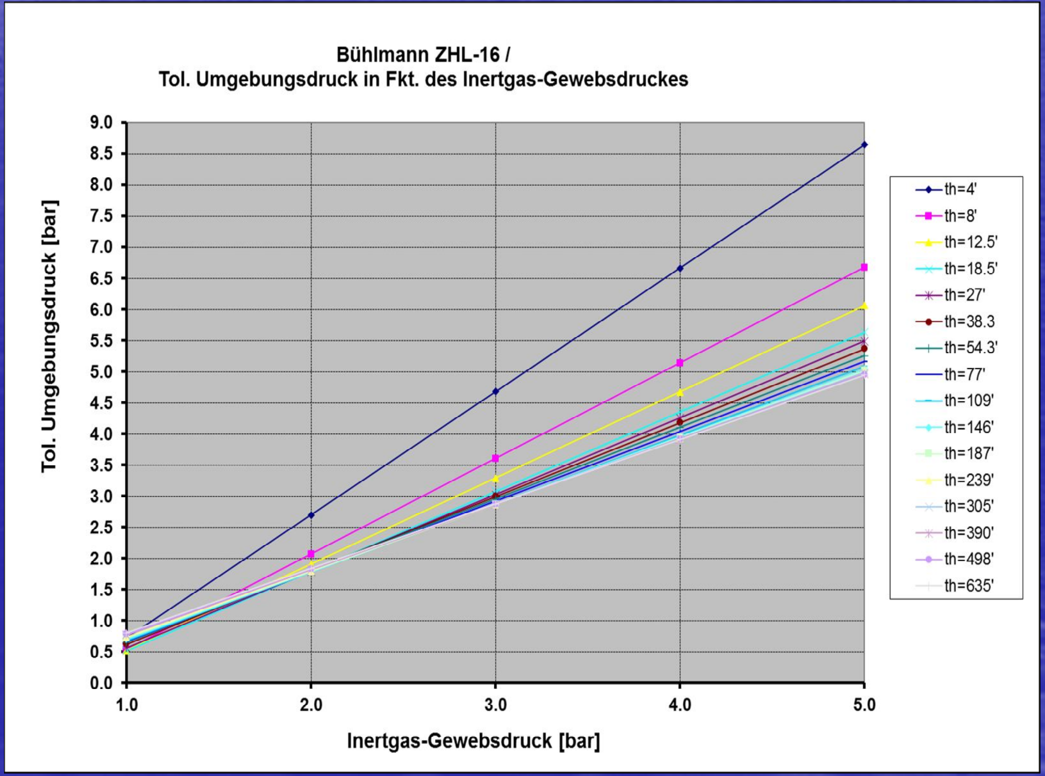
The Linear Perfusion Models ZHL12/16 (3b)

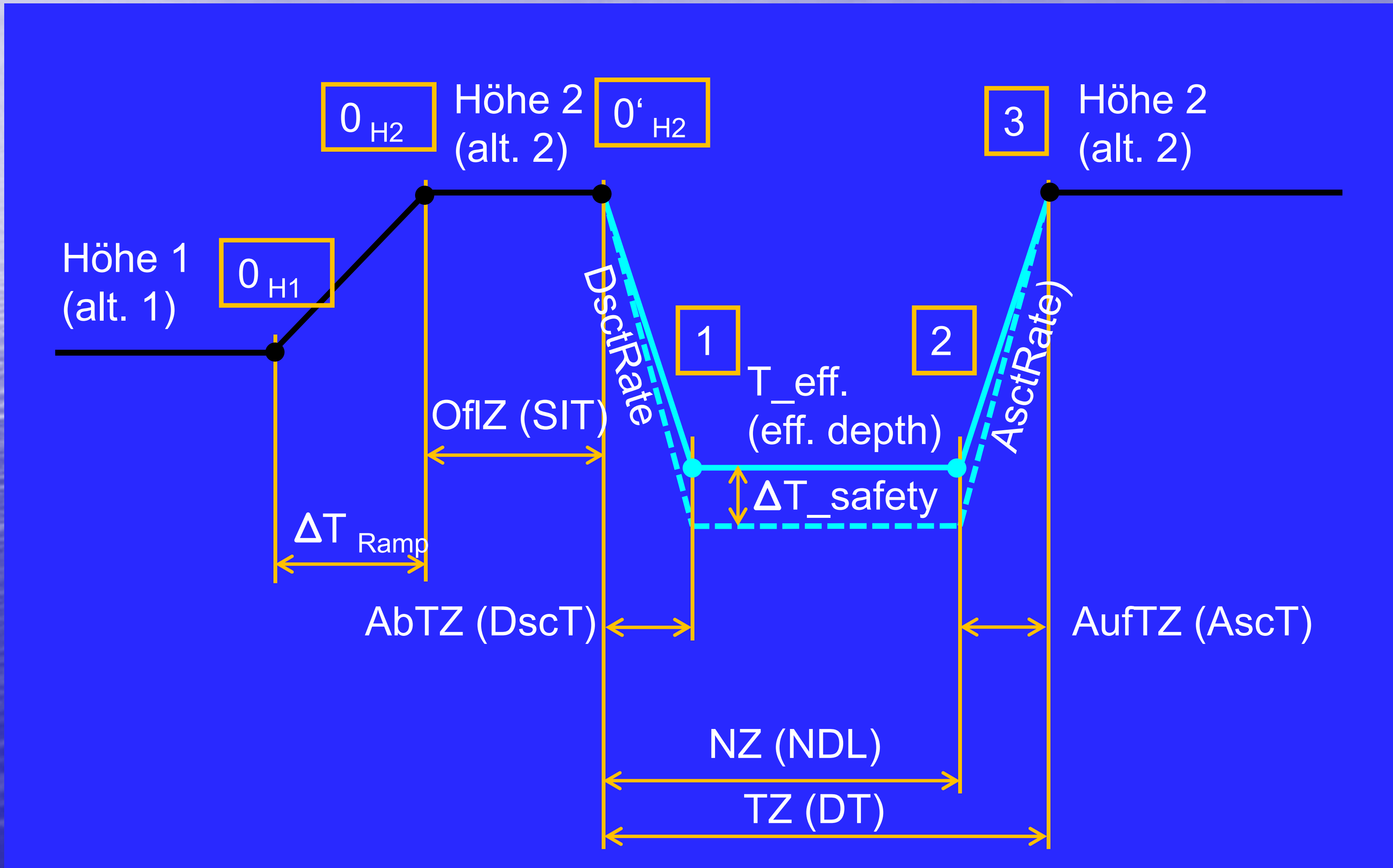
The new System ZHL-16 (as published)

	HWZ (tH)	Letter	a	b
#	[min]	Code	[bar]	[---]
1	th=4'	A	1.2599	0.5050
2	th=8'	B	1.0000	0.6514
3	th=12.5'	C	0.8618	0.7222
4	th=18.5'	D	0.7562	0.7825
5	th=27'	E	0.6667	0.8126
6	th=38.3	F	0.5600	0.8434
7	th=54.3'	G	0.4947	0.8693
8	th=77'	H	0.4500	0.8910
9	th=109'	I	0.4187	0.9092
10	th=146'	J	0.3798	0.9222
11	th=187'	K	0.3497	0.9319
12	th=239'	L	0.3223	0.9403
13	th=305'	M	0.2850	0.9477
14	th=390'	N	0.2737	0.9544
15	th=498'	O	0.2523	0.9602
16	th=635'	P	0.2327	0.9653



Parametric NDL calculations today

Parametric NDL calculations today…. (1)



Parametric NDL calculations today…. (2)

in Abhängigkeit von der Abstiegs- u. Aufstiegsrampe,
der Höhe und des Atemgasgemisches während des TG's

Physikalische Konstanten und Atemgas

alf_N2surf	0.790	--	dp_H2O/dT	1.0000	bar/10m	p_H2O	0.0628	bar
alf_N2TG	0.790	--	k_resp	0.8	--	p_CO2	0.0533	bar

Umgebungsbedingungen

Höhe 1	0	m ü.M.	psurf_H1	1.0132	bar	p_alv-N2_H1	0.7613	bar
dt_Ramp12	0	min	dpN2/dt_R	99999.999	bar/min			
Höhe 2	0	m ü.M.	psurf_H2	1.0132	bar	p_alv-N2_H2	0.7613	bar
dt_Adapt2	0	min				p_alv-N2_H2TG	0.7613	bar
						pO2_H2TG	0.2024	bar

Gewebemodell (ZHL-12) / **Max. Gewebewerte**

nr.	tH	a	b	k	pTIGmax1	pTIGmax2
--	min	bar	--	1 / min	bar	bar
1	4.0	1.9000	0.8000	0.173287	3.1665	3.1665
2	8.0	1.4500	0.8000	0.086643	2.7165	2.7165
3	12.5	1.0300	0.8000	0.055452	2.2965	2.2965
4	18.5	0.8820	0.8260	0.037467	2.1086	2.1086
5	27.0	0.7170	0.8450	0.025672	1.9161	1.9161
6	38.3	0.5750	0.8600	0.018098	1.7531	1.7531
7	54.3	0.4680	0.8700	0.012765	1.6326	1.6326
8	77.0	0.4410	0.9030	0.009002	1.5630	1.5630
9	109.0	0.4150	0.9080	0.006359	1.5309	1.5309
10	146.0	0.4160	0.9390	0.004748	1.4950	1.4950
11	187.0	0.3690	0.9460	0.003707	1.4400	1.4400
12	239.0	0.3690	0.9460	0.002900	1.4400	1.4400
13	305.0	0.2550	0.9620	0.002273	1.3082	1.3082
14	390.0	0.2550	0.9620	0.001777	1.3082	1.3082
15	498.0	0.2550	0.9620	0.001392	1.3082	1.3082
16	635.0	0.2550	0.9620	0.001092	1.3082	1.3082

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Parametric NDL calculations today…. (3)

Tiefe_nominell	18.0	m
ptot_Tnomin [H2]	2.7315	bar
pN2_Tnomin [H2]	2.1188	bar
pO2_Tnomin [H2]	0.5632	bar

Tiefe_effektiv	19.54	m
dT_surf	*1.0*	m
dT_rel	*3.0*	%
ptot_Teff [H2]	2.8855	bar
pN2_Teff [H2]	2.2405	bar
pO2_Teff [H2]	0.5956	bar

Beachte: Tauchgang findet auf Höhe 2 statt !

ABstieg:	dt_dsct	*0.60000*	min	--> v_dsct	30.00000	m/min	dpN2/dt_Dsct	2.37	bar/min
AUFstieg:	v_asct	*10.000*	m/min	-> dt_asct	1.80000	min	dpN2/dt_Asct	-0.79	bar/min

nr.	pTIG0_H1	pTIG0_H2	pTIG0_H2'	PTIG1	pTIG2'	NZ_tH'	pTIG2	pTIG3	pT3/pmax2	pT3/pmax2
--	bar	bar	bar	bar	bar	min	bar	bar	[H1] %	[H2] %
1	***0.7613***	0.7613	0.7613	0.8264	3.6843	*9999.99*	2.2403	2.0073	63.4	65.5
2	***0.7613***	0.7613	0.7613	0.7944	2.8212	*9999.99*	2.2221	2.1019	77.4	80.4
3	***0.7613***	0.7613	0.7613	0.7826	2.2782	*9999.99*	2.1514	2.0796	90.6	94.8
4	***0.7613***	0.7613	0.7613	0.7758	2.0523	*55.37*	2.0188	1.9785	93.8	98.4
5	***0.7613***	0.7613	0.7613	0.7713	1.8391	**51.15**	1.8376	1.8180	94.9	**99.9**
6	***0.7613***	0.7613	0.7613	0.7683	1.6666	*52.65*	1.6492	1.6413	93.6	99.0
7	***0.7613***	0.7613	0.7613	0.7663	1.5418	*59.10*	1.4658	1.4644	89.7	95.2
8	***0.7613***	0.7613	0.7613	0.7648	1.4737	*73.32*	1.3030	1.3047	83.5	88.6
9	***0.7613***	0.7613	0.7613	0.7638	1.4413	*97.15*	1.1687	1.1714	76.5	81.3
10	***0.7613***	0.7613	0.7613	0.7632	1.4081	*121.42*	1.0776	1.0804	72.3	76.7
11	***0.7613***	0.7613	0.7613	0.7628	1.3533	*138.26*	1.0146	1.0172	70.6	75.1
12	***0.7613***	0.7613	0.7613	0.7625	1.3534	*176.64*	0.9635	0.9658	67.1	71.3
13	***0.7613***	0.7613	0.7613	0.7622	1.2226	*164.78*	0.9222	0.9242	70.6	75.5
14	***0.7613***	0.7613	0.7613	0.7620	1.2227	*210.70*	0.8887	0.8904	68.1	72.8
15	***0.7613***	0.7613	0.7613	0.7619	1.2229	*269.04*	0.8621	0.8634	66.0	70.6
16	***0.7613***	0.7613	0.7613	0.7618	1.2230	*343.05*	0.8409	0.8420	64.4	68.8

Minimum aller NZ:	51.15	min
(abgerundete) NZ:	51.00	min

Parametric NDL calculations today…. (4)

Step 1

Tiefe:	**18m**	untere Höhenlage 1:	**0m**	Adaption Höhe 1:	**vollständig**
		obere Höhenlage 2:	**0m**	Adaption Höhe 2:	**vollständig**

Abstiegs-Geschwindigkeit (m/min)	Aufstiegs-Geschwindigkeit (m/min)						
	5	**10**	**15**	**20**	**25**	**30**	**9999**
5	**60.33**	57.84	57.08	56.71	56.49	56.35	**55.65**
10	59.35						54.67
15	59.02						54.35
20	58.86			**55.24**			54.18
25	58.76						54.09
30	58.70						54.02
9999	**58.37**	55.88	55.12	54.76	54.54	54.39	**53.70**

- values at the 4 corners of the "envelope"
- remaining values at the boundaries all around
-1 check value at the center (to detect a probable depression)

Step 2

Tiefe:	**18m**	untere Höhenlage 1:	**700m**	Adaption Höhe 1:	**vollständig**
		obere Höhenlage 2:	**700m**	Adaption Höhe 2:	**vollständig**

Abstiegs-Geschwindigkeit (m/min)	Aufstiegs-Geschwindigkeit (m/min)						
	5	**10**	**15**	**20**	**25**	**30**	**9999**
5	**56.54**						**52.56**
10							
15							
20				**52.00**			
25							
30							
9999	**54.59**						**50.61**

- values at the 4 corners of the "envelope" -> comparison
- 1 check value at the center (to detect a probable depression)

Parametric NDL calculations today…. (5)

Step 3

Tiefe: 18m	untere Höhenlage 1: 0m	Adaption Höhe 1: vollständig
	obere Höhenlage 2: 700m	Adaption Höhe 2: keine

Abstiegs-Geschwindigkeit (m/min)	Aufstiegs-Geschwindigkeit (m/min)						
	5	**10**	**15**	**20**	**25**	**30**	**9999**
5	**54.96**	52.85	52.2	51.89	51.7	51.58	**50.98**
10	53.94						49.96
15	53.6						49.62
20	53.43			**50.35**			49.45
25	53.33						49.35
30	52.26	**51.15**					49.28
9999	**52.92**	**50.81**	50.16	49.85	49.66	49.54	**48.94**

- values at the 4 corners -> comparison
- values at the boundaries all around -> comparison
- check value at the center (to detect a probable depression) -> comparison
- choose selected descent-/ascent rate and calculate the corresponding NDL for the table
- all remaining values just for academic interest

In this particular case (18m, 0-700m a.s.l.) a NDL of 51 minutes was chosen and published.

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Parameters for Bühlmann `86 Air Diving Tables and later developments

Bühlmann Memorial Symposium 2019

Parameters for Bühlmann `86 Air Diving Tables and later developments (1)

Table Calculation Parameters (English version)

Specifications for the Calculation of the Bühlmann `86 Air Diving Tables

Compartment model:	ZHL-12 and later ZHL-16; partially used in parallel during tests
Number of compartments	12, resp. 16
Pairs of coefficients	ZHL-12: 16 half times, with a total of 12 pairs of coefficients für N2 and He ZHL-16: one pair of (different) coefficients a, b for every compartment Remark: during the high altitude tests, profiles have been calculated with both sets of coefficients. In-water, generally the longer NDL and the shorter stop times were used.
Tolerated ambient pressure	pamb.tol(tH) = (p_TN2(tH) – a(tH)) * b(tH)
Letter coding of RG	in alphabetical order A-P; RG at end of dive = letter code of leading compartment; in case the next following compartment was also saturated to 95% or more, then the letter code of this compartment was used.

Physical and physiological parameters:	
In-water pressure rise	as a matter of simplicity, f_H2O = 0.10 bar/m H2O was assumed (average between fresh- and saltwater)
Alveolar p_N2alv	calculated under inclusion of -alveolar water vapor pressure (0.06028 bar), -alveolar CO2 pressure p_CO2 (0.0533 bar) and -respiratory coefficient QR (0.80); later changed to 1.0, therefor p_CO2 drops from equation; no consequences
Tissue adaption 0-700m	complete adaption and tissue saturation at 0m, NDL and stop times corresponding to surface pressure at 700m a.s.l.
Tissue adaption 701-2500m	complete adaption auf 700m a.s.l., ride for 1 hr to 2500m a.s.l., immediate dive

Altitude ranges:	
Range segmentation	two ranges: 0-700m a.s.l. and 701 -2500m a.s.l. (least number of tables)
Surface pressure at altitude	according to ISO/IATA formula for standard atmosphere
Surface pressure at sea level	standard atmosphere; p_surf-0 = 1.013bar

Composition of air:	
Inspiratory O2 fraction	20.8%
Inspiratory N2 fraction	79.2%

Dive profile for calculation:	
Increments of dive depths	3m/10ft as used internationally
Segmentation of last deco stop	3m divided in 2m/4m for upper altitude range table for reasons of more moderate pressure gradients
Descent ramp of dive	for depths down to 18m: rectangular profile; deeper depths: a fixed descent rate of 30m/min
Ascent ramp of dive	fixed ascent rate of 10m/min, for all depths; exact value for inert gas calculations, published value in table rounded to the next full minute
Safety margin for depth	fixed 1m, variable 3%: $T_{Tab} = T_{eff} \times 1.03 + 1$; NO margins for test dives!

Safety Stop:	
Safety stop	for all dives within the NDL 1'/3m (0-700m a.s.l.), resp. 1'/2m (701-2500m a.s.l.); there is no desaturation-related reason behind, but more a regulatory policy.

Decompression Stops:	
Ascent to next stop depth	always included in the stage stop time
Profile within stages	rectangular profile within stages
Depth of stages	without additional safety margins

Specifications for the Calculation of the Bühlmann `86 Air Diving Tables

Surface Interval (SI) table:	
Breathing gas	exclusively air
Waiting time until RG "0"	time until all compartments are desaturated from maximum tolerated tissue inert gas pressure to at least 5% above surface alveolar inert gas pressure. Fixed minimal waiting time is 2 hrs; thus, all compartments up to 20min half time are desaturated to 97% or more.
Rounding	for desaturation to RG "0": always to the next longer full hour For switch to next lower RG: always to the next full minute
Shunt effects	no effects included during the desaturation process

Residual Nitrogen Time (RNT) table:	
Residual Nitrogen Time	for reasons of simplicity in handling just one table, valid for the whole range up to 2500m a.s.l.
Calculation	based on a comparative analysis of the states of compartments at the end of all dive profiles contained in the table.
Rounding	always to the next full minute

Waiting Times for Flying after Diving in pressurized Aircraft:	
Waiting time until flying	calculation under the assumption of a timeless ascent (rectangular profile), not taking in account for the ongoing desaturation during the ascent ramp to cruising altitude. Fixed minimal waiting time is 2 hrs; thus, all compartments up to 20min half time are desaturated to 97% or more.
Assumed cabin pressure	0.58bar (approx. 4600m a.s.l.); value slightly below the lowest acceptable cabin pressure not yet classified as a technical failure (IATA). Normal are pressures are between 0.75-0.8bar (approx. 2000m-2400m a.s.l. at a cruising altitude of 35'000 to 39'000ft) Remarks: latest generation aircrafts (Boeing Dreamliner) use a minimal cabin pressure at cruising altitude corresponding approx. to 1800m a.s.l.
Rounding	always to the next longer full hour

Crossing a Pass and Flying after Diving in non-pressurized aircraft:	
Waiting time	minimum 1 hr at diving altitude before any further ascent, afterwards a steady ascent to target altitude, arrival not before indicated waiting time.
Surface ambient pressures	calculated according to ISO/IATA standard atmosphere; for the highest indicated altitude (4000m/0.615bar), the same waiting time was taken as for flying in a pressurized cabin (4600m/0.58bar).
Rounding	always to the next longer half hour

Table for Lake Titicaca (3800m a.s.l.):	
Basis (and specifications)	This table was a „customized" version for the diving expedition of a scientific diving detachment of the British Rhine Army. Full adaption of all tissues to lake altitude assumed.
Upper operation limit	4500m a.s.l. (calculation altitude)
Remaining parameters	identical to those of lower altitude range tables

Rounding:	
Calculated NDL	generally rounded to the next lower minute
Calculated stop times	generally rounded to the next higher minute (under usage of CS [common sense])
Ascent times to 1st deco stop	published values on table always rounded to the next full minute (reasons of practicability); exact value for inert gas tissue loading calculations

Parameters for Bühlmann `86 Air Diving Tables and later developments (2)

Table Calculation Parameters (German version)

Tabellen-Berechnungsparameter zu den Bühlmann `86 Tauchtabellen

Kompartimentsmodell:	ZHL-12, später ZHL-16; z.T. beide parallel während den Tests eingesetzt
Anzahl Kompartimente	12, resp. 16
Koeffizientensätze	ZHL-12: 16 Halbwertszeiten, mit insgesamt 12 Koeffizientenpaaren für N2 und He ZHL-16: je ein Satz Koeffizienten a, b pro Halbwertszeit Anmerkung: bei Höhentauchversuchen wurden die Profile jeweils mit beiden Koeffizientensätzen gerechnet und die jeweils längeren Nullzeiten, resp. kürzeren Stoppzeiten getaucht.
Tolerierter Umgebungsdruck	pamb.tol(tH) = (p_TN2(tH) – a(tH)) * b(tH)
Buchstaben-Codierung	alphabetisch A-P; RG am Ende des TG = Code des führenden Kompartimentes; falls nächstfolgendes Kompartiment ebenfalls zu 95% oder mehr aufgesättigt war, so wurde dessen Buchstabe verwendet.

Physikalische und physiologische Parameter:

Drucksteigerungsfaktor H2O	der Einfachheit halber wurde f_H2O = 0.10 bar/m H2O angenommen (Mittelwert zw. Süss- und Salzwasser)
Alveolärer p_N2alv	gerechnet mit Berücksichtigung von -Wasserdampfdruck (0.06028 bar), -alveolärer p_CO2 (0.0533 bar) und -Respirations-Koeffizient (0.80); später 1.0 verwendet, damit fällt p_CO2 aus der Gleichung weg; hat allerdings keine Auswirkungen
Vorsättigung 0-700m	vollständige Adaption auf 0m, Sättigung auf dieser Höhe, NZ und Dekozeiten entsprechend Oberflächendruck auf 700m
Vorsättigung 701-2500m	vollständige Adaption auf 700m, Fahrt 1 Std. auf 2500m, sofortiger TG

Höhenlagen:

Aufteilung	in 0-700m und 701 -2500m (möglichst geringe Anzahl Tabellen)
Oberflächendruck	jeweils mit ISO/IATA Formel gerechnet (Standardatmosphäre)
Druck auf Meereshöhe	Standardatmosphäre; p_surf-0 = 1.013bar

Luftzusammensetzung:

Inspiratorischer O2-Anteil	20.8%
Inspiratorischer N2-Anteil	79.2%

Tauchprofil zur Berechnung:

Tiefeninkremente	3m wie international üblich (10ft)
Aufteilung letzte Dekostufe	3m aufgeteilt in 2m/4m für Höhentabelle für kleinere Druck-Gradienten
TG-Abstiegsrampe	bei Tiefen bis 18m: Rechteckprofil; übrige Tiefen fix 30m/min
TG-Aufstiegsrampe	fix 10m/min, alle Tiefen; exakter Wert für Inertgasberechnung; publizierter Tabellenwert immer auf nächste ganze Minute gerundet
TG-Rampenberechnung	Alle Rampen mit der exakten Lösung der Differentialgleichung gerechnet
Tiefenzuschlag	fix 1m, variabel 3%: $T_{Tab} = T_{eff} \times 1.03 + 1$; für Test-TG: KEINE Zuschläge!

Sicherheitshalt:

Sicherheitshalt	bei allen NZ-TG von 1'/3m (0-700m ü.M.), resp. 1'/2m (701-2500m ü.M.); keinerlei entsättigungsbasierte Überlegung, sondern eher ordnungspolitischer Natur

Deko-Stopps:

Aufstieg zur nächsten Stufe	ist immer in Stufenzeit enthalten
Profil innerhalb Stufen	Rechteckprofil innerhalb Stufen
Stufentiefen	ohne Tiefen-Zuschläge

Tabellen-Berechnungsparameter zu den Bühlmann `86 Tauchtabellen

Oberflächenintervall-Tabelle:

Atemgas	ausschliesslich Luft
Wartezeit bis "0"	Zeit bis alle Kompartimente vom max. tolerierten Inertgasdruck bis mindestens 5% über den alveolären Inertgasdruck an der Oberfläche entsättigt sind. Minimum Wartezeit aber 2 Std. fix; damit sind alle Kompartimente bis 20min HWZ zu mind. 97% entsättigt
Rundung	für Entsättigung zu RG „0": immer auf nächste ganze Stunde für Wechsel in die nächst tiefere RG: immer auf ganze nächste Minute
Shunt Effekte	es wurden keine Shunt-Effekte während der Entsättigung berücksichtigt

Zeitzuschlagtabelle:

Zeitzuschlagtabelle	aus Gründen der einfachen Handhabung eine einzige Tabelle, gültig für gesamte Höhenlage bis 2500m ü.M.
Berechnung	erfolgte aus der vergleichenden Analyse der Kompartimentszustände am Ende sämtlicher in der Tabelle enthaltenen Tauchgangprofile
Rundung	immer auf nächste ganze Minute

Wartezeiten bis Fliegen MIT Druckkabine:

Wartezeit bis Flug	Berechnung erfolgt auf Basis eines zeitlosen Aufstiegs (Rechteckprofil), d.h. ohne Berücksichtigung der laufenden Entsättigung während der Rampe bis zum Erreichen der Flughöhe Minimum Wartezeit aber 2 Std. fix; damit sind alle Kompartimente bis 20min HWZ zu mind. 97% entsättigt
Annahme Kabinendruck	0.58bar (ca. 4600m); liegt ganz wenig unter dem tiefst möglichen Druck gem. IATA, der noch nicht als technischer Defekt gilt (0.60bar). Normal sind ca. 0.75-0.8bar (ca. 2000-2400m auf Flughöhe 35'000 bis 39'000ft) Anmerkung: bei Flugzeugen neuster Generation (Boeing Dreamliner) versucht man den minimalen Kabinendruck auf Reiseflughöhe entsprechend ca. 1800m ü.M. einzuhalten.
Rundung	immer auf nächste ganze Stunde

Passfahrten und Fliegen OHNE Druckkabine:

Wartezeit	mind. 1 Std. auf bisheriger Höhe vor Aufstieg, anschliessend gleichmässiger Aufstieg; Ankunft nicht vor Ablauf angegebene Wartezeit
Oberflächendrücke	wurden exakt nach ISO Standardatmosphäre gerechnet; für die grösste angegebene Höhe (4000m/0.615bar) wurde dieselbe Wartezeit angegeben wie für den Flug mit Druckkabine (4600m/0.58bar).
Rundung	immer auf nächste halbe Stunde

Tabelle Titicacasee (3800m ü.M.):

Grundlagen	Diese Tabelle war eine „Einzelanfertigung" für die Expedition der brit. Rheinarmee; es wurde eine vollständige Adaption am Tauchort vorausgesetzt
Obere Einsatzgrenze	4500m ü.M. (Berechnungshöhe)
Übrige Parameter	alle übrigen wie die „normalen" Tabellen

Rundungen:

Erhaltene NZ	in der Regel auf nächst ganze Minute abgerundet
Erhaltene Stoppzeiten	in der Regel auf nächst ganze Minute aufgerundet (unter Anwendung GMV [gesunder Menschenverstand])
Zeiten TG-Aufstiegsrampe	publizierte Werte auf Tabelle immer auf ganze nächste Minute aufgerundet (Praktikabilität); für Inertgasberechnung aber exakter Wert verwendet

Results and consequences (details)

Results and Consequences (1)

3.1 retrospective studies

type of dive	number of test series	number of test persons
simulated air dives:		
- single dives, 30-44m	31	457
- repetitive dives	9	166
- altitude decompression after a dive	14	190
simulated dives on Heliox, O2		
- single dives, 30-35m	11	159
- deep diving, 80-575m	24	193
- altitude decompression after a dive	1	15

3.2 prospective studies

During 1986 - 1988, 498 real open water dives at altitudes from 1400 - 3800m and depths from 12 - 60m have been carried out analysed.

3.3 repetitive-dive trials

- 127 divers, 127 second dives, 39 third dives depth range: 32-44m, bottom times: 13'-60', surface intervals: 10'-120'

All data from the period of 1981-1991

3.4 open water high altitude tests

- Lake Titicaca, Peru, 1987 / 3800m
  17 divers, 3 weeks, 290 dives, 12-39m (no symp.)
- Muttsee, Switzerland, 1988 / 2500m
  15 divers, 2 days, 56 dives, 24 - 52m (2 mild skin bends, 2 muscles)
- Mount Kenia Massiv, 1988, 4400-4780m
  18 dives (no symptoms)
- High altitude trials in the St.Gotthard region, 1984-1988, 2134m
  40-50 diver, approx. 60 dives (no symptoms)

3.5 some other relevant data ..
- highest altitude in chamber : 4200m
- used breathing gases : air, nitrox, heliox, oxygen-decompression
- deepest dive : 575m for 2 hrs, 1981
- saturation diving: depth range from 30 - 220m

3.6 practical applications (ref. also to Part II / 7.)

- construction subway Muenich, 1983-85
  1.6-2.1 bar, 6-8 hrs/day, 5days/week; bends rate 6/850 "dives" (down from 48/1377 while using German Tables from the Ministry of Health&Labour)
- railway construction work near Bern by Swiss Federal Railway Comp. 1988-91
  1.2-1.6 bar for 4-6 hrs a day
- dive tables in use in England,Germany,Switzer-land, Austria, Peruvian-and Bolivian Navy (appr. 40-50'000 divers overall since 1986)
- several dive computers (since 1984/85)

Results and Consequences (2)

3.7 Selected Trials: High Altitude Tests St.Gotthard, 1986 (Lago di Lucendro)

altitude : 2134m above sea level
adaption time: 4 hrs
first dive

team # 3 div. each	depth [m]	bott. time [min]	deco accord. T86 6m	4m	2m	tot.	effective deco-time 2m
1	33	18	--	2	5	7	1
2	36	16	--	4	6	10	4
3	37	15	--	4	6	10	2
4	32	15	--	-	3	3	1

second dive; surface interval: 60 minutes

team # 3 div. each	depth [m]	bott. time [min]	deco accord. T86 6m	4m	2m	tot.	effective deco-time 2m
4	32	15	1	4	9	14	1

3.8 Selected Trials: High Altitude Tests Muttsee (1988)

altitude : 2500m above sea level
adaption time: 2 hrs
first dive

profile	method	decompression 9m	6m	4m	2m	total
39m / 18'	effective	--	--	2	3	5
	acc. T86	--	2	3	7	12
45m / 18'	effective	--	2	3	4	9
	acc. T86	2	3	4	11	20
60m / 15'	effective	4	3	4	8	19
	acc. T86	5	5	8	18	36

3.8 Selected Trials: Comparison of Open Water Tests at low altitudes (Lake of Zuerich)

altitude: 400m above sea level
T86 : Buehlmann table '86, 0-700m

	depth [m]	bottom time [min]	decompression stages 12m	9m	6m	3m	total asct time	Sympt./ dives
T86	30	17				1	4	
experiment	32	20				-	3	0/15
T86	33	14				1	4	
experiment	35	18				-	3	0/12
T86	39	10				1	5	
experiment	41	13				-	4	0/12
T86	39	20			3	7	13	
experiment	41	23			3	5	11	0/16
T86	39	30		3	7	18	31	
experiment	41	33		3	5	15	26	0/16
T86	39	40	2	6	15	29	55	
experiment	41	40	2	5	13	27	50	0/24
T86	42	36	2	7	15	32	59	
experiment	44	35	2	5	11	26	47	0/20
experiment	44	37	3	5	12	28	51	0/9

(courtesy Prof. Buehlmann)

unknown no. of 14 divers,
123 dives, 30-44m, BT=10-40min

Results and Consequences (3)

3. M U T T S E E - V E R S U C H S - TG

a) Uebersichtszahlen

Anz. TG: ZHL-12: 41
ZHL-16: 11
TOTAL : 52

Tiefen: min.: 33m
max.: 60m

Zeiten: min.: 12'
max.: 25'

Anz. versch. Profile : ZHL-12: 12
ZHL-16: 2
TOTAL : 14

Erst.-TG: ZHL-12: 22
ZHL-16: 6
TOTAL : 28

Rep.TG: ZHL-12: 19
ZHL-16: 5
TOTAL : 24

Geschlecht	Anz.	Erst.TG	Rep.TG	Total
Maenner	11	22	19	41
Frauen	3	6	5	11
* Total	14	28	24 *	52 *

b) Nullzeitenvergleiche

Tiefe [m]	T86/2500	ZHL-12 *) (6 Std.)	ZHL-16 *) (6 Std.)
30	15'	20.4'	18.5
33	12'	17.3'	15.2
36	10'	15.0'	12.9
39	9'	13.3'	11.2
42	8'	11.8'	9.9

*) 3' Abstieg einberechnet

Results and Consequences (4)

3. M U T T S E E - V E R S U C H S - TG

c) Vergleiche von ERST-TG

Hoehe: 2500m

Profil	Methode	Dekompression 9m	6m	4m	2m	Total
39m / 18'	effektiv	--	--	2	3	5
	nach T86	--	2	3	7	12
45m / 18'	effektiv	--	2	3	4	9
	nach T86	2	3	4	11	20
60m / 15'	effektiv	4	3	4	8	19
	nach T86	5	5	8	18	36

d) Vergleiche von REPETIV-TG

1. TG	Int.	2. TG	M	Dekompression 12m	9m	6m	4m	2m	Tot.
60m/15'	180'	60m	E	--	1	2	3	4	10
		8'+ 15'	T86	2	4	3	6	14	29
57m/12'	210'	60m	E	--	4	3	4	8	19
		11' + 4'	T86	4	4	4	9	19	40
45m/18'	277'	42m	E	--	--	--	3	4	7
		13' + 6'	T86	--	1	3	3	10	17

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Results and Consequences (5)

3. M U T T S E E - V E R S U C H S - TG

e) PROBLEMKOMBINATION

Anmerkung: effektive Dekompressionsplaene berechnet mit Koeffizienten ZHL-16/A

ERST-TAUCHGANG:

Profil	Meth.	Dekompression 9m	6m	4m	2m	Tot.	HWZ	DCS n/d
39m/25' (AZ=3')	eff.	--	3	5	7	15	18.5, 27.0, 38.3	0/6
	T86	3	3	7	16	29		

REPETIV-TAUCHGANG:

Int.	Profil	Meth.	Dekompression 9m	6m	4m	2m	Tot.	HWZ	DCS n/d
99'		eff.	-	--	3	5	8		1/2
		T86	3	6	12	23	44		
103'	alle	eff.	-	--	3	5	8		1/1
	33m/25'	T86	3	6	12	20	41		
117'	(AZ=3')	eff.	-	--	3	5	8		2/2
		T86	3	6	12	20	41		

No DCS for this depth/time combination

Here, it looks differently….
Reason: most probably the shunt effects with delayed desaturation!

Results and Consequences (6)

3. M U T T S E E - V E R S U C H S - TG

f) Fuehrende Kompartimente b. Ausstieg
(nur Erst-TG)

Hoehe : 2500m

Umgebungsdruck: p_amb. = 0.741 bar (ISO)

alv. N2-Druck : p_alv.N2 = 0.537 bar

Anmerkung: Es wurden nur diejenigen Faelle beruecksichtigt, bei denen der Inertgas-Kompartimentsdruck beim Ausstieg mind. 95% des maximal zulaessigen Wertes (s. unten) betrug.

Halb-werts-zeit-Nummer	Halb-werts-zeit [min]	ZH-12 max. p_tN2 [bar]	ZH-16 max. p_tN2 [bar]	fuehrend bei folgenden TG	System ZHL-12 /T86 Anzahl	System ZHL-16 / A * Anzahl	Total
#3	12.5	1.957	1.888	#1,2,3,4, 5,6,7,8, 9,10	20	0	20
#4	18.5	1.779	1.703	#1,2,3,5,6 7,8,9,10, 12,13,14*	19	6	25
#5	27.0	1.594	1.579	#3,5,6,7, 8,9,10,11 12,13,14*	16	6	22
#6	38.3	1.437	1.438	#7,8,9,11, 12,13,14*	8	6	14
#7	54.3	1.320	1.347	#11	2	0	2

* : ZHL-16/A nur bei TG #12,13,14

„problematic“ tissues (skin, muscles)

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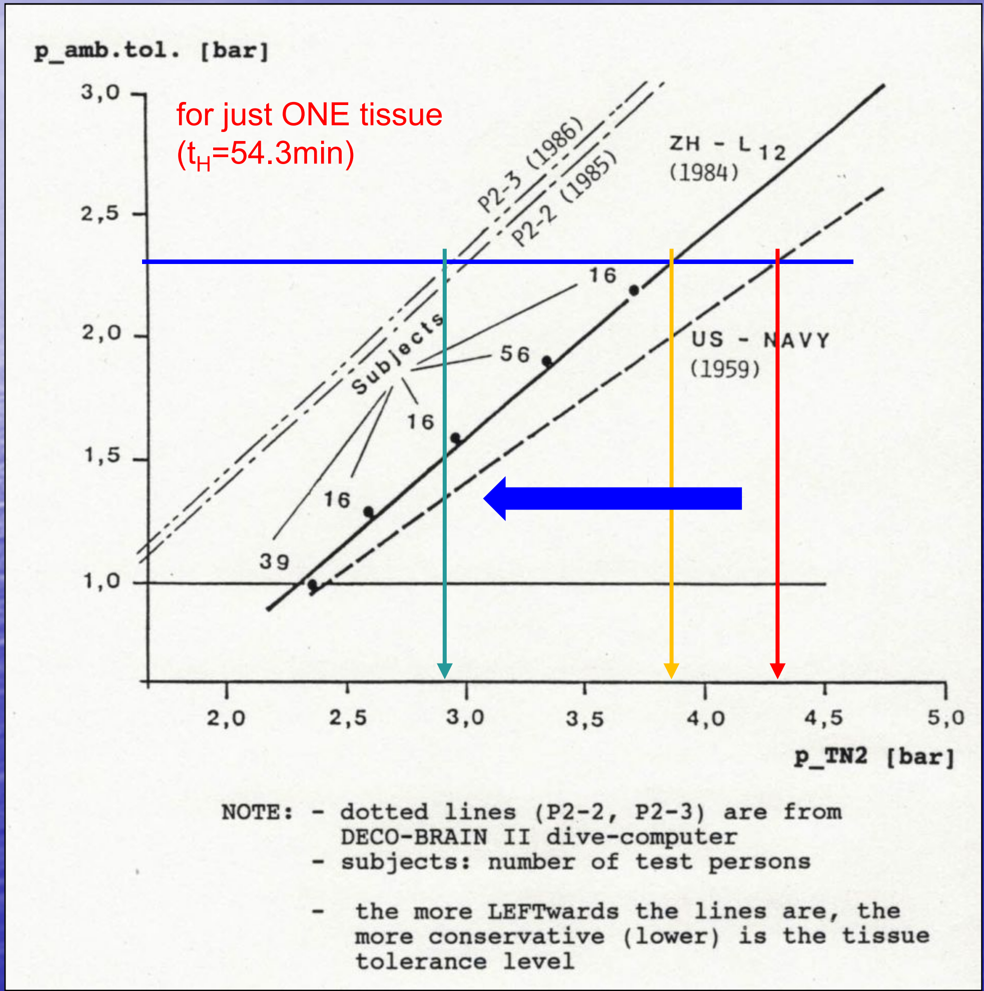
Results and Consequences (7)



Careful analysis of hundred of dive profiles executed with dive computers led to a refinement of the underlying set of coefficients towards higher tolerated ambient pressures (reduced gradients) for a given tissue inert gas pressure.

It also shows the dramatic change compared to US-Navy and the original ZHL-12 limits.

Different Versions of the Bühlmann Compartment Model

Several versions of the Bühlmann algorithm have been developed, both by Bühlmann and by later workers. The naming convention used to identify the algorithms is a code starting ZH-L, from Zürich (ZH), linear (L) followed by the number of tissue compartments or pairs of coefficients, and other unique identifiers.
The term “linear” say that there is a linear functionality between the tissue inert gas pressure and the tolerated ambient pressure (the coefficients a, b describe a this linearity).

- ZHL-16 or ZH-L16A: The original 16 compartment algorithm (no conservatism at all).
- ZHL-16B: The 16 compartment algorithm modified for dive table production, using slightly more conservative “a” values, mainly in the middle compartments.[8] Recently used in dive computers with high performance processor units, is it more flexible (especially in tech dives) compared to the ZHL16C
- ZHL-16C:The 16 compartment algorithm with further modification to the middle and faster “a” values, intended for use in dive computers as a "package". It can be used with almost all low-level processor units but it is less flexible compared to the ZHL16B.
- ZHL-8: A version using a reduced number of tissue compartments to reduce the computational load for personal dive computers.
- ZHL-8 ADT: 8-compartment adaptive model used by Uwatec. This model may reduce the no-stop limit or require the diver to complete a compensatory decompression stop after an ascent rate violation, high work level during the dive, or low water temperature. This algorithm is used in computers which can accurately monitor air consumption and instantaneous rate of air consumption to model work load (exertion) via changes in the rate of gas consumption, which allows plausible modelling of additional decompression obligation based on exertion at depth. It also monitors ambient temperature and selects the choice of risk tissue accordingly. This results in earlier and longer decompression requirements in colder water.[9][10]
- ZHL-8 ADT MB: A version of the ZHL-8 ADT claimed to suppress microbubble formation.[9]
- ZHL–8 ADT MB PDIS: Profile-Determined Intermediate Stops.[11]
- ZHL-8 ADT MB PMG: Predictive Multi-Gas.
- ZHL-16 ADT DD: 16-compartment adaptive model used by Uwatec for their trimix-enabled computers. Modified in the middle compartments from the original ZHL-C, is adaptive to diver workload and includes Profile-Determined Intermediate Stops. Profile modification is by means of "MB Levels" rather than gradient factors[12]
- ZHL-12 original 16 tissue compartment model, but with just 12 pairs of coefficients

Source: Wikipedia

Barometric Pressure as a function of Altitude

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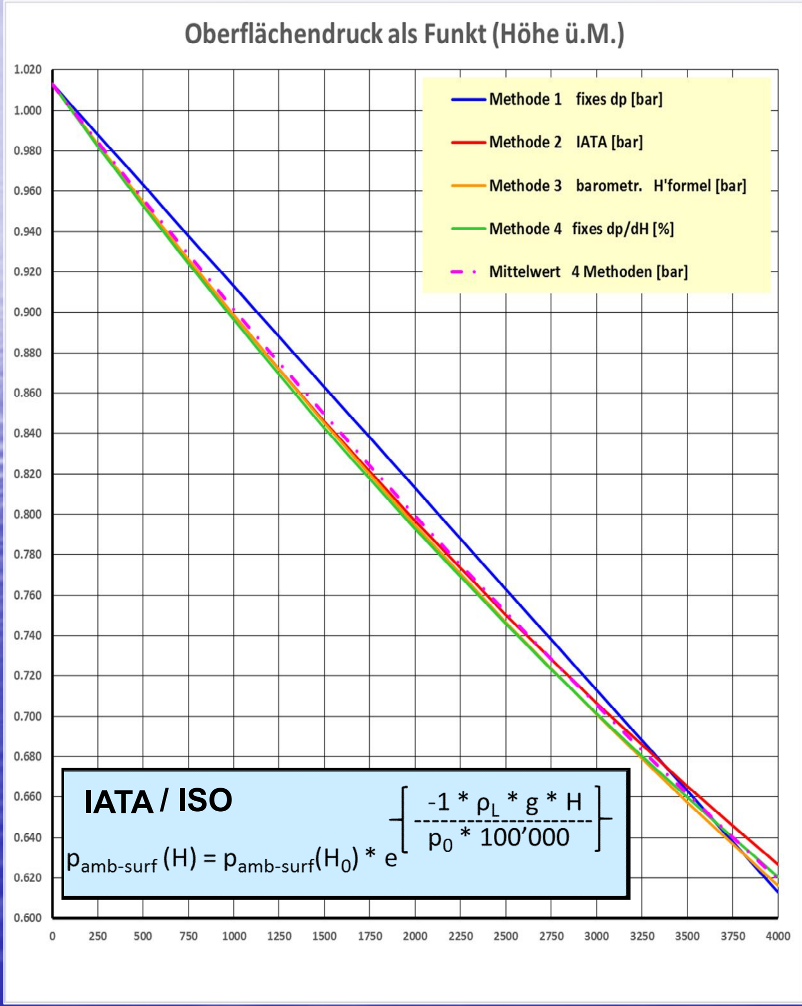
Barometric Pressure as a function of Altitude



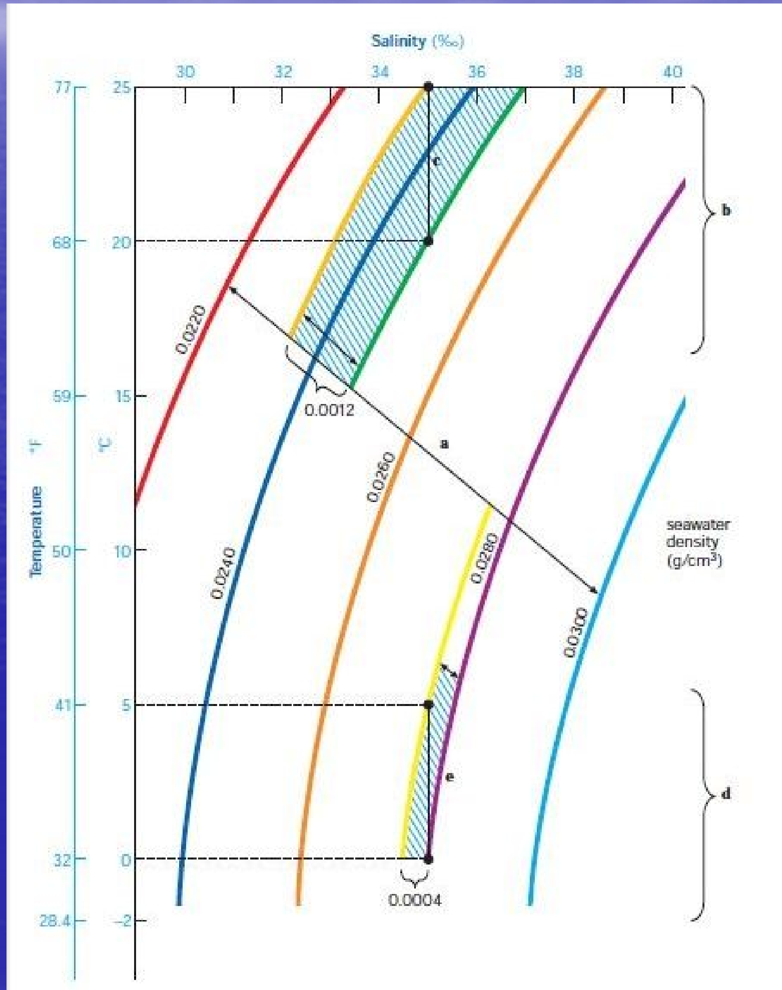
There are various methods (formulas) how to calculate the surface ambient pressure as a function of the altitude.
In aviation, the ambient pressure is a most critical value to calibrate altimeters.
Ambient pressure sea level = 1.013 bar.

For diver, the following assumption is fair enough:
a) ambient pressure at sea level = 1.00 bar
b) decrease of ambient pressure = 0.1 bar / 1000m altitude a.s.l, linear
Up to 4000m a.s.l., the error is neglectable.
The biggest deviation occurs at approximatly 1800-2000m a.s.l. and is around 200m (0.02 bar).
For the calculation of the table, the ISO / IATA formula was used.

Seawater density

Seawater Density as Function of Temperature and Sality

- The density of seawater is determined by temperature, pressure, and salinity.
- In the open ocean, the density of surface seawater varies between 1.022 and 1.03 grams per cubic centimeter (g/cm) (a).
- In tropical and subtropical regions (b) a 9°F (5°C) temperature difference (c) produces a density change of 0.0012 grams per cubic centimeter in seawater.
- In polar regions (d) a 9°F (5°C) temperature difference (e) produces a density change of only 0.0004 grams per cubic centimeter.
- In tropical and subtropical surface waters, temperature change has a greater influence on density, whereas in polar and cold temperate waters, salinity variation is of greater significance.
- In the open ocean, the relative densities of water bodies are of great importance. Relative density determines which will rise and which will fall. These vertical movements in turn influence biological productivity and generate vertical and horizontal currents.



Source: Marine Science; The Diagram Group

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Deco Brain Trials

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Deco Brain Trials(0a)

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B1

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(54) **Anzeigeeinrichtung für die Parameter eines Tauchganges.**

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(73) Patentinhaber: **Divetronic AG, Rennhofstrasse 546, FL- 9493 Mauren (LI)**

(72) Erfinder: **Hermann, Jürgen, Rennhof, FL- 9493 Mauren (LI)**
Erfinder: **Vogler, Roland, Ahornstrasse 35a, CH-9013 St. Gallen (CH)**

(74) Vertreter: **Flach, Dieter Rolf Paul, Dipl.- Phys., Patentanwälte Andrae/Flach/Haug/Kneissl Prinzregentenstrasse 24, D-8200 Rosenheim (DE)**

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LIBER, STOCKHOLM 1986

Patentansprüche

1. Anzeigeeinrichtung für die Parameter eines Tauchganges, wie z. B. aktuelle Tiefe, maximal getauchte tiefe, bisherige Tauchzeit oder dergleichen, die über

a) wenigstens einen Speicher für die Dekompressionsparameter bei einer Reihe von Tauchtiefen und -zeiten, und

b) eine Auswerte- und Verknüpfungsstufe für die gemessenen Werte des Tiefen- und des Zeitmessers mit den im Speicher gespeicherten Werten angesteuert ist,

dadurch gekennzeichnet, dass in jedem Zeitpunkt des Tauchganges die in Abhängigkeit von den durchtauchten Tiefen und Zeiten erforderliche Gesamtauftauchzeit inklusive der vorgeschriebenen Dekompressionshalte anzeigbar ist und/oder eine Wandlereinrichtung (5) für die Umwandlung der jeweils aktuellen Grundzeit (Verweilzeit in der jeweiligen Tauchtiefenstufe) beim Eintritt in eine neue Tauchtiefenstufe in die dieser neuen Tauchtiefenstufe äquivalente Grundzeit vorgesehen ist, die jener Zeit entspricht, während welcher der Taucher sich in der maximalen Tiefe seines Tauchprofiles befunden hätte.

2. Einrichtung nach Anspruch 1, dadurch gekennzeichnet, dass mit Hilfe der Wandlereinrichtung (5) auch der, vorzugweise jeweils mit Hilfe eines Messgerätes (6) gemessene, Luftdruck berücksichtigbar ist.

3. Einrichtung nach Anspruch 2, dadurch gekennzeichnet, dass ein einziger, vorzugsweise eine piezoresistive Messzelle aufweisender, Druckmesser (6) sowohl für den Luft- wie für den Wasserdruck mit der die Wandlereinrichtung (5) enthaltenden Schaltung verbunden ist.

4. Einrichtung nach Anspruch 3, dadurch gekennzeichnet, dass der Messbereich des Druckmessers (6) jeweils für Luft- bzw. für Wasserdruckmessung mit Hilfe einer Schalteinrichtung (34) umschaltbar ist.

5. Einrichtung nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, dass an den Ausgang des Druckmessers (6) eine Differenzierstufe (26) angeschlossen ist.

6. Einrichtung nach Anspruch 4 oder 5, dadurch gekennzeichnet, dass die Schalteinrichtung (34) eine Sprungerkennungsstufe (35) für den Druck umfasst, die beispielsweise von der ist.

7. Einrichtung nach Anspruch 4, 5 oder 6, dadurch gekennzeichnet, dass Verknüpfungsstufe begrenzten Arbeitsbereiches - mit Hilfe der der Schalteinri der Verstärkung oder des Bit-Bereiches eines der Auswerte- und Verknüpfungs Digital-Wandlers (122) eine Bereichsumschaltung durchführbar ist.

8. Einrichtung nach Anspruch 7, dadurch gekennzeichnet, dass eine dur umschaltbare Referenzspannungsquelle (24, 24′, 24″) vorgesehen ist, der zwe Wandler (22) nachgeschaltet ist.

9. Einrichtung nach einem der Ansprüche 4 bis 8, dadurch gekennzeichnet, d zumindest einen FET-Schalter aufweist.

10. Einrichtung nach Anspruch 9, dadurch gekennzeichnet, dass dem FE gegenüber dem Eingang der nachgeschalteten Stufe, insbesondere des Ana Impedanzwandler (40) nachgeschaltet ist.

11. Einrichtung nach einem der Ansprüche 1 bis 10, dadurch gekennzeich Abnormfunktion durch eine aus einem Zeitgeber und aus einem Druc Detektorschaltung ein Warnsignal (12) und/oder eine Schleppwertanzeige (1 Tauchtiefe einschaltbar ist (sind).

12. Einrichtung nach einem der Ansprüche 1 bis 11, dadurch gekennzeichnet, d einen Rechner (27) und Speicher für Grundzeiten und/oder Dekompressionszeit aufweist.

13. Einrichtung nach Anspruch 12, dadurch gekennzeichnet, dass d Tabellenspeicher (28) ist (sind).

14. Einrichtung nach einem der Ansprüche 1 bis 13 dadurch gekennzeichnet, d eine Speicherschaltung für die jeweils durchtauchten Tiefen und Zeiten, sow ergebenden Korrekturwerte aufweist.

15. Einrichtung nach einem der Ansprüche 1 bis 14, mit wenigstens ein gekennzeichnet, dass die Segmentanzeige (16a) wechselweise - z.B. vo Abnormfunktion - zur Anzeige verschiedener Angaben umschaltbar ist.

16. Einrichtung nach einem der vorhergehenden Ansprüche, dadurch geke Multivibratorschaltung zur getakteten Ansteuerung wenigstens einer Anzeige (10

Claims

Device for indicating the parameters of a dive, such as, for example, present d previous elapsed diving time or the like, which indicating device is driven throug

a) at least one memory for the decompression parameters at a series of diving

b) an evaluation and logic stage for the measured values of the depth gau stored in the memory,

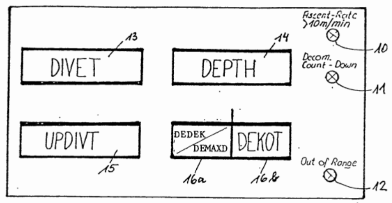

Fig. 7

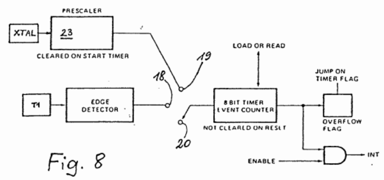

Fig. 8

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Deco Brain Trials(0b)

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Tabelle: 1

Dekompressionstabelle für 0-700 m über Meer

Tiefe m	Tauchzeit min	Dekompressionshalte m 15	12	9	6	3	Repetitivgruppe
15	90					5	J
	120					10	K
	150					15	L
20	50					4	H
	60					7	J
	75					18	K
	90					23	K
	105				3	31	K
25	30					5	G
	40					8	H
	50					12	J
	60					20	K
	75				3	30	K
	90				10	38	L
30	25					5	G
	30					9	H
	35					12	J
	40				5	14	J
	50				5	25	K
	60			6	8	32	K
	75			7	15	42	L
	90			8	25	52	L
35	20					5	G
	25					9	H
	30					12	J
	35				5	17	J
	40				7	30	J
	50			3	10	35	K
	60			7	15	45	K
	75			10	15	62	L
40	15				2	5	G
	20				2	10	H
	25				3	12	J
	30			2	5	20	J
	35			2	10	30	K
	40			5	15	35	K
	50		2	7	20	40	K
	60		2	10	25	50	L

Tabelle: 2

	Nullzeittauchgrenzen								
m	9	12	15	18	20	25	30	35	40
min		200	75	50	30	25	20	15	10

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Tabelle 9:

Bsp.	Punkt im Tauchgang	Repetitiv-Gruppe	Tauchtiefe (m)	Gesamt-tauchzeit (min)	aktuelle Tauchzeit (min)	äquivalente Tauchzeit (min bei m)	Nullzeitgrenze: innerhalb: N überschritten: ü	Dekompression entsprechend einem Tauchgang von min	bei m	Dekompressionshalte (min) bei 9m	6m	3m
1A	a		33	14	14	14/35	N	-		-	-	(ev.3)
	b		33	16	16	16/35	ü	20	35	-	-	5
	c		33	21	21	21/35	ü	25	35	-	-	9
	d		33	26	26	26/35	ü	30	35	-	-	12
	e		33	34	34	34/35	ü	35	35	-	5	17
1B	a		32	13	13	13/35	N	-		-	-	(ev.3)
	b		19	15	15	34/20	ü	50	20	-	-	4
	c		19	34	34+19=53	53/20	ü	60	20	-	-	7
			(herkömmlich:					35	35	-	5	17)
1C	a		33	20	20	20/35	ü	20	35	-	-	5
	b		17	21	21	21/35	ü	25	35	-	-	9
	c		9	26	26	26/35	ü	30	35	-	-	12
	d		9	30	30	30/35	ü	30	35	-	-	12
	e		9	34	34	34/35	ü	35	35	-	5	17
1D	a		20+	18	18	16/25	N	-		-	-	(ev.3)
	b		25+	18	16	13/30	N	-		-	-	"
	c		30+	19	13	10/35	N	-		-	-	"
	d		32	25	10+ 6=16	16/35	ü	20	35	-	-	5
	e		32	30	16+ 5=21	21/35	ü	25	35	-	-	9
	f		32	34	21+ 4=25	25/35	ü	25	35	-	-	9
			(herkömmlich:					35	35		5	17)
1E	a		19	32	32	32/20	ü	50	20	-	-	4
	b		20+	32	32	26/25	ü	30	25	-	-	5
	c		25+	32	26	22/30	ü	25	30	-	-	5
	d		30+	33	22+ 1=23	22/35	ü	25	35	-	-	9
	e		32	36	22+ 3=25	25/35	ü	30	35	-	-	12
	f		32	41	25+ 5=30	30/35	ü	30	35	-	-	12
			(herkömmlich, z.B. US Navy:					50	35	3	10	35)

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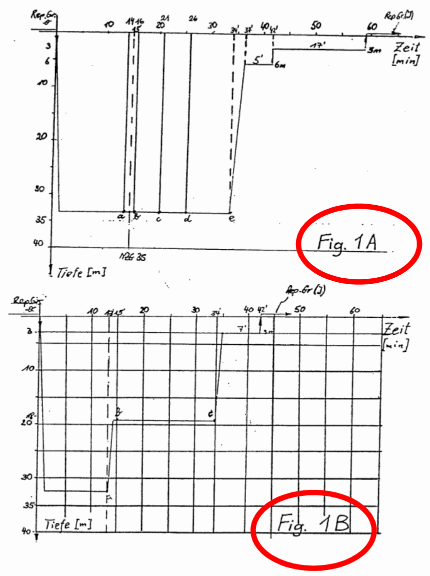
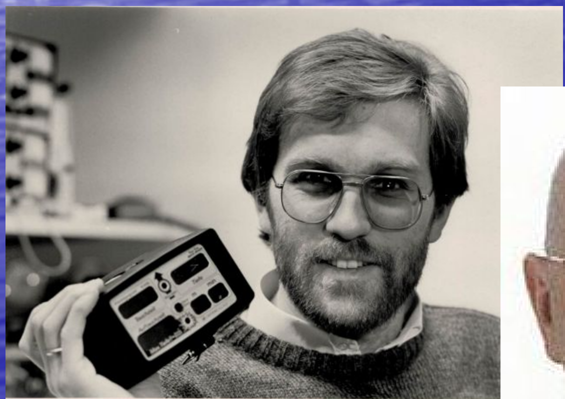


1

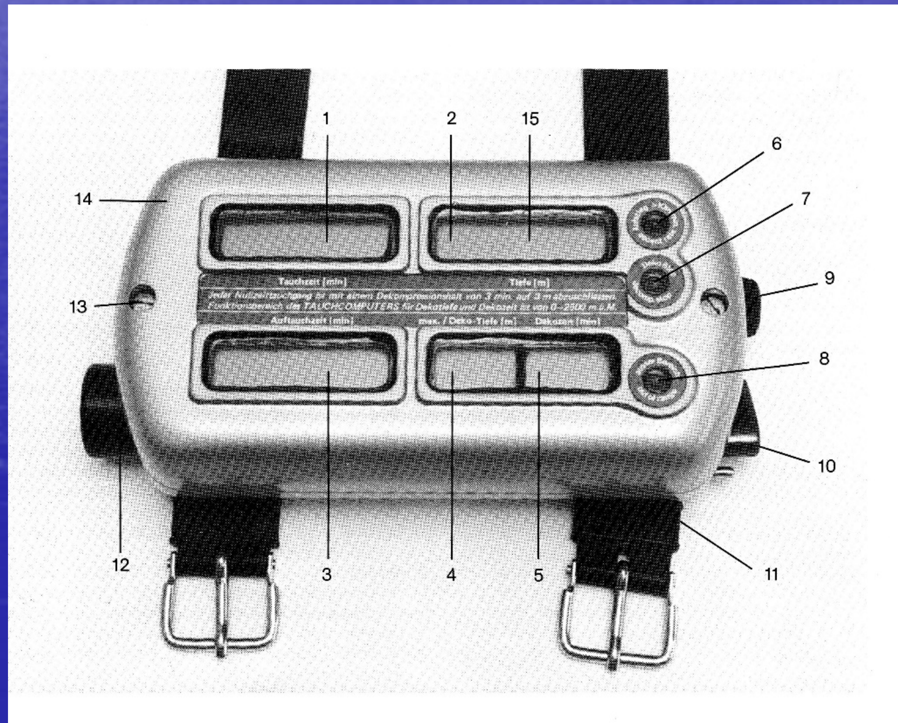
Program P1 (just reading out stored table values; no real saturation- / desaturation calculation)

Deco Brain Trials(1a)

Prof. Dr. H. Hass († 16. June 2013)



Jürgen Hermann as young engineer († 2014)



The very first version; casing in aluminum

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Deco Brain Trials(1b)

advertising, technical specifications

complete set as sold

From program P2 on real saturation- / desaturation calculation, based on ZHL-12 (P2-1) and ZHL-16 (P2-2 and P2-3).

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Deco Brain Trials(2a)

approx. 1985-87; Pgm-versions:
P1: reading stored table values only
P2-2: real calculation with ZHL-16
P2-3: similar; more conservative

manual simulator

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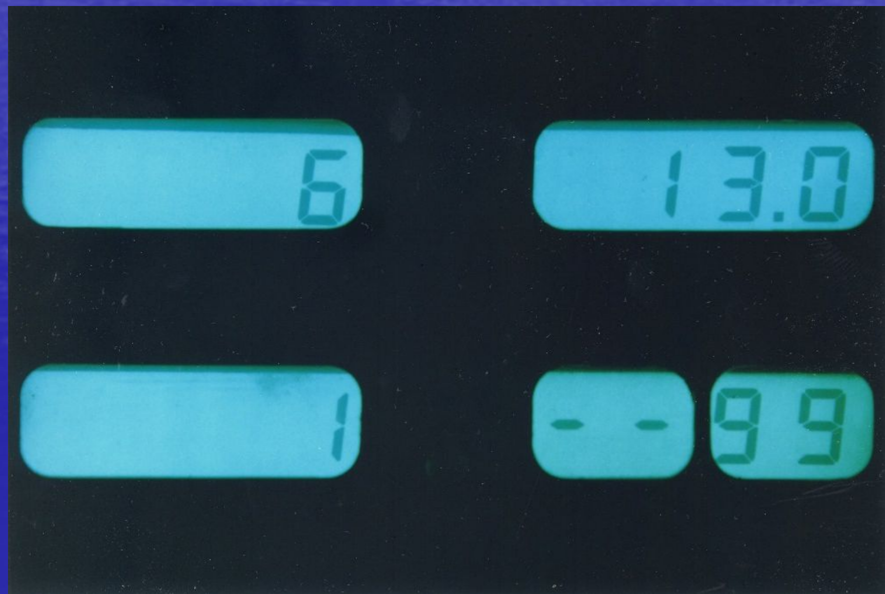
Deco Brain Trials(2b)

version with backplate illumination/ switch with inside reed contact for backplate illumination



backplate illumination in the dark

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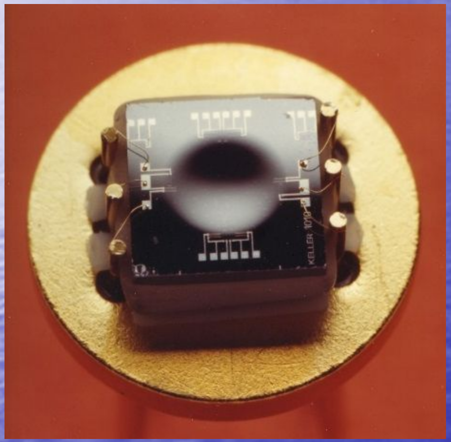
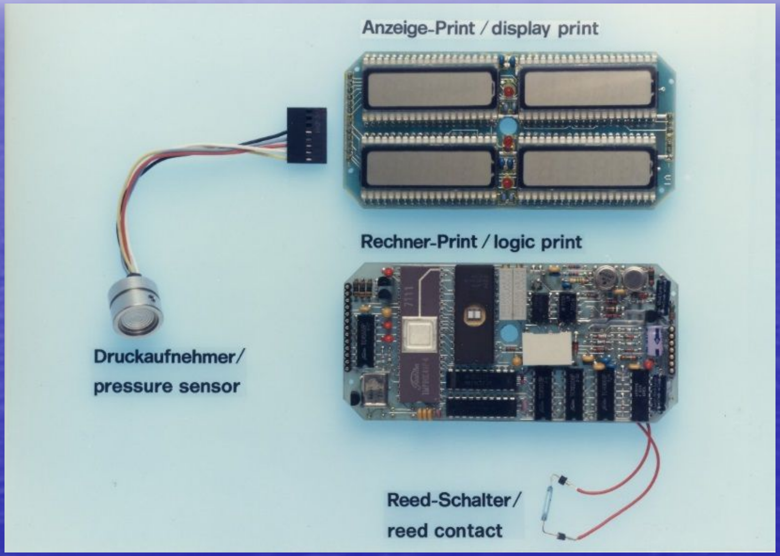
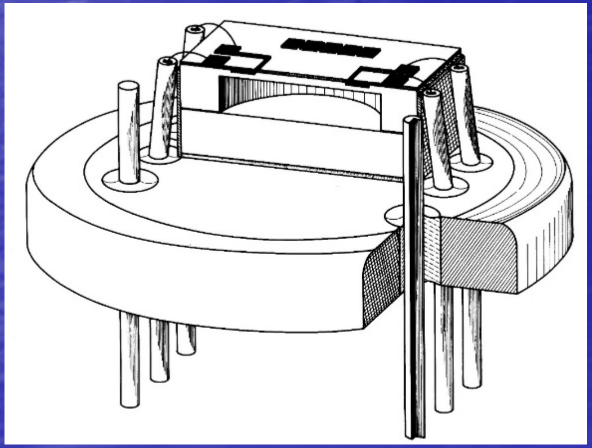
Deco Brain Trials(3)



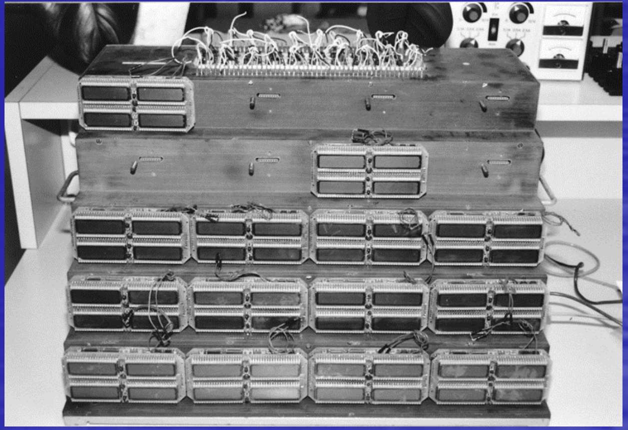


side length
approx. 4-5mm)

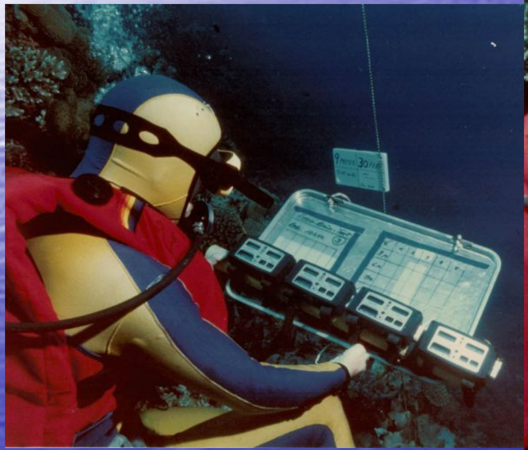


vacuum under
mebrane

display test rig

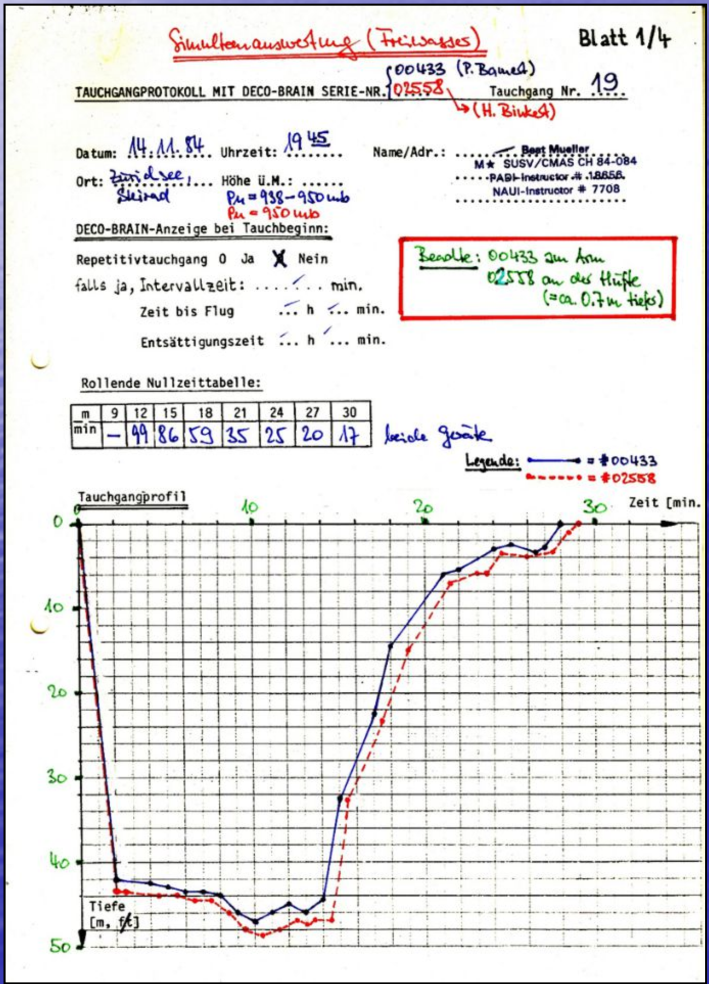


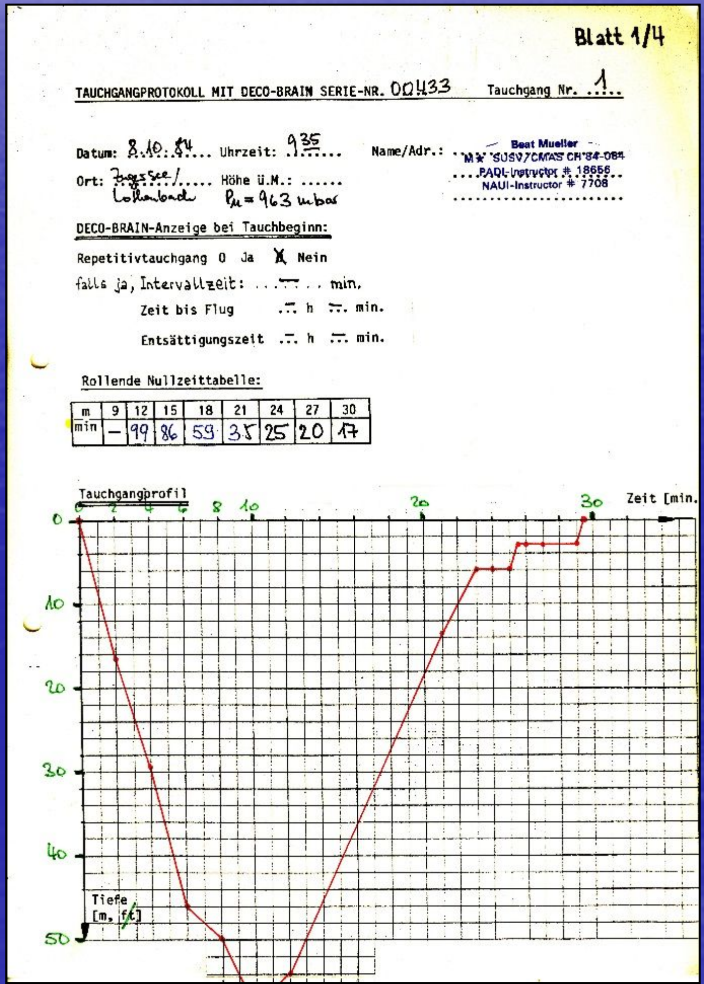
Deco Brain Trials(4)



photos by Kurt Amsler

Deco Brain Trials(5)





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Deco Brain Trials(6)

30 Der Tauchlehrer 5/1986

	Tiefe m	Abstieg min	Grundzeit min	Aufstieg 1. Stufe min	Stufen m 12	9	6	min 3	Gesamt min	Symptome
AA-13 Rpt.	41	2	11	—	—	—	—	—	3.9	0/12
Deco-Brain	41	2	11	3.8	—	—	—	1	4.8	
Intervall	0		120							
2. Tauchgang	41	2	58	2.7	8	15	27	51	103.7	1/12 Haut
Deco-Brain	41	2	58	2.7	12	18	32	57	121.7	
AA-18 Rpt.	35	2	16	—	—	—	—	—	3.3	0/12
Deco-Brain	35	2	16	3.3	—	—	—	2	5.3	
Intervall	0		30							
2. Tauchgang	35	2	20	3.0	—	—	—	13	16.0	2/12 Haut
Deco-Brain	35	2	20	2.9	—	—	1	21	24.9	
AA-20 Rpt.	32	2	18	—	—	—	—	—	3.0	0/12
Deco-Brain	32	2	18	2.9	—	—	—	1	3.9	
Intervall	0		10							
2. Tauchgang	32	2	22	2.4	—	—	2	17	21.4	0/15
Deco-Brain	32	2	22	2.4	—	—	2	25	29.4	
Intervall	0		20							
3. Tauchgang	32	2	13	2.7	—	—	—	15	17.7	2/15 Haut
Deco-Brain	32	2	13	2.7	—	—	—	18	20.7	
AA-35 Rpt.	44	3	32	3.0	2	5	11	26	47.0	0/20
Deco-Brain	44	3	32	3.0	2	5	16	30	56.0	
Intervall	0		90							
2. Tauchgang	38	3	23	3.0	—	—	3	15	21.0	0/20
Deco-Brain	38	3	23	3.0	—	—	3	23	29.0	
Intervall	0		90							
3. Tauchgang	41	3	22	3.3	—	—	4	19	26.3	0/20
Deco-Brain	41	3	22	3.3	—	1	4	29	37.3	
AA-40 Rpt.	41	3	37	2.7	2	5	13	27	49.7*	0/24 * 12 Vp. kontinuierlich 42.7 min
Deco-Brain	41	3	37	2.7	1	6	15	31	54.7	
Intervall	0		120							
2. Tauchgang	41	3	30	2.7	2	4	6	27	41.7	1/24 Muskulatur
Deco-Brain	41	3	30	2.7	2	4	13	38	59.7	

Tabelle 1: Wiederholungstauchgänge. Vergleich der im Experiment durchgeführten Dekompressionen mit den Angaben des Deco-Brain (Programm P2-2)

	Tiefe m	Abstieg min	Grundzeit min	Aufstieg 1. Stufe min	Stufen m 15	12	9	6	min 3	Gesamt min	
AA-13 Rpt.	41	2	11	—	—	—	—	—	—	3.9	
Deco-Brain	41	2	11	3.8	—	—	—	—	1	4.8	
ZH-83	41	2	11	3.6	—	—	—	2	4	9.6	Tab. 42 m 15 min
Intervall	0		120								
2. Tauchgang	41	2	58	2.7	—	8	15	27	51	103.7	
Deco-Brain	41	2	58	2.7	—	12	18	32	57	121.7	
ZH-83	41	2	58	2.7	7	13	22	31	51	126.7	Tab. 42 m 70 min
AA-40 Rpt.	41	3	37	2.7	—	2	5	13	27	49.7	
Deco-Brain	41	3	37	2.7	—	1	6	15	31	54.7	
ZH-83	41	3	37	2.6	1	3	8	16	31	61.6	Tab. 42 m 40 min
Intervall	0		120								
2. Tauchgang	41	3	30	2.7	—	2	4	6	27	41.7	
Deco-Brain	41	3	30	2.7	—	2	4	13	38	59.7	
ZH-83	41	3	30	2.6	1	3	8	16	31	61.6	Tab. 42 m 40 min

Tabelle 2: Wiederholungstauchgänge. Vergleich der real durchgeführten Dekompressionen mit den Angaben des Deco-Brain und der Tabelle ZH-83 für 0 bis 700 Meter über dem Meeresspiegel

from:
Bühlmann Albert A (1986) Dekompressionstabellen – Dekompressionscomputer, VDTL, Der Tauchlehrer, Heft 5, 1986

Decompression Problems in Space

Decompression Problems in Space (1)

Implications of DCS in Space Flight

- Drop from sea level pressure to ~4 psi, 100% O2 pressure
  - Equivalent to ascent from fully saturated 120 ft dive
  - Launch in early space flight
  - Extravehicular activity from shuttle or ISS

$$R = \frac{P_{N2}}{P_{amb}} = \frac{14.7(0.78)}{4} = 2.87$$

- To have "safe" (R=1.4) EVA from shuttle requires suit pressure of 8.2 psi

Decompression Problems in Space (2)

Current Denitrogenation Approaches

- Depress to 10.2 psi for 12-24 hours prior to EVA
  - Full cabin depress in shuttle
  - “Campout” in air lock module of ISS
- Exercise while breathing 100% O2
- In-suit decompression on 100% O2 (3.5-4 hours)

Decompression Problems in Space (3)

Historical Data on Cabin Atmospheres

Program	Cabin Pressure, kPa (psia)	Cabin Oxygen Concentration, volume %	EVA Suit Pressure,[1] kPa (psia)	EVA O_2 Pre-breathe Time, minutes	EVA Prebreathe Conditions
Mercury	34.5 (5)	100	-	-	-
Gemini/Apollo	34.5 (5)	100	25.8 (3.75)	0	-
Skylab	34.5 (5)	70	25.8 (3.75)	0	-
Shuttle	70.3 (10.2)	26.5	29.6 (4.3)	40	In-suit (after 36 hours at 70.3 kPa)
	101.3 (14.7)	21	29.6 (4.3)	240[3]	In-suit
ISS/US	101.3 (14.7)	21	29.6 (4.3)	120-140	Mask and in-suit; staged w/exercise
				240[3]	In-suit
Salyut, Mir, ISS/Russian	101.3 (14.7)	21	40.0 (5.8)[2]	30	In-suit

References: Carson, et al. (1975), McBarron, et al. (1993), Waligora, et al. (1993), NASA (2002), NASA (2003).

(1) 100% oxygen.

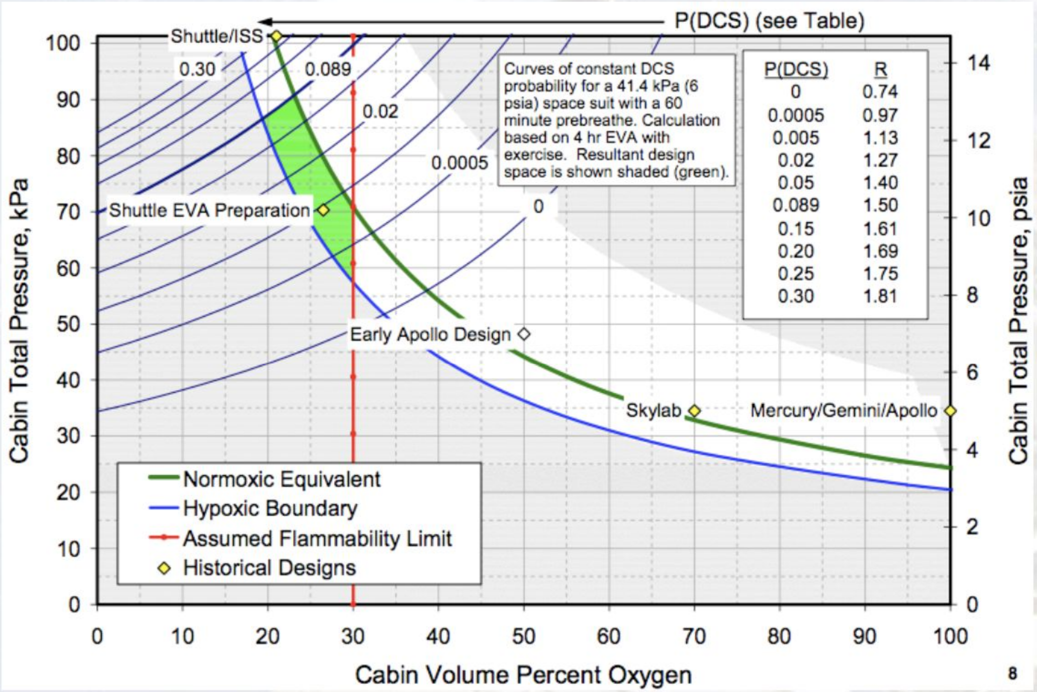
(2) In earlier versions of the Orlan suit, the pressure could be reduced to 26.5 kPa (3.8 psia) for short-duration work regime.

(3) Under emergency conditions, a minimum of 150 minutes of unbroken prebreathe is recommended.

from Scheuring et. al., "Risk Assessment of Physiological Effects of Atmospheric Composition and Pressure in Constellation Vehicles" 16th Annual Humans in Space, Beijing, China, May 2007

Decompression Problems in Space (4)

Atmosphere Design Space with Constraints



from Scheuring et. al., "Risk Assessment of Physiological Effects of Atmospheric Composition and Pressure in Constellation Vehicles" 16th Annual Humans in Space, Beijing, China, May 2007

Decompression Problems in Space (5)

Constellation Spacecraft Atmospheres

Environment	P_B psia mmHg	F_IO_2 (%)	P_IO_2 mmHg	P_AO_2 mmHg	Actual Altitude m feet	Equivalent Air Altitude m feet
CEV + LSAM						
normal	8.0 414	32.0	117	77	4,877 16,000	1,829 6,000
best case	8.2 424	34.0	128	86	4,816 15,800	1,158 3,800
worse case	7.8 403	30.0	107	68	5,029 16,500	2,438 8,000
HABITAT						
normal	7.6 393	32.0	111	71	5,182 17,000	2,286 7,500
best case	7.8 403	34.0	121	80	5,029 16,500	1,524 5,000
worse case	7.4 383	30.0	101	63	5,364 17,600	2,895 9,500

from Scheuring et. al., "Risk Assessment of Physiological Effects of Atmospheric Composition and Pressure in Constellation Vehicles" 16th Annual Humans in Space, Beijing, China, May 2007

About the Author

Bühlmann Memorial Symposium 2019

Professional and Diving Career

Born on 03.01.1953 in Bern (Switzerland), having a M.Sc. in Mech. Eng. from the Swiss Federal Institute of Technology (ETH), he has been working nearly 20 years in the computer science industry. From 2010 to his retirement in January 2016 he was working as a project manager in one of Switzer-lands biggest enterprises, with focus on energy procurement.

Beat Müller holds a certificate as a National Instructor (I**** CMAS) and numerous other instructor and Instructor Trainer certifications from CMAS, NAUI, PADI, FASSAS and SCD. Appointed Staff Instructor Cave Diving by cmas.ch in 2004, he looks back on approx. 4500 dives all over the world.

In the mid-eighties, cooperation with Prof. Dr. A.A. Bühlmann in Zurich, with his direct involvement in the high altitude diving research- and test-program up to 2500m asl. He was the responsible software engineer who wrote the software for the famous '86 Bühlmann air-diving tables, as well as the high altitude dive tables for the diving expedition of a group of divers of the British Rhine Army at Lake Titicaca at 3800m asl. He also gave contributions to publications such as “Decompression – Decompression Sickness (Bühlmann) and “Deeper into Diving” (J. Lippman) and numerous training aids of the Swiss Fede-rations SUSV and cmas.ch.

Other activities:2004 – 2008 Vice President of the Technical Committee of CMAS International, 2000-2013 Member of the Committee of Technical Diving of cmas.ch, from 2004 – 2013 Head of the Cave Diving Working Group in the Technical Committee of CMAS International. Working as an international ITC CMAS Course Director in Turkey, North Africa and Ireland. He is the author of the Cave Diving Standards and Training System of CMAS International and of Swiss Cave Diving.

Together with Fritz Schatzmann he is the author of the European reference book „Höhlentauchen“ (engl.: “Cave Diving”), and “Cavern Diver” (in German and English) , officially recommended by the World Underwater Federation CMAS.

He is also a founding member and former president until 2015 of the largest European cave diving association “Swiss Cave Diving” and co-owner of the registered trademarks "Swiss Cave Diving", "Swiss Cave Diving Instructors" and "Swiss Cave Divers". He is still working as a member of the board in the position of a Director of Standards.
Since 2006 he is the webmaster of the most visited cave diving website in Europe, www.swiss-cave-diving.ch . He lives with his wife in the greater Zurich area.

He has given numerous presentations on decompression modelling and on Prof. Bühlmann's work in Switzerland, many other European countries, North Africa and Mexico.

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Other Activities of Preference…

(hanging on the deco-bar after a 80m Trimix dive at the Milford Haven, Genova)