Bühlmann's (ZH research laboratory) sat diving algorithm and deep mixed tables - how they changed practice in occupational diving?

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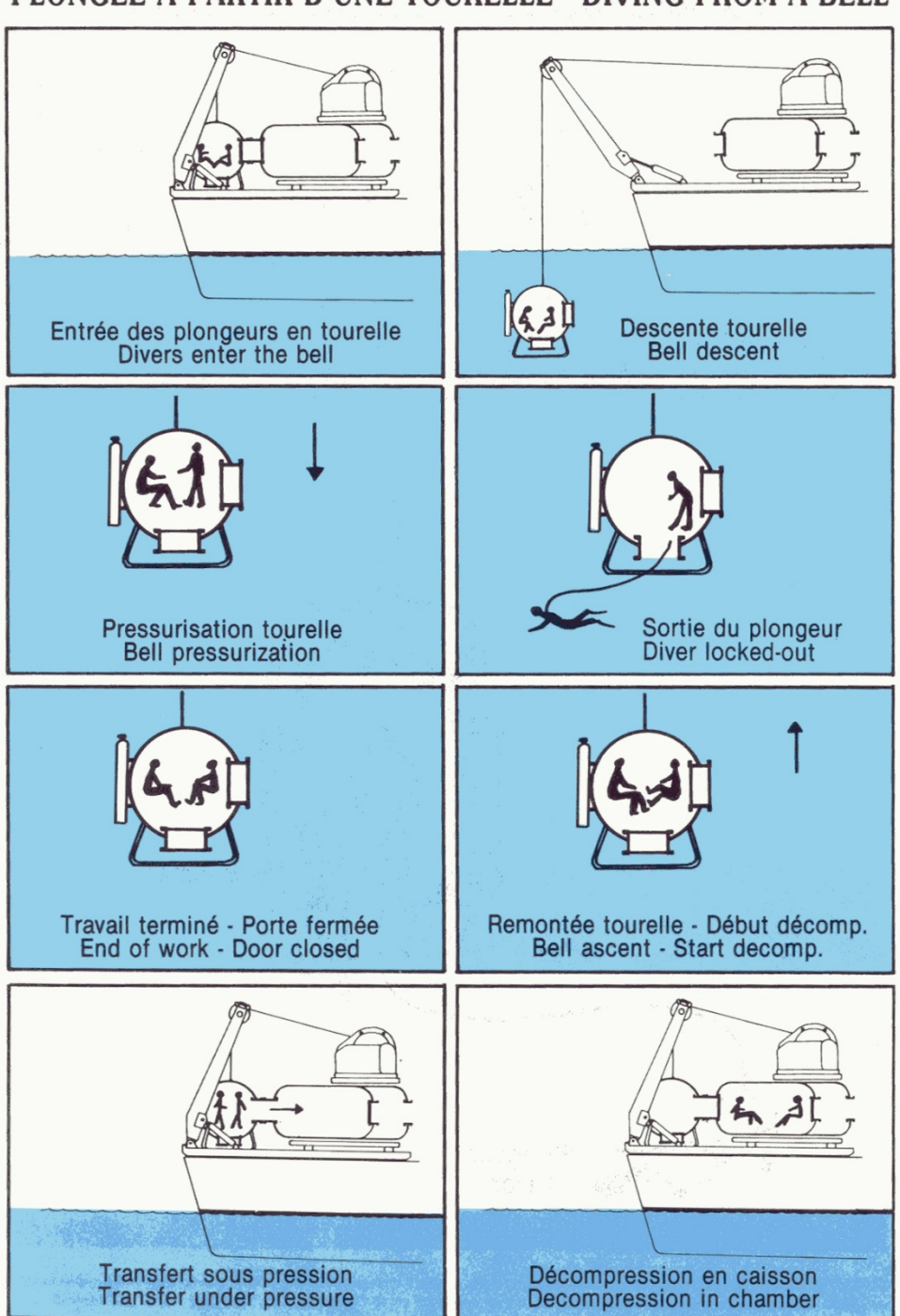
Universitätsspital Zürich (DKL-USZ)

Jürg Wendling, Biel-Bienne
mail@wendling.ch

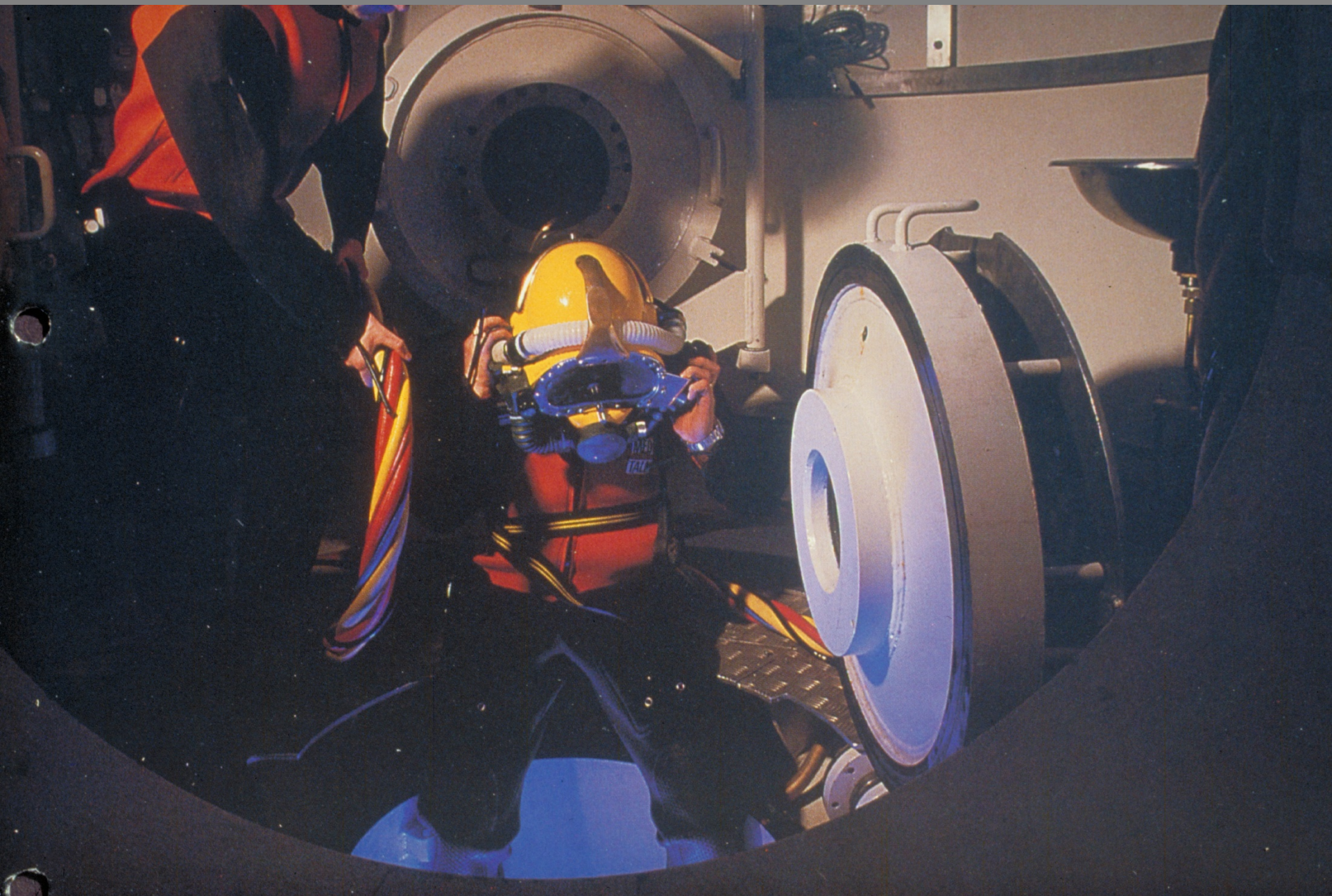
- Deep mixed gas tables (bounce diving)
  used during a few years for TUP-D (closed bell)
- Sat developed very rapidly under the lead of
  - Comex (with French gov support)
  - US Navy (with NOAA support)
  - Diving companies (Oceaneering, Tayler, Statoil)

  Bü'algorithm served as basis for empirical improvements of procedures

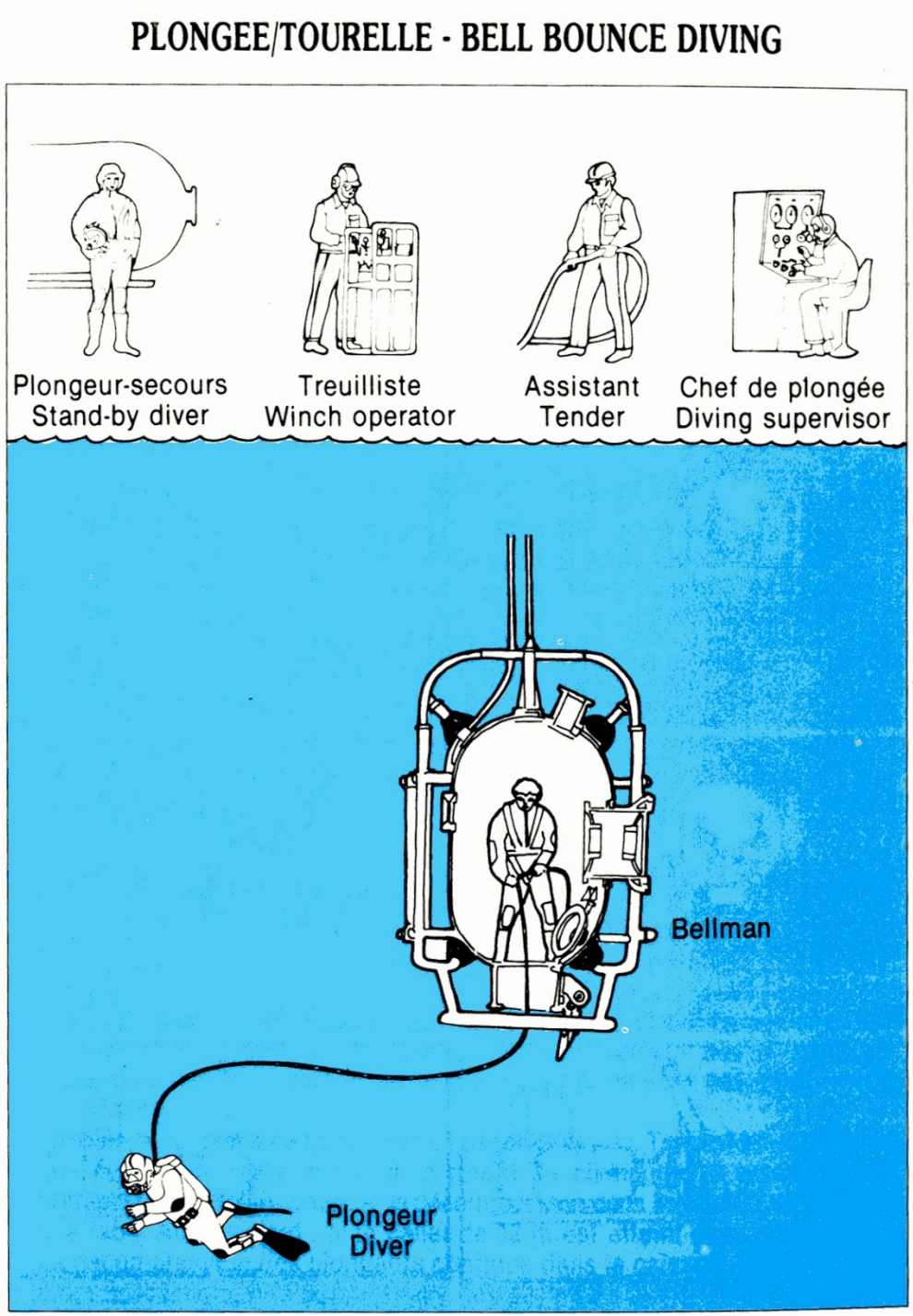


Closed bell bounce TUP

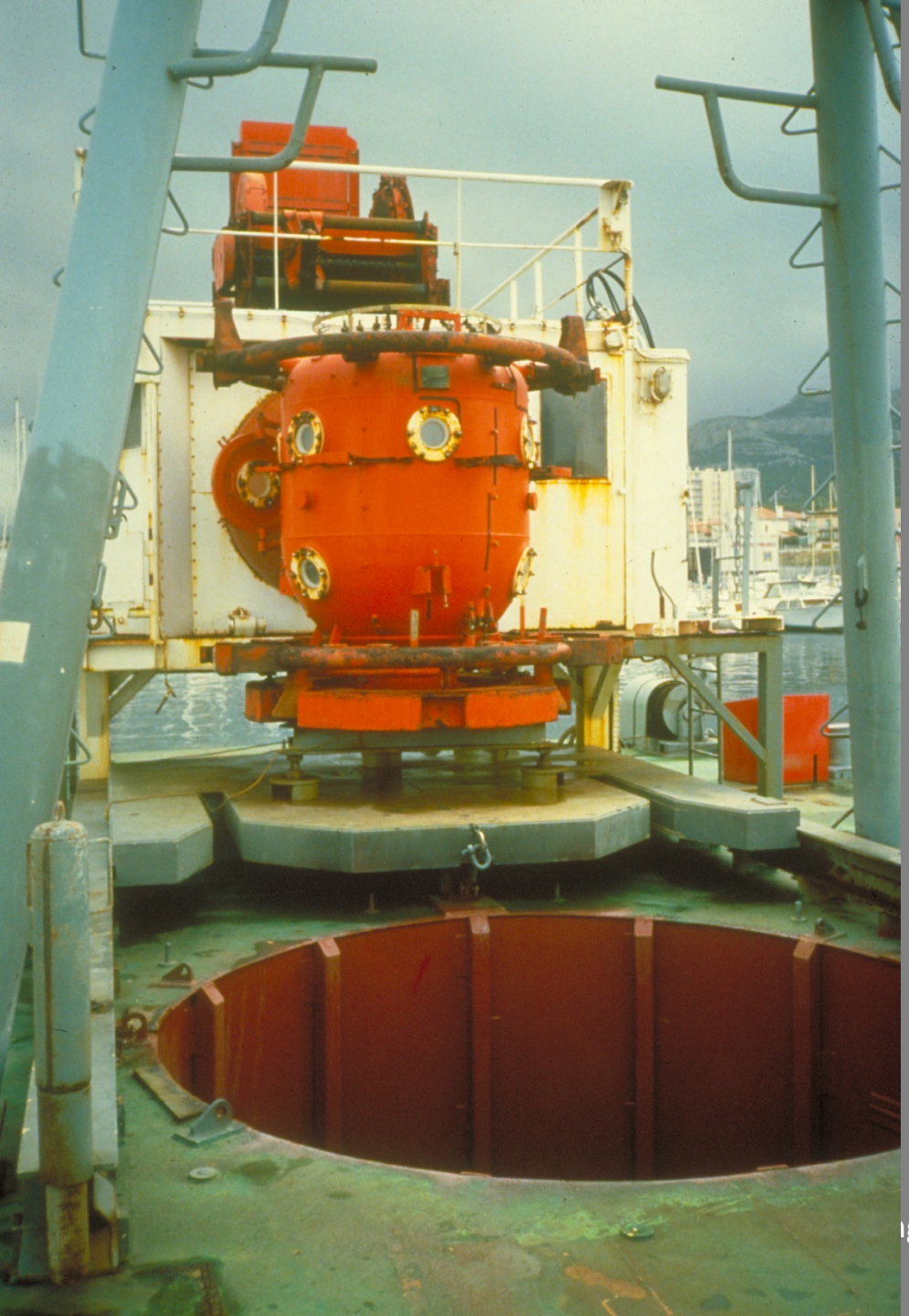
Closed bell bounce TUP



Closed bell bounce TUP



Closed bell bounce TUP



Closed bell bounce TUP

- Offshore diving industry had severe accidents
- Mostly technical and handling problems
- Also too many DCS

→AODC/IMCA (risk assessment, COP, training)
→EDTC (Europe stds for save practice, FTD, competence
→ADCi (same as IMCA in USA)
→National goverment regulations and norms

Disappearance of decompression incidents in offshore industry

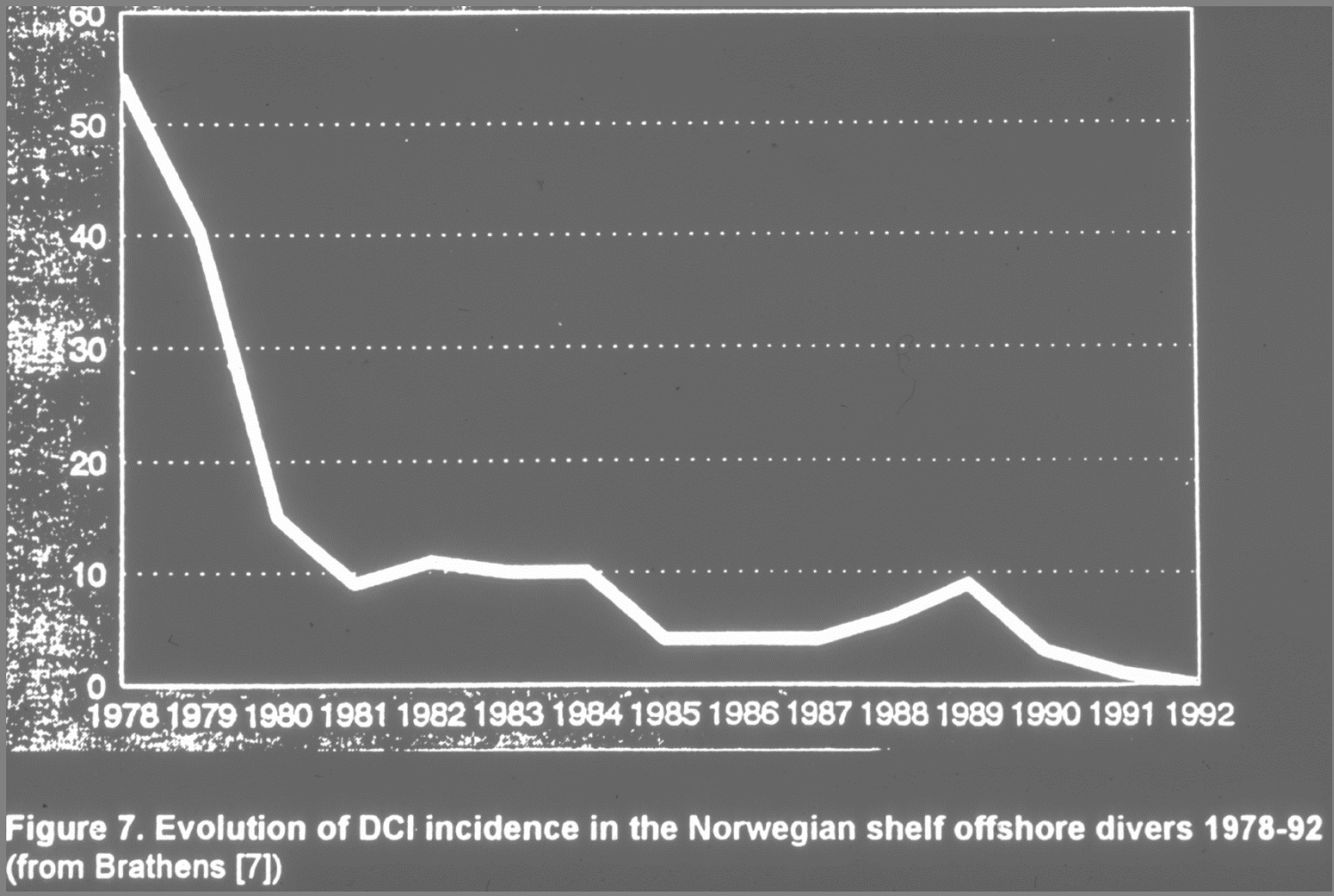


Figure 7. Evolution of DCI incidence in the Norwegian shelf offshore divers 1978-92 (from Brathens [7])

- Shell company provided Bü'tables to saturation contractors but these were used only as emergency procedures because too high accepted DCI risk

Sat deco as today in use:

- Conservative procedures with almost no DCI

  - Norsok (Norvegian standard)
  - HSE (UK)
  - US Navy (T7 Thalmann)
  - French gov tables (ex comex)

pO2 0.4 - 0.5 Depth (m)	France Cont	Norway Night stop	USN T7 Night stop
180 m	50	40	32.6 min/m
150 m	50	40	32.6 min/m
120 m	50	40	32.6 min/m
90 m	50	40	32.6 min/m
60 m	50	50	39.1 min/m
30 m	50	60	48.9 min/m
15 m	60	80	65.1 min/m
12 m	60	80	98.0 min/m
6 m	60	80	195 min/m

Bühlmann sat-tables: 0.3 min/m to 1st stop – 20-30 min/m to 30m – 60 min/m to surf

New challenge: HPCAW
(high pressure compressed air work)

- National regulations are behind the time

  (independent development for tunnelling, not using the lessons learned from deep diving)

1970 – 2000 – Tunnelling and Caisson

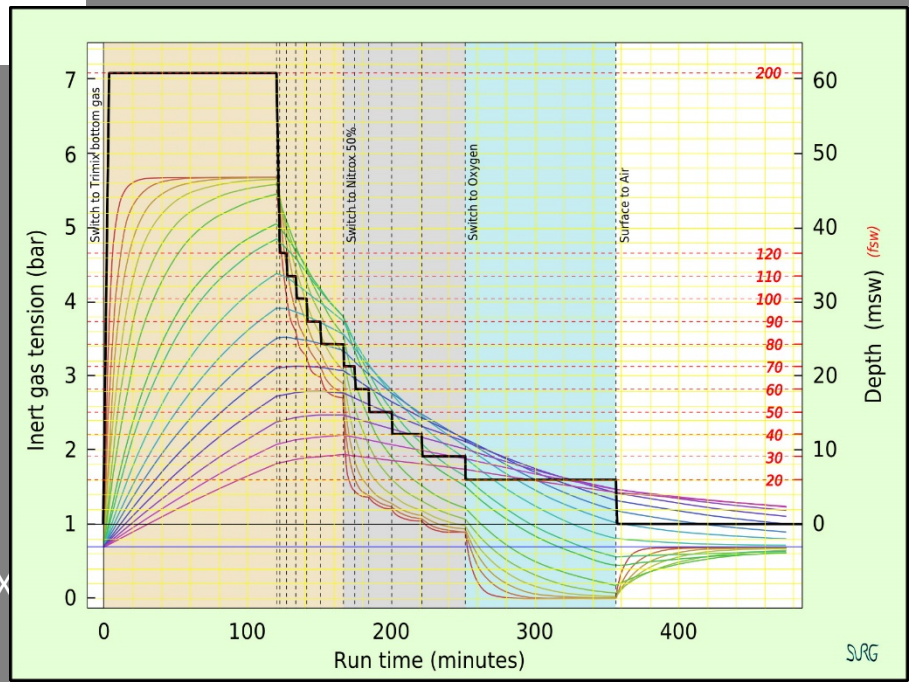
- ….: Washington tables (from 1963) in use until now (OSHA standard)
- 1979: new tables by Peter Edel (USN research), Eric Kindwall (Milwaukee Univ)
  Haldanian, many compartments, using computer algoritmes incl. table for saturation and (optional) O_2-deco (NIOSH standard at 1980, not OSHA)
- →Similar tables developed and got national standards in UK (1982), DE (1972), FR (1992)

1970 – 2000 – Tunnelling and Caisson

Oxygen decompression

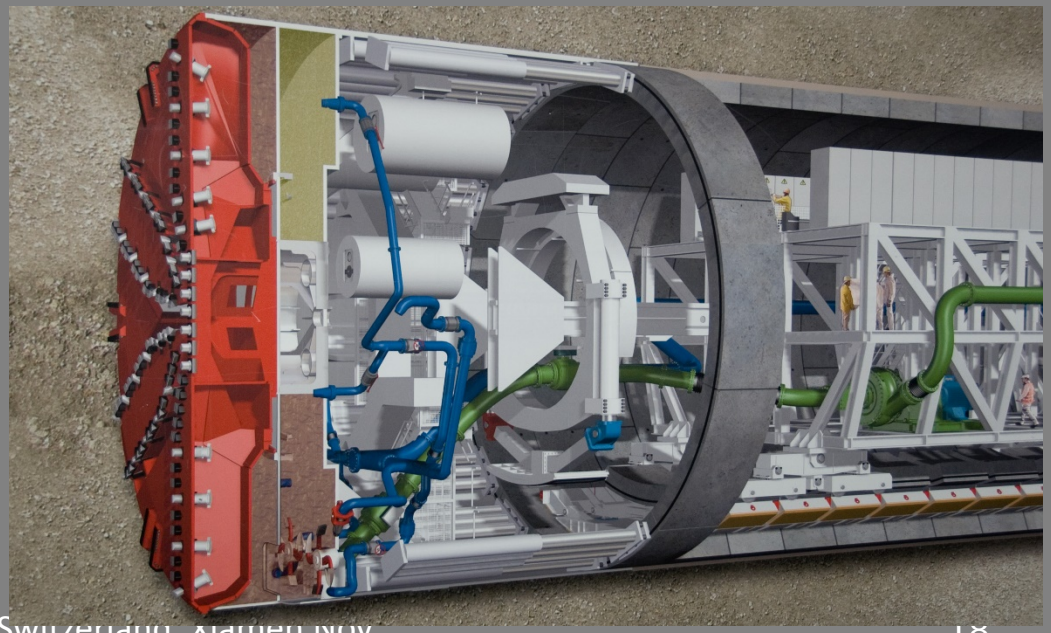
- 1970+: individual medical experts introduce O_2-deco in CAW: Brasil, France, Japan, Germany, NIOSH: better performance (shorter decompression) [40y after introduction in diving!]
- 2000: O_2-deco for tunnelling finally gets international standard (ITA guidance notes)

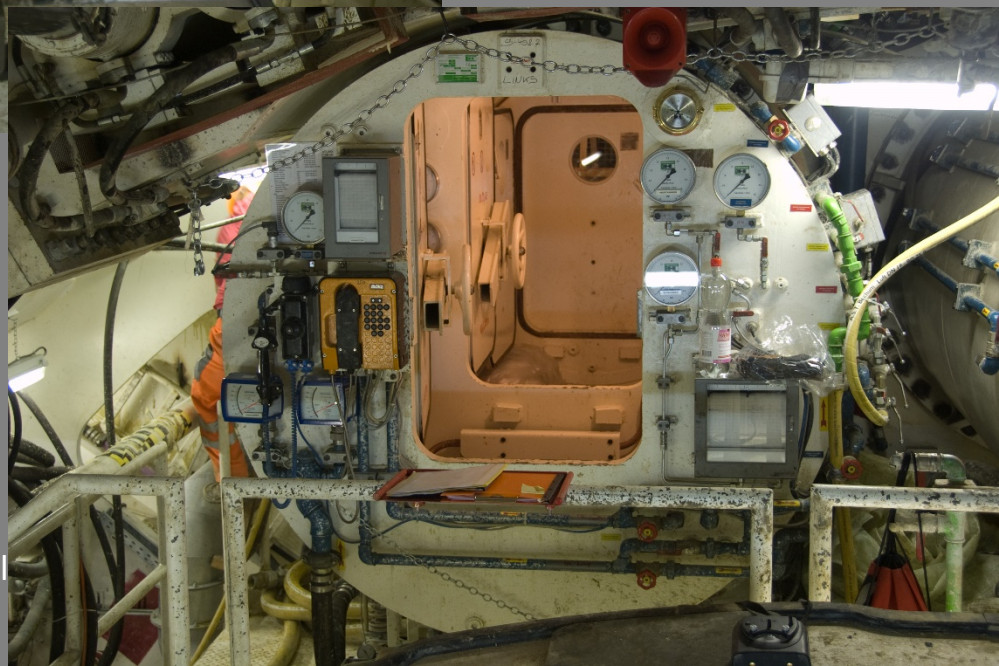
Sauerstoffdekompression



Actual practice in tunnelling

- ITA code of good practice for CAW is now worldwide recognised
- National H&S regulations limit operational depth to 30 – 35m
- Number of tunnel projects increasing
- CAW interventions get deeper and deeper (out of the range of accepted tables)

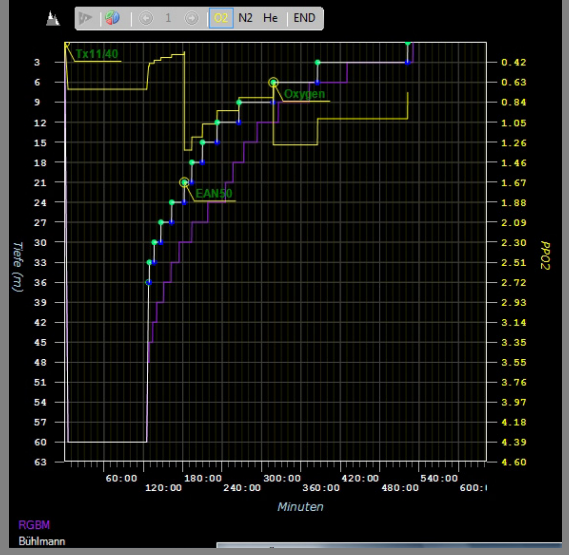


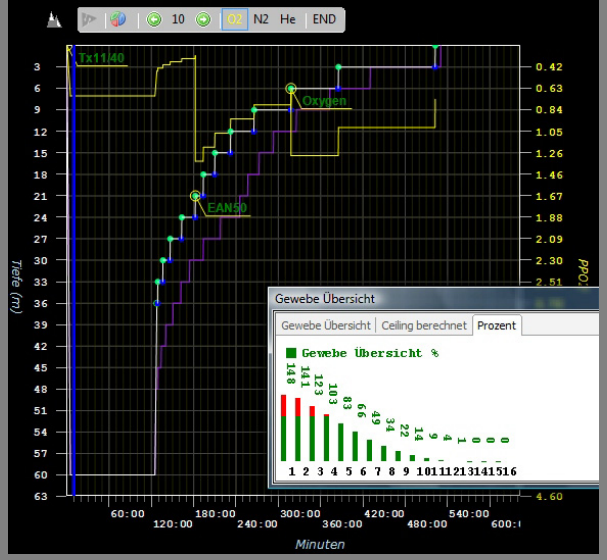


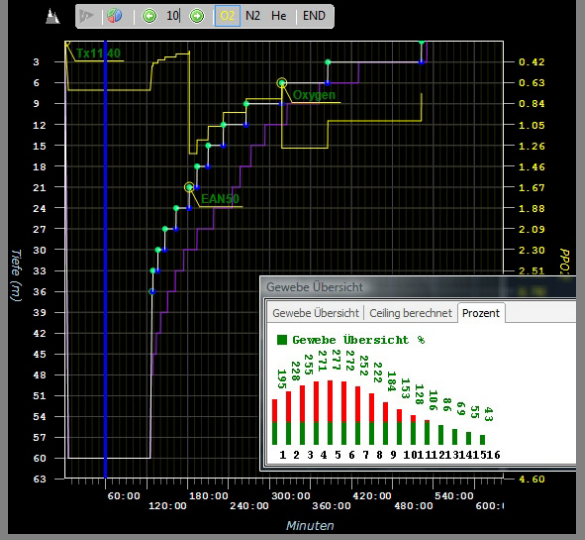
Evolution of municipal diving - Dr J Wendling, Switzerl
2017

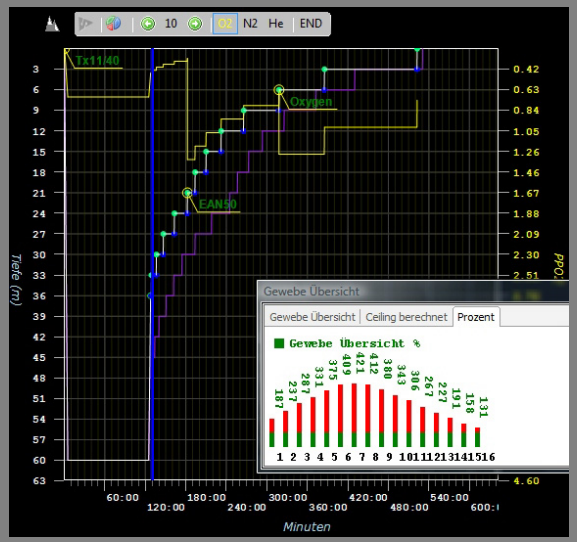
→ use of mixed gas (O_2/N_2/He) as working mix allows for deeper bounce interventions):

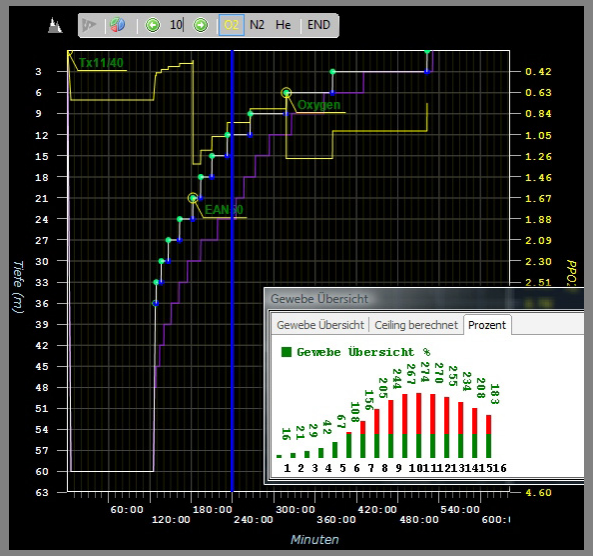
+ avoiding O2 toxicity
+ avoiding N2 narcosis
+ avoiding inacceptable work of breathing (WOB)
- Does not shorten total deco time
- Overall higher DCS risk and extremely long deco times make projects economically unfeasible

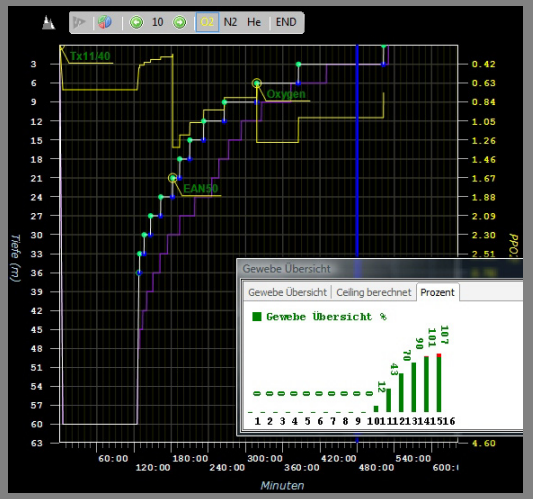

N2 He END
Tx11/40
Oxygen
EAN50
Tiefe (m)
PPO2
Minuten
RGBM
Bühlmann

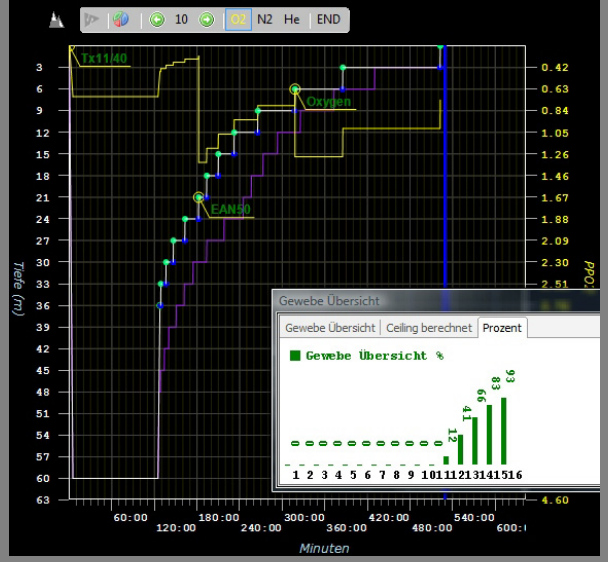

10
N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
148 141 123 103 83 66 49 34 22 14 9 4 1 0 0 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Tiefe (m)
Minuten

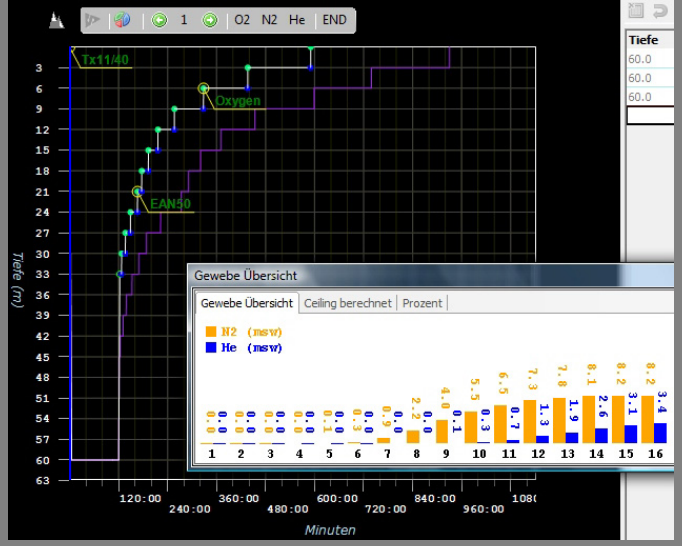

10
N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
195 228 235 271 277 272 252 222 184 153 120 106 86 69 55 43
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Tiefe (m)
Minuten

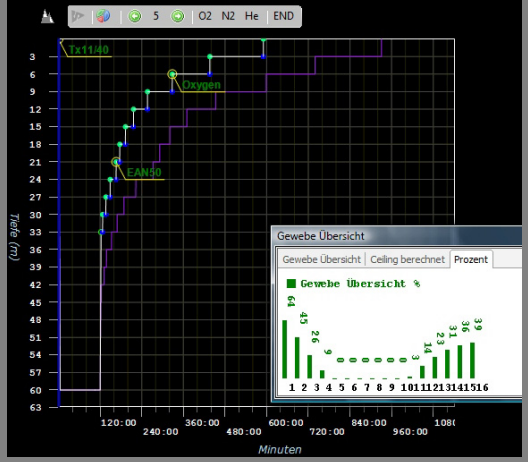

10
N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
187 237 287 331 373 409 421 432 380 343 306 267 227 191 158 131
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Tiefe (m)
Minuten

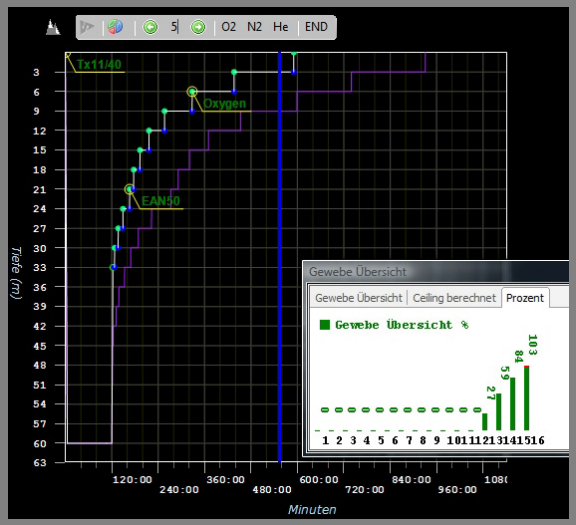

10
N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
16 21 21 42 67 108 156 205 244 267 274 270 255 234 208 183
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Tiefe (m)
Minuten

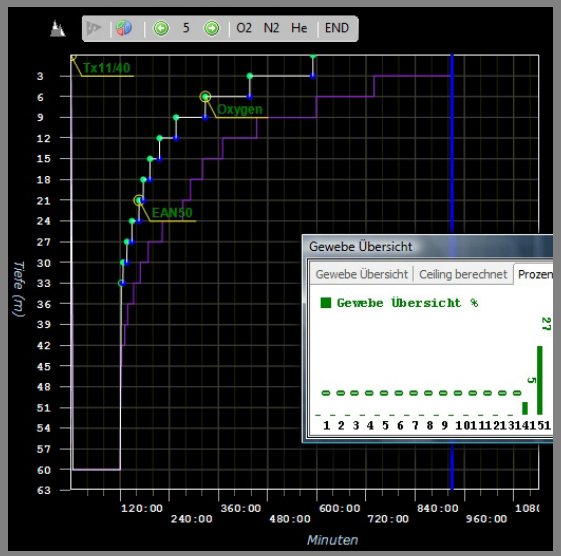

10
N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
0 0 0 0 0 0 0 0 0 12 43 70 98 101 107
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Tiefe (m)
Minuten


10
O2 N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
Tiefe (m)
Minuten


1
O2 N2 He END
Tiefe
60.0
60.0
60.0
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
N2 (msw)
He (msw)
Tiefe (m)
Minuten


5
O2 N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
Tiefe (m)
Minuten


5
O2 N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
Tiefe (m)
Minuten


5
O2 N2 He END
Tx11/40
Oxygen
EAN50
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozen
Gewebe Übersicht %
Tiefe (m)
Minuten


100
O2 N2 He END
Tx9/18
Oxygen
Gewebe Übersicht
Gewebe Übersicht | Ceiling berechnet | Prozent
Gewebe Übersicht %
Tiefe (m)
Minuten


100
O2
N2
He
END
Tx9/18
Oxygen
Tiefe (m)
Minuten
Gewebe Übersicht
Gewebe Übersicht
Ceiling berechnet
Prozent
Gewebe Übersicht %
45
53
61
68
79
92
102
111
119
128
137
149
164
183
203
231
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16


100
O2
N2
He
END
Tx9/18
Oxygen
Tiefe (m)
Minuten
Gewebe Übersicht
Gewebe Übersicht
Ceiling berechnet
Prozent
Gewebe Übersicht %
29
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

→ use of saturation technique (called MGSW) with habitat and TUP by a shuttle (closed bell) allows for safer interventions:

- Much less deco stress than daily bounce interventions
- Only one slow decompression at end of saturation (4 weeks)
- Much less risk of procedural "human errors"
- Much less psychological stress for MGSW
- Higher work efficiency and quality (long work shifts possible)
- High cost of investment and need for specially qualified personnel influence economical interest

- First tunnelling operations using sat technique:
  2003 in Westernshelde (NL), 65m
  2014 in Istanbul (TR), 110m
  2015 in Nanjing (China) and Hong Kong, 65m

- All projects were successful from H&S view:
  - no relevant traumatic accidents
  - no relevant DCS
  - technology adapted from offshore experience has proven to be reliable

2017


Close
Open

The future

→ going **deeper**:

Lessons learned from early projects:

- ppO_2 as low as reasonable
  Recent research shows that oxydative stress should be avoided in long term exposures (ppO_2 0.4 → 0.3 at storage?)
- ppN_2 as low as needed to avoid narcotic effects and stressing work of breathing (WOB) i.e. equivalent air depth ≤ 20m (ppN_2 2.4 bar)

→ going **safer**:

- Mixed gas bounce intervention to be considered from 25 – 50m (WOB, no narcotic effects)
- Sat operations may get economically and medically preferable from 30m upwards (MGSW can work 6h/d without need for deco during 4 weeks)

→ going **safer**:

- Deco from sat or Tx-bounce intervention
-
  - Should be monitored with US-bubble detectors, because there are no scientifically validated tables available
  - Safe procedures must be planned using a computer algorithm and a deco model which has to be up-to-date and "quasi validated" by multiple practical applications with acceptable or negligible incidence of DCS.
    (The hyperbaric medical advisor should propose such table or endorse them when provided from elsewhere).
  - An external audit of the procedures by an independent specialist will further ensure coherence to good practice.


handydop
ELCAT

Conclusions:

Bühlmann's (ZH research laboratory)
sat diving algorithm and deep mixed tables -
how they changed practice in occupational diving?

- ZHL Deep mixed gas tables had no impact
- Bü'Algorithm is again useful for setup and assessment of mixed gas procedures in tunnelling

Thank you ! Questions?