Rebreathers

Deep capability or deep trouble?

Associate Professor Simon Mitchell
MB ChB, PhD, FUHM, FANZCA

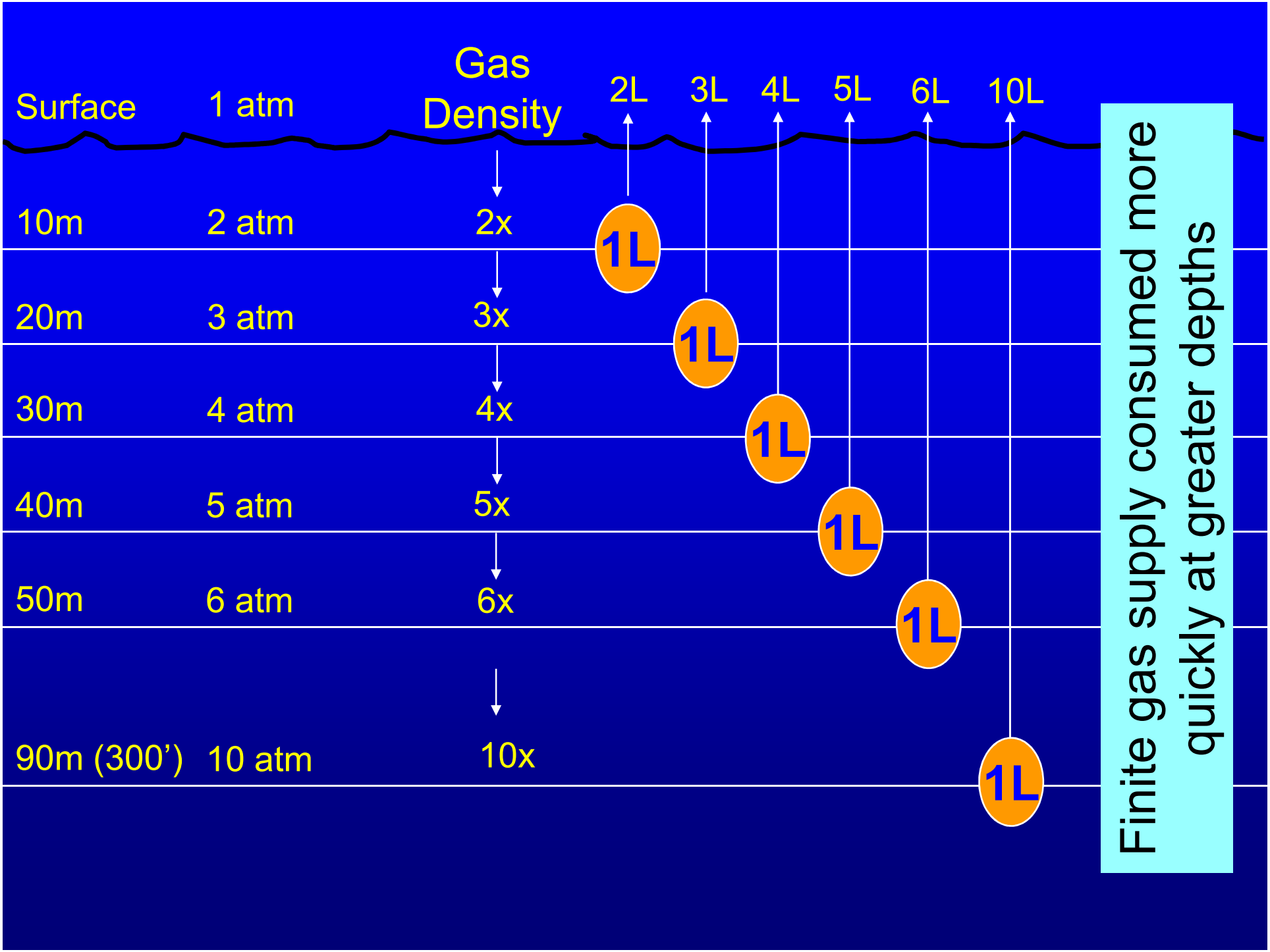
Department of Anesthesiology
University of Auckland

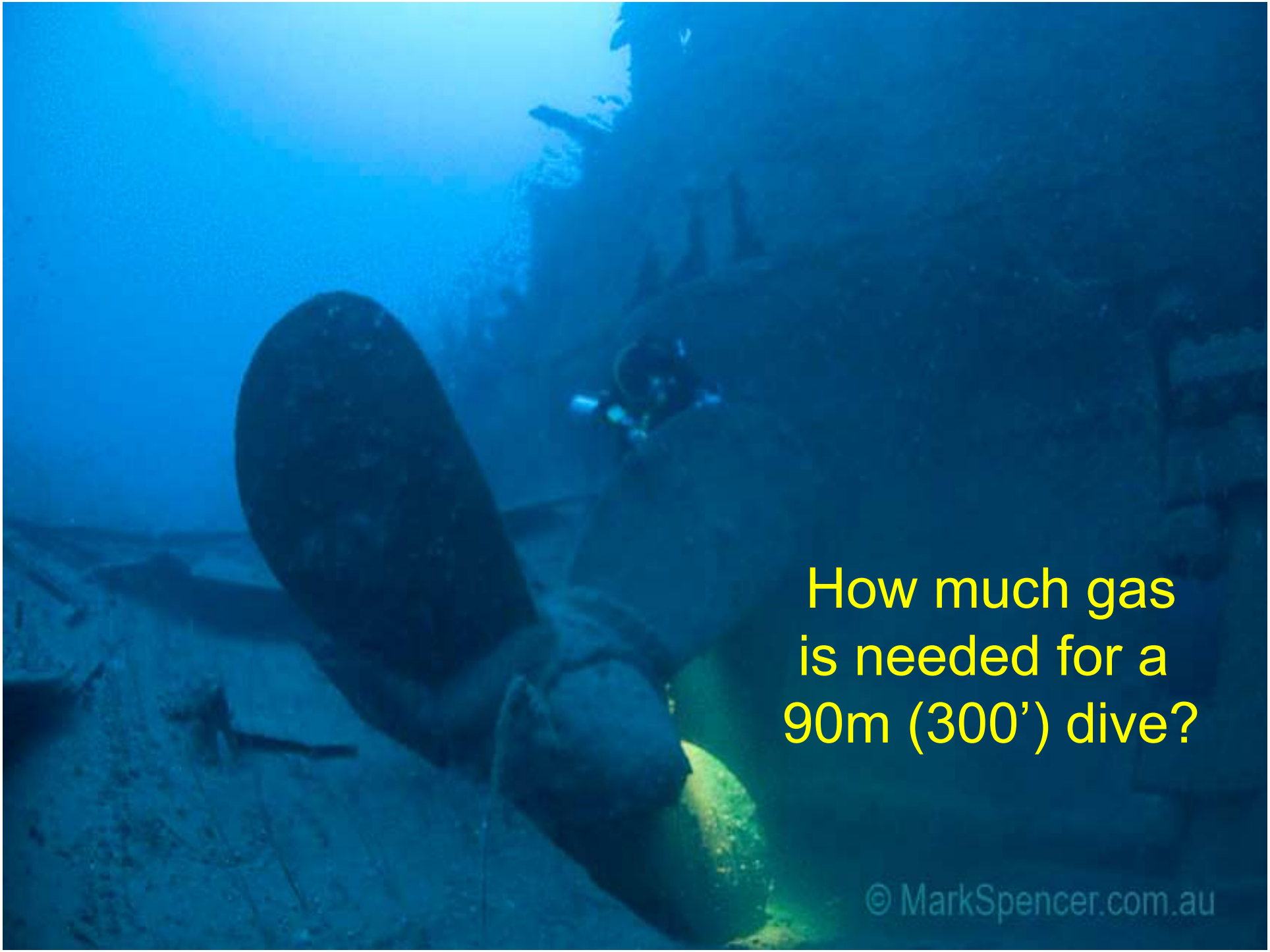
2013 UHMS ASM

THE UNIVERSITY OF AUCKLAND
FACULTY OF MEDICAL AND HEALTH SCIENCES

AUCKLAND DISTRICT HEALTH BOARD
Te Toka Tumai


Diving with open circuit
SCUBA has limitations


Surface
1 atm
Gas Density
2L
3L
4L
5L
6L
10L
10m
2 atm
2x
1L
20m
3 atm
3x
1L
30m
4 atm
4x
1L
40m
5 atm
5x
1L
50m
6 atm
6x
1L
90m (300')
10 atm
10x
1L
Finite gas supply consumed more quickly at greater depths


How much gas
is needed for a
90m (300’) dive?
© MarkSpencer.com.au

You need: a dive plan
a gas plan
a decompression regimen

86 Diving and Hyperbaric Medicine Volume 43 No. 2 June 2013

Review articles

Recreational technical diving part 1: an introduction to technical diving methods and activities

Simon J Mitchell and David J Doolette

You need: a dive plan
a gas plan
a decompression regimen

- 90m (300') for 20 minutes
- Bottom gas trimix 13:47
  - 13% oxygen; 47% helium; 40% nitrogen
- Decompression gases
  - Nitrox 36
  - Oxygen 100%

Decompression prescription: 90m 20 min

- 90 →
- 63 fo
- 60 fo
- 57 fo
- 54 fo
- 51 for 1
- 48 for 2
- 45 for 2

- 27 for 2
- 24 for 2
- 21 for 3

- 18 for 5
- 15 for 7
- 12 for 9
- 9 for 14
- 6 for 16
- 3 for 28
- 3 → 0
- Run time = 131:18

Trimix 13:47 Nitrox 36 Oxygen

Calculation for trimix 13:47

Depth	Pamb	Time	SAC	Pamb x Time x SAC
0→90	5.0	5	20	500
90	10.0	15	20	3000
90→63	8.4	4	20	672
63	7.3	1.5*	12	131
60	7.0	1.5	12	126
57	6.7	1.5	12	121
54	6.4	2.5	12	192
51	6.1	1.5	12	110
48	5.8	2.5	12	174
45	5.5	2.5	12	165
42	5.2	2.5	12	156
39	4.9	3.5	12	206
36	4.6	2.5	12	138
33	4.3	3.5	12	181
30	4.0	3.5	12	168
Total:				6040 L

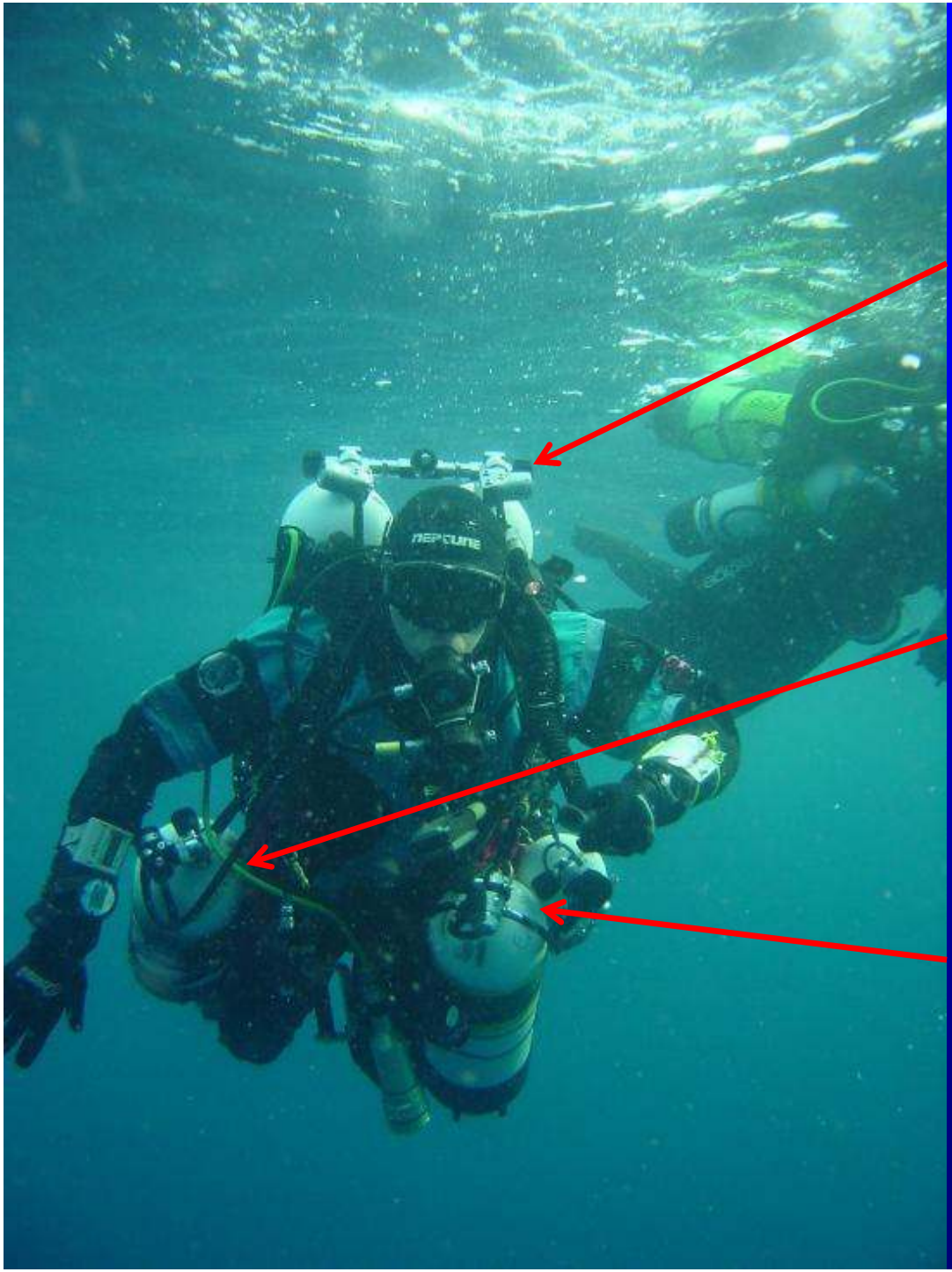
Usual to multiply by 1.3 for safety margin:

6040 x 1.3 = **7852 L**

Depth	P_{amb}	Time	SAC	P_{amb} x Time x SAC
Calculation for Nitrox 36				
27	3.7	2.5*	12	111
24	3.4	2.5	12	102
21	3.1	3.5	12	131
15	2.5	7.5	12	225
12	2.2	9.5	12	251
9	1.9	14.5	12	331
Total				1050 →
Calculation for oxygen				
6	1.6	16.5	12	317
3	1.3	28.5	12	445
Total				762 →

Nitrox 36
1050 x 1.3 = **1365 L**

Oxygen
762 x 1.3 = **991 L**



…then figure out how to carry it….

Trimix 13:47
Twin 18 L steel tanks
Can hold 8280 L
(7852 L required)

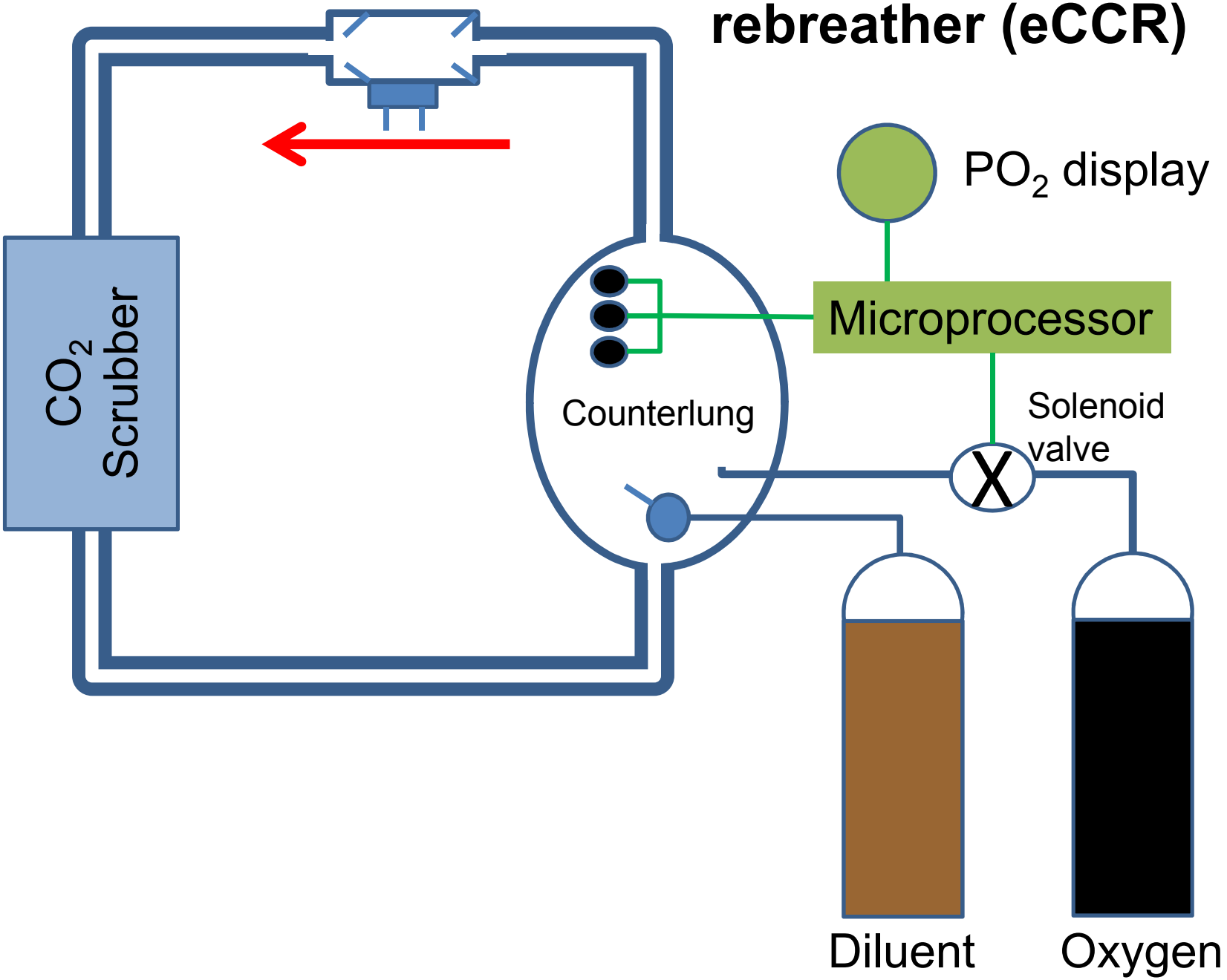
Nitrox 36 deco gas
10 L steel tank
Can hold 2300 L
(1365 L required)

Oxygen deco gas
10 L steel tank
Can hold 2300 L
(991 L required)

….and that was 90 m, what about deeper??

Useful dives to all of those depths could be done with nothing more than this

Electronic closed circuit rebreather (eCCR)

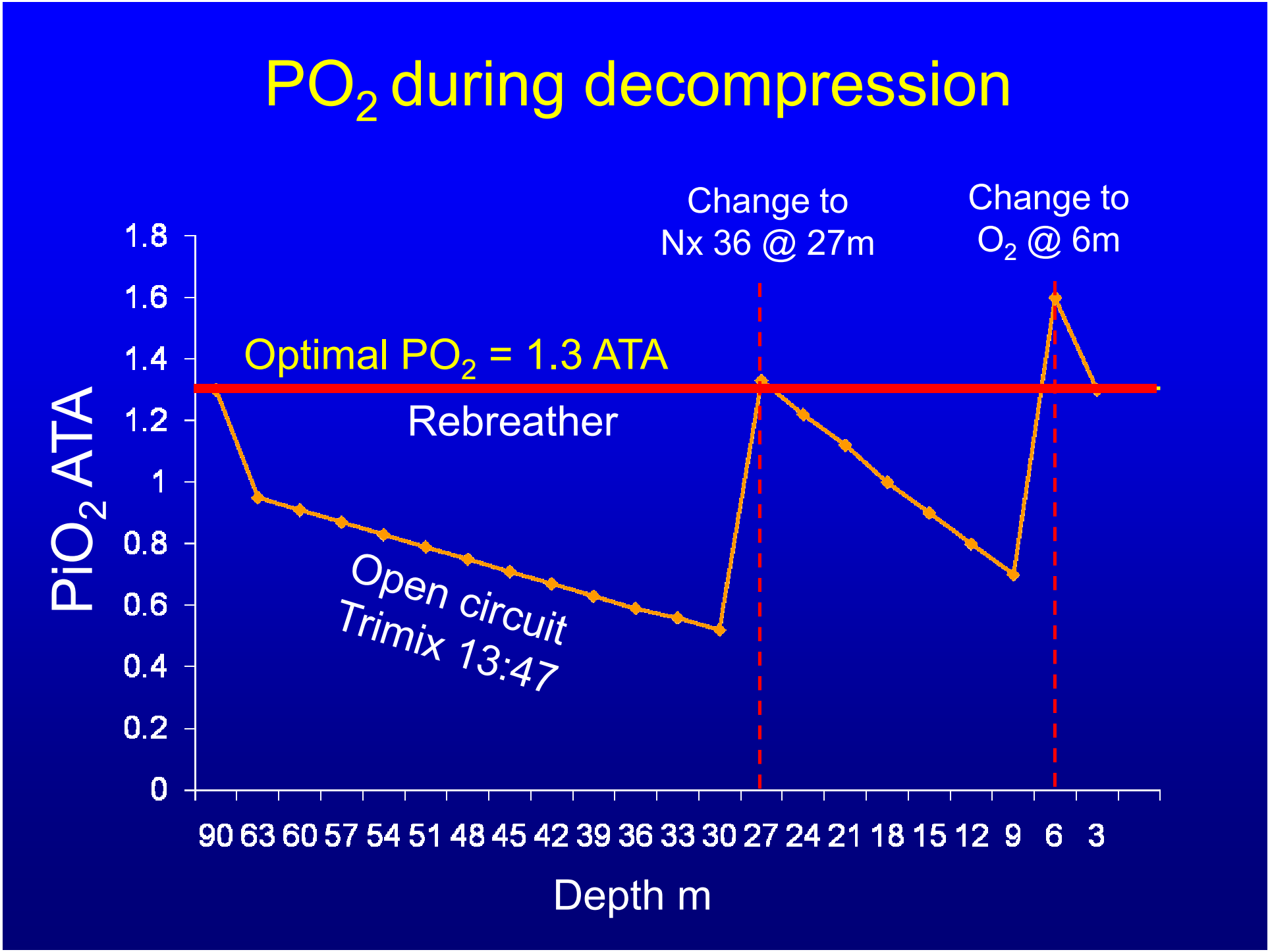


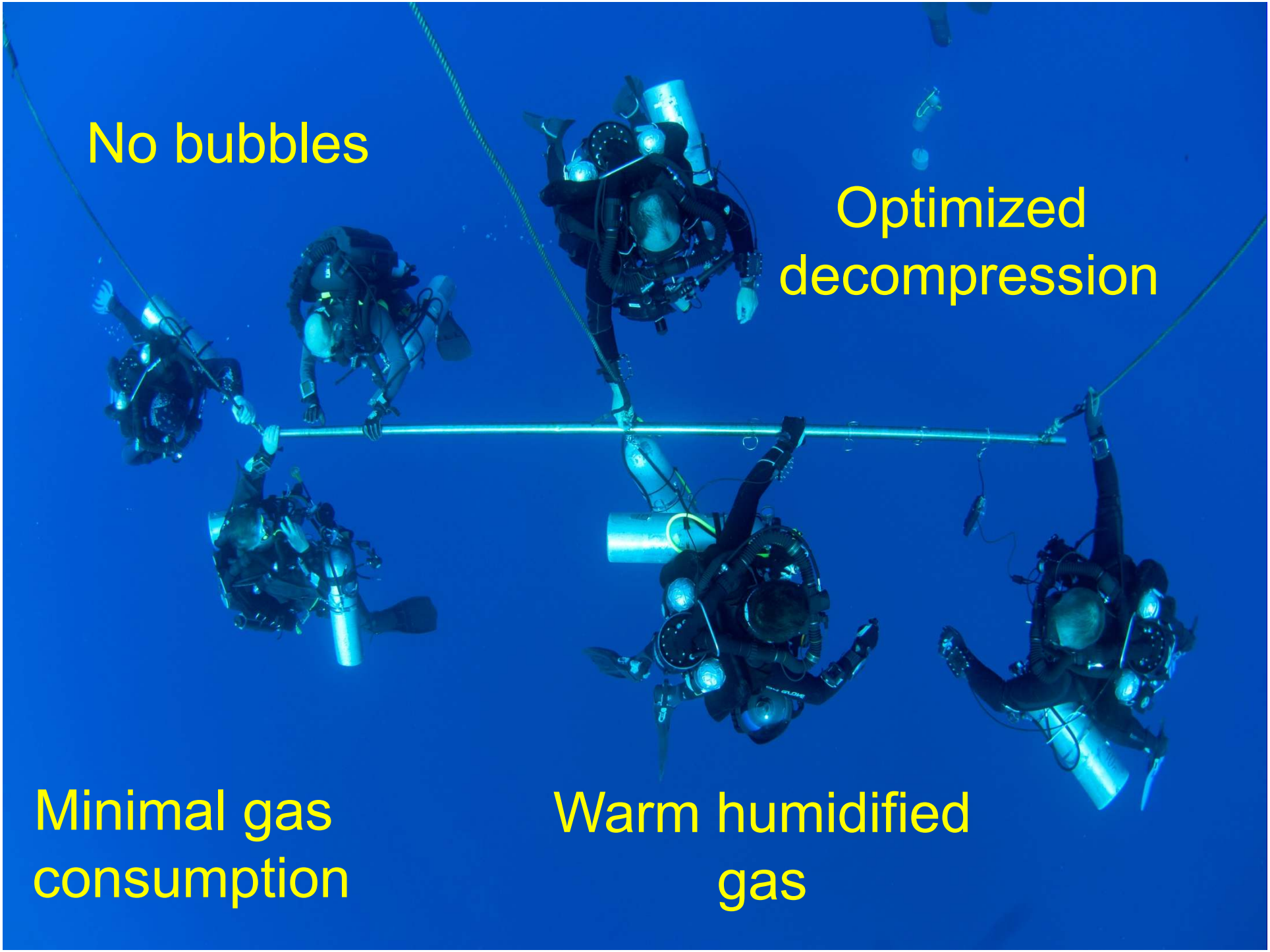
PO_2 is optimized across all depths

Generally agreed that the maximum safe inspired PO_2 during diving is around 1.3 ATA

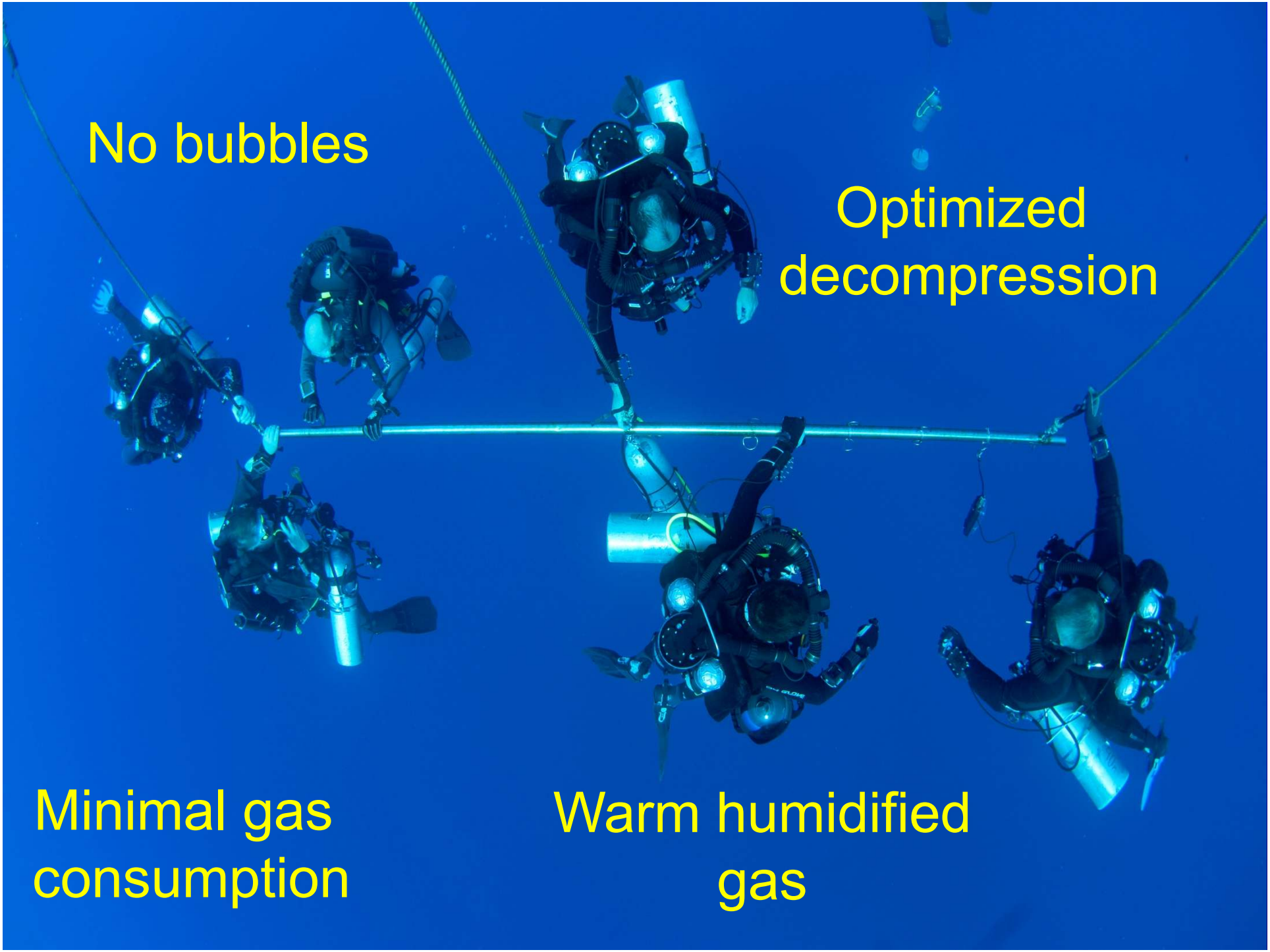
Staying as close to that as possible minimises inert gas uptake and maximizes inert gas elimination

PO_2 during decompression



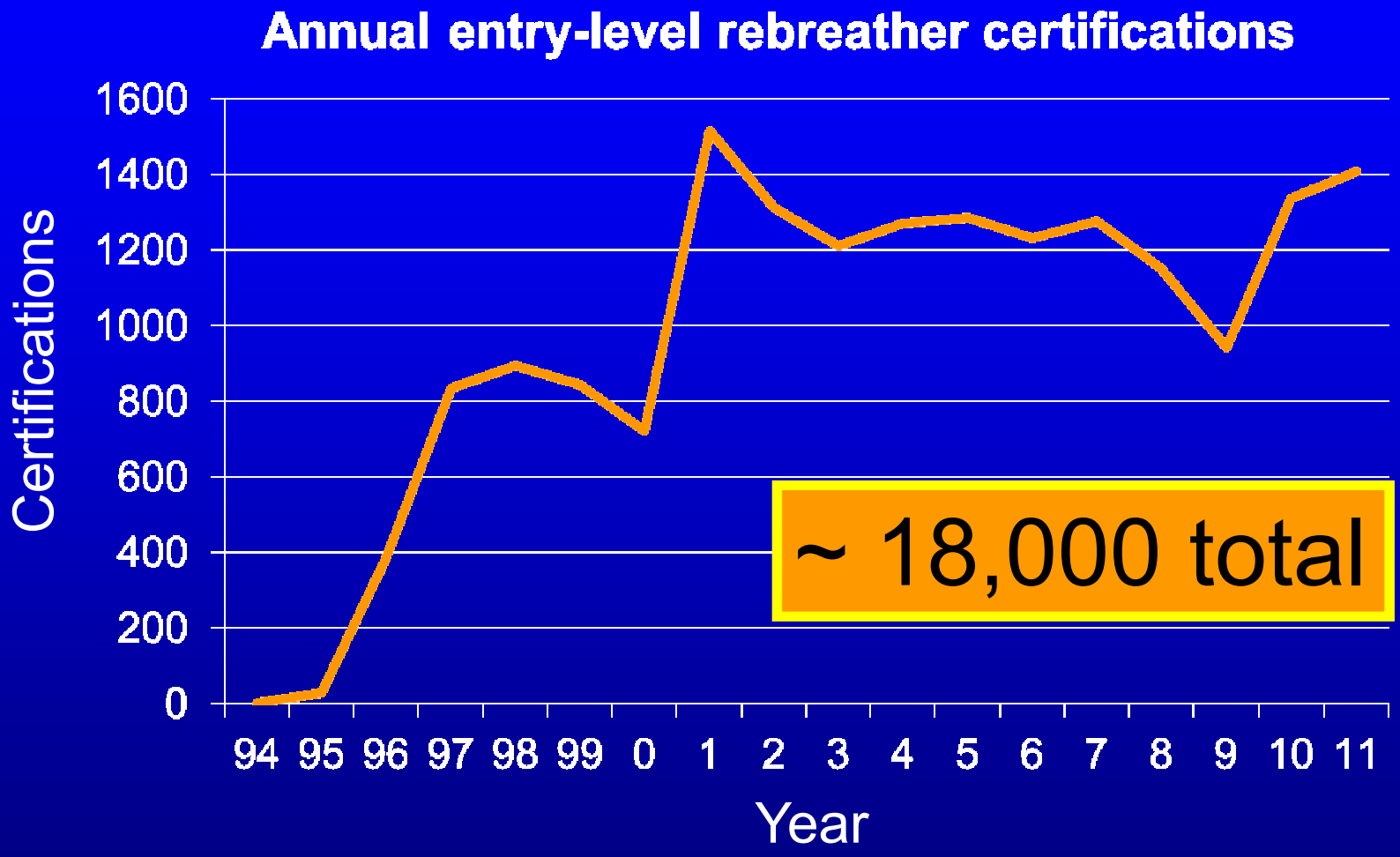

No bubbles
Optimized decompression
Minimal gas consumption
Warm humidified gas


S TEK
SCUBAPRO


No bubbles
Optimized decompression
Minimal gas consumption
Warm humidified gas


Steady uptake by recreational
“technical divers”

Data from IANTD, TDI, ANDI



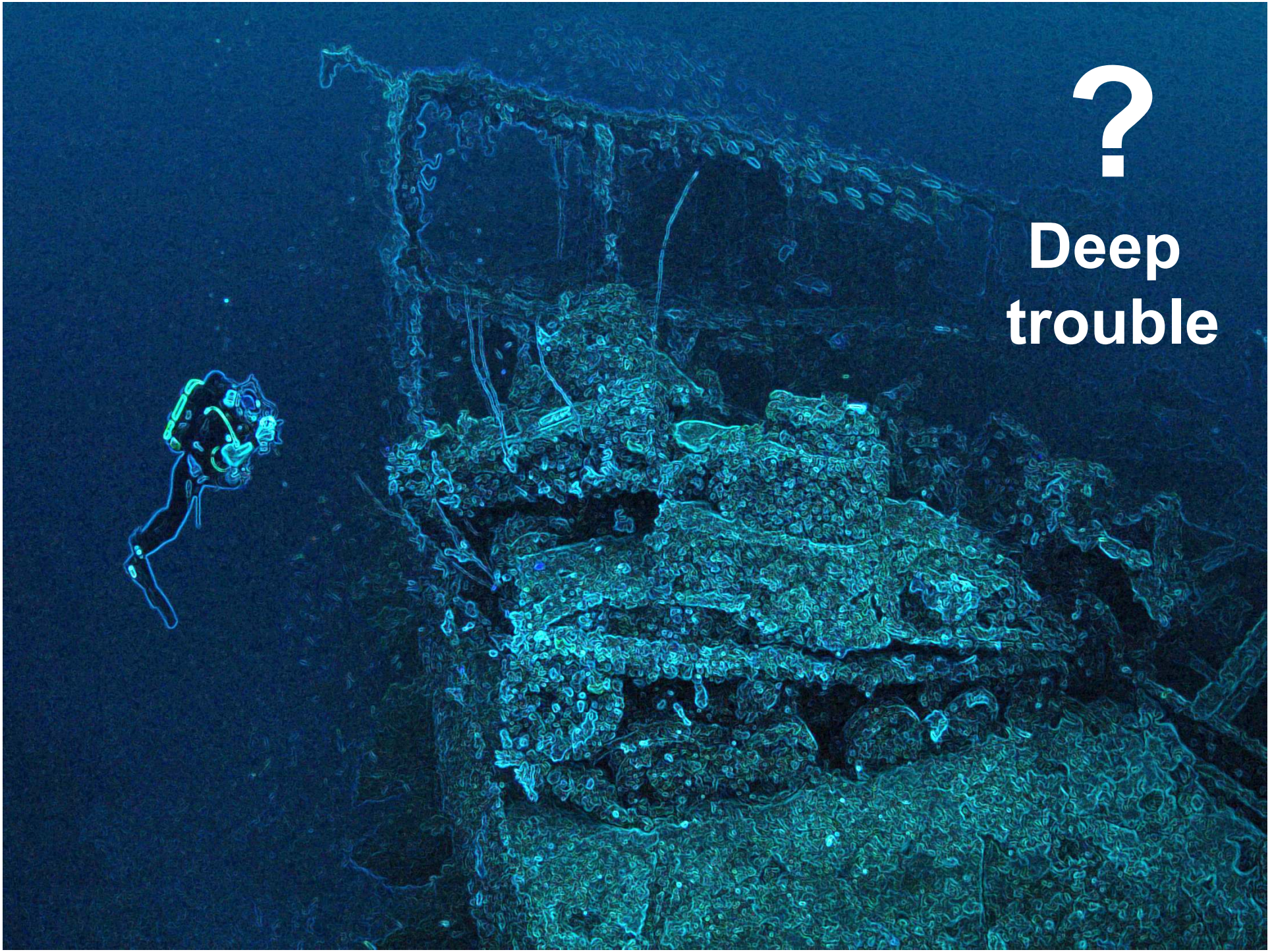
Dituri J, Carney B, Betts E. A tripartisan look at the state of rebreathers. ANDI, IANTD, TDI collective rebreather certification numbers and market analysis. Rebreather Forum 3 Proceedings, 2013: In press

Remarkable achievements

- Regular dives to depths around or in excess of 300’
- Wreck: wrecks deeper than 600’ located and explored
- Cave: 2008 11km at ~300’ over 7 hours bottom time followed by 15 hours of decompression. Wakulla – Leon Sinks system, Florida.


049
74.0m
-15
04/11/08
+0
16:26


Deep
capability?


?
Deep
trouble

Rebreathers are:

Complex maintenance-dependent devices

that

work well the vast majority of the time,

but with

multiple failure points

used by

highly motivated humans

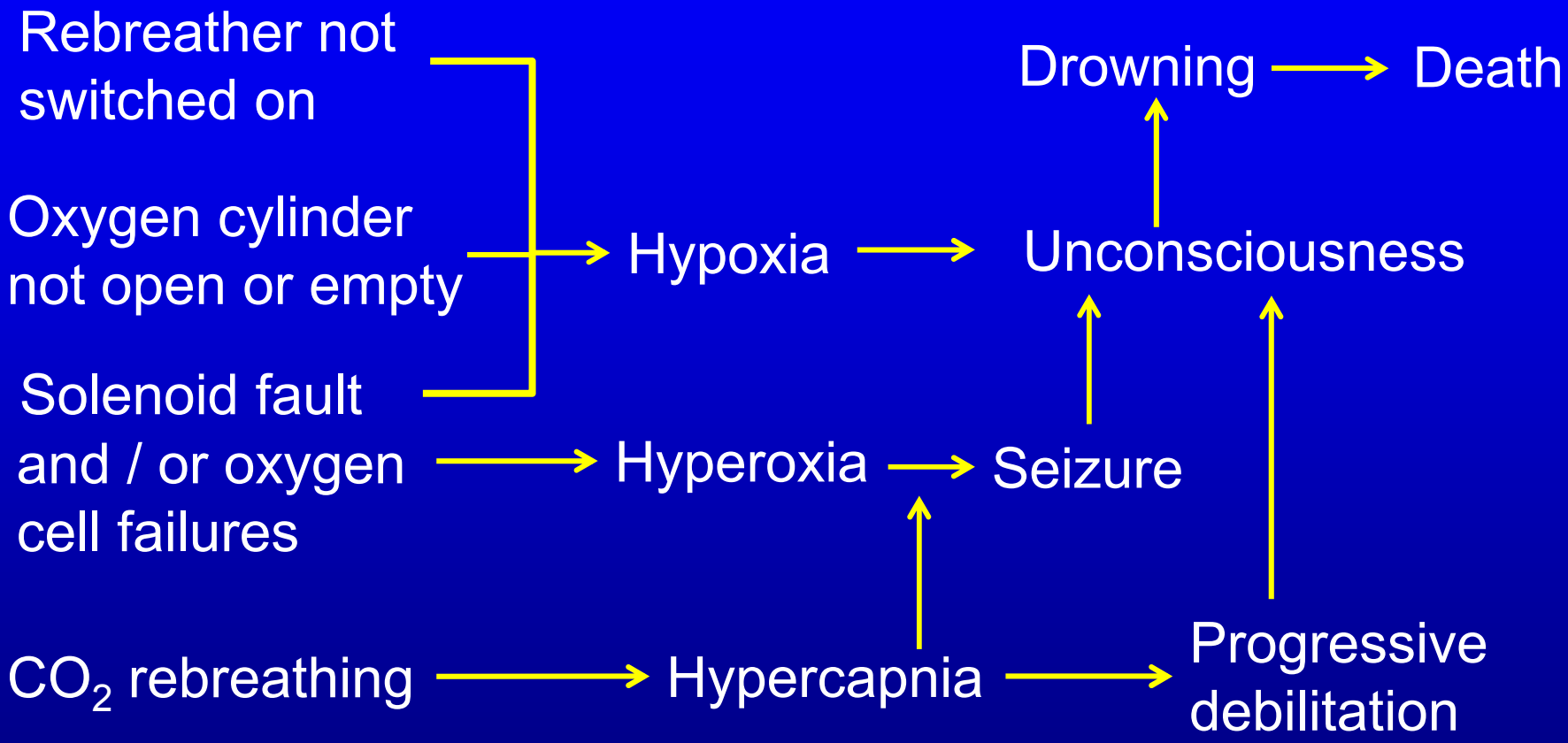
in a

hostile non-respirable environment

often with a

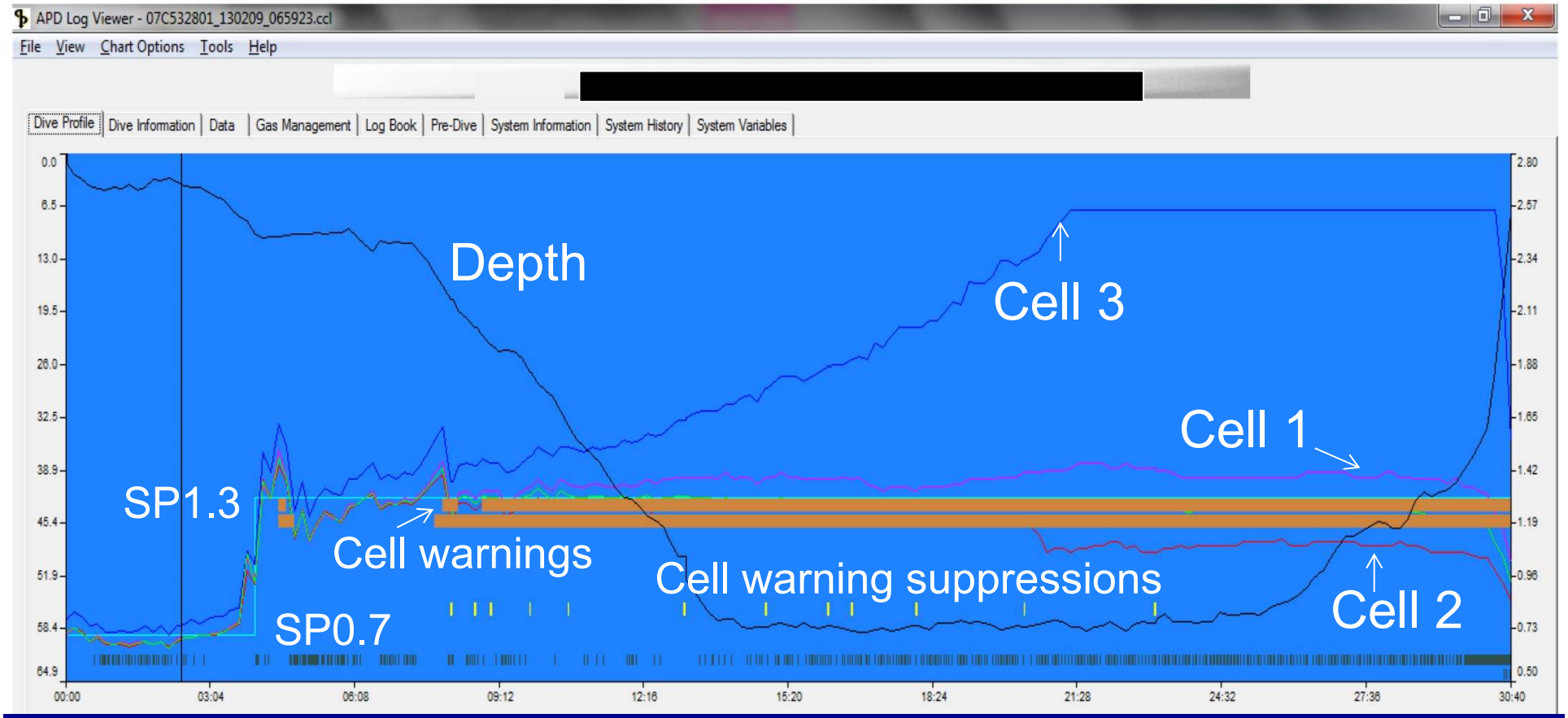
real or virtual ceiling

Examples of failure modes not present or less insidious in open circuit scuba



Problems related to human factors

- Human error
  - Especially at the human – machine interface
- Normalisation of deviance
  - Every time an undesirable behaviour doesn't result in a problem we become more tolerant of it
- Temporarily corrupted motivation paradigms
  - Divers prioritize completion of a goal or task over self preservation



SP = PO_2 set point in ATA


Data free zone

What do the numbers say?

Analysis of recreational closed-circuit rebreather deaths 1998–2010

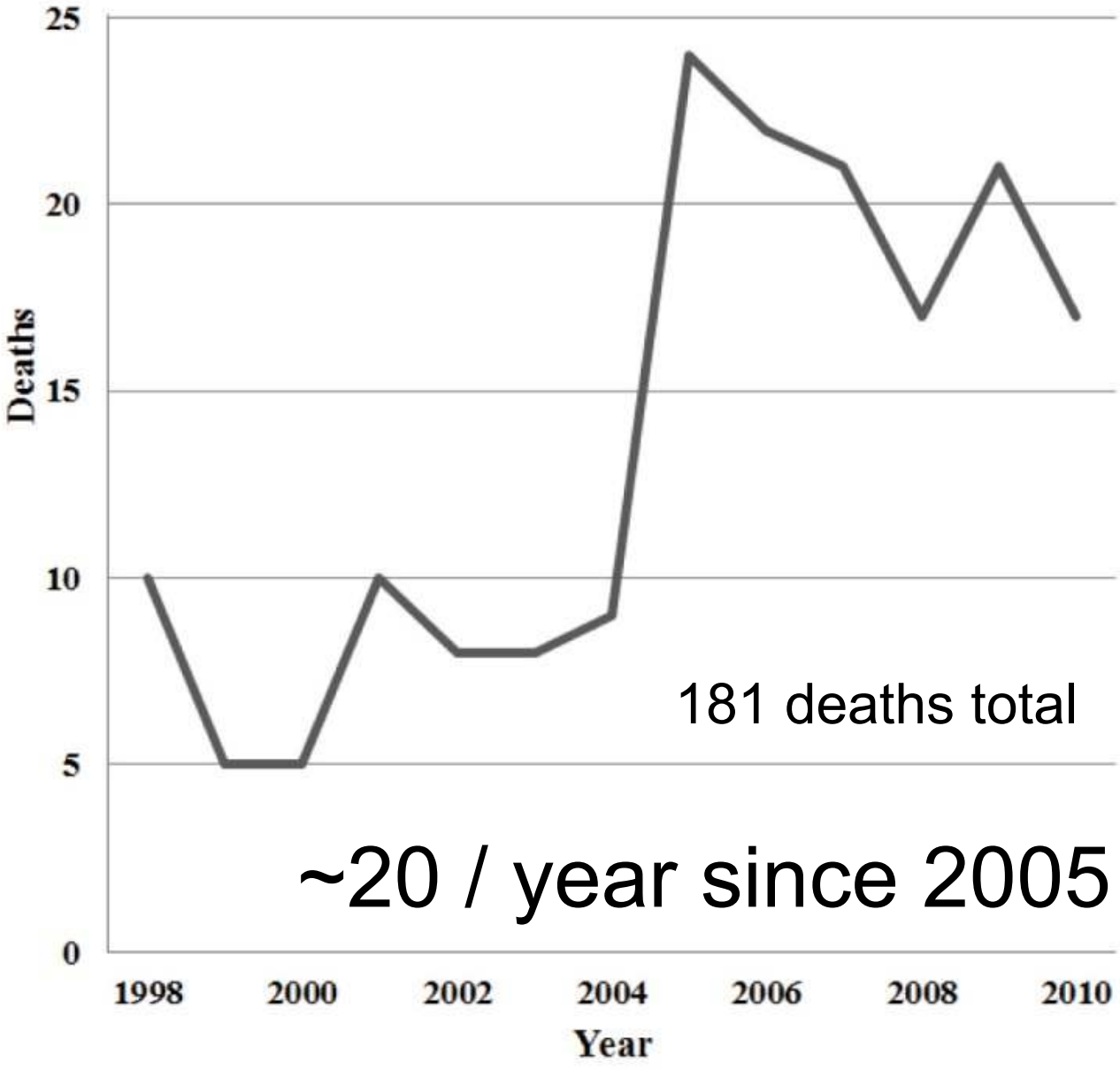
Andrew W Fock

DHM 2013;43(2):78-85


S TEK
SCUBAPRO

Figure 1

Recreational closed-circuit rebreather deaths by year 1998–2010



Rebreather diving mortality

- ~20 deaths per year
- ???How many rebreather divers???
  - 18,000 entry level certifications
    - Plus ? more
  - Some drop-outs must have occurred
- If 15,000, 20 deaths = 133 / 100,000 / yr
- If 10,000, 20 deaths = 200 / 100,000 / yr

Recreational scuba air fatalities

Original articles

Scuba injury death rate among insured DAN members

Petar J Denoble, Neal W Pollock, Panchabi Vaithiyanathan, James L Caruso, Joel A Dovenbarger and Richard D Vann

Insured DAN members – vast majority scuba air

Death rate 16 per 100,000 participants per year

Rebreathers: 130 - 200 / 100,000 / yr

Insured DAN members (SCUBA air):
16 / 100,000 / yr

Denoble et al. Diving Hyperbaric Med 2008;38:182-188

Analysis of recreational closed-circuit rebreather deaths 1998–2010

Andrew W Fock

2010: there were ~14,000 active rebreather divers

Survey data suggest 30 dives per year per diver

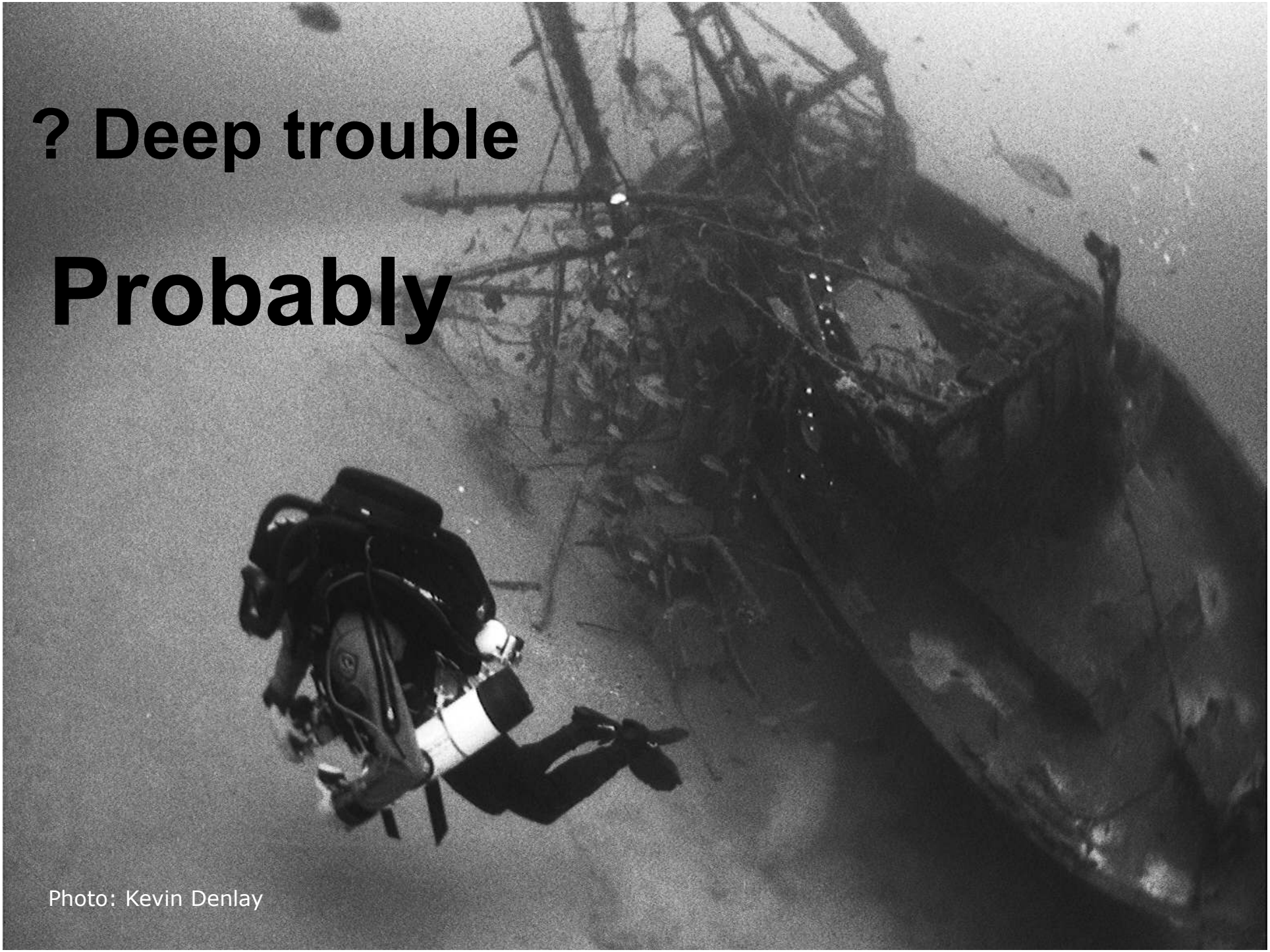
20 deaths per year = 4 – 5 deaths per 100,000 dives

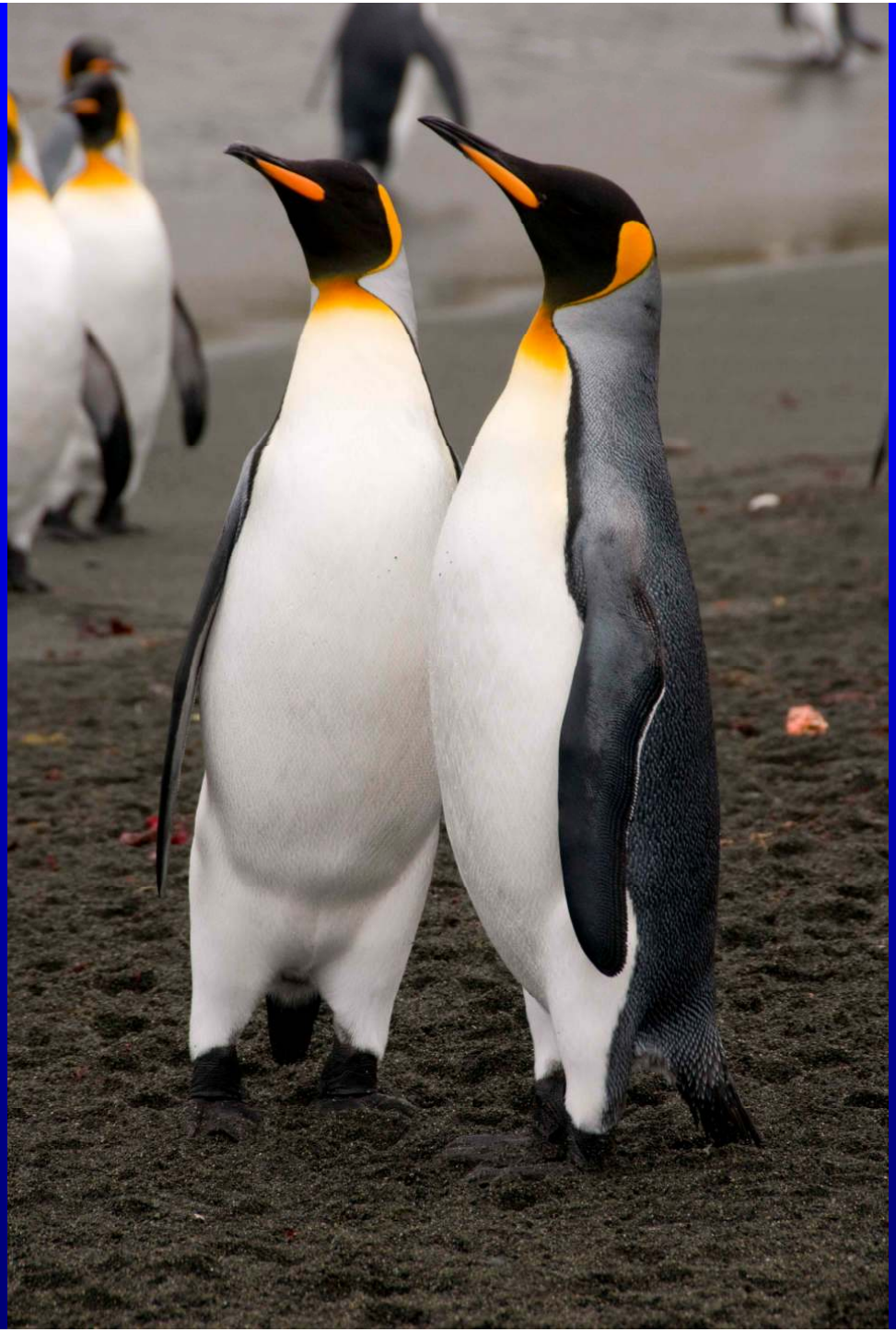
Training Scuba Divers: A Fatality and Risk Analysis

Drew Richardson
PADI Worldwide
30151 Tomas Street
Rancho Santa Margarita, CA 92688 USA

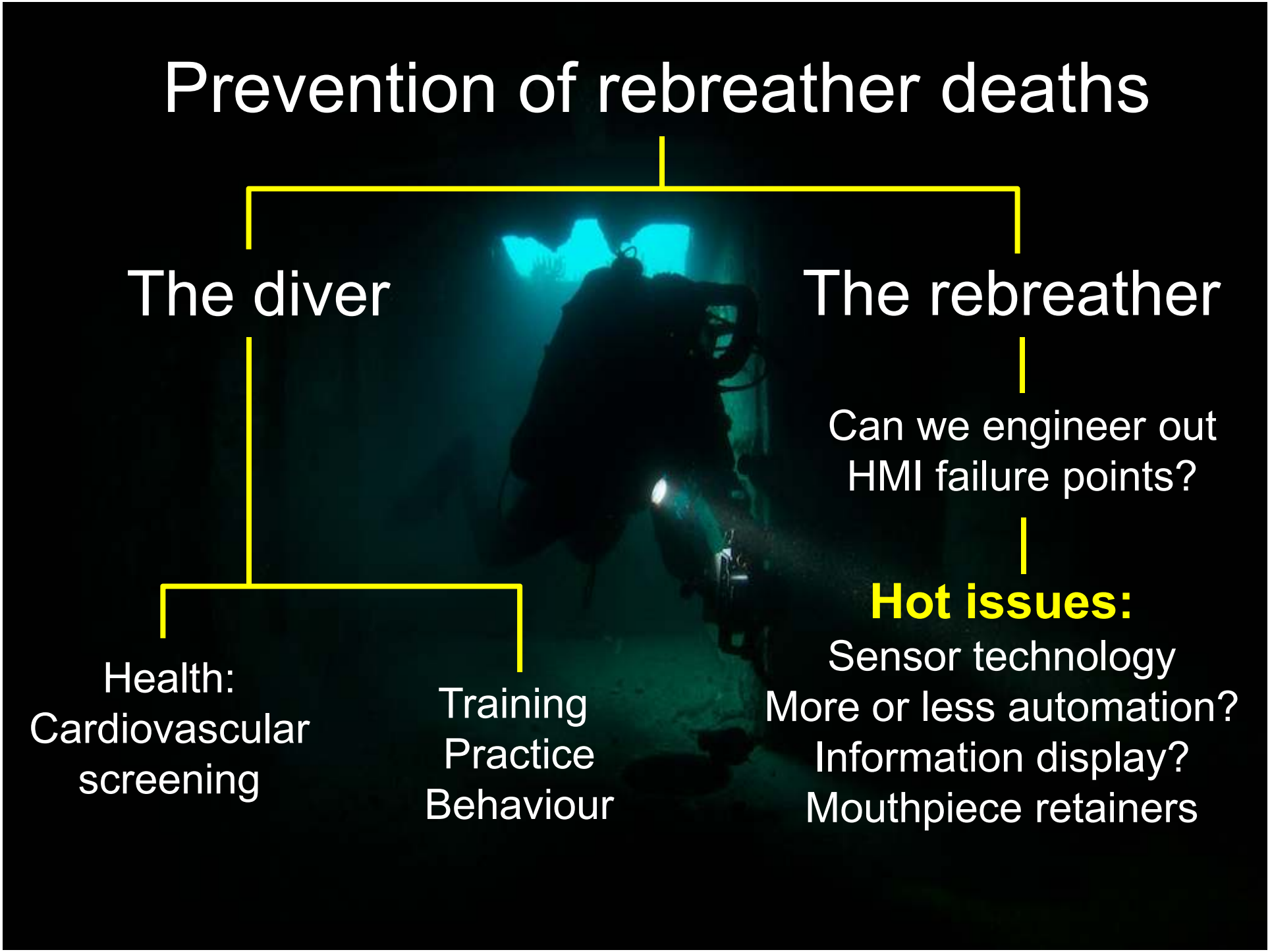
0.48 deaths per 100,000 open circuit training dives

Vann RD, Lang MA, eds. *Recreational Diving Fatalities.* Proceedings of the Divers Alert Network 2010 April 8-10 Workshop. Durham, N.C.: Divers Alert Network, 2011. ISBN #978-0-615-54812-8.


? Deep trouble
Probably
Photo: Kevin Denlay



Prevention of rebreather deaths



The diver

- Health:
  Cardiovascular
  screening
- Training
  Practice
  Behaviour

The rebreather

Can we engineer out
HMI failure points?

Hot issues:

Sensor technology
More or less automation?
Information display?
Mouthpiece retainers

RECREATIONAL DIVING FATALITIES WORKSHOP PROCEEDINGS

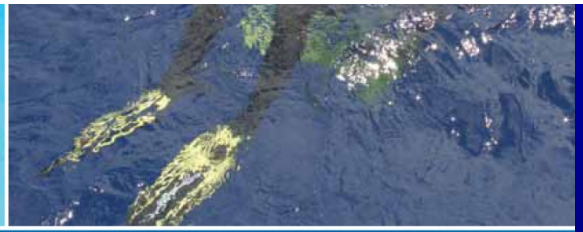
UHM 2011, VOL. 38, NO. 4 – MEDICAL SCREENING OF DIVERS FOR CARDIOVASCULAR DISEASE

Medical screening of recreational divers for cardiovascular disease: Consensus discussion at the Divers Alert Network Fatality Workshop

SIMON J. MITCHELL M.B. CH.B., PH.D, FANZCA[1]; ALFRED A. BOVE M.D., PH.D. [2]

[1] Department of Anesthesiology, University of Auckland, Auckland, New Zealand

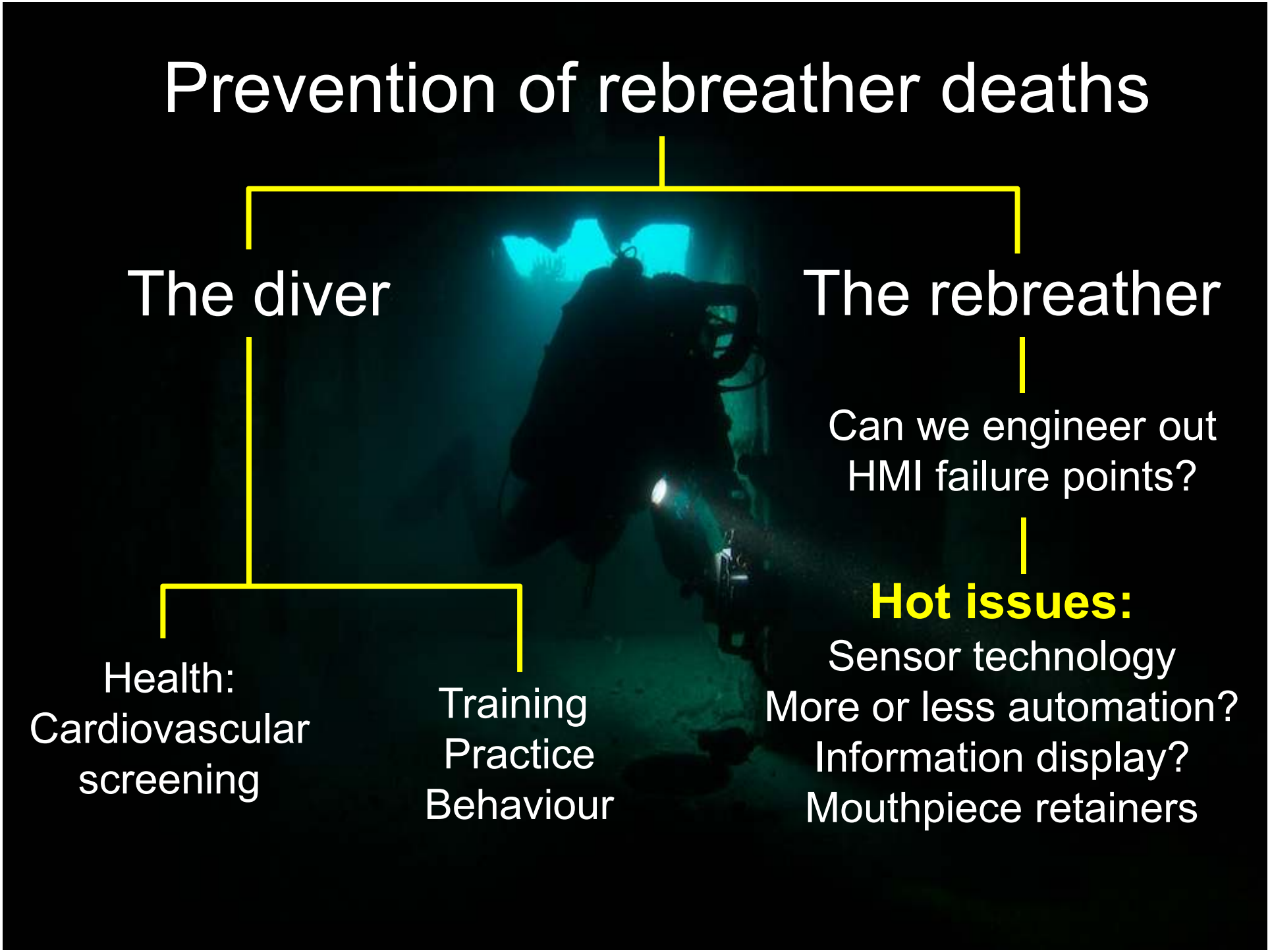
[2] Emeritus Professor of Medicine, Cardiology Section, Department of Medicine, Temple University Medical School. Philadelphia, PA, USA



DURHAM, NORTH CAROLINA

DAN

Prevention of rebreather deaths



The diver

- Health:
  Cardiovascular
  screening
- Training
  Practice
  Behaviour

The rebreather

Can we engineer out
HMI failure points?

Hot issues:

Sensor technology
More or less automation?
Information display?
Mouthpiece retainers


Silver Supporters
ExtendAir
LIGHT MONKEY
M·R·DIVING
M/V SPREE
SSI XR
Bronze Supporters
Dive Rite
TDL
IN THE LOOP
RF3
REBREATHER FORUM 3
www.rf30.org
MAY 18-20 2012
Caribe Royale Hotel
Orlando, Florida
IN THE LOOP
RF3
REBREATHER FORUM 3
www.rf30.org
MAY 18-20 2012
Caribe Royale Hotel Orlando, Florida
POWERED
BY
AAUS
AMERICAN ACADEMY OF UNDERWATER SCIENCES
DAN
PADI
padi.com

CHECKLISTS:

"The forum acknowledged the overwhelming evidence demonstrating the efficacy of checklists in preventing errors in parallel fields that share similar technical complexity. Two recommendations regarding checklists were consequently agreed".

The NEW ENGLAND JOURNAL of MEDICINE

SPECIAL ARTICLE

A Surgical Safety Checklist to Reduce Morbidity and Mortality in a Global Population

NEJM 2009;360:491-9

Introduction of a surgical safety checklist significantly reduced mortality and morbidity in a multicentre study

CHECKLISTS 1.

The forum recommends that rebreather manufacturers produce carefully designed checklists, which may be written and / or electronic, for use in the pre-dive preparation (unit assembly and immediate pre-dive) and post-dive management of their rebreathers.

– Written checklists should be provided in a weatherproof or waterproof form.

– The current version of these checklists annotated with the most recent revision date should be published on the manufacturer's website

CHECKLISTS 2.

The forum recommends that training agencies and their instructors embrace the crucial leadership role in fostering a safety culture in which the use of checklists by rebreather divers becomes second nature.

DESIGN AND TESTING 4.

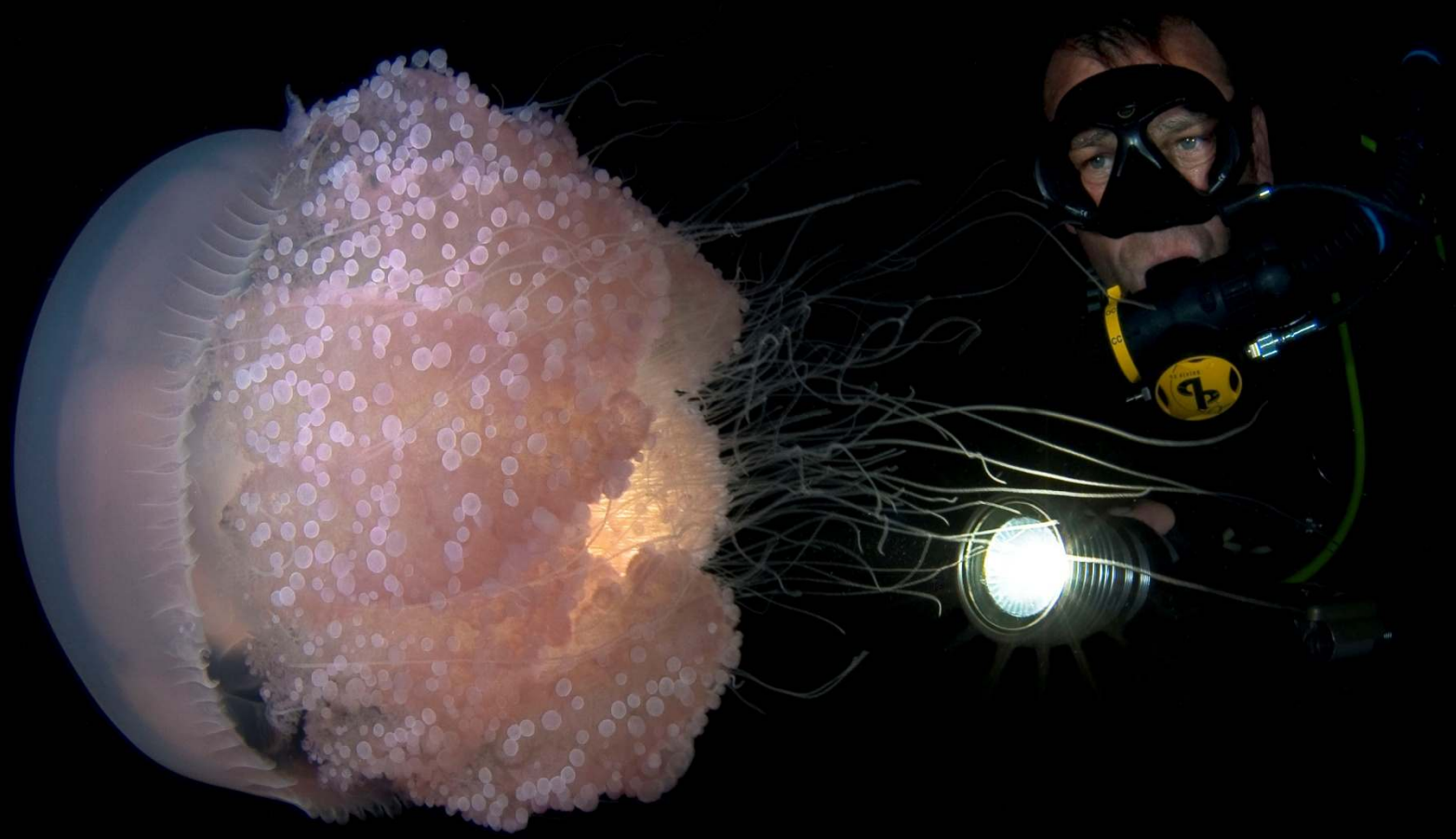
The forum strongly endorses industry initiatives to improve oxygen measurement technologies, and advocates consideration of potentially beneficial emerging strategies such as dynamic validation of cell readings and alternatives to galvanic fuel cells.

Consensus statements at:

http://rubicon-foundation.org/News/rf3-consensus/

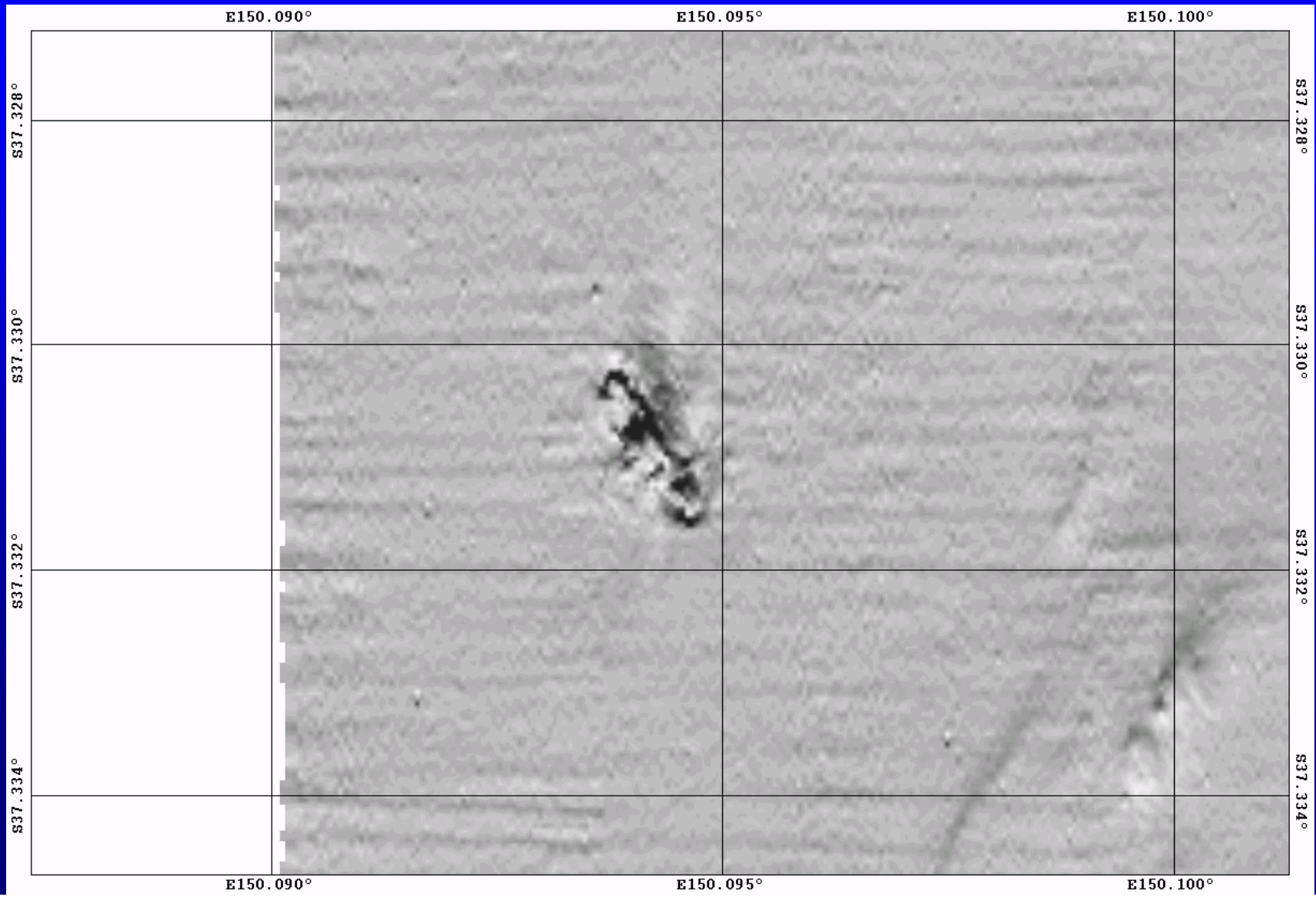
Safety will be in the spotlight over the next few years with the advent of “recreational rebreather” training

Deep capability or deep trouble?



Both!!

?? possibly the Cumberland




Thank you