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On the theoretical evaluation of one yo-yo diving profile on air for fish-farming

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Abstract:

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A yo-yo diving profile is one with very rapid and repeated depth changes. Due to the speed of depth changes in excess of 20 m/min and the quickly repeated ascents and descents within 1 to 5 min, a standard decompression model based on perfusion or a dive computer or a logging device can no longer track the changes in the inertgasload in the diver's body properly.

One form of ubiquitious yo-yo diving is done in fish-farming, clearly needed to change air-tanks, tools, debris and locations within a multiple array of the fish-nets.

The already available historic sources ([1], [2], [4], [5] & [6]) address this topic clearly and the connected risks but without hints of complete mitigation.

We propose simple & straightforward modifications of an existing perfusion model [12] to mitigate the risk of decompression sickness and/or arterial/ cerebral air embolism.

Methods (1):

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The yo-yo profile in question is the one from: [5], p. 24:

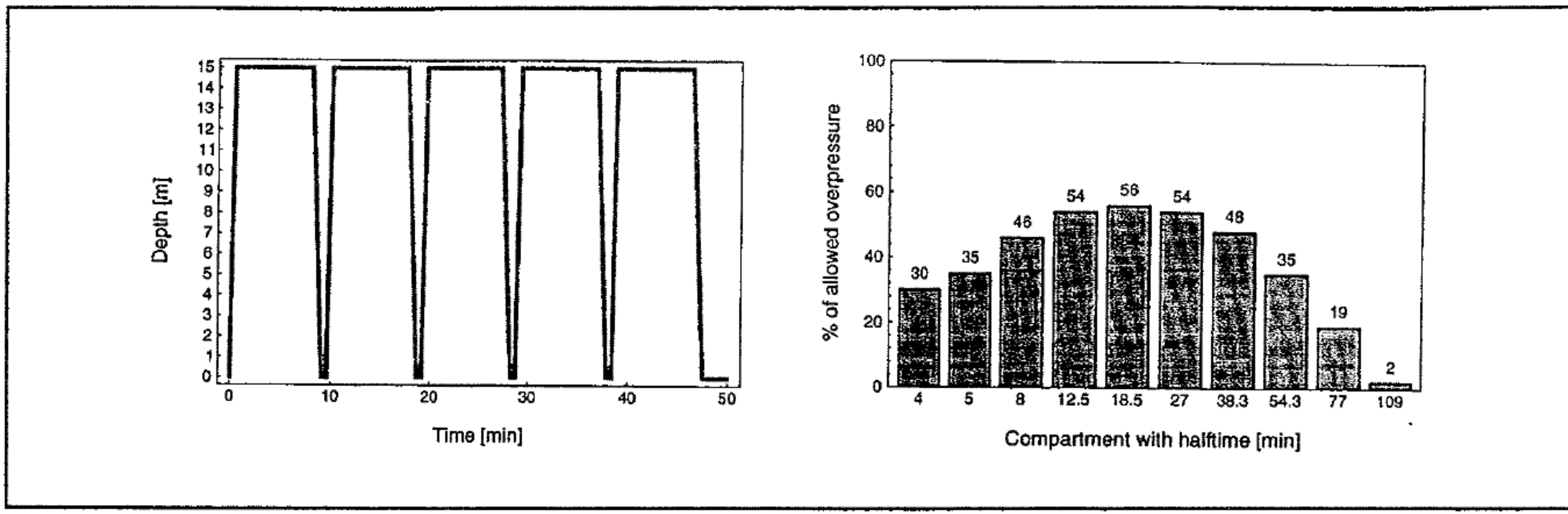

Figure 9. Fish-farming yo-yo profile resulting in DCS (left). Musculoskeletal DCS successfully treated with US Navy Table 6 (Douglas and Milne, 1991). Right, the comparatively low supersaturation by ZH-L16C model (Bühlmann, 1993).

Methods (2):

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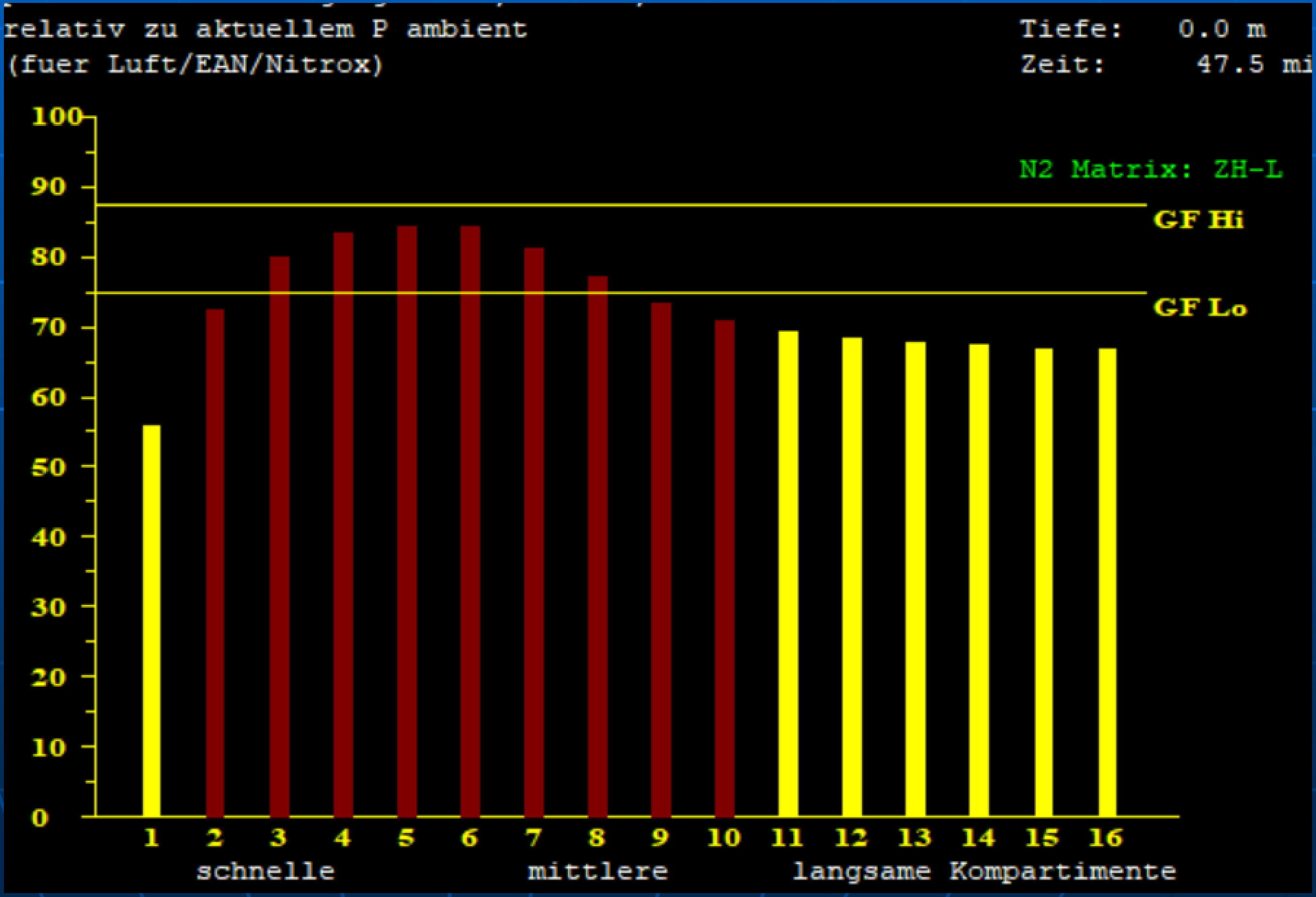
A quick check with available desktop deco software programs (pls. cf. the „Bonus Material" at the end of this presentation and [3]) confirmed the findings from [1], [4], [5] & [6];

the calculated inertgas loads do not suggest any decompression or safety stop:

(the used color scheme for the heat maps was proposed by DAN within the DSL framework)



Methods (3):

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To keep track on the inertgas loads in the various theoretical tissue-compartments during the rapid pressure changes due to fast ascents and descents, compartments with very small half-times (HT), i.e.
high perfusion rates, have to be introduced.

Since 6 halftimes are needed to saturate (or desaturate) these theoretical compartments, haltimes in the minute resp. sub-5-minute ranges are clearly required, so one compartment with a halftime of ca. 70 secs and a 2 min compartment are added on the fast side of the halftime-spectrum from [12]; and one intermediate compartment with a HT of ca. 9 min is added as well ([7]).

These new fast compartments are pretty well in-line with the data, extracted from Paulev [9], [10] & [11] resp. [8] on p.19.

Methods (4):

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With [7], p. 6 and the aid of [12], p. 129:

$$a = 2\ \text{Bar} * \tau^{-1/3}$$

$$b = 1.005 - \tau^{-1/2}$$

where, in the a-coefficient, the 3rd. root of the half-time τ is, according to Buehlmann, an indicator to the excess volume of inertgas and thus could be mapped onto the simulated bubble volumes of [7].

Methods (5):

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Source: [7], p. 5:

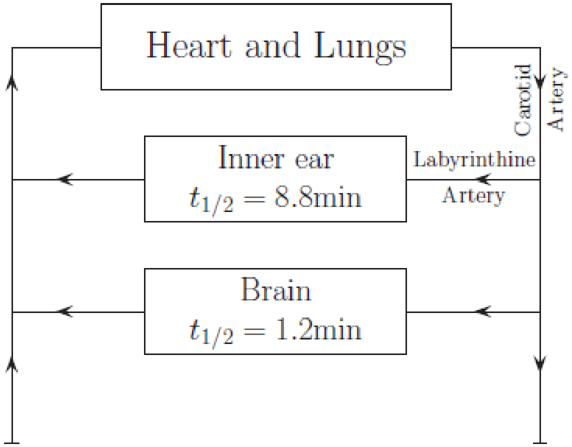
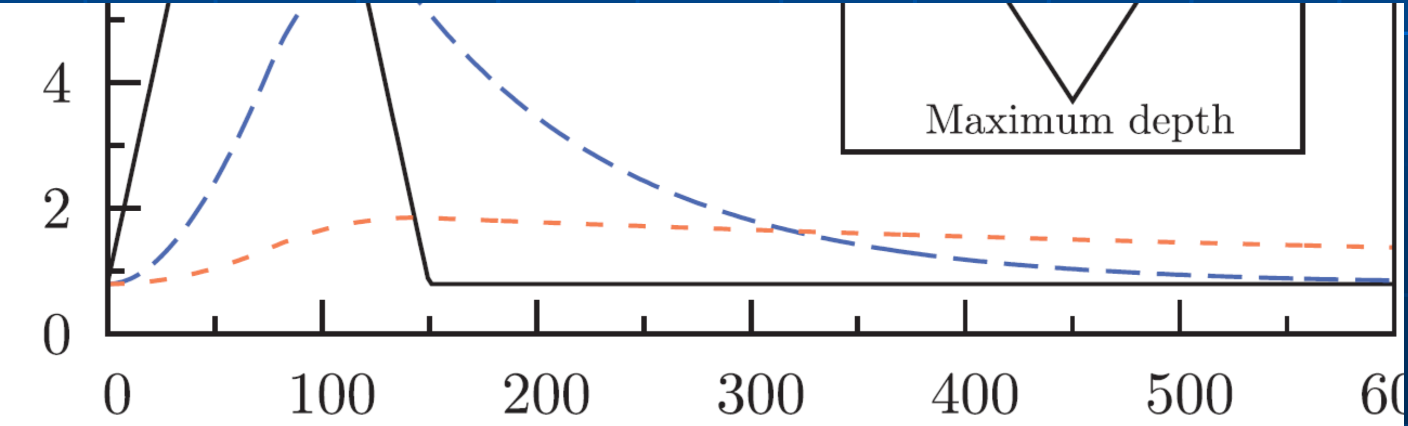


Fig. 3. Independent parallel compartmental model of the head showing the brain and inner ear, each represented as independent mono-exponential compartments, with their respective half-lives ($t_{1/2}$).

[7], p. 6:



Methods (6):

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The new compartments were tailored to the a-/b coefficient scheme of the ZH-L 16 framework [12] with a clear stress to fast compartments to keep track of the expedited change in inertgas loads. The yellow display are the new and overpressure-sensitive fast compartments.

Compartment #2 with 2 min halftime (TAU) is calculated according to the rule from [12], p. 129, but was never used by Buehlmann.

The rest of the compartments are original Buehlmann et.al., the gradient factors High & Low equal to 1.0, i.e.: 100 %.

N2COEFF.TXT - Editor

Datei Bearbeiten Format Ansicht ?

#	TAU	A	B	HI	LO
01	1.20	0.3500	0.7500	1.0	1.0
02	2.00	1.5874	0.2978	1.0	1.0
03	4.00	1.2599	0.5050	1.0	1.0
04	5.00	1.1696	0.5578	1.0	1.0
05	8.00	1.0000	0.6514	1.0	1.0
06	8.80	0.3500	0.7500	1.0	1.0
07	12.50	0.8618	0.7222	1.0	1.0
08	18.50	0.7562	0.7825	1.0	1.0
09	27.00	0.6200	0.8126	1.0	1.0
10	38.30	0.5043	0.8434	1.0	1.0
11	54.30	0.4410	0.8693	1.0	1.0
12	77.00	0.4000	0.8910	1.0	1.0
13	109.00	0.3750	0.9092	1.0	1.0
14	146.00	0.3500	0.9222	1.0	1.0
15	187.00	0.3295	0.9319	1.0	1.0
16	239.00	0.3065	0.9403	1.0	1.0

Methods (7):

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Since Haldane [13], p. 346 the abundance of inertgas (micro-)bubbles is associated with delayed de-saturation, i.e. prolonged half-times. This is as well addressed, for example, in the EL-algorithm used for the new USN air diving tables ([14]).

Here, we use a compartment matrix with increased halftimes of 50 % in the first 8 compartments only for the 5 ascents of this yo-yo profile:

#	TAU	A	B	HI	LO
01	1.80	0.3500	0.7500	1.0	1.0
02	3.00	1.5874	0.2978	1.0	1.0
03	6.00	1.2599	0.5050	1.0	1.0
04	7.50	1.1696	0.5578	1.0	1.0
05	12.00	1.0000	0.6514	1.0	1.0
06	13.20	0.3500	0.7500	1.0	1.0
07	18.75	0.8618	0.7222	1.0	1.0
08	18.50	0.7562	0.7825	1.0	1.0
09	27.00	0.6200	0.8126	1.0	1.0
10	38.30	0.5043	0.8434	1.0	1.0
11	54.30	0.4410	0.8693	1.0	1.0
12	77.00	0.4000	0.8910	1.0	1.0
13	109.00	0.3750	0.9092	1.0	1.0
14	146.00	0.3500	0.9222	1.0	1.0
15	187.00	0.3295	0.9319	1.0	1.0
16	239.00	0.3065	0.9403	1.0	1.0

Results (1):

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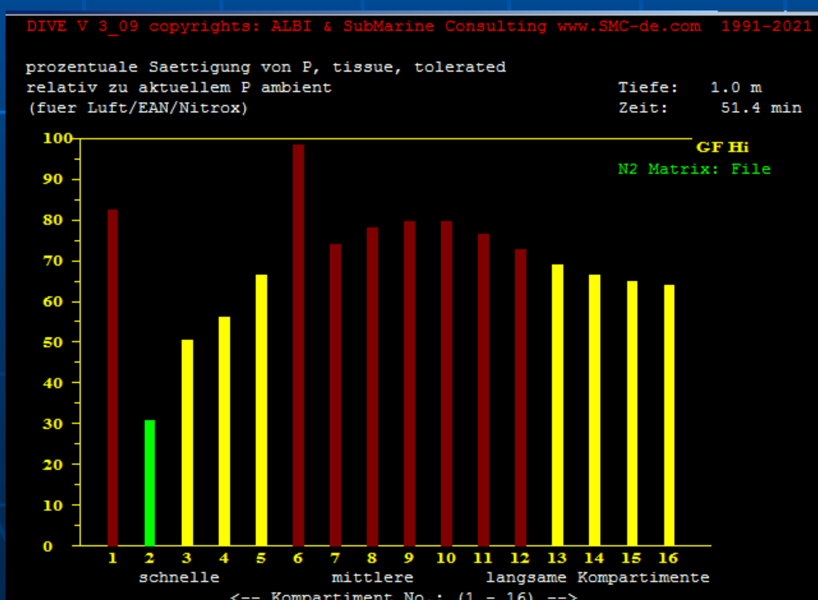
By using these modified ZH-L coefficients matrices (pls. cf. slide #8 for descent, slide #9 for ascent) already during the first ascent a decompression / safety stop of ca. 1 min is suggested:

```
 was jetzt?a
maximale Ceiling:  2.37
Vorschlag Haldane 2:1 [m] =  2.5
Vorschlag Hills, B. A.: DEEP STOP [m] =    8
PDIS fuer TAU = 10 min:   6.46 [m]
PDIS fuer TAU = 20 min:   3.73 [m]
PDIS fuer TAU = 30 min:   2.64 [m]
Eingabe der Austauchstufe in Metern & cm:(m.cm):
          Austauchstufe ist zu hoch:
          niedriger wie Ceiling waehlen!
 Deko Prognose:
 3m Stopp Prognose Dekozeit:     1.0  Komp.#:  1
TTS =      2.0
```



This even more so after the consecutive 4 descents/ascents:

Results (2):

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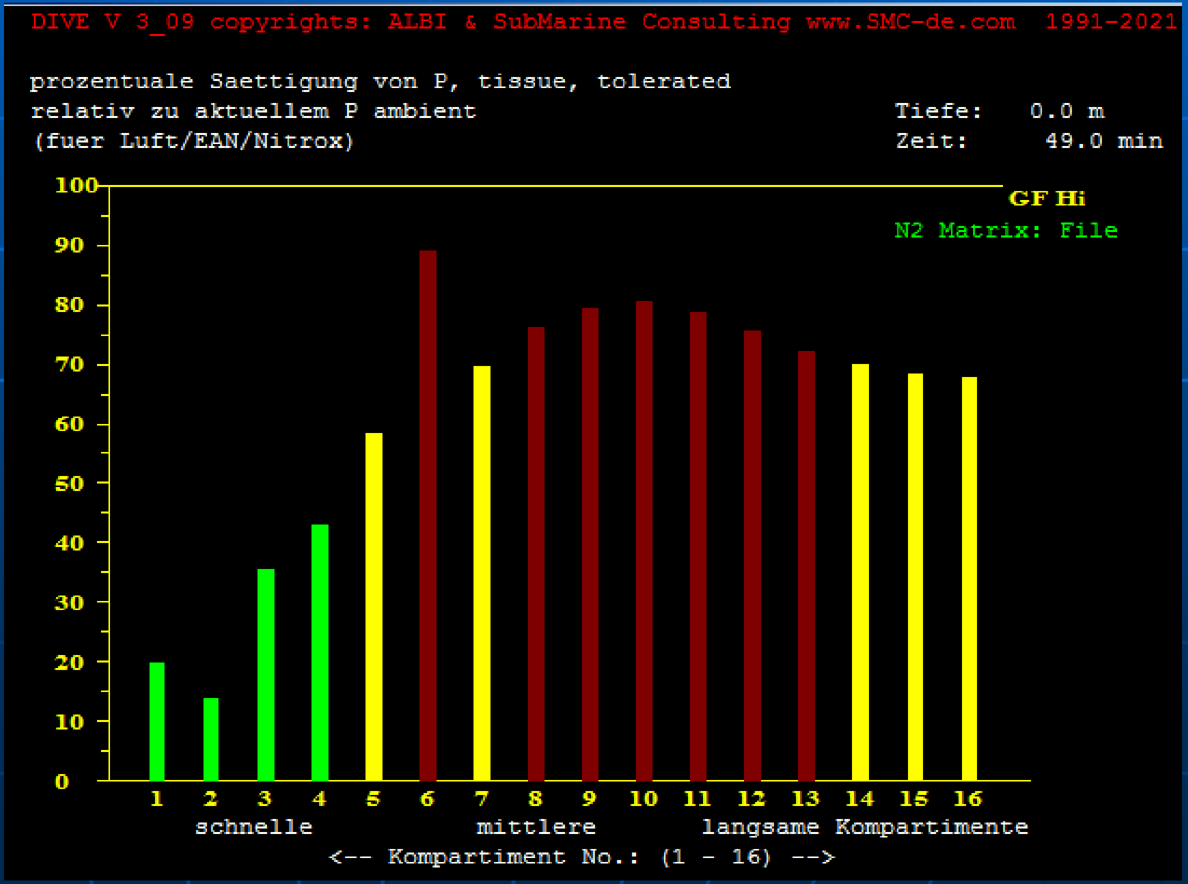
During the consecutive ascents the ceiling / safe ascent depth increases from ca. 2.35 m to 2.45 and the stop times accumulate from 1 min to ca. 4 min: after the complete series of 5 bottom times and 5 ascent spikes, our modified model suggests a

decompression stop > 4 min at a stop depth of ca. 4 +/-2 m.

However:
an even higher benefit in terms of reduced inertgas load could be achieved by changing the breathed gas to 100 % oxygen at approx. 6 m during the last, the 5th. ascent and a final stop:



Discussion:

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The extreme form of repetitive diving like the yo-yo profiles used for professional fish-farming can not be adequately adressed neither by standard perfusion models like the ZH-L16 or a Workman algorithm ([2], [5], [6]) nor by standard diffusion models ([1], [4]) since the used compartment half-times resp. diffusion coefficients are not fitting to the fast inertgas absorption / release processes during the spikes of the yo-yo profile.

Instead, fast compartments with half-times in the sub-minute region should be added.

We extracted fast-compartment data [8] with a half-time of ca. 70 sec from [9] → [11] which are in-line with a recently developped new model [7].

Thus the tested profile required short and shallow decompression resp. safety stops already for the first spike of the yo-yo series. After the complete series of spikes, our model suggest a stop > 4 min @ 4 m +/- 2 m.

Sources / References (1):

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[1] Smart DR, Van den Broek C, Nishi R, Cooper PD, Eastman D. Field validation of Tasmania's aquaculture industry bounce-diving schedules using Doppler analysis of decompression stress. Diving and Hyperbaric Medicine. 2014 September:44(3):124-136

[2] Bühlmann, A.A. (1987) Decompression after repeated dives, Undersea Biomed Res. Vol. 14, #1, p. 59 - 67 (3810993)

[3] the SubMarineConsulting Group(1991) DIVE: a decompression suite; pls. cf. slide #16

[4] Diving methods and decompression sickness incidence of Miskito Indian underwater harvesters RG DUNFORD, EB MEJIA, GW SALBADOR, WA GERTH, NB HAMPSON, UHM 2002, Vol. 29, #2, p. 75 -85 (12508972)

Sources / References (2):

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[5] Hahn, Max. H. (1995) Workman-Bühlmann Algorithm for Dive Computers: a critical analysis; in: Hamilton, R.W. (ed.) The effectiveness of dive computers in repetitive diving; p. 19 – 25

[6] Hahn, M.H. (1992) Dive Computers – Today and Tomorrow; in: Wendling /Schmutz (eds.) Safety Limits of Dive Computers, Dive Computer Workshop, p. 30 – 35

[7] SaulGoldman,J.M.Solano-Altamirano (2015) Decompressionsickness in breathholddiving and its probable connection to the growth and dissolution of small arterial gasemboli, Mathematical Biosciences262(2015)1–9; http://dx.doi.org/10.1016/j.mbs.2015.01.001

[8] Salm, Albrecht (2018) Essay on fast and super-fast compartments;
DOI: 10.13140/RG.2.2.30451.35366
Or there: **Tech Diving Mag, Issue 30 / 2018:
On Fast- and Super-fast Compartments, p. 10 -20**

Sources / References (3):

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[9] PAULEV, P. Decompression sickness following repeated breathhold dives. J. Appl. Physiol. 20(5) : 1028-1031. 1965

[10] PAULEV, POUL-ERIK, AND NOE NAERAA. Hypoxia and carbon dioxide retention following breath-hold diving. J. Appl. Physiol. 22(3) : 436-440. 1967.

[11] PAULEV, POUL-ERIK. Nitrogen tissue tensions following repeated breath-hold dives. J. Appl. Physiol. 22(4): 714-718. 1967

[12] Bühlmann, Albert A., Völlm, Ernst B. (Mitarbeiter), Nussberger, P. (2002): Tauchmedizin, 5. Auflage, Springer, ISBN: 3-540-42979-4

[13] Haldane, J S. Respiration, Yale University Press, 1922, 1927

[14] Thalmann ED, Parker EC, Survanshi SS, Weathersby PK. Improved probabilistic decompression model risk predictions using linear-exponential kinetics. Undersea Hyper. Med. 1997; 24(4): 255 – 274

Bonus Material (1): Source for DIVE Version 3_09

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Download free of charge:

→ DIVE V 3_09
(https://www.divetable.info/DIVE_V3/index.htm)

→ and the german manual
https://www.divetable.info/DIVE_V3/DOXV3_0.pdf

The release train for
→ the english version (V3_04) is somewhat slower …
DIVE V 3_09 is not compatible with all older versions!

https://www.divetable.info/DIVE_V3/V3e/index.htm

Bonus Material (2):

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3 ASCII (text) files with the data,
for easy reference & download

→ The nitrogen coeffcients matrix für saturation
(descents & bottom time), slide #8:
https://www.divetable.info/beta/Fishfarm/N2COEFF.TXT

→ The nitrogen coeffcients matrix für de-saturation
(ascents & decompression / safety stops), slide #9:
https://www.divetable.info/beta/Fishfarm/F10.TXT

→ The calculated inertgas pressures in the 16 compartments,
after the 5th. spike, that is: the completed yo-yo profile,
prior to ascent, i.e. run-time 46.5 min):
https://www.divetable.info/beta/Fishfarm/Fishfarm.TXT

Bonus Material (3):

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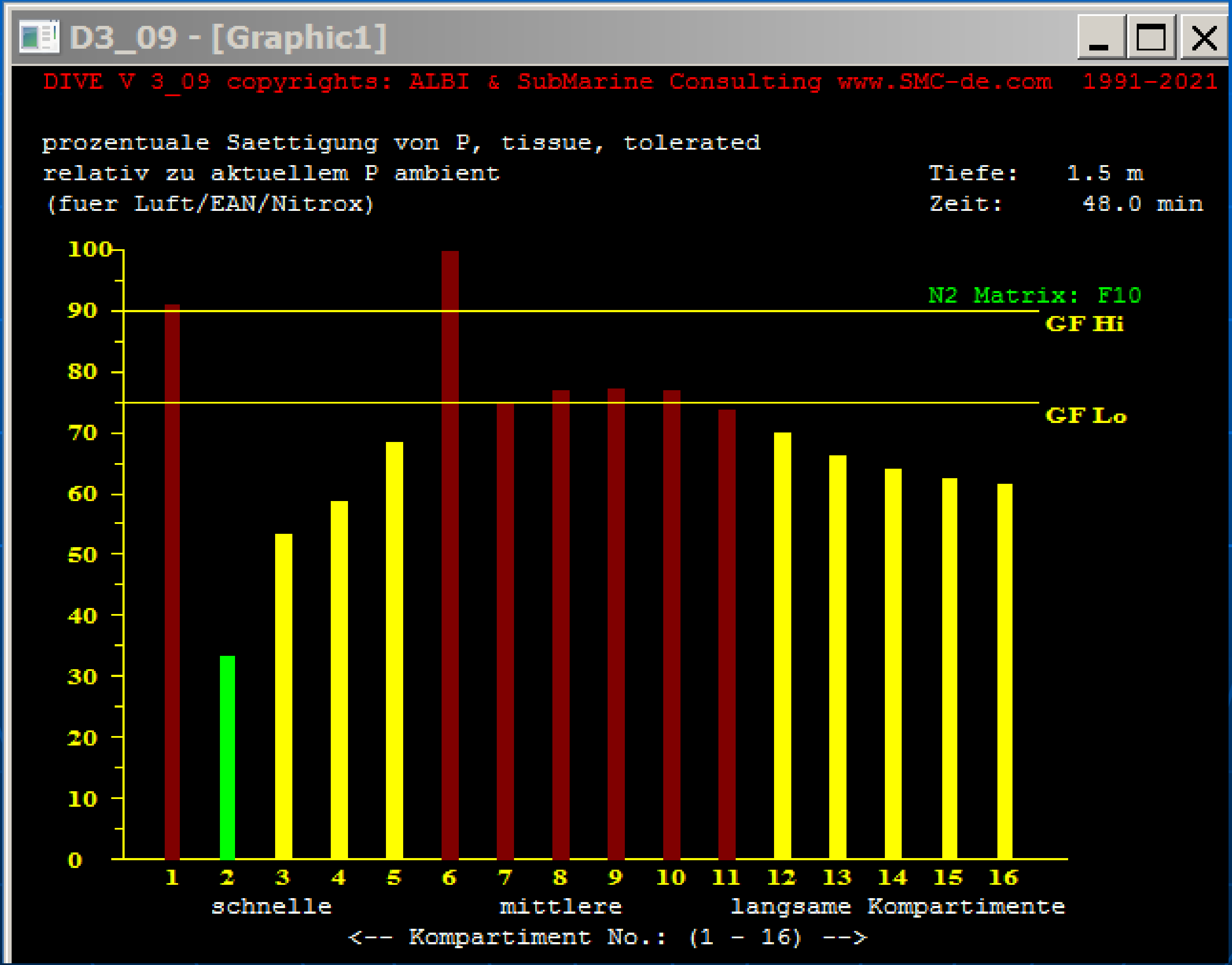
→ the heat-map, prior to the last stop, run-time 48 min



Handling of DIVE:

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The paradigm dive from above via these commands,
the input of commands and parameters are in the quotes: „ “

→ „**d**“ (simulation of one spike of the yo-yo box profile with these parameters:)

→ „**15.**“ (bottom depth)

→ „**8.**“ (bottom time)

→ „**a**“ (ascent)

→ the manipulation of the coefficients matrices is done via:

→ „**nc**“ (nitrogen coefficients):

```
 was jetzt?nc
Eingabe der N2-Koeffizienten Matrix:
 1 = Buehlmann ZH-L 16C Computer,
 2 = Dr. Max Hahn,
 3 = File: N2COEFF.TXT,
 4 = U.S. Navy 1965,
 5 = USN: VVAL18,
 6 = USN: VVAL76-1,
 7 = Buehlmann ZH-L 16B Tabelle,
 8 = Buehlmann ZH-L 12 (1983),
 9 = M. Hahn DECO-BRAIN P2-2, (1985)
10 = File: F10.TXT,
11 = File: F11.TXT.
```

with the option 3 the matrices from slides #8 & 9 could be loaded into the service engine of the DIVE software.

The heat maps are generated via:

→ **„%p“**

Fine tuning of DIVE:

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Fine tuning could be done via the commands:

→ ascent rate („**AR**“)

→ ambient atmospheric pressure at start („**L**“)

→ the respiratory coefficient („**R**“)

→ the ambient (water)-temperature („**te**“)

→ the water density („**di**“)

→ Buehlmann Safety Factor („**B**“)

→ last stop depth („**LS**“)

And with: „**a**“ we recieve the complete decompression prognosis; i.e.: the stop times in min per stage, modulo 3 m and the **responsible leading compartment & the rounded up TTS** in min. The latest DIVE Version for beta testing is always staged there:

https://www.divetable.info/beta/index.htm

along with information on production date, size in bytes, new features and the checksums for verifying the download.