

Hyperbaric Safety: A Half-Century Commitment 1965-2015

Paul J. Sheffield, PhD, CAsP, CHT, FUHM

2015 UHMS ASM
Montreal, Canada

Disclosure: Paul J. Sheffield, PhD President, International ATMO, Inc



- Provider of wound care & hyperbaric medicine mgt, consulting, and education services
- No relevant financial relationships with commercial interests



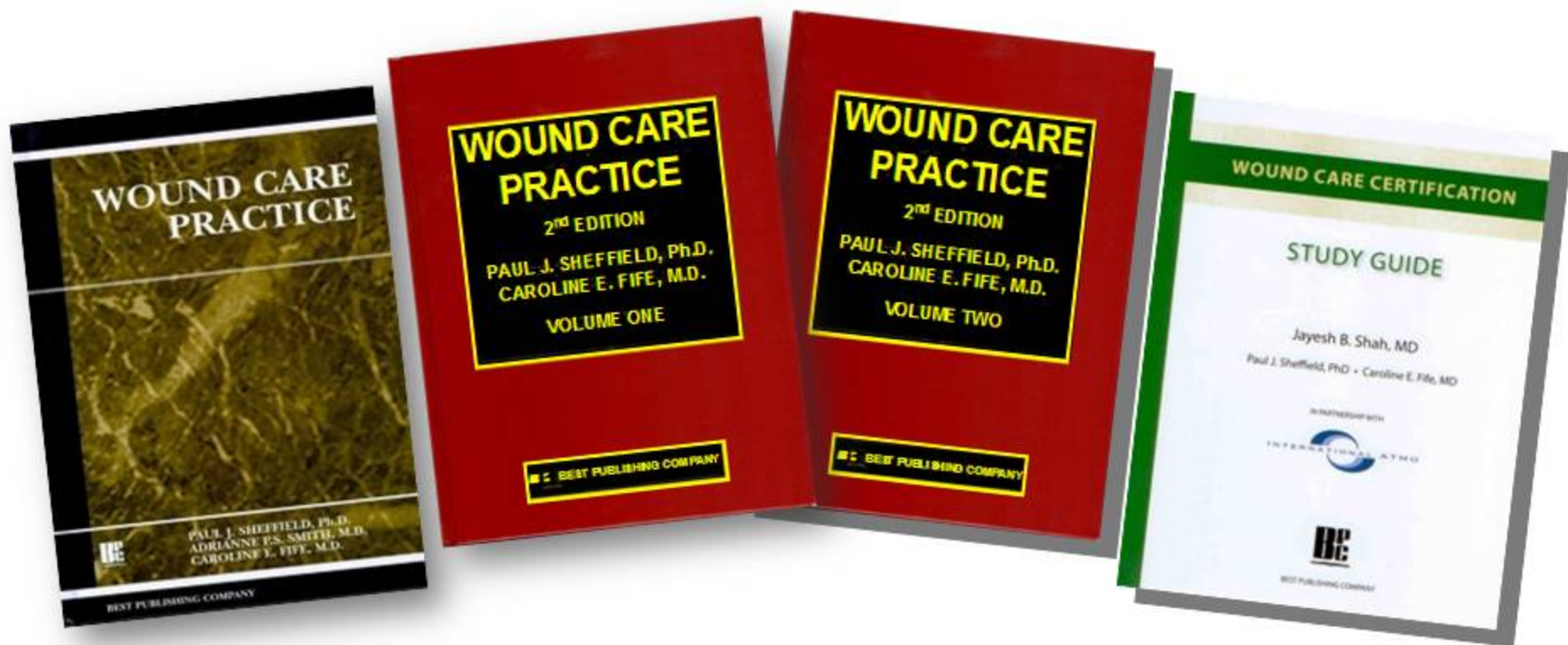
Disclosure: Paul J. Sheffield, PhD

Medical Seminars' CME Program Director

- No relevant financial relationships with commercial interests



Disclosure: Paul J. Sheffield, PhD Book Royalties



Objectives

- Explain our strong commitment to safety
 - Focus on chamber fire safety
- Describe a half-century journey with lessons learned at stops along the way

In Memory of Jefferson C. Davis, MD 1933-1989

- My Mentor
 - My instructor (1960s)
 - My boss (1970s)
 - My partner (1980s)



STOP 1

4500 USAF HOSP
LANGLEY AFB VA
1962-1965



- Medical Squadron Commander
- Hospital Safety Officer
- Hospital Fire Marshall

Langley Hospital Safety Officer **LESSON LEARNED**



Event: The Shooting
Lesson: Take safety seriously

Langley Hospital Fire Marshal **LESSON LEARNED**

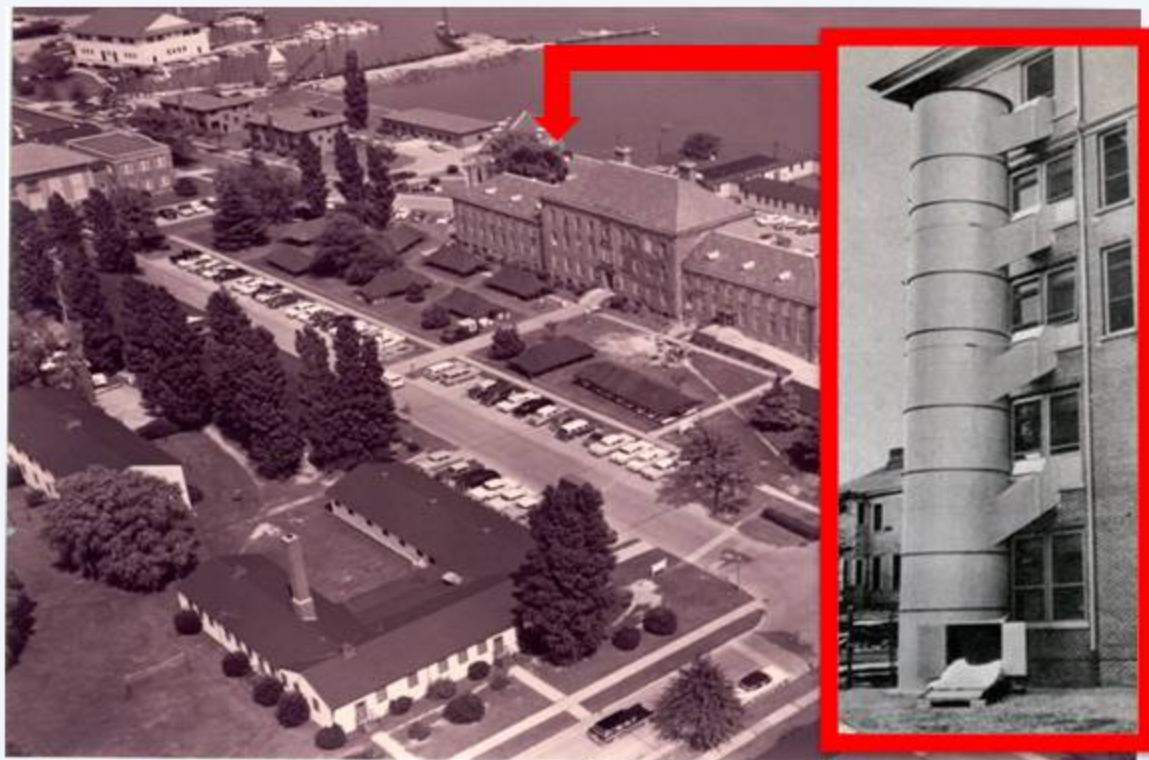


Photo is not the Langley Hospital fire escape chute

Event: The Fire Escape Chute

Lesson: Have an fire escape plan and practice fire drills

Langley Hospital Fire Marshal **LESSON LEARNED**



Event: The Dumpster Fire
Lesson: False alarms are disasters
waiting to happen

2015 San Antonio Senior High-Rise Blaze Kills 5

San Antonio Express News,
12/28/2015

Survivor: *"I heard the first two alarms go off, then they turned off," she said. "A lot of people are used to it being a false alarm. I thought for sure it was false, then the third alarm went off, and it stayed on."*



- Residents ignored alarms
 - Frequent false alarms
- >75 evacuated
- 5 deaths

STOP 2

USAFSAM

BROOKS AFB, TX

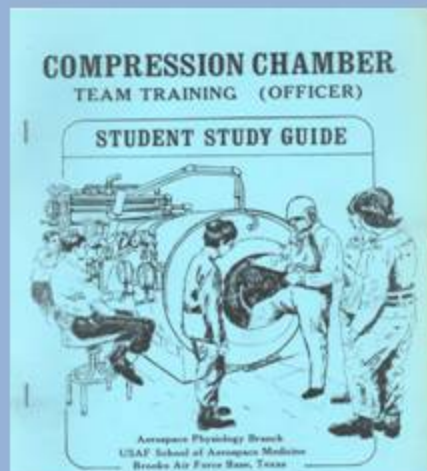
1965



Photo courtesy of George Wolf, MD

- Aerospace Physiologist Training

Aerospace Physiologist Training -1965



**Altitude Chamber
- Pressure Suit**
0.06 ata (65,000 ft)



Hyperbaric Chamber
6 ata (165 fsw)

Aerospace
Physiologist
Training
LESSON LEARNED



Col W.P. Fife
Man-Rated
Chamber



Brooks AFB Hypo/hyperbaric
Research Chamber

SD Leverett et al, Studies in DCS, 1963

- Lesson: HBO2 is the treatment for altitude DCS

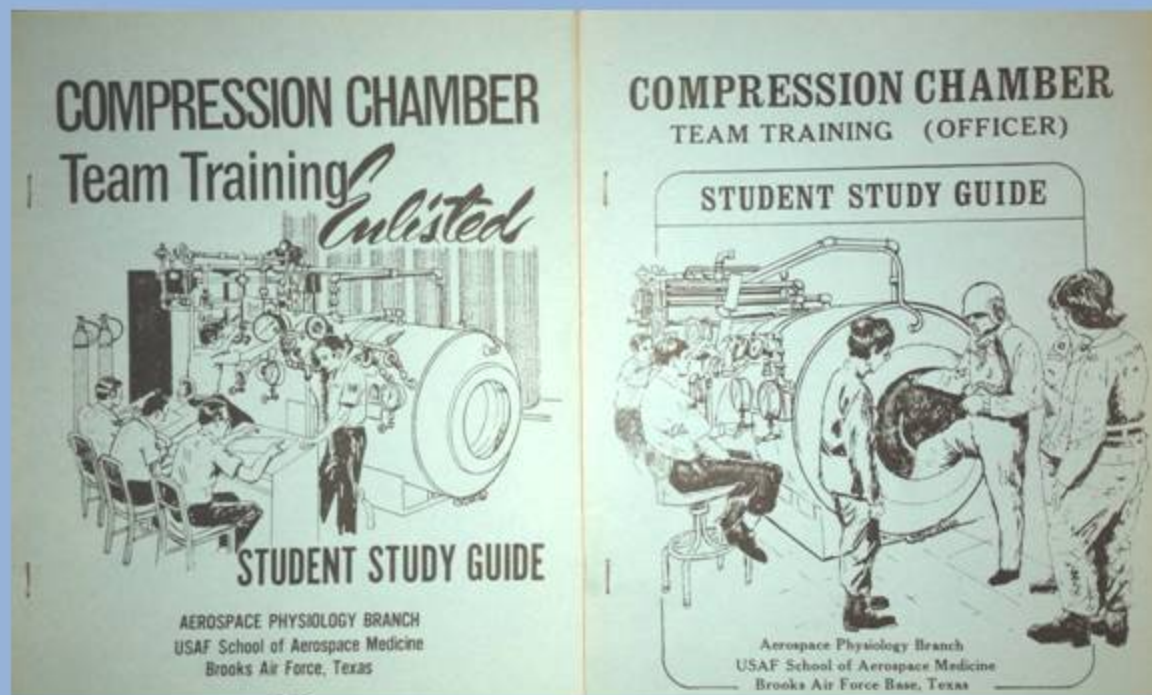
USAF Interest in Hyperbaric Medicine: Treatment of Altitude DCS

- 1941 – USN Alt DCS case (Behnke)
- WWII to 1959- 18 fatalities, 743 serious altitude DCS
- 1959 – Langley Alt DCS case (Donnell & Norton)
 - 1959 - USAFSAM research chamber installed
- 1963 – Brooks alt DCS studies (Leverett et al)
 - c1963 – Davis & Bassett attend USN DMO course
- 1965 – Compression (HBO2) became standard of care for altitude DCS (Davis)
- 1965 – USAF first hyperbaric medicine course in USA (CCTT)



c1965

USAFSAM Compression Chamber Team Training Instructors



USAF Compression Chamber Team Training (1965-1980) First Hyperbaric Medicine Course in USA

Aerospace Physiologist Training

LESSON LEARNED

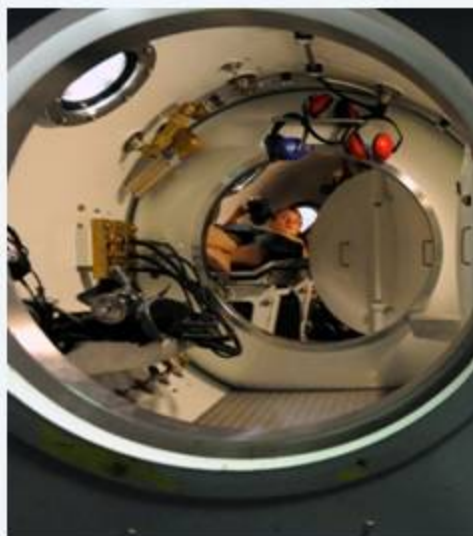


Photo is not Navy EDU

- Incident Report: 1965 Chamber Fire, Navy EDU, Wash DC
 - 2 sailors killed, 2 injured
- Lesson: Fire is a risk for hyperbaric chambers

STOP 3

AEROSPACE PHYSIOLOGY UNIT

Langley AFB, VA
1965-1969



- Altitude Chamber Aircrew Training
- Lesson: Oxygen is good

Langley
Aerospace
Physiology Unit
LESSON LEARNED



Excerpts from: Air Force Training Film TF 8233, 1969

- Event: The Plasma Bubble Film
- Lesson: Bubbles respond to ΔP
 - Presentation is important

Langley
Aerospace
Physiology Unit
LESSON LEARNED



Pressure Gage (+ press)



Altimeter (- press)

- Event: The Altimeter Failure
- Lesson: Glass fails without warning

Langley
Aerospace
Physiology Unit
LESSON LEARNED



- Incident Report: Aircraft Window Failure at FL350
 - Copilot extruded
 - Crew held onto his legs
- Lesson: Glass windows fail without warning

Copilot Suffers Frostbite



- Frostbite of face & hands when extruded through window at 35,000 ft

Langley
Aerospace
Physiology Unit
LESSON LEARNED



- Incident Report: Pilot burned while smoking
- Lesson: Smoking and oxygen don't mix

2008 NFPA Report: Home Medical Oxygen Fires in USA

- 2002-05: Ave 182 home medical oxygen fires
 - 46 deaths annually
- Smoking was leading factor (75%)

Ref: Ahrens M. Fires & Burns Involved in Home Medical Oxygen, Quincy, MA: NFPA, 2008.

Langley Aerospace
Physiology Unit
LESSON LEARNED



- Incident Report: Jan 1967 Apollo 1 fire at Cape Canaveral
- Lesson: Need national fire safety standards

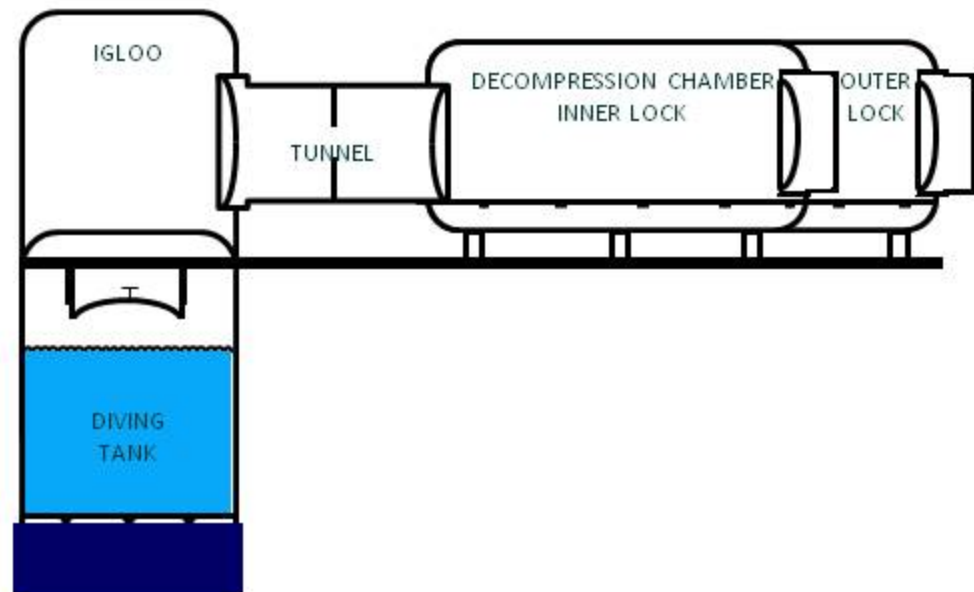
Origin of NFPA Hyperbaric Fire Safety Codes

- Based on 3 Fatal Fires
 - USN Experimental Diving Unit, Washington DC (1965)
 - NASA Apollo 1 Command Module, Cape Canaveral FL (1967)
 - USAF Altitude Research Chamber, Brooks AFB, TX (1967)

USN EDU Washington DC (1927-1975)

Fire occurred on 16 Feb 1965

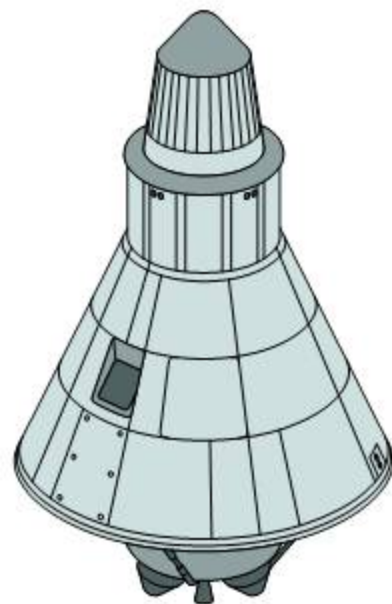
- Fatalities: 2
- Oxygen: 28%
- Pressure: 91 fsw
(3.8 ata)
- Probable Cause: CO₂ scrubber
- Overheated motor ignited
cellulose filter that had been
impregnated with kerosene



Apollo 1 Command Module Fire

Cape Canaveral, Florida, 27 Jan 1967

- Fire occurred on launch rehearsal
- Fatalities: 3 astronauts
- Oxygen: 100%
- Pressure: 16.7 psia
(1.14 ata)
- Probable Cause: Electric arcs
- Engulfed in flames within seconds





Apollo I Command Module Fire
Cape Canaveral, Florida, Jan 27, 1967



Apollo 1 Command Module Fire
Cape Canaveral, Florida, Jan 27, 1967

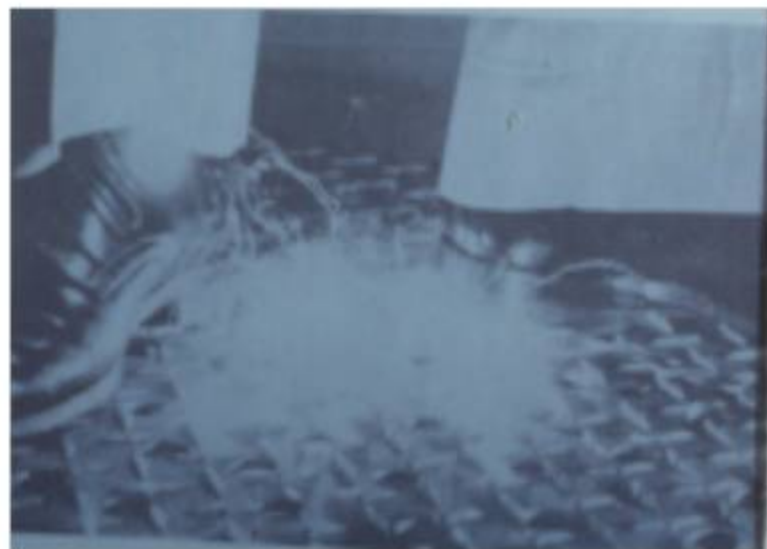
USAF Altitude Research Chamber Fire

Brooks AFB, TX (January 31, 1967)

- Fire occurred during animal study
- Fatalities: 2 airmen
- Numerous animals
- Oxygen: 100%
- Pressure: 0.34 ATA (25,000 ft)
- Probable Cause: Electric arc
- Engulfed in flames within seconds



Abraided Lamp Cord Ignites Clothing



No Survivors

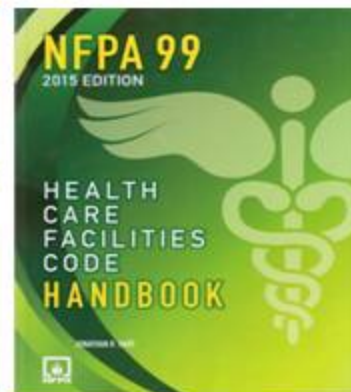
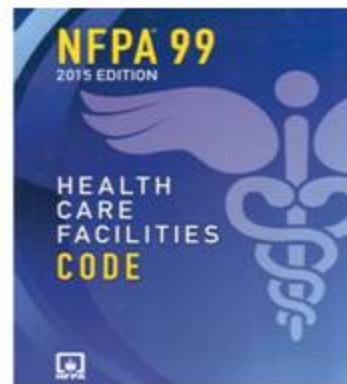


Unused Fire
Extinguisher



NFPA Health Care Facilities Fire Standards for Hyperbaric Facilities

- Purpose: Minimum safeguards for fire protection of patients and hyperbaric personnel
 - 1968 NFPA 56D-T – tentative safety standard
 - 1970 NFPA 56D - first chamber fire safety standard
 - 2015 NFPA 99, Ch 14 – current standard



Stop 4

Univ of Southern
California
Los Angeles, CA
1969-1971



PJ Sheffield

BJ Pfoff



- Graduate Student: MS & PhD in Physiology

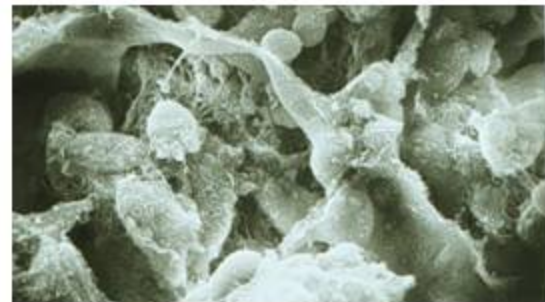
Pulmonary Oxygen Toxicity Studies

Sheffield, Pfoff, 1971



Normal Lung

Photos by
BJ Pfoff

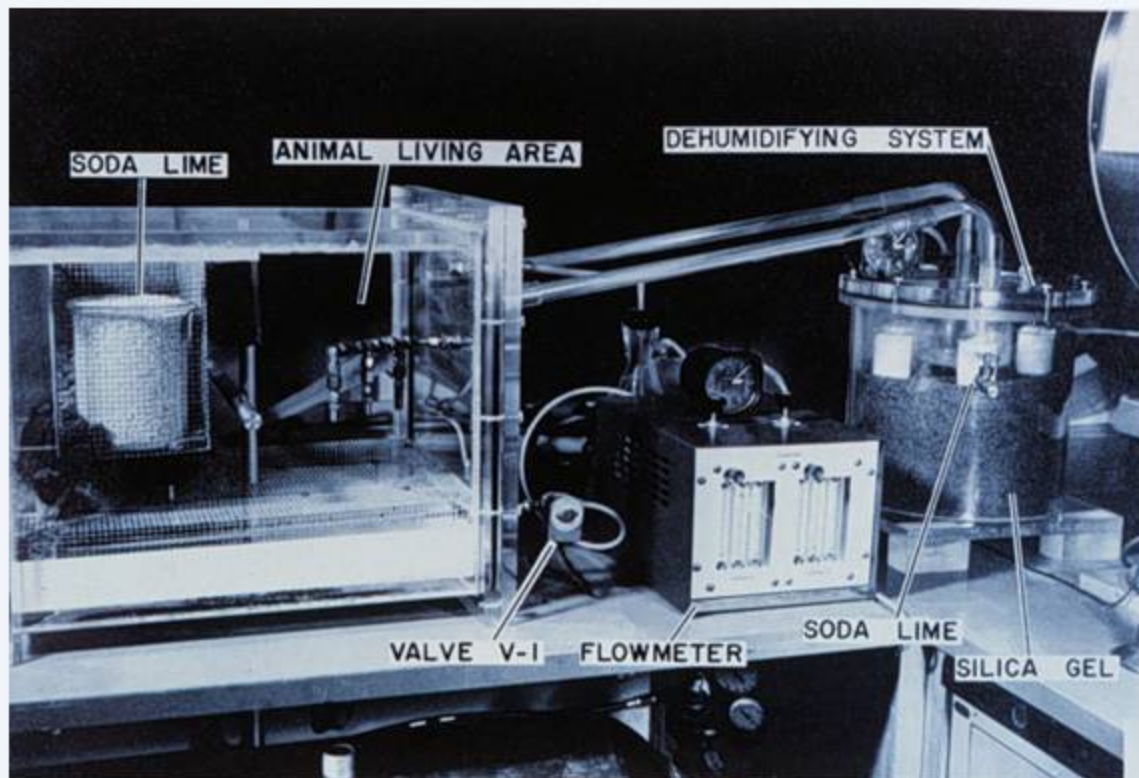


Oxygen Toxic Lung

Exposure	pO ₂	Survival
100% O ₂ at SL (1 ata)	760 mm Hg	5 days
100% O ₂ at 5,000 ft (0.8 ata)	632 mmHg	7-15 days
100% O ₂ at 22,500 ft (0.4 ata) with monthly incr pressure increments	315 mm Hg	5 months*

*incl 30 days survival at 5,000 ft when experiment terminated COPYRIGHT © 2015 · Paul J. Sheffield, PhD

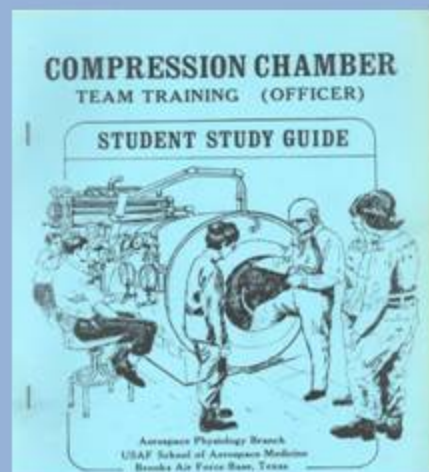
USC Grad School
Los Angeles, CA
LESSON LEARNED



- Event: Mouse House for Space
- Lesson: Too Much Oxygen Is Bad
 - Toxic to lungs & other organs

Stop 5

USAF School of Aerospace Med Brooks AFB, TX 1971-1974



- Aerospace Physiology Instructor
- USAFSAM Flying Safety Officer
- CCTT Course Director

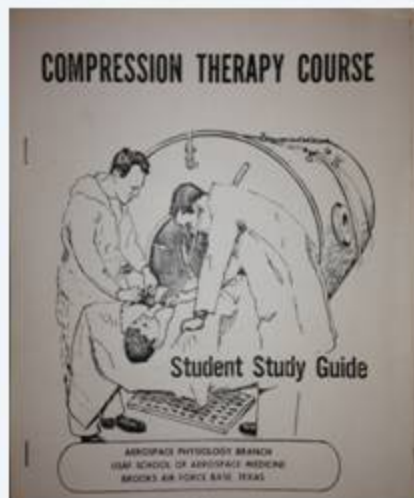
USAFSAM Flying
Safety Officer 1972-
74

LESSON LEARNED



- Event: Aircraft Accident Investigation
- Lesson: Restraint is important for survival
- Lesson: Eyewitness accounts must be verified by physical evidence

USAFSAM CCTT/CT Course Director **LESSON LEARNED**



- 1st Compression Therapy Course 1972
- Fire safety instruction is a priority
 - Fibreglas suits in hyperbaric chambers

Early Hyperbaric Safety Education

- 1965 USAF -Compression Therapy Team Training Course
- 1972 USAF -Compression Therapy Course
- 1976 Kindwall -Clinical Hyperbaric Medicine Course
- 1978 Hart & Strauss -Intro to Hyperbaric Medicine Course
- 1980 International ATMO -Hyperbaric Medicine Team Training
 - 1998 HMTT = First Approved UHMS Intro Course in HM

USAFSAM CCTT/CT
Course Director
LESSON LEARNED



- Event: AF IG Site Visit 1974
 - IG: “Potential lethal device”
 - 1965-1973: AF treated ~100 DCS & AGE emergency cases
 - Most were returned to duty
- Lesson: Data are important

How Did USAF Get Involved With HBO2 For Wound Healing?

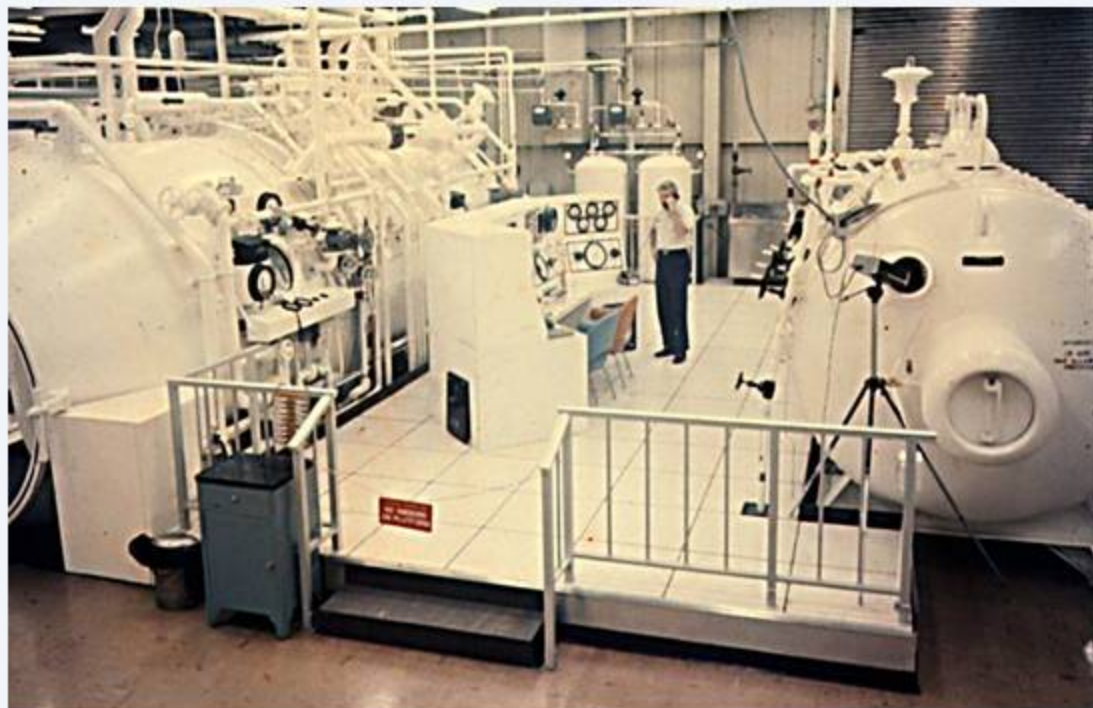
- Jefferson C. Davis, MD
 - RAM Course Director
 - LEOFAST Consultant
- 1974- Convinced AF SG to create USAF Hyperbaric Center
 - Treat aviator and diver DCI
 - To satisfy an operational need for treating war injuries



Jefferson C. Davis, MD
(1933-1989)

STOP 6

USAF Hyperbaric Medicine Center, Brooks AFB TX (1974-1984)



- Director, Operations & Research
 - Study war related injuries
 - Manage USAF Hyperbaric Safety Program

Research Chamber Converted to Clinical



USAF Hyperbaric Center, Brooks AFB TX

Documenting Pressure Test of World's Oldest Operational Chamber



- 1903 - Berkley Steel Construction Co
- 1911 - Panama Canal Zone
- 1974 - Brooks AFB Texas
- 2008 – Removed from service

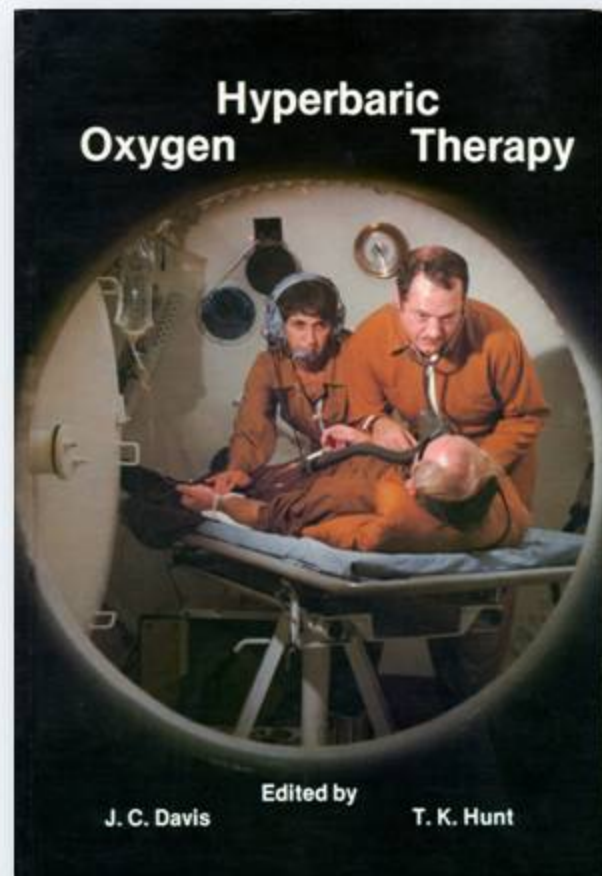
The First Hyperbaric Medicine Textbook



JC Davis, MD

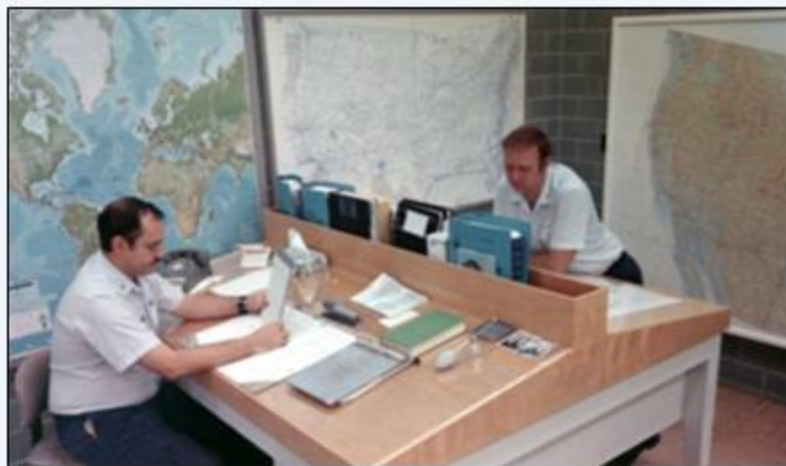


TK Hunt, MD



- **Hyperbaric Oxygen Therapy, 1977**

LEOFAST (Consult Service for Divers & Aviators) preceded DAN



RD Heimbach at USAF Hyperbaric Medicine Center c 1974

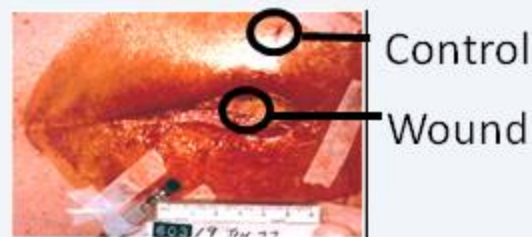
- 1964 – AF created LEOFAST (536-3278)
- 1974 - Managed by USAF Hyperbaric Center
 - 35 chambers worldwide accept diver/aviator DCS
- 1979 - Managed by Dr JC Davis (ATMO)
- 1980 – Divers Alert Network created

Tissue Oxygen Studies

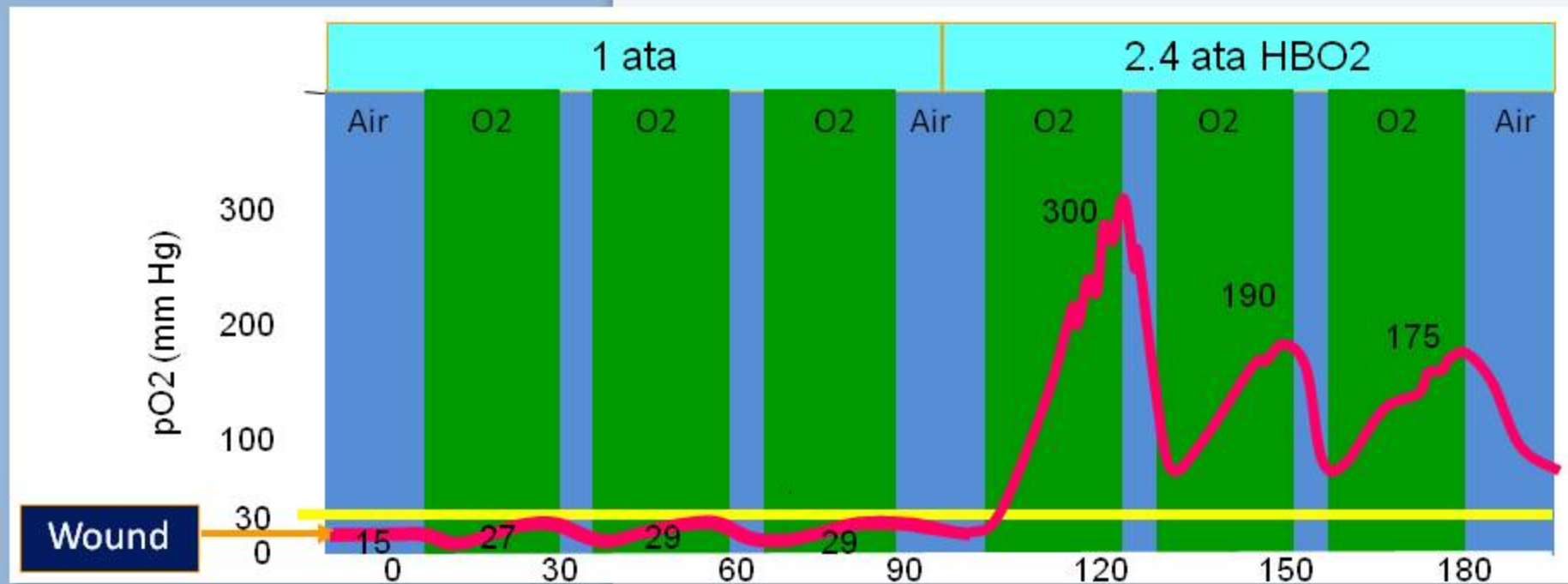


- Invasive Tissue Oxygen Studies
- 1977: First report
- 1985: UMS Hyperbaric Oxygen Review

O₂ Electrodes Confirm: Wounds Not Responsive to GLO₂ Respond Well to HBO₂

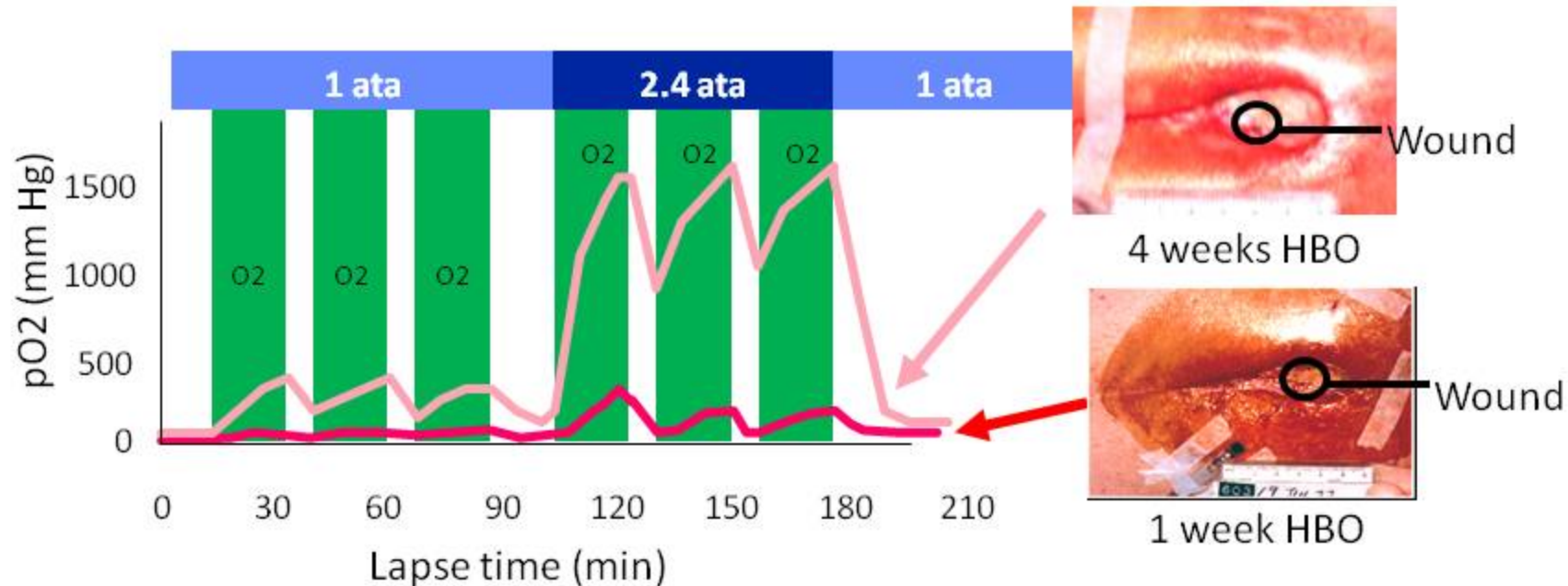


Patient 603EM: Soft Tissue Radionecrosis – Week 1



O2 Electrodes Confirm: Multiple HBO2 Elevates Wound pO2 to Correct Local Tissue Hypoxia

Patient 603EM: Soft Tissue Radionecrosis – Week 1 & 4



Sheffield PJ, Dunn JM, 1979

Paul J. Sheffield, PhD

Origin of In-Chamber TCOM? Transcutaneous O2 Studies, 1980



WT Workman, USAF Hyperbaric Medicine Center, 1980

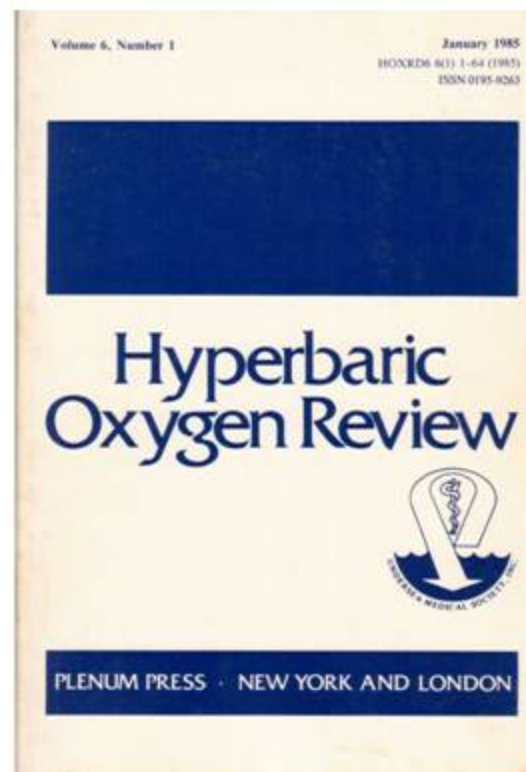
- 1980: Invasive electrode out of production
 - Radiometer TCM1 to the rescue
- 1983: First report of in-chamber data
- 1985: UMS Hyperbaric Oxygen Review

Tissue Oxygen Assessment Articles

UMS Hyperbaric Oxygen Review 6(1),1985

EP Kindwall, Editor; Leah Blackburn, Asst Managing Editor

- “...featured papers on tissue oxygen measurements.”
 - Sheffield: Tissue oxygen measurements with respect to soft tissue wound healing with normobaric and hyperbaric oxygen.
 - Sheffield & Workman: Noninvasive tissue oxygen measurements in patients administered normobaric and hyperbaric oxygen by mask.



Tissue Oxygen Assessment Articles

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- “...featured papers on tissue oxygen measurements.”
 - Sheffield: Tissue oxygen measurements with respect to soft tissue wound healing with normobaric and hyperbaric oxygen.
 - Sheffield & Workman: Noninvasive tissue oxygen measurements in patients administered normobaric and hyperbaric oxygen by mask.
- “Due to demand, a second printing is underway...This is by far the largest printing in the history of the REVIEW.”
 - 550 copies printed
 - 150 chamber facilities in USA



1 March 1985

Dr. Paul Sheffield
3257 Ridge Road
Beale AFB, CA 95903

Dear Dr. Sheffield:

I have enclosed two copies of the HBD REVIEW featuring both of your papers on tissue oxygen measurements.

Our publishers had initially printed 350 copies of this issue. Due to demand, a second printing is currently underway for an additional 200 copies. Perhaps this accounts for the delay in your receiving the journal on a timely basis. This is by far the largest printing in the history of the REVIEW.

In any event, please enjoy these copies in good health.

Thank you, once again, for your contributions.

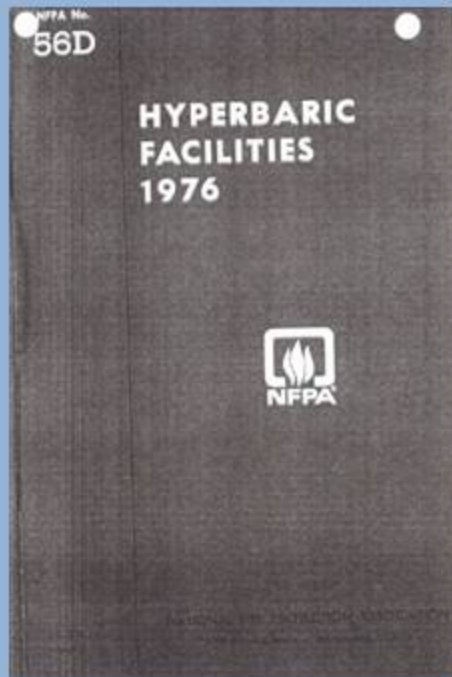
Sincerely,


Leah Blackburn

LB/

encl.

USAF Hyperbaric Safety Program: **LESSON LEARNED**



- Event: 1975 USAFSAM Safety Code Review Panel
- NFPA 56D/E Fire Code Review
 - 1970 code too strict for AF compliance
 - 1975 Panel Findings
 - 150 changes to NFPA 56D
 - 138 changes to NFPA 56E
- 1976 NFPA 56D/E codes – could comply
- Lesson:
 - Code Committee is receptive to good ideas
 - Be careful what you ask for

USAF Hyperbaric Safety Program: Pressure Vessels for Human Occupancy

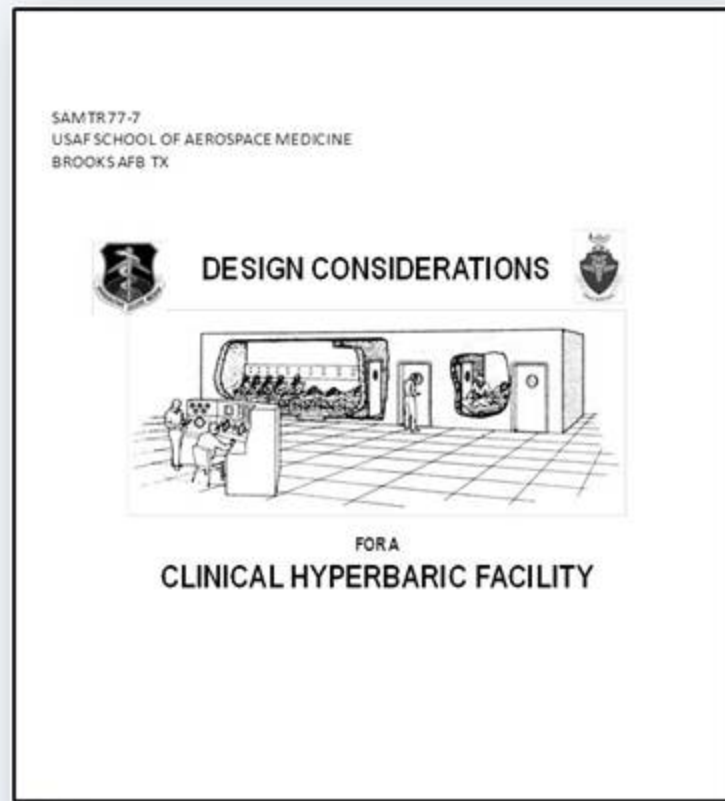


ASME PVHO-1 Safety Standard

- Purpose : Rules for fabrication, testing & inspection, and acrylic viewport design
- 1960s - Glass viewport failures occurred during chamber pressure tests
- 1977 - first ASME-PVHO Safety Standard
- 2012 - Current standard
 - Requires acrylic viewports

USAF Hyperbaric Safety Program:

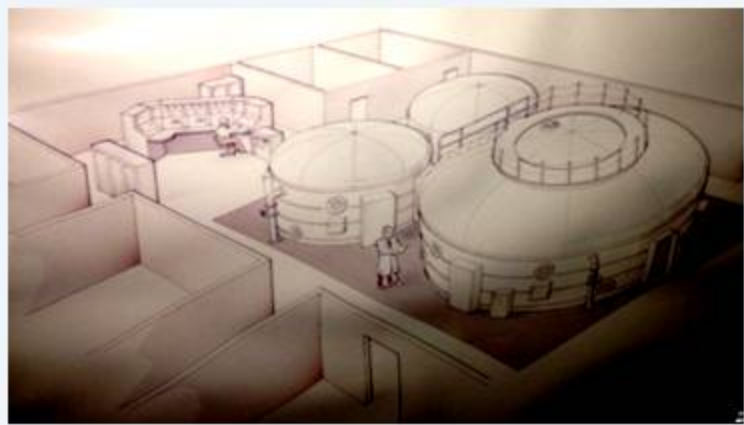
Design concept for future AF Clinical Chambers



Authored by Sheffield PJ, Davis JC, Cutrona CJ, 1977

- Treatment capacity
 - Simultaneous wound and emergency cases for up to 80 patients per day

USAF Hyperbaric Safety Program: **LESSON LEARNED**



Wright Patterson CHF -1985-2014



WPAFB Main Chamber (20 patients)

- Treatment capacity can be achieved by an upright cylinder or rectangular design

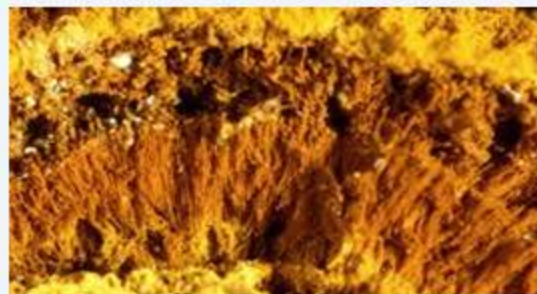
USAF Hyperbaric Safety Program

LESSON LEARNED



Photo courtesy of J Gorum

FES weld leak site



Gallionella ferruginea
oxidizes iron for a living

- Incident: FES stainless steel pipes leak
 - Bacteria ate through stainless steel welds
- Lesson: Chlorinate and circulate water in the FES

USAF Hyperbaric Safety Program: Design concept for future AF Clinical Chambers



1998 Rectangular Concrete Chamber Test
Brooks AFB , San Antonio, Texas



2009 Rectangular Chamber Installed
Wilford Hall CHF, San Antonio, Texas

Stop 7

Physiological
Support Division
Beale AFB, CA
1984-1987



- Chief, Physiological Support Division
- Dir, U-2/SR-71 Pressure Suit Depot

Beale PSD
Aerospace
Physiologist
LESSON LEARNED



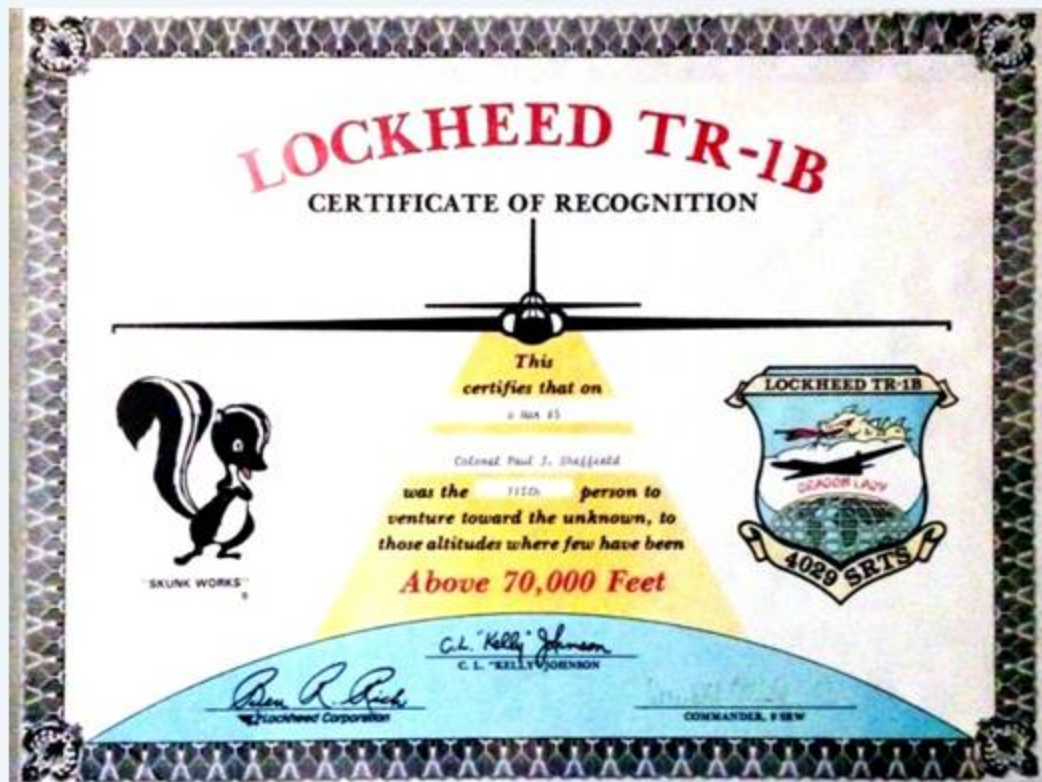
TR1-B = Two-seat version of the U2 Dragon Lady

- Event: TR1-B Flight
- Lesson: An effective instructor knows the student's environment

Beale AFB, CA 1984-1987



TR-1 B is 2-seat version of the U-2



Lockheed TR-1 B Certificate of Recognition

On 6 Mar 1985, Colonel Paul J Sheffield was the 112th person to venture toward the unknown, to those altitudes where few have been above 70,000 feet.

Signed: CL "Kelly" Johnson / Ben R Rich, Lockheed Corp / David H Pinsky, Commander



Capt Susan Richardson, USAF, BSC
First woman to fly in TR1-B, 1986

Beale Pressure Suit Depot

LESSON LEARNED



Pressure suit protection required above 50,000 ft
Armstrong's Line (63,000 ft) – fluids boil at body temp

- Event: Pressure Suit Inspection
- Lesson: Smoking must be limited

Stop 8

Office of the ATC
Surgeon
Randolph AFB, TX
1987- 1988



"Taj Mahal", Randolph Air Force Base, Texas

- Senior Aerospace Physiologist
- Command Coordinator for Aircrew Physiological Training

**ATC Senior
Aerospace
Physiologist**
LESSON LEARNED



Helen T. Davis BBA



Jefferson C. Davis, MD

- Event: 1987 Problem Wound Symposium
 - Problem Wounds: The Role of Oxygen
- Lesson: Hyperbaric medicine is reoriented to treating problem wounds

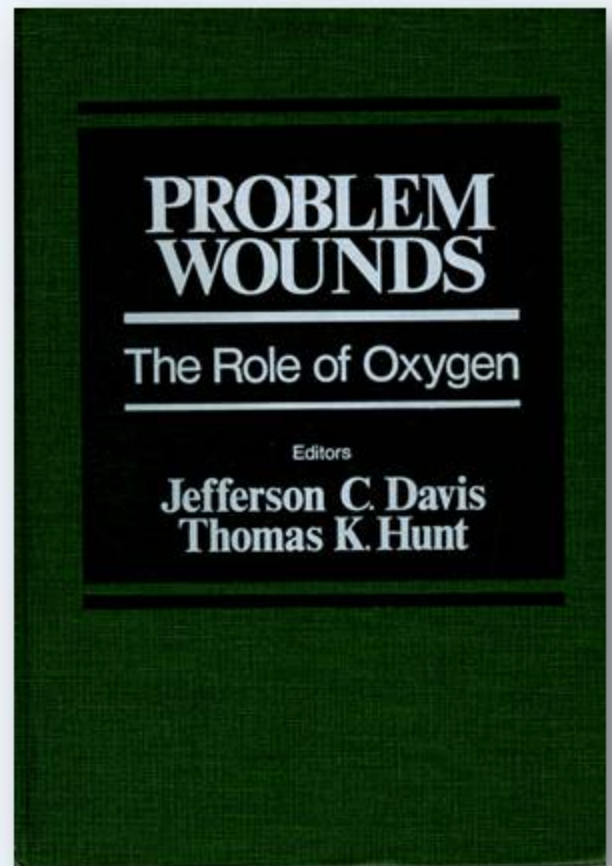
The Second Hyperbaric Medicine Textbook



JC Davis, MD



TK Hunt, MD



- **Problem Wounds: The Role of Oxygen
1988**

Stop 9

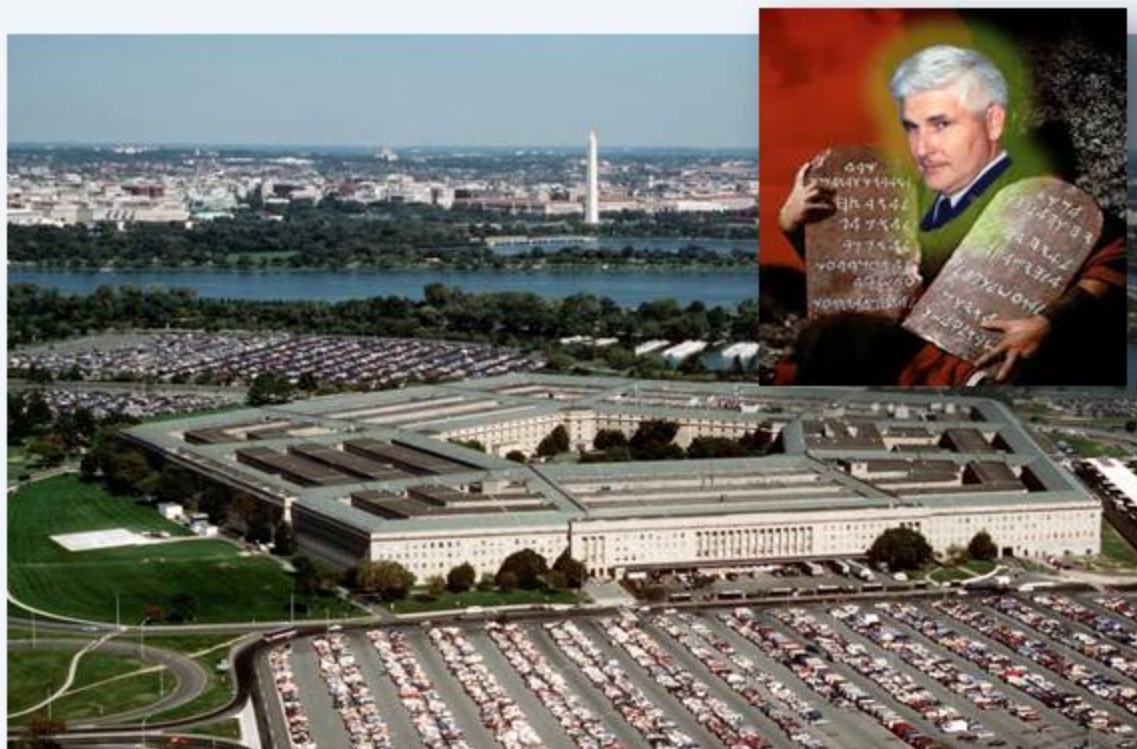
Office of the USAF
Surgeon General
Washington DC
1988-1992



- Chief Aerospace Physiologist
- Aircrew Physiological Training
- USAF Hyperbaric Medicine Program

Stop 9

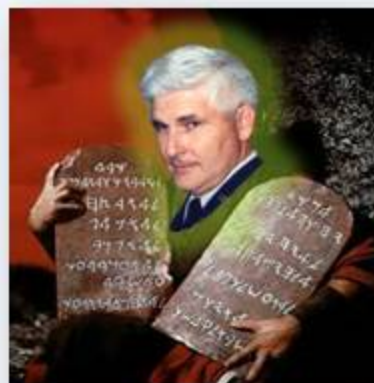
Office of the USAF
Surgeon General
Washington DC
1988-1992



- Chief Aerospace Physiologist
- Aircrew Physiological Training
- USAF Hyperbaric Medicine Program

USAF Hyperbaric Medicine Program

LESSON LEARNED

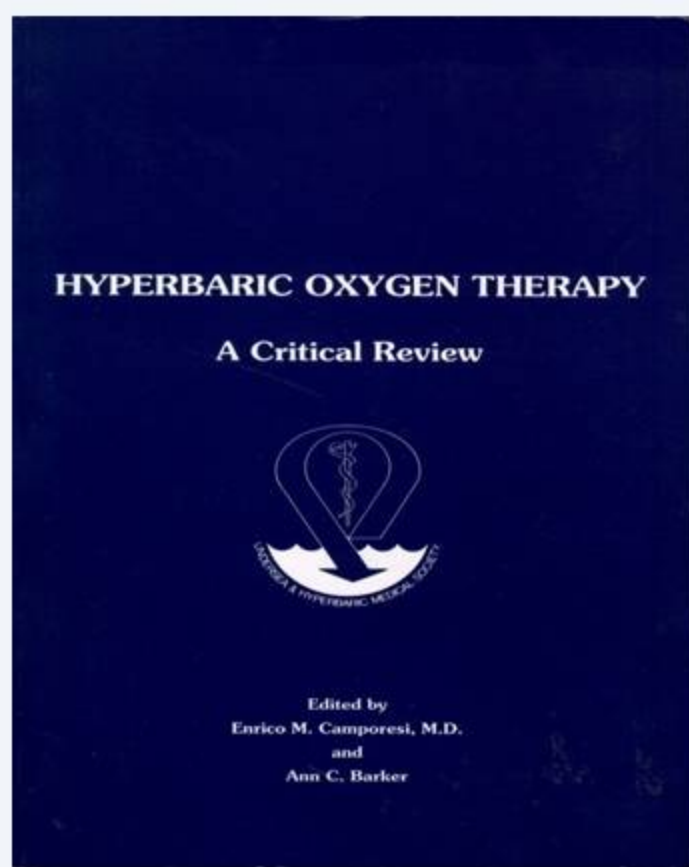


- Event: 1989 Challenge to close USAF Hyperbaric Medicine Program
 - “No role for HBO2 in USAF”
 - “Statistics errors in HBO studies”
- UHMS HBO Committee Critical Review
- Lesson: Importance of critical review

Camporesi & Barker
(eds).

**Hyperbaric Oxygen
Therapy: A Critical
Review**

Bethesda, MD,
UHMS, 1991



- Critical review of 13 indications approved by UHMS HBO Committee in 1986 & 1989 plus acute cerebral edema

USAF Hyperbaric Medicine Program

LESSON LEARNED



Not the actual fire

- Incident Report: 1989 Chamber Fire, Danville, PA
 - Microwave heated blanket began to burn when it was sent via lock into chamber.
 - Chamber operator extinguished fire with FES saving lives of 4 patients and 2 attendants
- Lesson: Chamber fire is survivable

USAF Hyperbaric Medicine Program **LESSON LEARNED**

- Incident Report: 1989
Chamber Fire, Danville, PA



Tom Workman Betty Knox Brown
stand-in



P Sheffield BK Brown R Sheffield
Danville fire

2012: Betty Knox Brown receiving UHMS
GCC Workman Safety Award for heroic
action as chamber operator during Danville
hyperbaric chamber fire

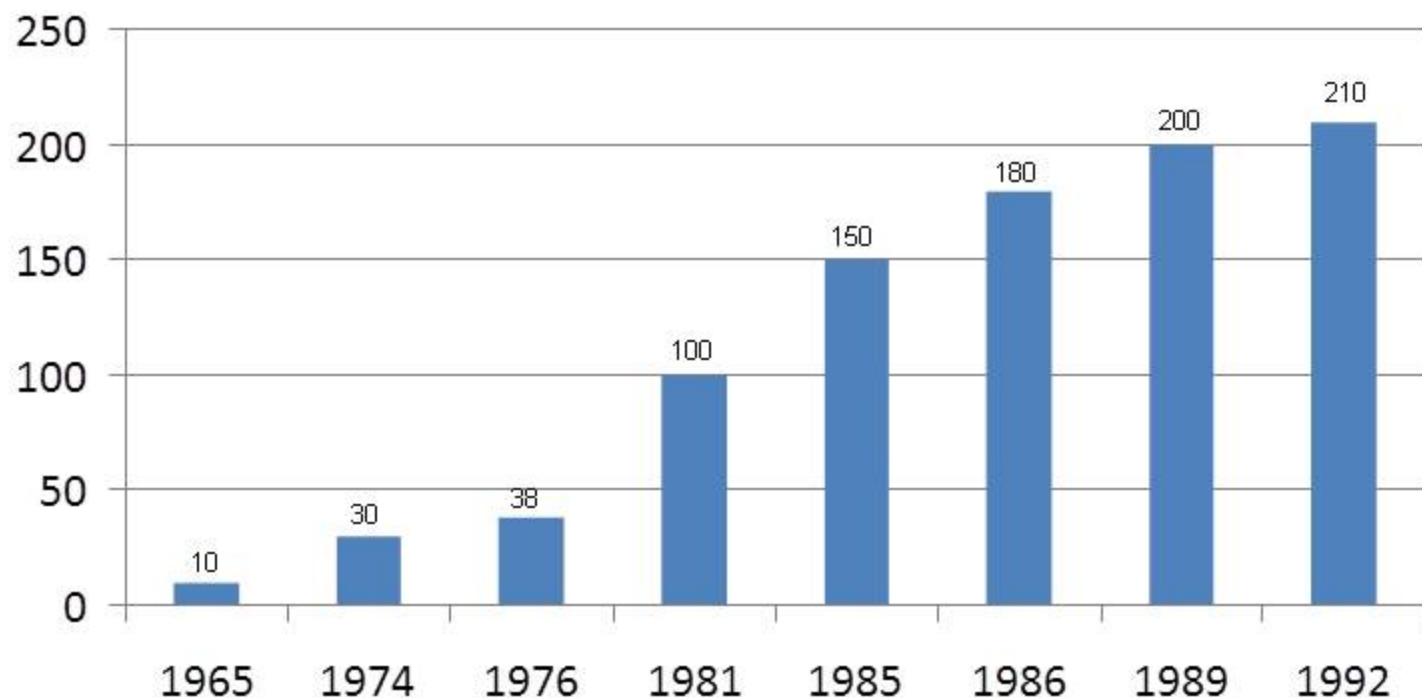
USAF Hyperbaric Medicine Program **LESSON LEARNED**



JB Slade, MD appointed Medical Director of the new Travis CHF, 1990

- Event: 1990 Travis CHF opens
 - 10th USAF hyperbaric facility
- Lesson: Hyperbaric medicine is growing

Clinical Hyperbaric Facilities in USA 1965-1992



Stop 10

International ATMO
San Antonio, TX
1992-Present



- Dir, Research & Education (1992-2000)
- President (2000-Present)

International ATMO

LESSON LEARNED



Hyperbaric Facility at Methodist Hospital in San Antonio, TX

- Emphasis on Safety
 - Hyperbaric Safety Seminars
 - Hyperbaric Safety Director Course
 - Reps on safety code committees
 - HMTT: 5 hrs on safety instruction
- Lesson: Need to collect hyperbaric mishaps

International ATMO LESSON LEARNED

Event: 1997

Chamber Fire Article



Hyperbaric Chamber at Nix Hospital, San Antonio, Texas

- Hesitancy to publish
 - Patients willing to receive treatment?
 - Physicians willing to refer patients?
 - Administrators willing to install chambers?
 - Lawyers?

International ATMO

LESSON LEARNED

Hyperbaric and hypobaric chamber fires: a 73-year analysis

P.J. SHEFFIELD and D.A. DESAUTELS

Jefferson C. David Island Care & Hyperbaric Medicine Center, 4499 Medical Drive, St. J. San Antonio, Texas 78226, and Wound Care & Hyperbaric Medicine Center, St. Joseph's Hospital, 3801 Martin Luther King Boulevard, Tampa, Florida 33607

Sheffield PJ, Desautels DA. Hyperbaric and hypobaric chamber fires: a 73-year analysis. *Undersea Hyperb Med* 1997; 24(3):153-164. — Fire can be catastrophic in the confined space of a hyperbaric chamber. From 1923 to 1996, 77 human fatalities occurred in 35 hyperbaric chamber fires, three human fatalities in a pressurized Apollo Command Module, and two human fatalities in three hypobaric chamber fires reported in Asia, Europe, and North America. Two fires occurred in diving bells, eight occurred in recompression (or decompression) chambers, and 25 occurred in clinical hyperbaric chambers. No fire fatalities were reported in the clinical hyperbaric chambers of North America. Chamber fires before 1980 were principally caused by electrical ignition. Since 1980, chamber fires have been primarily caused by prohibited sources of ignition that an occupant carried inside the chamber. Each fatal chamber fire has occurred in an enriched oxygen atmosphere (>28% oxygen) and in the presence of abundant combustible material. Chambers pressurized with air (<23.5% oxygen) had the only survivors. Information in this report was obtained from the literature and from the Undersea and Hyperbaric Medical Society's Chamber Experience and Mishap Database. This epidemiologic review focuses on information learned from critical analyses of chamber fires and how it can be applied to safe operation of hypobaric and hyperbaric chambers.

hyperbaric oxygen therapy, hyperbaric chamber fires, National Fire Protection Association chamber fire codes, chamber fire safety, chamber accidents

Modern hyperbaric oxygen (HBO₂) therapy originated with the clinical trials of Dr. I. Churchill-Davidson of London in 1955 (1) and the first reports on the use of HBO₂ by Professor I. Boerema of Amsterdam in 1956 (2). In 1960, Professor Boerema and associates published an article, *Life Without Blood* (3), that provided the rationale for HBO₂, and ushered in the practice of administering oxygen to patients under hyperbaric conditions. In the 1960s, several large clinical chambers were constructed to support surgical operations, and a few diving decompression chambers were adapted for clinical use (4). Oxygen was administered to the patient while pressurized inside the air-filled chamber. In 1964, a "monoplace" hyperbaric chamber, the Vickers Hyperbaric Oxygen Bed, was introduced in which a single patient could be totally immersed in the pure-oxygen environment (5). It was also a time of expanded exploration of the deep sea and outer space. Research chambers were fabricated for the use of pure O₂ and special gas mixes. Before 1970, there were no national fire safety standards for clinical hyperbaric chambers in the United States, so fire prevention was a matter left to common sense of the operators.

This paper is an analysis of fires in human-occupied chambers reported in Asia, Europe, and North America

from 1923 to 1996. Data were obtained from reports in the literature and from the Undersea and Hyperbaric Medical Society (UHMS) Chamber Experience and Mishap Database (6). The UHMS Safety Committee Chairperson maintains the UHMS database, which contains reports of fire, structural failure, and other operator experience. Individuals who contribute to the database are promised anonymity as well as confidentiality of location. Thus, cases described in this report that were obtained from the UHMS database have the source and location omitted. When the UHMS database is referenced as the source in this report, it is because there were no published accounts of the mishap available to be cited.

Table 1 shows fires that occurred in diving and hypobaric (altitude) systems. Pure-oxygen fires in the Apollo Command Module and hypobaric chambers served as initiating events to develop strong fire safety codes that now govern hyperbaric facilities in the United States. Table 2 lists fires that occurred in clinical hyperbaric chambers. Of the 39 fires reported, 10 occurred in dive chambers (2 bells, 8 decompression chambers), 3 occurred in altitude chambers, 1 occurred in a spacecraft, and 25 occurred in clinical hyperbaric chambers.

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Sheffield PJ, Desautels D. Hyperbaric and hypobaric chamber fires: a 73-year analysis. *Undersea Hyperb Med*. 24(3); 1997:153-64.

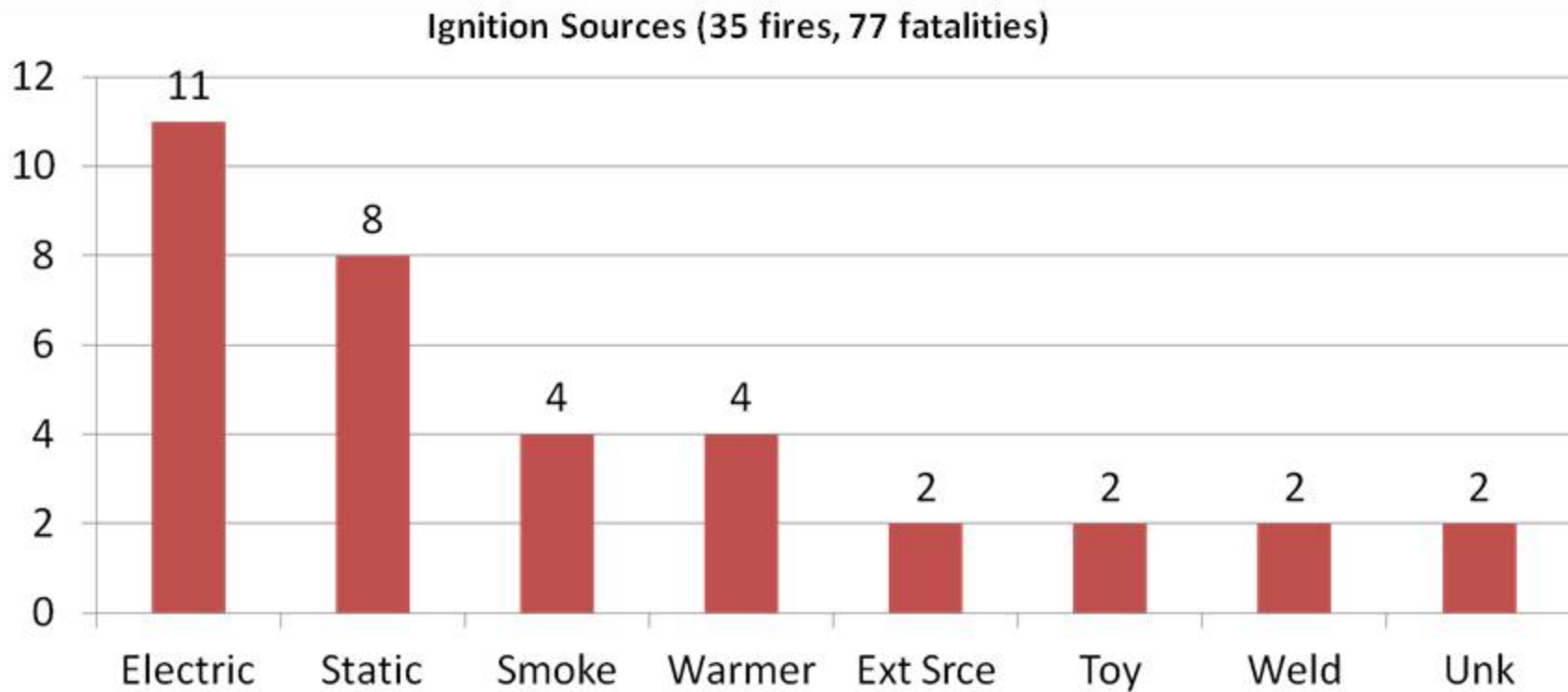
- Event: Chamber Fire Report, Sep 1997
- Lesson: Need to publish safety data

Hypo/Hyperbaric Fires Reported 1923-96

	Fires	Fatalities
Hypobaric Systems	4	5
Diving chambers/bells	10	17
Clinical Chambers	25*	60
Total Reported	39	82

* 3 occurred outside chamber

Cause of Clinical/Diving Chamber Fires (1923-1996)



International ATMO LESSON LEARNED

- Event: Oct 1997
Milan Chamber Fire
- 1 month after Fire
Article



Milan, Italy Chamber (1 year before fire) Photo courtesy of H. Takahashi

- Air filled chamber – 21% O₂
 - Fire occurred during pressurization
 - FES activated but it had no water
 - 11 fatalities
- Lesson: Periodically test the FES

International ATMO

LESSON LEARNED



Butane Hand Warmer



Photos courtesy of H. Takahashi

- Milan chamber fire was caused by concealed handwarmer
- Lesson: Check patients for prohibited items

Event: Multiplace Chamber Fire

Milan, Italy, Oct 1997

Before



After



Court Findings for 1997 Milan Multiplace Chamber Fire (11 fatalities)



Photo courtesy of H. Takahashi

- 3 Hospital Officials
 - Accused of reckless regard for safety regulations and failing to have adequate documents
 - Judged guilty of manslaughter, sentenced 3- 4.5 yrs
 - No prison for sentence <5 yrs

Court Findings for 1997 Milan Multiplace Chamber Fire (11 fatalities)

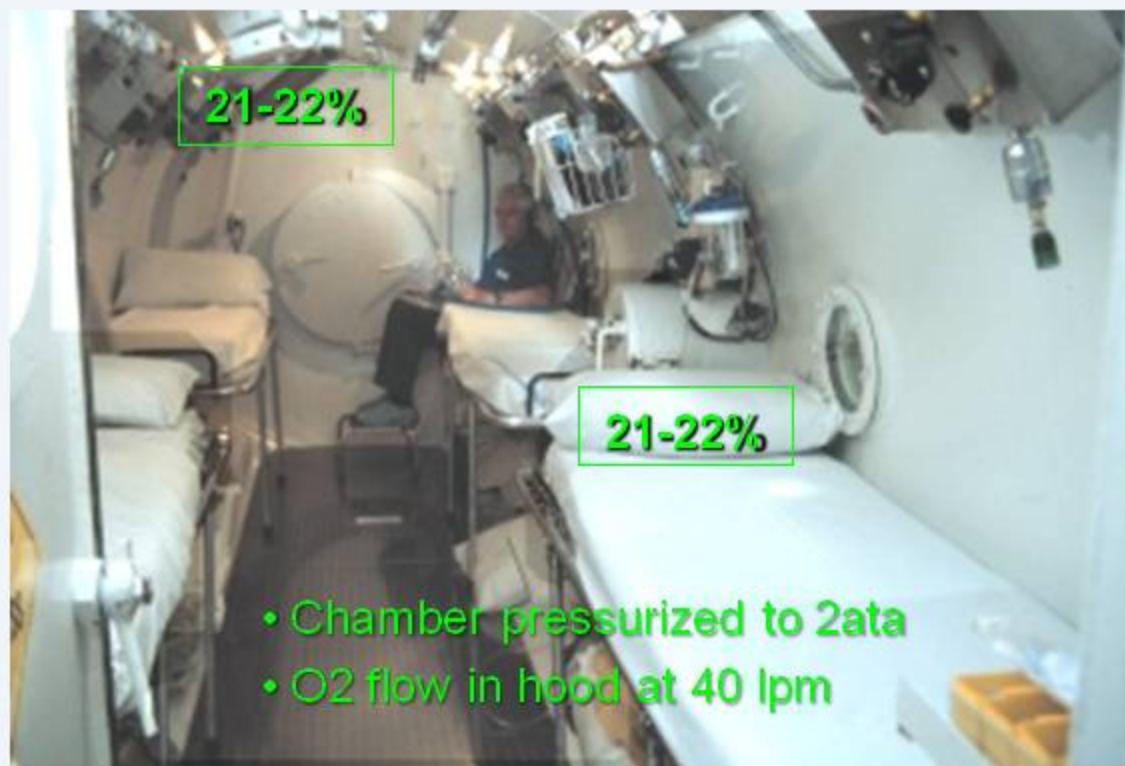


Photo courtesy of H. Takahashi

- Medical Director
 - Accused of reckless regard for safety regulations and failing to have adequate documents
 - Judged guilty of manslaughter, sentenced 5.5 yrs
 - Served 2.5 yrs (Nov 03 - July 06)
- Chamber closed

International ATMO Study

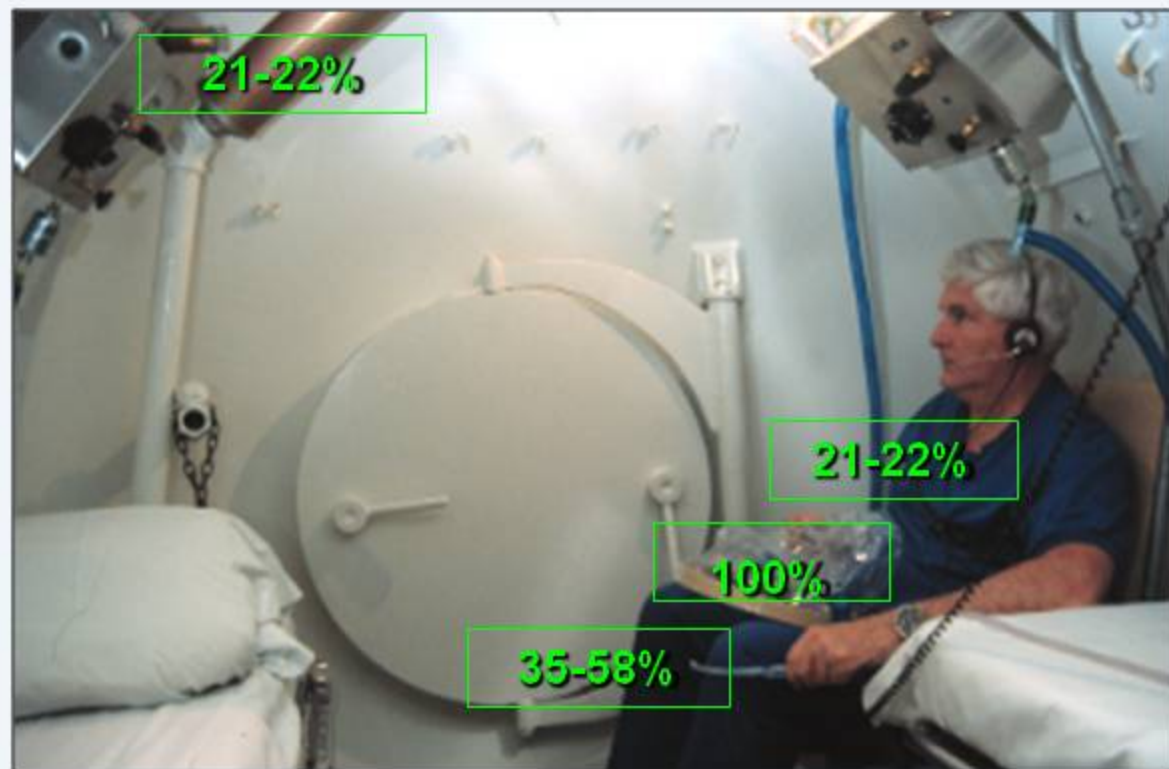
LESSON LEARNED



- Event: The oxygen flow study
- Question: How could the fire propagate and burn so quickly in air environment?
- Lesson: Oxygen pools near the source

International ATMO Study

LESSON LEARNED



- Oxygen > 50% was undetected by analyzer that was 4 feet away
- Lesson: Oxygen pooling can occur undetected during compression

To What Extent is the Hyperbaric Chamber Fire Problem?

- Clinical chamber fires are rare
- Spanning 88 years worldwide (1923-2011)
 - 43 clinical chamber fires (4 in USA)
 - 96 deaths (2 in USA)
 - Too few for government statistics
- Fires occurred in oxygen AND air filled chambers
- Largest Problem: Allowing ignition source in chamber

Sheffield PJ Sheffield RB, Sheffield JC. Review of Recent Clinical Hyperbaric Chamber Fires (1992-2011), UHMS ASM, (Abstract E86). UHM 2012:1014-15.

Total Clinical Chamber Fires Reported 1923-2011 Spanning 88 yrs worldwide

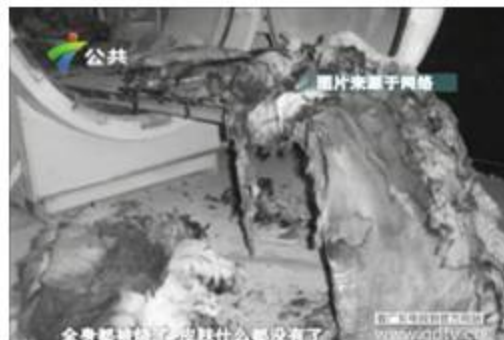
	# of Fires
Fires Inside	40
Fires Outside	3
Fatalities	96

15% of fires caused by smoking materials



Recent Hospital Chamber Fire - China, July 2014

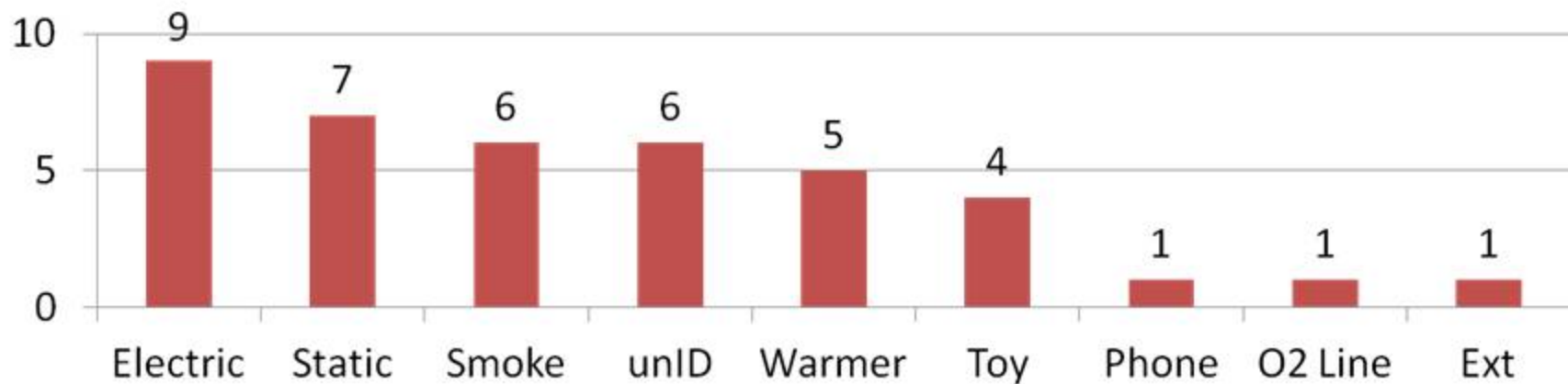
(www.dailymail.co.uk/news/article/2711646)



- “Chinese man died after blowing up hospital ward when he decided to smoke a cigarette while undergoing treatment...”
- Family demanded to know why hospital didn't take away his lighter.
- Hospital admitted responsibility and is negotiating with family over compensation.

Fires Inside Clinical Chambers (1967- 2011)

Ignition Sources (40 fires, 96 fatalities)

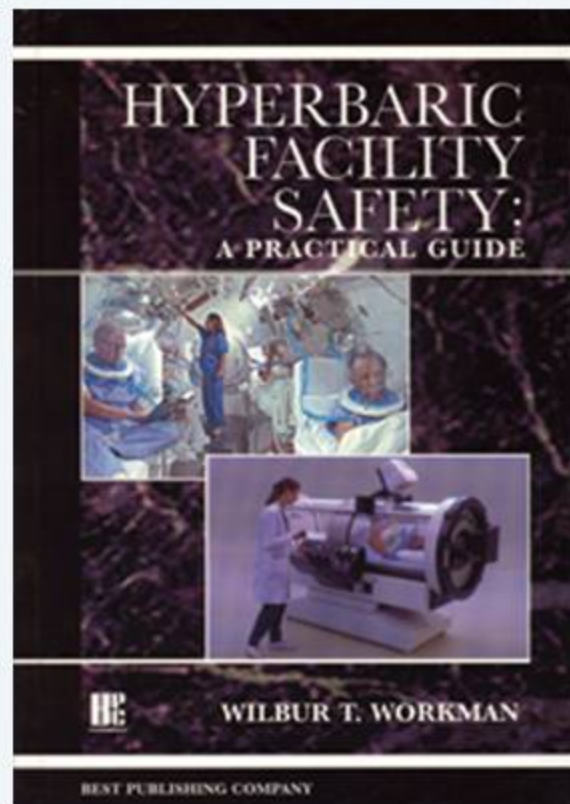


- Best way to avoid fire: Ensure patients and staff do not take ignition sources into the chamber

First Hyperbaric Facility Safety Textbook



W Tom Workman



**WT Workman. Hyperbaric Facility Safety:
A Practical Guide, 1999**

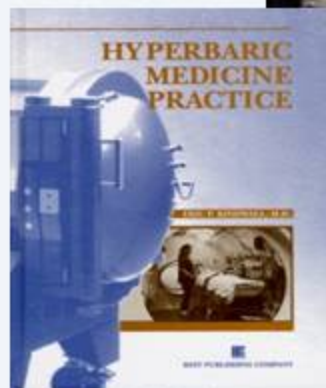
Kindwall's Hyperbaric Medicine Practice Textbooks



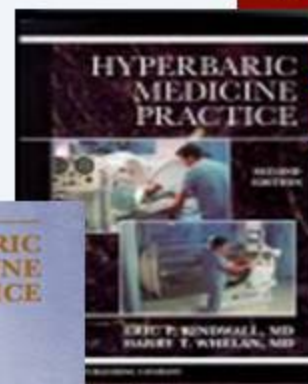
EP Kindwall, MD



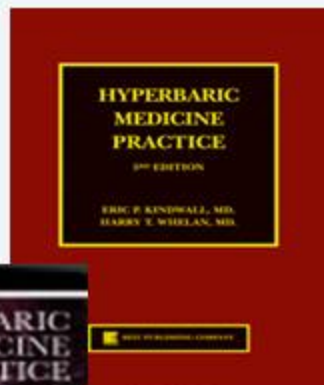
HT Whelan, MD



1994



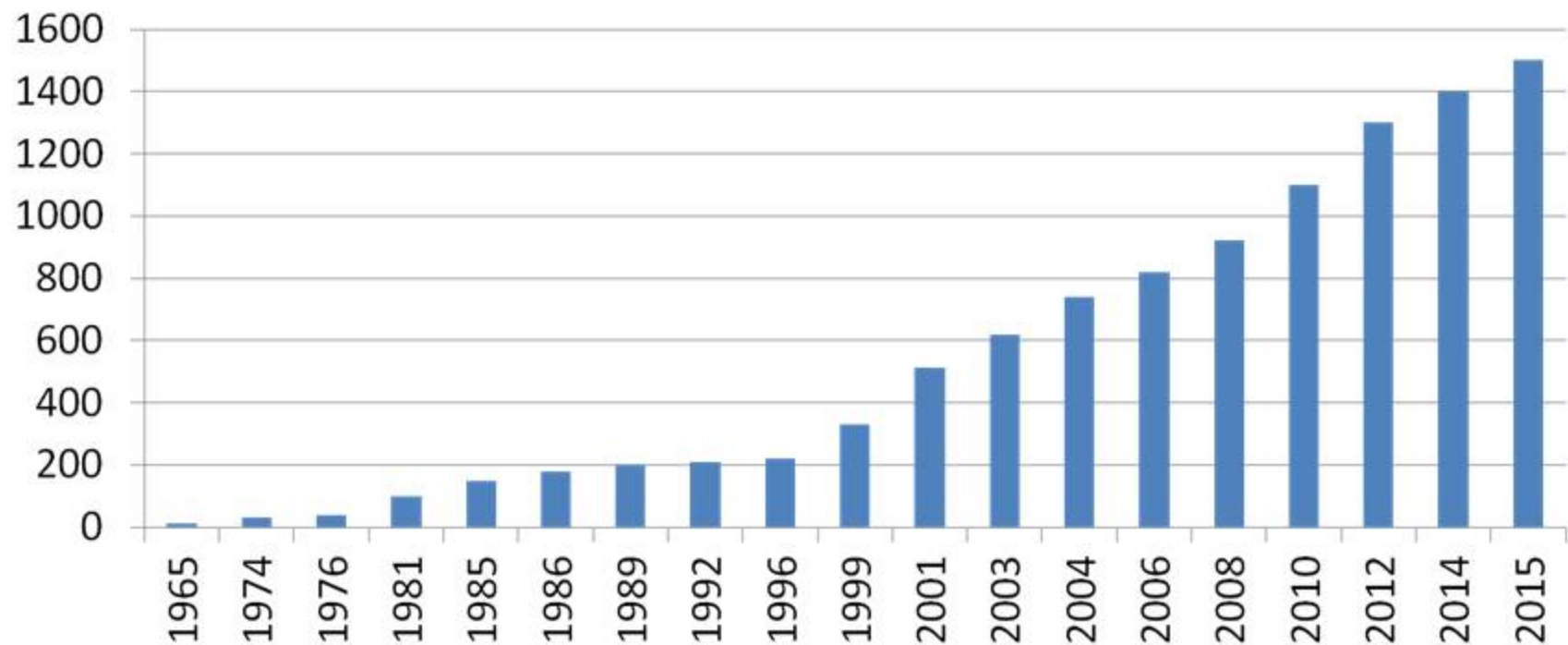
1999



2008

- Hyperbaric Medicine Practice, 1994, 1999, 2008
 - Has a fire safety chapter

Half Century Growth of Clinical Hyperbaric Facilities in USA (1965 – 2015)



Growth in Hyperbaric Medicine

- More Acceptance in Mainstream Medicine
- Published Clinical Trials
- Maturity of the Field
 - Fellowships
 - Board Certification
- Access to training
 - UHMS Approved Introductory Courses in HM
 - ATMO trained > 10,000 MDs, RNs, & Techs
- Reimbursed by Medicare/ Medicaid & Private Insurance

Conclusion

Lessons Learned

- Consider patient needs
 - Hypoxic tissue needs oxygen
- Insist on quality
 - Critical review of indications
- Insist on safety
 - Set reasonable safety standards



We Must Have A Strong Commitment to Safety

Conclusion

Lessons Learned

- Consider patient needs
 - Hypoxic tissue needs oxygen
- Insist on quality
 - Critical review of indications
- Insist on safety
 - Set reasonable safety standards
- We must work together



We Should Have Fun Doing It!

Conclusion

Lessons Learned

- Consider patient needs
 - Hypoxic tissue needs oxygen
- Insist on quality
 - Critical review of indications
- Insist on safety
 - Set reasonable safety standards
- We must work together



David brought down Goliath with one well-placed rock

What About The Future?

“We must welcome the future remembering it will soon be past.

And we must respect the past knowing that once it was all that was humanly possible.”

Santayana

Thank You!

Thank you for
making our
Hyperbaric
Medicine
Practices both
safe and fun!

*Thank
You*

Quiz

1. **The purpose of NFPA 99, Standard for Health Care Facilities is to set forth:**
 - a) Minimum safeguards for fire protection of patients and hyperbaric personnel
 - b) Rules for fabrication, testing and inspection, and acrylic viewport design
 - c) Monoplace chamber operating procedures
 - d) Multiplace chamber operating procedures
2. **ASME PVHO-1, Safety Standard for Pressure Vessels for Human Occupancy, specifically addresses:**
 - a) Minimum safeguards for fire protection of patients and hyperbaric personnel
 - b) Rules for fabrication, testing and inspection, and acrylic viewport design
 - c) Monoplace chamber operating procedures
 - d) Multiplace chamber operating procedures
3. **The best way for the hyperbaric medicine staff to prevent a fire in a hyperbaric chamber is to:**
 - a) Limit oxygen concentration below 21 percent
 - b) Limit the burnable material by prohibiting all paper products
 - c) Limit smoking products to only E-cigarettes
 - d) Ensure patients and staff do not take ignition sources into the chamber