Milestones of the deep diving research laboratory Zurich

Bühlmann Symposion 29./30. März 2019

Universitätsspital Zürich (DKL-USZ)

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Deep-Diving Research Laboratory Zürich

Hannes Keller (Project Director -64)
Prof.A.A.Bühlmann (Medical Director, †94)
Benno Schenk (Technical Director, 64-)

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- 1959–1963 Proving the feasibility of deep-diving with Heliox
- 1964-1981 Development of deco-tables for offshore work
- 1972-1986 Altitude dive-tables for SCUBA bounce-diving
- 1983-1994 Support for development of dive computers
- Conclusions

Hannes Keller

- Scuba Diver
- Mathematics High-School Teacher
- Friend of IBM Manager and Programmer
- Knowledge of USN Heliox Tables

Hypothesis: Diving deeper than 180 m possible with

- avoiding narcosis by replacing N_2 by He
- pre-oxygenation (max. N_2 elimination)
- reducing inert gas load by ultra-fast descent
- fast decompression by using counter-diffusion effect, multiple gas switches

Prof. A.A. Bühlmann

- Medical Doctor, Internal Medicine Specialist, University Zürich
- Research in lung physiology
- Interested in Haldane and Dwyer approach for gas exchange simulation

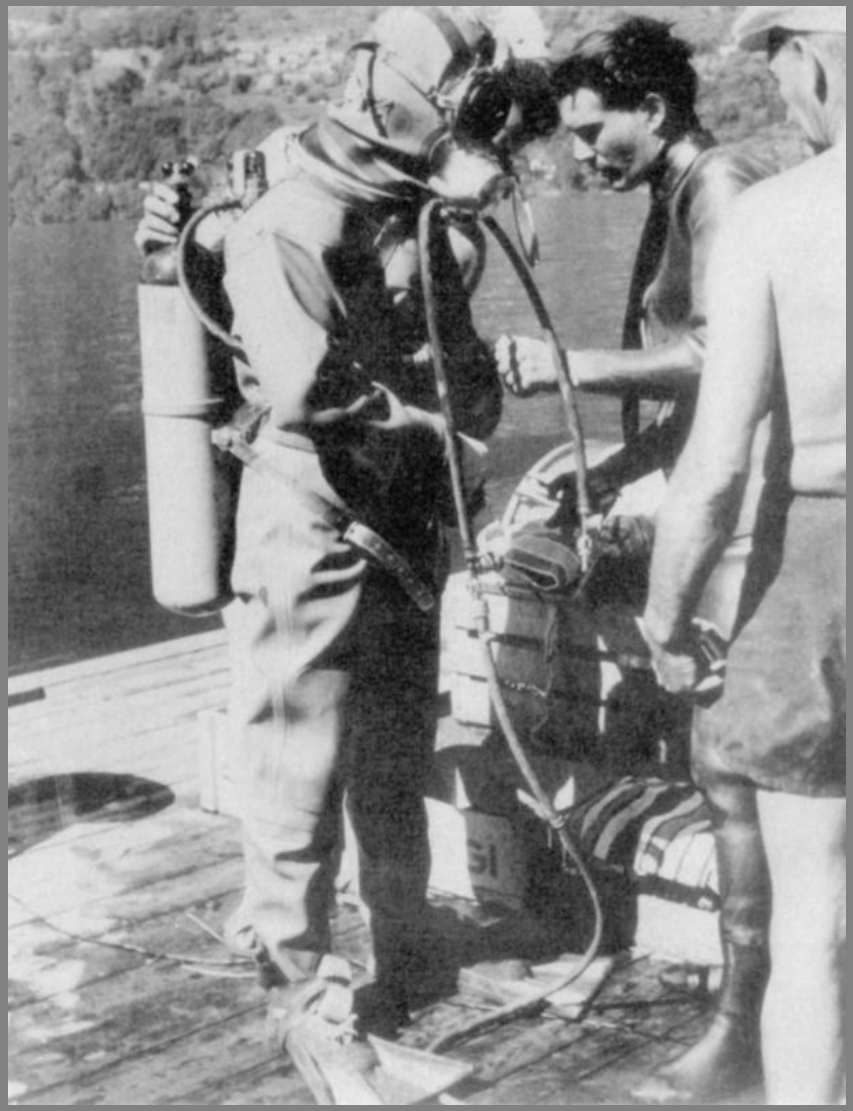
Hypothesis:
Diving with air would work even for deeper dives, if sufficient CO2 elimination was assured (Narcosis = CO_2 retention phenomenon)

Early Deep-diving experiments

1915	91 m	air (free dive)	USN [N_2 narcosis]
1919	?	heliox (experiments)	Thompson
1937	127 m	heliox (free dive)	Nohl/End
1937	150 m	heliox (simulation)	Nohl/End
1939	73 m	heliox (squalus lifting)	USN [He Tbles,closed circ.]
1945	159 m	H_2–O_2 (free)	Zetterströhm [blow-up, †]
1956	180 m	heliox (free)	RN [surface supplied]
1958	*Start of H. Keller/A. Bühlmann-experiments*		

Proving the feasibility of deep-diving to 300m 1959-63

- 1959 Fresh water record 122m Lake of Zurich
- 1960 Fresh water record 222m Locarno
- 1961 60min work 90m research cham.
- 1961 10min work 220m sim. (4bar)
- 1961 10min work 220m cham. (Toulon)
- 1961 10min work 220m cham. (USN)
- 1962 World record (sea) 300m California

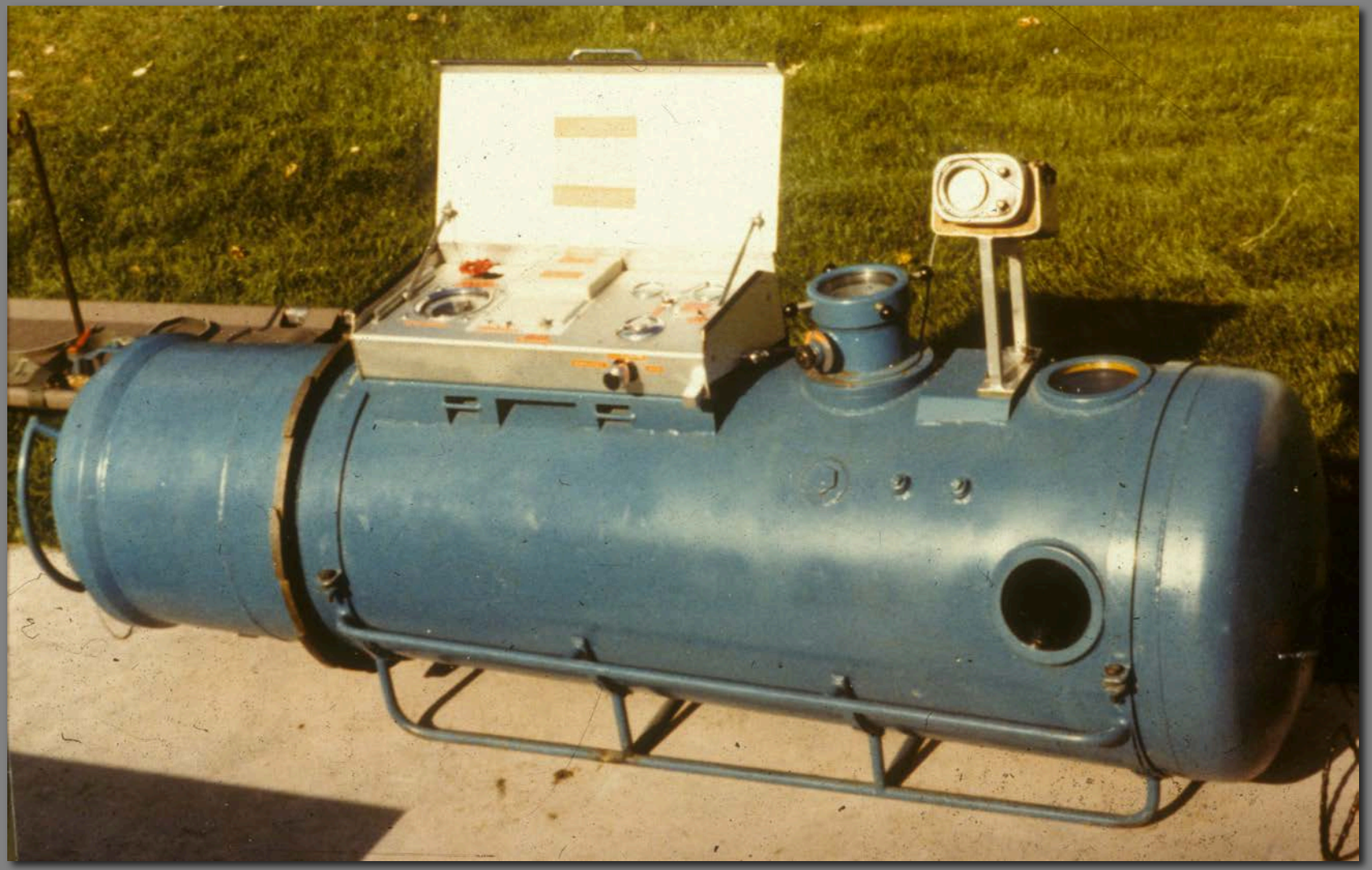


video

	Gas	O_2	N_2	He	Arg.	min
A	I	21	79	-	-	
	II	20	-	80	-	3+60+3·66
	IV	30	-	-	70	10
	V	50	-	-	50	24
	VI	100	-	-	-	50
B	I	21	79		-	10
	II	8	-	92	-	3+60+3·66
	V	50	50		-	35
	VI	100	-	-	-	75

FIG. 2. Nine subjects, 300-ft dive with 60 min bottom time.

Vorausberechnung und Testung des Versuchs in einer 1-Mannkammer mit 5 verschiedenen Atemgasgemischen



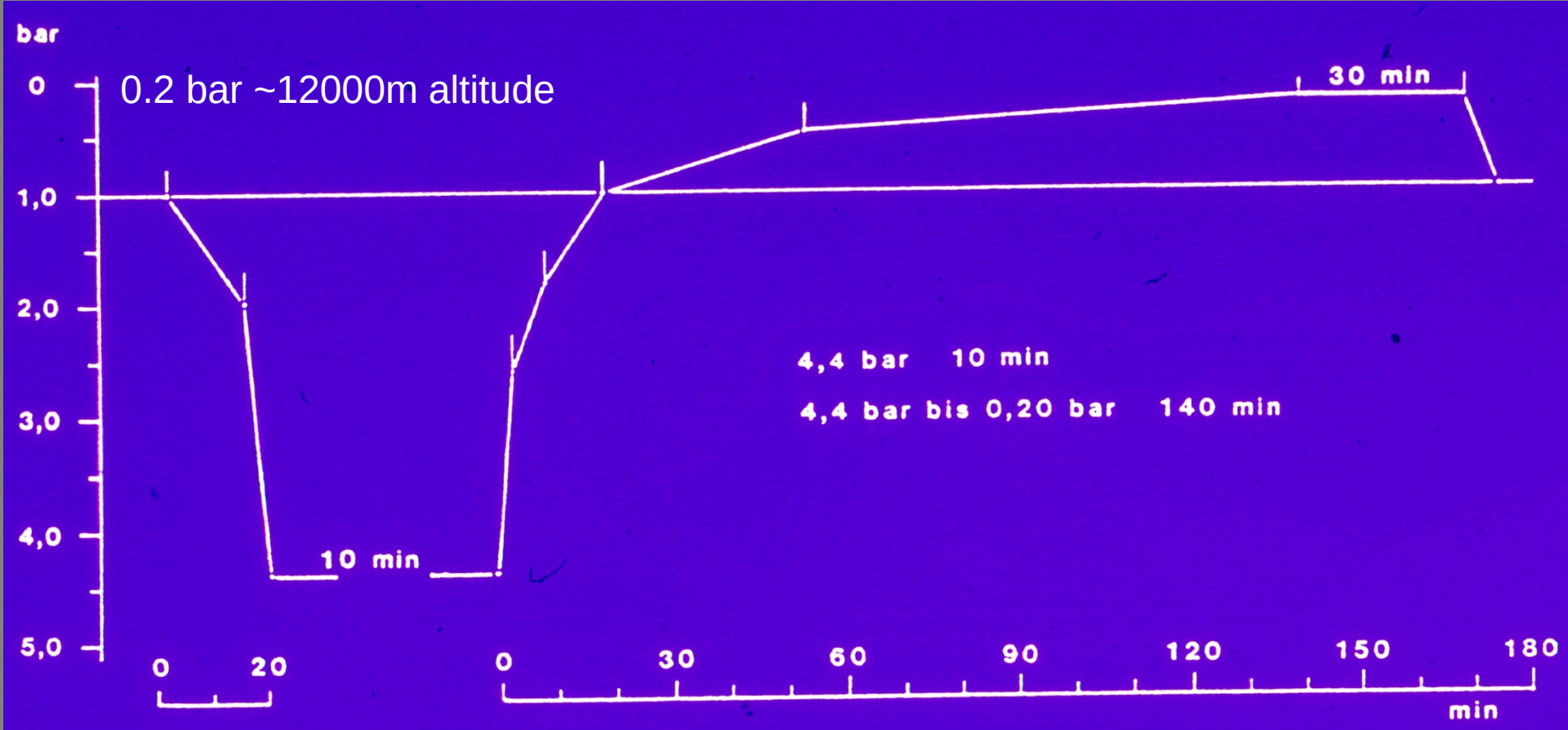


Abb. 2. Vorherige Testung des Dekompressionsprofils der Tauchgänge am 26. 04. 1961 und 10. 05. 1961 mit der Kombination von Überdruck und Unterdruck. Von 1,0 bar bis 0,5 bar wurde 50% O_2 + 50% N_2 und von 0,5 bis 0,2 bar 100% O_2 eingeatmet. Der Aufenthalt bei 0,2 bar dauerte 30 min, was für das Auftreten von Schmerzen als Zeichen einer ungenügenden Dekompression zu kurz ist

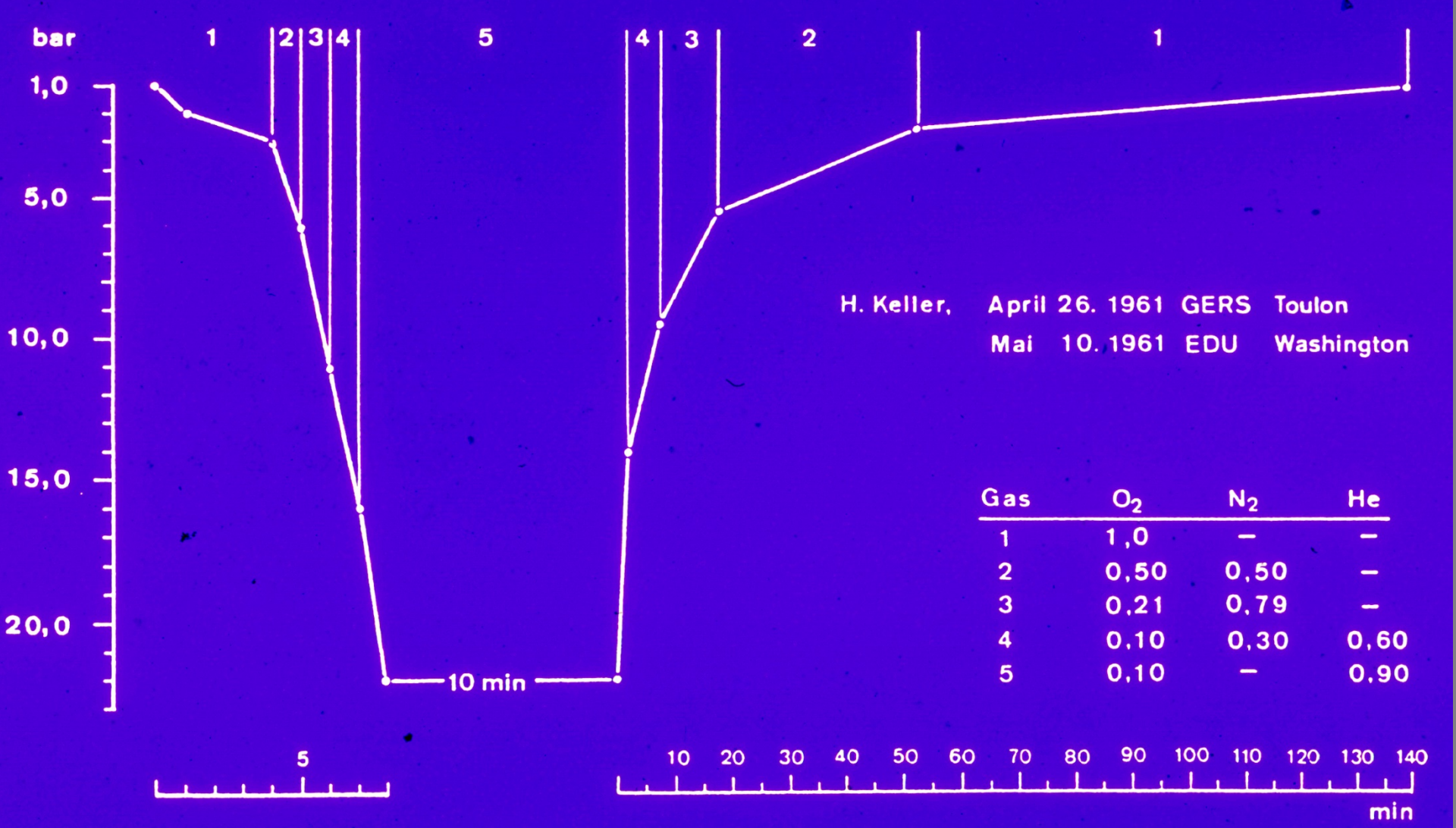
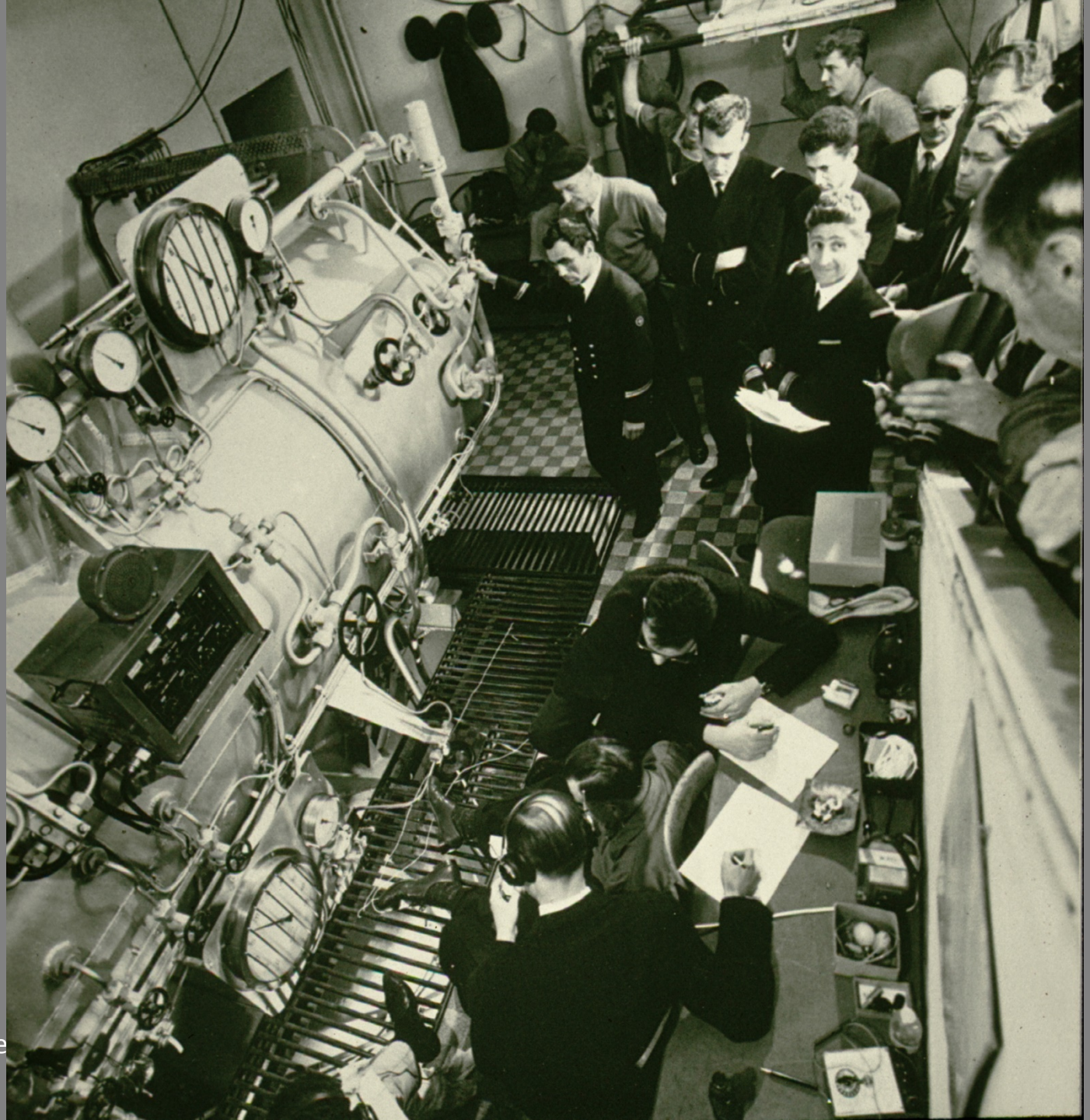


Abb. 1. Exposition während 10 min bei 22,0 bar. Kontinuierliche Kompression und Dekompression mit 5 verschiedenen Atemgasen. Bei 22,0 bar leichte Arbeit mit Gewichtheben im Wasser. Dekompressionszeit 140 min



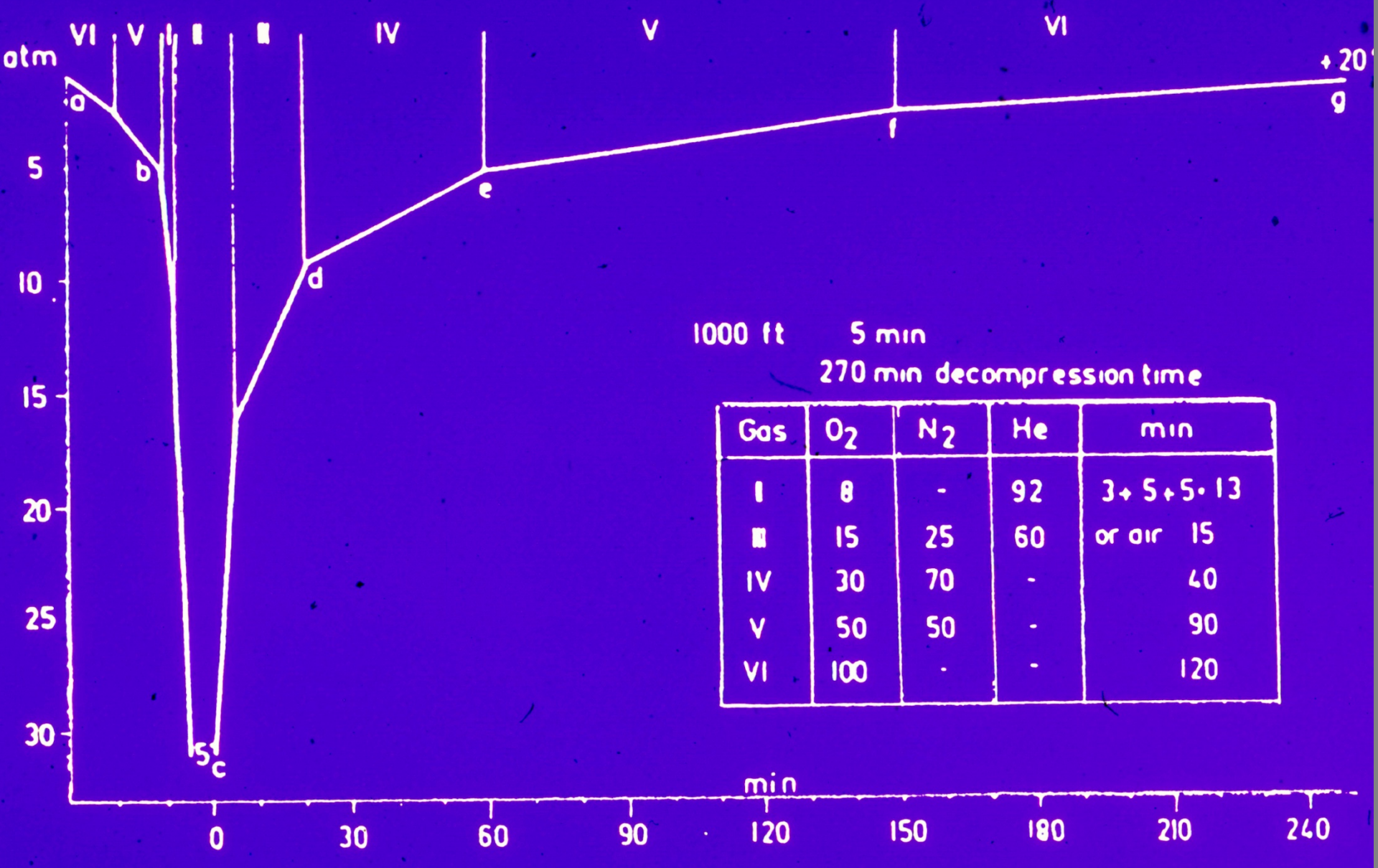
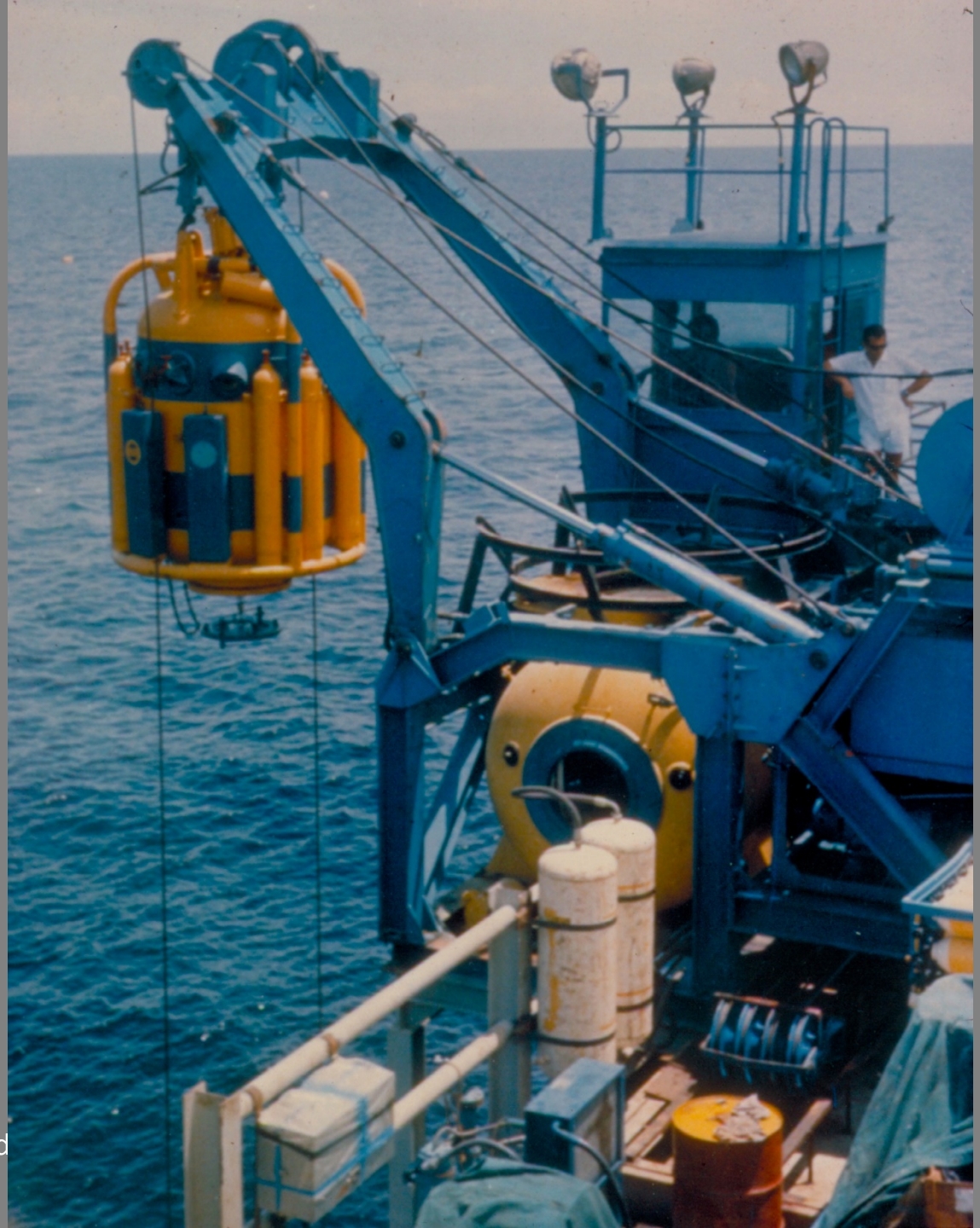
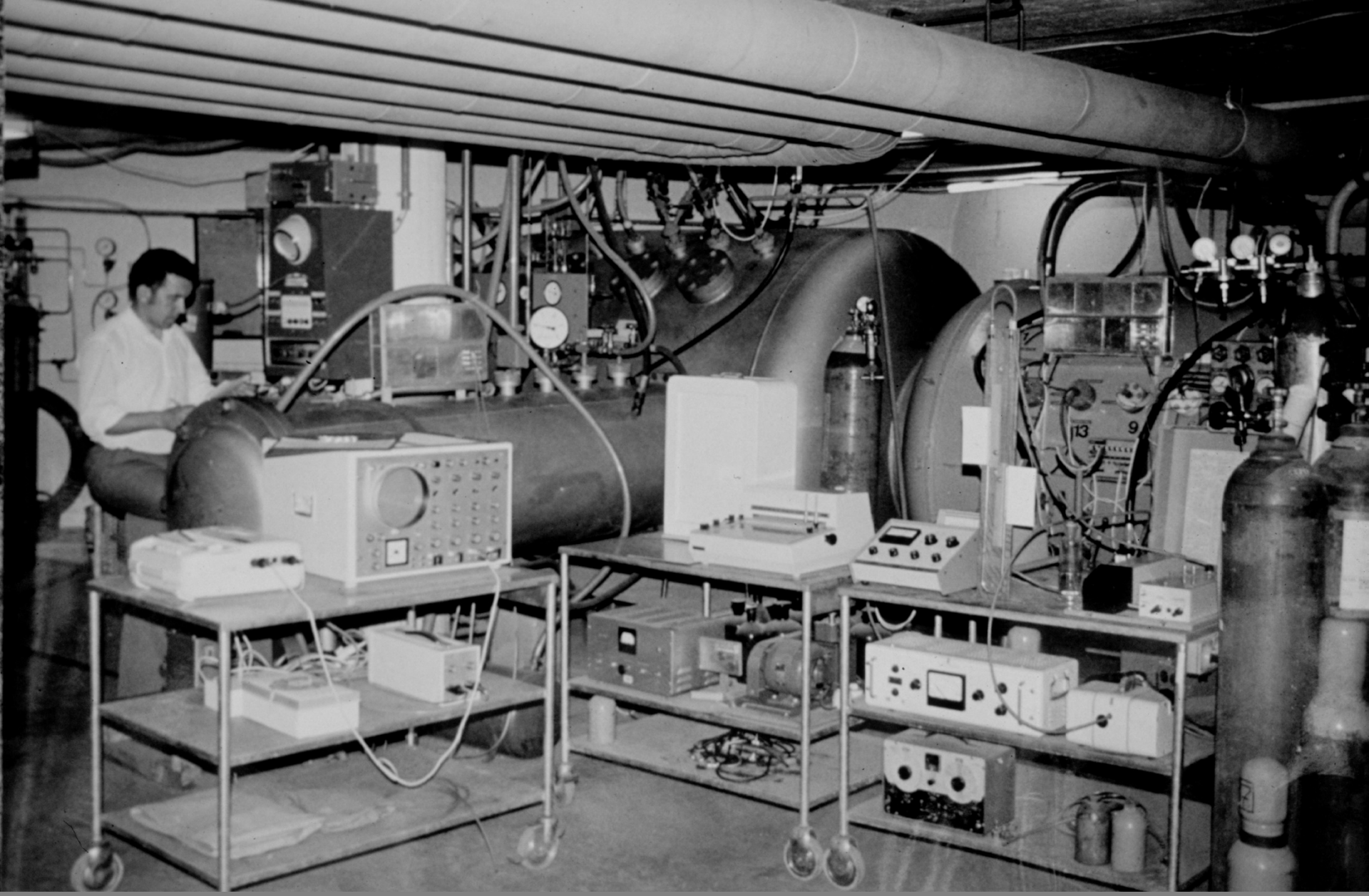


FIG. 6. Two subjects, 1,000-ft dive with 5 min bottom time.



Development of decompression tables for offshore work 1964-1981

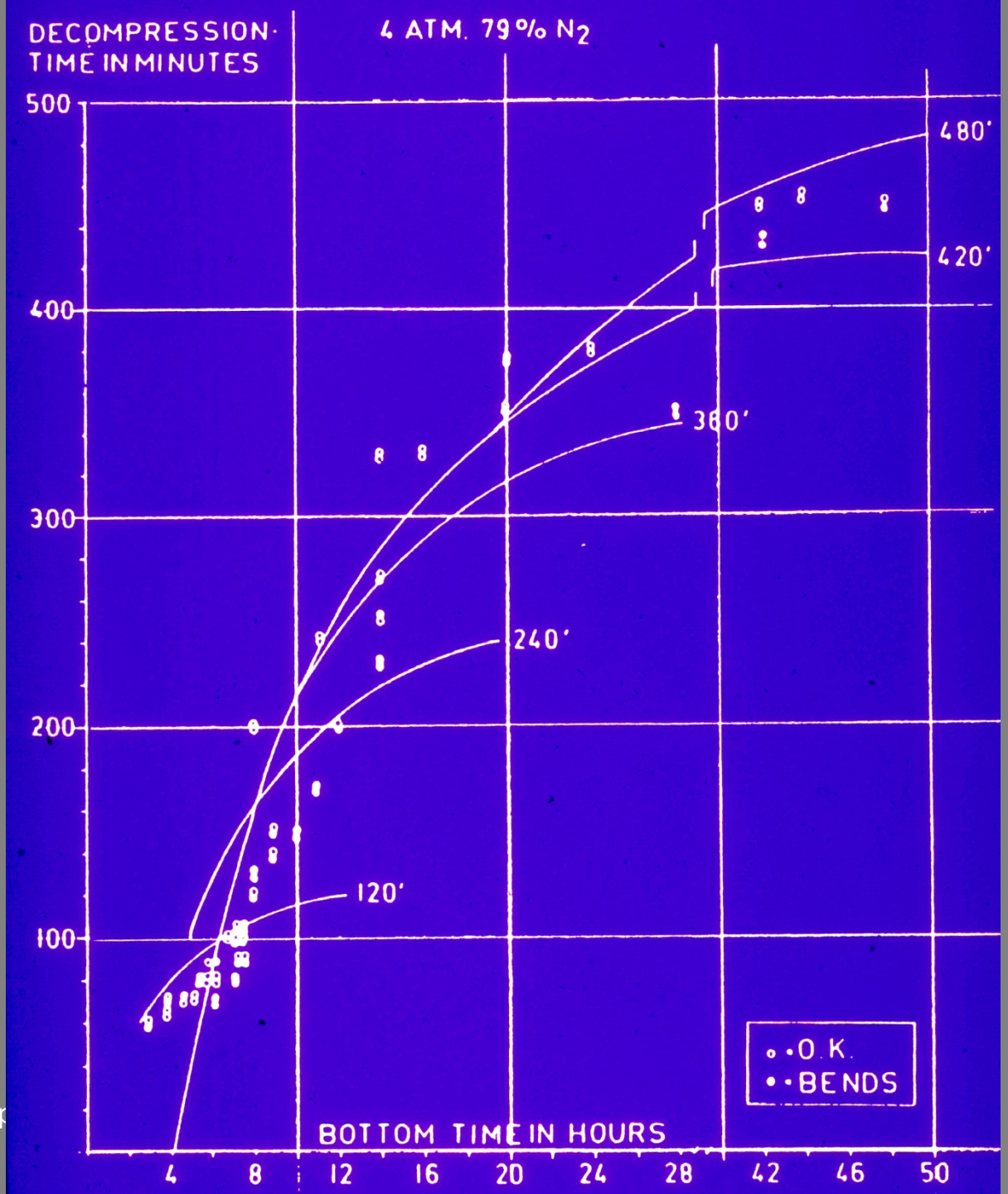
- 3 compartment sat system at ZHL designed for 4bar (30m) in 1964
- 2 chamber sat system with wet bell at ZHL designed for 100bar, Helium mixes, in-water working) in 1972
- Verification dives with SSOS and Micoperi
- Mixgas tables for bounce and sat deco to 300m

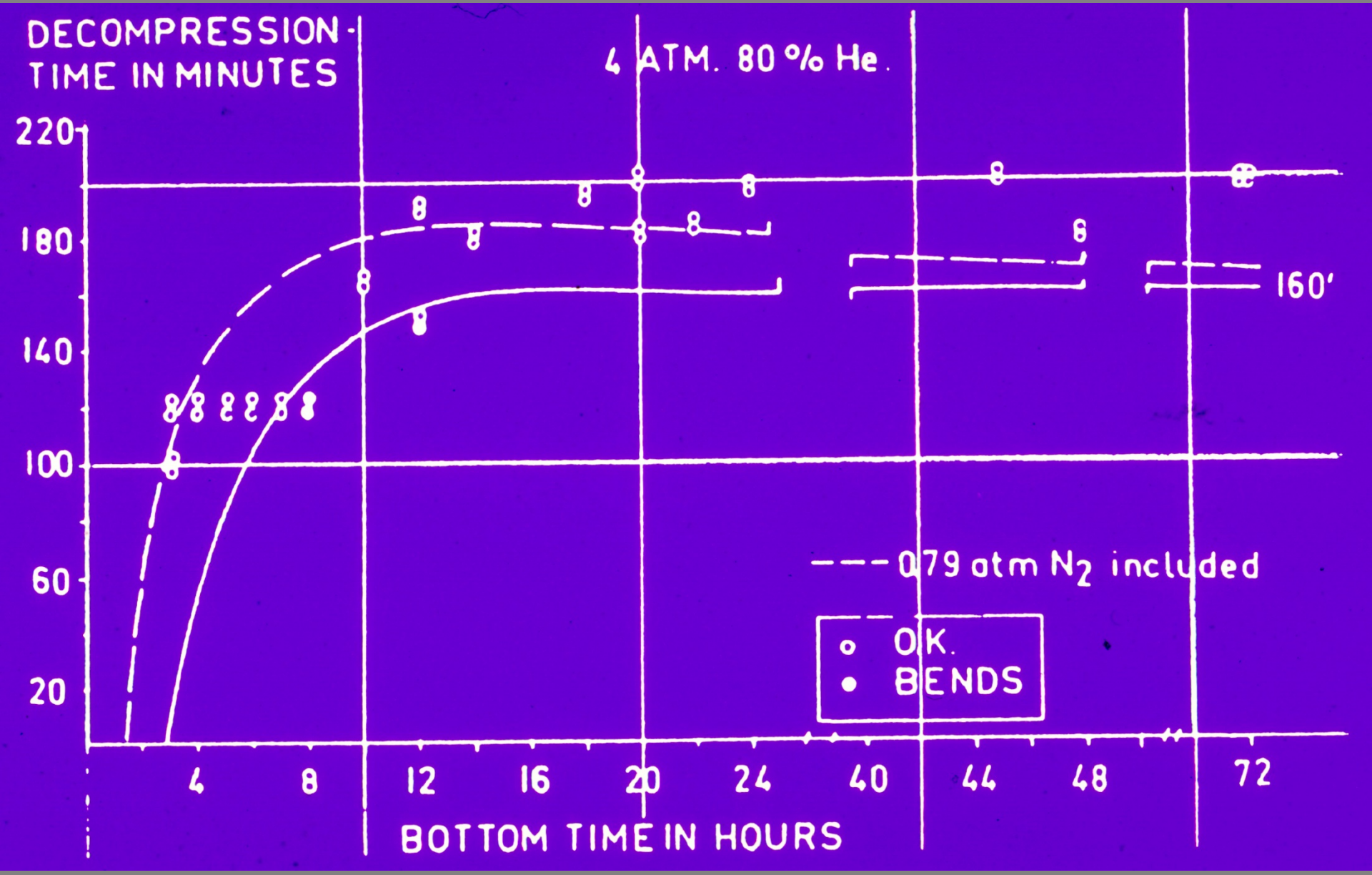


Experimental long Air Dives at 4 ATA (30 m), Decompression with O2

Bottom Time (h)	Effect. Decotime (min)	Calculat. Deco-time forO_2(min)	% O_2	OK	DCI	Skin	Muscles	Shoulder	Hip	Knee	Foot
3h	58'	58'	100	o	●		●				
4h	73'	73'	100	o	●		●				
4h	62'	62'	100	oo							
5h	70'	70'	100	ooo	●				◗	◗	
6h	70'	70'	100		●●		◗	◗			●
6h	80'	80'	100	oo oo	●●		●			●	
6h	90'	90'	100	o	●				●		
7h	80'	80'	100		●●	●◗	◗	◗			
7h	90'	90'	100	oo	●●	◗	◗	◗	◗◗		
7h	100'	100'	100	ooo oo	●●● ●●	●	◗	◗◗	◗	●●◗	
8h	120'	120'	100	o	●					●	
8h	130'	130'	100		●●					●●	
8h	585'	200'	20	oo							
9h	140'	140'	100	o	●			●			
9h	150'	150'	100	o	●					●	
10h	150'	150'	100		●●		◗		◗	●◗	
11h	170'	170'	100		●●				◗	●◗	
11h	335'	270'	80	oo							
12h	200'	200'	100	o	●					●	
14h	230'	230'	100		●●				◗	●◗	
14h	250'	250'	100	o	●		◗			◗	
14h	270'	270'	100	o	●				◗	◗	
14h	330'	330'	100	oo							
16h	330'	330'	100	oo							
20h	350'	350'	100	o	●					●	
20h	500'	375'	70	oo							
24h	510'	380'	70	oo							
28h	460'	350'	70		●●					●●	
42h	560'	430'	70		●●		◗◗		◗	◗	◗
42h	600'	450'	70	oo							
44h	615'	450'	70	oo							
48h	600'	450'	70	o	●		●				
			Total	43	37						

A. Bühlmann, P. Frei, H. Keller, 1967, Saturation and Desaturation with N2 and He at 4atm


DECOMPRESSION-
TIME IN MINUTES
4 ATM. 79% N2
500
400
300
200
100
480'
420'
360'
240'
120'
O.K.
BENDS
BOTTOM TIME IN HOURS
4
8
12
16
20
24
28
42
46
50

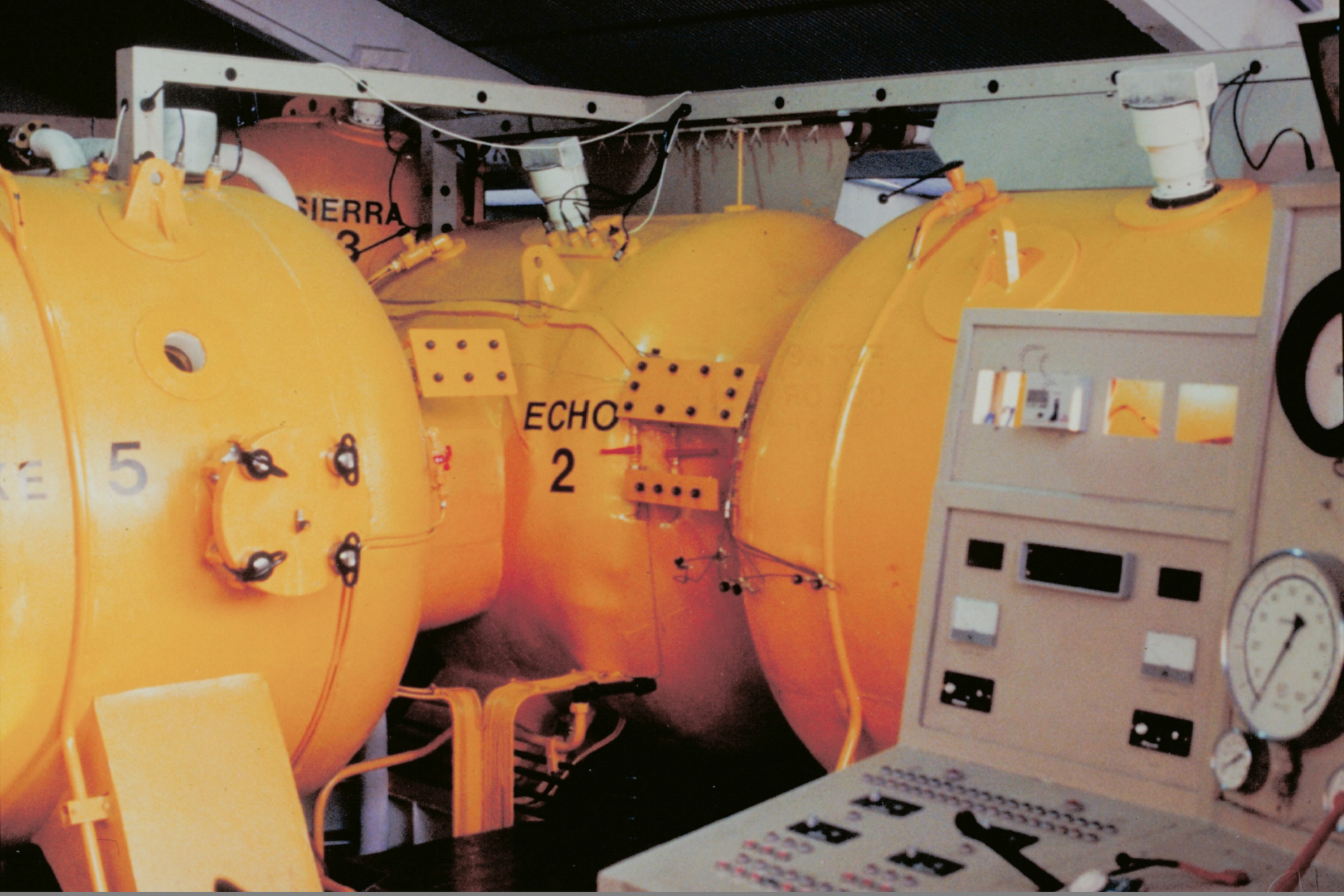

DECOMPRESSION-
TIME IN MINUTES
4 ATM. 80 % He.
220
180
140
100
60
20
160'
0.79 atm N2 included
O K.
BENDS
4
8
12
16
20
24
40
44
48
72
BOTTOM TIME IN HOURS

Development of Decompression Tables for offshore Work (1964 – 1981)

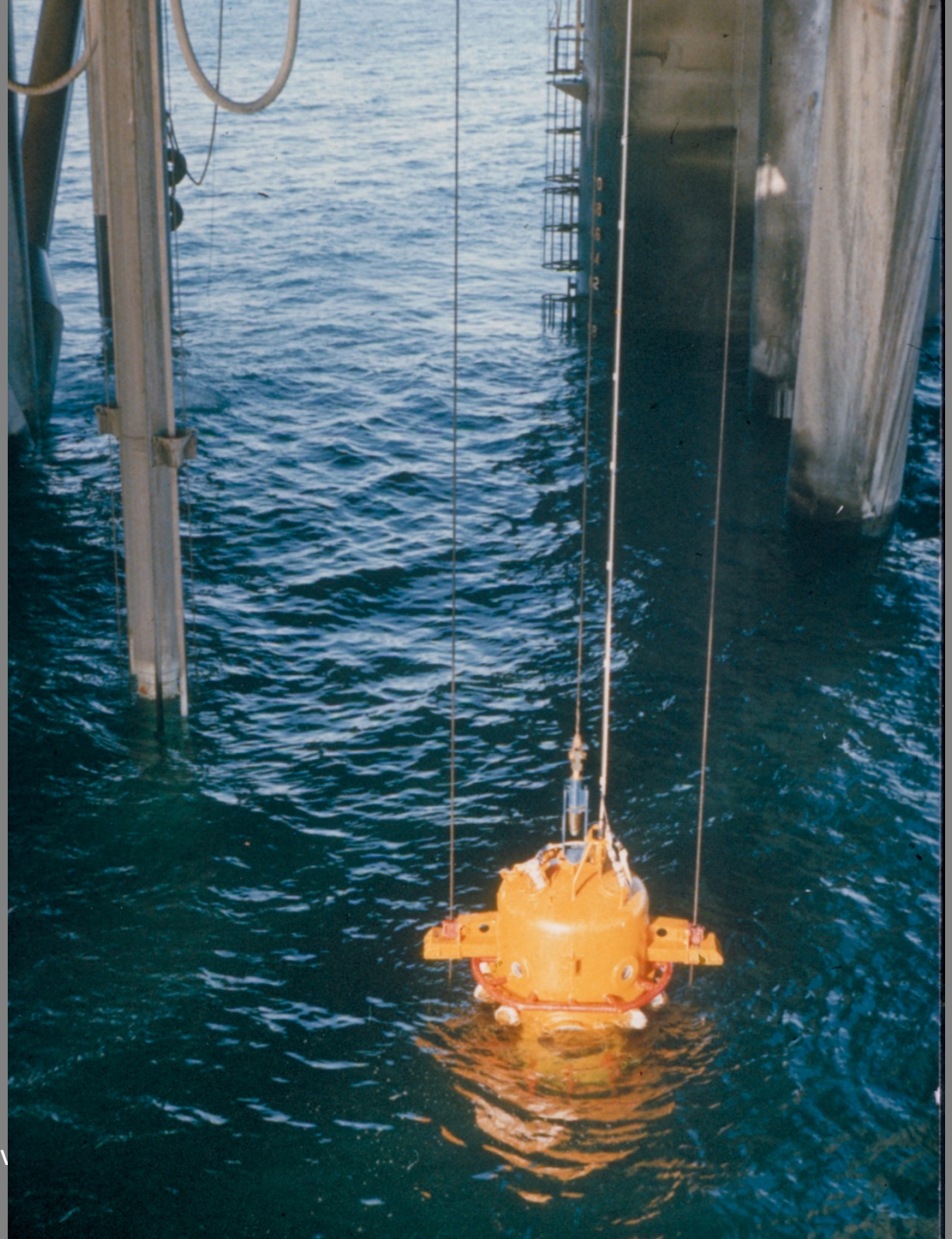
- Capshell series
- Alverstoke series
- Atlantis series
- DKL 72 series

J Wendling, Nussberger, Schenk, Milestones of the deep-diving DKL Zürich, SPUMS Cong Palau 11.–16.5.98

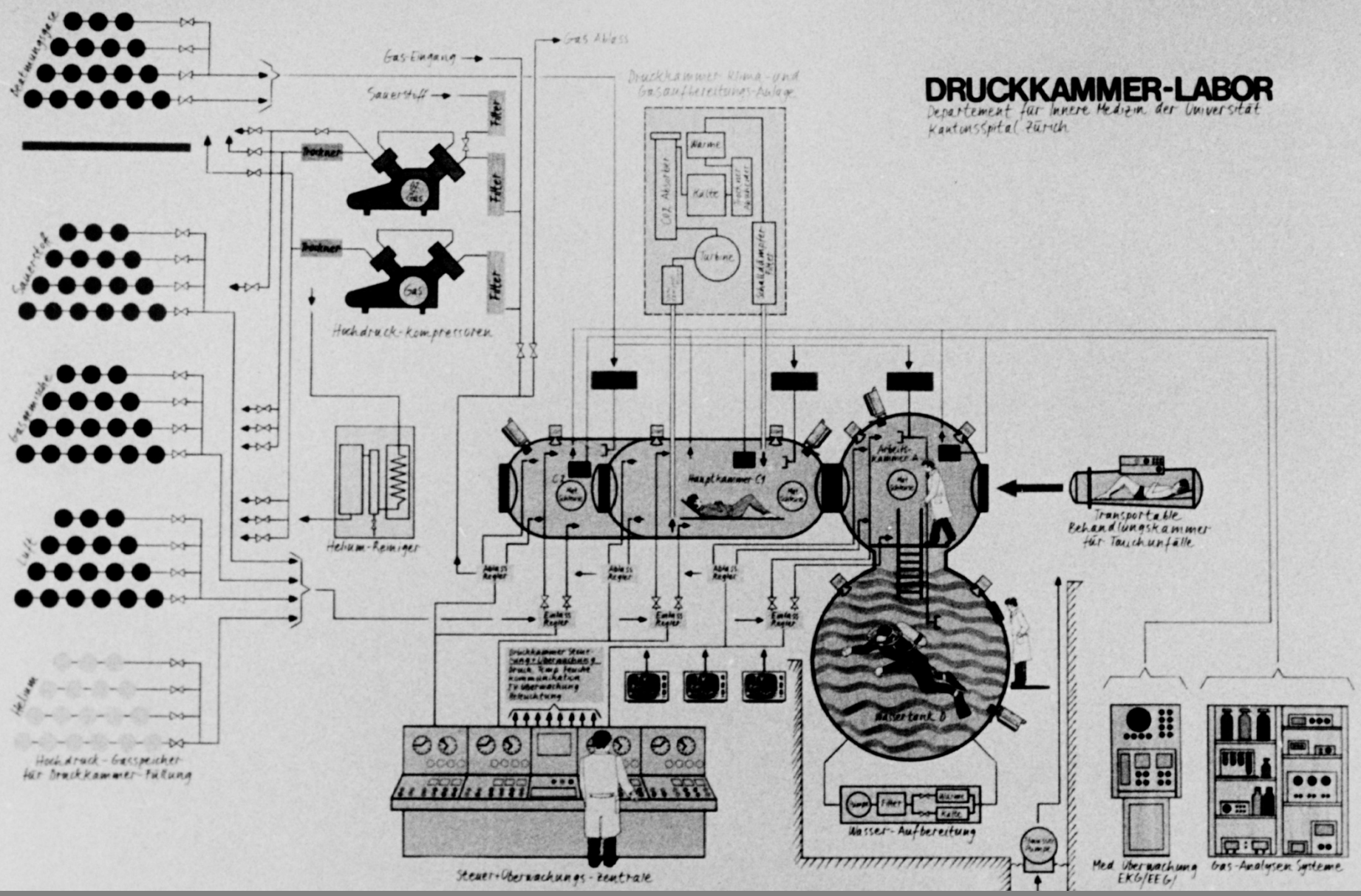
Ppalau98tab2.doc

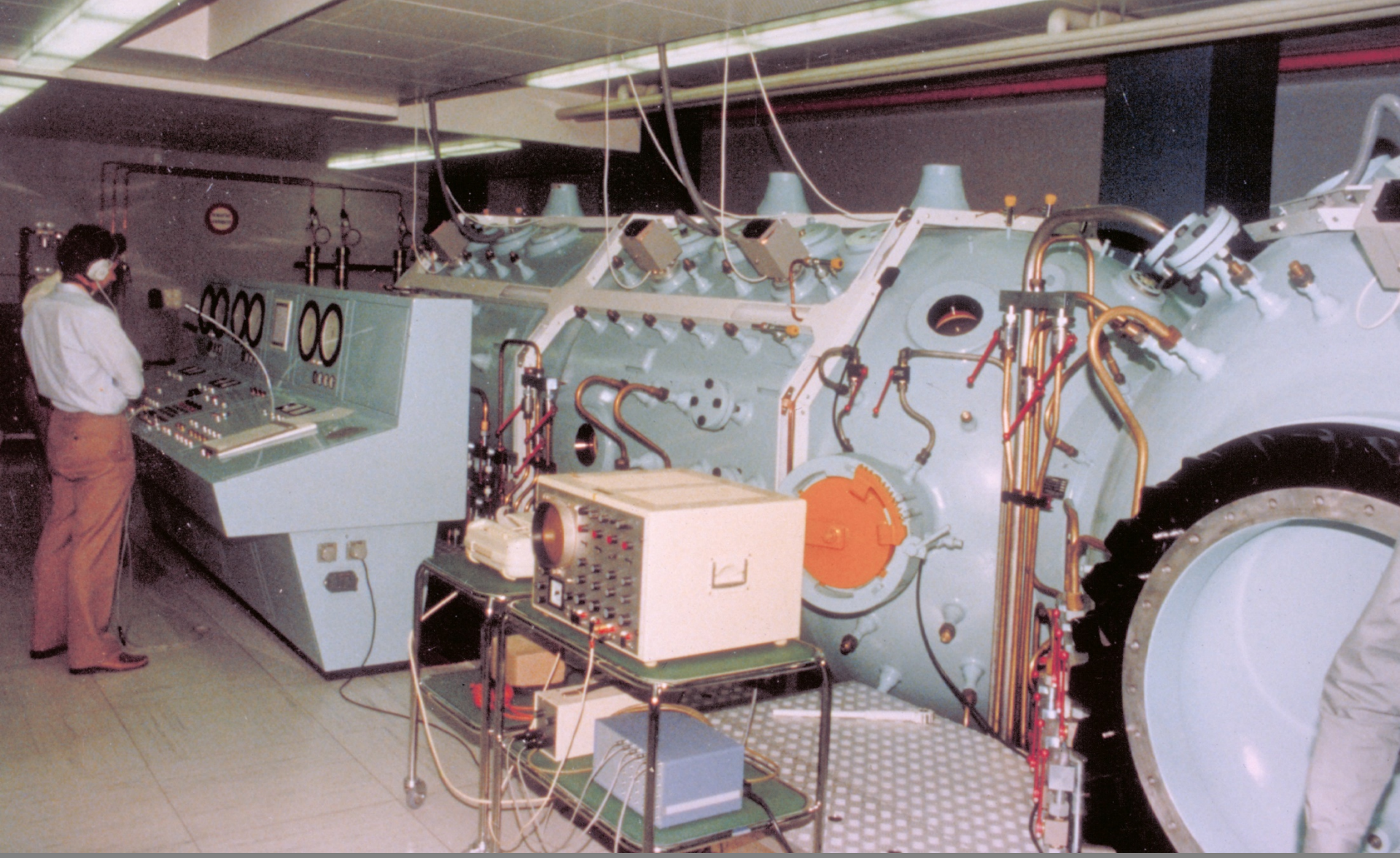

SIERRA
3
ECHO
2
5

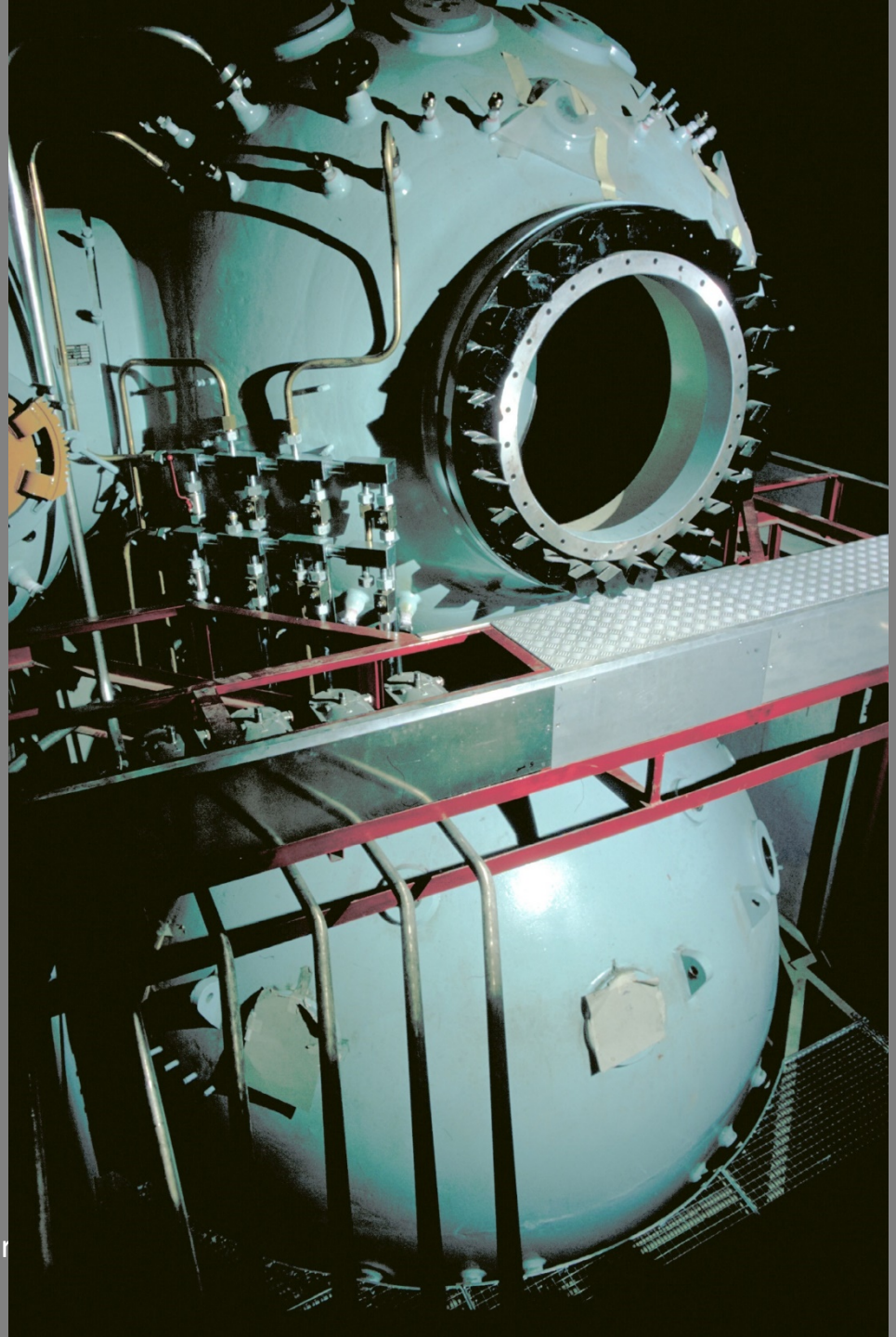

CAPALONGA



AUFBAU UND FUNKTIONS-PRINZIP DES DRUCKKAMMERSYSTEMS KSZ







Bounce dives to 40–250m

DEEP DIVING RESEARCH LABORATORY
DEPARTMENT OF INTERNAL MEDICINE
UNIVERSITY HOSPITAL ZURICH

DECOMPRESSION TABLE

BREATHING MIXTURE
5 % O_2 / 95 % He

COMPRESSION TIME 22 min.

BREATHING MIXTURES FOR DECOMPRESSION
10 % O_2 / 90 % He
Air
50 % O_2 / 50 % N_2
100 % O_2

Code No. 220. HHAMO. 70. A1

220 — BOTTOM TIME (excluding compression time)

	15		30		45		60		75		90		105		120		135		150		165		180	
	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min
to 1. STOP		5		5		5		5		5		5		5		5		5		5		5		5
STOP 1	163	5	169	5	170	5	170	5	170	5	170	5	170	5	170	5	170	5	170	5	170	5	170	5
2	142	10	147	5	150	5	155	5	158	5	159	5	161	5	161	5	161	10	161	10	162	10	163	10
3	110	10	130	10	140	10	147	10	150	10	151	10	152	10	153	10	151	10	153	10	154	10	155	10
4	98	10	117	10	125	10	131	10	134	10	138	10	141	10	144	10	142	15	143	15	150	10	151	10
5	86	15	104	10	111	15	119	10	124	15	130	15	133	15	135	10	136	15	138	15	144	10	147	10
6	72	15	92	15	100	15	111	15	114	30	118	15	125	30	127	10	129	15	131	15	138	15	142	10
7	65	30	83	30	91	30	104	30	101	30	113	30	117	30	123	15	119	15	124	30	131	15	137	15
8	57	30	71	30	85	30	91	30	92	30	101	30	105	30	116	15	114	15	115	30	126	15	131	15
9	49	30	63	30	75	30	80	30	84	30	93	30	97	30	110	30	109	30	107	60	121	30	126	15
10	37	60	57	30	68	30	74	30	79	60	87	30	92	30	101	60	106	60	98	60	115	30	124	30
11	26	60	52	30	65	30	70	60	70	60	81	60	86	30	92	60	95	60	91	60	105	60	116	30
12	19	60	49	30	59	60	63	60	66	60	75	60	81	60	85	60	88	60	86	60	100	60	109	60
13	14	60	41	60	54	60	57	60	61	60	68	60	76	60	79	60	83	60	83	60	93	60	102	60
14	11	60	35	60	48	60	53	60	59	60	66	60	72	60	75	60	79	60	78	60	90	60	95	60
15	9	60	28	60	39	60	51	60	56	60	62	60	68	60	71	60	75	60	75	60	85	60	92	60
16	7	60	22	60	32	60	48	60	52	60	58	60	64	60	68	60	72	60	71	60	80	60	87	60
17	4	60	19	60	27	60	40	60	50	60	55	60	61	60	65	60	69	60	69	60	77	60	83	60
18	2	60	15	60	19	60	34	60	43	60	53	60	58	60	61	60	66	60	66	60	74	60	79	60
19	0		12	60	14	90	29	60	37	60	50	60	56	60	59	60	63	60	64	60	71	60	76	60
20			10	60	11	90	25	60	32	60	44	60	54	60	57	60	61	60	61	60	69	60	73	60
21			8	60	9	60	21	60	27	60	38	60	52	60	55	60	58	60	59	60	66	60	71	60
22			6	60	7	60	17	90	22	90	33	60	49	60	52	60	56	60	57	60	64	60	68	60
23			3	60	5	60	12	120	17	120	29	90	43	60	50	90	54	60	55	60	61	60	66	60
24			[illegible]	15	3	60	9	60	13	120	25	120	37	90	44	90	52	60	53	60	59	60	63	60
25			0		2	60	7	60	10	60	18	120	30	90	36	90	50	60	51	60	57	60	61	60
Total Decompr. Time		700		915	turn over		turn over		turn over		turn over		turn over		turn over		turn over		turn over		turn over		turn over	

Code No. 220. HHAMO. 70. A2

220

	15		30		45		60		75		90		105		120		135		150		165		180	
	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min
STOP 26					0		5	60	7	60	13	120	25	120	30	90	43	90	49	60	55	60	59	60
27							3	60	5	60	9	60	18	120	24	120	35	90	42	90	53	60	57	60
28							2	45	3	60	7	60	13	120	18	120	28	120	35	90	51	60	55	60
29							0		2	60	5	60	9	60	13	120	22	120	29	120	49	60	53	60
30									0		3	60	7	60	9	60	16	120	22	120	44	90	51	60
31											2	60	5	60	7	60	12	120	15	120	35	90	49	60
32											0		3	60	5	60	9	60	11	120	28	120	44	90
33													2	60	3	60	7	60	9	60	21	120	35	90
34													0		2	60	5	60	7	60	16	120	28	120
35															0		3	60	5	60	11	120	21	120
36																	2	60	3	60	9	60	16	120
37																	0		2	60	7	60	11	120
38																			0		5	60	9	60
39																					3	60	7	60
40																					2	60	5	60
41																					0		3	60
42																							2	60
43																							0	
44																								
45																								
46																								
47																								
48																								
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50																								
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54																								
55																								
56																								
57																								
58																								
59																								
60																								
Total Decompr. Time					1115		1336		1520		1655		1790		1915		2055		2175		2255		2325	

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SION TABLE

HHAMO. 70. A1

BREATHING MIXTURE

5 % O_2 / 95 % He

COMPRESSION TIME 22 min.

BREATHING MIXTURES FOR DEC

10 % O_2 / 90 % He

Air

50 % O_2 / 50 % N_2

100 % O_2

BOTTOM TIME (excluding compression time)

15		30		45		60		75		90		105		120		135		150		165	
m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min	m	min
	5		5		5		5		5		5		5		5		5		5		5
163	5	169	5	170	5	170	5	170	5	170	5	170	5	170	5	170	5	170	5	170	5
142	10	147	5	150	5	155	5	158	5	159	5	161	5	161	5	161	10	161	10	162	10
110	10	130	10	140	10	147	10	150	10	151	10	152	10	153	10	151	10	153	10	154	10
98	10	117	10	125	10	131	10	134	10	138	10	141	10	144	10	142	15	143	15	150	10
86	15	104	10	111	15	119	10	124	15	130	15	133	15	135	10	136	15	138	15	144	10
72	15	92	15	100	15	111	15	114	30	118	15	125	30	127	10	129	15	131	15	138	15

75	90		105		120		135		150		165		180	
min	m	min	m	min	m	min	m	min	m	min	m	min	m	min
60	13	120	25	120	30	90	43	90	49	60	55	60	59	60
60	9	60	18	120	24	120	35	90	42	90	53	60	57	60
60	7	60	13	120	18	120	28	120	35	90	51	60	55	60
60	5	60	9	60	13	120	22	120	29	120	49	60	53	60
	3	60	7	60	9	60	16	120	22	120	44	90	51	60
	2	60	5	60	7	60	12	120	15	120	35	90	49	60
	0		3	60	5	60	9	60	11	120	28	120	44	90
			2	60	3	60	7	60	9	60	21	120	35	90
			0		2	60	5	60	7	60	16	120	28	120
					0		3	60	5	60	11	120	21	120
							2	60	3	60	9	60	16	120
							0		2	60	7	60	11	120
									0		5	60	9	60
											3	60	7	60
											2	60	5	60
											0		3	60
													2	60
													0	
1520	1655		1790		1915		2055		2175		2255		2325	
25.3h	27.6h		29.8h		31.9h		34.3h		36.3h		37.6h		38.7h	

Saturation deco-tables

BREATHING MIXTURE	10 % O_2 / 90 % He						5 % O_2 /
DIVING DEPTH m	20	30	40	50	60	70	80
	m min	m min	m min	m min	m min	m min	m min
to 1. STOP	5	5	5	5	5	10	10
STOP 1	11 55	19 55	27 55	35 55	43 55	50 50	63 80
2	9 60	16 60	25 60	31 90	41 120	48 90	60 90
3	7 60	14 90	21 60	25 90	38 120	45 90	57 90
4	5 60	11 90	18 90	20 90	28 120	42 120	53 90
5	3 90	8 90	14 90	17 90	22 120	38 120	50 120
6	2 90	5 120	10 120	14 90	18 120	28 120	46 120
7	0	3 120	7 120	12 120	13 120	22 120	42 120
8		2 90	5 120	9 120	9 120	18 120	38 120
9		0	3 120	7 120	7 120	13 120	28 120
10			2 120	5 120	5 120	9 120	22 120
11			0	3 120	3 120	7 120	18 120
12				2 90	2 120	5 120	13 120
13				0	0	3 120	9 120
14						2 120	7 120
15						0	5 120
16							3 120
17							2 120
18							0
19							
20							
21							
22							
23							
24							
25							
Total Decompr. Time	7^h	12^h	16^h	20^h	23^h	26^h	32^h

90	100
m min	m min
10	10
71 80	80 80
68 90	75 9
64 90	72 9
60 90	68 9
57 120	64 9
53 120	60 9
50 120	57 12
46 120	53 12
42 120	50 1
38 120	46 1
28 120	42 1
22 120	38 1
18 120	28 1
13 120	22 1
9 120	18 1
7 120	13 1
5 120	9
3 120	7
2 120	5
0	3
	2
	0
36^h	

BREATHING MIXTURES FOR DECOMPRESSION

- 5 % O_2 / 95 % He
- 10 % O_2 / 90 % He
- Air
- 100 % O_2

2 % O_2 / 98 % He											
	200		210		220		230		240		250	
	m	min	m	min	m	min	m	min	m	min	m	min
0		20		20		20		20		20		20
0	174	70	183	70	194	70	202	70	212	70	222	70
0	170	90	179	90	188	90	197	90	206	90	217	90
0	165	90	174	90	183	90	190	90	200	90	210	90
0	161	90	170	90	179	90	185	90	195	90	206	90
0	156	90	165	90	174	90	179	90	190	90	200	90
0	152	90	161	90	170	90	174	90	184	90	195	90
0	146	90	156	90	165	90	170	90	179	90	190	90
0	140	90	152	90	161	90	165	90	174	90	184	90
0	135	90	146	90	156	90	161	90	170	90	179	90
0	130	90	140	90	152	90	156	90	165	90	174	90
0	124	90	135	90	146	90	152	90	161	90	170	90
0	120	90	130	90	140	90	146	90	156	90	165	90
0	114	90	124	90	135	90	140	90	152	90	161	90
0	110	90	120	90	130	90	135	90	146	90	156	90
0	106	90	114	90	124	90	130	90	140	90	152	90
		90	110	90	120	90	124	90	135	90	146	90

Problem: HPNS
high pressure nervous syndrom

- After first experiments HPNS existence denied
- From increasing compression speed to constant speed to depth
- From constant speed to staged compression

HPNS with varying descent techniques

A. Continuous compression, increasing with depth

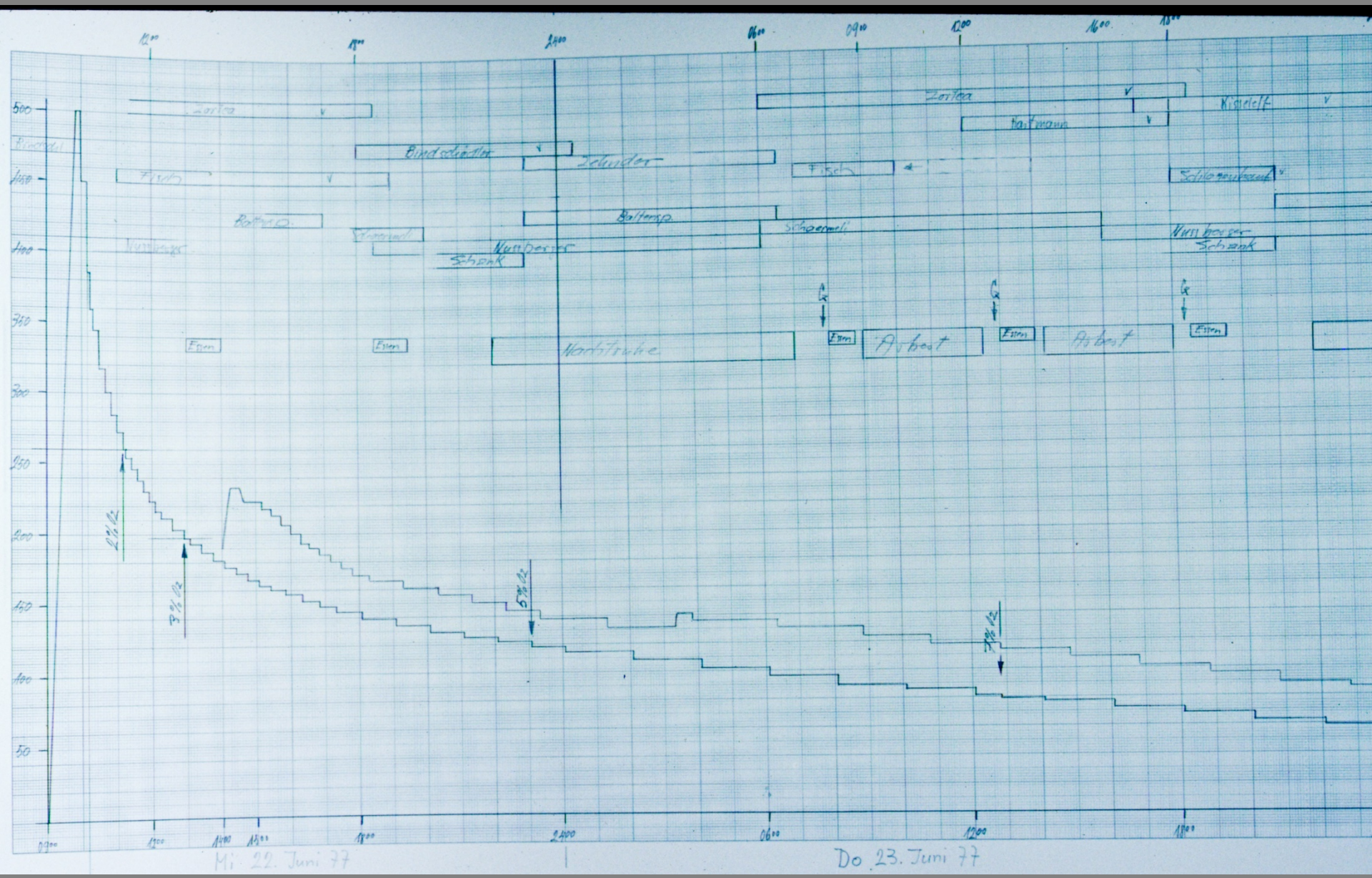
215 m	in 3‘	(20-50 m/‘↓)	O_2-N_2-He	**HPNS -**	(n=2, 1961)
250 m	in 5‘,10‘	(20-50 m/‘↓)	O_2-N_2-He	**HPNS -**	(n=3, 1960/62)
300 m	in 16‘	(20-50 m/‘↓)	O_2-N_2-He	**HPNS (+)**	(n=5, 1961/62)

B. Continuous compression, constant

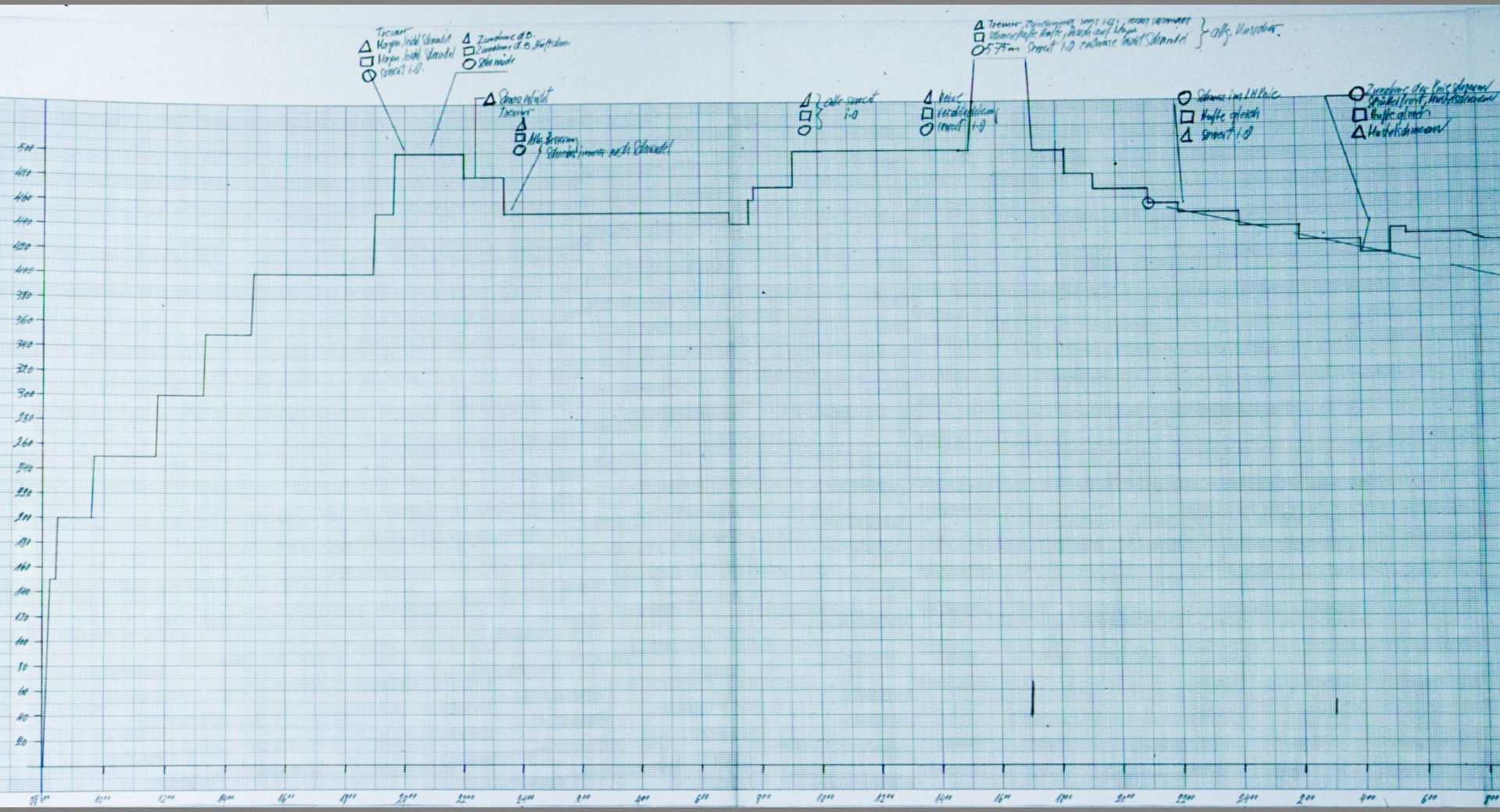
220 m	in 22‘	(10 m/‘↓)	O_2-He	**HPNS -**	(n=16, 1965-68)
250 m	in 25‘	(10 m/‘↓)	O_2-He	**HPNS +**	(n=11, 1967-80)
300 m	in 30‘	(10 m/‘↓)	O_2-He	**HPNS +**	(n=30, 1967-80)
350 m	in 35‘	(10 m/‘↓)	O_2-He	**HPNS ++**	(n= 6, 1977)
500 m	in 50‘	(10 m/‘↓)	O_2-He	**HPNS +++**	(n= 3, 1977)

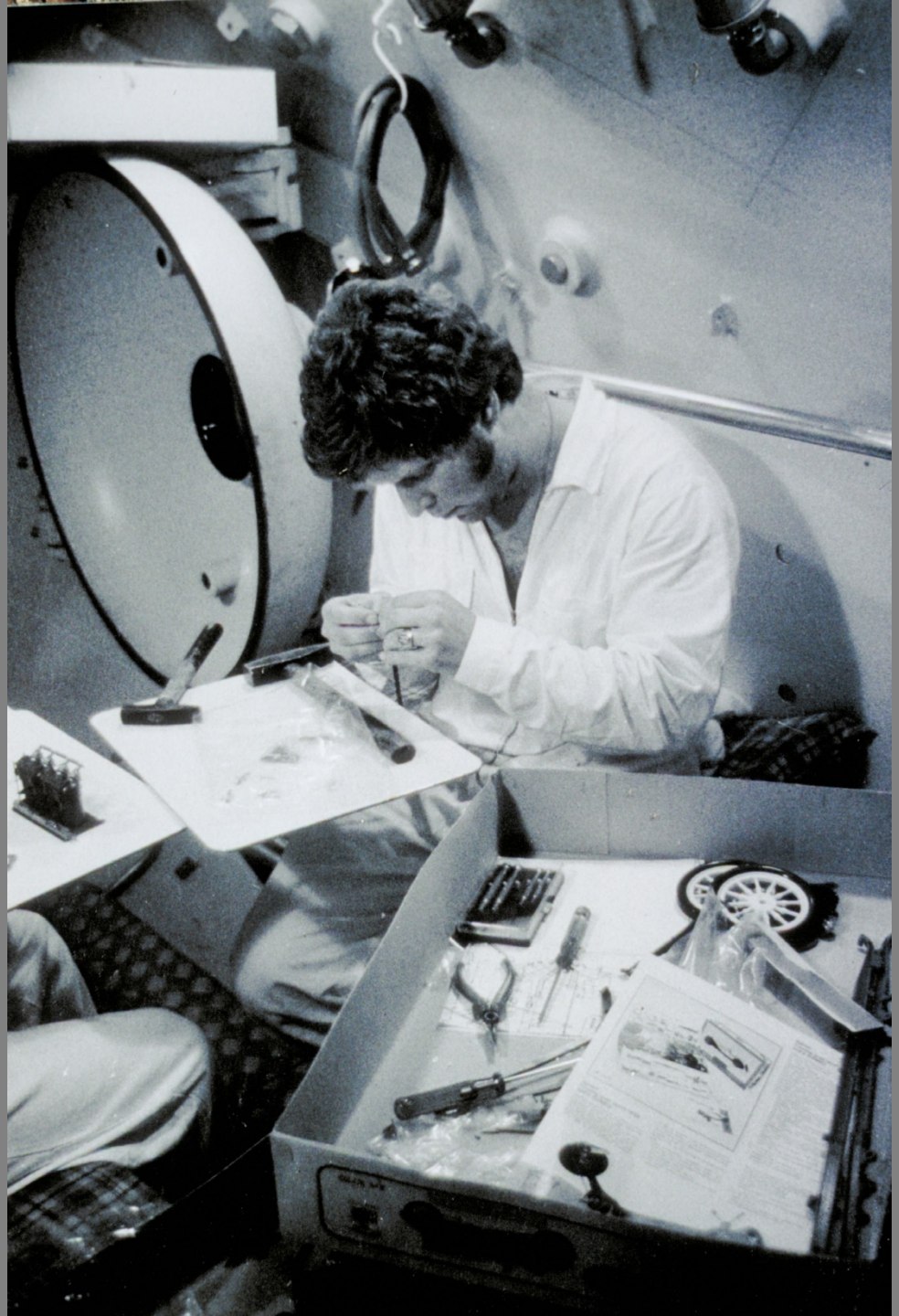
C. Staged compression, continuous compression rate

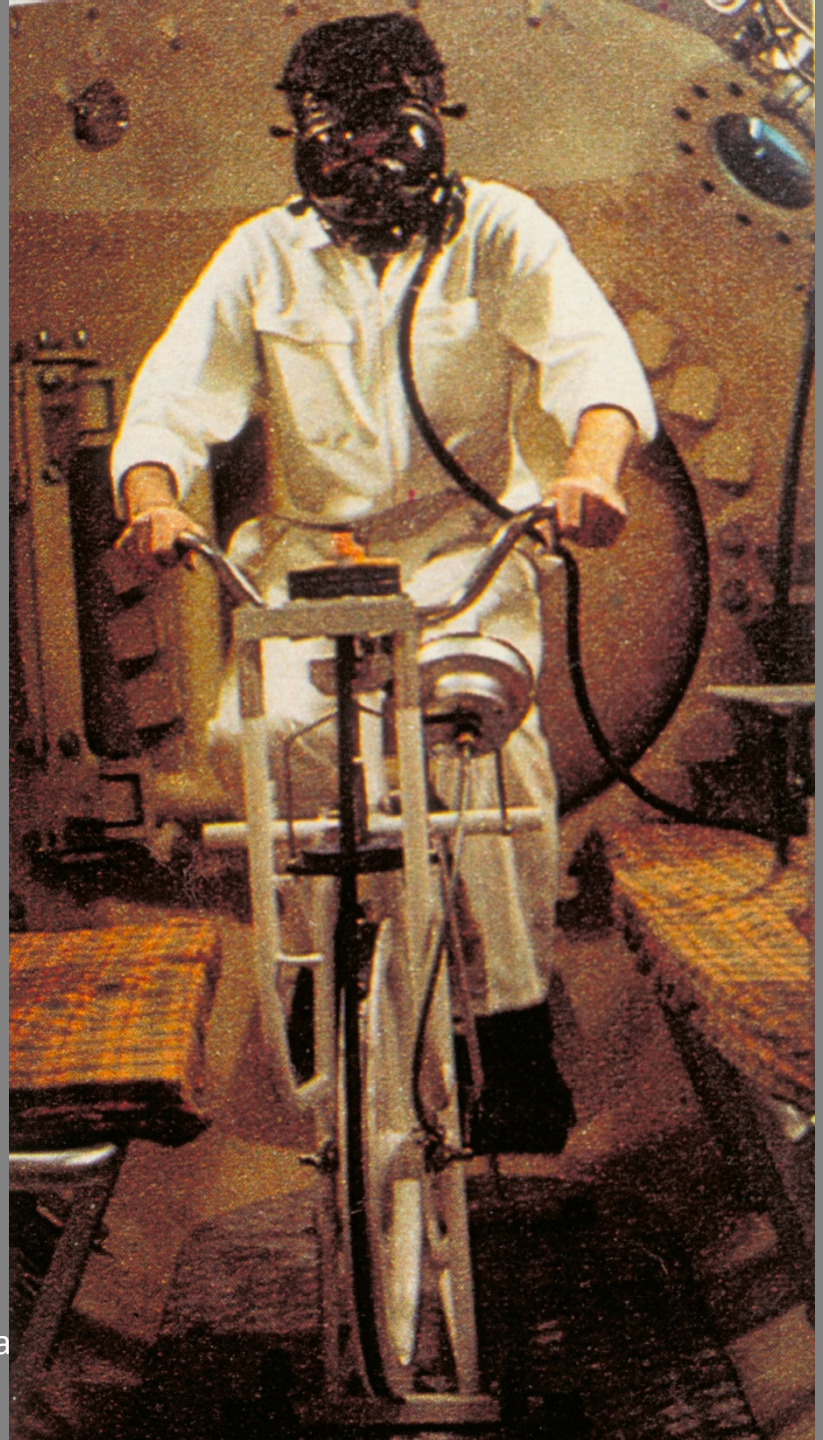
300 m	in 155‘	(10 m/‘↓)	O_2-He	**HPNS (+)**	(n=6, 1978)
350 m	in 325‘	(4 m/‘↓)	O_2-He	**HPNS -**	(n=3, 1969)
400 m	in 255‘	(10 m/‘↓)	O_2-He	**HPNS ++**	(n=3, 1979)
400 m	in 415‘	(10 m/‘↓)	O_2-He	**HPNS -**	(n=3, 1981)
500 m	in 700‘	(10 m/‘↓)	O_2-He	**HPNS +**	(n=3, 1981)

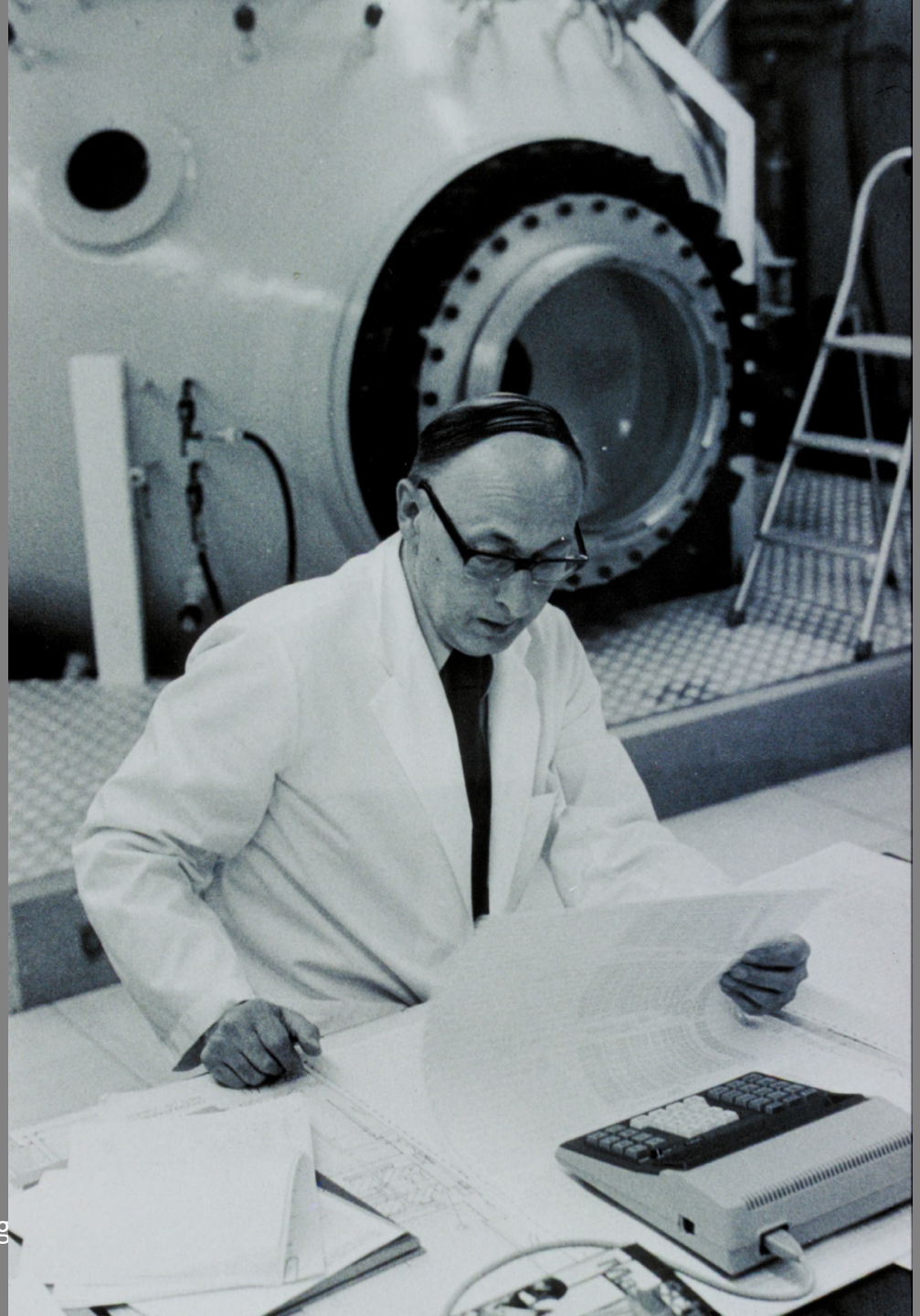

Zeitlos
Bindschädler
Zelinder
Fisch
Hartmann
Kiselelf
Schlossbrauch
Ballemp.
Schaemeli
Nussbaumer
Schenk
Eisen
Hartstrube
Arbeit
Mi. 22. Juni 77
Do 23. Juni 77

1981









The global decompression algorithm ZHL 16A

- Model valid for any gas composition
- Model valid for short, medium and long exposures to saturation
- Deterministic model (based on max. tolerated tissue supersaturation)

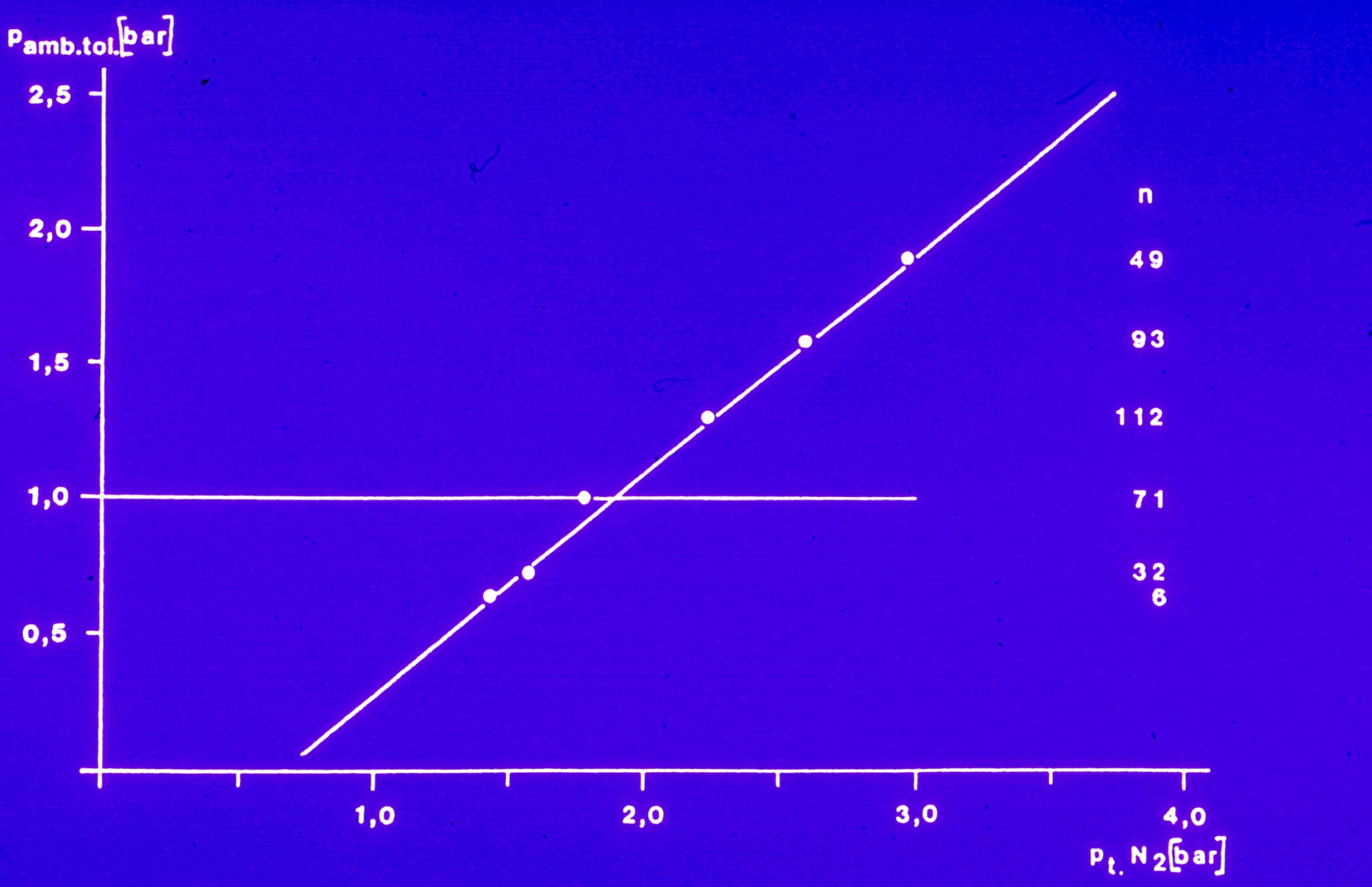


Abb. 26. N_2-Halbwertszeit 27,0 min. Die experimentellen Werte für den $p_{t.}N_2$ weichen nur wenig von der „theoretischen" Linie entsprechend den Koeffizienten von ZH-L16A ab.

$p_{amb.tol.} = (p_{t.}N_2 - 0{,}6667) \cdot 0{,}8126$

(A. A. Bühlmann, Tauchmed. 3. Aufl.)

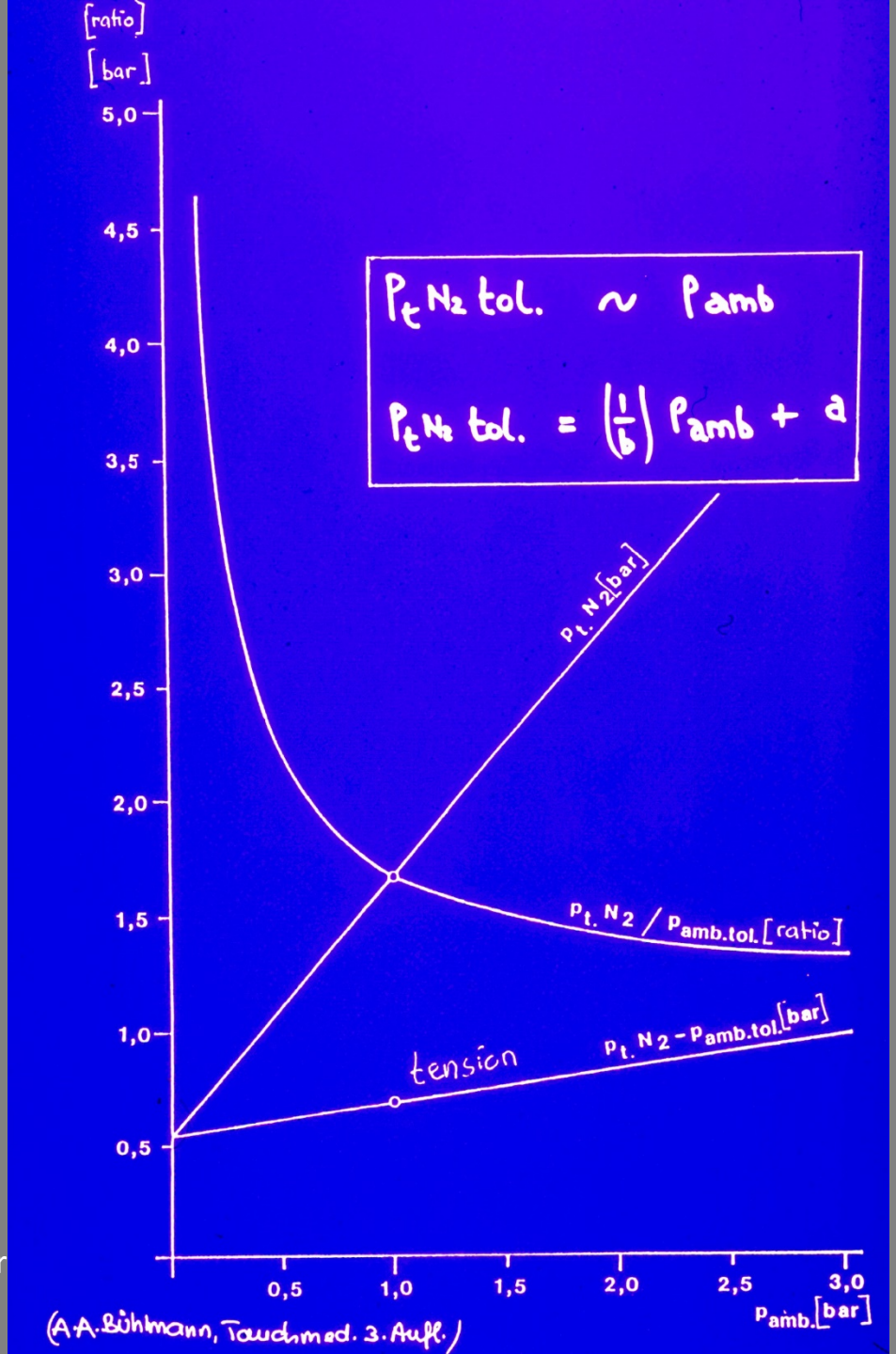
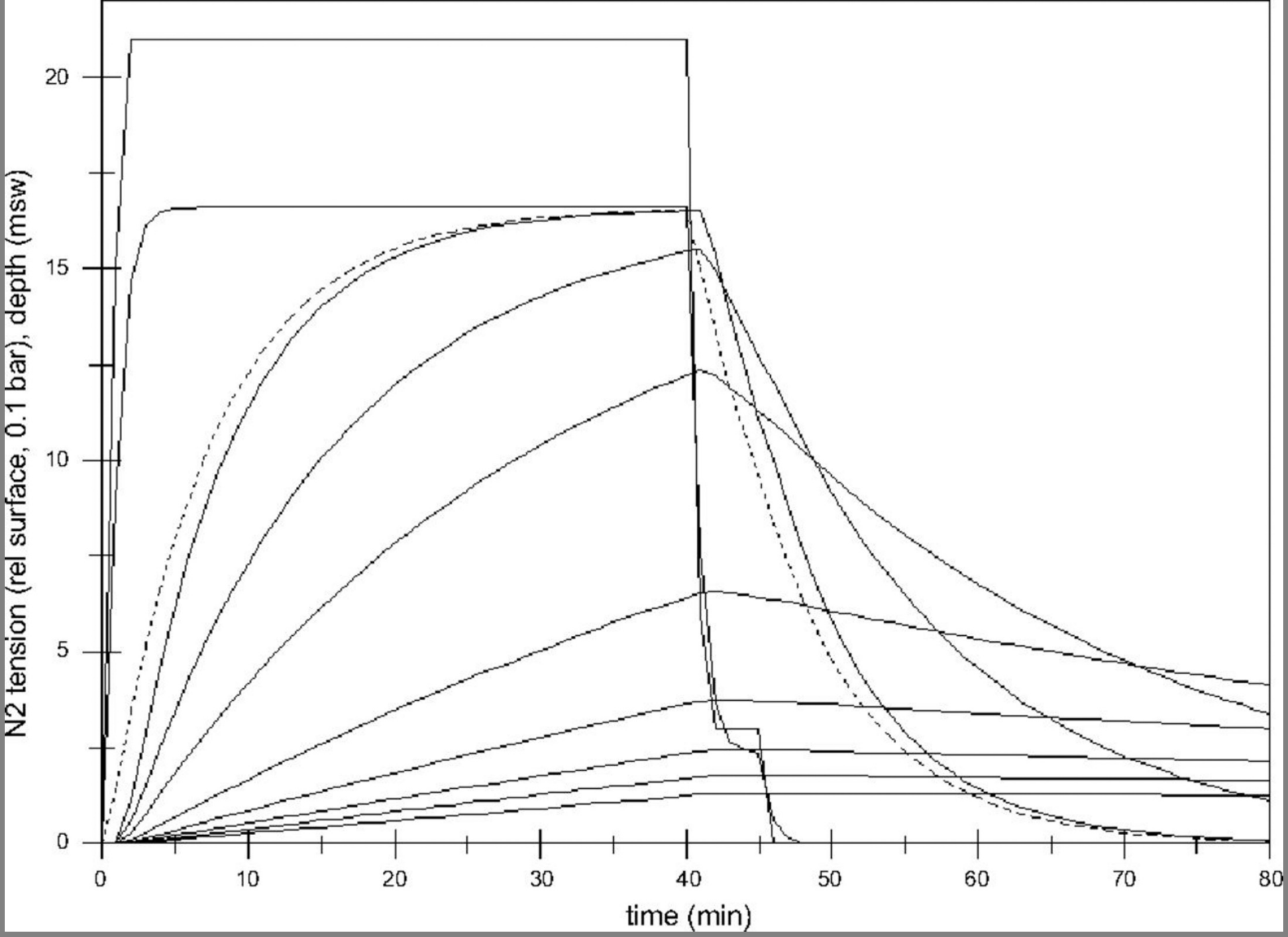
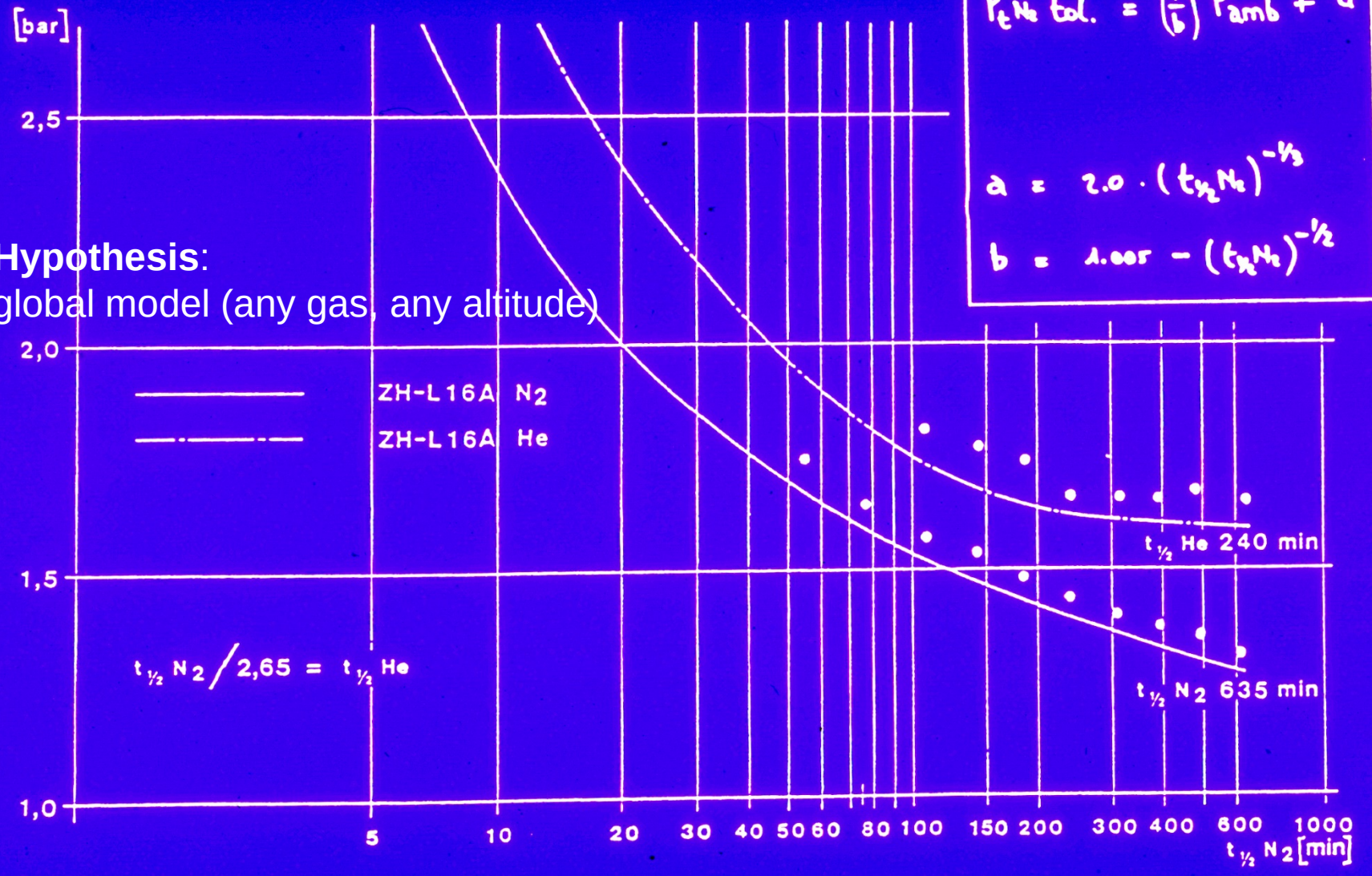

[ratio]
[bar]
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
$P_t N_2$ tol. ~ P_{amb}
$P_t N_2$ tol. = $\left(\frac{1}{b}\right) P_{amb} + a$
$p_{t.}N_2$ [bar]
$p_{t.}N_2 / p_{amb.tol.}$ [ratio]
$p_{t.}N_2 - p_{amb.tol.}$ [bar]
tension
0,5
1,0
1,5
2,0
2,5
3,0
$p_{amb.}$ [bar]
(A.A. Bühlmann, Tauchmed. 3. Aufl.)

FIG. 31-1: A TYPICAL DECOMPRESSION DIVE PROFILE WITH CEILING LINE VISIBLE. THE NUMBERS REPRESENT DIFFERENT PHASES (SEE PHASES IN FIG. 31-2)


N2 tension (rel surface, 0.1 bar), depth (msw)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
time (min)

Hypothesis:
global model (any gas, any altitude)



$$p_t N_2 \text{ tol.} = \left(\frac{1}{b}\right) p_{amb} + a$$

$$a = 2.0 \cdot (t_{½} N_2)^{-1/3}$$

$$b = 1.005 - (t_{½} N_2)^{-1/2}$$

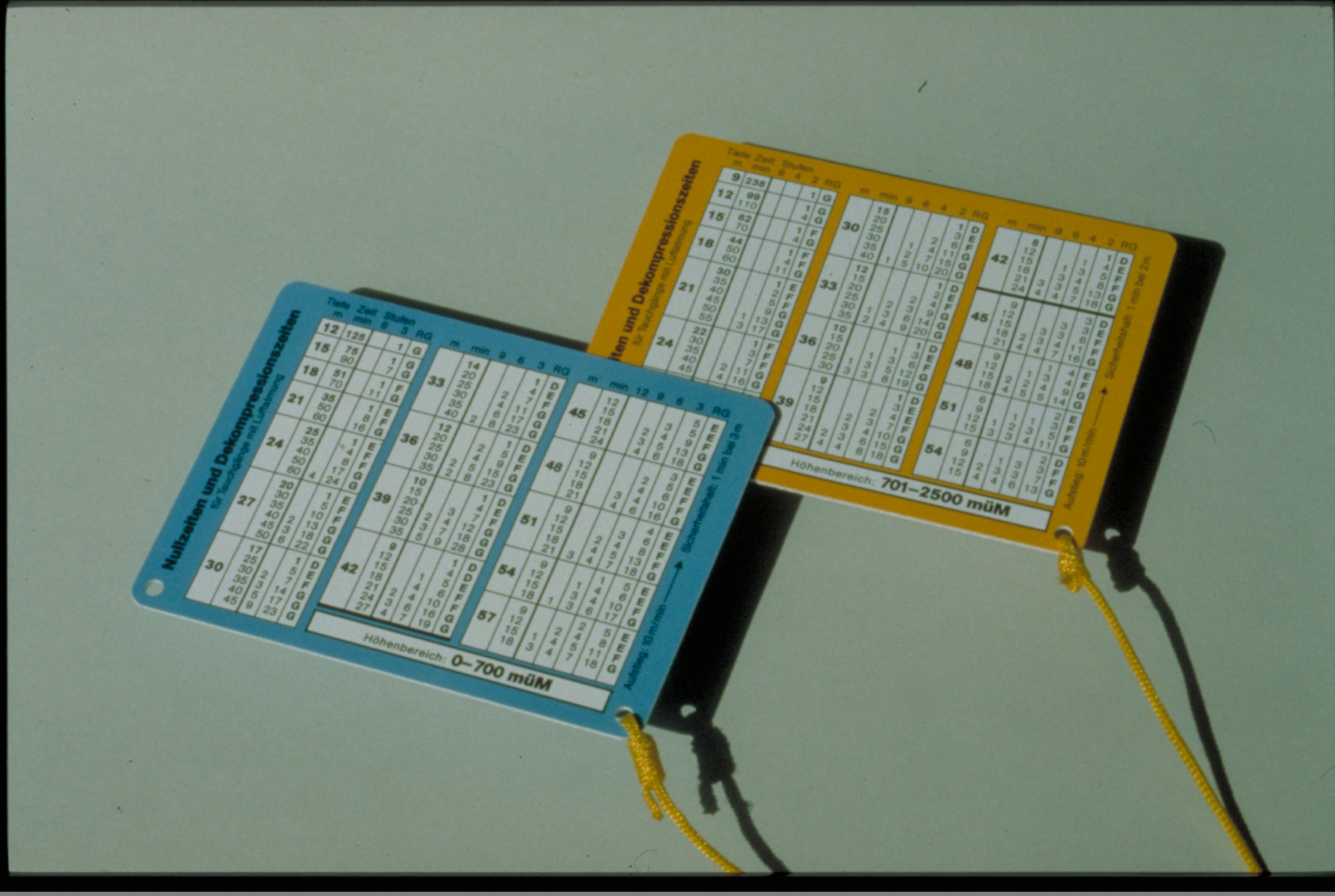
Abb. 24. Theoretisch tolerierter p_t.He und p_t.N_2 bei einem Umgebungsdruck von 1,0 bar entsprechend den Koeffizienten ZH-L16A. Abhängigkeit von den Halbwertszeiten. Längste He-Halbwertszeit 240 min, längste N_2-Halbwertszeit 635 min. ● p_t.He- und p_t.N_2-Werte mit Symptomen der Dekompressionskrankheit bei verkürzter Dekompressionszeit auf der letzten Stufe (Tabellen 21 und 22)

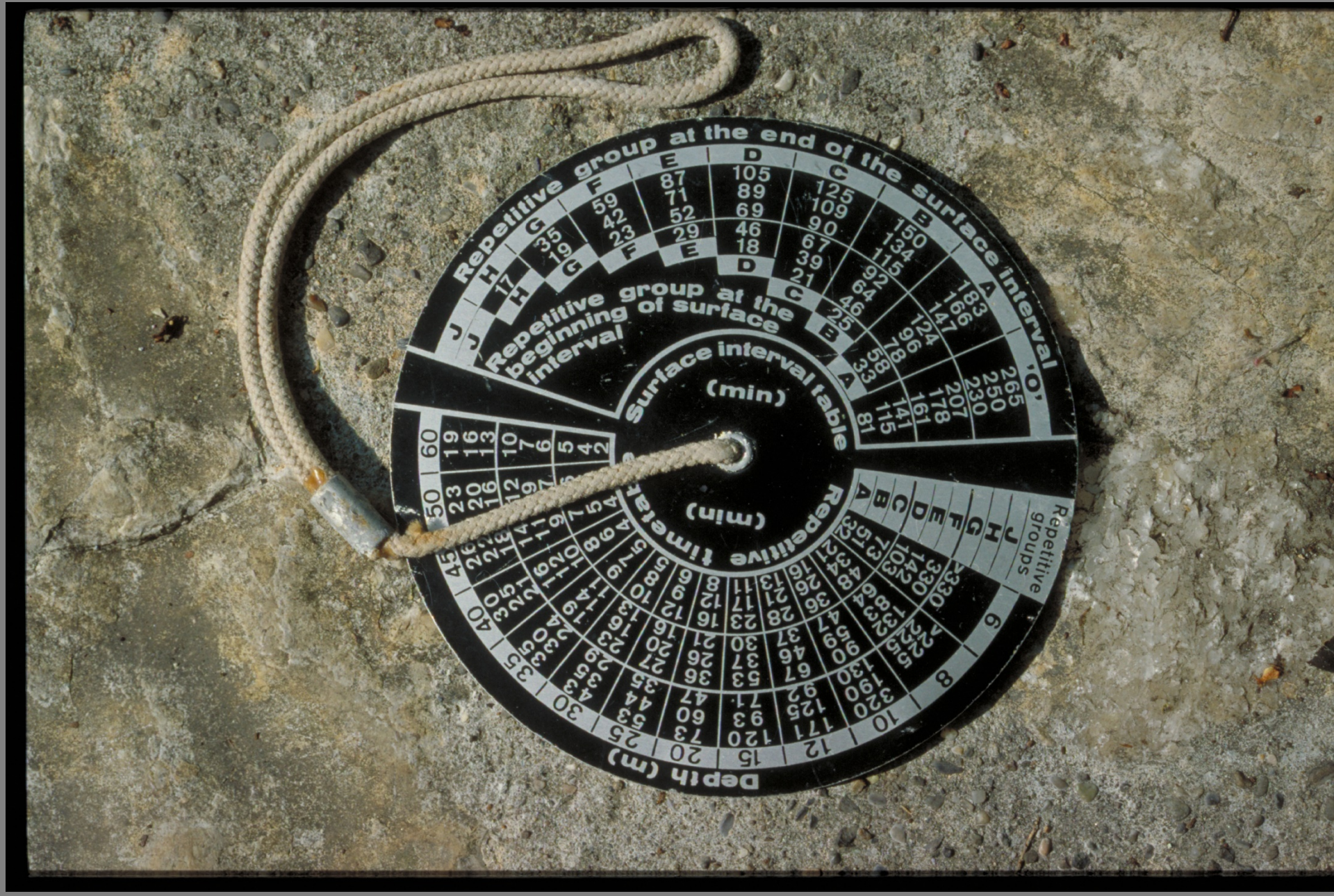
(A.A. Bühlmann, Tauchmed.)

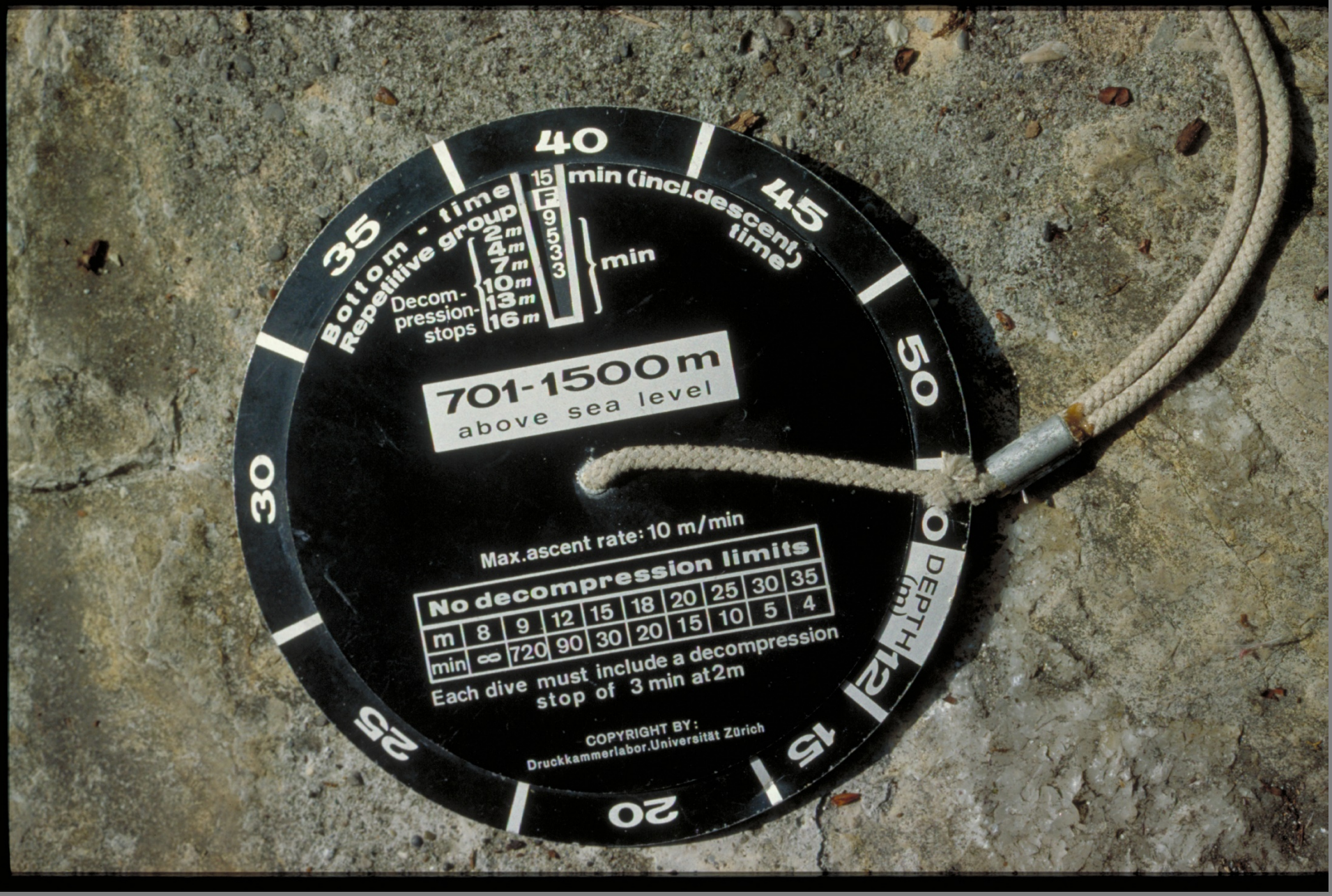
Verification studies for air bounce tables

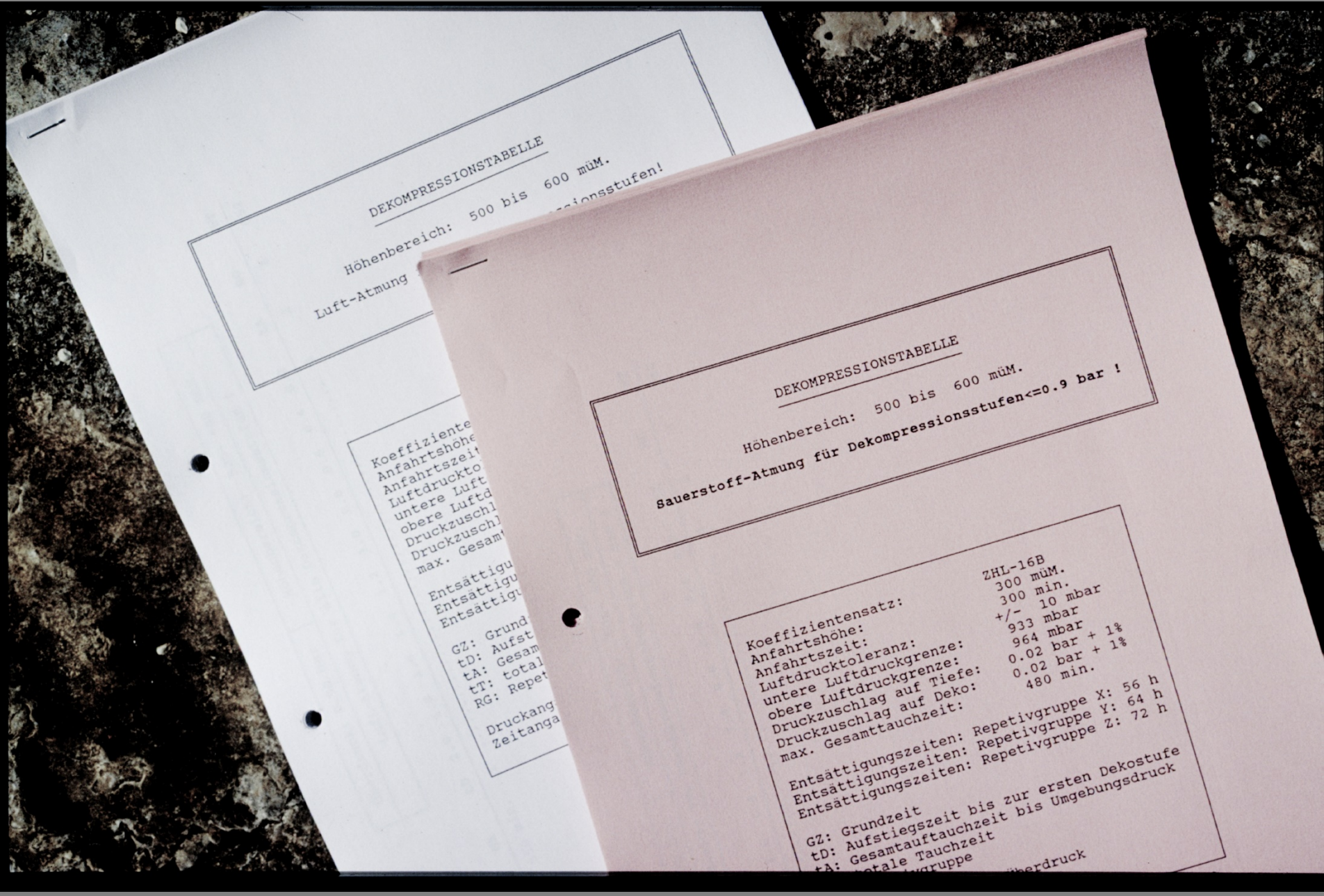
- Aim to get standard for SCUBA diving guidance
- Verification using altitude dives
- Validation experiments with reduced decompression stops
  (+ 10% deco-stress → 30% increase of DCS)
  DCS treated in the recompression chamber


Schweizerische
Rettungsflugwacht
SWISS AIR-RESCUE
RETTUNGSFLUGWACHT


Nullzeiten und Dekompressionszeiten
für Tauchgänge mit Luftatmung
Tiefe m
Zeit min
Stufen 6 3 RG
Höhenbereich: 0–700 müM
Aufstieg: 10 m/min
Sicherheitshalt: 1 min bei 3m
Höhenbereich: 701–2500 müM
Aufstieg: 10 m/min
Sicherheitshalt: 1 min bei 2m

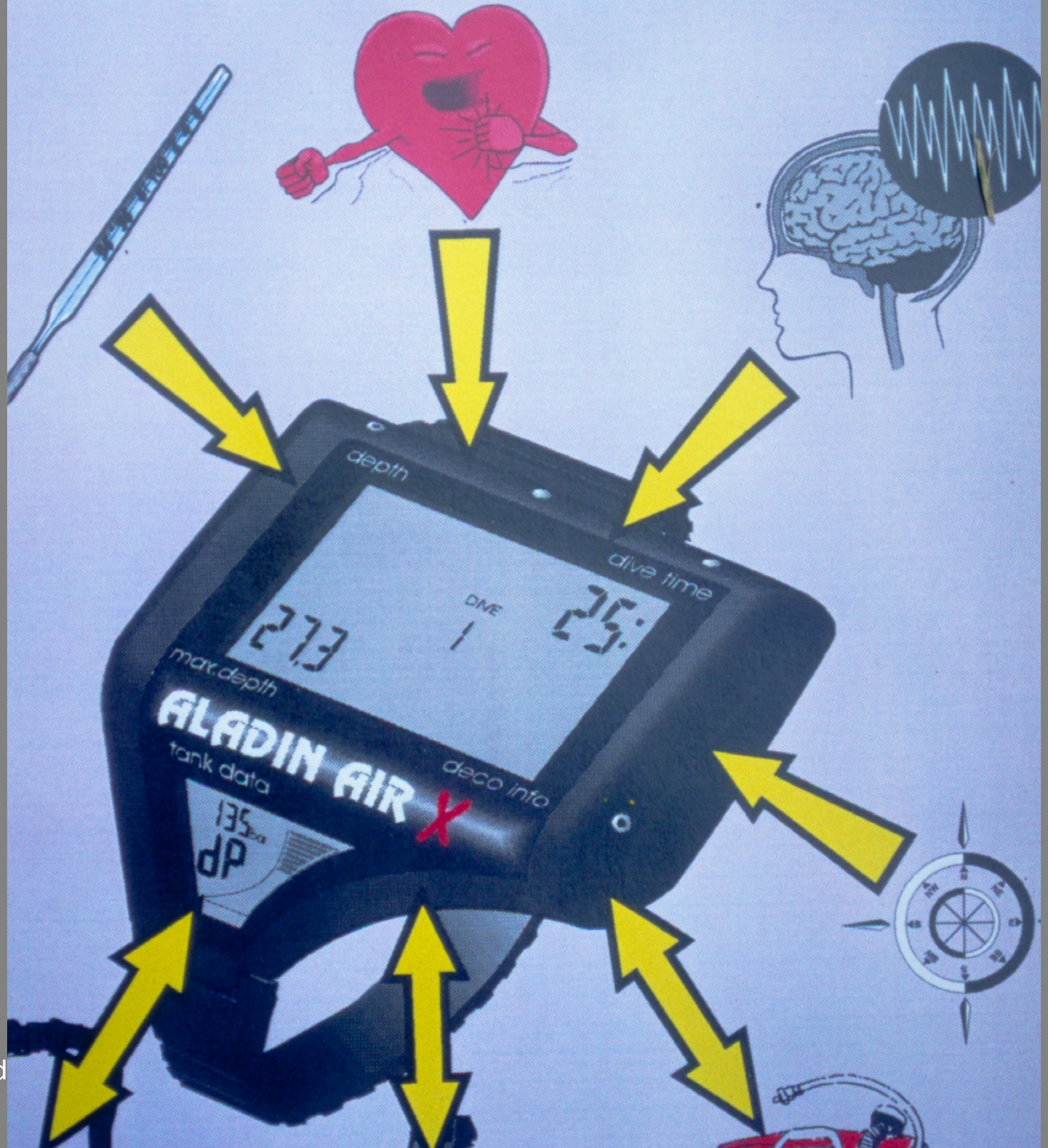

Repetitive group at the end of the surface interval 'O'
Repetitive group at the beginning of surface interval
Surface interval table (min)
Repetitive timetable (min)
Repetitive groups
Depth (m)


40
45
50
0
DEPTH (m)
12
15
20
25
30
35
min (incl. descent time)
Bottom - time
Repetitive group
15
F
9
5
3
3
min
Decom-
pression-
stops
2m
4m
7m
10m
13m
16m
701-1500m
above sea level
Max.ascent rate: 10 m/min
No decompression limits
m 8 9 12 15 18 20 25 30 35
min ∞ 720 90 30 20 15 10 5 4
Each dive must include a decompression stop of 3 min at 2m
COPYRIGHT BY:
Druckkammerlabor.Universität Zürich


DEKOMPRESSIONSTABELLE
Höhenbereich: 500 bis 600 müM.
Luft-Atmung
DEKOMPRESSIONSTABELLE
Höhenbereich: 500 bis 600 müM.
Sauerstoff-Atmung für Dekompressionsstufen<=0.9 bar !
Koeffizientensatz: ZHL-16B
Anfahrtshöhe: 300 müM.
Anfahrtszeit: 300 min.
Luftdrucktoleranz: +/- 10 mbar
untere Luftdruckgrenze: 933 mbar
obere Luftdruckgrenze: 964 mbar
Druckzuschlag auf Tiefe: 0.02 bar + 1%
Druckzuschlag auf Deko: 0.02 bar + 1%
max. Gesamttauchzeit: 480 min.
Entsättigungszeiten: Repetivgruppe X: 56 h
Entsättigungszeiten: Repetivgruppe Y: 64 h
Entsättigungszeiten: Repetivgruppe Z: 72 h
GZ: Grundzeit
tD: Aufstiegszeit bis zur ersten Dekostufe
tA: Gesamtauftauchzeit bis Umgebungsdruck

Support for development of dive computers 1983 - 1994

- First challenge was to use limited hardware for real time calculation of N2 partial pressures
- Second challenge was to introduce arterial bubbles and pulmonary blood shunting into the algorithm
- Many more adaptations later with increasing hardware resources and scientific input of influencing factors


depth
dive time
DIVE
max.depth
ALADIN AIR X
tank data
deco info
dP


elba
diving
center
PERFETTO

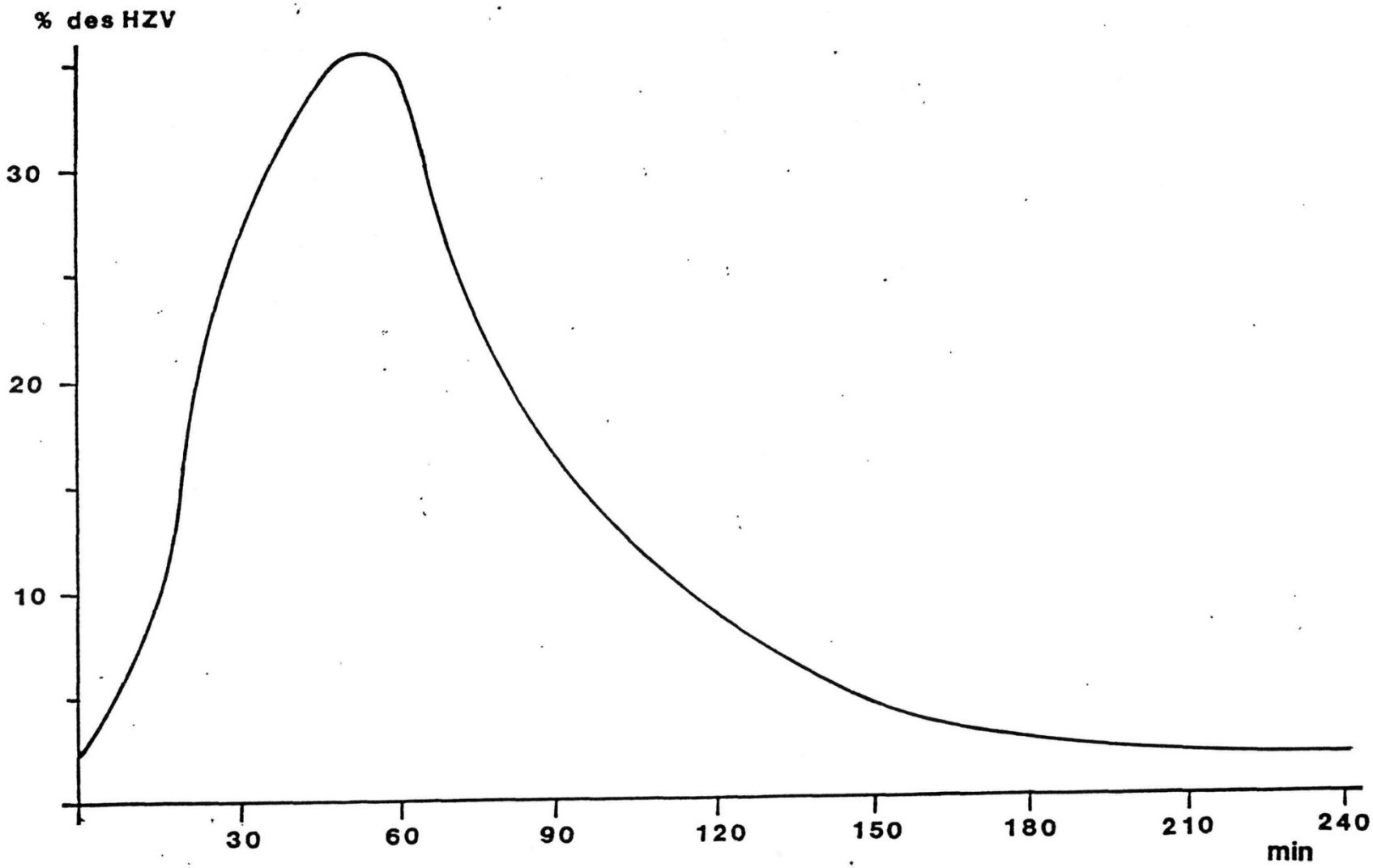
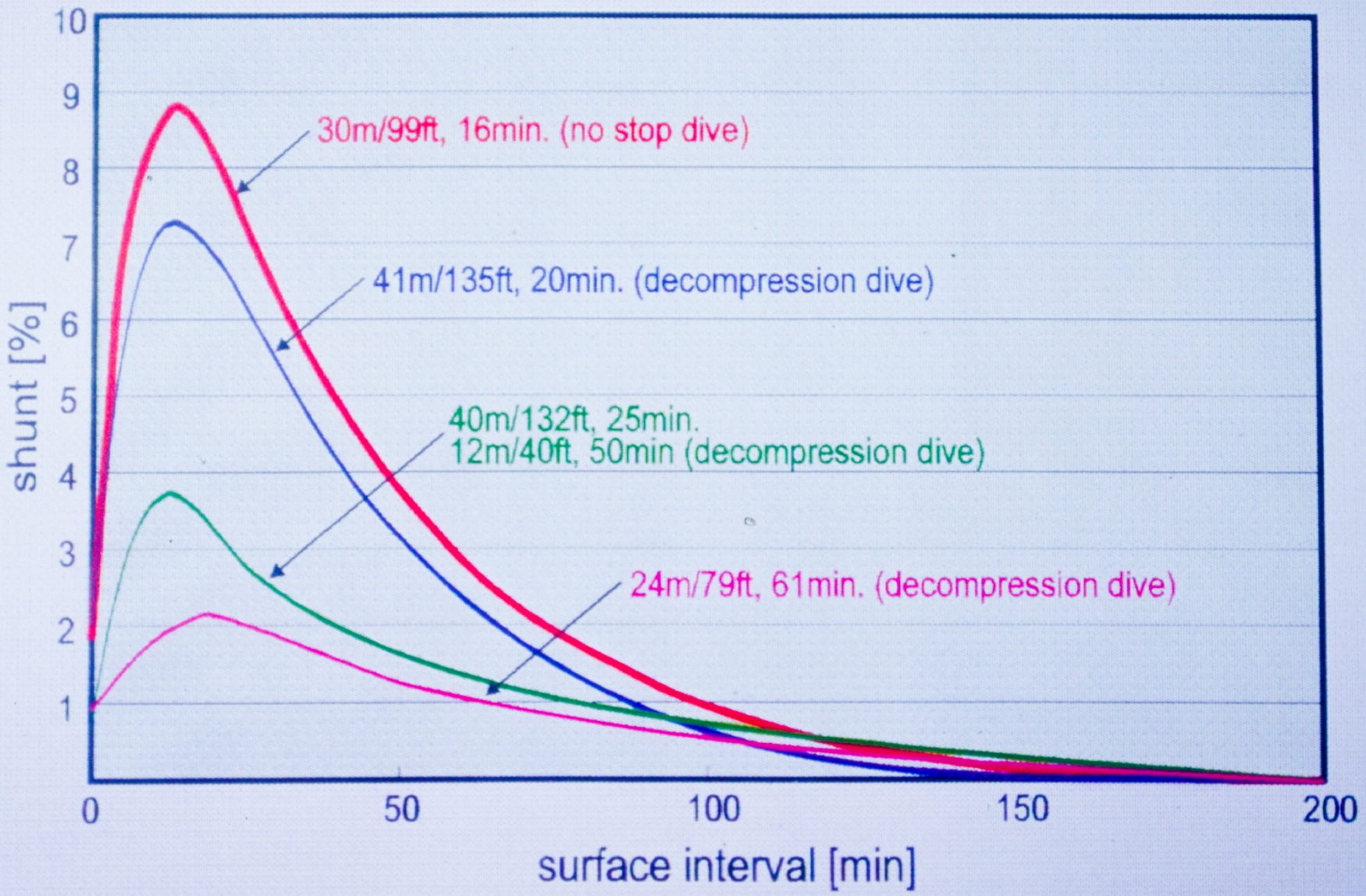


Abb. 22. Intrapulmonaler Rechts-links-Shunt in Prozent des Herzzeitvolumens nach einem Tauchgang. Infolge Kumulation der Mikrogasblasen in den Lungenkapillaren wird kurzfristig ein Maximum erreicht. Der Shunt nimmt ab, sobald der Abbau der Mikrogasblasen in der Lunge den Nachschub von Mikrogasblasen aus dem Gewebe übertrifft

aus Bühlmann

Intrapulmonary right-to-left shunt

Size for some single dives



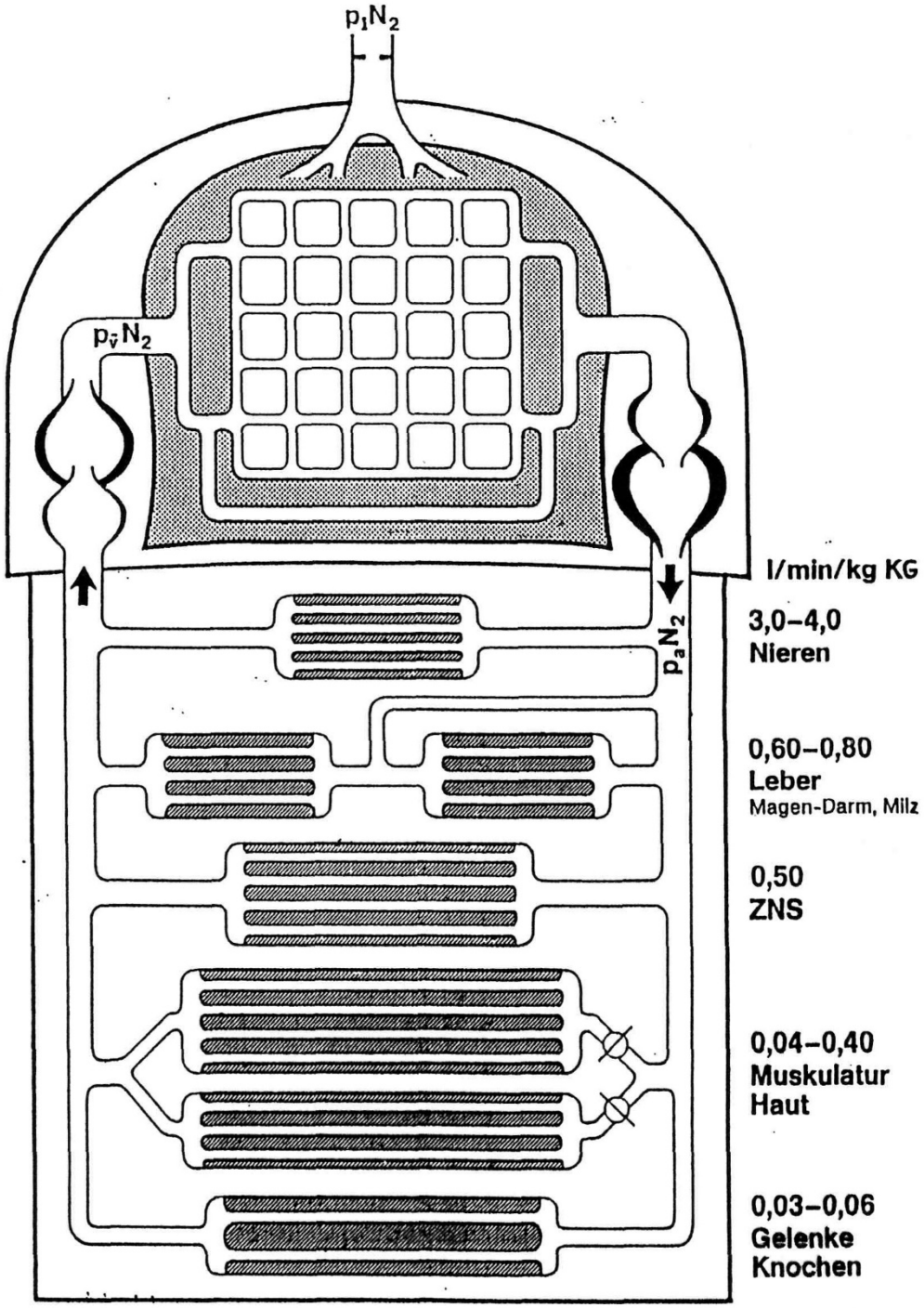
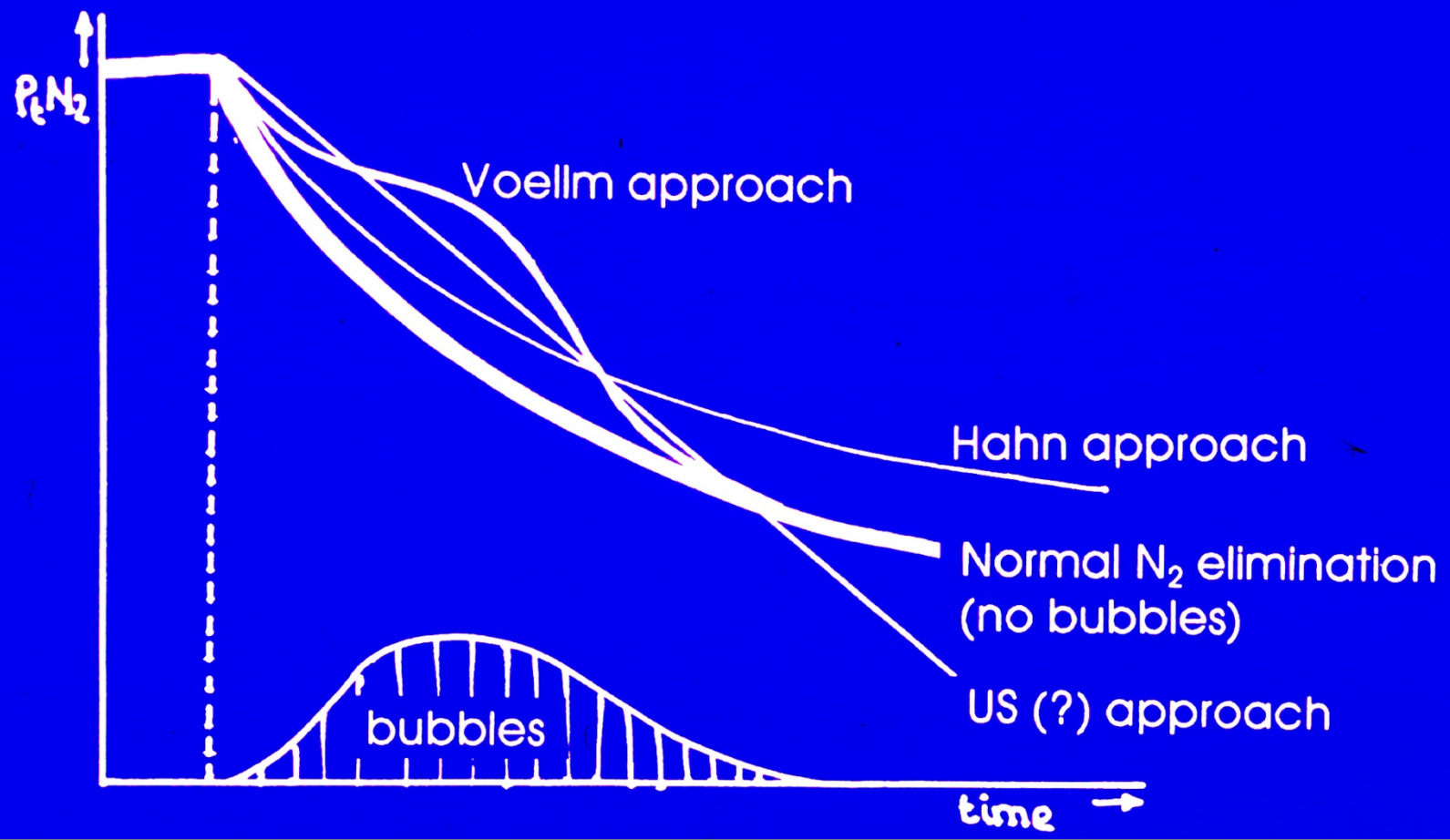
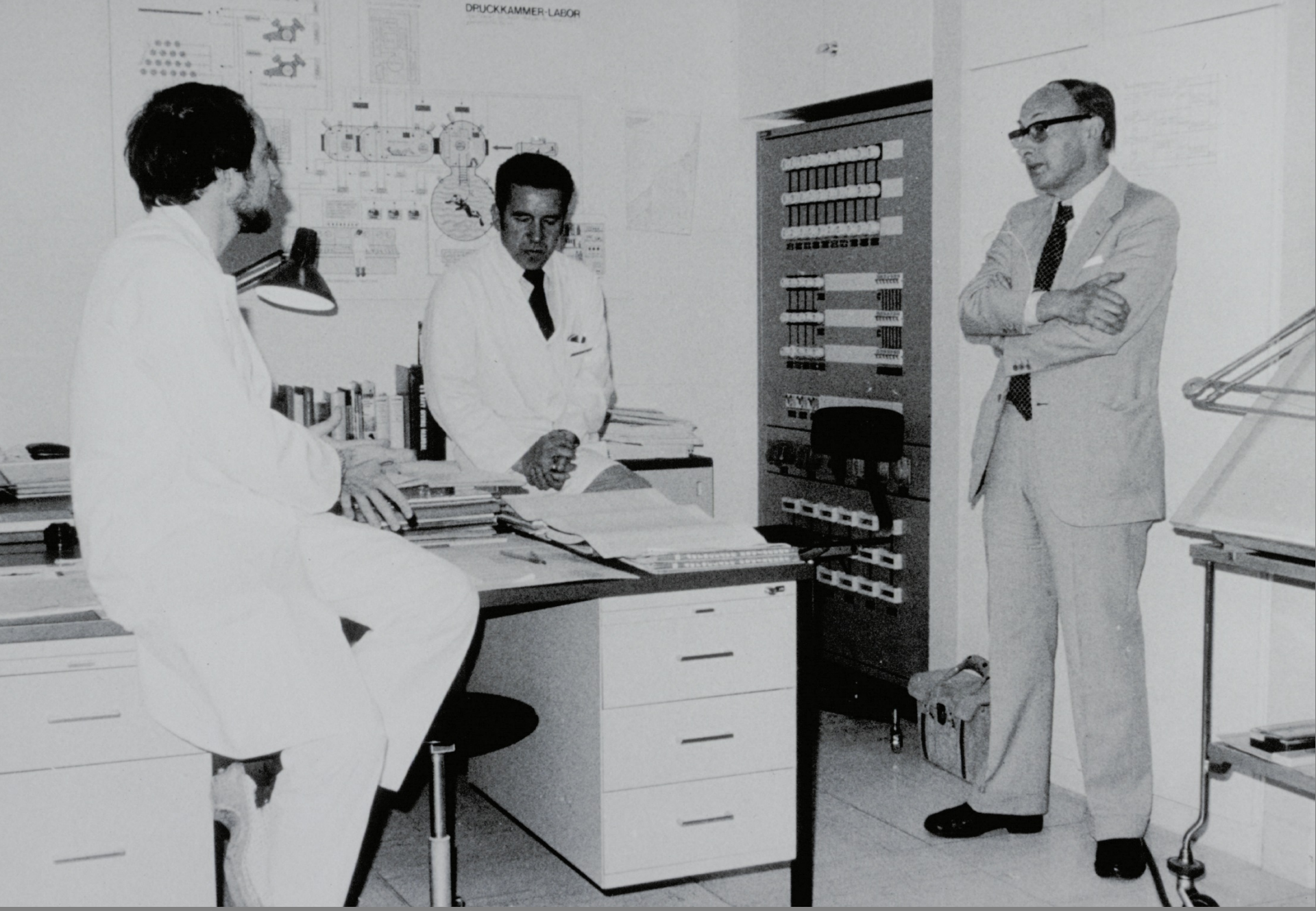


Abb. 14. Schematische Darstellung des Lungen- und Körperkreislaufs mit unterschiedlichen und variablen Durchblutungsanteilen der verschiedenen Organe

Adaptation of Decompression Algorithm

to bubble induced changes in gas exchange of the lung




DRUCKKAMMER-LABOR

Clinical hyperbaric oxygen treatment

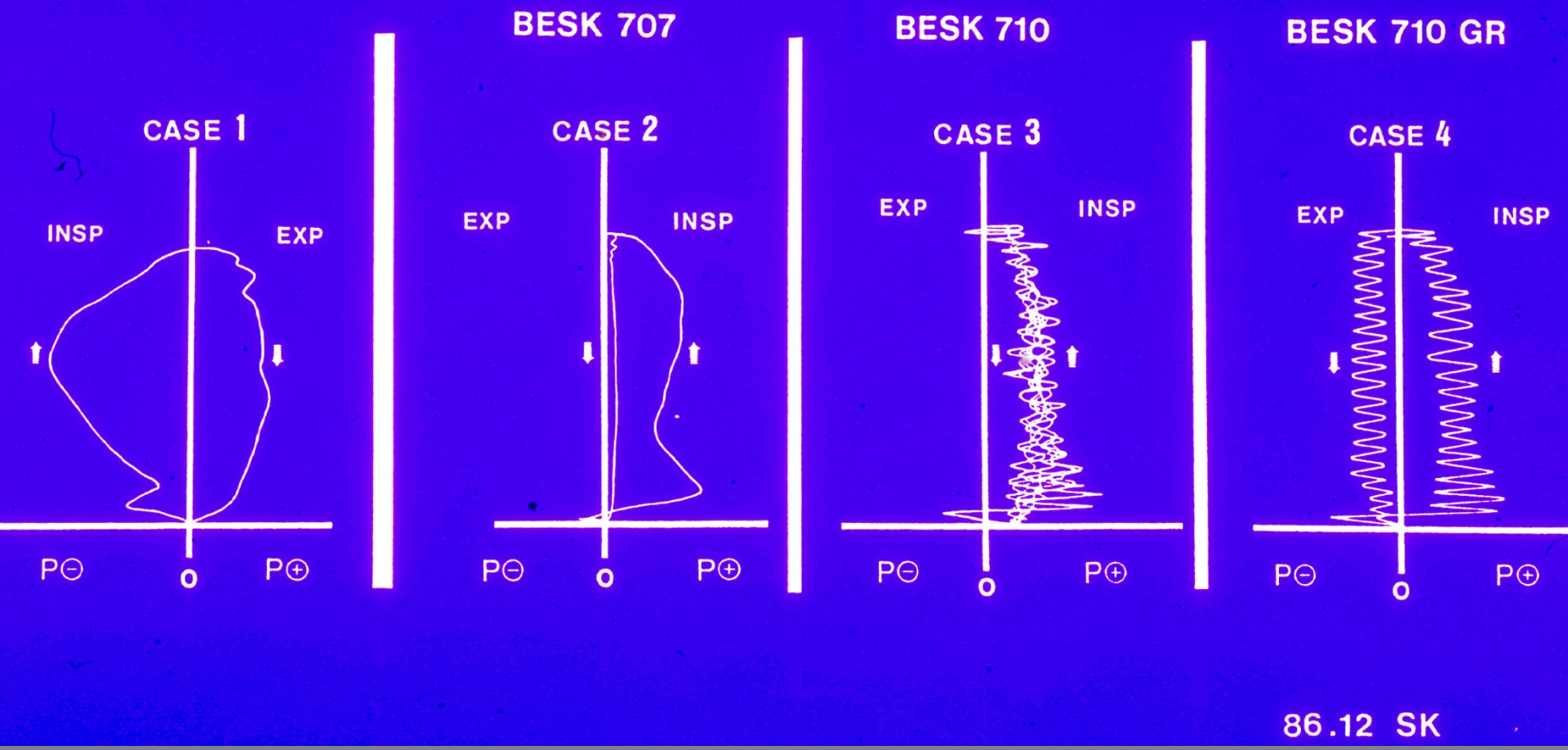
HBOT

Development of a high-frequency ventilation breathing system

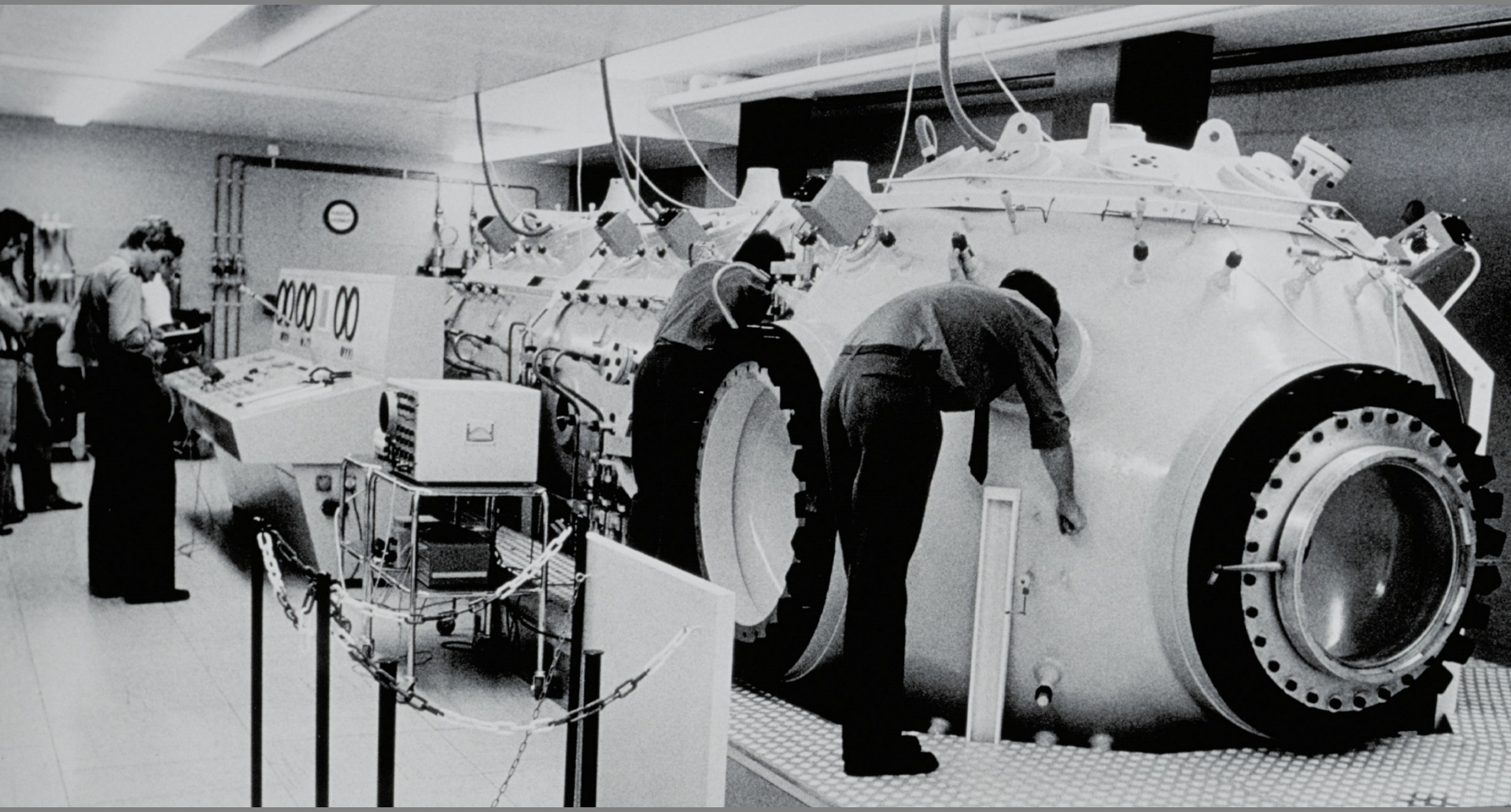
by benno schenk

UBA CHARACTERISTICS – DEVELOPMENT PROGRESS

… to reduce work of breathing in deep dives




BESK 710/710GR
USZ DKL 850217 SK



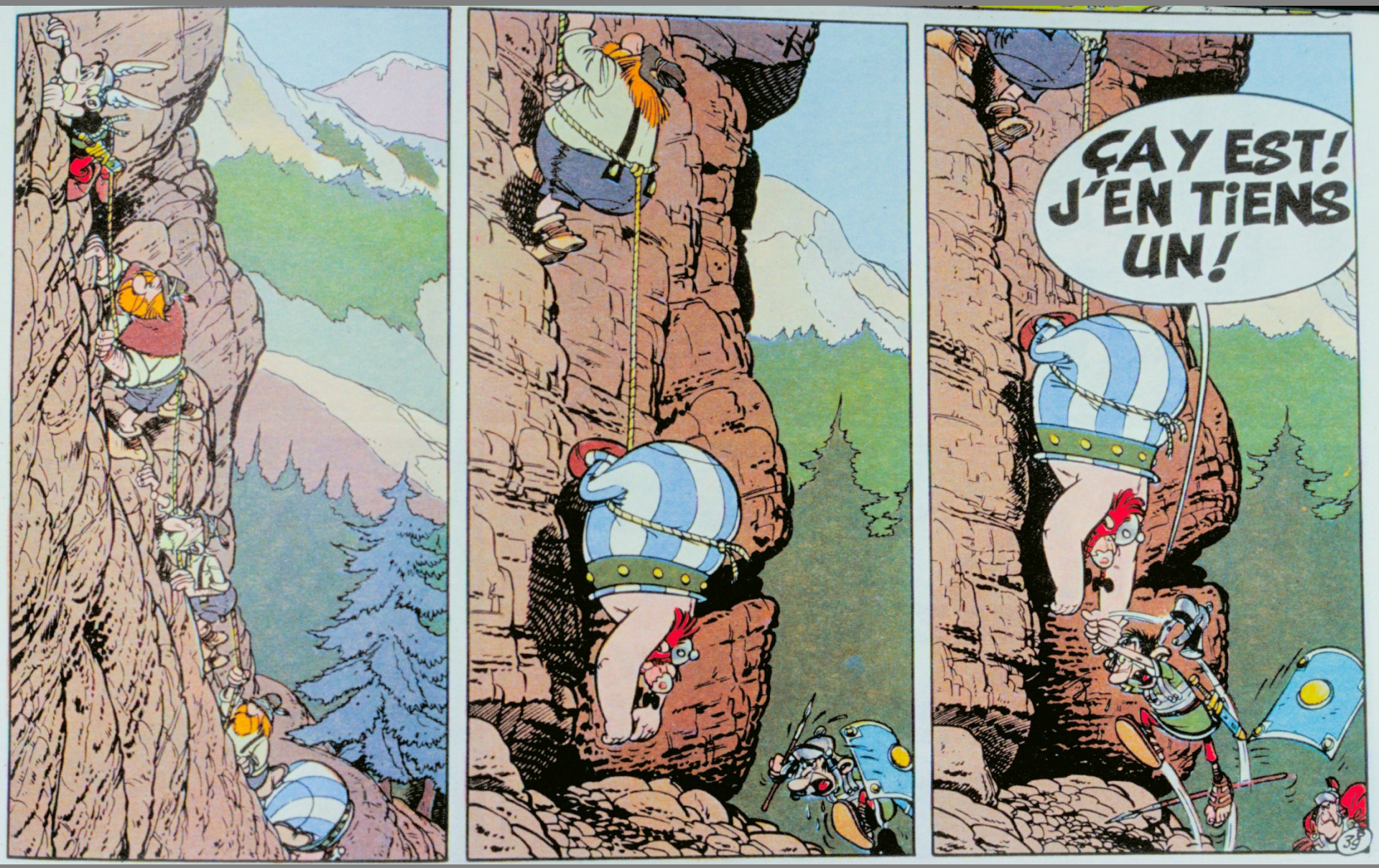
Conclusions (1)

- The combination of
  - enthusiasm,
  - scientific commitment
  - opportunity of up-to-date IT-resources

  at the ZHL led to a series of spectacular records and research exploits.

Conclusions (2)

- In spite of many improved and modern decompressions models and hypothesis, Bühlmann's validated model with all its simplifications is still the basis for
  - recreational diving computers
  - planning of professional mixed gas operations
  - Teck-dives
  - assessment of profiles from dive accidents.


ÇA Y EST! J'EN TIENS UN!