



USN Diving Manual Revision 6

Critical Changes that Affect You

Dr. Ed Flynn
CAPT John Murray MC USN

Naval Sea Systems Command
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Major Changes

- New Air Decompression Tables with In-Water Oxygen Decompression Capability
- Seamless Air/MK 16 Repetitive Diving
- Elimination of Air Surface Decompression Procedures
- Revised Flying After Diving Limits
- New Rules for Chamber Deployment
- New Rules for Multi-Day Oxygen Exposure



New Air Tables

- Why did we revise the 1957 tables?
- What algorithm did we use?
- What do the new tables look like?
- How do they compare to other tables?
- How did we test the tables?



Why Revise 1957 Tables?

- Safety
 - Widespread criticism by government and industry over many years
 - Ad hoc schedule jumping common in USN
 - Modification of tables common in industry
 - Newer tables prescribe longer decompression
 - Risk of DCS increases with increasing depth and bottom time.

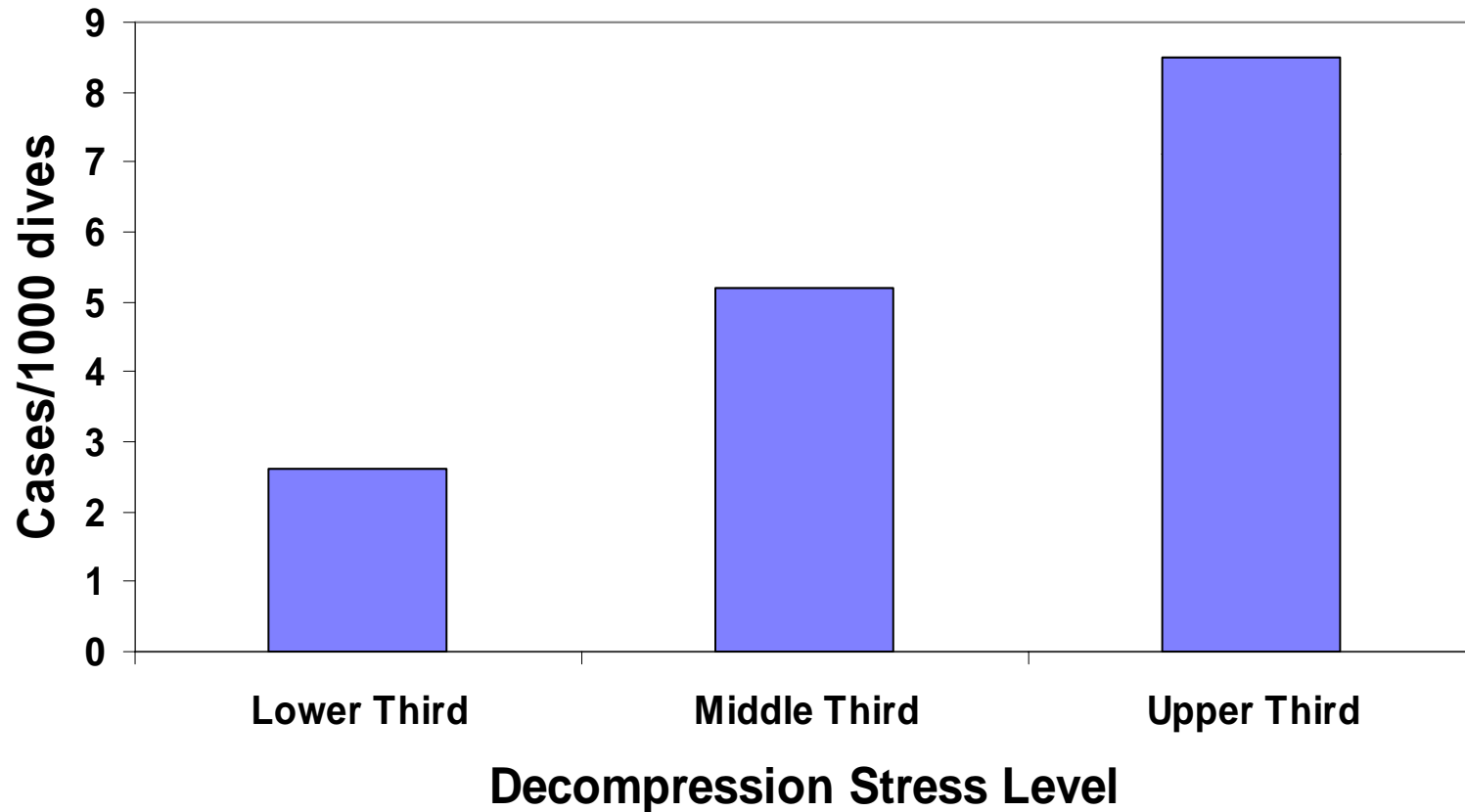


Why Revise 1957 Tables?

- Capability
 - SurDO₂ limited to 170 fsw for 40 min
 - No repetitive group designators for SurDO₂
 - No capability for in-water O₂ decompression
 - No capability to change decompression mode on the fly
 - Air and MK 16 repetitive group designators not compatible



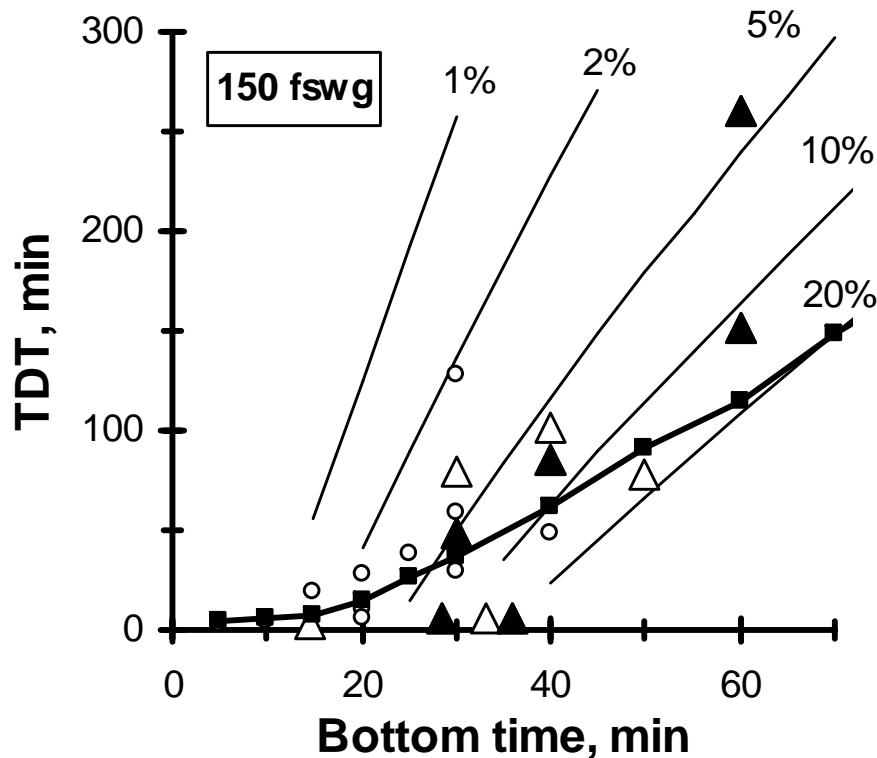
DCS Incidence with Standard Air Table 1971-96 (38,172 dives, 207 cases)





Safety Concerns Example

Standard Air at 150 fsw



- Circles -experimental dives with no DCS
- △ Triangles-dives with DCS
- ▴ Black Triangles-dives with DCS >2% with 95% certainty
- Standard Air does not provide enough decompression time



TWA 800 SurDO2 Experience 120-130 fsw

Prescribed Schedule	5/34	14.7 %
Schedule + 1 Jump	1/56	1.8 %
Schedule + 2 Jumps	0/303	0.0 %
Schedule + 3 Jumps	2/290	0.7 %

RCC Oxygen Time (min)

No Jump	3 Jumps	Canada	VVal-18
120/60	32	51	60

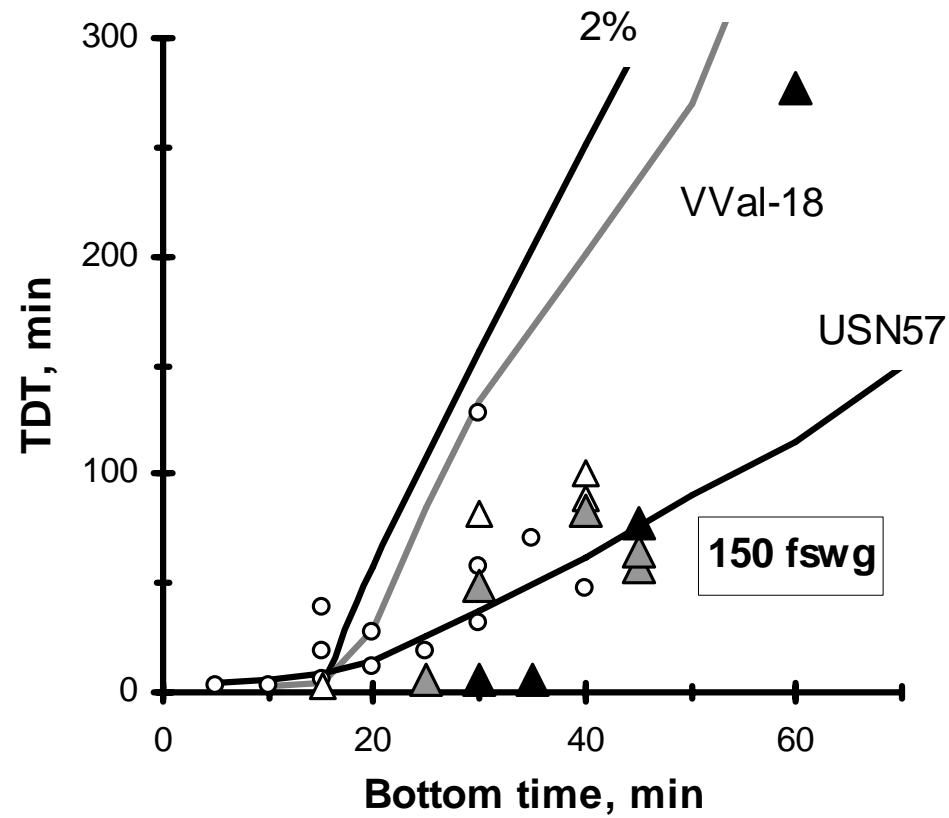


VVal-18 Algorithm

- Developed by CAPT Ed Thalmann in 1983
- Features
 - Nine tissue compartments
 - Exponential uptake, linear washout of inert gas
 - Ascent controlled by VVal-18 M-value matrix
- Basis of
 - USN MK 16 constant PO_2 tables
 - Navy Decompression Computer



VVal-18 vs. USN 57



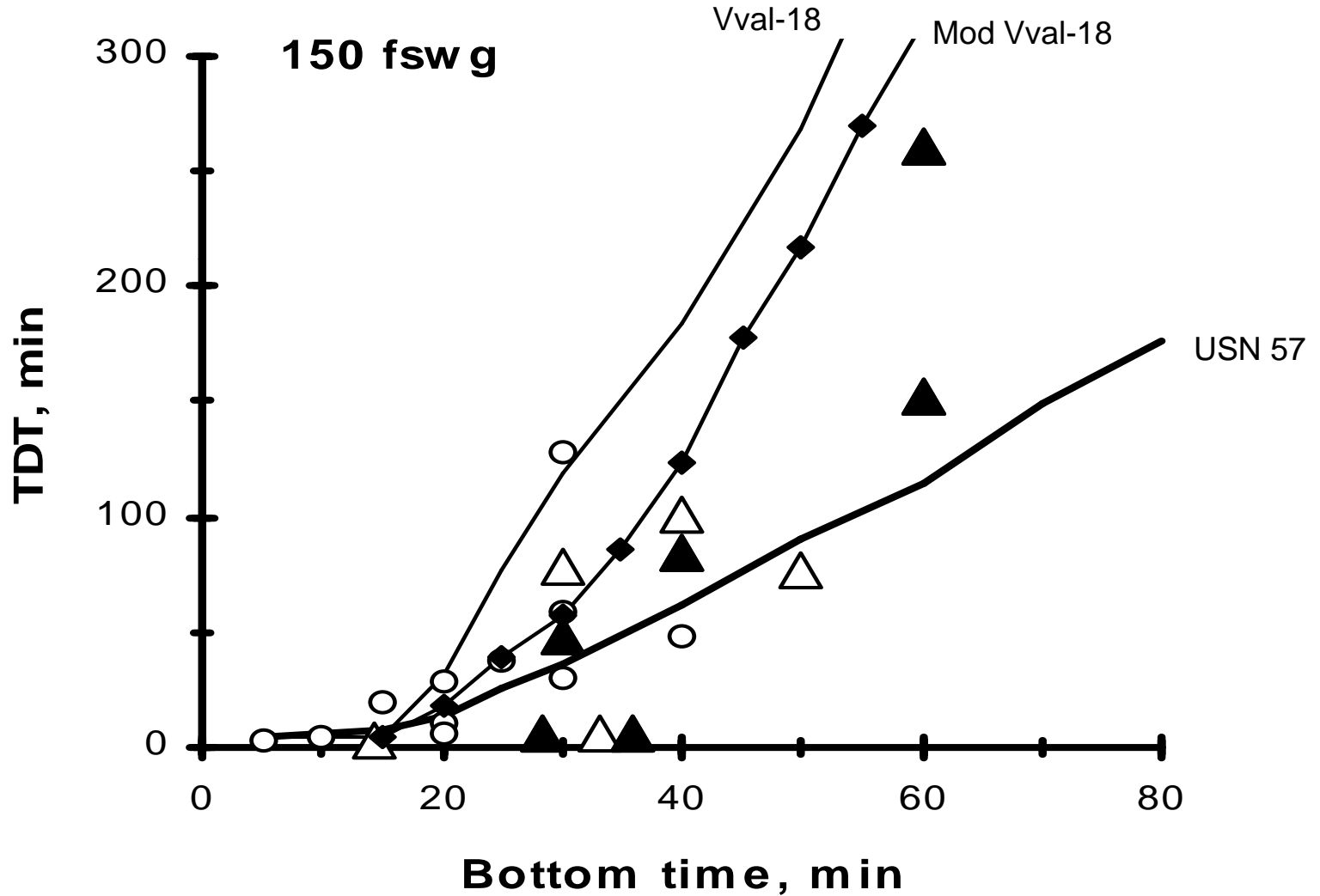


VVal-18 Algorithm Modified

- For air decompression
 - Increase bubble overpressure (PBOVP) from 0 fsw to 10 fsw to shorten air stop times
- For oxygen decompression
 - Keep bubble overpressure at 10 fsw
 - Reduce sat/desat ratio from 1 to 0.7 to re-lengthen oxygen stop times.
 - Consistent with reduced tissue blood flow on O₂
- Modifications do not affect no-stop times



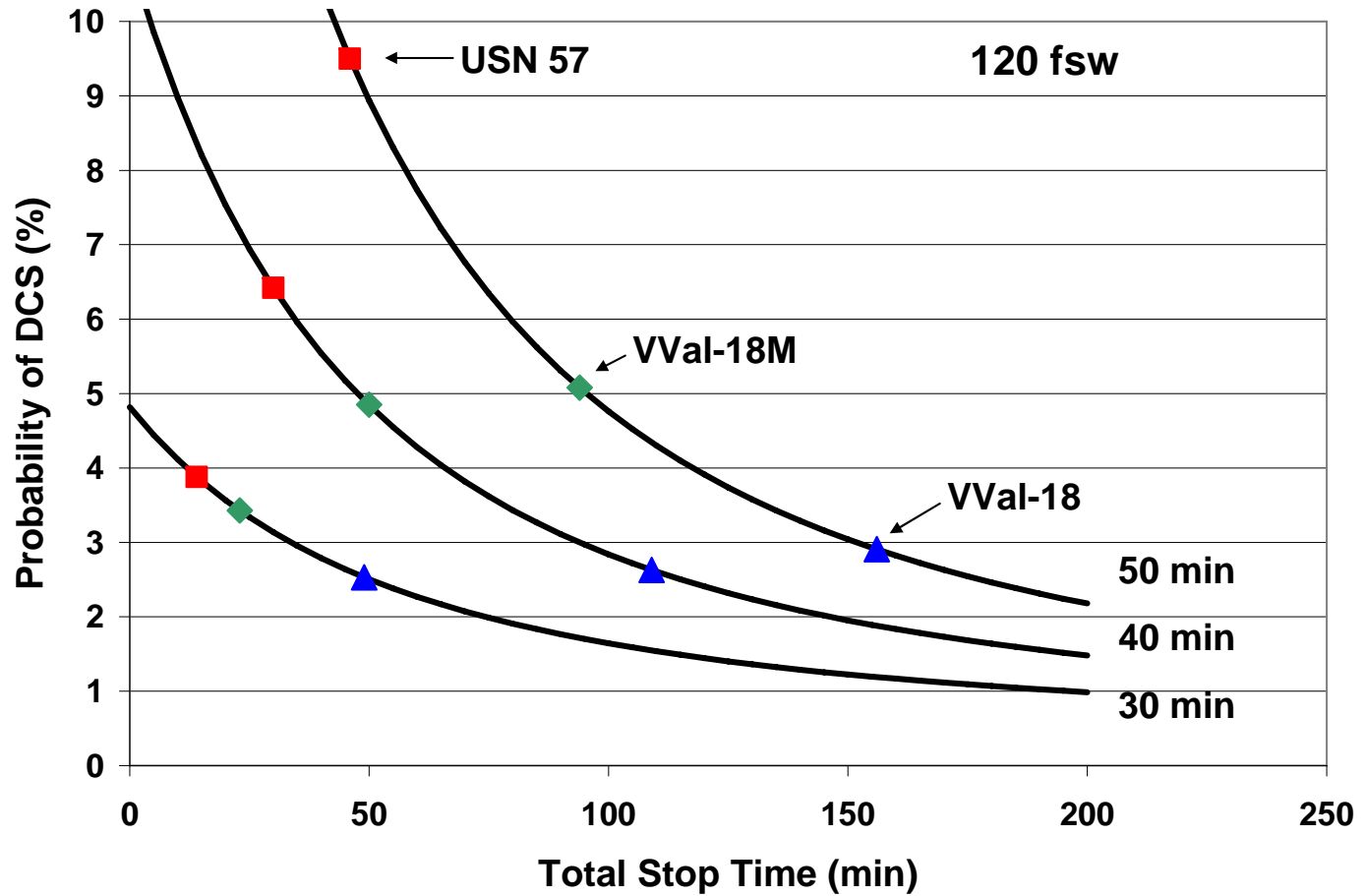
VVal-18 Mod Vs Experimental Data at 150 fsw





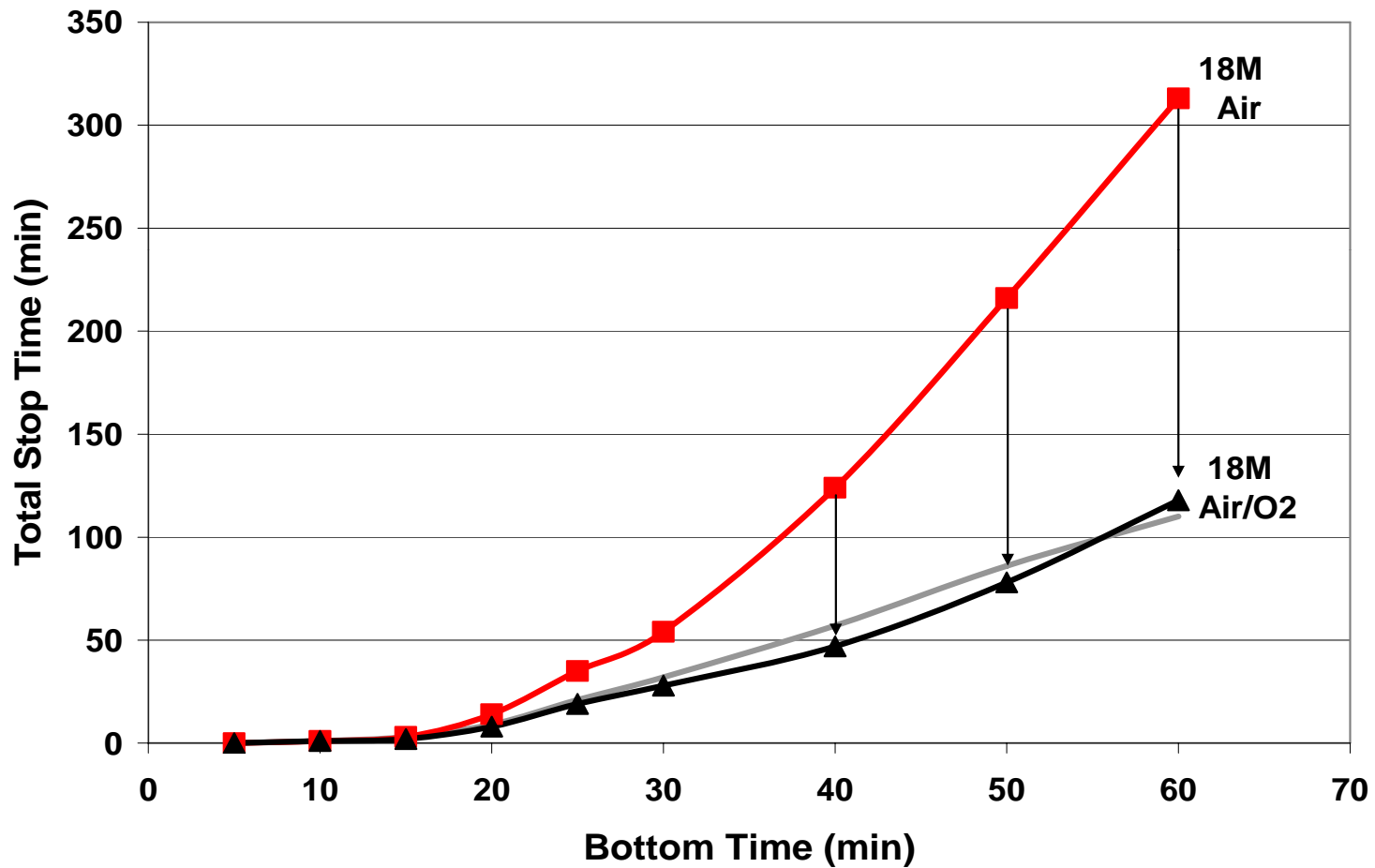
VVal-18M vs. USN 57

120 fsw



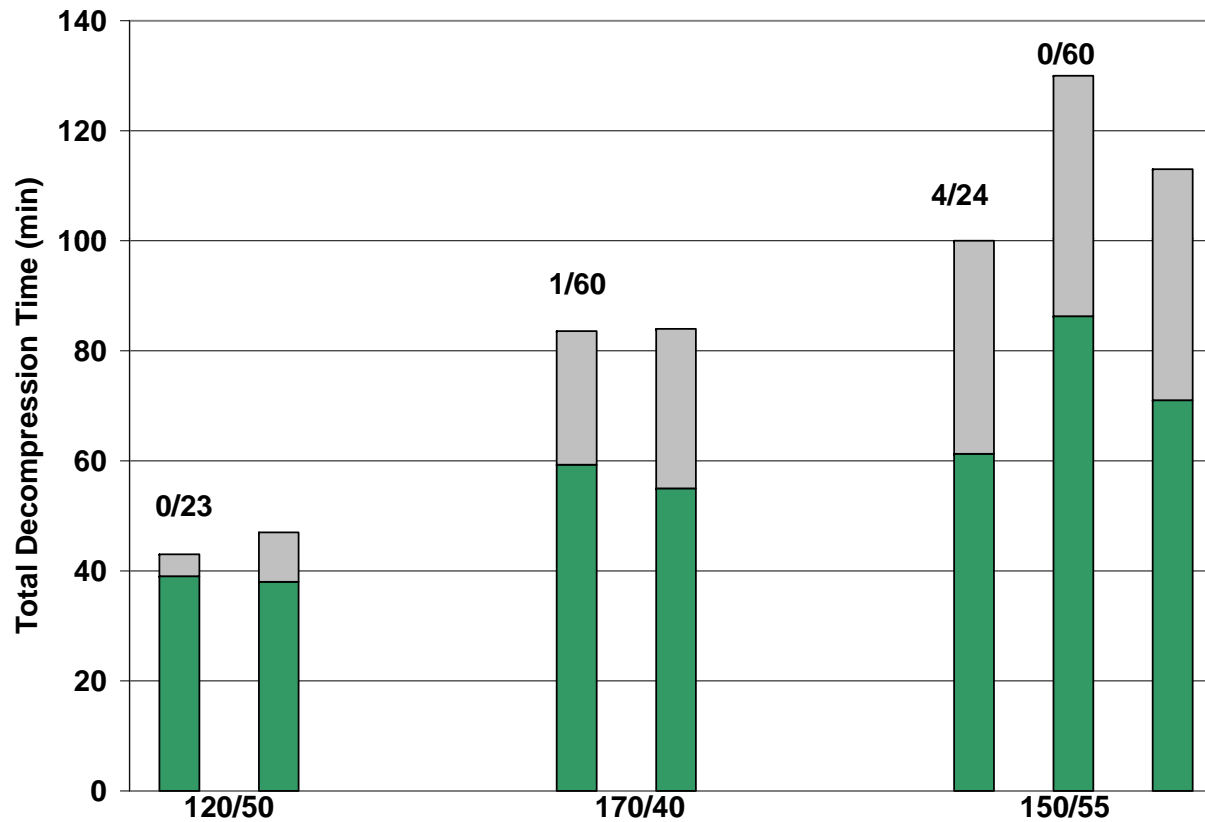


Reduction of TST with In-Water Oxygen—150 fsw





VVal-18M vs. Experimental Oxygen Decompression Data



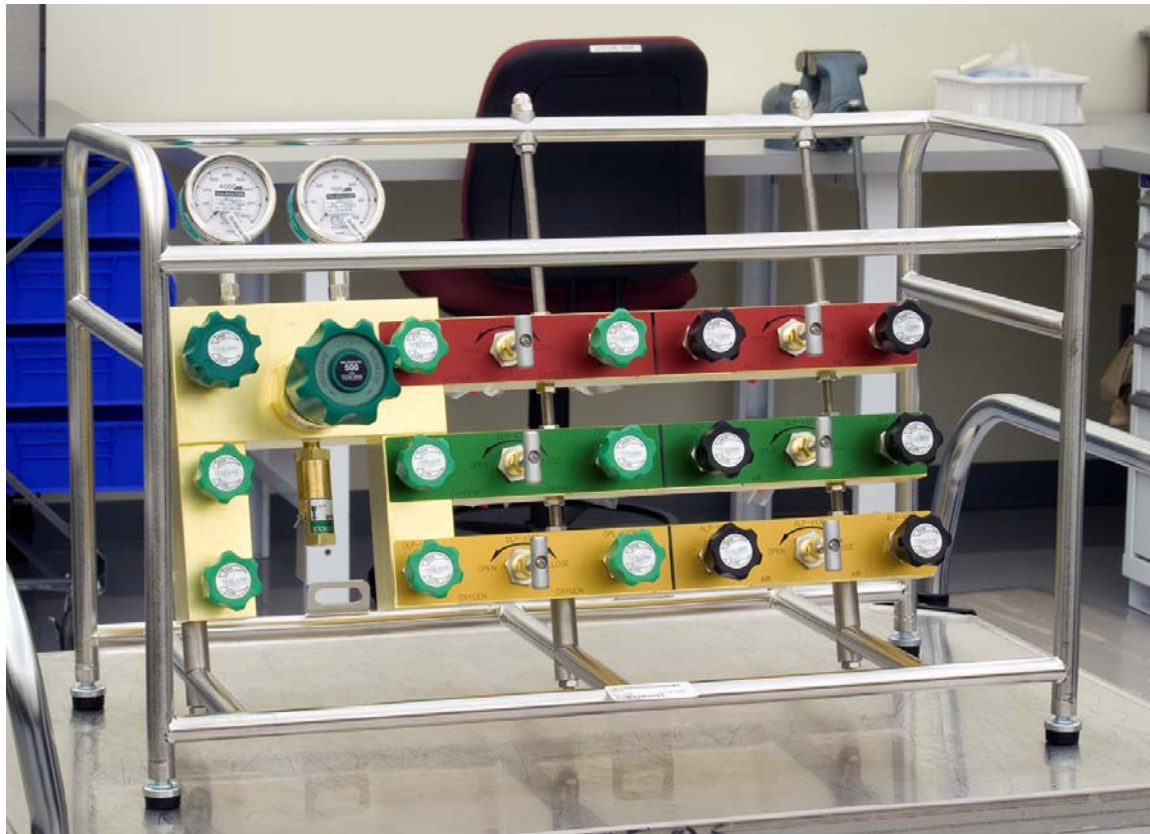


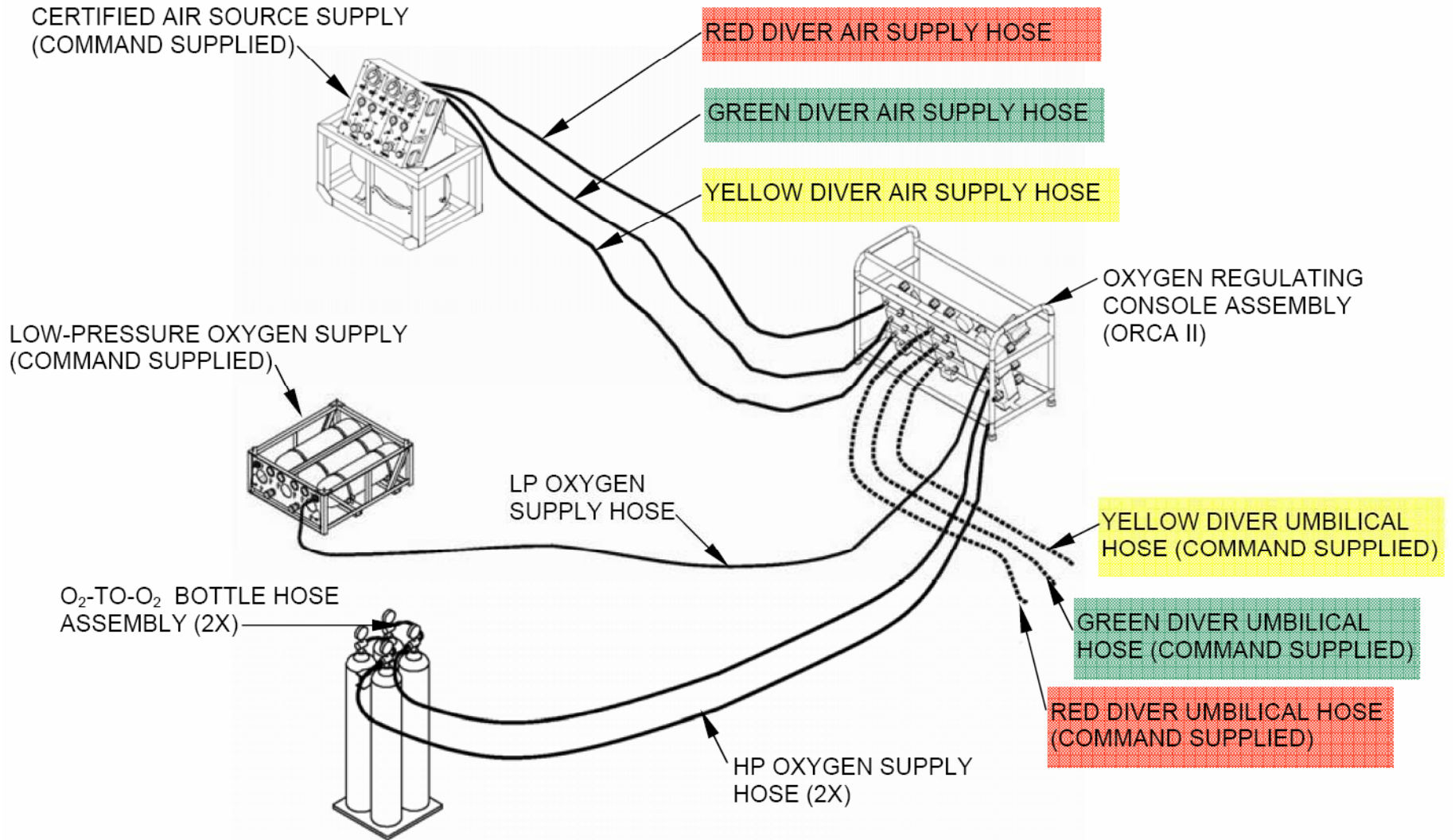
DCS Risk with Air and O₂ 120 fsw

Bottom Time	Air		Air/O ₂	
	<u>TDT</u>	<u>Pdcs</u>	<u>TDT</u>	<u>Pdcs</u>
25	12	2.20	8	1.96
30	28	2.62	17	2.17
40	55	4.18	31	2.71
50	99	5.81	47	3.28
60	173	7.17	62	3.74



ORCA II







New Air Table Set

- **Air Decompression Table** which gives the decompression schedules and repetitive group designators.
- **No-Decompression Table** which gives the no-decompression limits and repetitive group designators for no-decompression dives.
- **Surface Interval Credit Table**
- **Residual Nitrogen Time Table**
- **Flying After Diving Table**



Air Decompression Table

- Contains schedules for 3 modes of ascent
 - Air decompression in water
 - Air/O₂ decompression in water
 - SurDO₂
- Upon completion of 40 fsw stop
 - Complete decompression on air at 30/20 fsw
 - Complete decompression on O₂ at 30/20 fsw
 - Surface and complete decompression on O₂ in RCC



Surface Decompression on Oxygen

- Rules identical to Surface-Supplied Heliox
 - Surface upon completion of 40 fsw stop
 - Surface interval not to exceed 5 min
 - Recompress to 50 fsw. Breathe O₂ for 15 min
 - Ascend to 40 fsw. Complete remaining chamber O₂ time at 40 fsw
- Air Decompression Table gives number of O₂ periods required
 - Each O₂ period 30 min long
 - 5 min air break after each O₂ period



20 fsw Last Stop

- Choice based on operational considerations
- Animal evidence supports superiority over 10 fsw during decompression on air
 - Hills BA, J. Appl Physiol., 1968
 - Hills BA, Clinical Science, 1970
- Inherently superior to 10 fsw during oxygen decompression
- Standard for all tables in Manual except MK 16 MOD 0, where it is optional.
- Tables can be recomputed for 10 fsw



Air Decompression Table

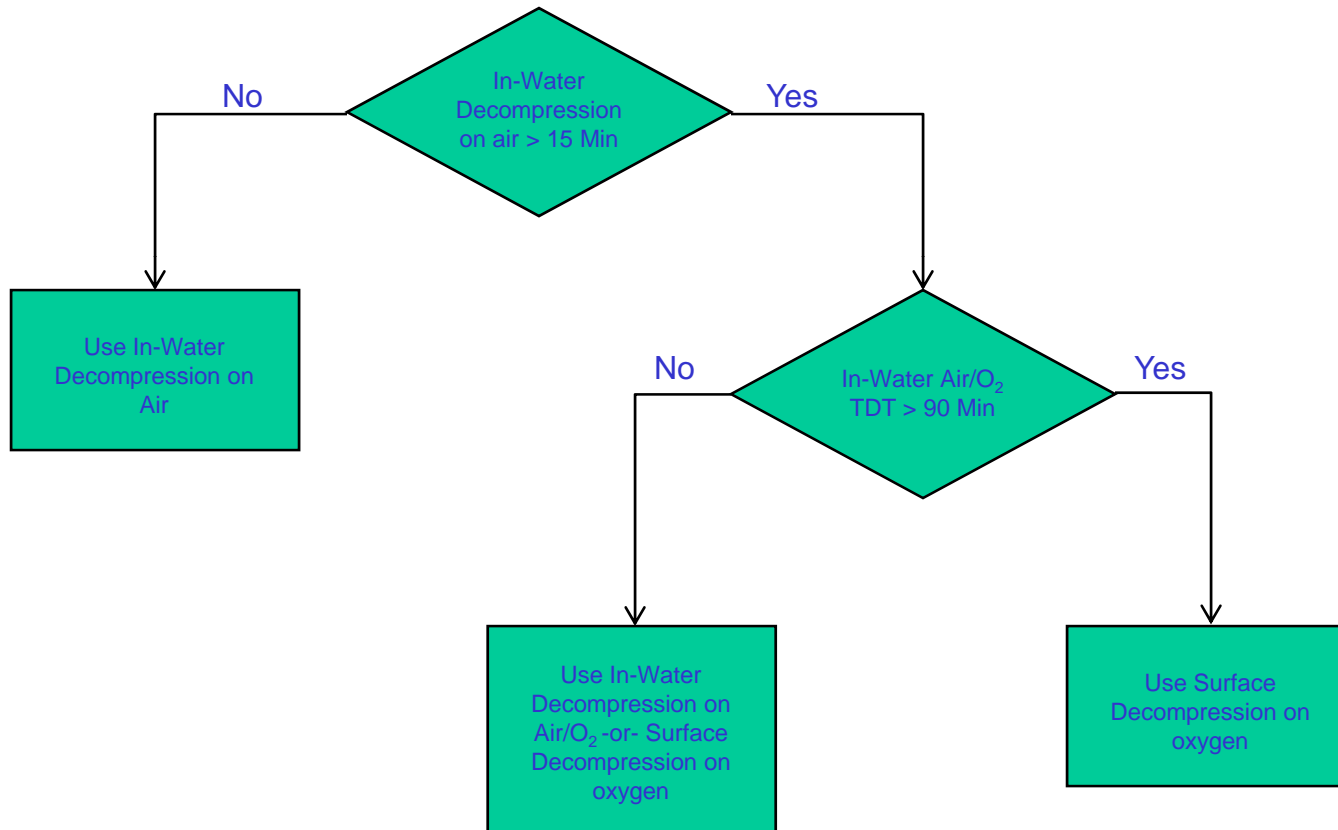
150 fsw

150 fsw

Bottom Time(min)	Gas Mix	80	70	Decompression Stops (fsw)				20	Total Ascent Time (M:S)	Chamber O2 Periods	Repetitive Group
				60	50	40	30				
5	Air Air/O2							0 0	5.00 5.00	0	C
10	Air Air/O2							1 4	6.00 9.00	0.5	F
15	Air Air/O2							3 5	8.00 10.00	0.5	H
20	Air Air/O2							13 10	18.00 15.00	0.5	K
25	Air Air/O2							34 21	39.00 26.00	1	M
30	Air Air/O2						3 5	50 26	58.00 36.00	1.5	O
35	Air Air/O2						11 9	70 30	86.00 49.00	1.5	Z
40	Air Air/O2				4 4	17 13	99 32	125.00 59.00		2	Z

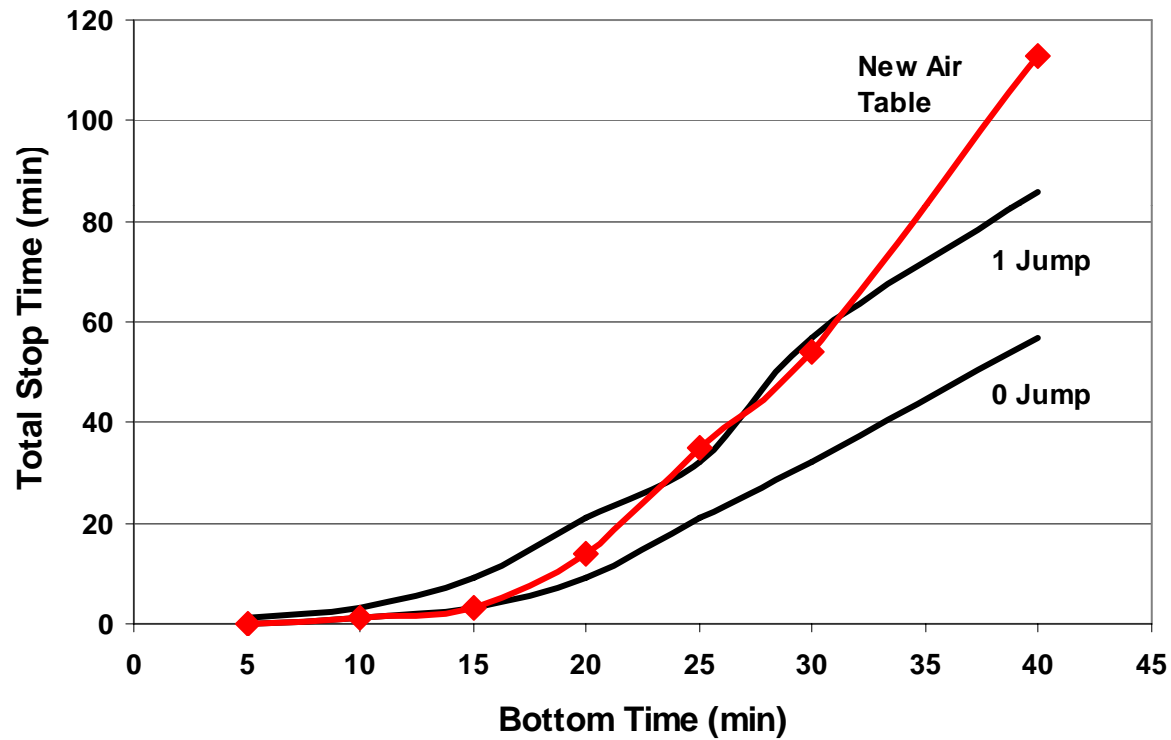


Table Selection



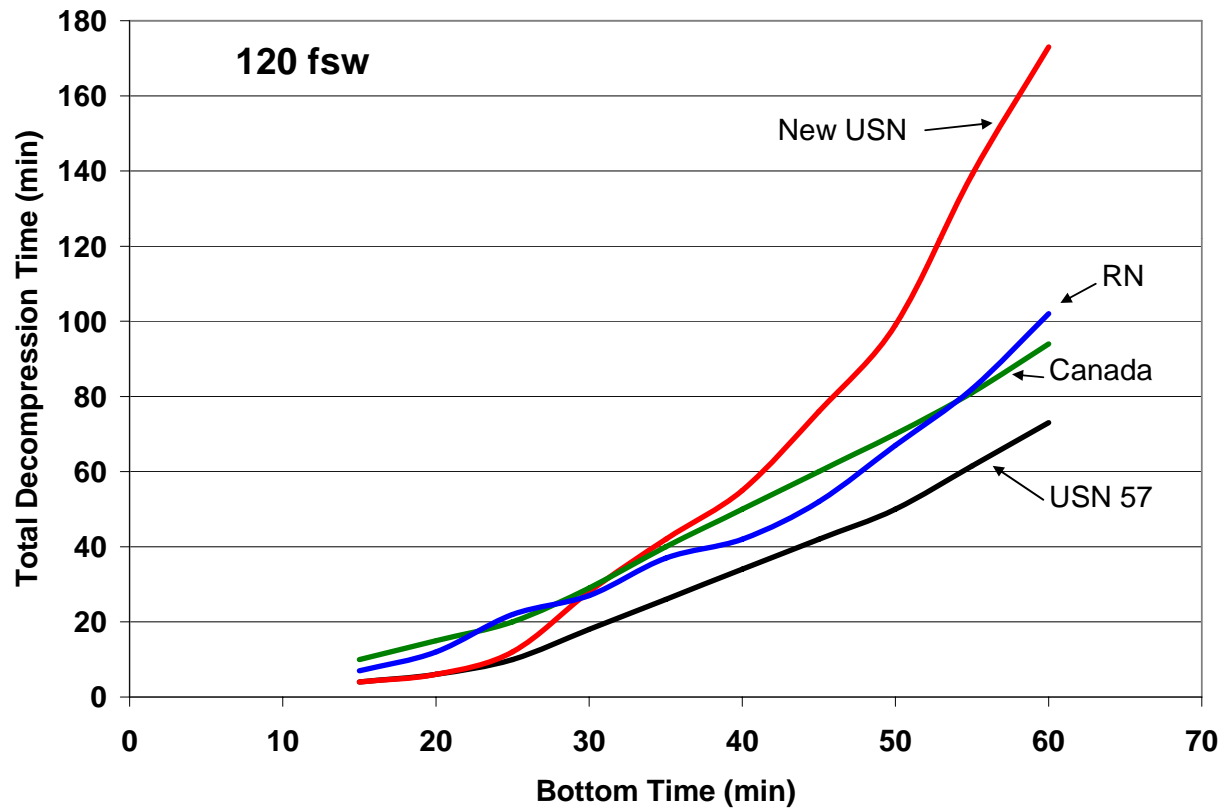


VVal-18M vs. USN 57 150 fsw Air Dive



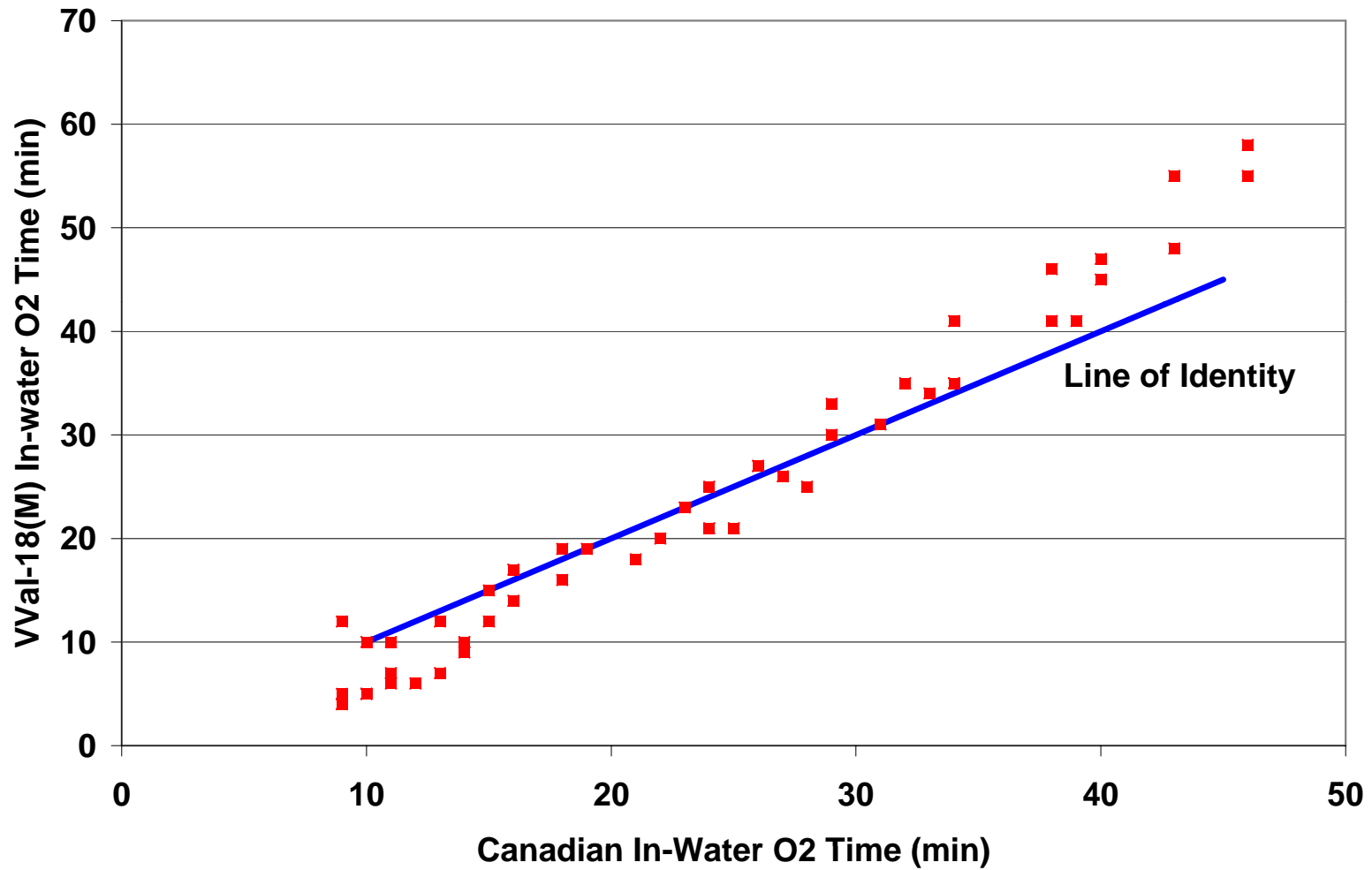


Comparison with Other Air Tables



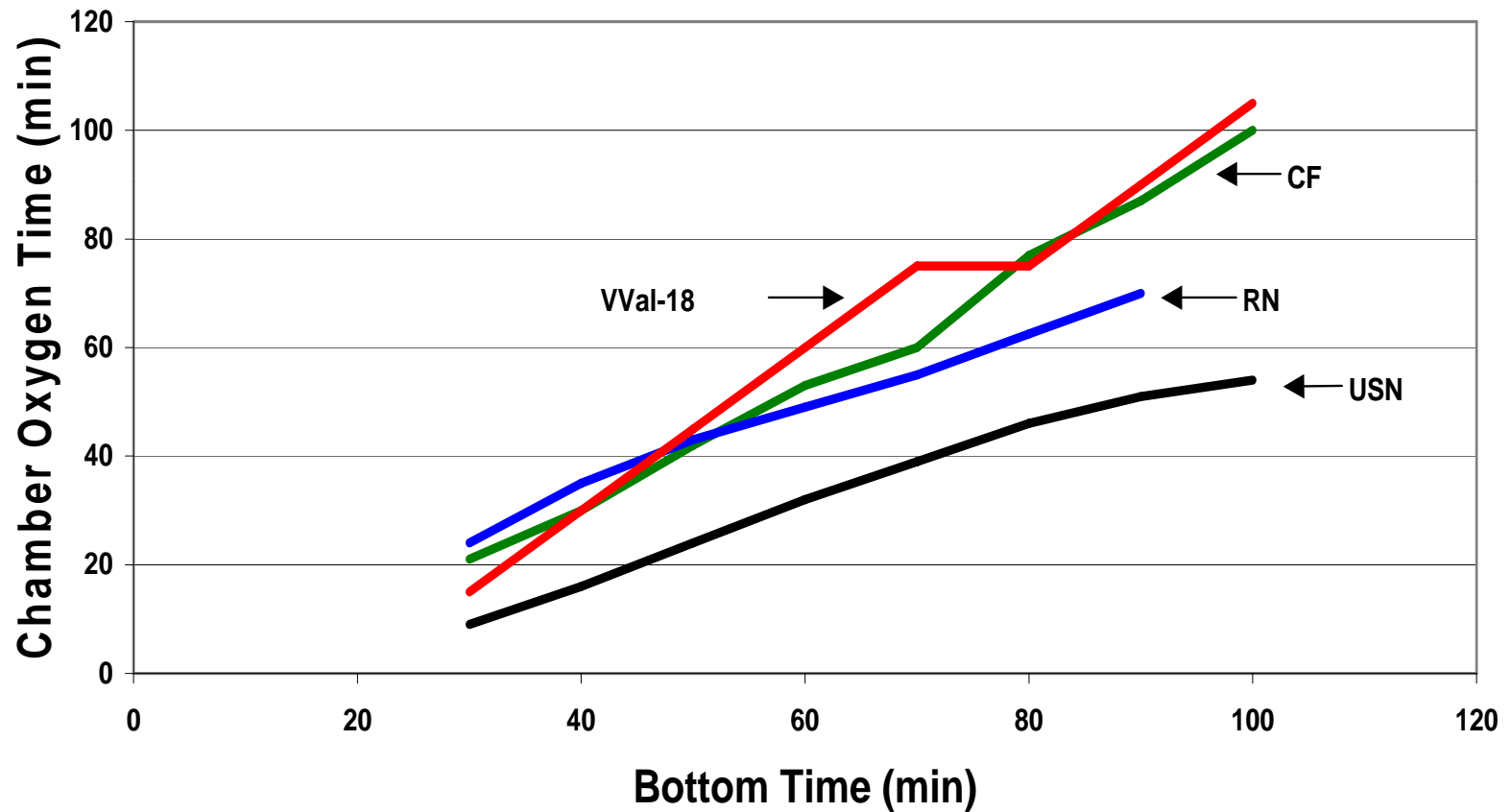


In-Water Oxygen Times





Chamber Oxygen Time 120 fsw Sur D O₂ Dive





Testing

No formal laboratory testing

- Schedules felt to be inherently safer than existing USN 57 schedules
- Safety of in-water oxygen validated in Canada

Field testing

- Ulithi Atoll (USS Mississinewa oil removal)
- Apra Harbor, Guam
- La Maddalena, Italy (Emory S. Land cleanup)



2003 SurDO2 Testing U.S.S. MISSISSINEWA

DEPTH	BOTTOM TIME	OUTCOME
(fsw)	(min)	
83-90	46-99	0/78
91-100	44-108	0/22
104-110	41-74	0/16
112-114	32-53	0/6
	Total	0/122



2007 Field Test Results

USS Emory S. Land Cleanup

<u>Mode</u>	<u>Depth</u>	<u>Bottom Time</u>	<u>Outcome</u>
Air	60-120	25-80	0/26
Air/O ₂	55-120	25-110	0/133
SurDO ₂	60-130	20-90	0/291
		Total	0/450



VVal-18 vs. USN 57 Shallow No-D Limits (min)

<u>Depth</u>	<u>USN 57</u>	<u>VVal-18</u>
25 fsw	595	1103
30 fsw	405	372
35 fsw	310	232
40 fsw	200	164
50 fsw	100	92
60 fsw	60	63



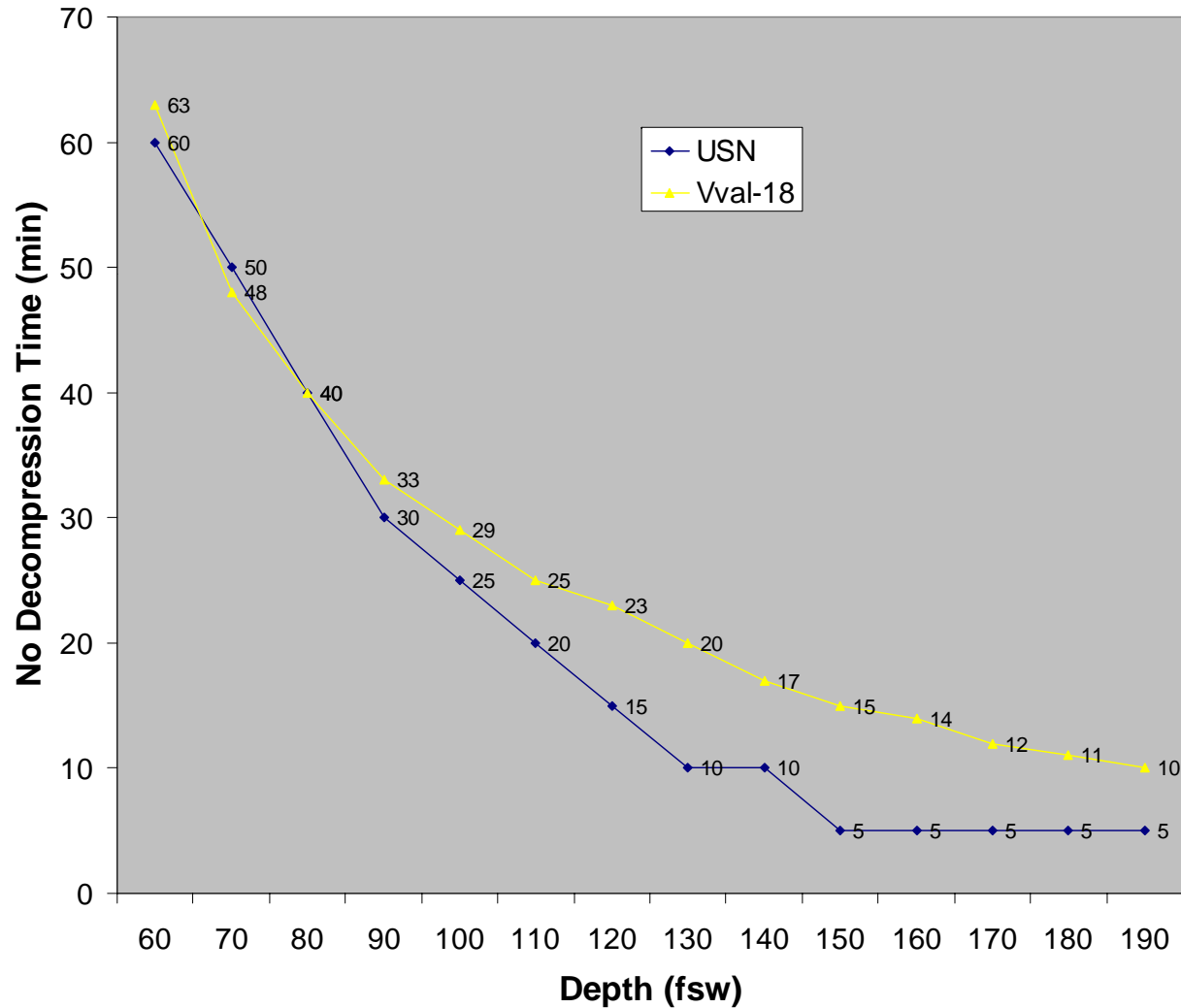
Experience with 40 fsw 200 min No-D Limit

- NMRI Study (103 subjects, 3 cases of DCS)
 - Auditory/cerebral DCS, residual memory loss after multiple treatments
 - Cutis marmorata, scintillating scotoma
 - Elbow pain
- Seaward Marine CVN hull cleaning ops
 - 11 cases of DCS, 9 Type II over 20 years
 - Dizziness, blurred vision, confusion, weakness
 - 200 min no-d dives restricted to depth of 37 fsw



VVal-18 vs. USN 57

No Decompression Time



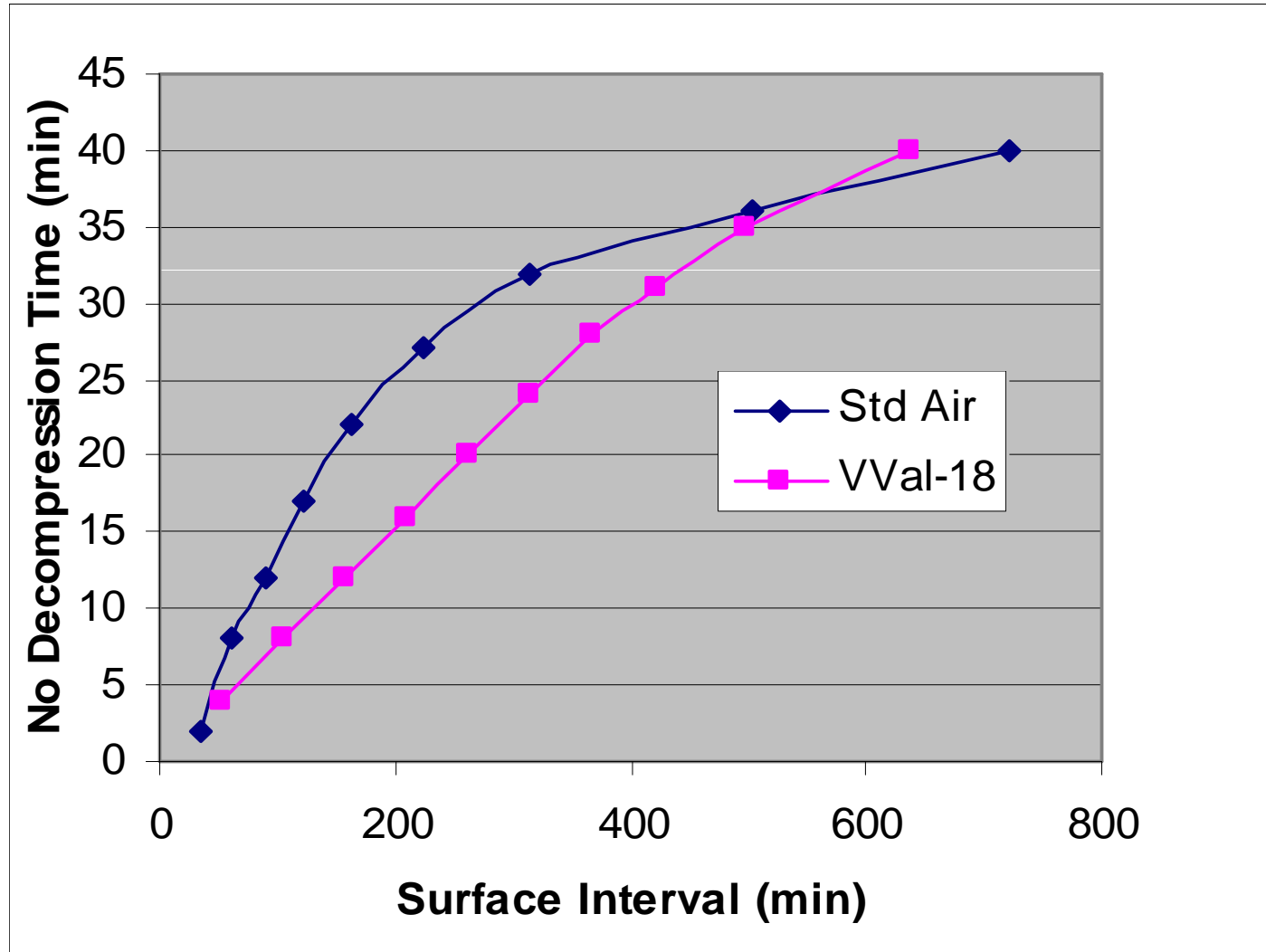


Repetitive Dive Clean Time

Repet Group	Hr:Min
A	2:20
D	5:23
G	8:00
J	10:36
L	12:21
N	14:05
Z	15:50

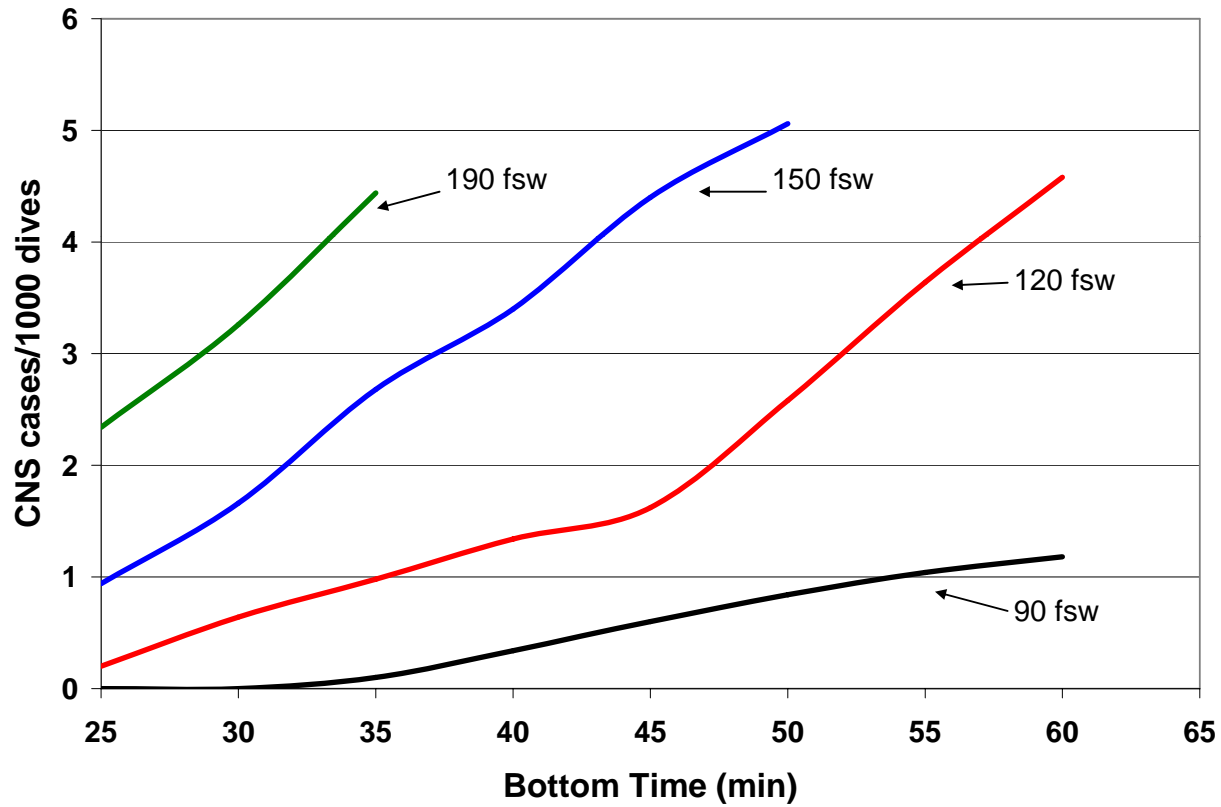


Allowable No-D Time at 80 fsw after 80 /40 No-D dive





CNS Oxygen Toxicity Risk





Ascent Rate and Stop Time

- 30 fsw/min standard for all tables in Manual
- Ascent time between decompression stops included in the subsequent stop time
 - Standard for all tables in Manual
 - Required re-computation of MK 16 Nitrogen-Oxygen and Helium-Oxygen Tables for Revision 6.



Recompression Chamber Requirements

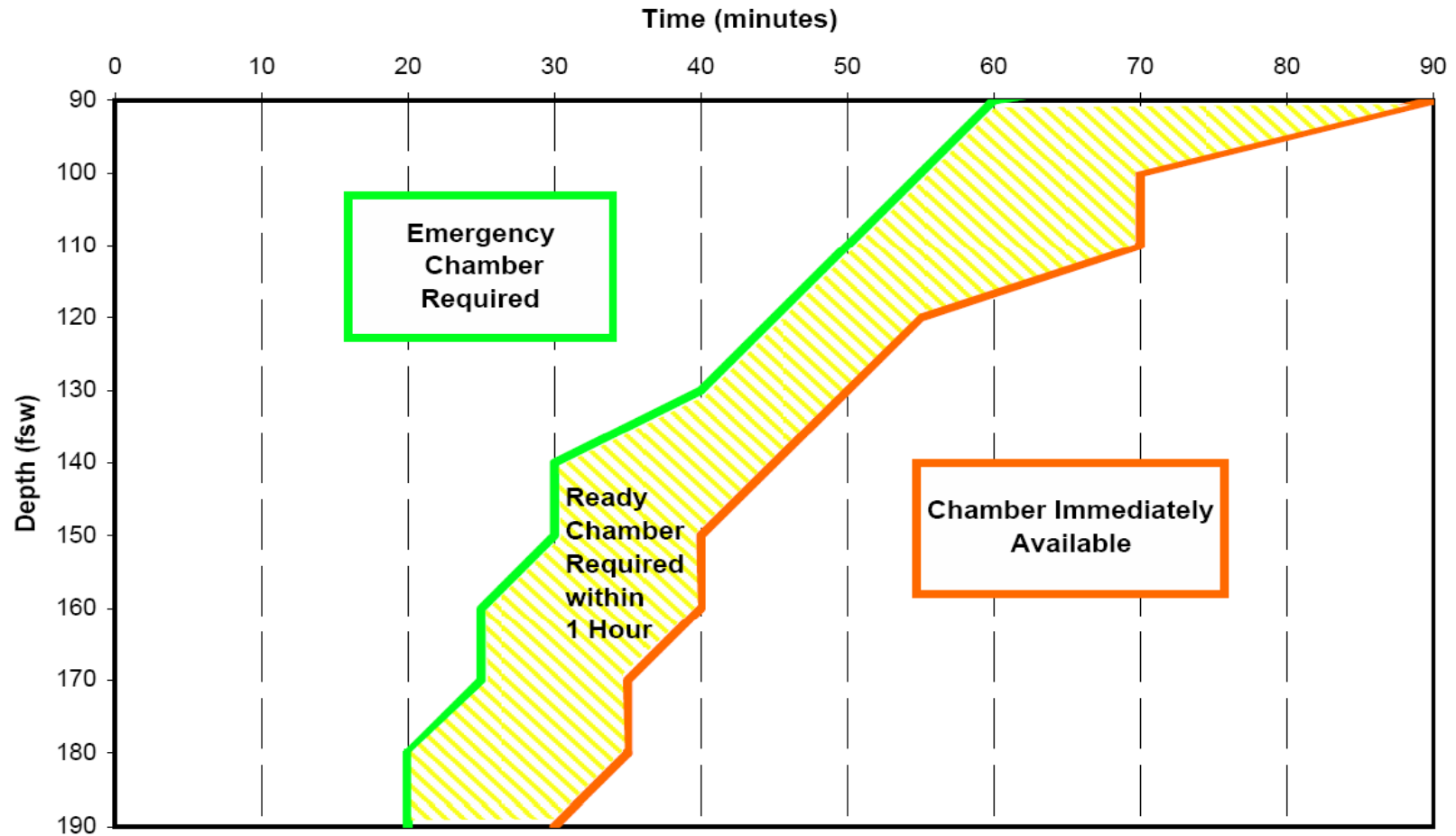


Figure 9-23 - Air Diving Recompression Chamber Requirements, 90 - 190 Feet.



Required Surface Interval Before Flying to 8,000 Feet

<u>Repet Group</u>	<u>Old Time</u>	<u>New Time</u>
C	0:00	0:00
D	3.28	1:45
G	12:05	9:13
J	17:35	14:13
M	21:37	18:00
Z	24:00	21:01



Multi-day Oxygen Exposure Limits

- For MK 16 MOD 1 ($PO_2 = 1.3 \text{ atm}$)
 - Maximum of 4 hours dive time per day
 - Maximum of 16 hours dive time per week
 - If pulmonary or visual symptoms develop, stop diving until symptom free for 24 hours
- Limits for other PO_2 exposures not yet established



New USN Air Tables -Advantages-

- Improves safety compared with current tables
- Provides SurDO₂ capability to 190 fsw
- Provides repetitive dive capability after SurDO₂
- Provides in-water O₂ decompression
 - Alternative to SurD for contaminated water
 - Reduces water time to acceptable level
- Allows repetitive diving between all modes of air and nitrox diving
- Repetitive group designator allows interface with VVal-18 based computers



New Air Tables -Disadvantages-

- Long decompression times on air force greater use in-water O₂ or SurD O₂ options
- Logistic burden correspondingly increased
- Small but finite risk of CNS oxygen toxicity exists with in-water oxygen decompression
- Oxygen cleanliness rules must be followed
- Shorter 35-40 fsw No-D times will impact ship husbandry dives unless computers used
- Repetitive dive rules less permissive; some clean times greater than 12 hours



Summary

A new way of diving air

- Emphasis on use of oxygen for all but the shortest decompression dives
 - Either in-water oxygen decompression or SurDO₂
 - Allows a increase in safety without an increase in in-water decompression time



Acknowledgements



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Shallow versus Deep Stops

Gerth et al., 2008

170 fsw/30 min Air Dive, TDT = 174 min

Decompression profile

	<u>70</u>	<u>60</u>	<u>50</u>	<u>40</u>	<u>30</u>	<u>20</u>	<u>10</u>
Shallow Stops:	0	0	0	9	20	52	93
Deep Stops:	12	17	15	18	23	17	72

Outcome

- Shallow Pattern: 3 hits in 192 dives
- Deep Pattern: 11 hits in 198 dives



Dive Frequency at 120 fsw 1979-1996

Bottom Time	No. Dives
20	539
25	571
30	390
40	295
50	91
60	10



Oxygen Hazard Mitigation

Material Selection Evaluation

- Metals (Evaluate IAW ASTM G94)
- Non-Metals (Evaluate IAW ASTM G63)
- System Design (Evaluate IAW ASTM G88)

System Cleanliness

- MIL-STD-1330 (Navy Use)
- ASTM G93 Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments

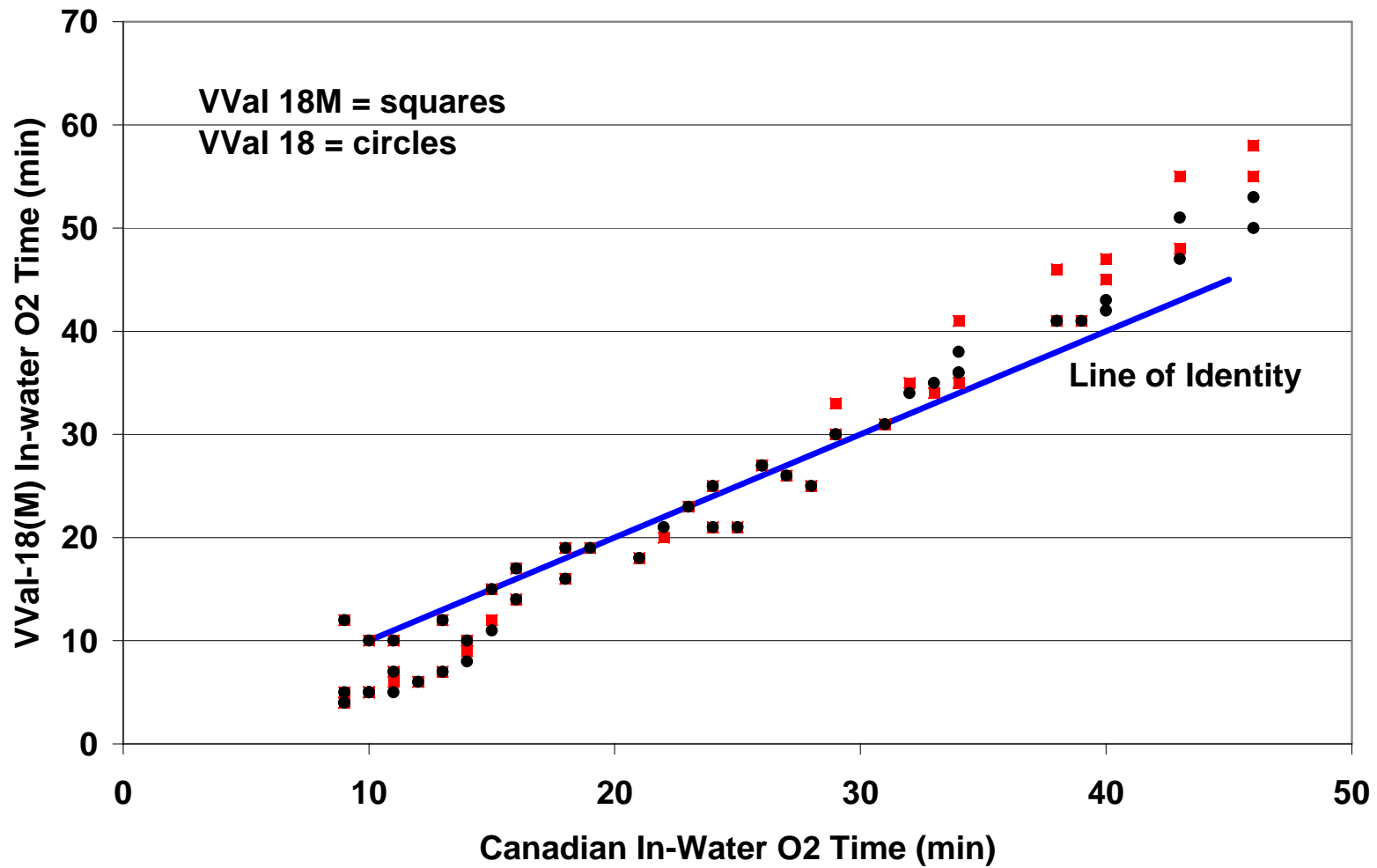
Training of Personnel

- Maintaining System Cleanliness
- Dangers of Oxygen Systems
- Oxygen System Operation Guidelines

Any questions regarding oxygen safety and hazard mitigation can be addressed to Mr. Ryan Webb following this presentation.

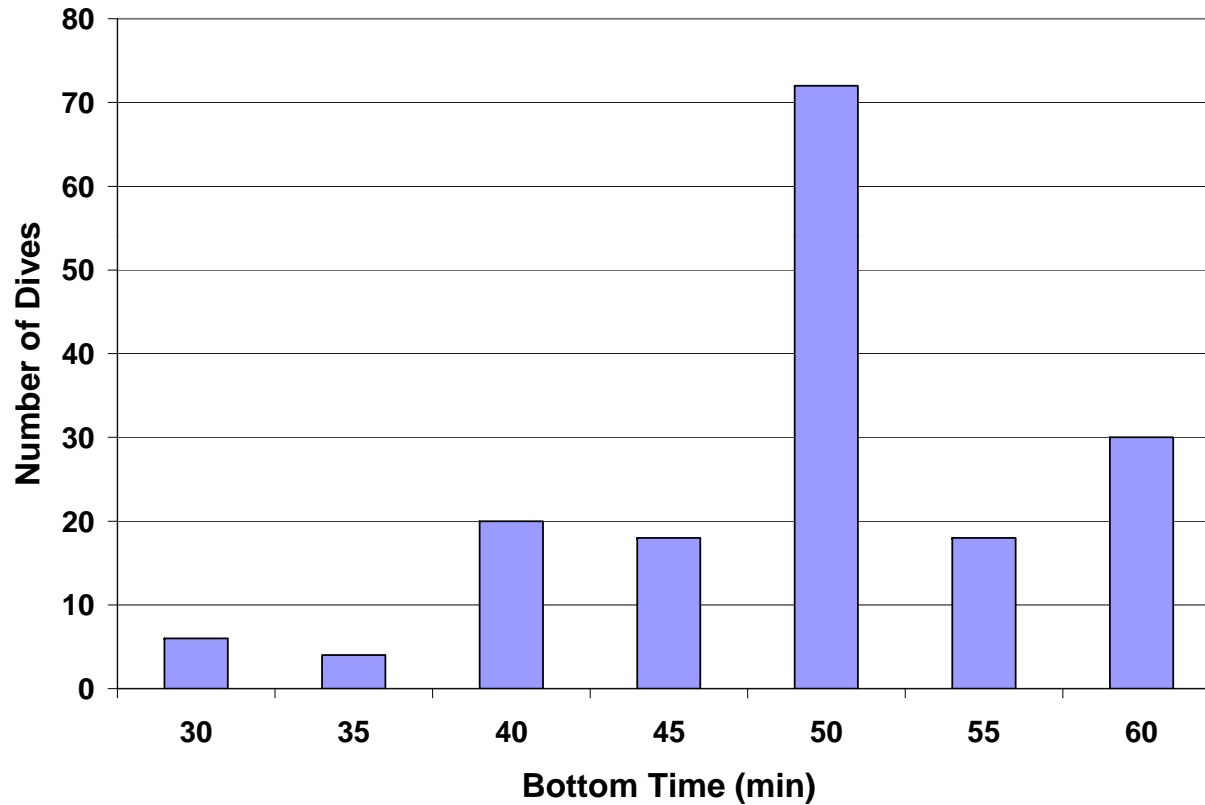


In-water Oxygen Times





2007 SurDO₂ Dive Frequency 120 fsw





Why not 50/50 nitrox?

Advantages

- Minimal risk of CNS O₂ toxicity in the water
- No risk of making a mistake on composition

Disadvantages

- Did not provide enough reduction of decompression times to satisfy operators
- More difficult to obtain in remote areas
- Mixing and oxygen analysis required



Recompression Chamber Requirements

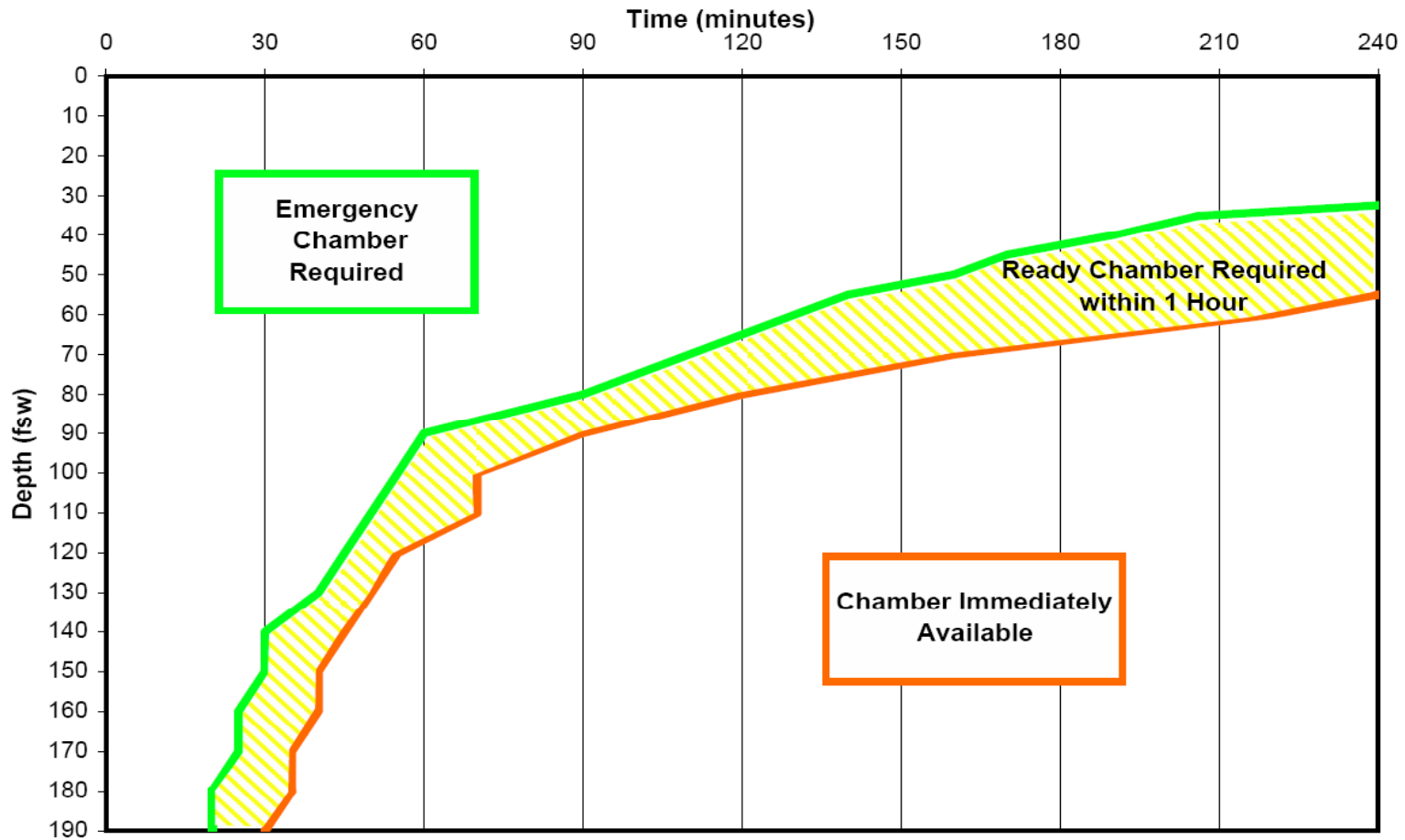


Figure 9-22 - Air Diving Recompression Chamber Requirements, 0 - 190 Feet.