

Flying After Diving: History, Research & Guidelines

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Divers Alert Network

DEMA 2002

Las Vegas

1961 – 1st Report

- **Cabin altitude 8-10,000 ft**
- **Pilot & copilot were incapacitated**
 - ◆ **Flew <4 hrs after diving to <30 fsw**
- **Flight engineer was less severely affected and landed the aircraft**
 - ◆ **Flew ~12 hrs after diving**
 - Miner (1961) Flight Safety Foundation J
 - Blumkin (1991) FSFJ 38(5):1-5

1967 – 1st Animal Study

- Dives: 53-88 fsw for 7 hrs
- PFSI: 1, 3, 6, or 12 hr
- Altitude: 10K ft for 2 hrs
- Results:
 - ◆ 93% DCS with 1 hr surface interval
 - ◆ No DCS with 12 hr surface interval



- Furry et al. (1967)
Aerosp Med 1967;38(8):825-28

1969 – 1st Human Study

- Dives: 40 fsw/200 min; 120 fsw/15 min
- SI: 5 min, 30 min, 1 hr, 2 hrs, or 3 hrs
- Altitude: 8K ft/112 min & 16K ft/5 min
- Results: in 41 exposures at ≤ 2 hrs, 1 DCS at 8,000 ft & 9 DCS at 16,000 ft
- Application: basis of 2 hr USN FAD rule for single no-D dives from '85-99

- Edel et al. Aerosp Med 1969;40(10):1105-10

1982 - Direct Ascent Study

Altitude: 10K/4h-16K/1h; 8.5K/4h-14K/1h

<u>D (fsw)</u>	<u>T (min)</u>	<u>DCS</u>	<u>Exposures</u>	<u>USN RG</u>
11	1440	1@16K	20	H
40	34	1@16K	20	E
60	20	2@14K,16K	36	D
80	14	1@10K	35	D
100	10	1@16K	38	D
130	7	0	20	D

- Bassett (1982) USAF SAM Report

FAD Situation in 1970s-80s

- Sparse data from manned testing
- >30 guidelines published since 1980
- 0 - 24 hr range for PFSI
- Controversy between advocates of
 - ◆ Maximum dive time & PFSI = 0-4 hrs
 - ◆ Zero DCS & PFSI \geq 24 hrs

UHMS FAD Workshop

24 Feb 89

- Literature review
- Fundamental issues of decompression
- FAD research
- Expert opinion



UHMS FAD Workshop

Recreational Diving Guidelines

Type of Diving

- No-D diving (<2 hr/48 hrs)
- No-D multi-day diving
- D-stop diving

PFSI

12 hrs

24 hrs

24-48 hrs



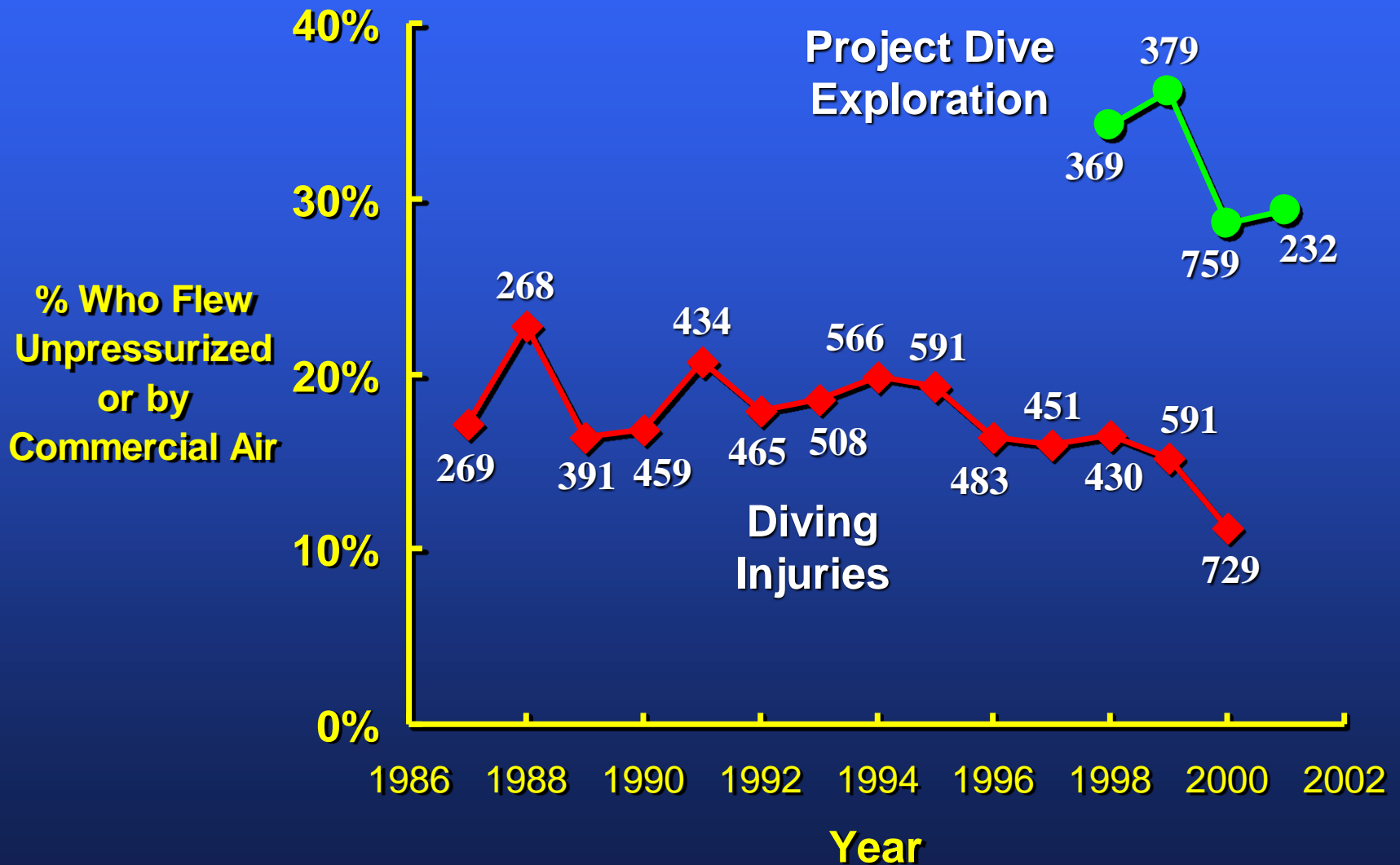
More Controversy

- **DAN & certifying agencies revised all guidelines to 24 hrs**
- ***Skin Diver Magazine* took exception arguing 24 hrs was not justified by the low incidence and hotels and dive operators would lose money**

1991 Resolution

- Jun 91 UHMS, DAN, certifying agencies met
- 1991 DAN revised recommendations
- Type of Diving SI (hrs)
- No-D diving 12 hr minimum
- No-D multi-day diving
or D-stop diving >12 hr

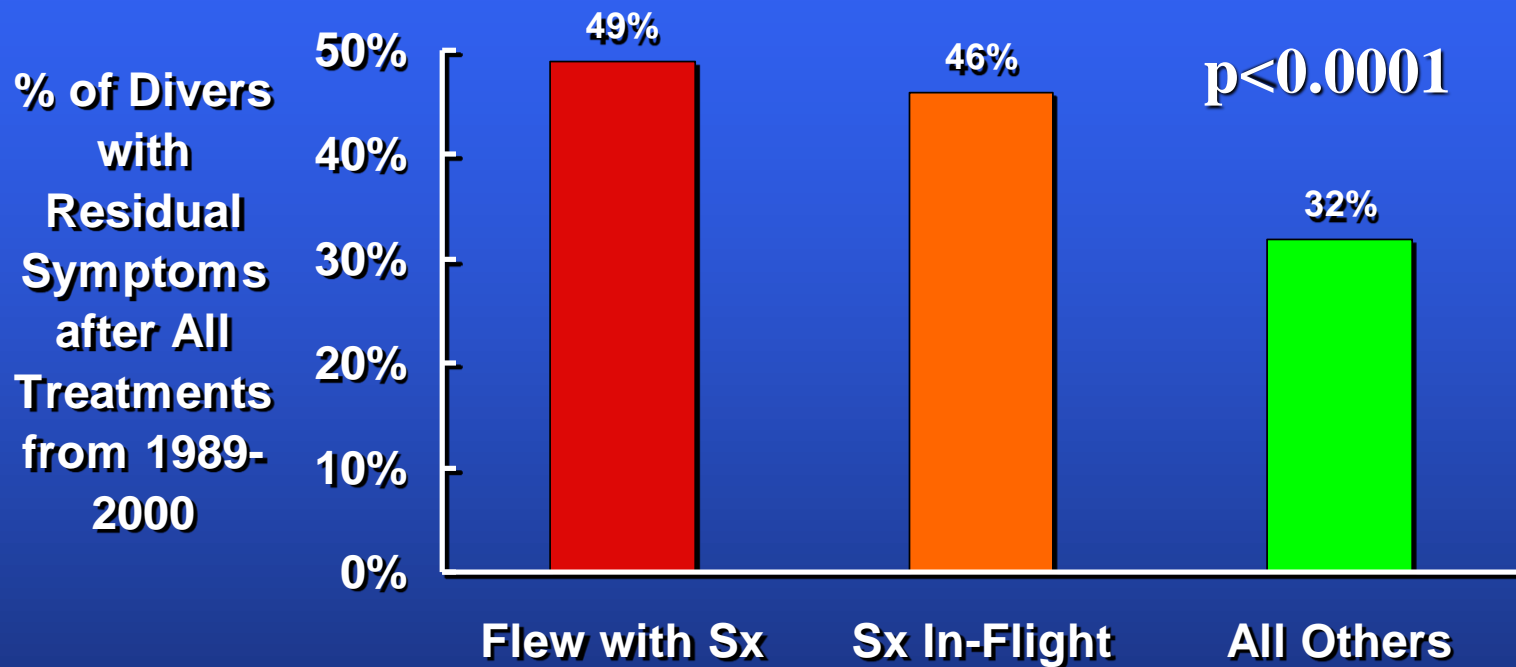
Proportion of Divers Who Fly



Divers with Symptoms Before Flying

- From 1998 to 2000, 278 injured divers were involved with flying after diving
- Of these, 55% had symptoms before they flew
- This is an educational problem: divers are not recognizing their symptoms

FAD Affects DCS Severity



- The incidence of any residual symptoms after all treatments was 14-17% greater for divers who flew than for divers who did not fly

PFSI & Recreational Diving

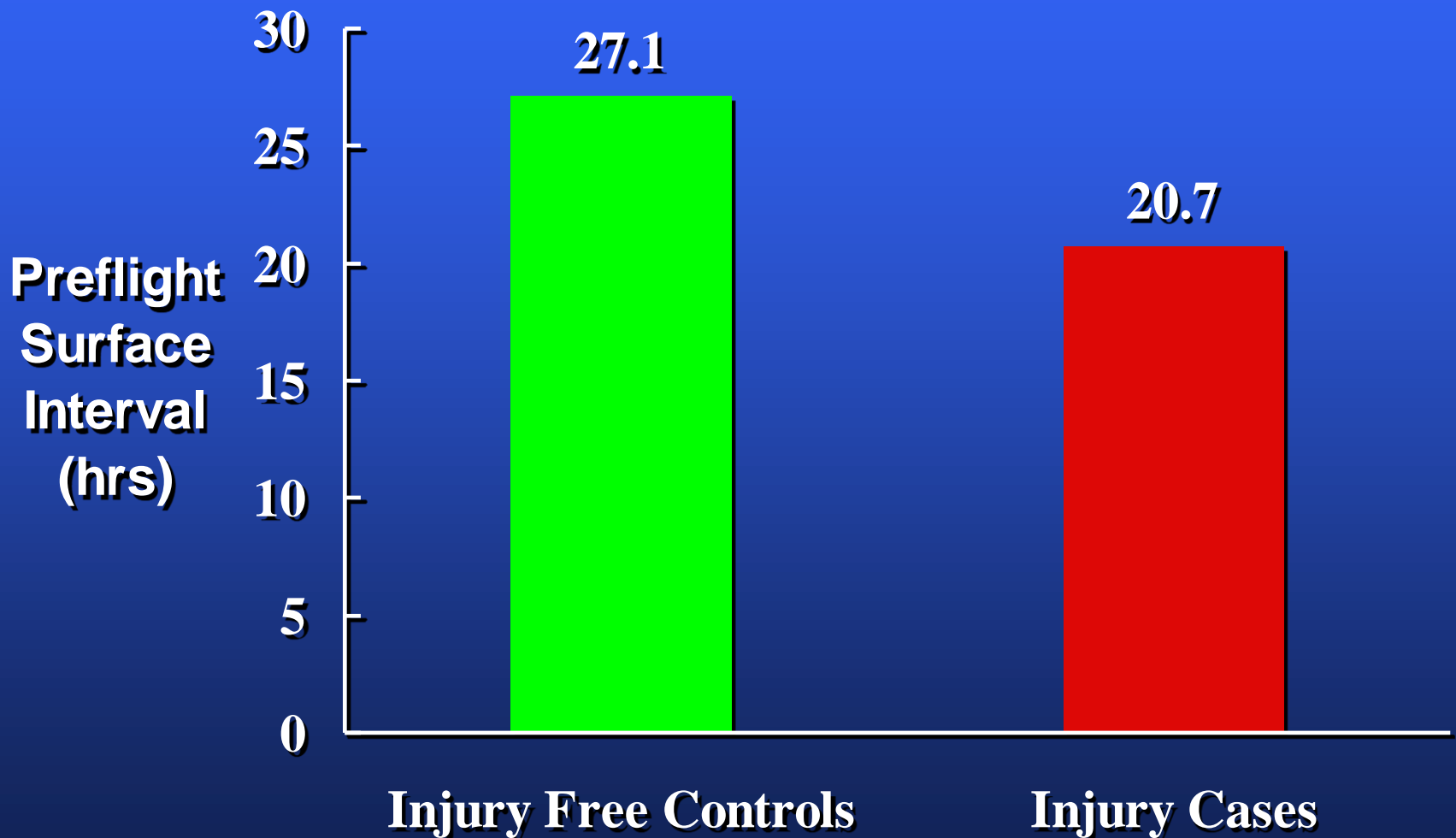
- Does PFSI affect DCS risk after repetitive, multi-day diving?
- We don't know the PFSIs for the entire population, but we have data for
 - ◆ 382 injured divers (no preflight Sx)
 - ◆ 245 injury-free controls from Project Dive Exploration

Case-Control Study

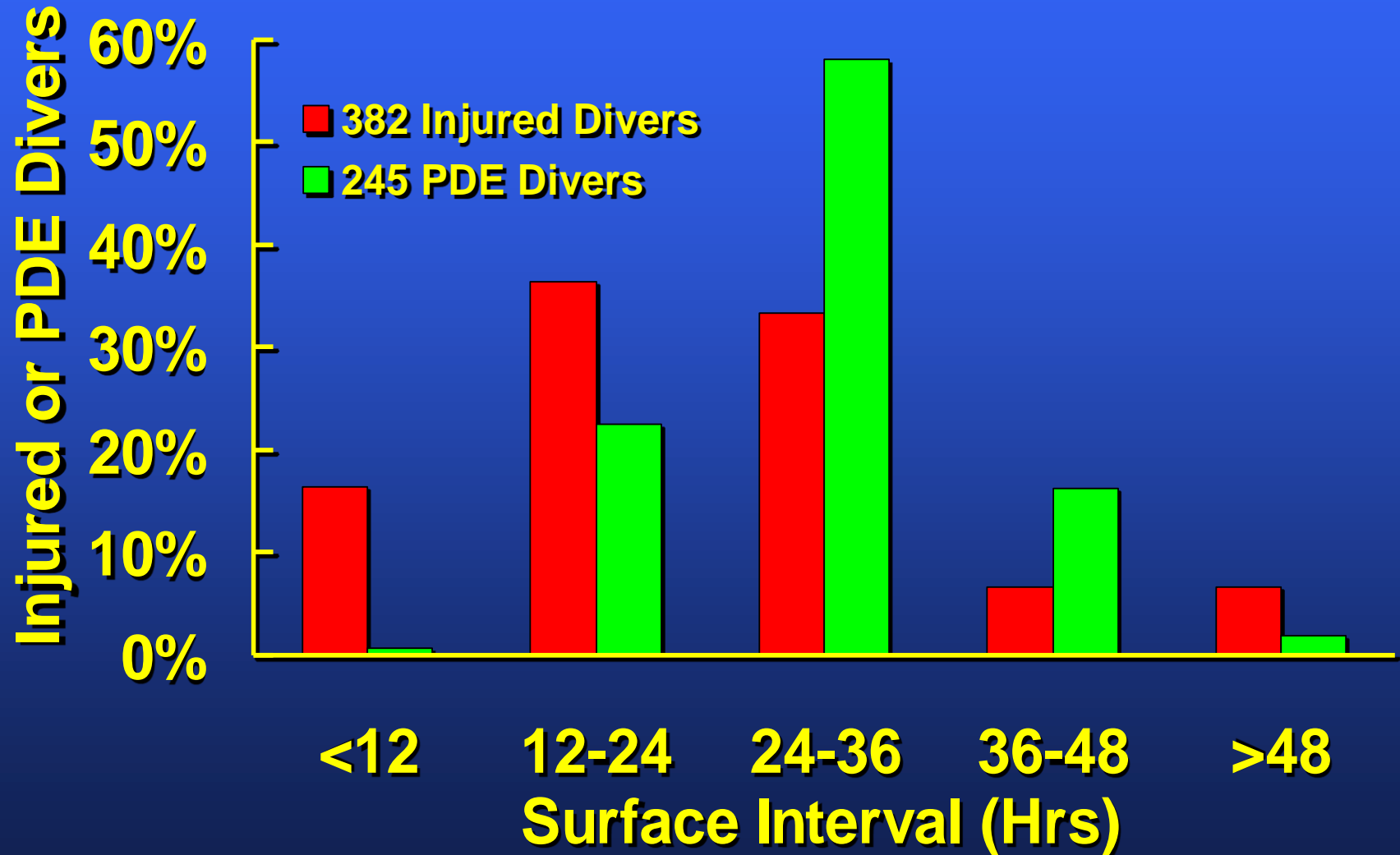
- Can't estimate absolute injury rates without the entire population
- Can estimate the relative risk of one condition compared with another
- Is the relative risk at short surface intervals greater than at longer surface intervals?

- Freiburger et al., ASEM 2002; 73:980.

Average PFSI



PFSI Distribution

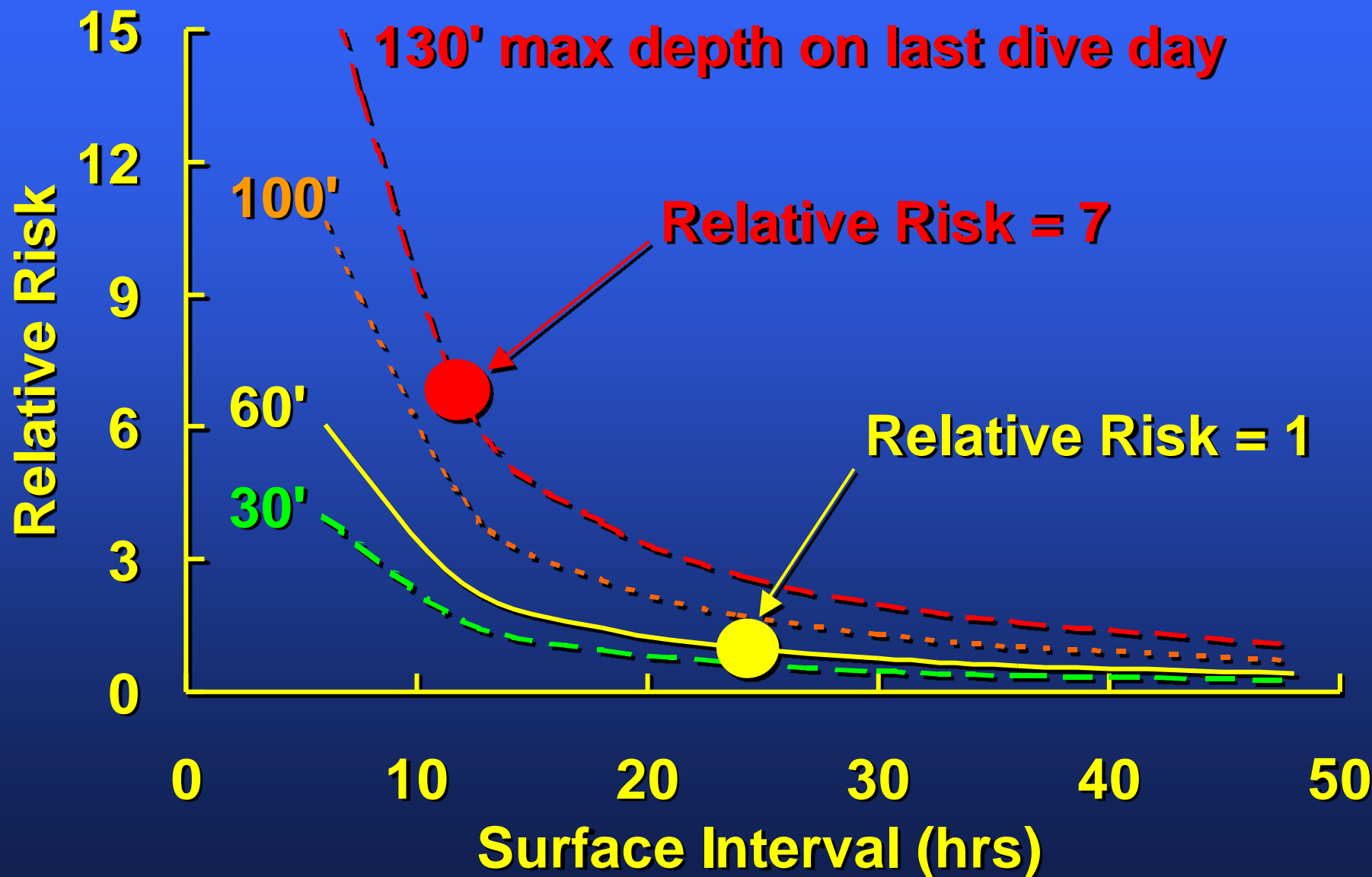


Relative Risks

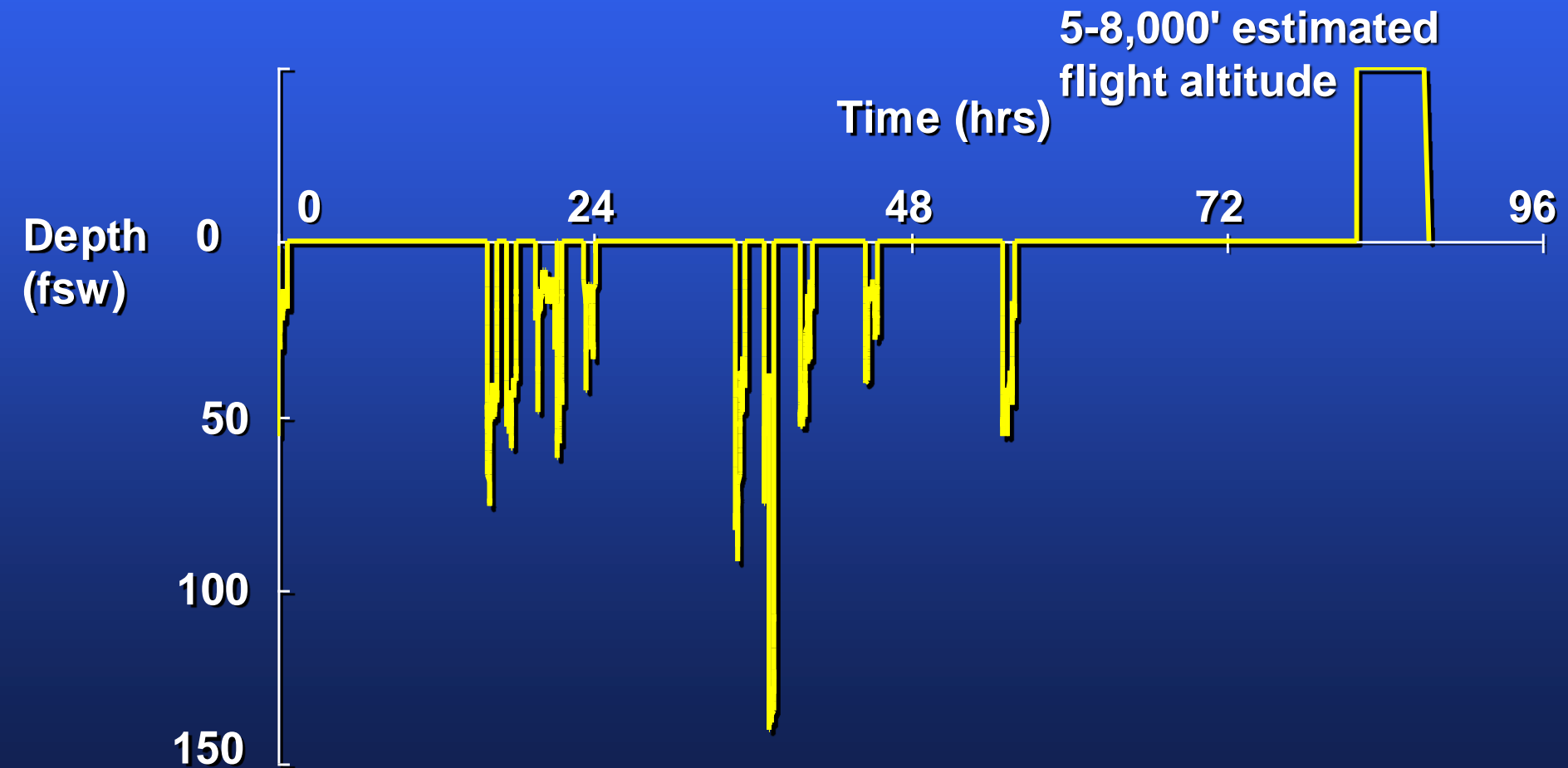
- **Increased relative risk of DCS for**
 - ◆ **shorter surface intervals**
 - gradual increase for SIs from 24→12 hrs
 - steep increase for SIs from 12→0 hrs
 - ◆ **deeper dives on the last day of diving**
- **Define Relative Risk = 1 for**
 - ◆ **24 hr surface interval**
 - ◆ **60 fsw maximum depth on last dive day**

PFSI & Relative Risk

19



In-Flight Pain & Neuro Sx at 26 Hrs After Diving



PFSI & Absolute Risk

- **Estimate PFSIs that have low DCS risk after no-decompression dives near the recreational exposure limits**
 - ◆ **Chamber study**
 - ◆ **1993 to 1999**

Experimental Design



Flight

**Decrease the PFSI and
observe the change
in DCS incidence**

Dive

PFSI (3-17 hrs)

**8,000 feet
for 4 hours**

DCS Severity

- **Mild DCS**

- ◆ limb pain, localized abnormal sensation

- **Moderate DCS**

- ◆ sensory deficit, weakness

- **Serious DCS**

- ◆ paralysis, difficulty breathing, fainting, cerebral dysfunction, death

Sequential Design

- Accept a surface interval if only a “few” mild DCS incidents occur.
 - ◆ Test a shorter interval.
- Reject a surface interval if “too many” mild DCS incidents occur or if DCS is moderate or serious.
 - ◆ Test a longer surface interval.

Recreational Dive Planner (RDP)

-start-up funding provided by PADI

START

DEPTH (feet) ▶

RECREATIONAL DIVE PLANNER™

DIVING SCIENCE & TECHNOLOGY CORP.

TABLE 2

SURFACE INTERVAL CREDIT TABLE

PRESSURE GROUP

40

NO-DECOMPRESSION LIMITS

TABLE 1

NO-DECOMPRESSION LIMITS AND GROUP DESIGNATION TABLE

PADI
DISTRIBUTED BY
INTERNATIONAL PADI, INC.

DEPTH (feet)	35	40	50	60	70	80	90	100	110	120	130	140																			
A	10	9	7	6	5	4	4	3	3	3	3	↓																			
B	19	16	13	11	9	8	7	6	6	5	5	4																			
C	25	22	17	14	12	10	9	8	7	6	6	5																			
D	29	25	19	16	13	11	10	9	8	7	7	6																			
E	32	27	21	17	15	13	11	10	9	8	↓	7																			
F	36	31	24	19	16	14	12	11	10	9	8	8																			
G	40	34	26	21	18	15	13	12	11	10	9																				
H	44	37	28	23	19	17	15	13	12	11	10																				
I	48	40	31	25	21	18	16	14	13	↓																					
J	52	44	33	27	22	19	17	15	↓	12																					
K	57	48	36	29	24	21	18	16	14	13																					
L	62	51	39	31	26	22	19	17	15																						
M	67	54	41	33	27	23	21	18	16																						
N	72	59	45	37	31	26	22	19	17	15																					
O	79	64	50	41	35	29	25	21	18	16																					
P	85	69	53	43	37	31	26	22	19	17	15																				
Q	92	74	57	46	40	34	29	25	21	18	16																				
R	100	79	61	50	43	37	31	26	22	19	17	15																			
S	108	85	66	54	46	40	34	29	25	21	18	16																			
T	117	91	71	59	50	43	37	31	26	22	19	17	15																		
U	127	97	75	62	53	46	40	34	29	25	21	18	16																		
V	139	104	81	67	57	50	43	37	31	26	22	19	17	15																	
W	151	114	89	74	63	54	46	40	34	29	25	21	18	16																	
X	165	125	99	83	71	60	51	43	37	31	26	22	19	17	15																
Y	180	139	111	94	81	69	58	49	41	34	29	25	21	18	16																
Z	205	140	119	101	87	75	63	52	43	35	29	25	21	18	16																

Z Y X W V U T S R Q P O N M L K J I H G F E D C B A

CONTINUE ON OTHER SIDE

RDP FAD Procedures

- Wait 4 hrs after one no-D dive of less than 60 min
- Wait 12 hrs after one no-D dive of more than 60 min or after repetitive dives
- Wait 24 hrs after emergency decompression

Single Dive Profiles

- 40' for 60 min
- 40' for 120 min
- 60' for 55 min*
- 100' for 20 min*

* Recreational Dive Planner (RDP) limit

Repetitive Dive Profiles

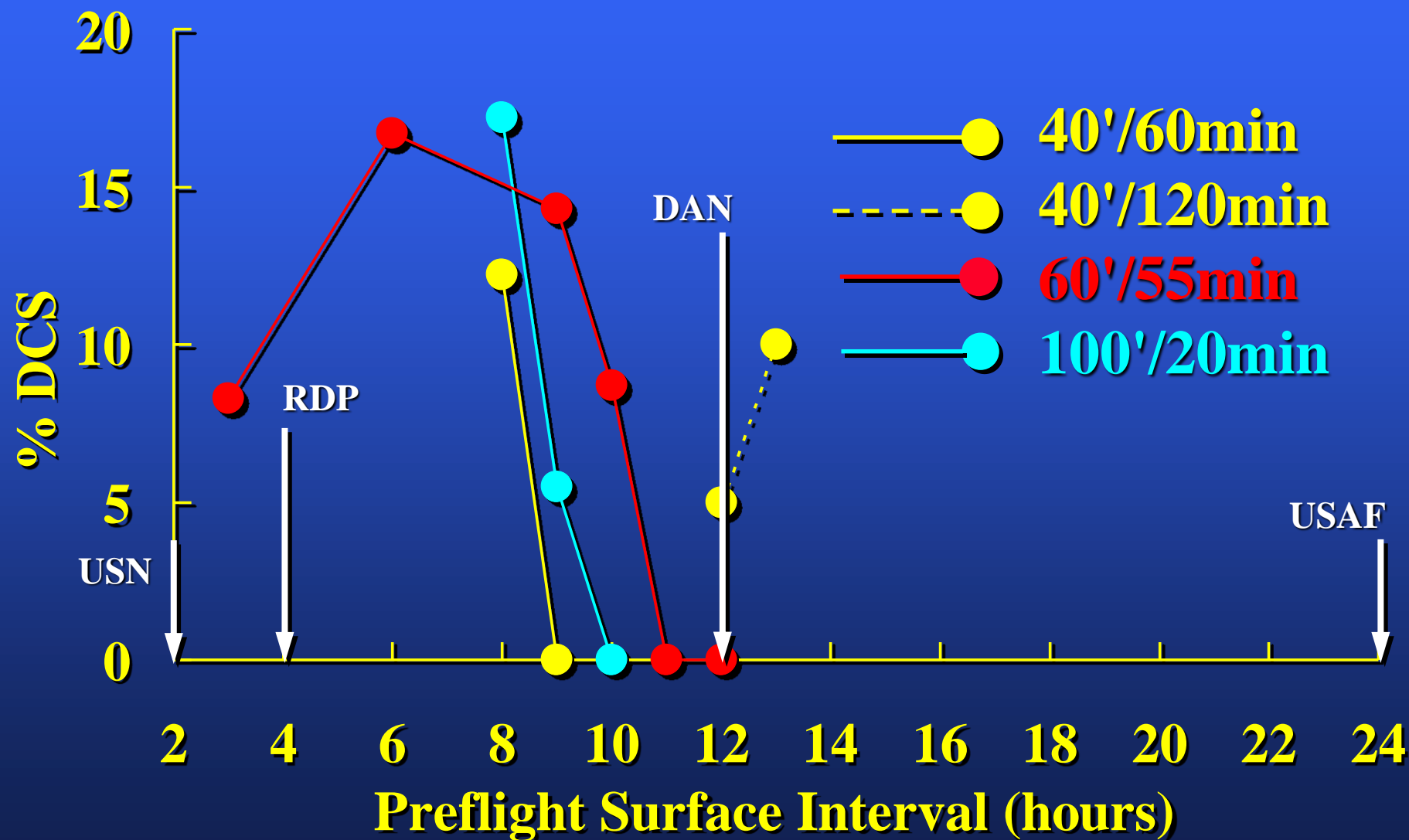
- 40'/60 min -1 hr SI- 40'/60 min
- 60'/55 min -1 hr SI- 60'/20 min*
- 60'/55 min -1 hr SI- 60'/20 min -1 hr SI- 60'/20 min*
- 100'/15 min -1 hr SI- 60'/35 min*

* Near RDP limits

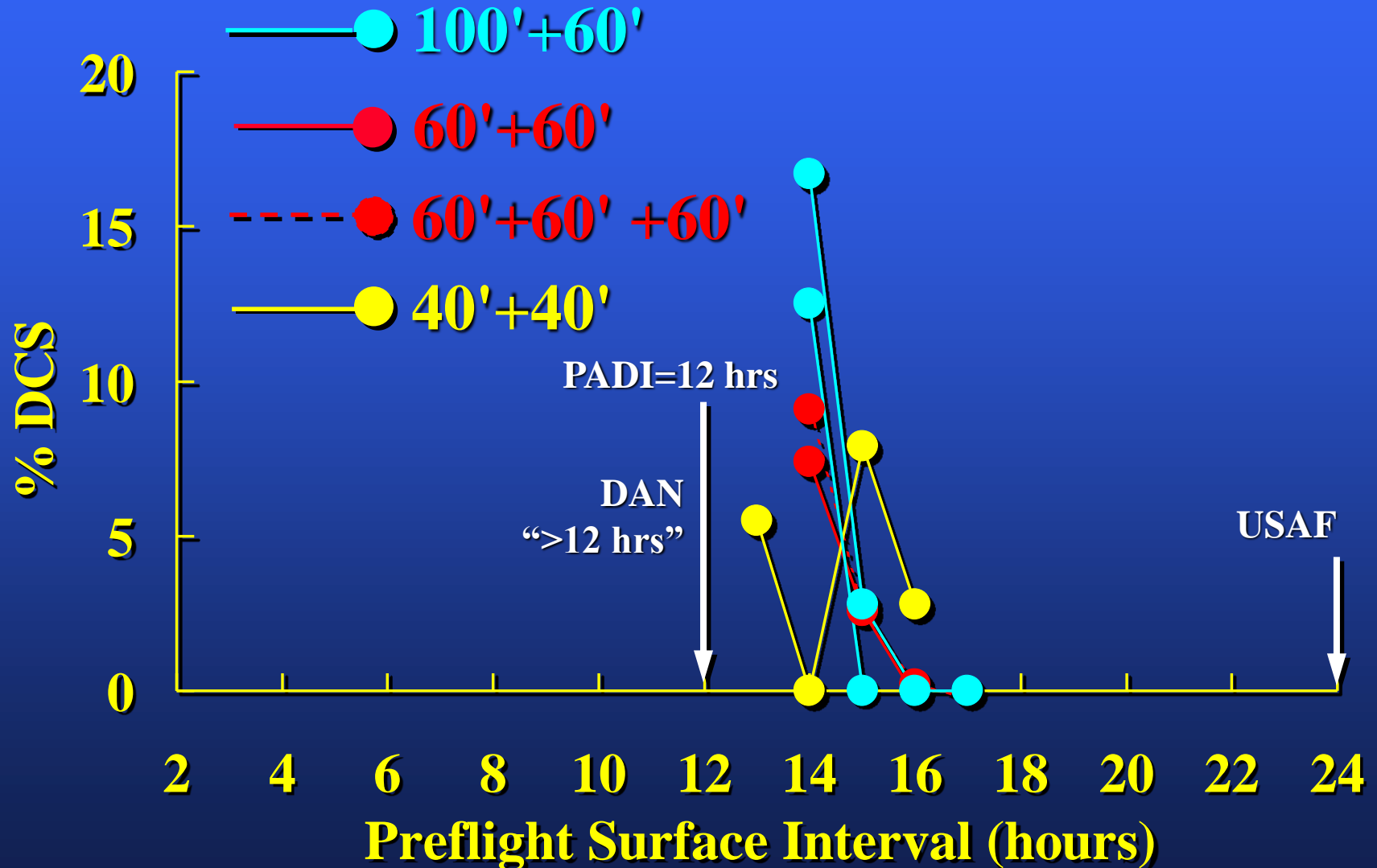
Results

- **802 FAD exposures**
- **40 DCS incidents (5%)**
 - ◆ **21 Moderate DCS**
 - ◆ **18 Mild DCS**
 - ◆ **1 Serious DCS**

Single Dives (n=344)



Repetitive Dives (n=458)



FAD Trials Summary

- **No DCS for single dives less than 60 min at PFSIs of 11 hrs or more**
- **No DCS for repetitive dives at a 17 hr PFSI**
- **Results apply only to the dive profiles tested with dry, resting divers**

1999 USN FAD Rules

- **Why change?**
 - ◆ **Duke studies indicated that a 2 hour PFSI was too short**
 - ◆ **Need to perform low level flights as soon as possible after a dive**
 - ◆ **Need procedures to allow further ascent to altitude after performing a dive at altitude**

1999 USN Dive Manual

Table 9-5. *Required Surface Interval Before Ascent to Altitude After Diving.*

Repetitive Group Designator	Increase in Altitude									
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
A	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00
B	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	2:11
C	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	3:06	8:26
D	0:00	0:00	0:00	0:00	0:00	0:00	0:09	3:28	7:33	12:52
E	0:00	0:00	0:00	0:00	0:00	0:51	3:35	6:54	10:59	16:18
F	0:00	0:00	0:00	0:00	1:12	3:40	6:23	9:43	13:47	19:07
G	0:00	0:00	0:00	1:23	3:34	6:02	8:46	12:05	16:10	21:29
H	0:00	0:00	1:31	3:26	5:37	8:05	10:49	14:09	18:13	23:33
I	0:00	1:32	3:20	5:15	7:26	9:54	12:38	15:58	20:02	24:00
J	1:32	3:09	4:57	6:52	9:04	11:32	14:16	17:35	21:39	24:00
K	3:00	4:37	6:25	8:20	10:32	13:00	15:44	19:03	23:07	24:00
L	4:21	5:57	7:46	9:41	11:52	14:20	17:04	20:23	24:00	24:00
M	5:35	7:11	9:00	10:55	13:06	15:34	18:18	21:37	24:00	24:00
N	6:43	8:20	10:08	12:03	14:14	16:42	19:26	22:46	24:00	24:00
O	7:47	9:24	11:12	13:07	15:18	17:46	20:30	23:49	24:00	24:00
Z	8:17	9:54	11:42	13:37	15:49	18:17	21:01	24:00	24:00	24:00

Exceptional Exposure

Wait 48 hours before flying

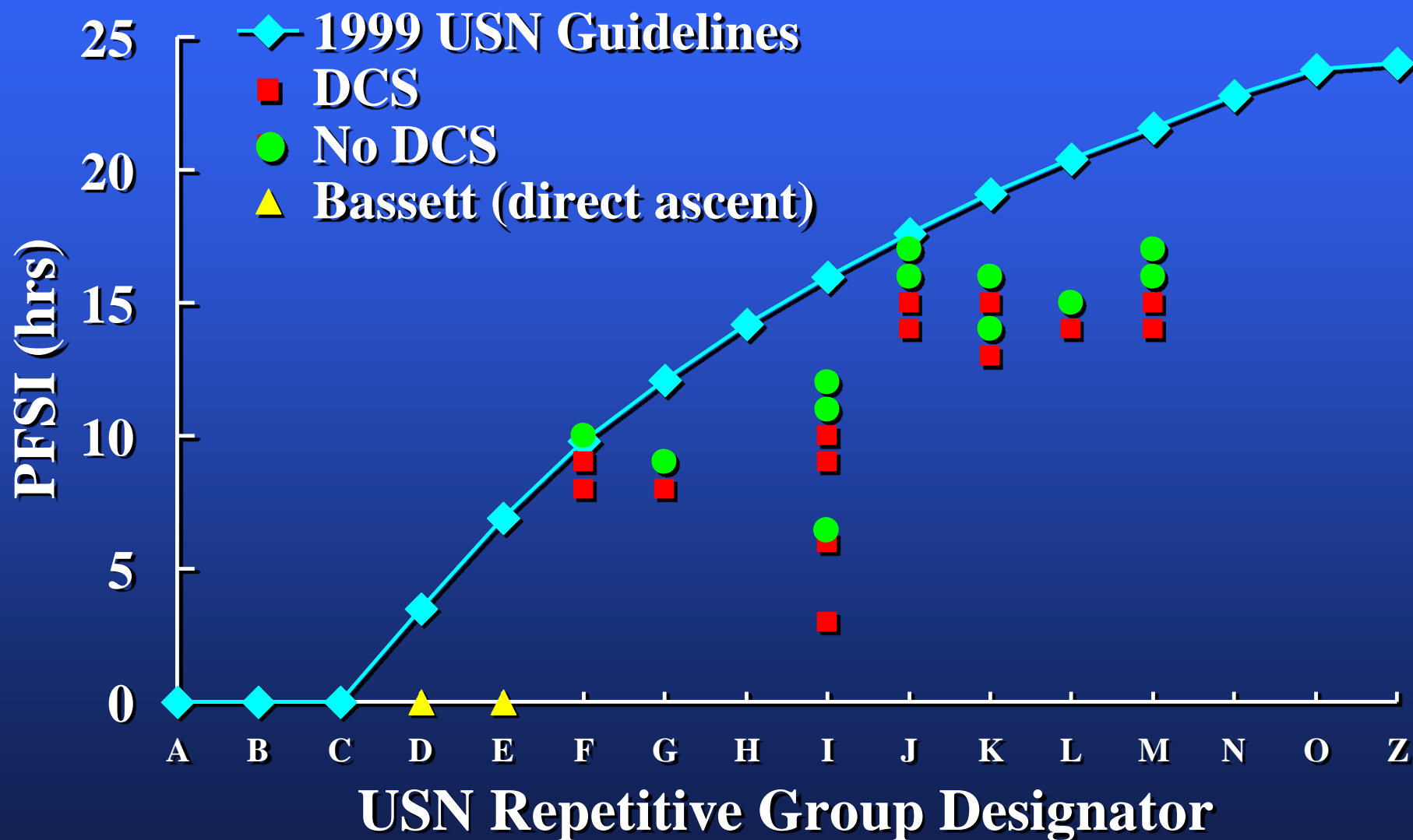
1999 USN FAD Rules

SI Before Ascent to Altitude

<u>RG</u>	<u>1,000'</u>	<u>4,000'</u>	<u>8,000'</u>	<u>10,000'</u>
<u>C</u>	0:00	0:00	0:00	8:26
<u>F</u>	0:00	0:00	<u>9:43*</u>	19:07
<u>I</u>	0:00	5:15	<u>15:58*</u>	24:00
<u>K</u>	3:00	8:20	<u>19:03*</u>	24:00
<u>Z</u>	8:17	13:37	24:00	24:00

** based on DAN trials*

USN Guidelines at 8,000'



Fleet Feedback

- **Procedure is too complex**
 - ◆ **Prefer simple 12 or 24 hour rule**
- **Procedure is too restrictive**
 - ◆ **Prevent some working on waterfront from going home to mountains after work**
 - ◆ **Desire to return to 2300 foot unlimited ascent rule**

May 2002 Workshop: Revised Recreational FAD Guidelines

- Are any FAD guidelines needed at all?
- Are current FAD guidelines acceptable?
- What is the longest PFSI needed after multi-day, repetitive diving at the limits of the recreational dive tables?

2002 FAD Workshop:

Consensus Recommendations (1)

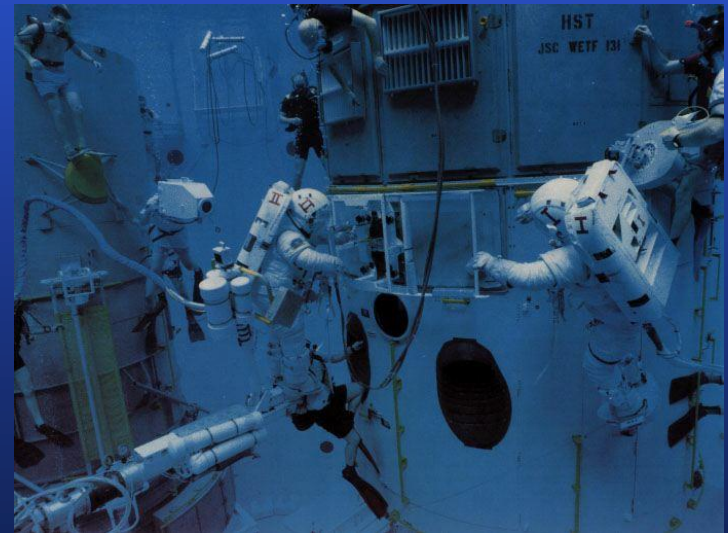
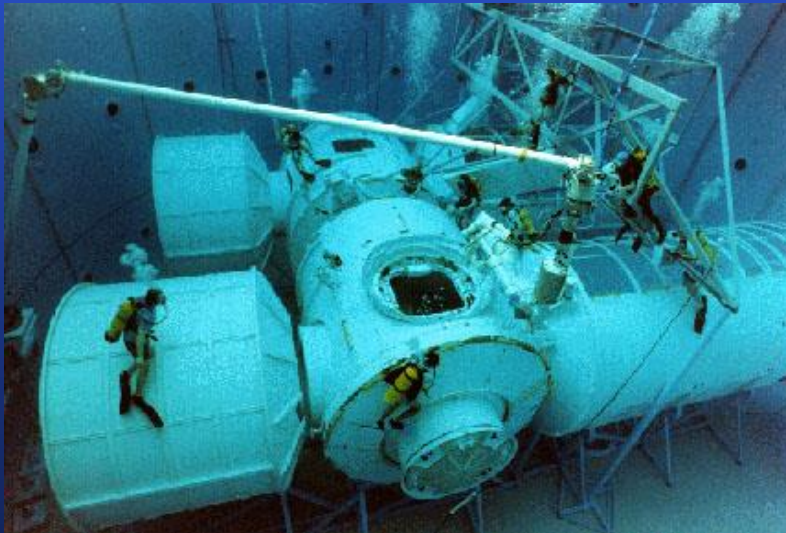
- **Apply to air dives followed by flights at cabin altitudes of 2,000 to 8,000 feet for divers who do not have symptoms of DCS**
- **Recommendations should reduce DCS risk but do not guarantee avoidance**
- **Longer preflight surface intervals will further reduce DCS risk**

Consensus Recommendations (2)

- **Dives within the No-D Limits**
 - ◆ Single No-D Dive: a minimum preflight surface interval of 12 hours is suggested
 - ◆ Multiple Dives per Day or Days of Diving: a minimum preflight surface interval of 18 hours is suggested
- **Dives Requiring Decompression Stops**
 - ◆ Little experimental or published evidence
 - ◆ A preflight surface interval substantially longer than 18 hrs appears prudent

NASA O₂ FAD Tables

- NBL dive profile – 40 fsw for 240-390 min
- Breathing gas – nitrox (46% O₂)
- Dry suit (EMU) – pressurized to 4.0 psid
- Equivalent Air Depth – 23.9 fsw



*NBL - Neutral Buoyancy Laboratory, Johnson Space Center, Houston

*EMU - Extravehicular Mobility Unit (standard U.S. 'space suit')

FAD Limits (Nitrox) - EAD=25 fsw

Duration (min)	Air PFSI (hr) (USN PFSI)	Oxygen PFSI (hr)
1-45	3 (8:26)	0.33
46-80	5 (16:18)	0.67
81-290	14 (24:00)	2
291-400	24 (24:00)	3

Cabin altitude <10,000 ft MSL
No flight restrictions > 24 hr post-dive

Operational Experience

- **Anecdotal – no database**
- **Average 3-5 individuals annually**
- **PFSI of 4-18 hours**
- **No cases of DCI**

On-Going USN FAD Study

- Evaluate untested USN FAD guidelines including decompression dives
- Evaluate effectiveness of post-dive O₂ breathing in reduce PFSI
- Use echocardiography to search for arterial bubbles in the heart
- Three year project with 500-700 subjects

Come Dive and Fly with Us

