

Trouble with Bubbles: Lessons in Altitude Decompression Sickness



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Disclaimers

The opinions, interpretations, conclusions, and recommendations are those of the presenter and are not necessarily endorsed by the Navy Operational Medicine Training Center, the Naval Safety Center, the U.S. Navy or the Department of Defense.

CME Disclosure: I have no financial interests or potential conflicts of interest to disclose.



Topic Outline

- Aviator Symptom after Rapid-D Events
- DCI in Sub-Atmospheric Environments
- Altitude Injury Statistics
- Rational Approach to Rapid-D Events
- Anticipated Case Outcomes and Conclusions

Aviator Symptoms After Rapid-D Events Case Reports

Excerpts from Re

FA-18. No adverse
experienced symptom
with Type II decompr
treatment.

FA-18. As pilot clin
feet, ECS and OBOGS s
a rapid change in cabi
his ears popping. Eme
followed and 30 minu
flight surgeon determ
DCS and he was mede
ashore. Pilot med-dow

FA-18. A loose nut
pressure safety valve

problems. Once on dec
thought to have had h
had decompression sic

THE NAVY & MARINE CORPS AVIATION SAFETY MAGAZINE

www.public.navy.mil/navsafecen/ • July-August 2012

Approach



The True Meaning of
PROFICIENCY

ht. Pilot
by flight surgeon
l rounds of



Aviator Symptoms After Rapid-D Events

Case Reports



- F/A-18F Completed Run
- WSO Symptomatic
- LOC for 7-11 min
- Referred to Chamber
- Diverted to ER



Aviator Symptoms After Rapid Decompression Events



Aviator Symptoms After Rapid-D Events

Scope of Symptoms Reported

➤ Constitutional Symptoms

- Fatigue / Malaise
- Nausea / Vomiting

➤ Cranial Neurologic Symptoms

- Headache / Dizziness / Vertigo
- Concentration / Memory Issues
- Personality / Affect Changes
- Visual / Auditory Changes
- Speech Difficulties
- Loss of Consciousness



Aviator Symptoms After Rapid-D Events

Scope of Symptoms Reported

➤ Spinal Neurologic Symptoms

- Trunk Numbness / Tingling
- Radicular Symptoms
- Motor Weakness

➤ Peripheral Neurologic Symptoms

- Peripheral Numbness / Tingling
- Motor Weakness



Aviator Symptoms After Rapid-D Events

Scope of Symptoms Reported

➤ Pulmonary Symptoms

- Dry Cough
- Substernal Chest Pain
- Shortness of Breath

➤ Musculoskeletal Symptoms

- Joint Pain
- Soft Tissue Discomfort
- Skin Mottling



Aviator Symptoms After Rapid-D Events

Potential Differential Diagnoses

- Barotrauma } Typically straightforward diagnosis
- Hypoxia
- Gravity / Motion
- Toxicity
- Hyperventilation } Generally self limiting with return to site level / stimulus removal
- Decompression Sickness (DCS) } May appear / persist / progress after landing
- Arterial Gas Embolism (AGE) }



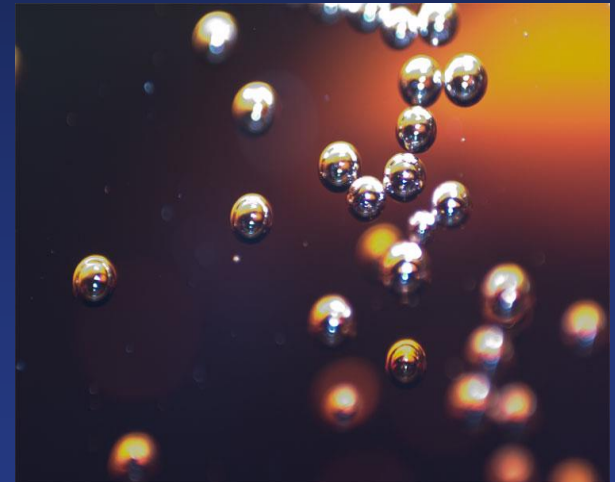
Sub-Atmospheric Environment Decompression Illness (DCI)



Sub-Atmospheric Environment DCI

Troubles with Bubbles

- DCI – Physical signs and symptoms caused by inert gas emerging from solution...
- Presence of inert gas bubbles is a necessary condition...
- But not a sufficient condition...



Sub-Atmospheric Environment DCI

Troubles with Bubbles

➤ 1670 – Sir Robert Boyle



- Demonstrated a rapid reduction in ambient pressure resulted in tissue bubbles
- “I once observed a Viper furiously tortured in our Exhausted Receiver... that had manifested a conspicuous bubble moving to and fro in the waterish humour of one of its eyes”





Sub-Atmospheric Environment DCI

Troubles with Bubbles

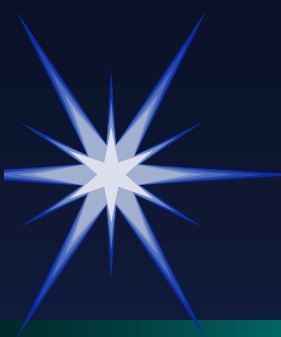
- ~ 260 Years Later... Altitude DCI a Possibility
- By 1930s, noted occurrence with balloon altitude record setting



- By 1959...
- 743 serious cases
- 18 deaths



- Ongoing USAF & U2 Pilot Issues
- Altitude DCI = Cases induced by exposure to decreased atmospheric pressure



Sub-Atmospheric Environment DCI

Physiologically – What it is Not!



Diving at Altitude



Flying after Diving



Sub-Atmospheric Environment DCI

Physiologically – What it Is!



Sub-Atmospheric Environment DCI

Primary Risk Factors

➤ Altitude



➤ Time



➤ Previous Diving / Altitude Exposure

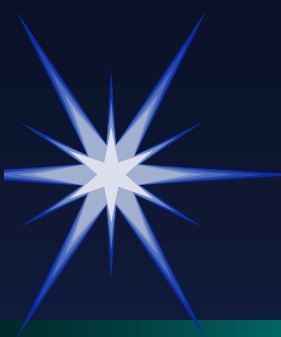




Sub-Atmospheric Environment DCI

Primary Risk Factors

- 18,000 ft “theoretical” DCS minimum limit
- 13% of cases present below 25,000 ft
- 79% of cases present greater than 25,000 ft
- Altitude Chamber cases at 13,000 -14,000
- Flying After Diving cases at only 5,000 ft
- Commercial aircraft pressurization 8,000 ft



Sub-Atmospheric Environment DCI

Primary Risk Factors

- DCS a Product of Time at Altitude
 - Minutes to hours vs. seconds)
 - Increased Dose ➔ Increased Risk
- Speed of Decompression?



Sub-Atmospheric Environment DCI

Primary Risk Factors

➤ Speed of Decompression

- Increase or decrease DCS incidence depending on study
- Chronic exposure may reduce risks (habituation)
- Rapid repeat exposures enhances risk (cockpit surges)



=





Sub-Atmospheric Environment DCI

Secondary Risk Factors

- Fatigue / Sleep Loss
- Increasing Age
- Previous Injury
- Hydration Status
- Exercise at Altitude
- Poor O₂ Pre-breathing
- Individual Variations





Sub-Atmospheric Environment DCI

Defining Altitude DCS / AGE / DCI

➤ Type I DCS

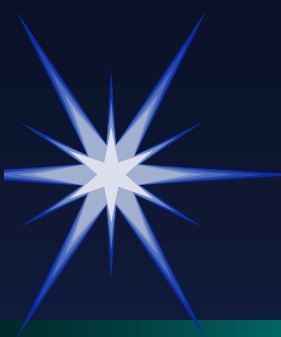
- Joint Pain
- Skin Symptoms
- Lymphatic Symptoms

➤ Type II DCS

- Neurologic Symptoms
- Inner Ear Symptoms
- Cardiopulmonary Symptoms

➤ AGE

- Neurologic Symptoms



Sub-Atmospheric Environment DCI

Type I Altitude DCS

- *Historically* 65-70% of altitude DCS cases
- Knee most common in aviation DCS
- Shoulder & elbow next most common
- Wrists and ankles uncommon
- Fingers almost always spared
- If truncal or bilateral ➔ ? Type II DCS





Sub-Atmospheric Environment DCI

Type II Altitude DCS

- *Historically* 30-35% of all Altitude DCS cases
- 35-50% not resolved at “site level”
- Onset
 - Usually quick (minutes)
 - May develop over time (hours, not days)
- Symptoms => Neurologic tissue affected





Sub-Atmospheric Environment DCI

Type II Altitude DCS

- Spinal Cord DCS typical of Diving Exposures
 - Weakness
 - Paraplegia
- Brain DCS typical of Altitude Exposures
 - Altered levels of consciousness
 - Coordination difficulties
 - Visual changes
 - Complete hemiplegia, unilateral sensory changes
 - Loss of Consciousness



Sub-Atmospheric Environment DCI

Altitude Arterial Gas Embolism (AGE)

- Onset Sudden & Dramatic
 - Typically CNS Manifestations
- Unlikely Unless...
 - Diving / HABD Training
 - Rapid Decompression





Sub-Atmospheric Environment DCI

Altitude Arterial Gas Embolism (AGE)

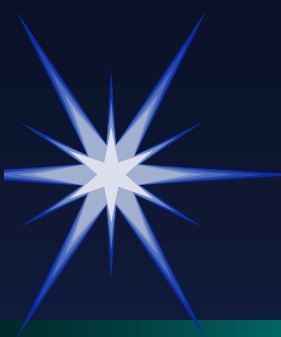
- Rapid Decompression
 - USAF Studied 1055 Events
 - 83% Slow Decompressions
 - 1/3 Resulted in Adverse Physiology
 - 22% Hypoxia
 - 8.3% Decompression Sickness
 - Only 7.1% Barotrauma
- USN Data ~ 72% of Decompressions Rapid



Sub-Atmospheric Environment DCI

Altitude AGE = DCI

- AGE 2° Decompression Sickness?
 - Tissue gas capacity (M-values & compartments)
 - Primarily a venous phenomenon
 - Pulmonary “filter” function
- Significance of “Right to Left” Shunts
 - Pulmonary A-V Malformations
 - Atrial and Ventricular Septal Defects
- Debunking the “10 Minute” Rule



Sub-Atmospheric Environment DCI

What About Hypoxia?

- Altitude Dependent
- Exposure Time Dependent
- Concurrent Neurologic Findings
 - Motor Symptoms
 - Vestibular Symptoms
 - CNS Symptoms



DCS vs Hypoxia vs “Other”

- Often Hard to Differentiate
- NASA – Altitude DCI Experts



- False Positive DCI Dx: 13-83%
- False Negative DCI Dx: 1-32%

- Rely on History and Physical Exam



Altitude Injury Statistics



Altitude Injury Statistics

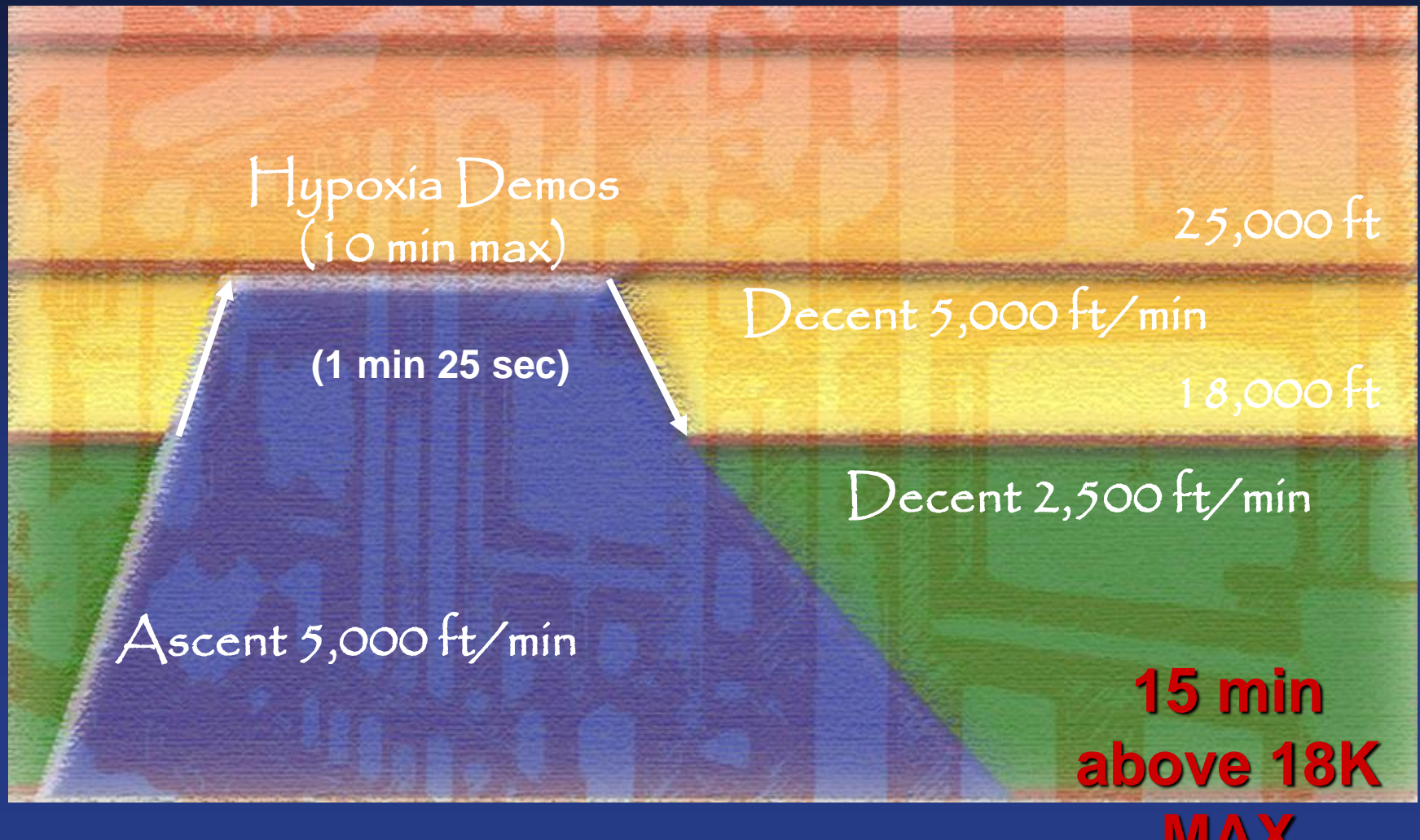
Altitude Chamber Environments





Altitude Injury Statistics

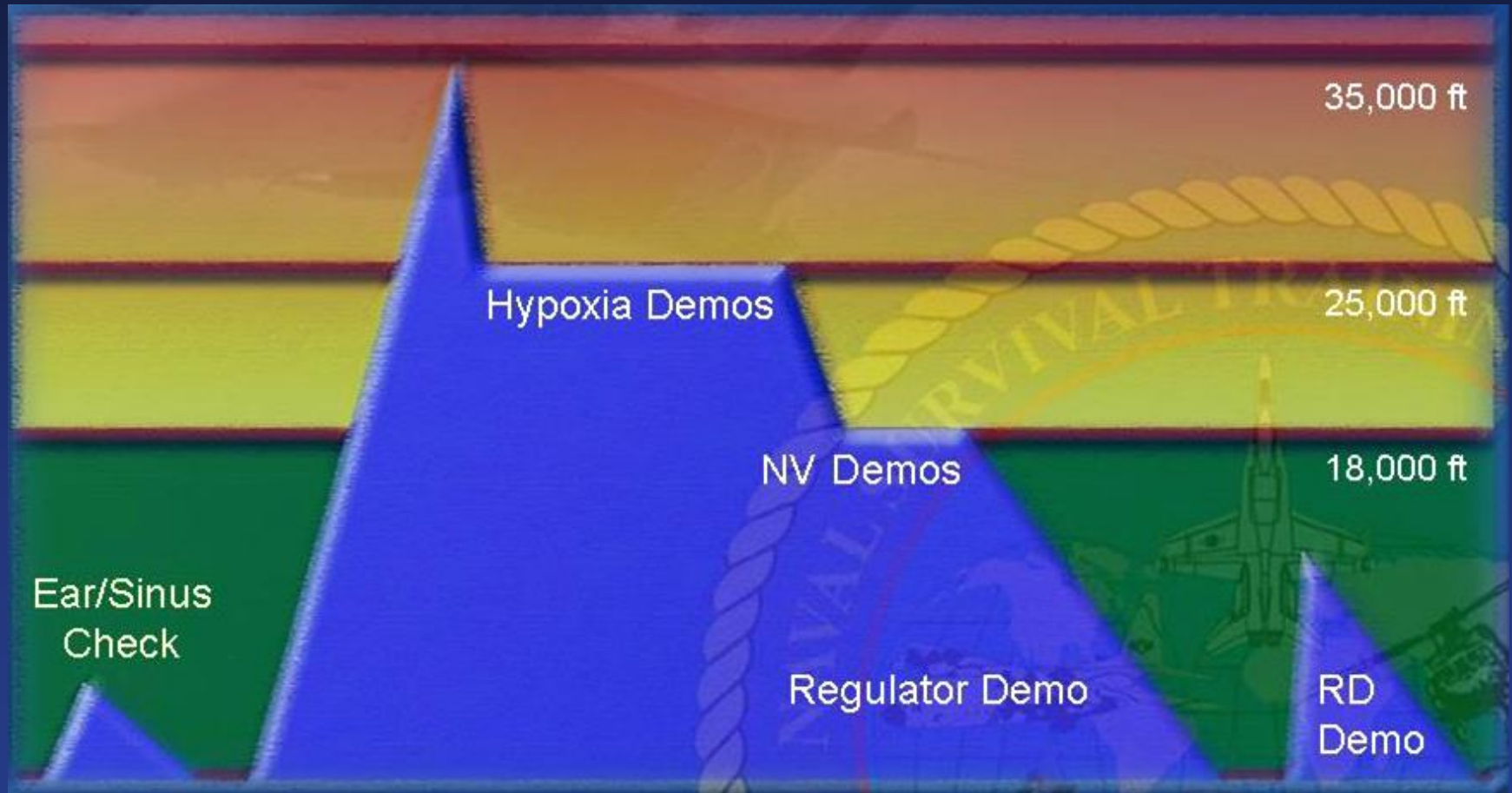
Type II Chamber Training Profile





Altitude Injury Statistics

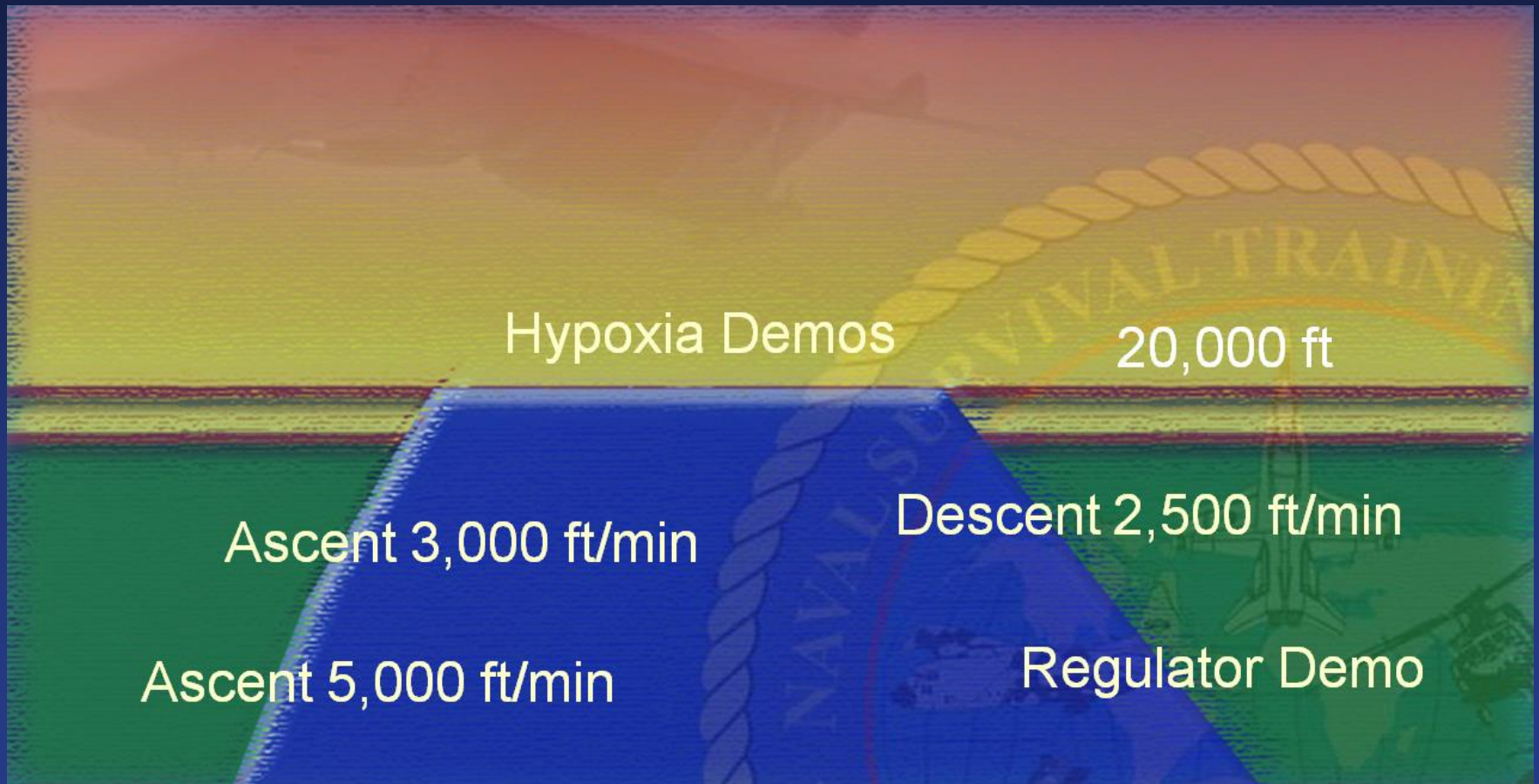
Type IIa Chamber Training Profile





Altitude Injury Statistics

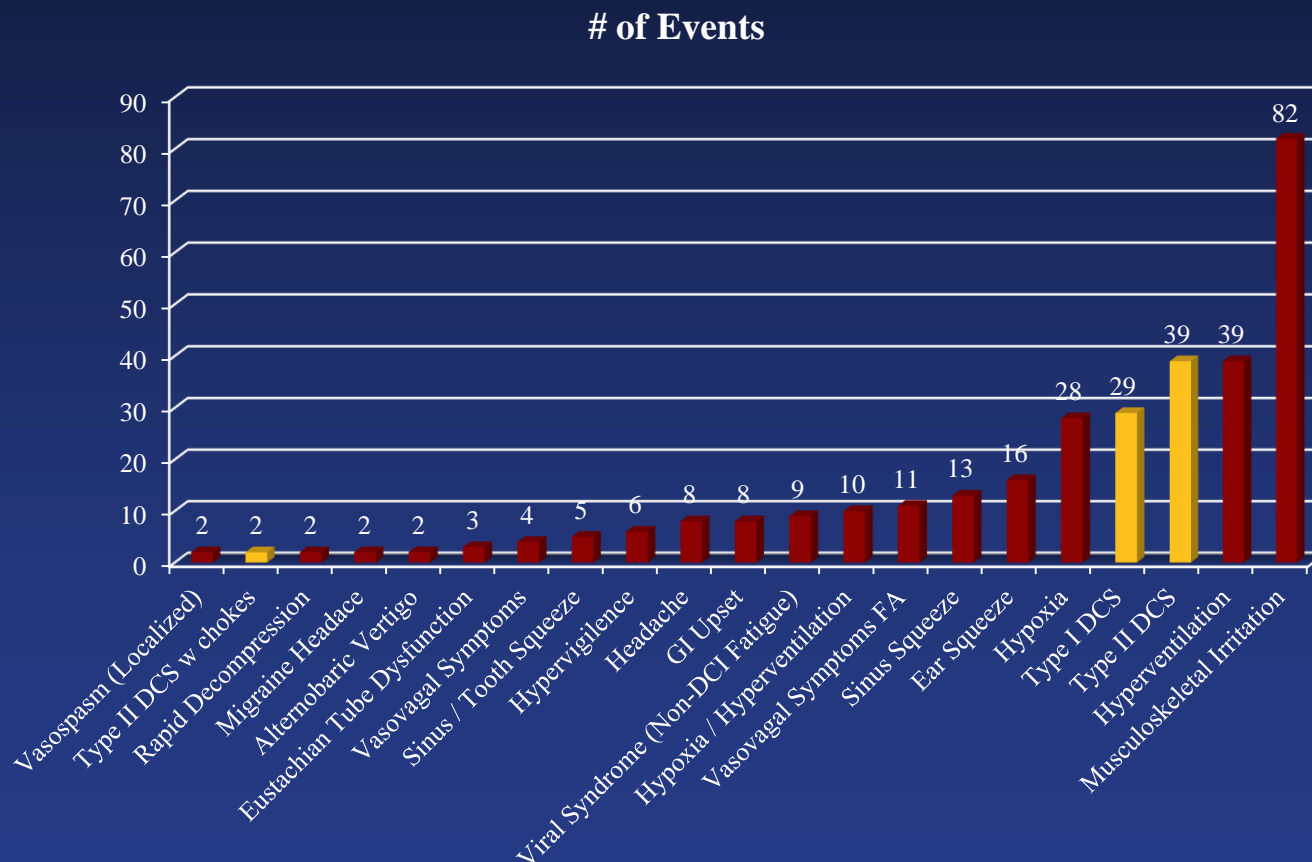
Type III Chamber Training Profile





Altitude Injury Statistics

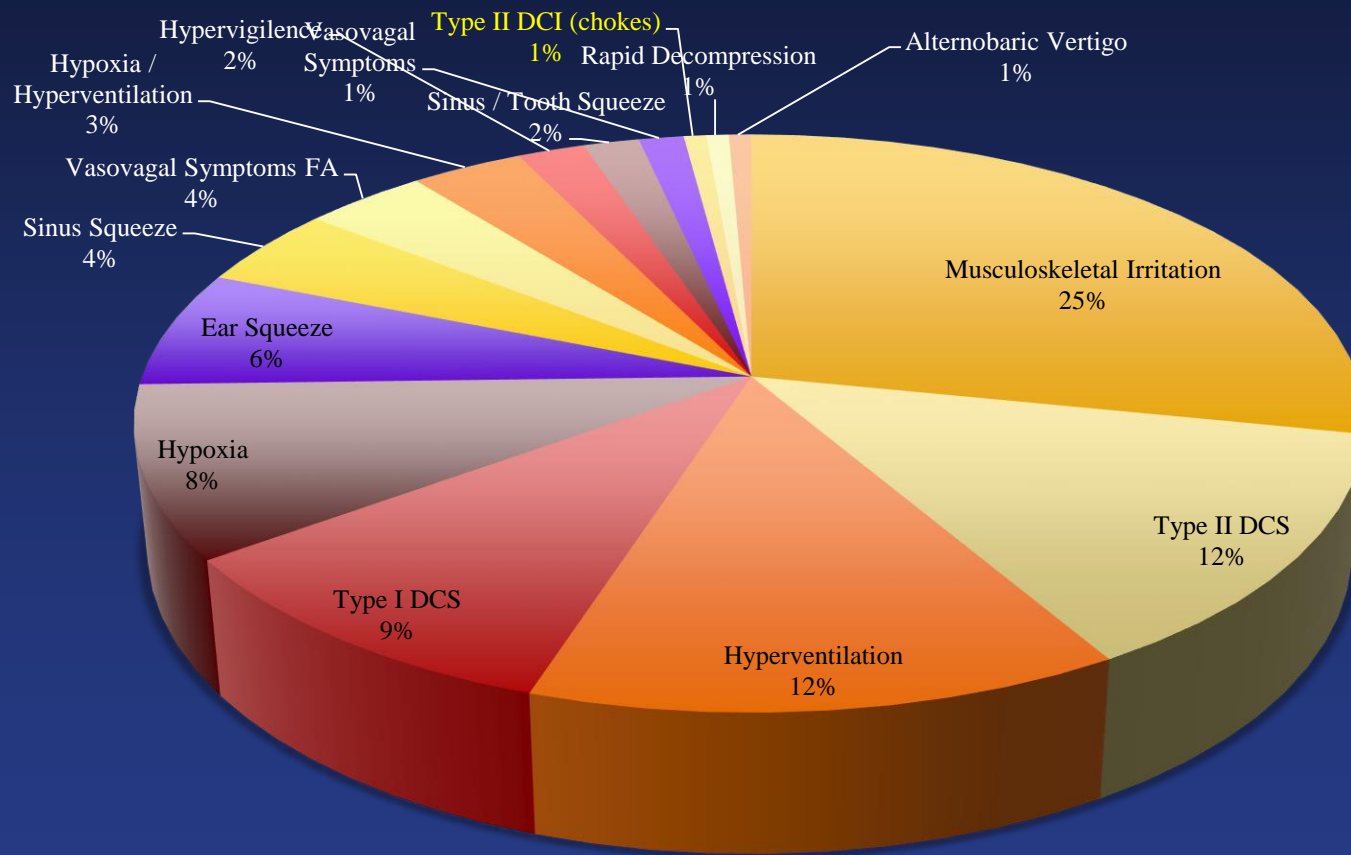
The “NSTI” Experience (‘07-‘12)



N = 334
~ 60 Evals / Yr

Altitude Injury Statistics

The “NSTI” Experience (‘07-‘12)



DCI Accounts for ~ 22% of Cases



Altitude Injury Statistics

Chamber DCS Rates: '98-'03 vs. '04-'08

➤ Students

➤ 15 per 10,000 – '98-'03

➤ 2.6 per 10,000 – '04-'08

➤ Inside Observers

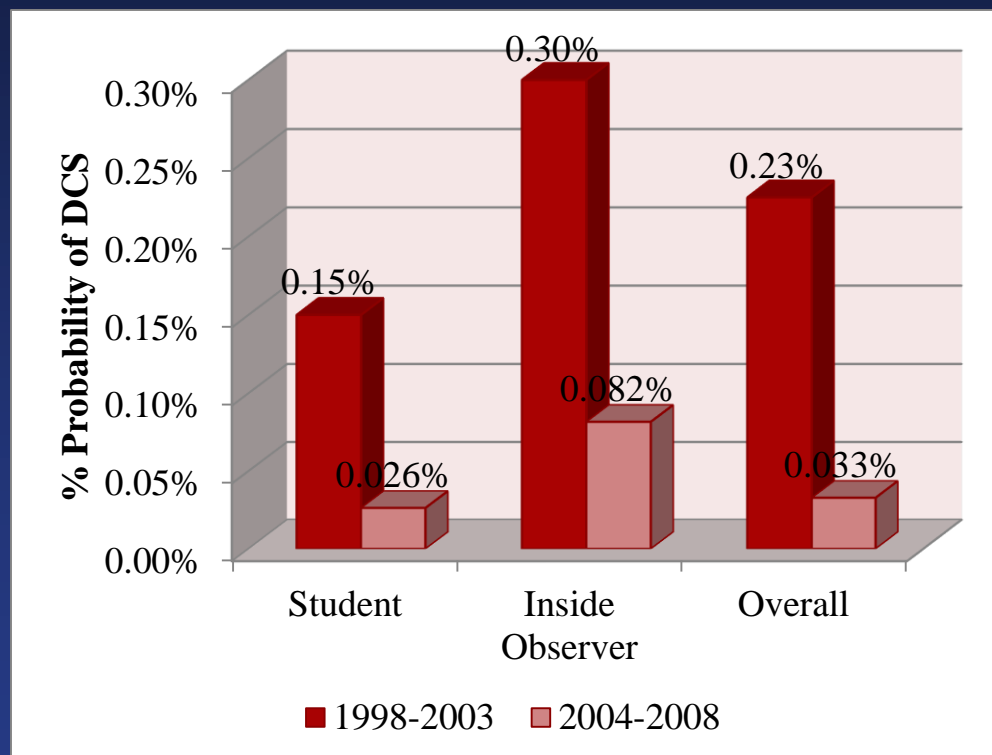
➤ 30 per 10,000 – '98-'03

➤ 8.2 per 10,000 – '04-'08

➤ Overall

➤ 22 per 10,000 – '98-'03

➤ 3.3 per 10,000 – '04-'08

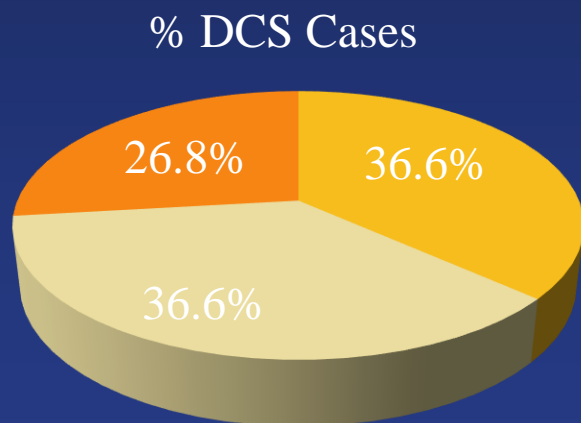


Altitude Injury Statistics

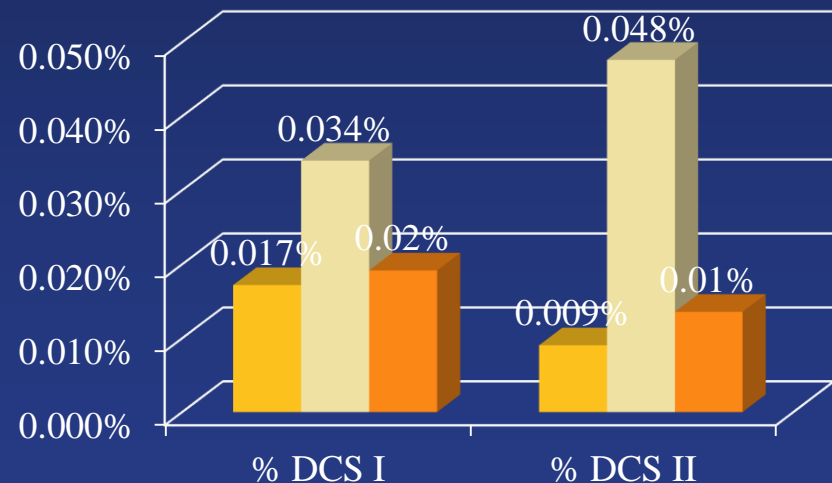
Chamber DCS Rates ('04-'08)

➤ Flight Profile

- Type II – 37% of DCS Cases (0.52% probability)
- Type IIA – 37% of DCS Cases (**1.09% probability**)
- Type III – 27% of DCS Cases (0.39% probability)



■ Type II ■ Type IIA ■ Type III

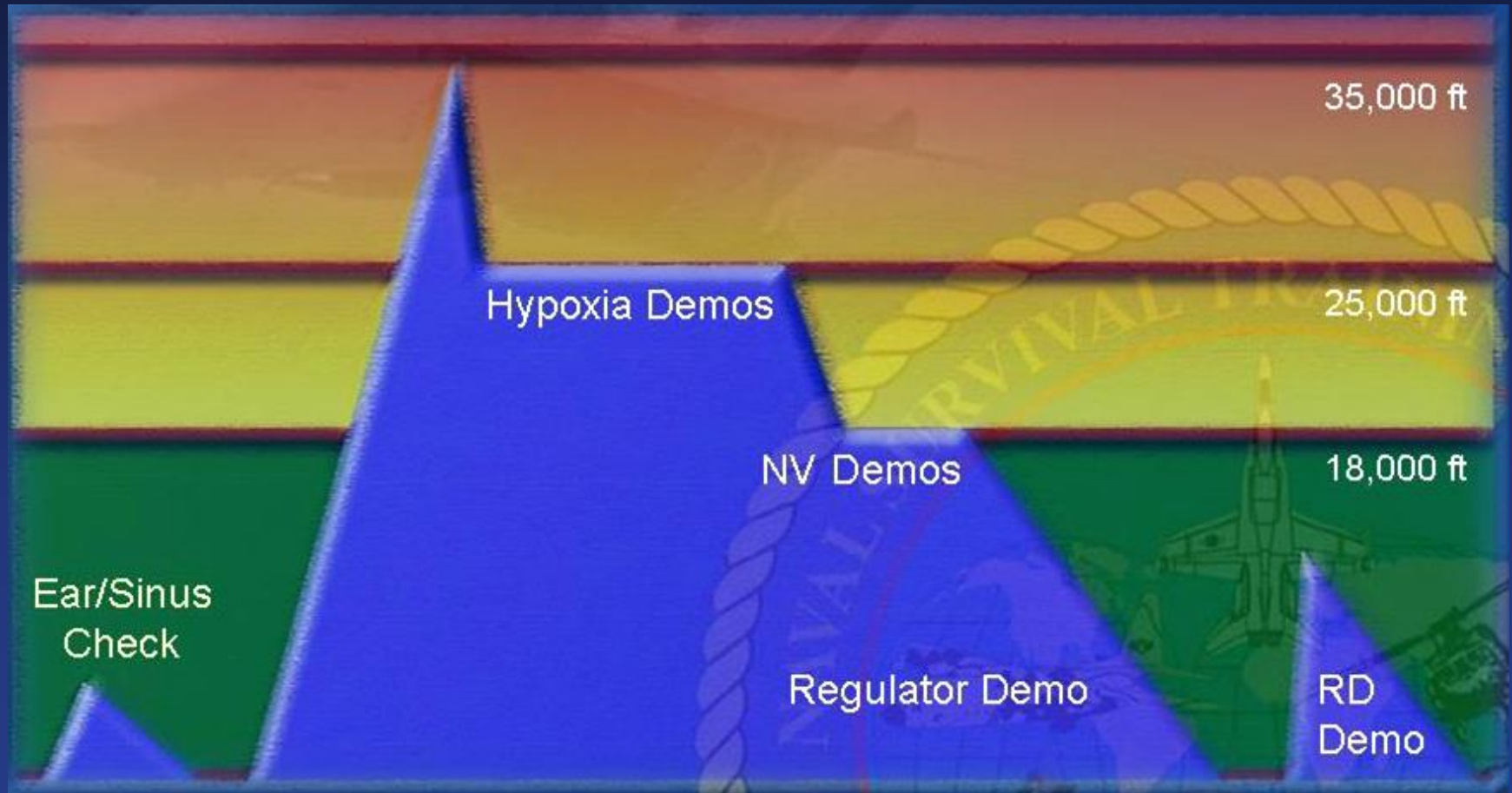


■ Student ■ Inside Observers ■ Overall



Altitude Injury Statistics

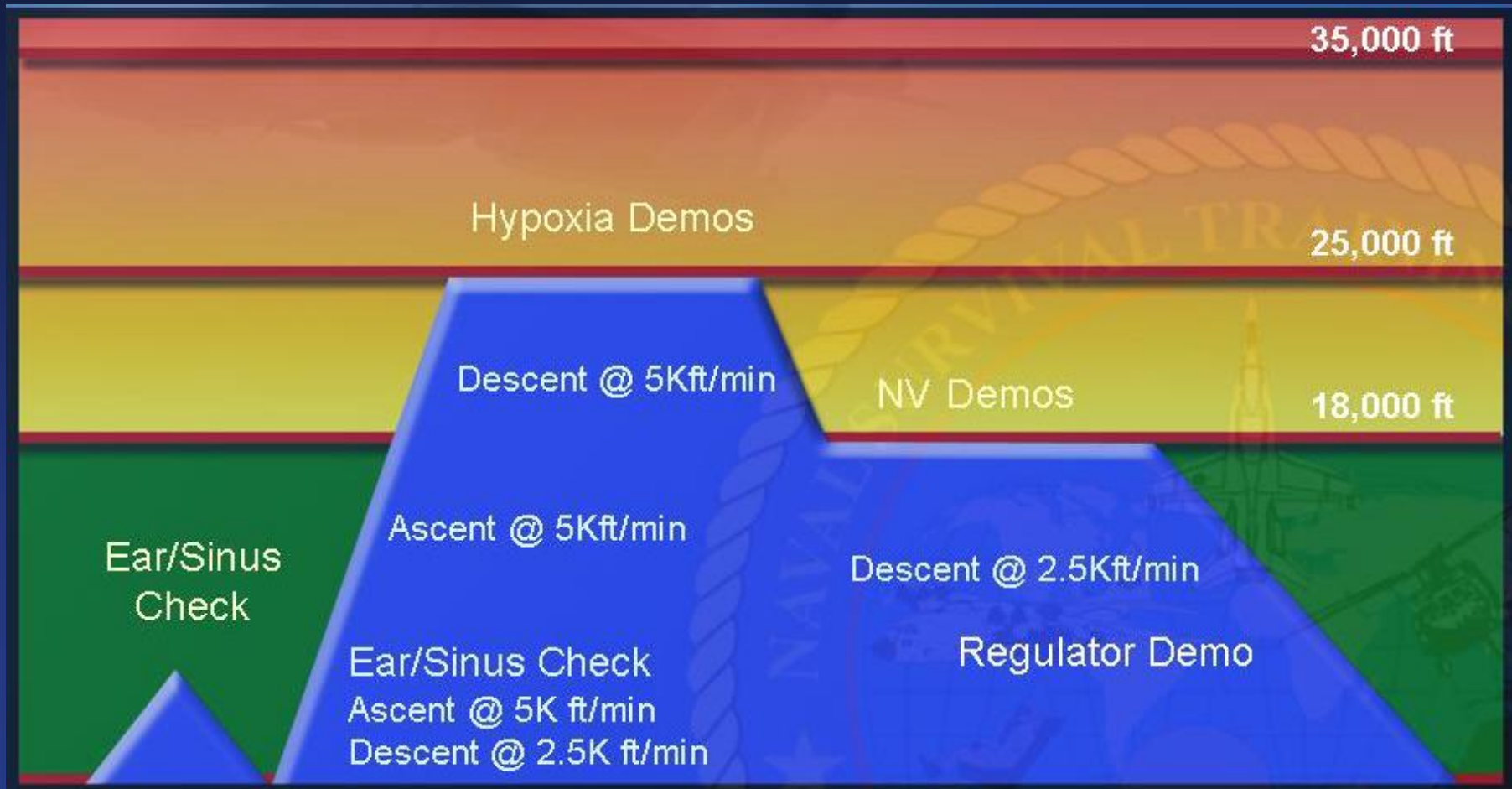
Type IIa Chamber Training Profile





Altitude Injury Statistics

Type VII Chamber Training Profile

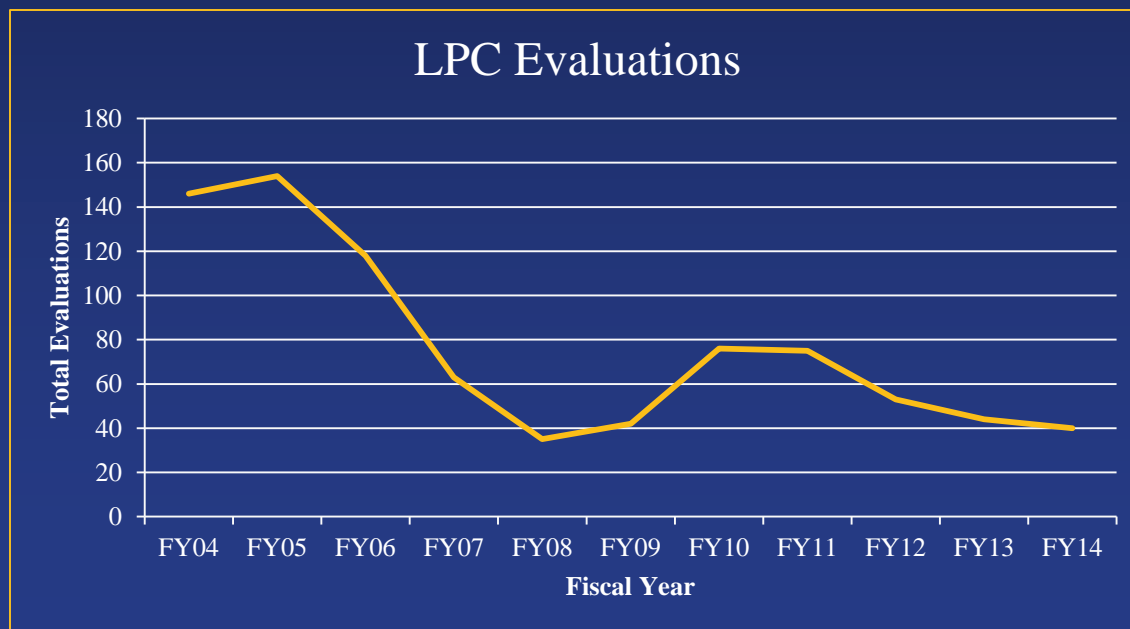




Altitude Injury Statistics

The New “NSTI” Experience (‘08-‘14)

- Average Injury Rate (FY 04-07): 0.52%
- Average Injury Rate (FY 08-14): 0.16%
- Declining / Stable LPC-Related Injury Evaluations...

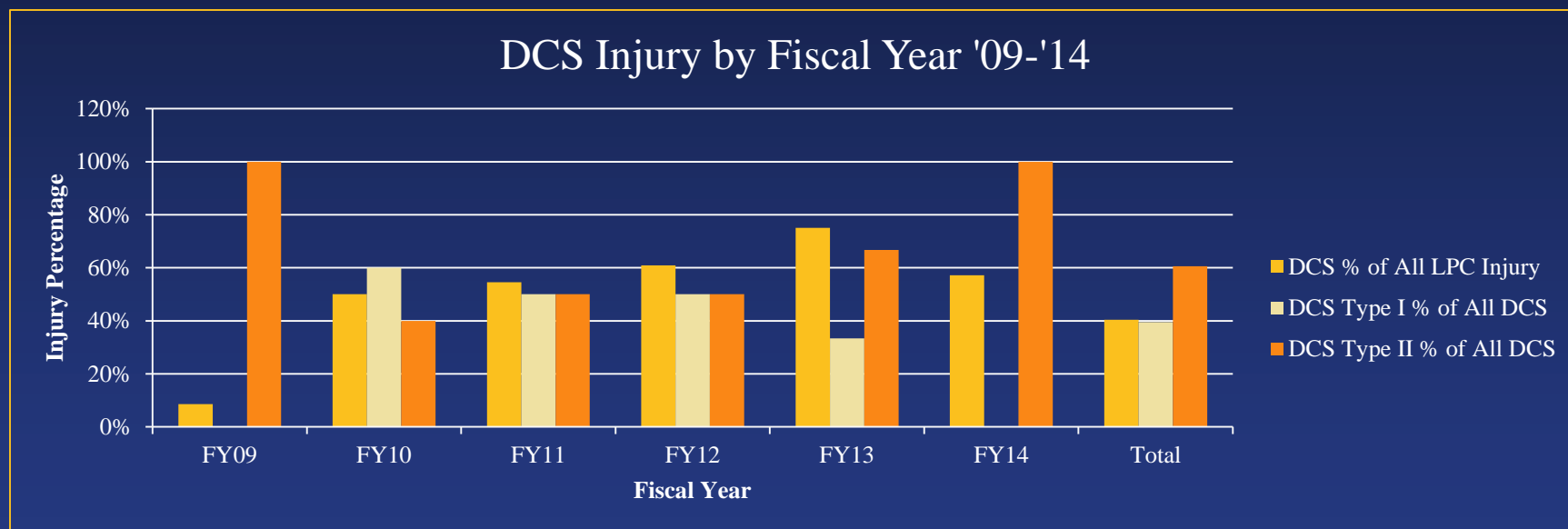




Altitude Injury Statistics

The New “NSTI” Experience (‘08-‘14)

➤ DCS still 22% of ASTC injuries; 40% of LPC Injuries



➤ Overall Incidence – 6 / 10,000 Exposures

➤ DCS Type I - 39%, DCS Type II - 61%,

Altitude Injury Statistics

Aircraft Environments





Safety Center HAZREP Review

All Airframes ('04 - '14)

➤ Decompression Events

- 72 Total Events
- 52 Rapid (72%)
- 17 Surging (23%) – Recent clustering

➤ Decompression Sickness

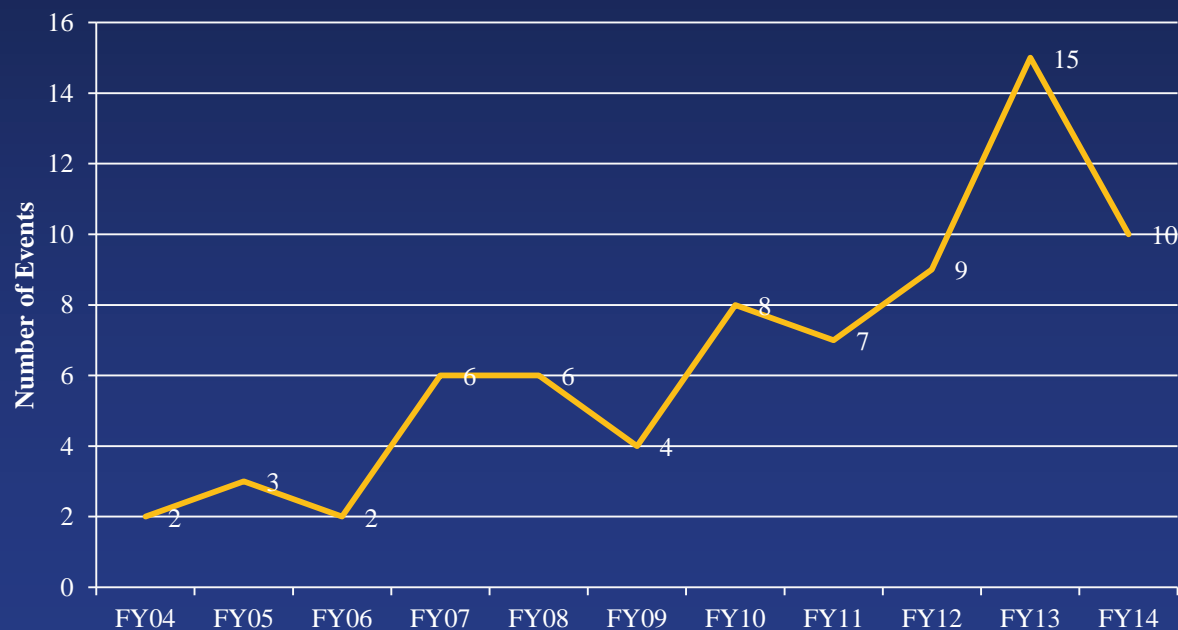
- 32 Total Cases
- Type I – 5 Cases
- Type II – 27 Cases (84%)



Safety Center HAZREP Review

All Airframes ('04 - '14)

Aircraft Decompression Events





Safety Center HAZREP Review

F/A-18 DCI Incidence ('12 - '14)

Fiscal Year	# DCI Cases	Flight Hours	Incidence / 100K Hours
FY12	5	276,559	1.80
FY13	9	252,523	3.56
FY14	11*	247,914	4.44



Rational Approach to Rapid-D Events



Establish Exposure History

- What was the Exposure
 - Altitude, time at altitude
 - Rapid-D, surging, cabin pressure
 - Activities at altitude
- Symptoms
 - Type and Time of Onset
 - Progression of Symptoms

Physical Examination

➤ Looking for Alternative Diagnosis



➤ DCI has Few Physical Findings by Itself



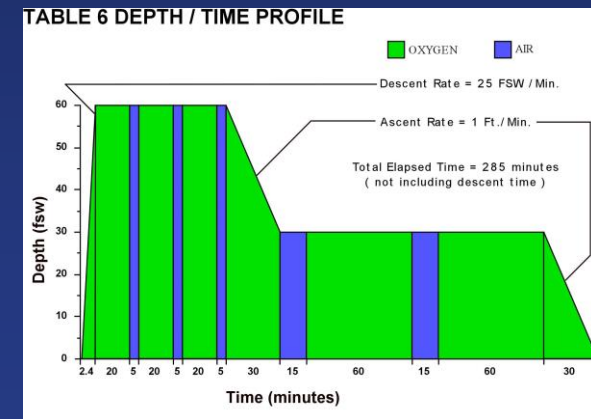
Neurological Examination

- “Must” Prior to Referral
- Be Complete (i.e. all 6 exam components)
- If Sought... Most Findings Not Subtle



Importance of Correct Diagnosis?

- Determines need / site / urgency for medevac
- Determines need for recompression
- Determines initial recompression table





COMNAVAIRFOR Message

R 296172 May 12

- Aircrew Physiological Events serious Concern
- NAVAIR has several initiatives in Development
- Revisions to Parts A, B, and C of HAZREP
- Squadrons incorporating DCS details into Premishap Plan and Duty Binders
- Include location of Two Closest 24/7 Hyperbaric Chambers (with recompression Tx capabilities)



Safety Center Announces Hotline

Naval Safety Center
COMNAVSAFECEN



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Aeromedical

Reporting of Laser Illumination of Aircraft **New!**

Ebola Information **New!**

Aviation DCS Hotline: (850) 449-4629

The Naval Aerospace Medical Institute (NAMI) is the world's leader in aerospace medical standardization and education. NAMI encourages flight surgeons and aviators to call their Aviation Decompression Sickness Consultative hotline at (850) 449-4629. It is available 24 hours a day, seven days a week, providing expert, real-time support to Flight Surgeons and aviators involved in suspected or confirmed altitude-associated decompression events.

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Fatigue Resource Packet Aviation Part 1 (pages 1-38) **New!**

Fatigue Resource Packet Aviation Part 2 (pages 52-98) **New!**

Fatigue Resource Packet for Shipping **New!**

Heat Stress Resource Packet **New!**

Cold Water Survival Information Packet **New!**

Cold Weather Flying and Survival Information Packet **New!**



NATOPS Revisions

- F/A-18 Flight Manual Revisions Underway
- OPNAVINST 3710.7U Revision?

8.2.4.6 Decompression Sickness

When an occupant of any aircraft is observed or suspected to be suffering from the effects of DCS, 100 percent oxygen or available aircraft oxygen will be started and the pilot shall immediately descend to the lowest possible altitude and land at the nearest civilian or military installation suitable for safe landing and obtain qualified medical assistance. Consideration shall be given to whether the installation is in proximity to a medical recompression chamber. It is extremely important to be able to recognize symptoms and convey this and the altitude profile to medical support and follow reporting procedures in reference (t).



Anticipated Case Outcomes and Conclusions





Navy DCI Outcomes Analysis

Altitude Chamber

- ASTC Chamber-Induced DCI ('07-'14)
 - Type I – 29 Cases
 - Type II – 39 Cases
- Persistent Symptoms in 4 Cases
 - 2 with delayed presentation / treatment
 - 1 with inadequate initial treatment
 - 1 no delay (returned to full duty)



Navy DCI Outcomes Analysis

Aircraft Platforms

- Aircraft-Induced DCI ('04-'14)
 - Type I – 5 Cases
 - Type II – 27 Cases
 - Several required multiple HBO₂ treatments
- Persistent Symptoms in 2 Cases
 - 1 with delayed presentation / treatment
 - 1 with inadequate initial treatment



Conclusions

- Rapid-D Events Increasing (F/A-18)
- DCI can be Challenging to Diagnose
- Requires Aviator & Flight Surgeon Vigilance
- NAVAIR / Safety Center Initiatives
 - NATOPS Revisions Underway
 - Local DCS / Rapid-D Triage Protocol
 - NAMI DCS Hotline: (850) 449-4629
- Timely Treatment Limits Adverse Outcomes



HBO₂ - Mechanisms of Action

Questions?

