



To The Very Depths

UHMS Annual Scientific Meeting

Lambertsen Lecture

June 2014

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DISCLOSURE

I have no relevant financial relationships with commercial interests related to the content of this presentation.



TO THE VERY DEPTHS



**International Scientist
Entrepreneur
Recreational Diver
Deep Diving Research**

A Memoir of
Professor Peter B. Bennett, Ph.D., D. Sc



BEST PUBLISHING COMPANY

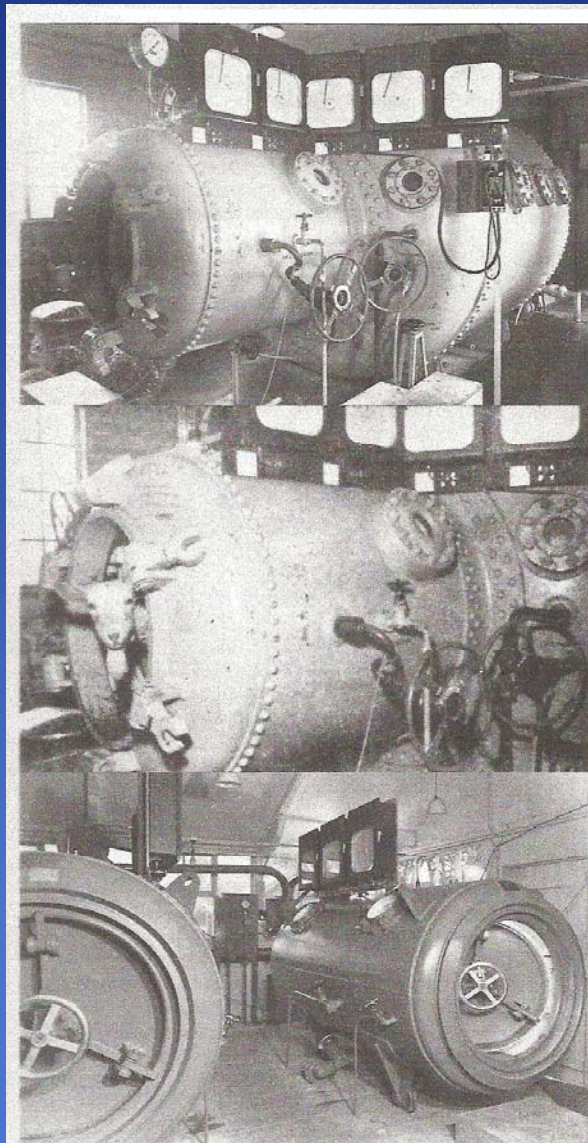




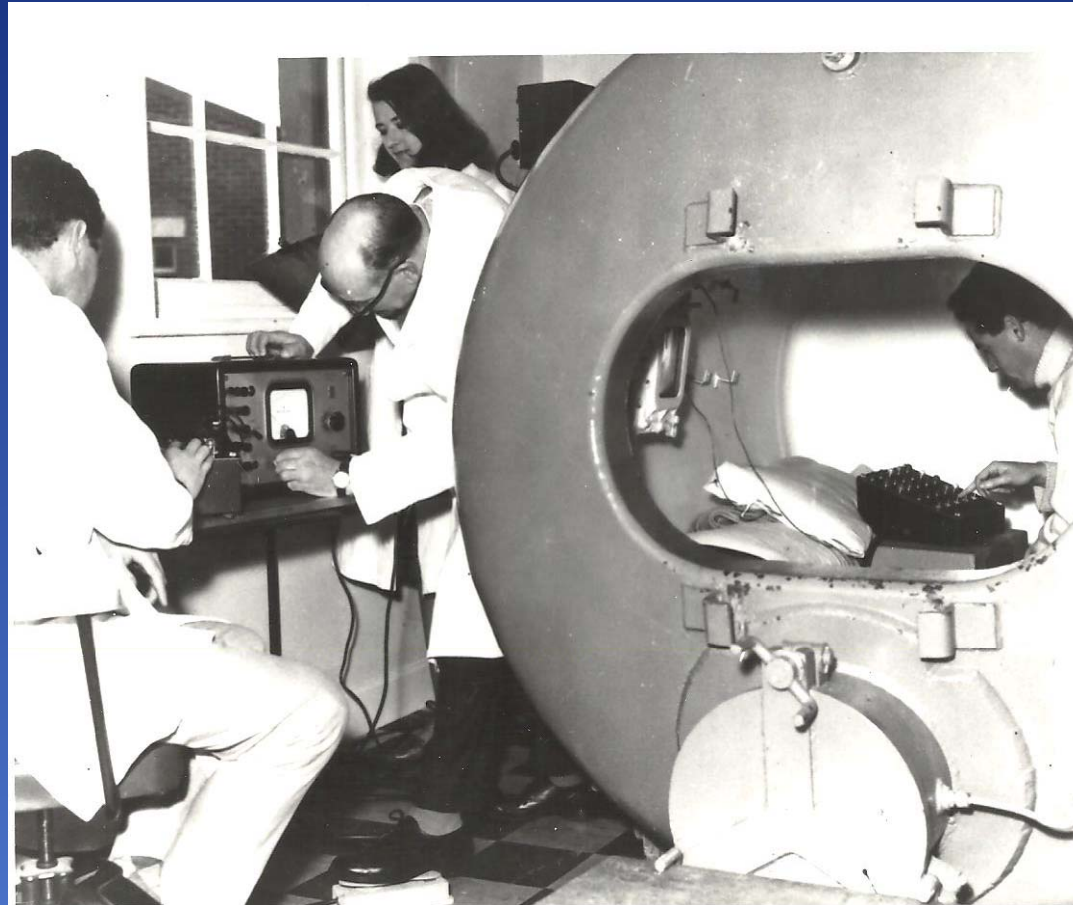




Royal Navy Physiological Laboratory
Alverstoke, Hampshire, UK 1970



Pressure chambers at R.N. Physiological Laboratory



Inside RNPL chamber doing N₂
Narcosis reaction time studies, 1960



RNPL, 1963



H.M. Submarine Affray

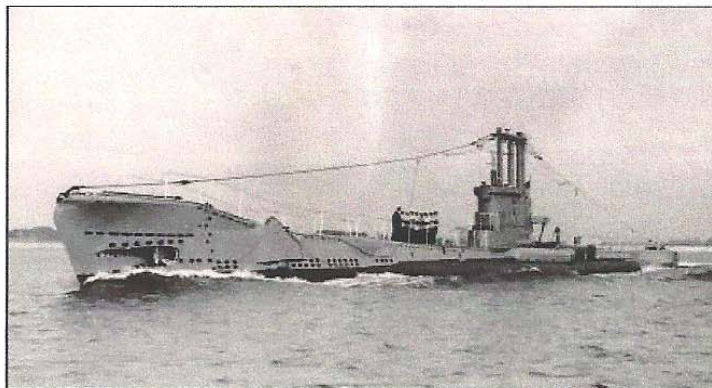
[Her last crew](#)

[The Search](#)

[At rest](#)

[Portrait of a disaster](#)

[The "Affray"](#)
[Submarine Memorial](#)
[Fund](#)



[In better times](#)

[Other crew](#)
[members](#)

[Special stories](#)

[Poems](#)

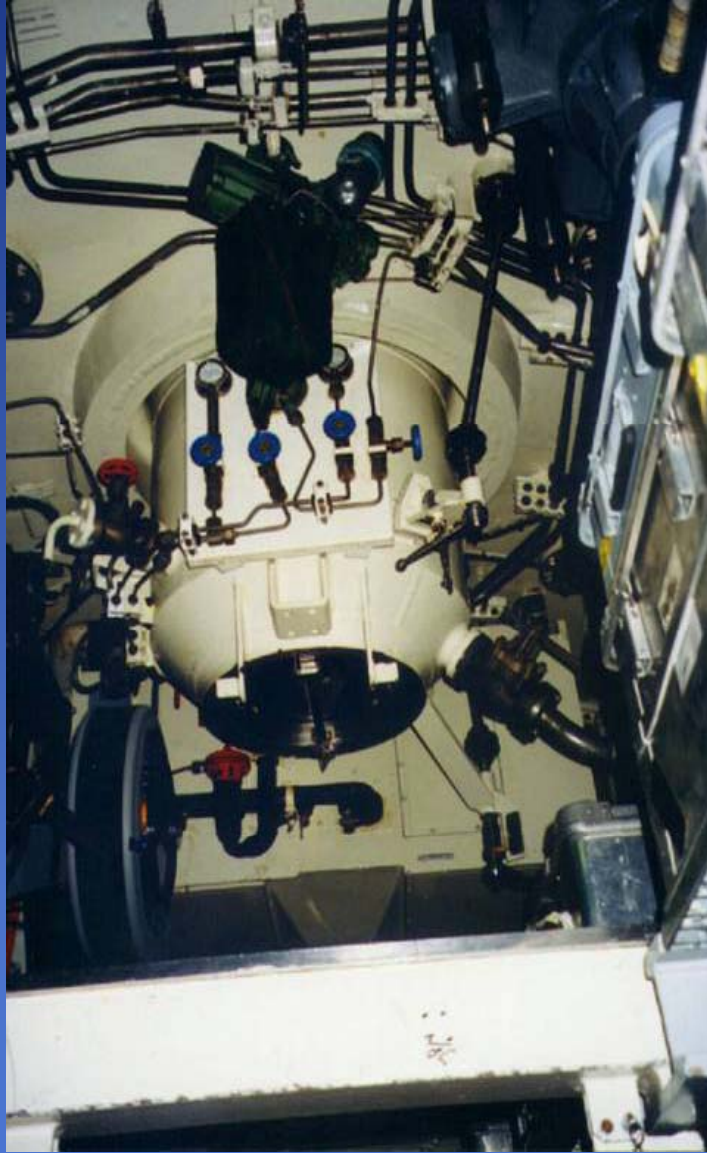
[Alderney](#)
[Memorial](#)

[2013 Gosport](#)
[Memorial Update](#)

This site is dedicated to the memory of the crew of HMS Affray lost in the English Channel off Hurd Deep on the 17th April 1951 - and to my father L/S George Cook who was a member of that crew.

It is intended to be a record of the life of Affray and the special submariners who served in her.







Mean Results Two Choice Reaction Time (1/100 Seconds)

	<u>400 Feet</u>	<u>500 Feet</u>
1. Atmospheric pressure	40.1 ± 6.8	30.7 ± 4.4
2. Expected result (learning)	37.8 ± 5.8	29.9 ± 3.7*
3. Actual result	37.2 ± 4.8	34.2 ± 4.0*
4. Difference 2-3	+0.06 ± 2.3	+4.4 ± 2.2
5. Return to atmospheric pressure	36.1 ± 5.8	30.0 ± 3.8

* $P = 0.02$

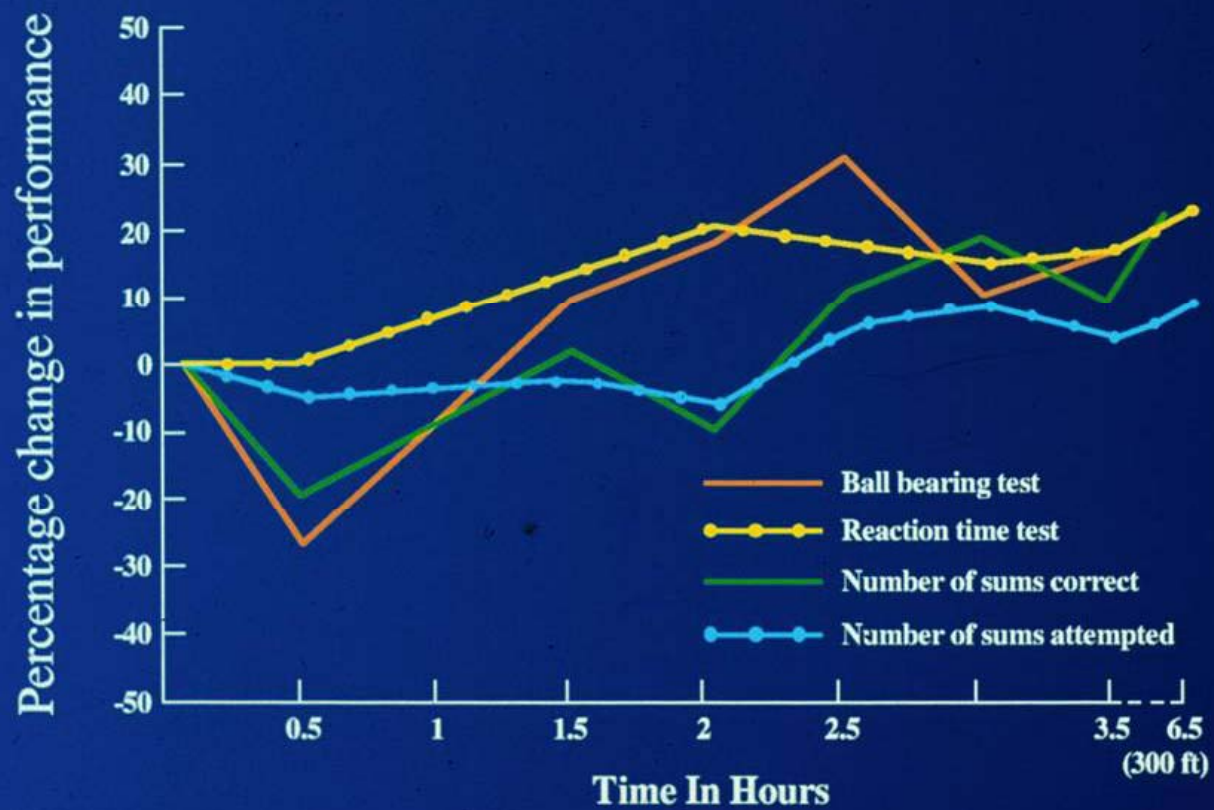








Lt. Wookey 1956: Dives with He/O₂ to 600 ft



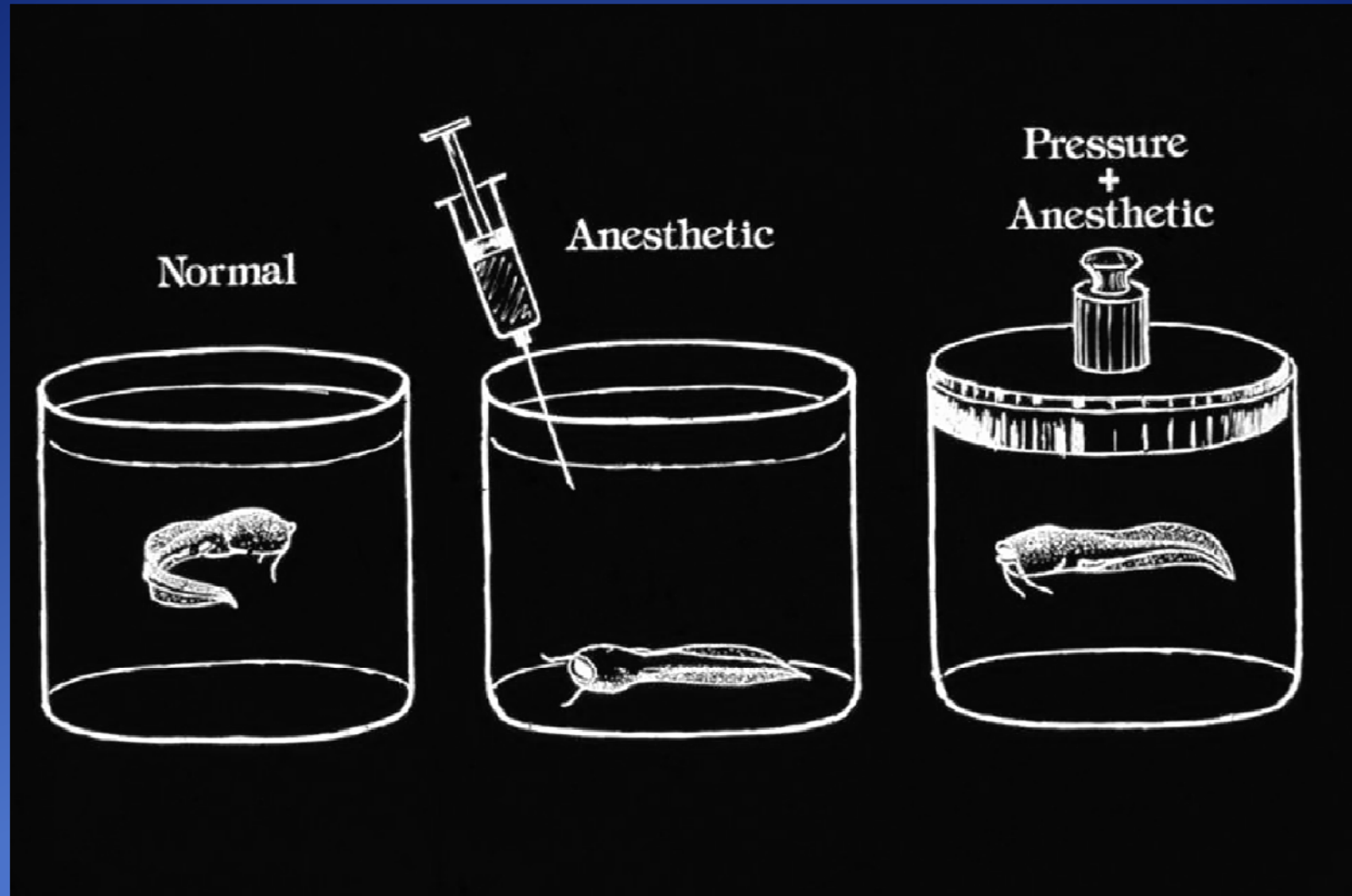


1965: Dr. Bennett monitors divers at 800 ft on oxygen-helium and records first occurrence of the High Pressure Nervous Syndrome



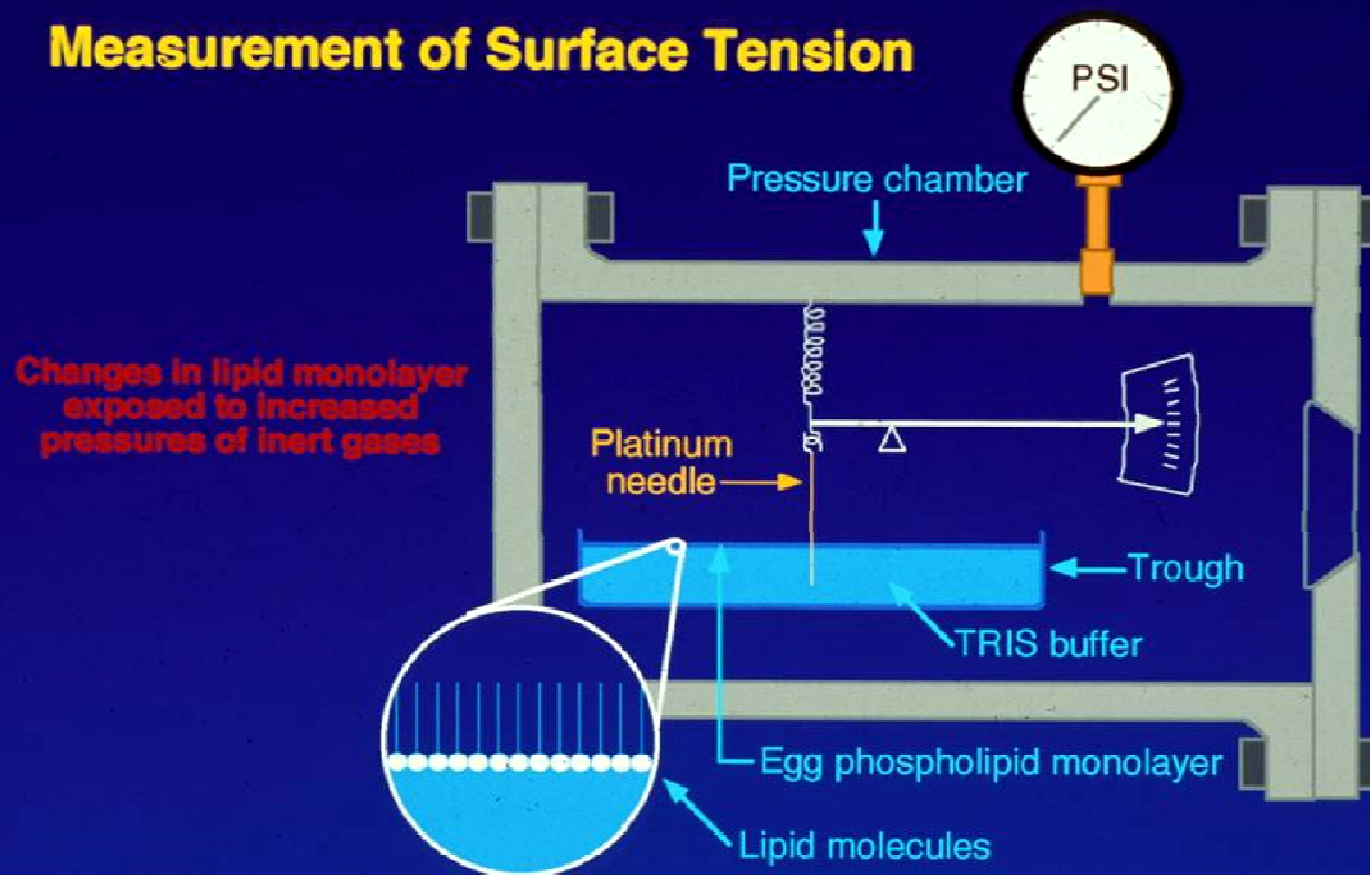
Comparative Percentage Impairment with Increasing Depth Breathing He/O₂

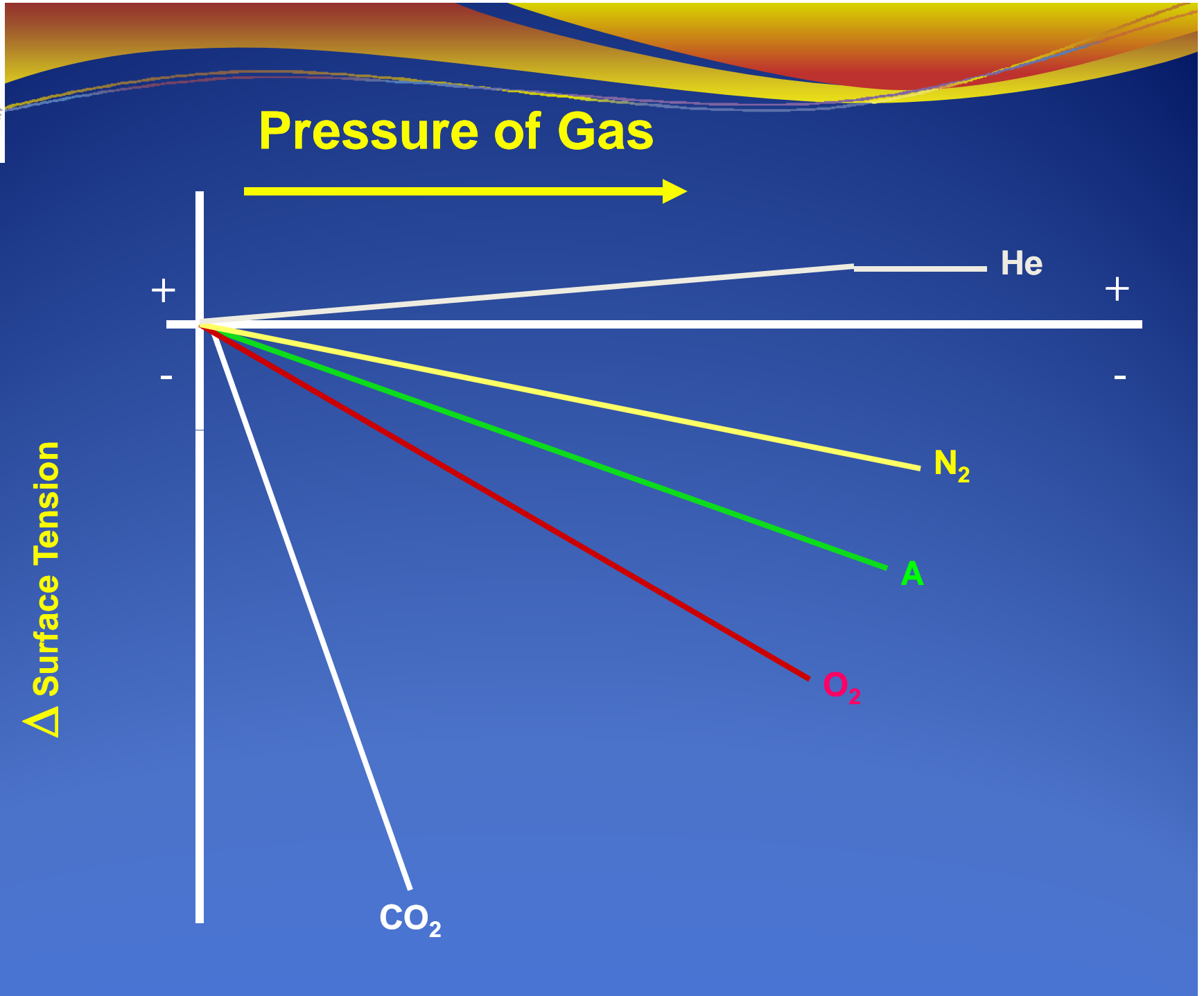
	600 ft (6)	800 ft (4)
Sums correct	-18%	-42%
Sums attempted	-4%	-6%
Number of ball bearings	-25%	-53%



Johnson & Flagler, 1950

Measurement of Surface Tension







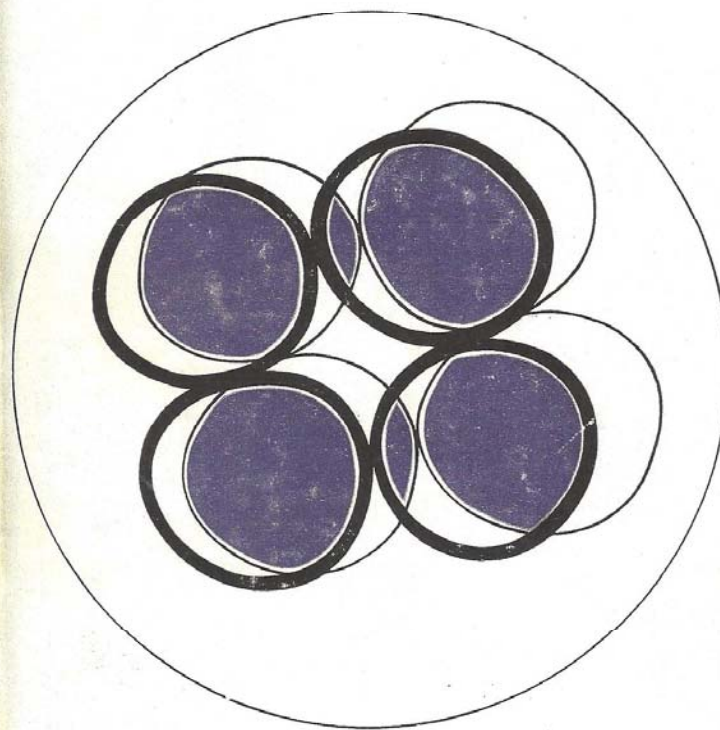
Pergamon Press

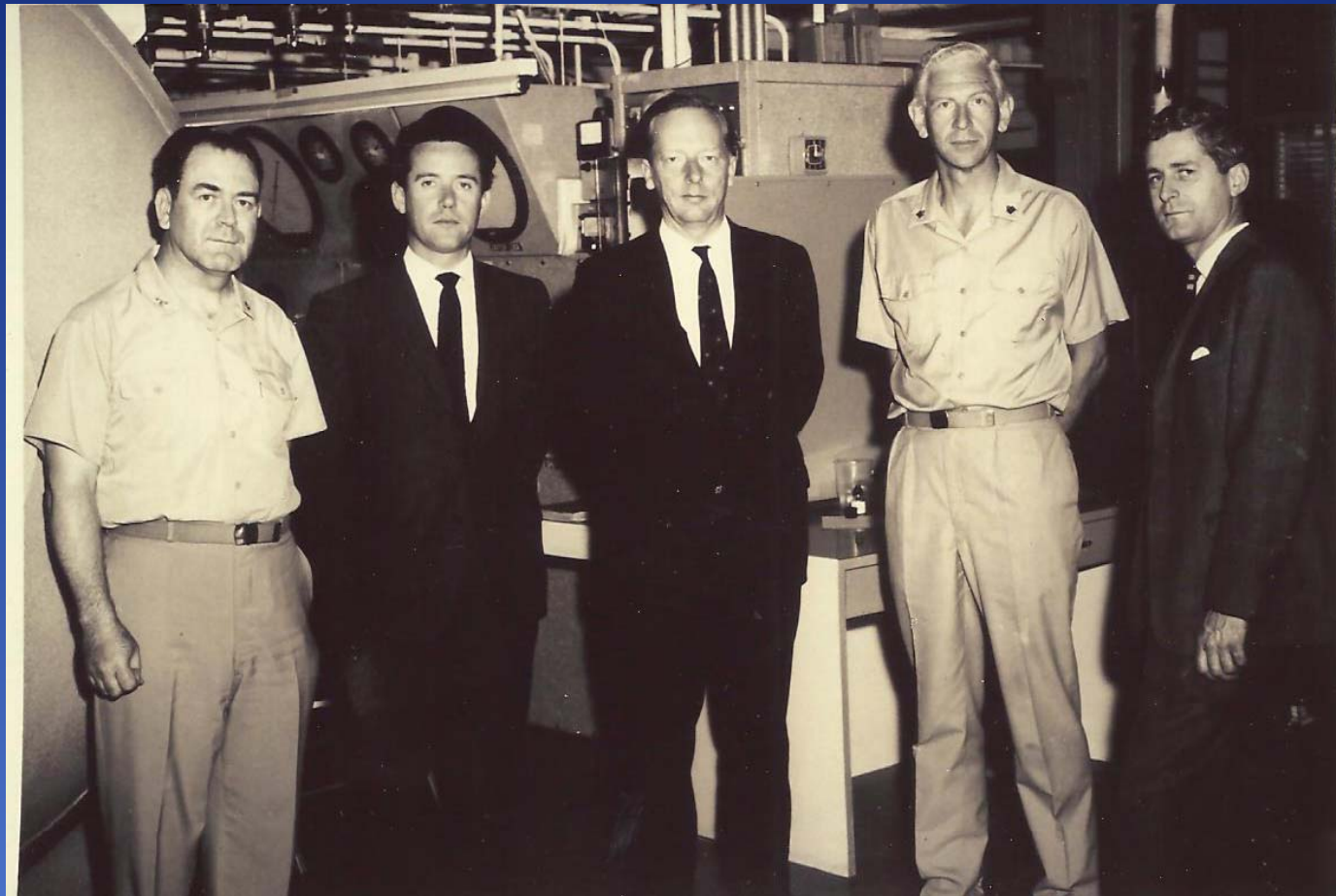
International Series of Monographs in
Pure and Applied Biology/
Zoology Division/Volume 31

**The Aetiology of Compressed Air
Intoxication and Inert Gas Narcosis**

P.B. Bennett

Royal Naval Physiological Laboratory, Alverstoke

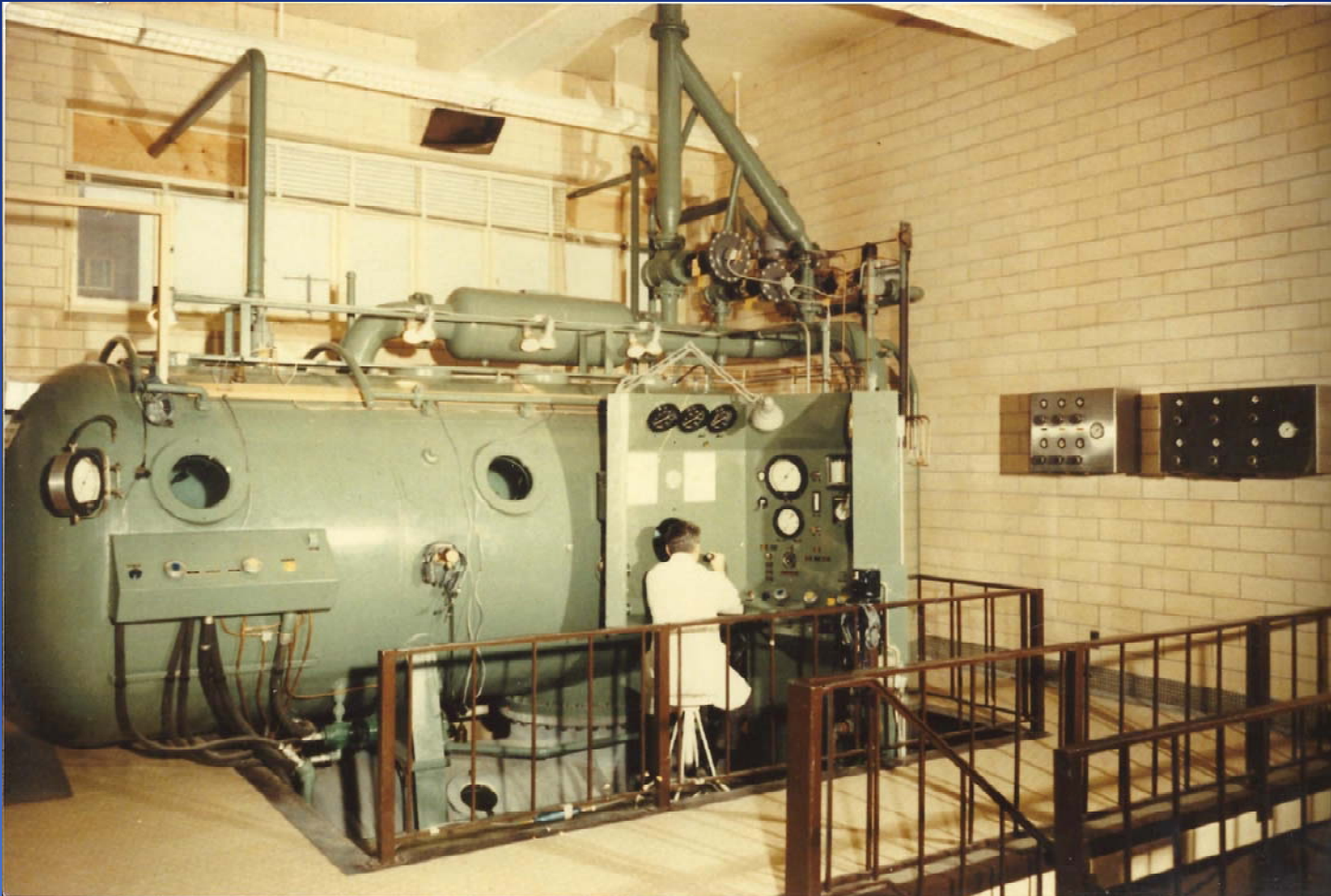




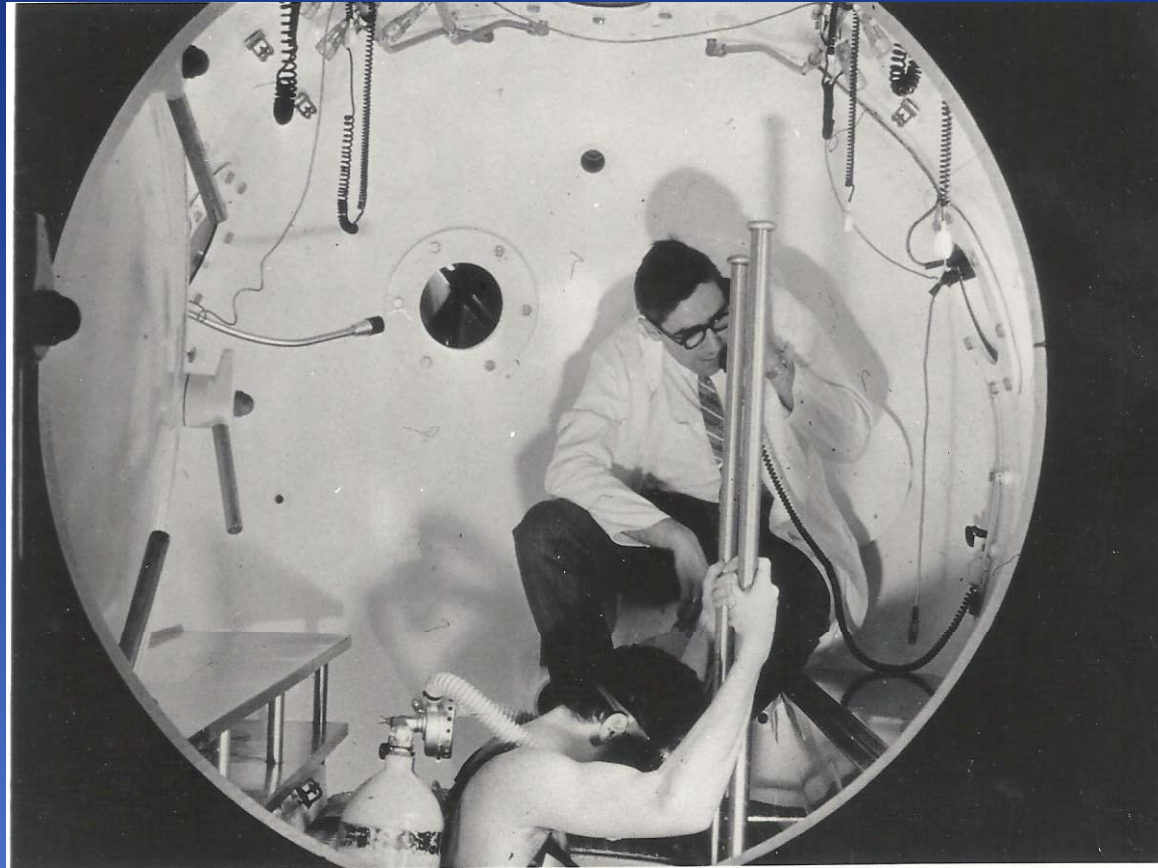
USN Experimental Diving Unit Washington 1966
From left: David Elliott, Peter Bennett,
Val Hempleman, John Rawlins, Bob Workman



DCIEM: Toronto, Canada
1966



New pressure chamber at DCIEM Toronto installed
for new Pressure physiology group under the
direction of Dr. Bennett, 1966



Dr. Bennett descends into the wet pot at the DCIEM chamber, 1967.
He made 79 dives 200 ft to 300 ft testing the new DCIEM
decompression computer and table.





THE PHYSIOLOGY AND MEDICINE OF DIVING

Third Edition

Edited by
Peter B. Bennett and David H. Elliott



Baillière Tindall - London

МЕДИЦИНСКИЕ ПРОБЛЕМЫ ПОДВОДНЫХ ПОГРУЖЕНИЙ

Под редакцией
П.Б.Беннетта и Д.Г.Эллиотта

Перевод с английского
канд.мед.наук М.И.Харченко

Под общей редакцией
члена-корр. АМН СССР В. С. Кошсеева



Москва «Медицина» 1988

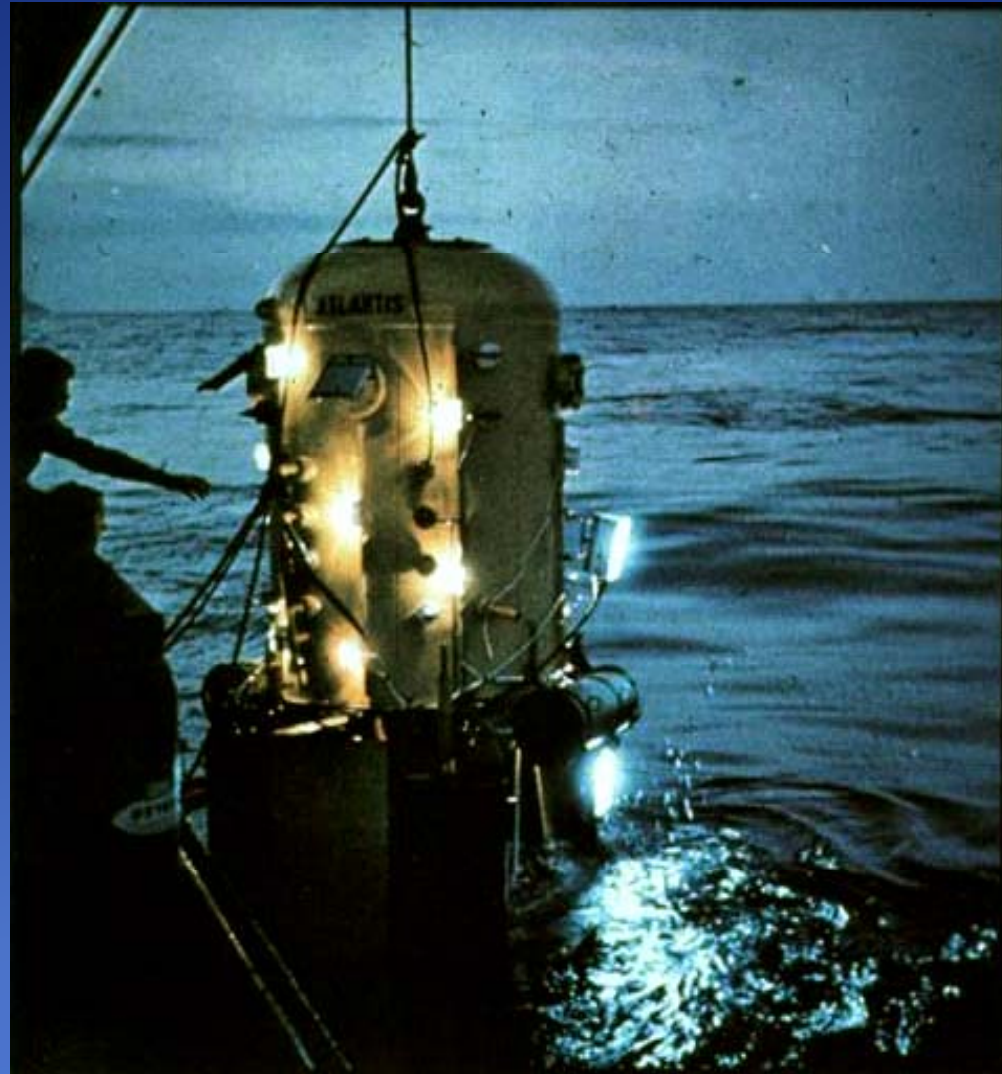


Keller prepares for his 1000-foot dive in 1962. His was the deepest penetration of the sea that had ever been made by an unarmored diver. He used three different cylinders of breathing gases.





Keller climbing into the water tank of the pressure chamber Navy in Toulon on 25 April 1961. The first simulated dive to a depth of 300 m



Hannes Keller left this chamber at 1,000ft and swam free using O₂/He (1962)



Comex 1968 Physalis III

- ➡ 2 Divers
- ➡ Oxygen/Helium
- ➡ Compression in 2 hrs, 3 min
- ➡ 1,189 ft
- ➡ Aborted after 4 min
- ➡ Strong HPNS tremors, EEG changes, fatigue, somnolence



Duke Hyperbaric Center

USN Dive 1968

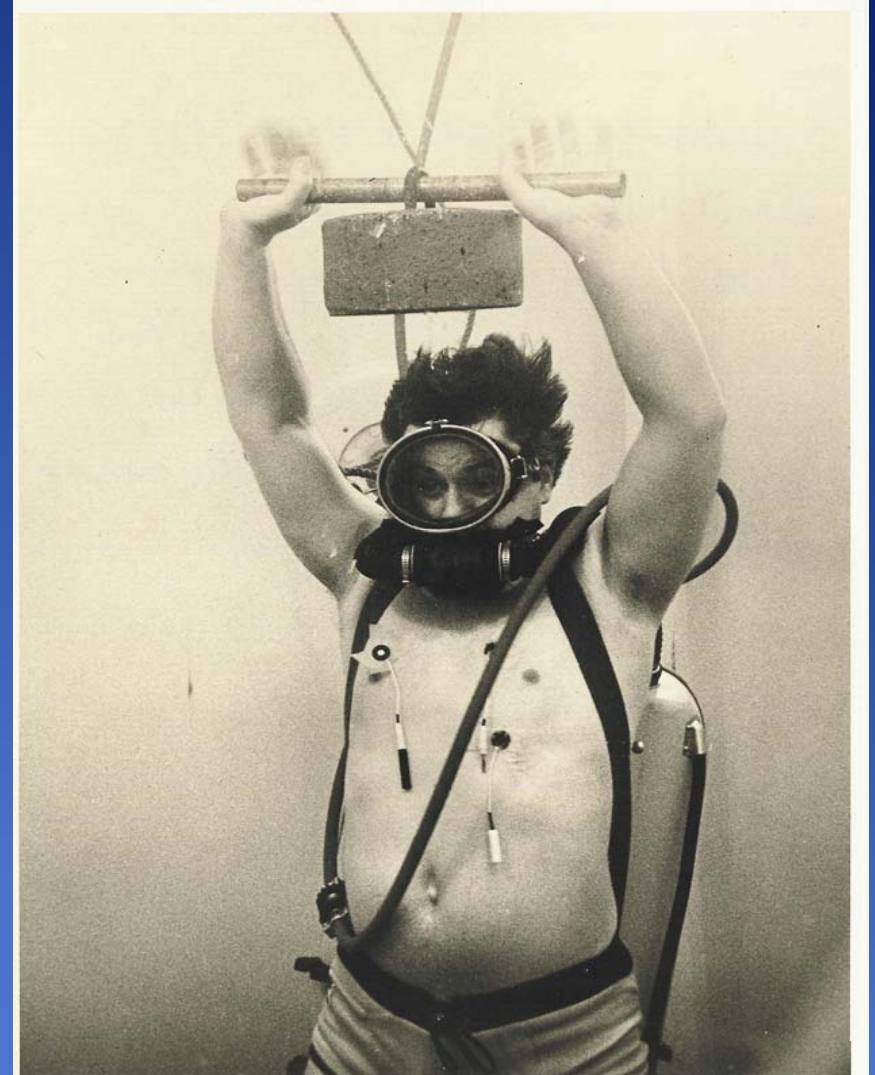
- ➡ 5 divers
- ➡ 305 msw (1000 fsw)
- ➡ 24 hr 22 min compression
- ➡ 77 hr 30 min
- ➡ 2 of 5 fine tremors
- ➡ Arthralgias
- ➡ Concluded “divers can perform well at pressure equivalent to 300 msw”



**August Kalin:
First diver at 1,150 ft with
closed circuit Draeger
breathing apparatus.
Swiss research Dive at
RNPL Alverstoke.**

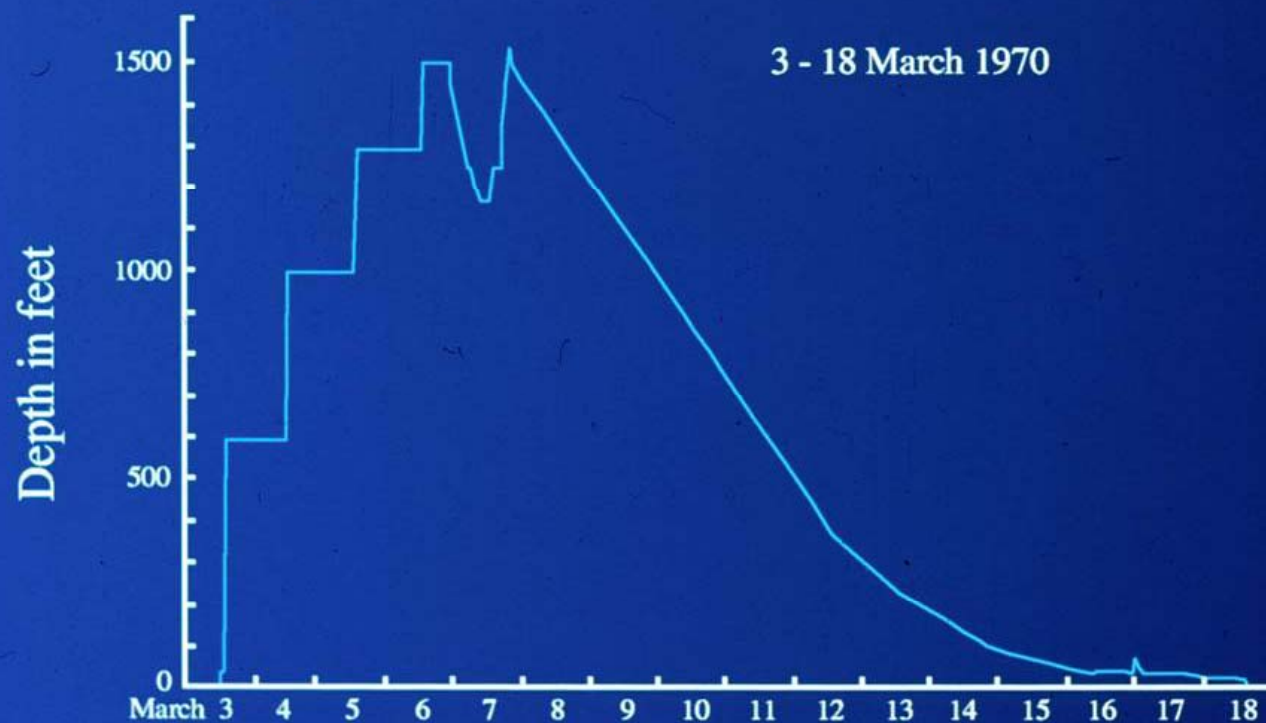
**1 hr 10 min compression
to 1,000 ft**

(Buehlmann & Bennett 1969)





Dive profile 1500 feet for 10 hours



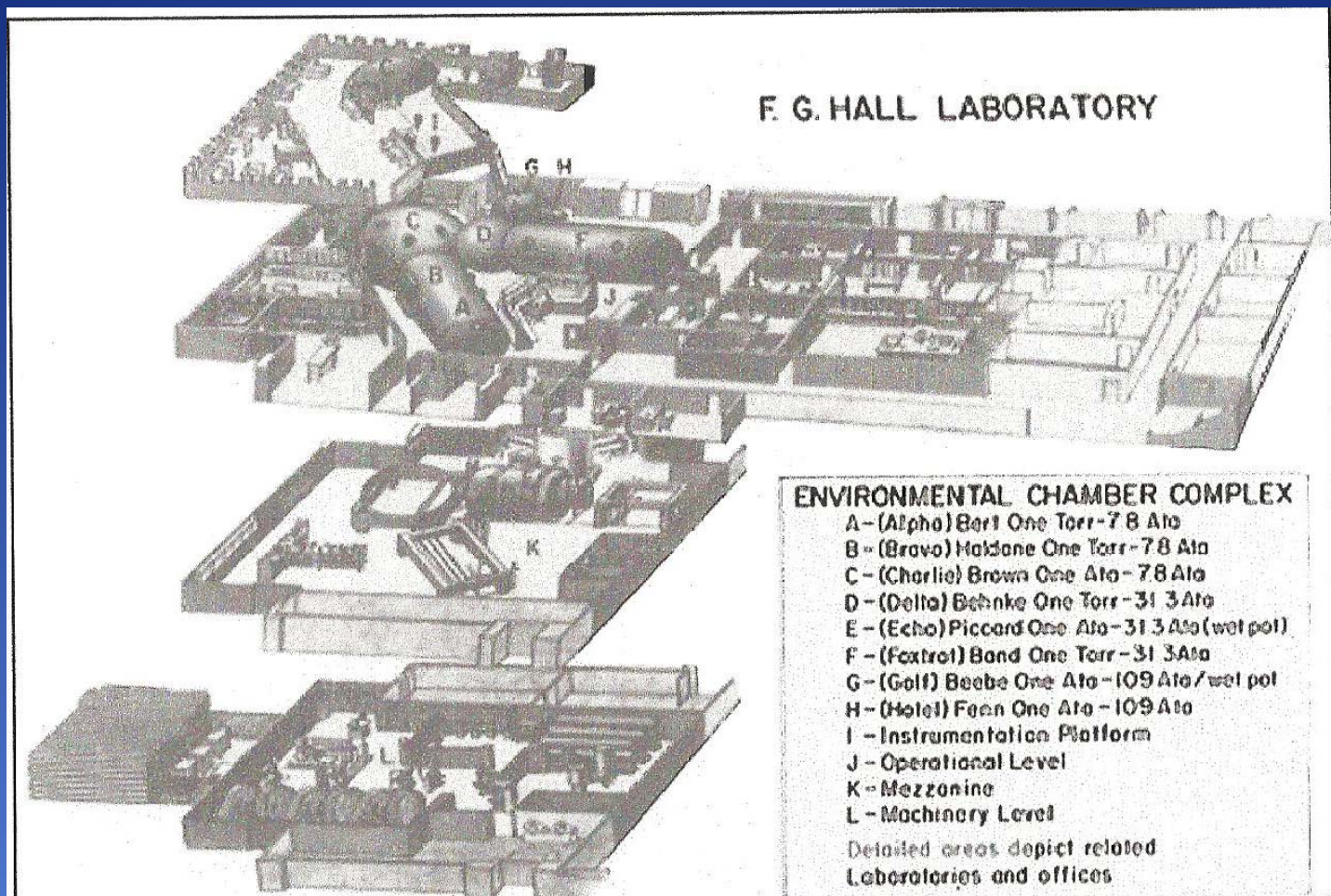




John Bevan (left) and Peter Sharp (right)
subjects for RNPL 1,500 ft record dive



Dr. Val Hempleman (left) presents Dr. Bennett (right) with
farewell silver cigarette box from RNPL on leaving for Duke
September 1972



F.G. Hall Hyperbaric Laboratory, Duke University Medical Center



From Left to Right:
Hotel Manager,
Margaret Bennett,
Peter Bennett,
Ruth Behnke,
Al Behnke,
Ken Donald,
Hotel Marketing Dir.



UHMS International Symposium on Underwater
Physiology & Medicine organized by Dr. Bennett
Grand Bahamas, 1972



First Symptoms Lung O₂ Toxicity Occurrence at 2 ATA in Hours

	Cont O ₂	25 min O ₂ /5 min Air	10 min O ₂ /20 min Air
	2	4.6	3.75
	3	4.8	3.0
	3	5.0	3.75
		5.4	
		5.4	
Mean O ₂ Time	2.6	4.3	3.3
Total Time	2.6	5.1	9.9



Severe Symptoms Lung O₂ Toxicity Occurrence at 2 ATA in Hours

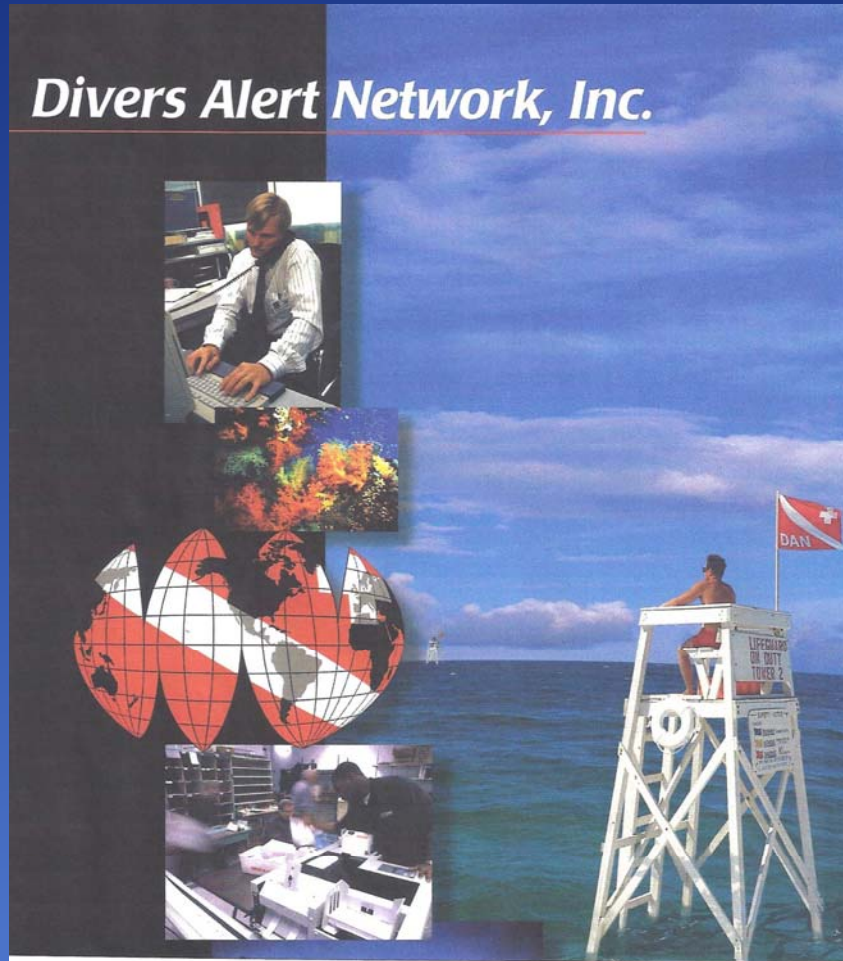
	Cont O ₂	25 min O ₂ /5 min Air	10 min O ₂ /20 min Air
	3.5	7.5	4.0
	6.6	7.5	5.5
	7.5	7.5	6.0
		9.2	
		9.2	
Mean O ₂ Time	5.8	8.2	5.1
Total Time	6.0	9.8	15.4



Dr. Chuck Shilling Awards Dr. Bennett the Undersea Medical Society Albert R. Behnke Award, June 1983



Divers Alert Network, Inc.

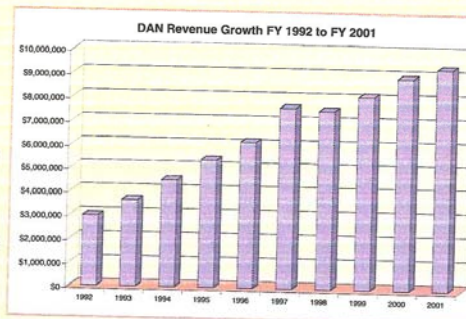


1980 DAN Founded



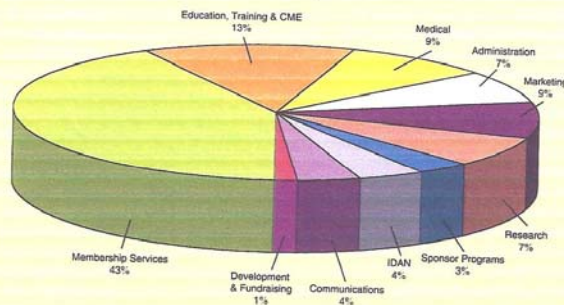
DAN experienced another record year in 2001 as revenues climbed 10 percent to \$9.75 million. More than 92 percent of DAN's operating budget was used for program services including over \$2.75 million contributed towards recreational diving research, medical programs, and training and education.

Since 1992, DAN has grown rapidly from less than 75,000 members to over 225,000 members worldwide and is now a very sophisticated association with two insurance subsidiaries. DAN is a 501(c)(3) non-profit organization, but many may not realize that most of DAN's funding comes from members rather than outside support. Since funding is primarily from dues, product sales, donations, course fees, and insurance royalties, the organization continues a focused mission and responsive attitude towards member concerns. The result is an association that listens to its members, operates efficiently, and constantly tries to improve services.



Membership and related services continued to represent a significant amount of DAN's operating budget in 2001. The \$29 regular membership contribution supported membership benefits such as DAN *TravelAssist* and services for all divers including the 24-hour emergency hotline, with 53 percent of revenues derived from membership dues. Members also helped fund DAN programs by purchasing safety products, insurance and related services that generated more than 23 percent of total revenues this year. In 2001 more than \$8.49 million went into programs that benefited members and recreational scuba divers worldwide, a 14 percent increase over the prior year. This increase in funding and continued success is a result of very dedicated staff maintaining focus and providing programs and services that support DAN's safety and health mission. You can expect more of the same in the future. The continued health and safety of members and divers around the world depends on our success.

2001 DAN Expenses



DAN Financial Summary



DAN's home 1990-1997
University Tower, Durham, NC





Divers Alert Network
Durham, NC



DAN 1980-2003

Members	200,000
Emergency Hotline	33,000 divers
Information Hotline	180,000 advice requests
DAN O ₂ Instructors	10,000
DAN O ₂ Providers	150,000
Over 50 courses on diving medicine	

INTERNATIONAL DAN

Europe
Japan
SE Asia Pacific
South Africa



Hiro Mano (left) with Peter Bennett (right)



HPNS SIGNS AND SYMPTOMS

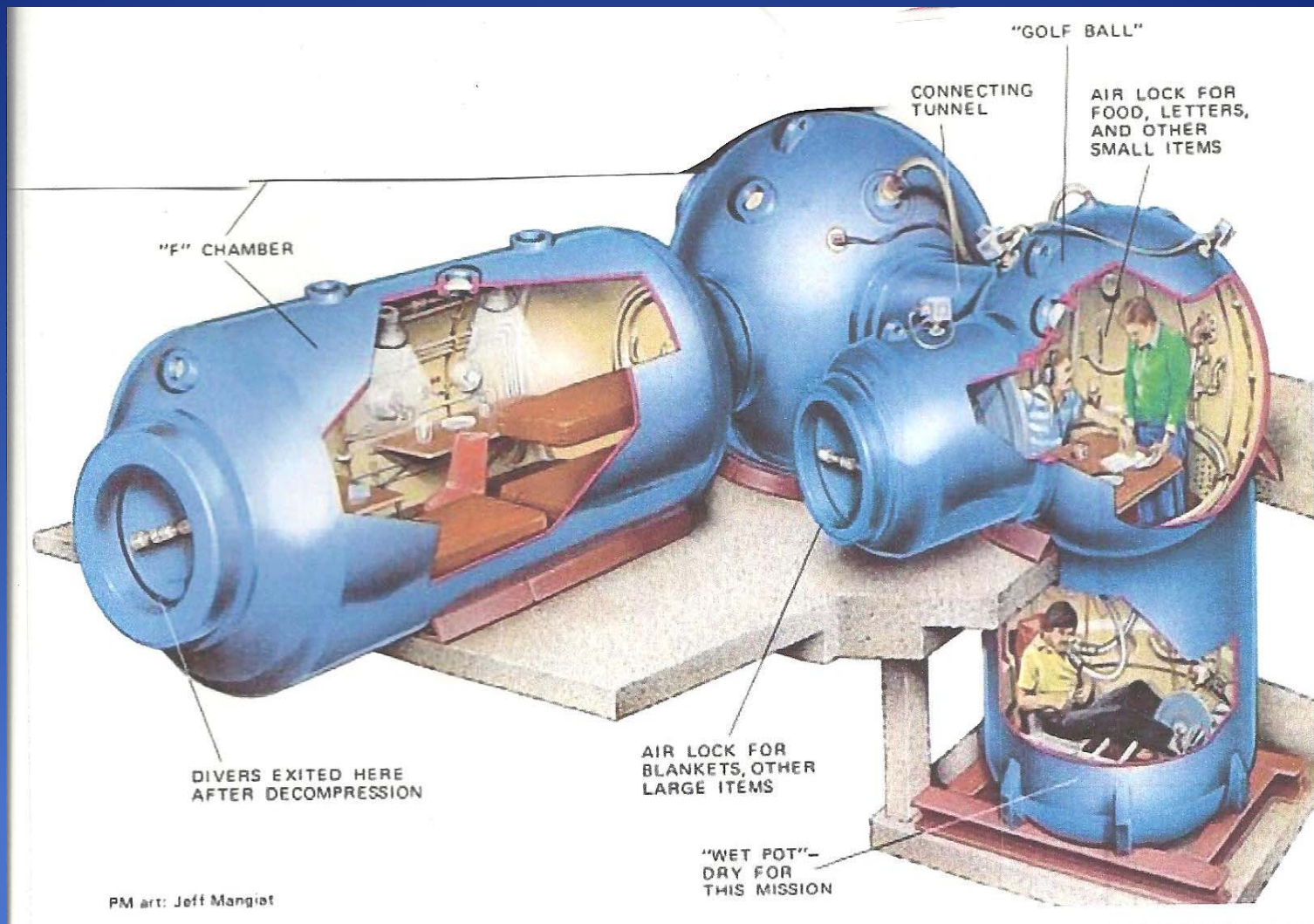
- Tremors of the hands
- Myoclonic jerking of the limbs
- Increased reflexes
- Nausea and vomiting
- Loss of appetite, weight loss
- Dizziness
- Fatigue and somnolence (microsleep)
- Animals – convulsions
- EEG theta (3-7 hz) ↑
- EEG alpha (8-13 hz) ↓
- Evoked potentials ↑
- Decrement in performance
- Poor sleep, vivid dreams
- Visual/auditory hallucinations
- Dyspnea



US NAVY 1979

1800 fsw/4 ½ days

1. 6 Divers
2. 8 Days, 650 fsw
3. 3 ¾ Days compression to 1800 fsw
4. Severe HPNS
 - Fatigue, Dizziness, Nausea, Vomiting, Aversion to food, 8% weight loss, Poor Sleep, Diarrhea, Stomach Cramps, Dyspnea, Myoclonic Jerking
5. Future diving restricted to 1,000 fsw

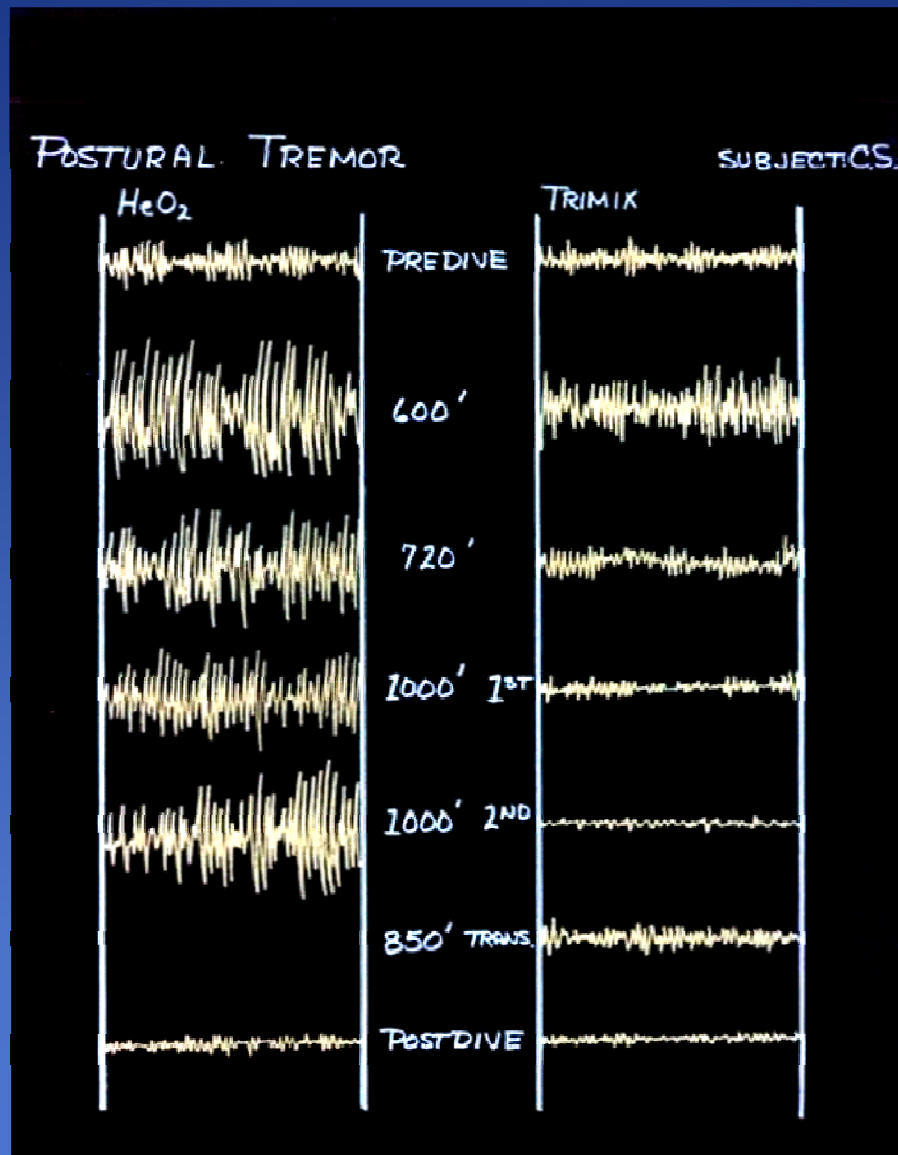




TRIMIX

Duke Medical Center 1974

Depth	Compression Time	HPNS
1000 ft	33 mins	No tremors; no EEG changes
2 hrs	Expon & stages	
10% N ₂		No narcosis or HPNS, under-water work – mild euphoria



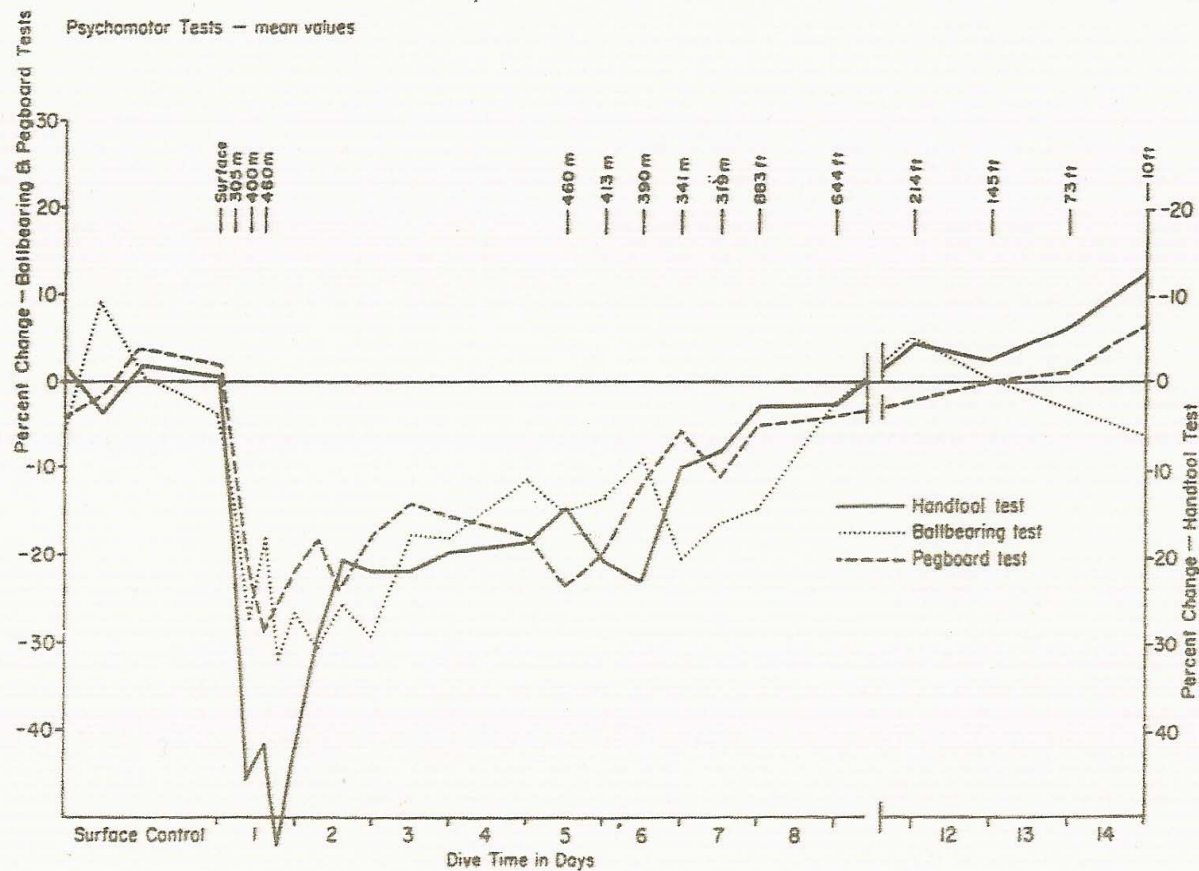


Atlantis I 460 msw 5% N₂

- ➡ Compression 12 hr 30 min
- ➡ Nausea, fatigue, somnolence
- ➡ Poor sleep, nightmares
- ➡ Marked intention tremor
- ➡ EEG theta, delta increase
- ➡ Performance decrements



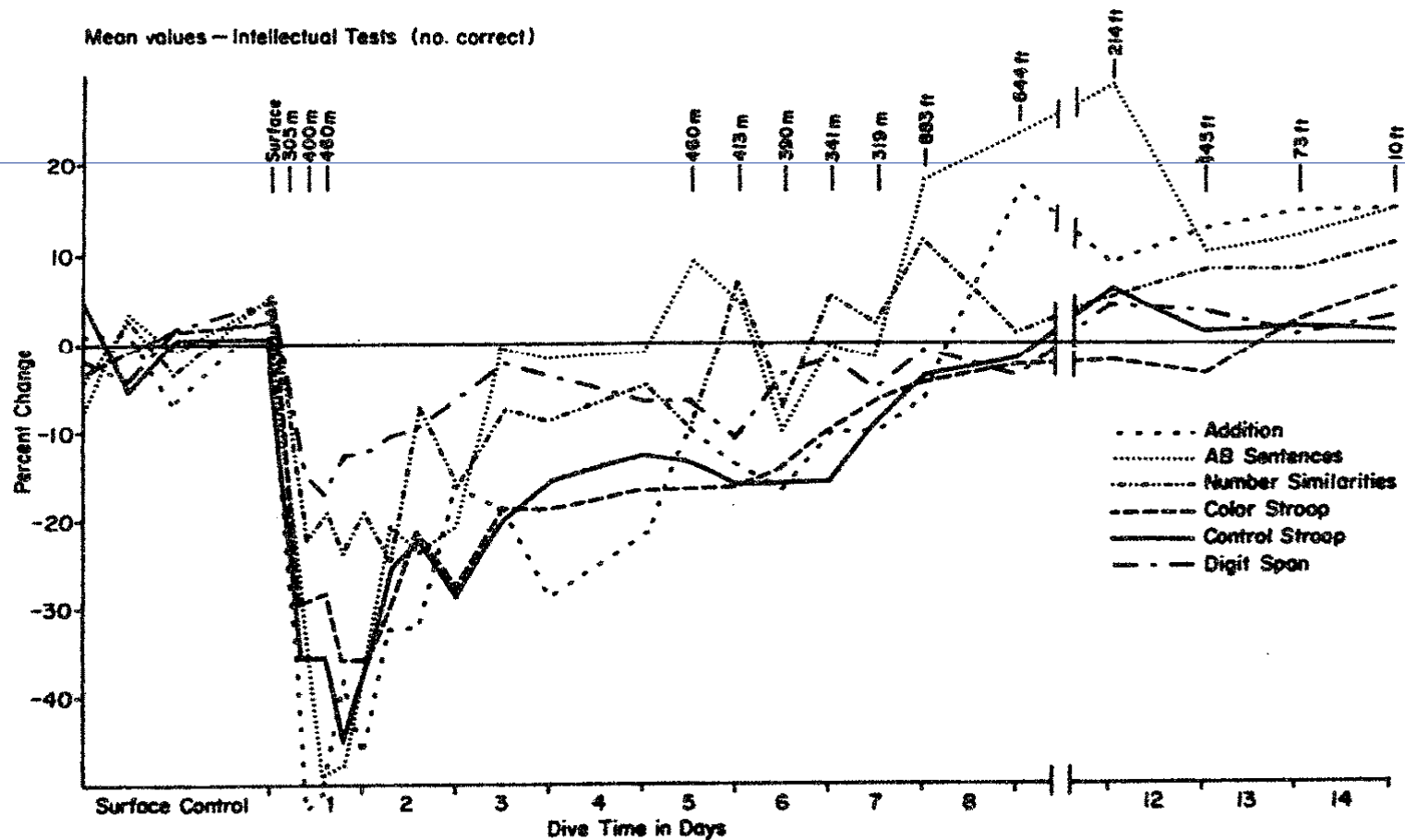
ATLANTIS I PSYCHOMOTOR TESTS

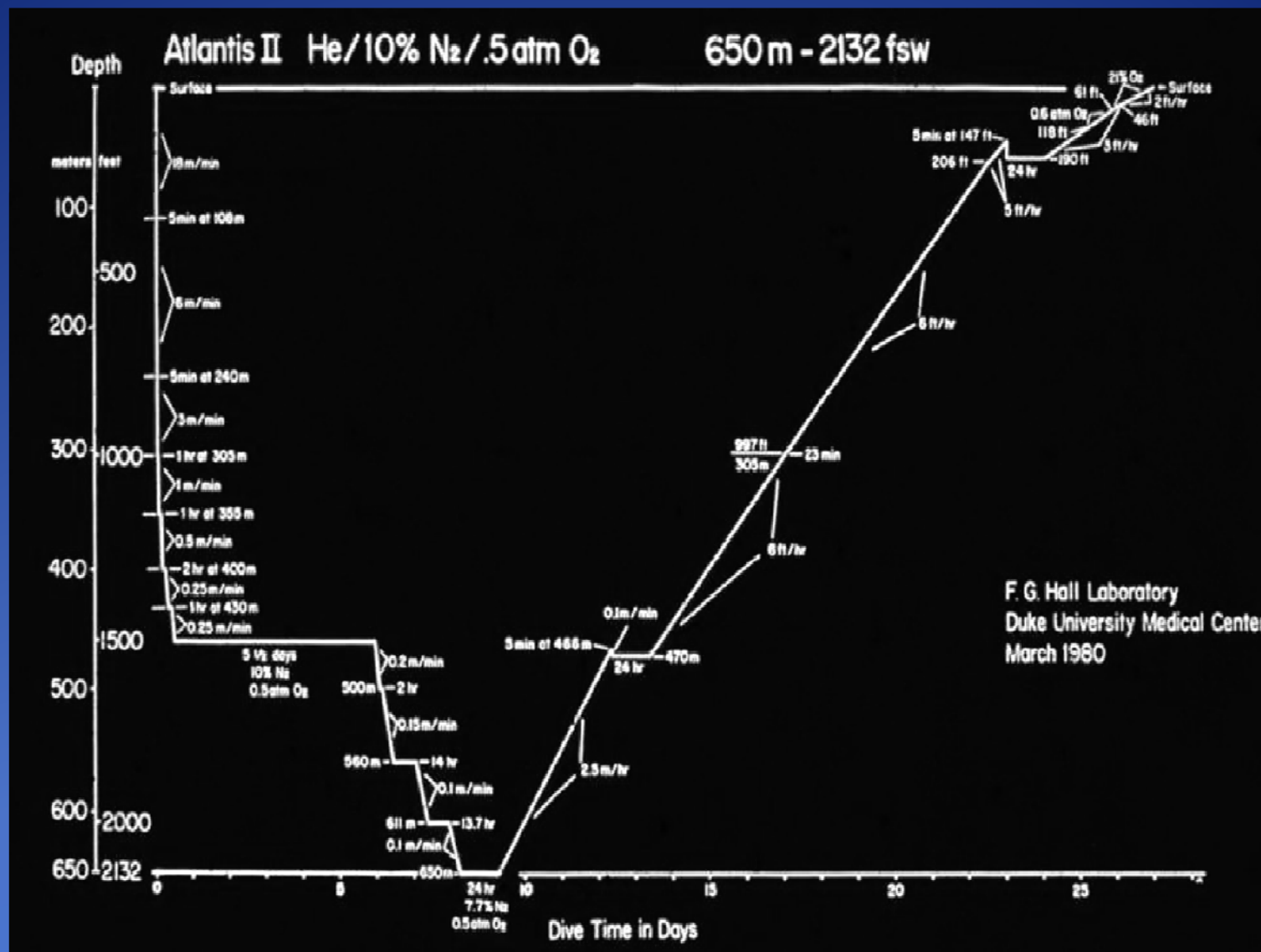


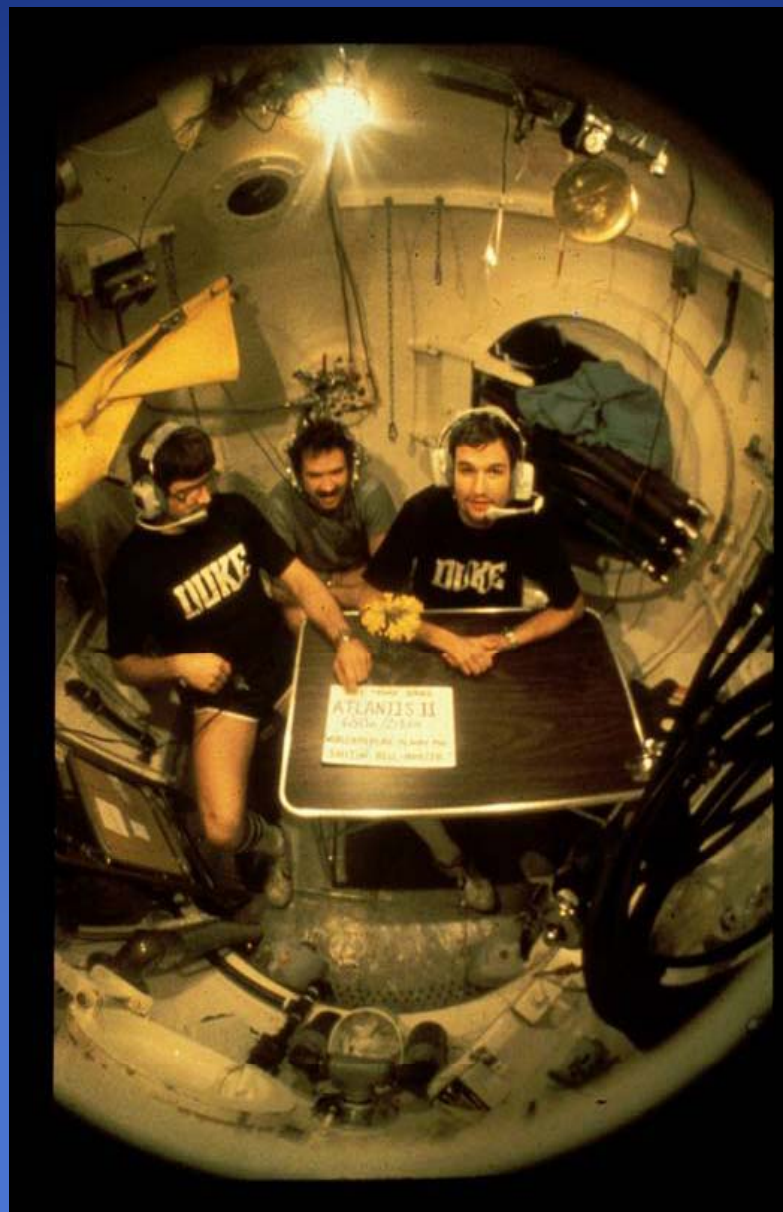


ATLANTIS I

INTELLECTUAL PERFORMANCE









Atlantis II (460 msw) 10% N₂

- ➡ Compression 12 hr 30 min
- ➡ Work to 180 watts
- ➡ No nausea, tremors, vomiting
- ➡ Inspiratory dyspnea less than I
- ➡ Felt better than Atlantis I
- ➡ Good sleep – no nightmares

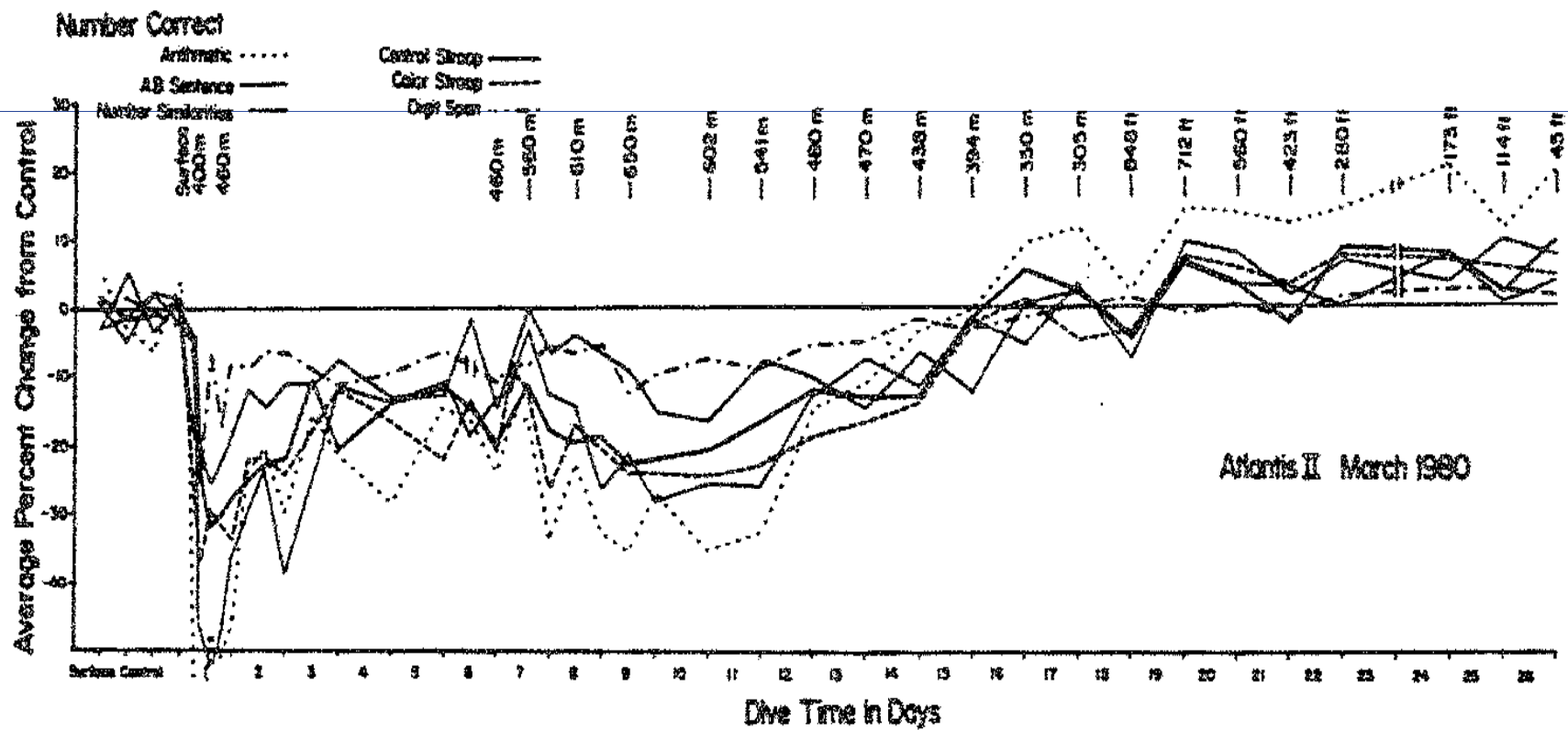


Atlantis II (650 msw) 10% N₂

- ➡ 1 case mild nausea/tremor during compression
- ➡ No nausea, tremors, somnolence, vomiting
- ➡ Worked to 120 watts
- ➡ Arterial catheterizations done
- ➡ Performance decrements < 460 msw

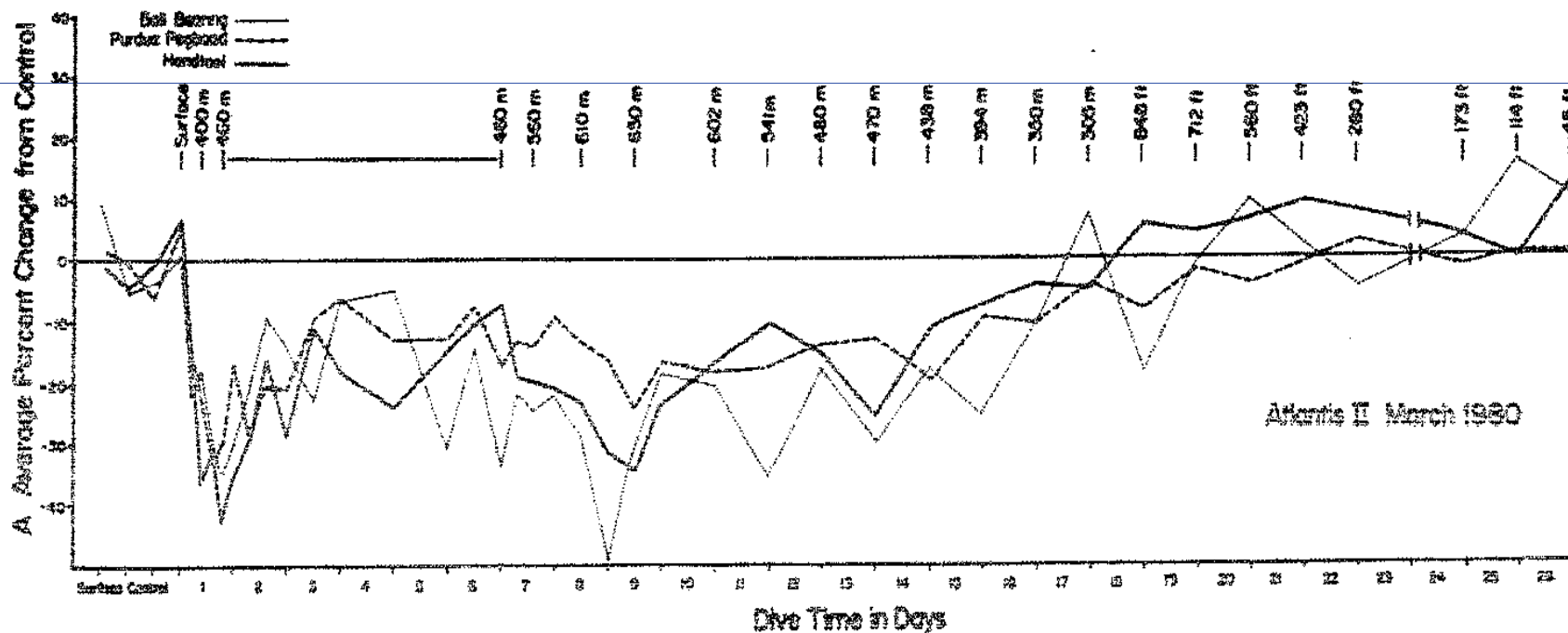


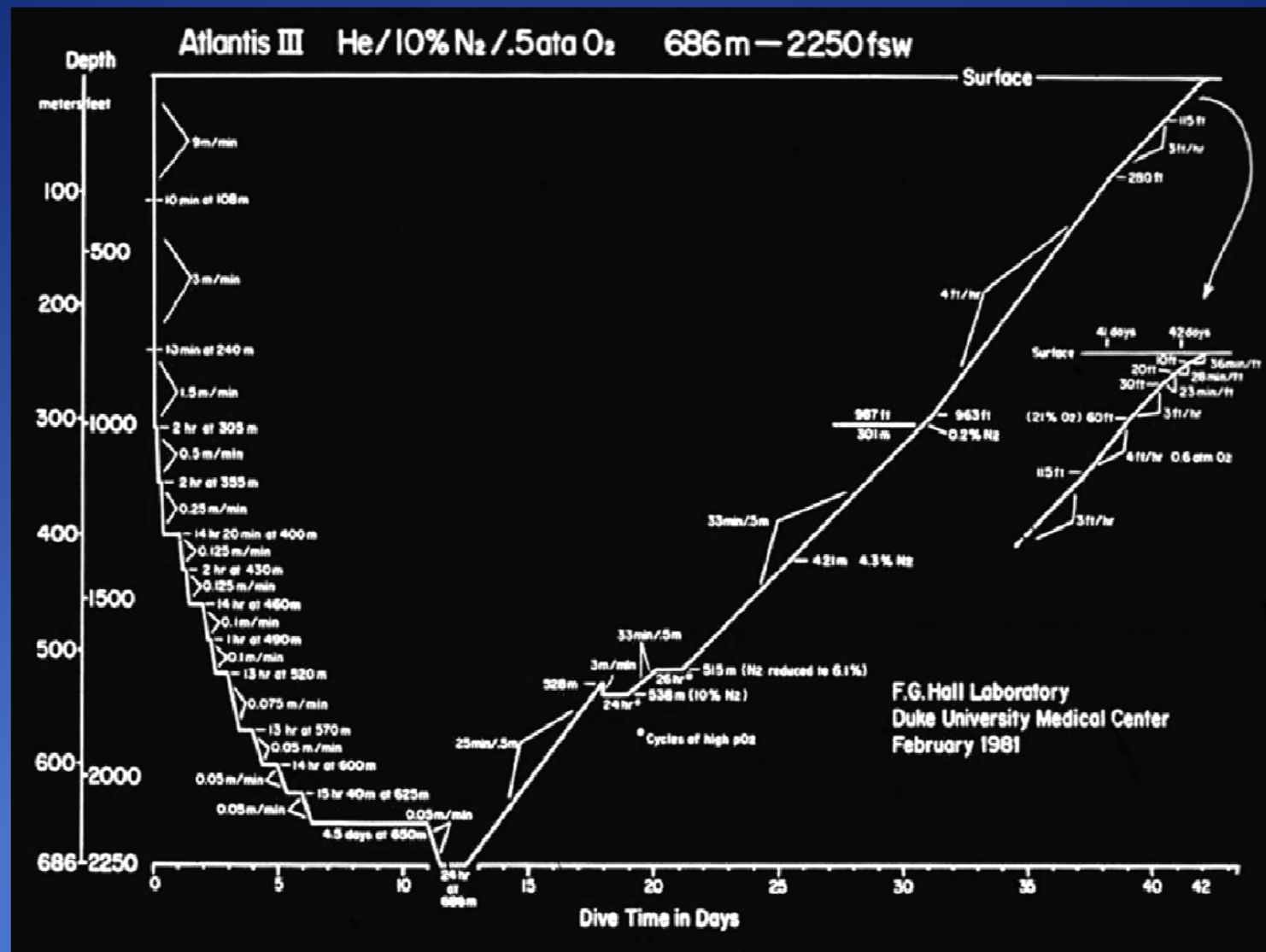
Atlantis II Intellectual Tests





Atlantis II Psychomotor Tests









Atlantis III

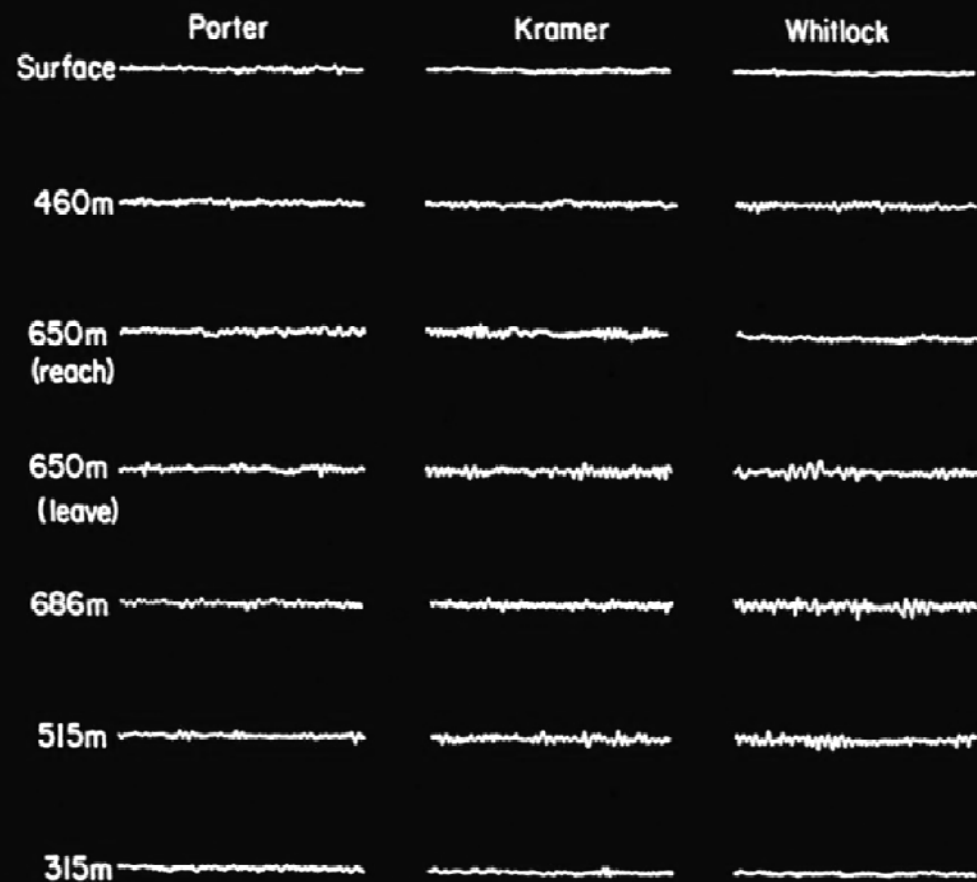
686 msw (2250 fsw) 10% N₂

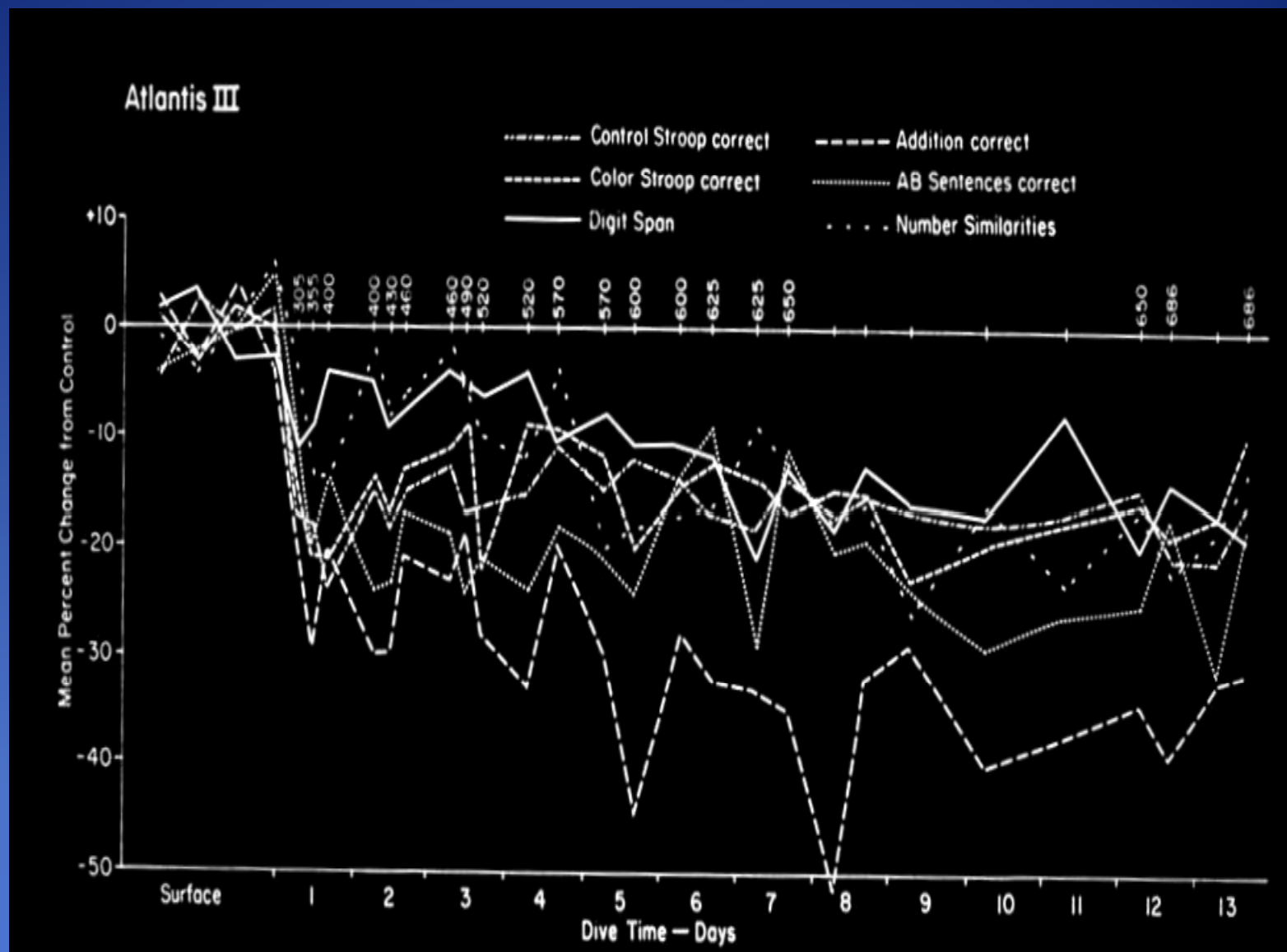
- ➡ Compression 7 d 9 h (2 x slow as I or II)
- ➡ No nausea, vomiting, tremors, somnolence
- ➡ Sleep problems
- ➡ Some impaired concentration/attention span
- ➡ No large performance decrement in compression
- ➡ Increase in theta and delta EEG

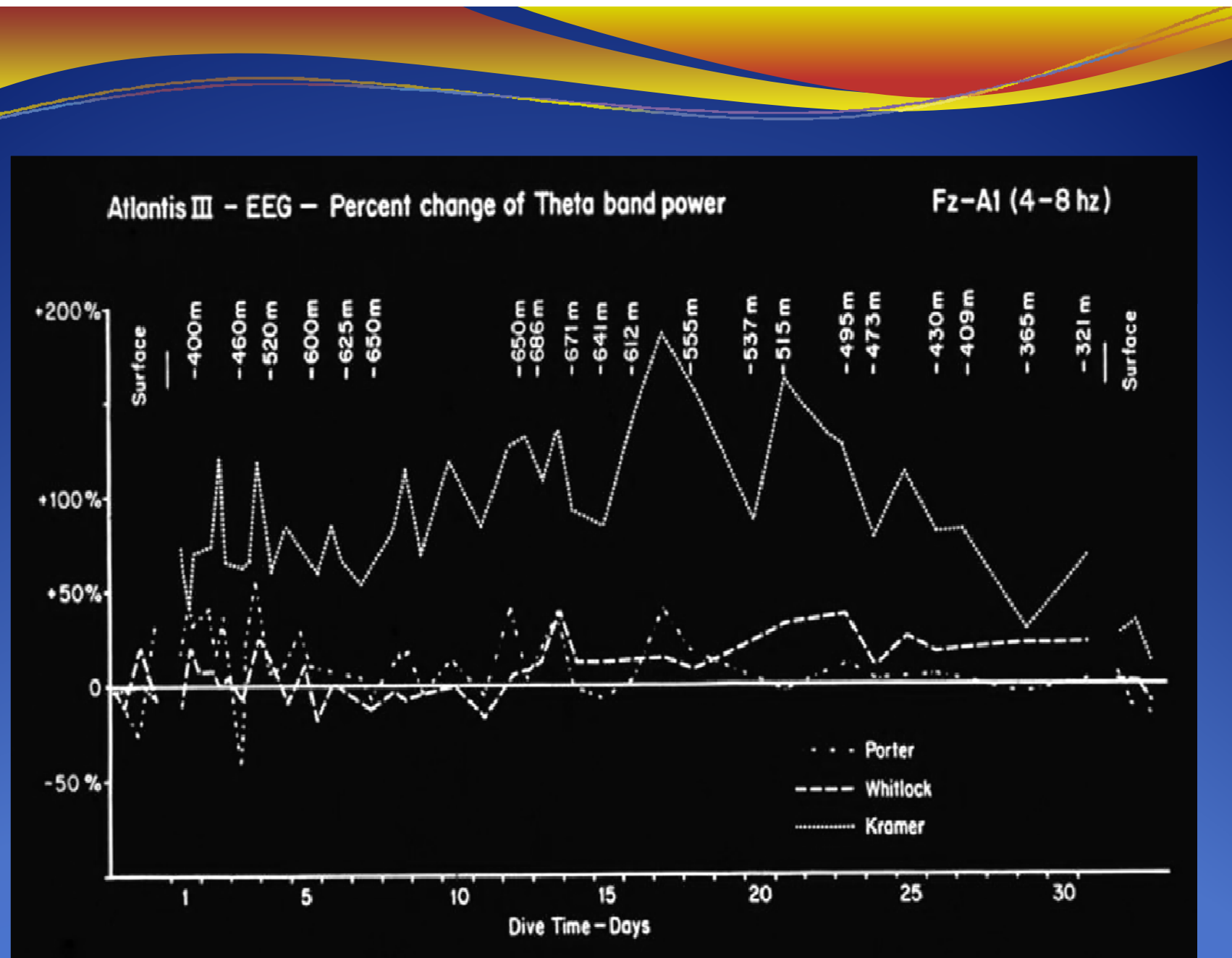




Atlantis III — Tremor









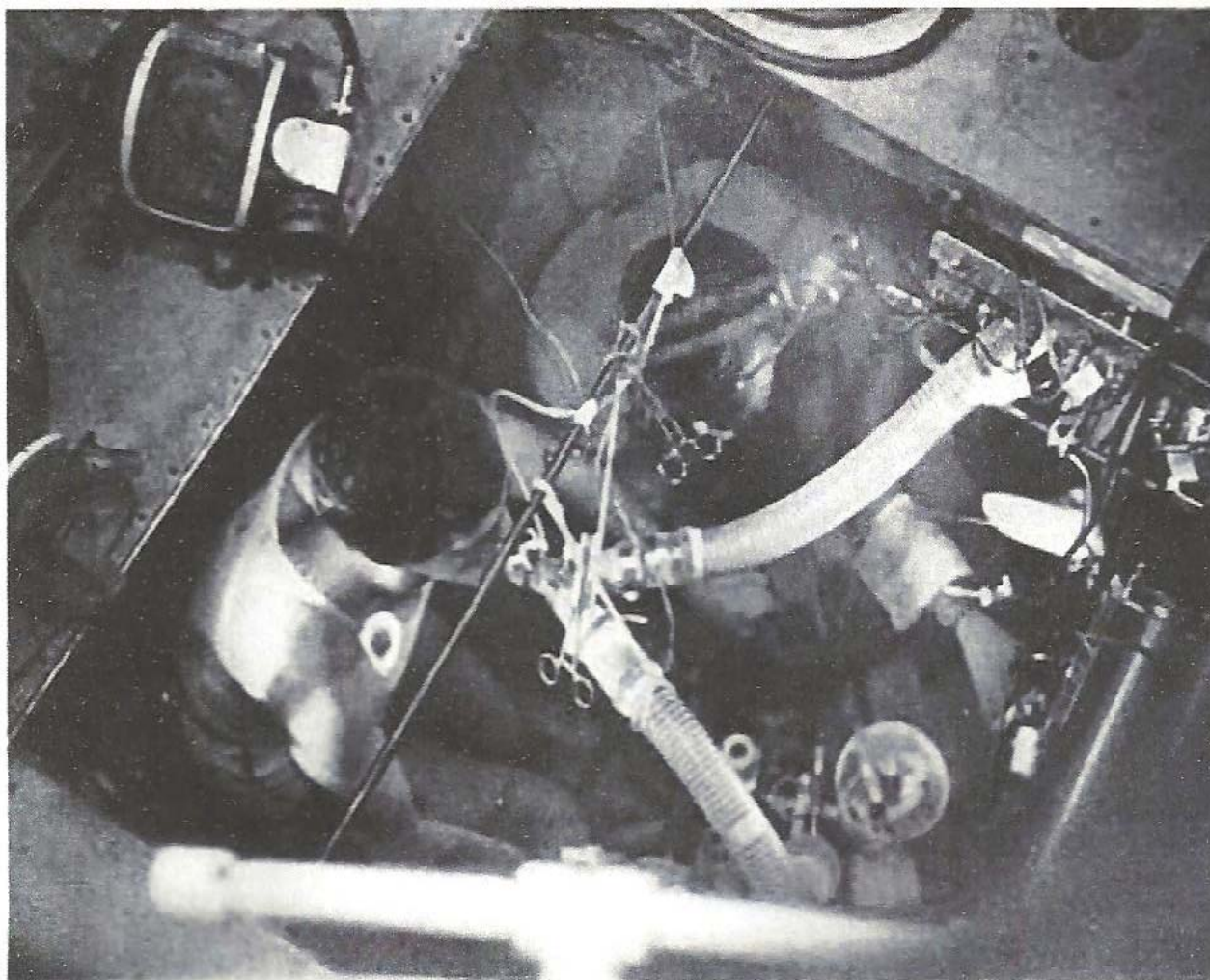
Respiration

Dyspnea

Thalmann/Piantadosi (1981) 56 ATA Heliox

- Profound dyspnea
- Limits underwater exercise to 30-40% of surface levels
- Reduced by application of +VE pressure at mouth
- Not relieved by increased oxygen





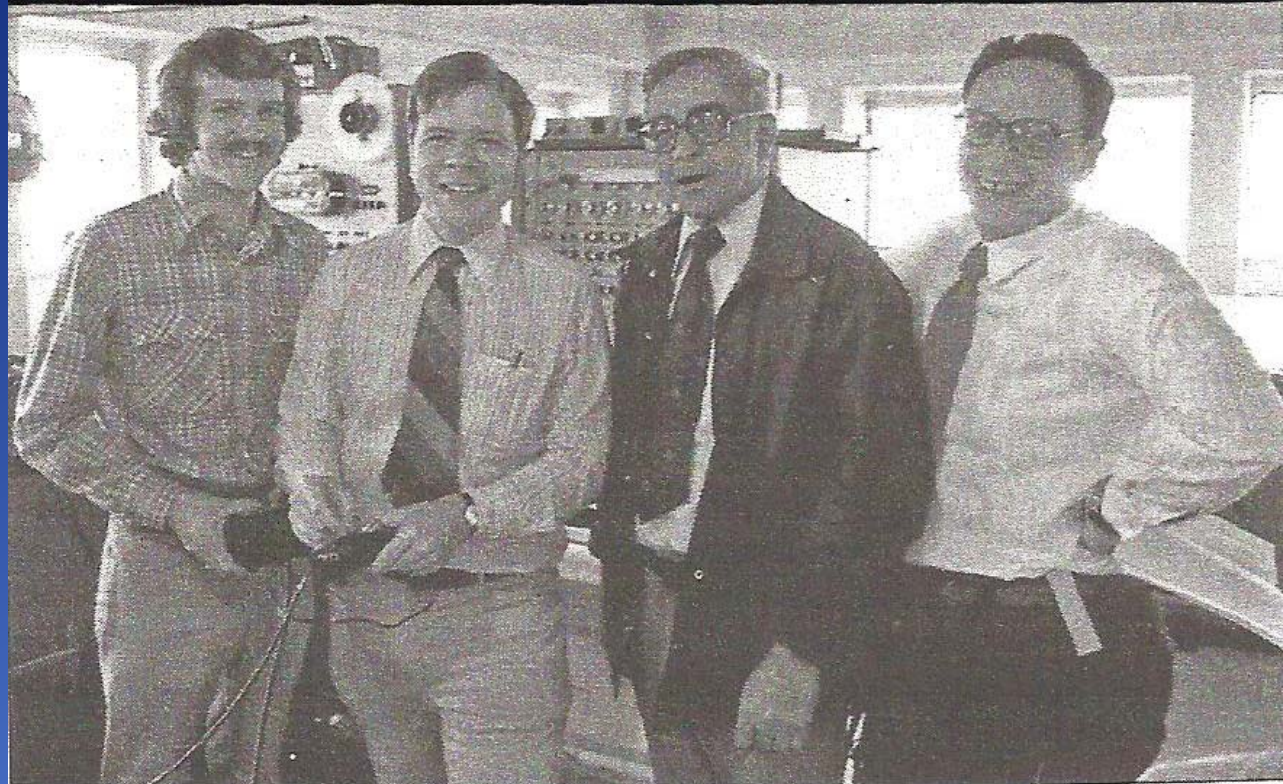
In pre-dive practice sessions, the divers rehearse taking blood samples (top) and exercising on a stationary bicycle, while Duke researchers monitor their breathing-gas flows.



Respiration Dyspnea

Salzano et al. (1981) 47-66 ATA Trimix

- Not related to arterial PCO_2 , PO_2 or pH
- 5 or 10% N_2 ameliorative
- Present also at rest, light physical activity, talking, eating, drinking, sleeping leading to sudden arousal, mouth breathing



Left to right: Bret Stolp, Richard Moon, John Salzano, Enrico Camporesi
Duke deep diving pulmonary physiology investigators, 1981



Congratulatory letter from President Ronald Reagan February 13, 1981

CONGRATULATORY LETTER FROM PRESIDENT RONALD REAGAN

THE WHITE HOUSE

WASHINGTON

February 13, 1981

Dear Dr. Bennett:

Congratulations to you and your colleagues on your recent dive of 2250 feet, setting a world's record for both depth and duration. Your achievement has added greatly to our ability to explore and use the vast resources of the ocean.

I want to recognize in particular the dedication of Stephen Porter, Len Whitlock, and Eric Kramer to this vital project. The nation is grateful for your contribution to the advancement of scientific knowledge.

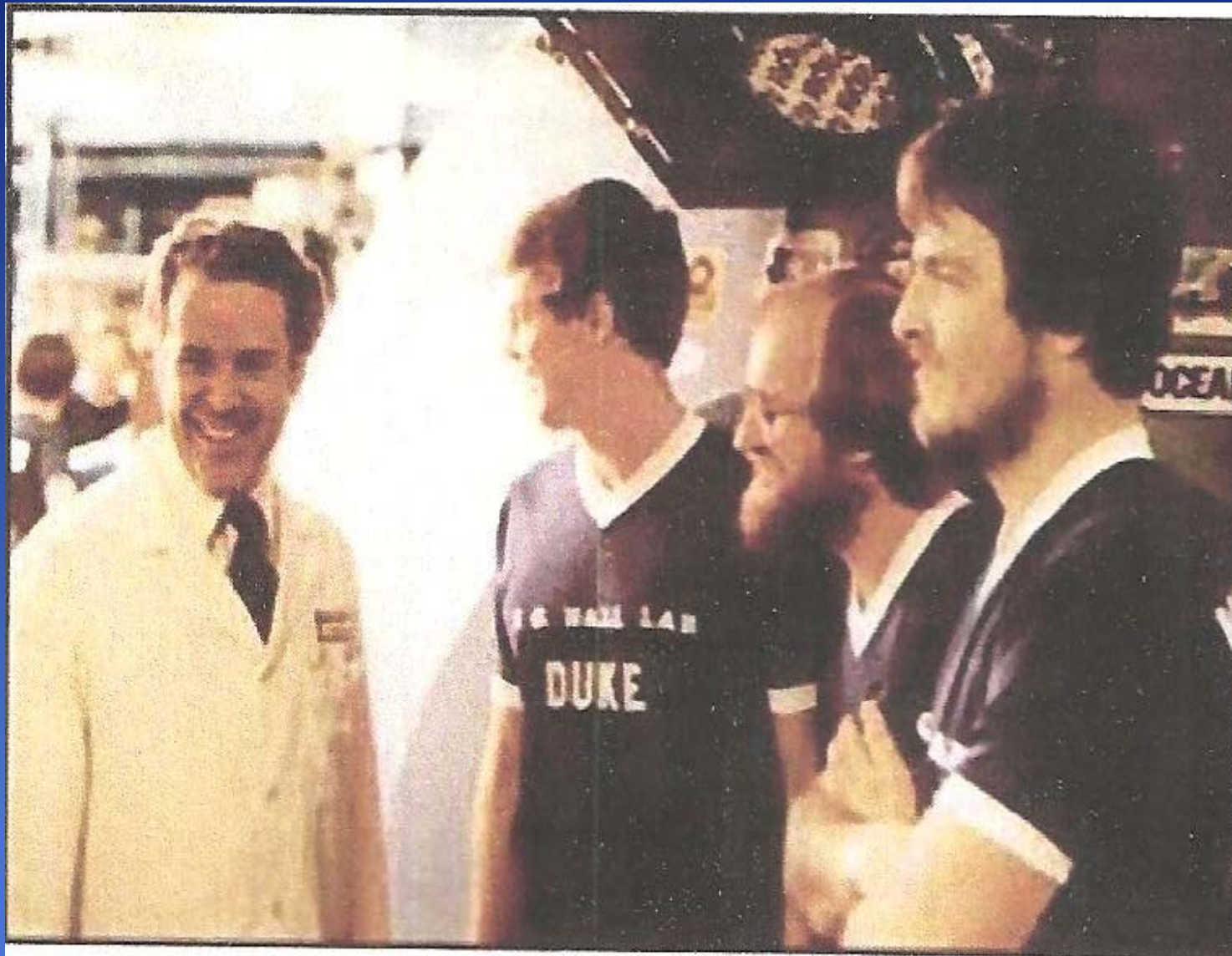
With best wishes,

Sincerely,

Ronald Reagan

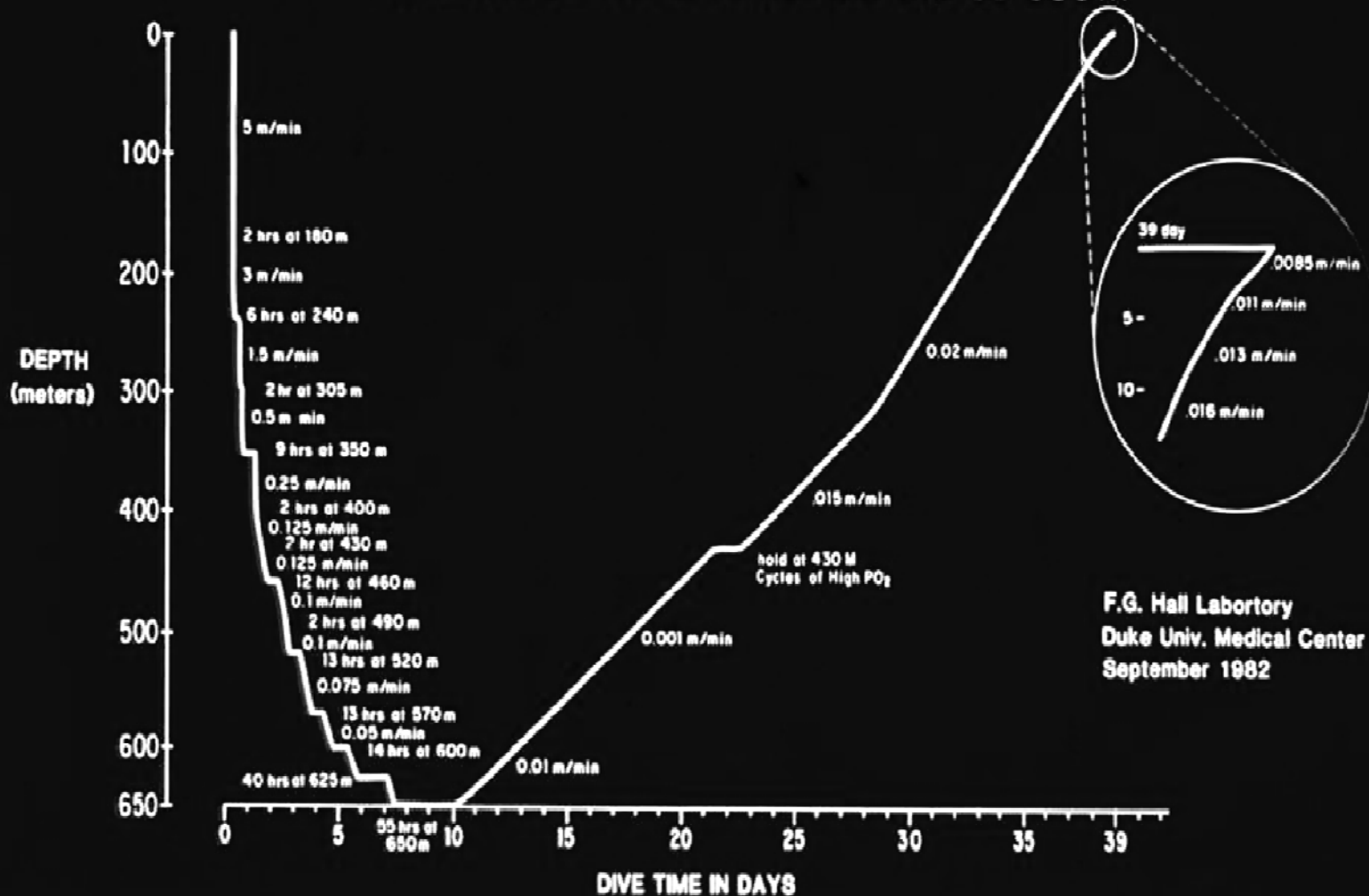
Dr. Peter Bennett
Director F.G. Hall Laboratory
Duke University Medical Center
Box 3823
Durham, North Carolina 27710







Atlantis IV He/5% N₂/0.5 ata O₂ 650m



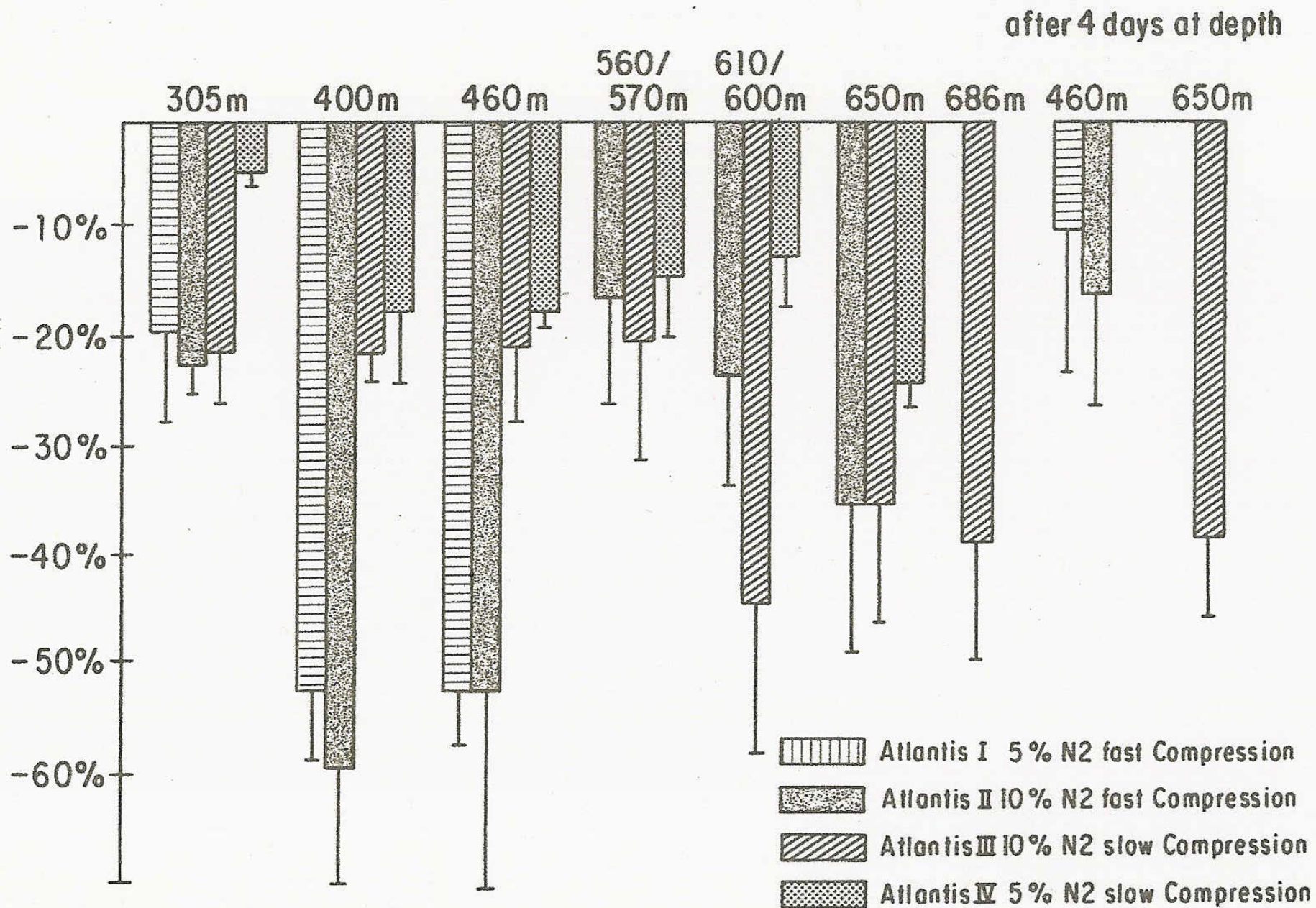


Atlantis IV

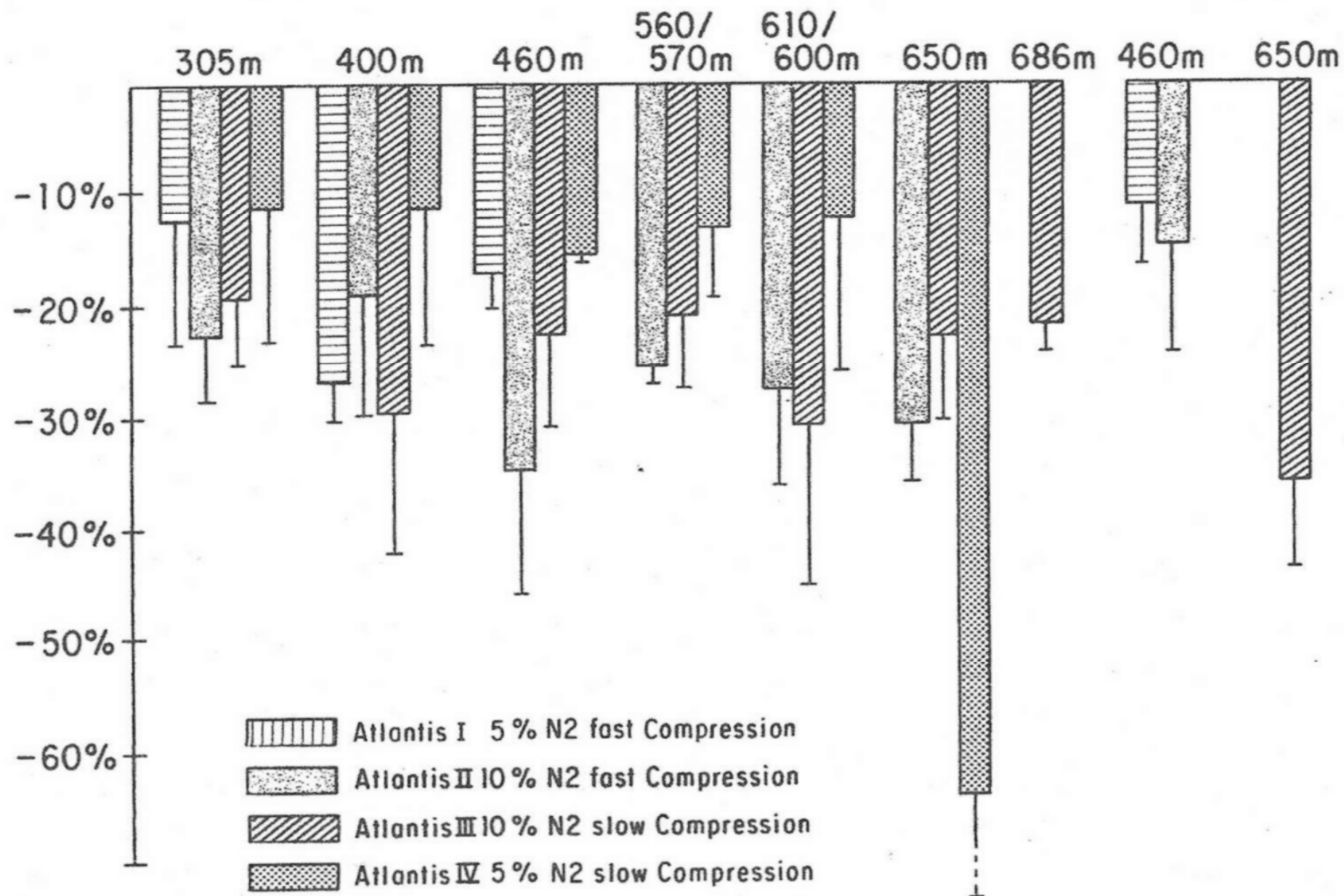
650 msw (2132 fsw) 5% N₂

- ➡ Compression 7 d 9 h (2 x slow as I or II)
- ➡ No nausea, vomiting, somnolence
- ➡ Lowest decrement in performance of all 4 dives
- ➡ No signs of narcosis
- ➡ Mild tremors at 650 msw
- ➡ 2 divers “very comfortable”
- ➡ 1 diver hypomanic, delusions of grandeur
- ➡ Full recovery on decompression
- ➡ No permanent neurologic effects

COMPARISON FOR ATLANTIS SERIES- ADDITION TEST

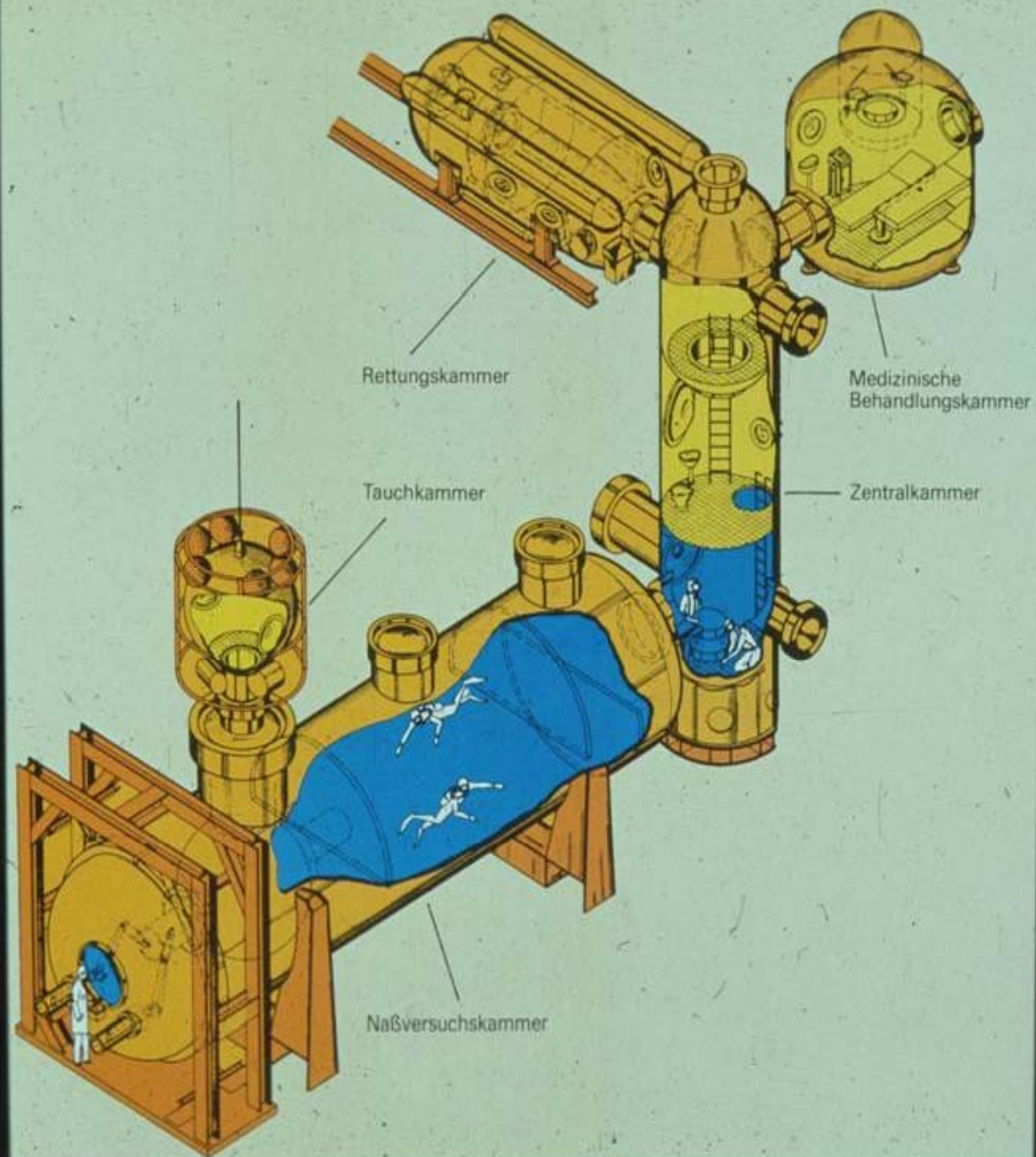


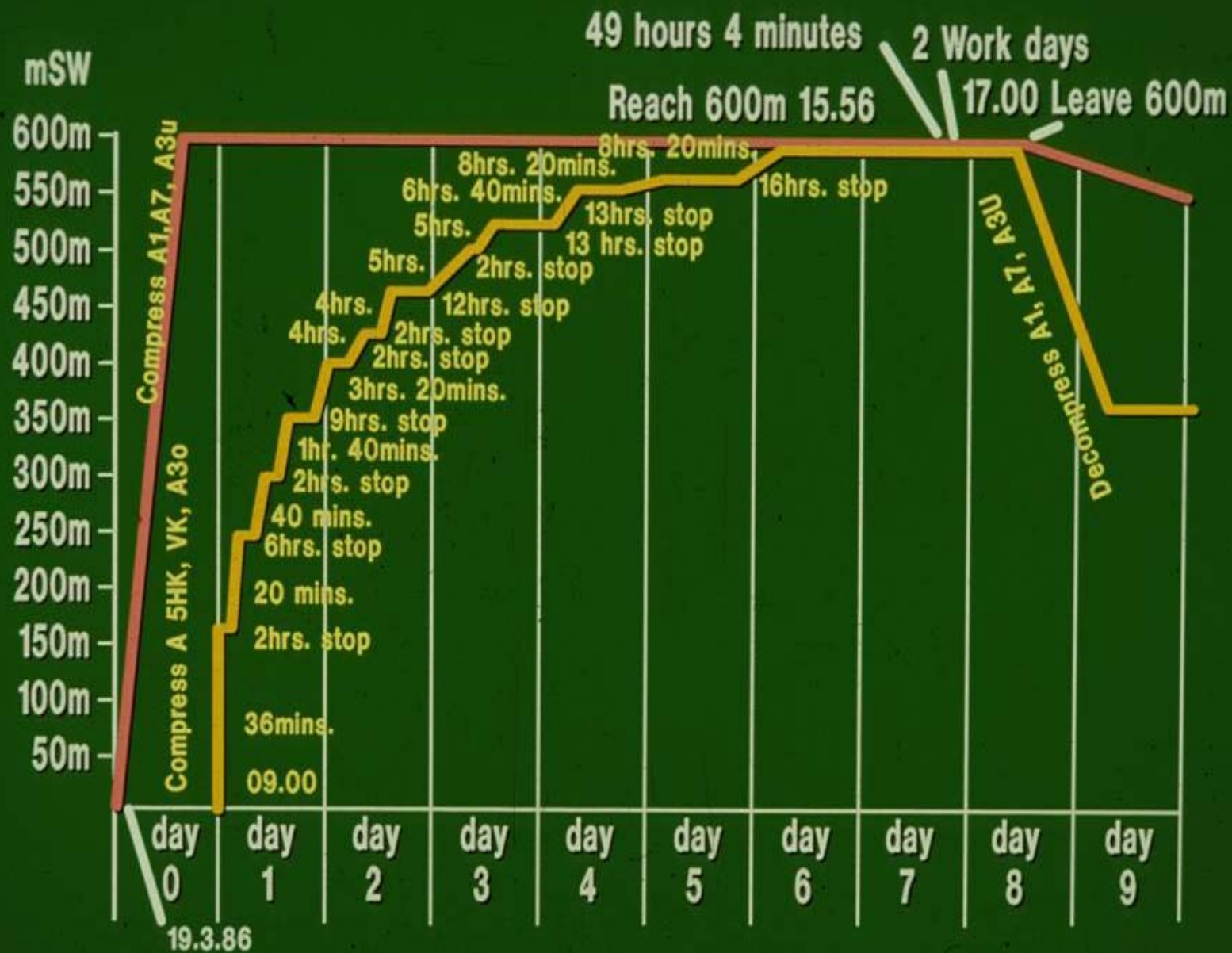
COMPARISONS FOR ATLANTIS DIVE SERIES-BALL BEARING





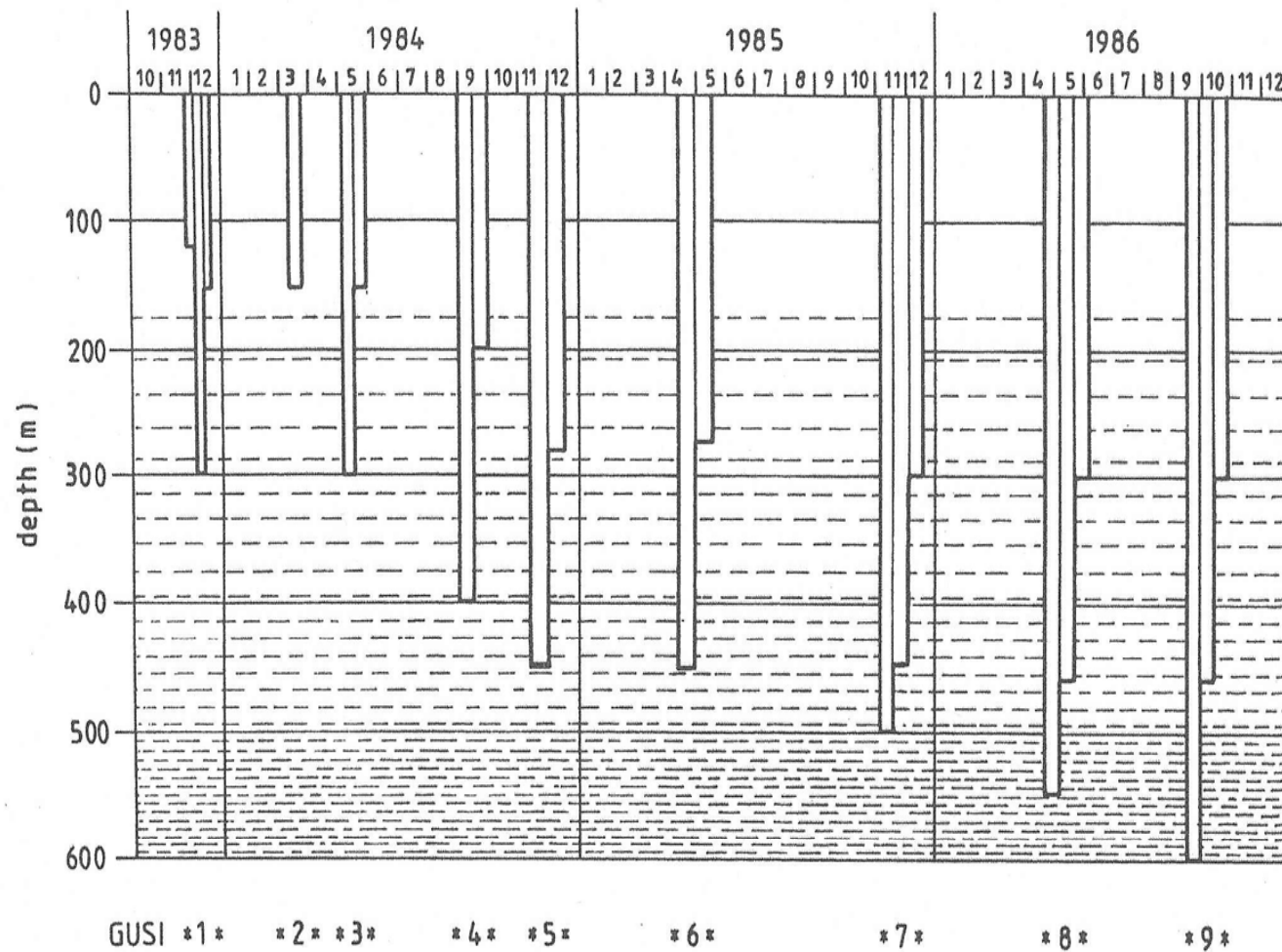
GERMAN UNDERWATER SIMULATOR (GUSI) (NEAR HAMBURG)







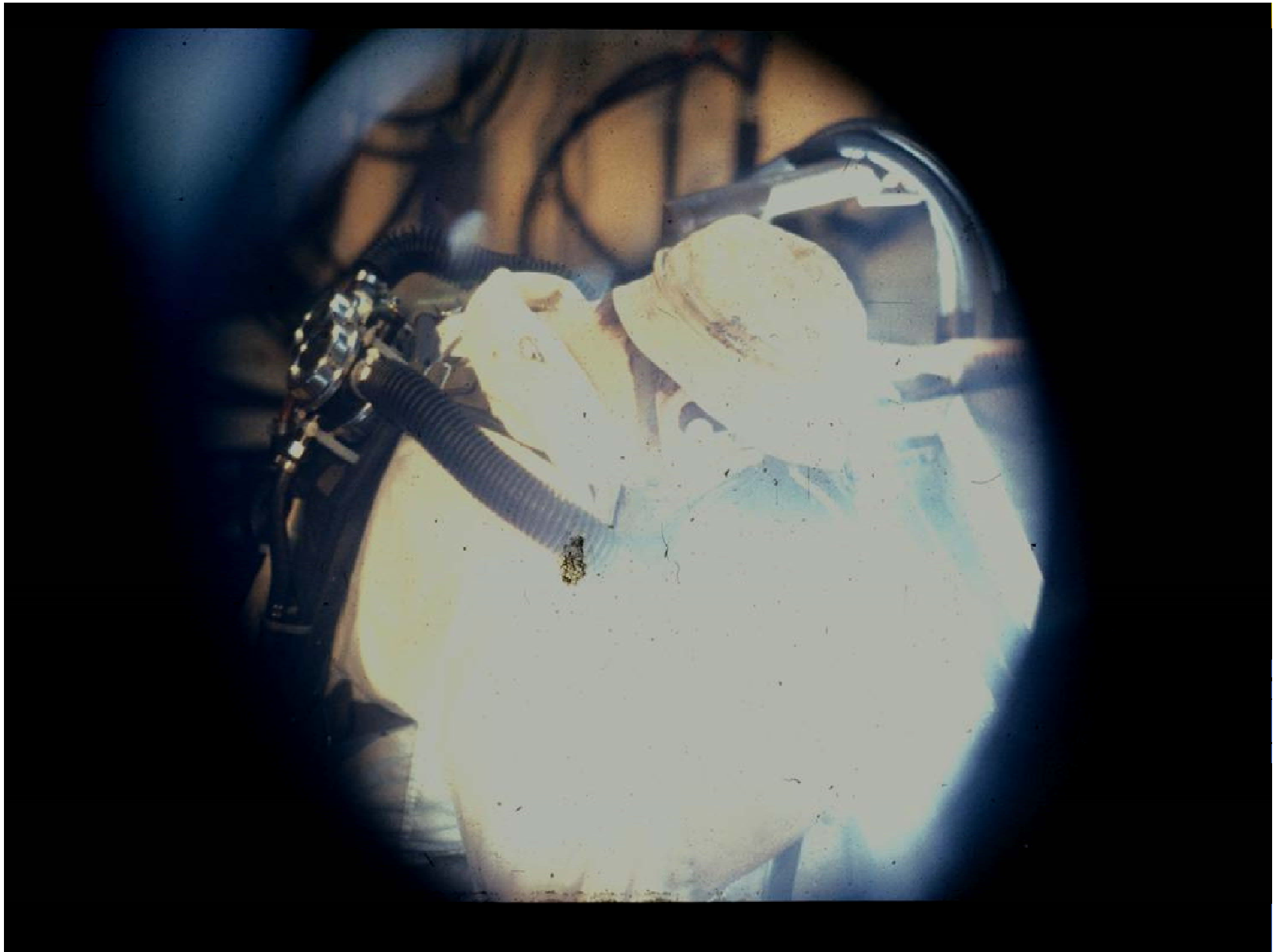
GUSI DIVES 1983-1986





GUSI 1983-86

- ➡ 14 deep dives (300 msw – 600 msw)
- ➡ 13 divers
- ➡ Certified weld 2 French divers (450 msw)
- ➡ No nausea, vomiting, tremors, fatigue
- ➡ Some performance decrements from 500 msw







GUSI 1986-90

- ➡ 17 more deep Trimix 5% N₂ dives to 450 m
- ➡ Total 2662 man-days saturation
- ➡ 983 welding days to 450 msw
- ➡ Divers able to work and function well
- ➡ No permanent neurological deficits



Conclusions DUKE and GUSI

“ A slow exponential compression with stages using TRIMIX 5 can be considered a safe and effective method for deep underwater work with no evidence of permanent residual signs and symptoms.”



Control of HPNS

- Selection of divers
- Slow exponential compression rate
- Long stages during compression
- Use of nitrogen (trimix)
- Allow time for adaptation
- Use of excursion dives



Narcosis **+0.04% Neuronal Membrane** **Expansion**

- Hyporeflexia
- Fall in surface tension (monolayer)
- Protected by LiCl (rats)
- Acetylcholine receptor binding increased in electroplaque (fish)
- Reverses suppression dopamine sensitive cyclic AMP response
- Facilitates GABA mediated transmission
- **DECREASED SYNAPTIC EXCITEMENT**

HPNS **-0.04% Neuronal Membrane** **Contraction**

- Hyperreflexia
- Rise in surface tension (monolayer)
- Enhanced by LiCl (rats)
- Acetylcholine receptor binding decreased in electroplaque (fish)
- Suppressed dopamine sensitive cyclic AMP response
- Reduces GABA mediated inhibition
- **INCREASED SYNAPTIC EXCITABILITY**

TRIMIX



The Abyss

Movie and liquid breathing 1987

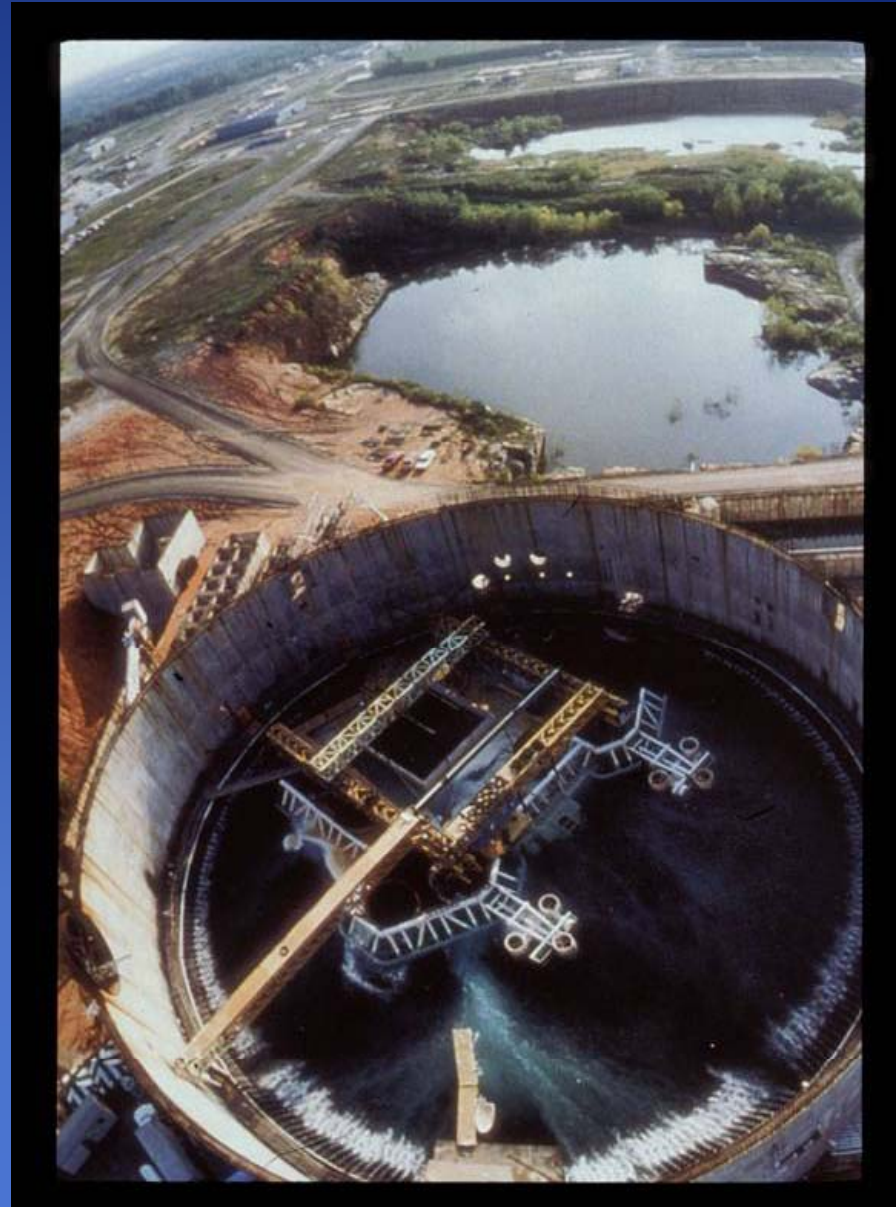




Figure 40. As portrayed by Ed Harris in the 1989 Twentieth Century-Fox film *The Abyss*, the character Bud Brigman readies himself to plunge into the ultra-deep. If ever realized, liquid breathing would allow divers to descend hundreds if not thousands of feet into the depths. (Courtesy, Twentieth Century-Fox Film Corporation, 1997)



30,000 ft

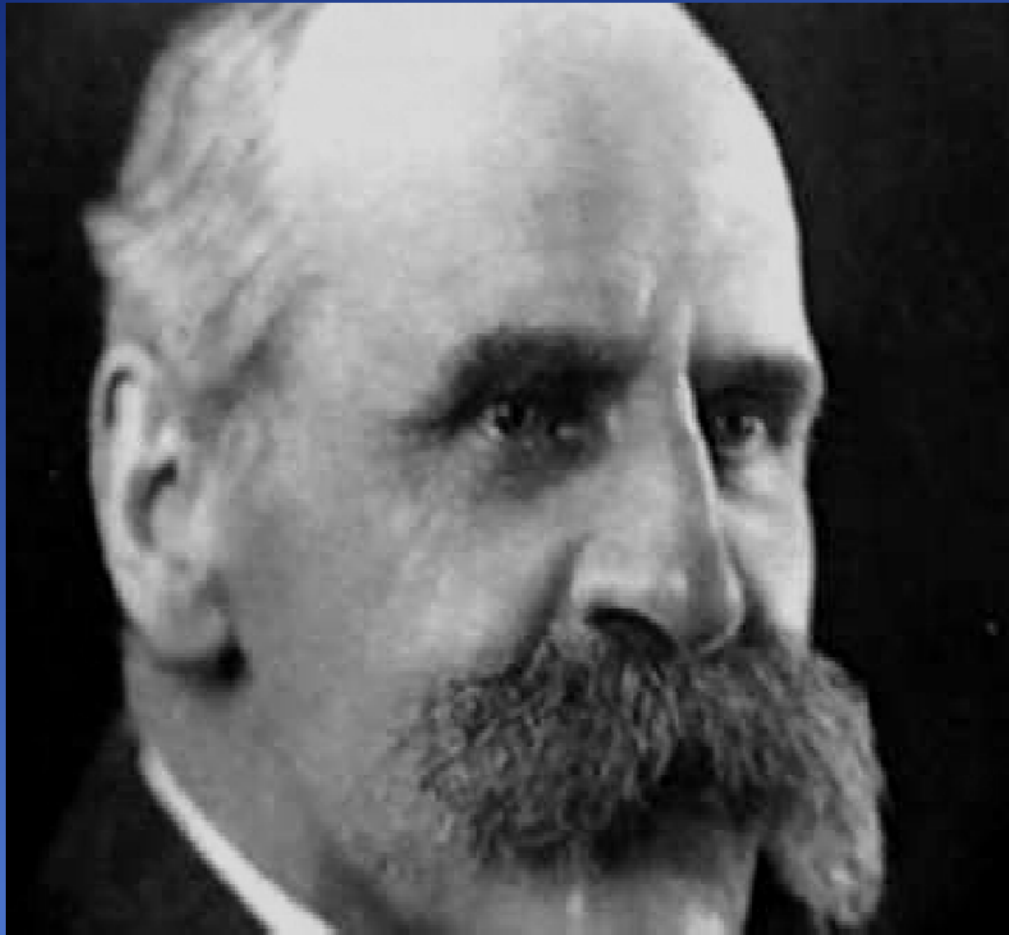


THE DEEP DECOMPRESSION STOP



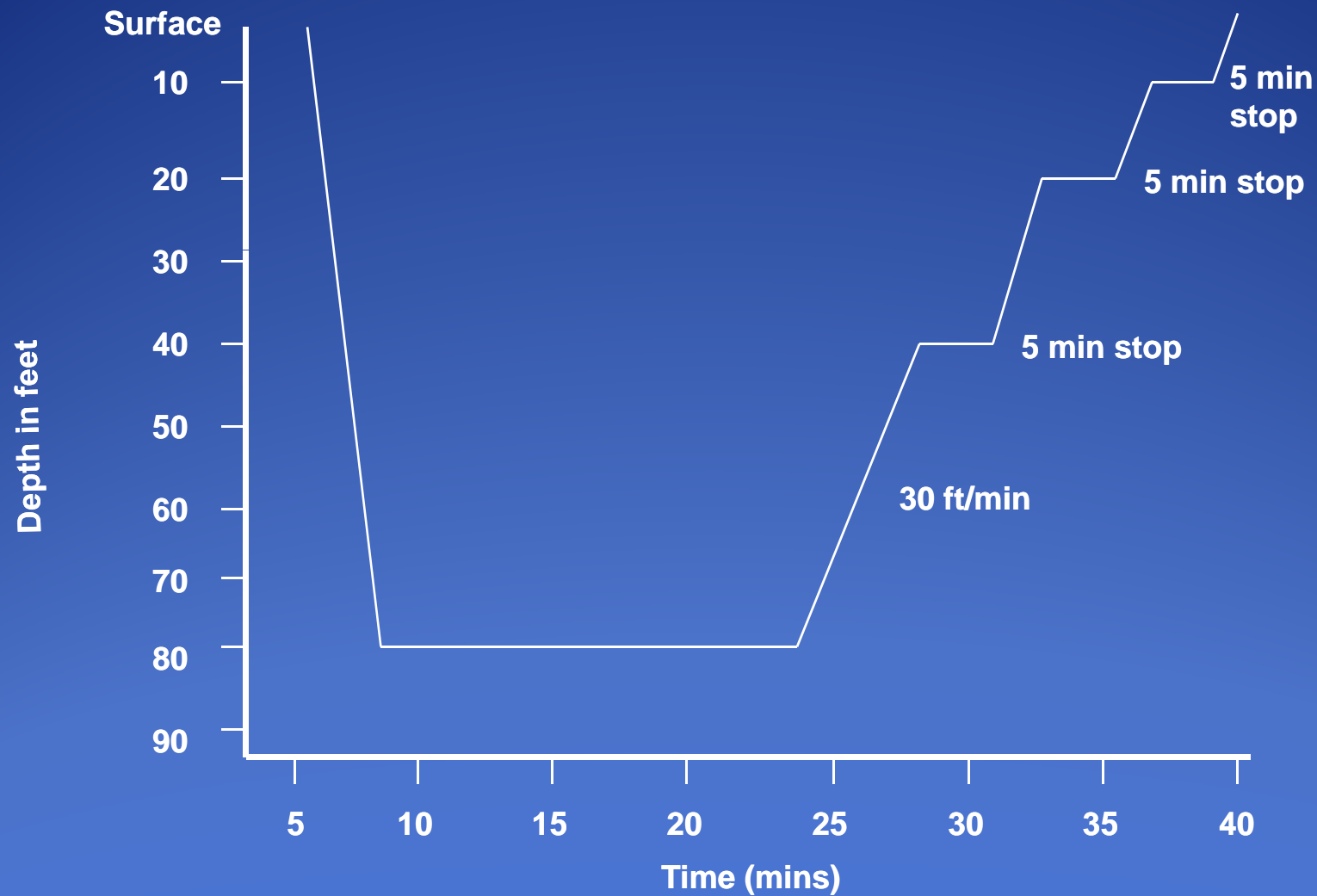


Professor John Scott Haldane



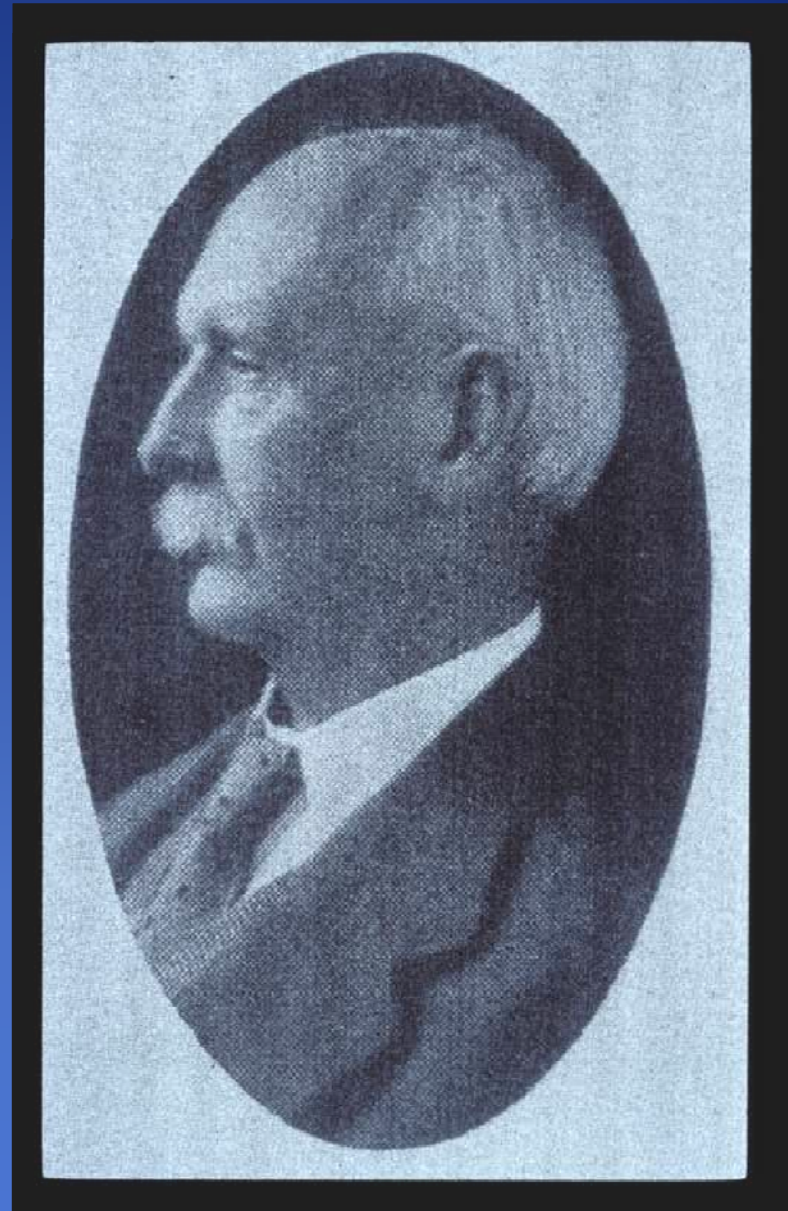


HALDANE (2:1 Ratio)



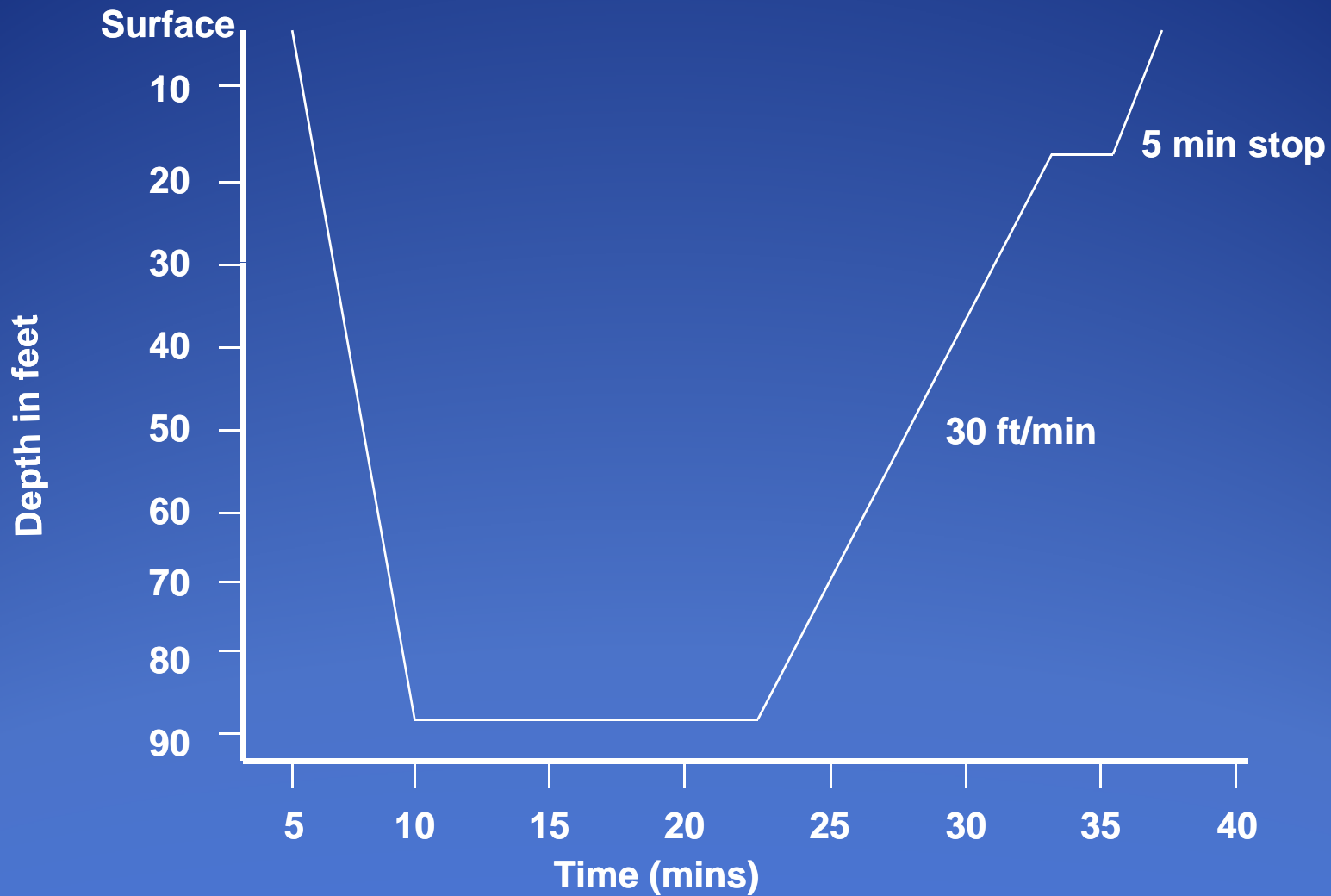


Sir Leonard Hill





HILL (Linear Ascent)





Haldane or Hill (1906)?

Haldane

Postulated could ascend quickly to half the absolute pressure of their depth (2:1 ratio) followed by slow return to surface with stops.

Hill

Uniform ascent rate and SDC (submersible decompression chamber).

Tests

Proved 'stage decompression' better than uniform ascent. Rapid decompression worst of all.

Tables

Published in 1907 down to 204 ft.



BUT ASCENTS TODAY

- Still like L. Hill
- Linear ascent at 30 ft/min
- 5 min stop at 15 ft
- But it **DID NOT WORK!**
- What happened to Haldane 2:1 ratio

Which was safer?



Variations of NDL

Computer/Table	1 st Dive (mins)	2 nd Dive (mins)
Edge/SkinDip	10	23
Aladin	7	19
Monitor	9	17
DataMaster	10	16
DSAT Tables	10	16
Datascan II	5	14
DCIEM Tables	8	12
56 USN Tables	10	10
92 USN Tables	15	4
BSAC Tables	13	0
RN Tables	11	0



Tissue Compartments & Half-Times of Computers Tested*

Computer	Tissues	Half Times (min)
Solution	9	2.5, 5, 10, 20, 40, 80, 120, 240, 480
Vytec	9	2.5, 5, 10, 20, 40, 80, 120, 240, 480
Aladin Pro	6	6, 14, 34, 64, 124, 320
Aladin Smart	8	5, 10, 20, 40, 80, 160, 320, 640
Versa	12	5, 10, 20, 40, 80, 120, 160, 200, 320, 400, 480
Commander	16	0 - 1000
Cyber Aqua	4	Approximately 21

**Taken from manufacturers' literature provided directly by manufacturer.*



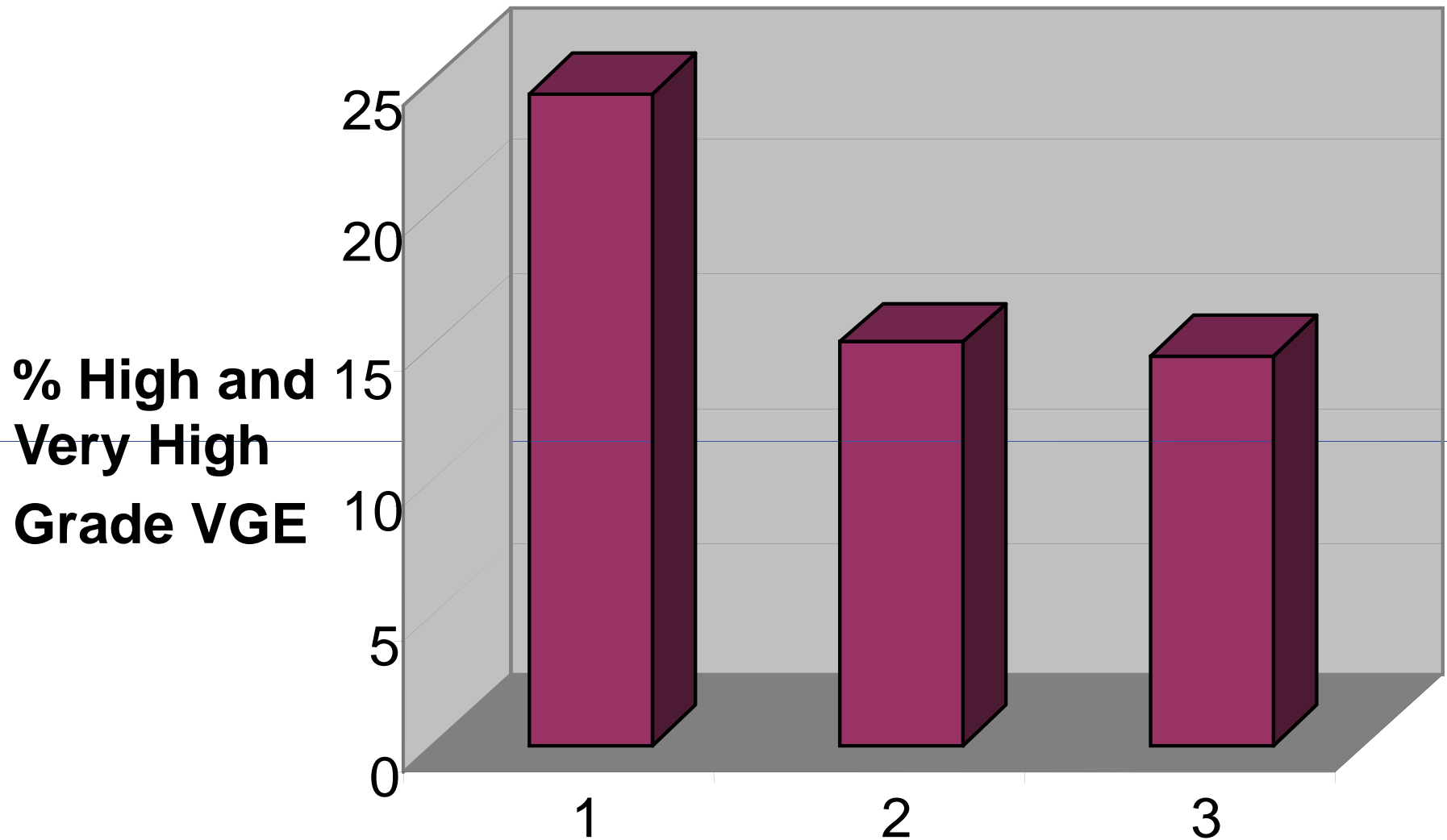
Tissue Half-Times for Nitrogen (From Edmonds et al. 1992)

Blood	Very short
Spinal cord	12.5 mins
Inner ear	146-238 mins
Joints and bones	304-635 mins



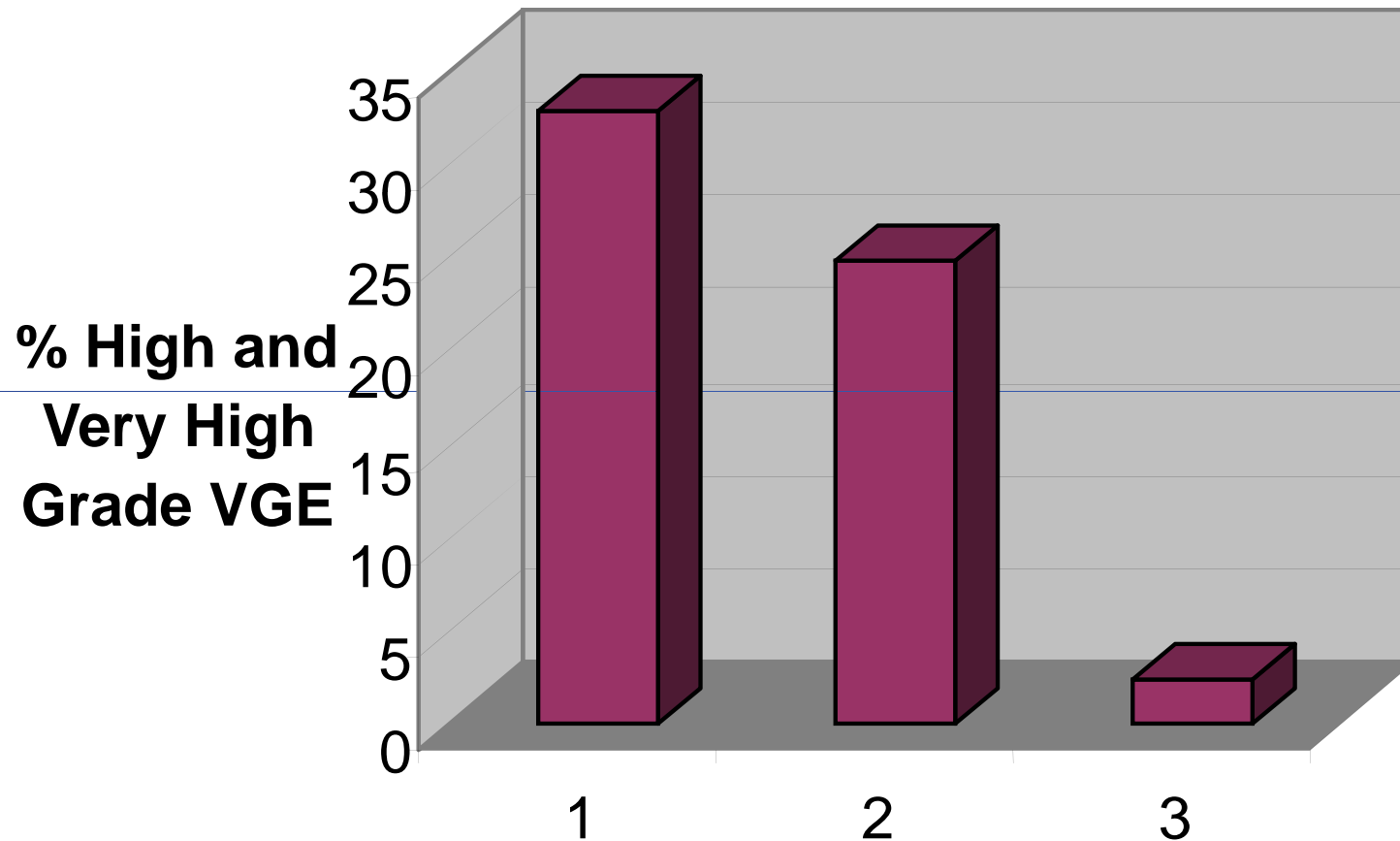
IDAN RESEARCH 2001

Dive Profile	Depth meters	Bottom Time, including descent, minutes	Rate of Decompression m/min	Stop Depth meters	Stop Time minutes
1	25	20	10	No Stop	No Stop
1R	25	15	10	No Stop	No Stop
2	25	20	3	No Stop	No Stop
2R	25	15	3	No Stop	No Stop
3	25	20	18	6	5
3R	25	15	18	6	5
4	25	20	10	6	5
4R	25	15	10	6	5
5	25	20	3	6	5
5R	25	15	3	6	5
6	25	20	10	15 6	5 5
6R	25	15	10	15 6	5 5



Ascent Rates:

1 = 3m/min ; 2 = 10 m/min; 3 = 18 m/min



Dive Profiles:
1 = No stops; 2 = 6m stop only;
3 = 18 & 6m stops

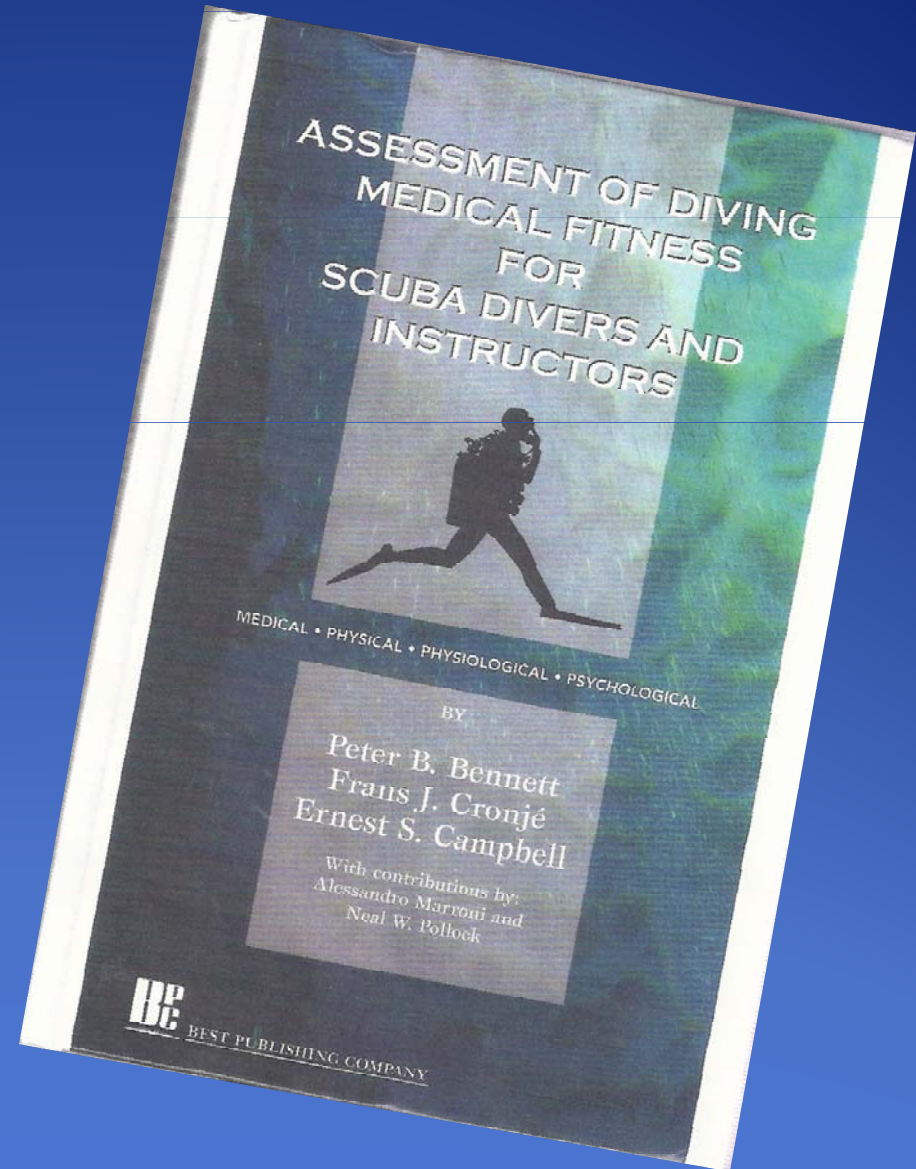


DEEP STOP

- Many types of deep stop
- $\frac{1}{2}$ the depth still controversial
- Used in NAUI tables and some computers
- More research required



Assessment of Diving Medical Fitness for Scuba Divers and Instructors





Peter and Margaret Bennett