Hyperbaric Chamber Fires:
Lessons Learnt

Dick Clarke, CHT

Hyperbaric Chamber Fires

Lessons Learnt

Primary Training in Hyperbaric Medicine

Columbia, South Carolina

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Factors Precipitating Chamber Fires

Absence of design/manufacturing codes; code non-compliance

Lack of a formal fire safety plan

Inadequate fire safety plan

Apparently adequate fire safety plan not adhered to

Unanticipated factors

Absence of design/manufacturing codes: code non-compliance

Steel monoplace at 2.4 ATA

air compressed; mask O_2; inboard dump

no analyzer so unknown 02 concentration

Flash fire

structural integrity maintained

hot gases melted door seal, cut through concrete floor, blew out building windows

Cause of ignition: non-intrinsically safe communication system

Intrinsically safe

keeping level of electrical energy too low to cause ignition
thereby preventing sparks & keeping temperatures low

device designs that exclude oxygen
plus, purging device with inert gas

device strong enough to contain explosion

moving device outside hazardous (chamber) area

No chamber design/construction codes & standards in Peru
some such countries adopt authoritative standards

Lack of adequate operational safety procedures

no overboard O2 dump

unknown chamber O2 concentration

no pt. grounding

oil lubricated air compressor ? filtration

Monoplace Chamber Fire
Lima, Peru, 2006

Incident Report

Glenn J. Butler,
President & CEO §

R.W. "Bill" Hamilton, Ph.D
Hamilton Research

Michael W. Allen,
Senior Vice President – Operations & Safety †‡

Life Support Technologies group

Absence of design/manufacturing codes: code non-compliance

Absence of design/manufacturing codes: code non-compliance

Lack of a formal fire safety plan

Lauderdale-by-the-Sea, Florida. May 2009

fire engulfed chamber & 2 occupants at 1.75 ATA O_2
- *~ 4 yo CP pt., 62 yo grandmother*
- *~ his txs started 7 months earlier!*

operator (trainee) didn't know procedure for emergent decompression
- *~ tried several times to open door while pressurized*

both occupants succumbed

Vickers "clam shell" manufactured in 1967

Burn pattern again suggested internal speaker as source

Legal proceedings:

Adult "reached to adjust cushion, static discharge from her clothing jumped to earphone jack"

Adult "banged on chamber for five minutes to attract attention"

"Nobody was monitoring them and when fire started victims were required to scream and bang on glass (sic) dome to get the attention of a bystander who in turn notified staff of the fire, which caused a delay in decompressing the chamber and freeing the victims before the flash fire occurred. When police deputies arrived, the victims were still in the chamber and on fire"

Numerous pages of safety violations

Most damning, set up fictitious inspection company
"Certified Hyperbarics" *for federal facility certification application*

Medical Director & CHT *"exhibited gross lack of competency, gross inattention, criminal indifference to pt. safety"*

Both guilty of *"aggravated manslaughter of a child & manslaughter by reckless disregard of human life & safety of persons exposed to dangerous effects"*

Lack of a formal fire safety plan

Steel oxygen-filled monoplace chamber

single pt. fatality

attempted to smoke cigarette

Hospital admitted responsibility…

"We did not warn pt. that smoking or taking a lighter into the chamber could be dangerous"

Inadequate fire safety plan

Multiplace chamber Milan, Italy

personal clothes; synthetics/pockets

no pt. or IA checks…pockets

hood exhaust system disconnected

"improperly modified hood latex neck seals allowed O2 to escape into pt. clothes making patients flammable cylinders"

chamber O2 concentration commonly exceeded permissible limit

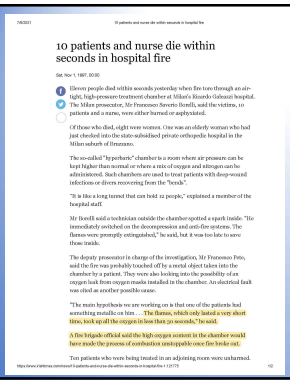
" O2 monitor alarm manipulated"

Fire occurred during compression

"red flame explodes on screen, video goes black"

Water delude system activated…no water emitted

10 pts 1 nurse quickly succumbed



10 patients and nurse die within seconds in hospital fire

Sat, Nov 1, 1997, 10:10

Eleven people died within seconds yesterday when fire tore through an air-tight, high-pressure treatment chamber at Milan's Rizzoli-Galeazzi hospital. The Milan prosecutor, Mr Francesco Saverio Borrelli, said the victims, 10 patients and a nurse, were either burned or asphyxiated.

Of those who died, eight were women. One was an elderly woman who had just checked into the state-subsidised private orthopedic hospital in the Milan suburb of Treviano.

The so-called "hyperbaric" chamber is a room where air pressure can be kept higher than normal or where a mix of oxygen and nitrogen can be administered. Such chambers are used to treat patients with deep-wound infections or divers recovering from the "bends".

"It is like a long tunnel that can hold 12 people," explained a member of the hospital staff.

Mr Borelli said a technician outside the chamber spotted a spark inside. "He immediately switched on the decompression and anti-fire systems. The flames were promptly extinguished," he said, but it was too late to save those inside.

The deputy prosecutor in charge of the investigation, Mr Francesco Fois, said the fire was probably touched off by a metal object taken into the chamber by a patient. They were also looking into the possibility of an oxygen leak from oxygen masks installed in the chamber. An electrical fault was cited as another possible cause.

"The main hypothesis we are working on is that one of the patients had something metallic on him … The flames, which only lasted a very short time, took up all the oxygen in less than 30 seconds," he said.

A fire brigade official said the high oxygen content in the chamber would have made the process of combustion unstoppable once fire broke out.

Ten patients who were being treated in an adjoining room were unharmed.

Several newspaper accounts/Letter to Lancet

Fire lasted ~ 30 seconds

led some to believe it was extinguished vs burning itself out

Fire dept official; "fire unstoppable in high O_2 content"

inconsistent with previous water deluge experience

Initial official report

"Patients going into the chamber were checked by two doctors for flammable objects, but something must have slipped through"

Court proceedings

"A lady enters the hyperbaric chamber where she is to undergo treatment and brings with her an alcohol-based hand warmer, those with flame. From that hand warmer starts the fire that kills, after a slow agony, all the people who were inside."

Initial official report

"Automatic in-chamber fire-fighting system went into immediate action and the fire was put out within less than one minute"

Court proceedings

"The fire extinguishing system was not functioning as the tank that was supposed to contain the water was empty, the propellant compressed air cylinder had the tap closed and the water supply hose valve was closed. The hand shower inside the hyperbaric chamber, foreseen in the design phase, had not been installed."

Inadequate fire safety plan

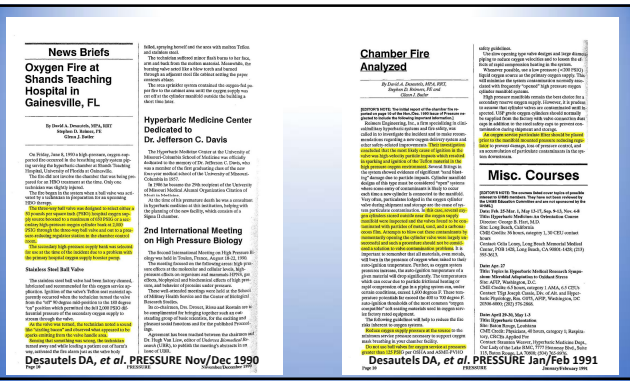
Chamber operator opened 3-way valve to select BIBS O_2 source

- *selected >2,000 psig (non-reduced) option*
- *reported hearing 'sizzling bacon' sound*

Fire immediately erupted from chamber control panel

- *flame shot out 3 feet/1 meter, spraying molten stainless steel*
- *penetrated steel filing cabinet igniting contents*
- *chamber tech burned on face, arms, back, as she moved pt.*
- *fire extinguished only when O_2 supply secured*

Facility sprinkler system & fire alarm activated



News Briefs

Oxygen Fire at Shands Teaching Hospital in Gainesville, FL

Hyperbaric Medicine Center Dedicated to Dr. Jefferson C. Davis

2nd International Meeting on High Pressure Biology

Chamber Fire Analyzed

Misc. Courses

Desautels DA, *et al.* PRESSURE Nov/Dec 1990

Desautels DA, *et al.* PRESSURE Jan/Feb 1991

"Likely cause…high-velocity particle impacts"

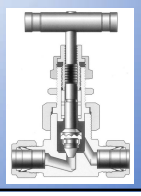
- *ignited valve's Teflon seating & seal material*
- *several fittings significant for "sand blasting" appearance*
- *likely source of particles…HP O_2 cylinder valves & piping*

Auto-ignition temperature of valve seating 400-700 F/200-370 C

- *particle friction heating in HP O_2 exceeds 1,600 F / 870 C*

Lessons learned-safety standard failures

- *protect disconnected oxygen piping*
- *oxygen piping "cleaned for oxygen service"*
- *HP oxygen reduced at source*
- *quarter turn valves contraindicated*
- *filtration at source/prior to reducing regulator*
- *larger diameter piping reduces oxygen velocity/related heating*



Apparently adequate fire safety plan not adhered to

Istanbul University Medical Center

Multiplace chamber fire July 1998

3 fatalities: 2 divers, 1 physician

Latter stages extended USN TT 6

Chamber O_2 atmosphere not monitored nor routinely flushed
- *one diver/pt. using mask with overboard exhaust, second using hood with inboard exhaust*

Two "lightsaber-like" oxygen flames seen emitting (via viewport)
- *spontaneous ignition within regulators*

Chamber operator did not/could not activate water deluge
- *Internal fire extinguisher not activated*
- *Flames only died out when oxygen system exhausted*

Relief valves lifted (10 ATA)

Inadequate system maintenance; particularly O2 delivery system cleanliness

Operational practices inconsistent with recognized standard of care

Physician entered chamber with cigarette lighter

"In all incidents I have encountered in my 30-year hyperbaric practice, the people who accidently put a lighter or mobile phone inside are inside attendants and doctors, because patients are checked before each entrance"

Inadequate/non-existent emergency drills

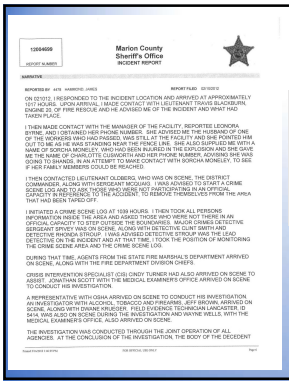
Apparently adequate fire safety plan not adhered to

Steel oxygen-filled multiplace chamber

- *animal pt. fatality*
- *chamber operator fatality*

Patient treatment #5 underway

- *horse unsettled; kicking out*
- *dislodged protective padding overlying steel hull*
- *'massive spark' & flames per CCTV*
- *urgent decompression initiated*



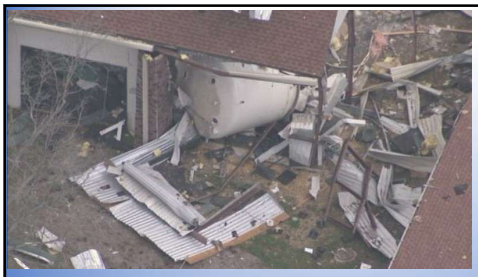
Marion County
Sheriff's Office
INCIDENT REPORT

Assistant ran to alert fire service; heard two explosions

first smaller, followed in ~1 second by massive one, as chamber exploded

sound reported to have been heard several miles away

piece of chamber went through apartment window > 2 miles away



Operator (29 yo) died immediately; blunt force trauma/thermal injuries

remains found buried under chamber debris

Assistant/trainee suffered multi-trauma, including severe head injuries

evacuated to regional trauma center; survived

Horse remained shod (steel)

Not sedated

His coat contained oil-based lotion

not washed with approved soap per FSP

No formal hyperbaric safety training

Authoritative codes re animal chamber construction

guided but not certified per human standards?

Formal training in hyperbaric technology/safety

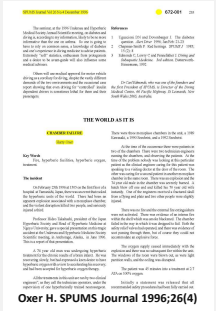
Water deluge system?

Methane gas detector-chamber flushing issue?

becomes explosive 5-17% range in air…? HBO

loudest explosions >10% in air…? HBO

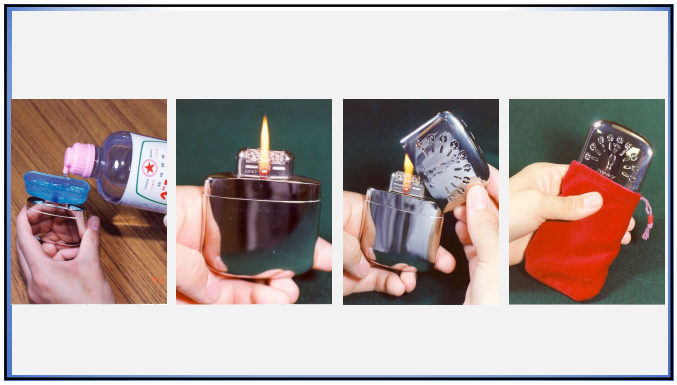
Apparently adequate fire safety plan not adhered to



THE WORLD AS IT IS

Oxer H. SPUMS Journal 1996;26(4)

Initial statement released by hospital was that all recommended safety procedures were carried out



NBS Monthly Safety Notice

January 2002 National Baromedical Services, Inc.

Importance of Optimizing Chamber Gas Flow

In this notice, attention is focused on the importance of being fully and constantly cognizant of the state of gas flow through the chamber.

Background

The Sechrist 3200B monoplace hyperbaric chamber operates under a state of constant gas (oxygen) flow. Flow can be adjusted via a control valve located within the oxygen exhaust assembly. In the "closed" position the control valve permits approximately 240 lpm of flow. By design, and to avoid a potentially hazardous accumulation of CO2, flow cannot be completely stopped. In the fully open position, flow peaks at approximately 400 lpm. Adjustment of the control valve between these two extremes provides a corresponding flow volume ranging between 240 and 400 lpm.

This constant flow of gas serves to eliminate metabolic waste gases and provides a useful source of temperature control for the patient. Higher flow rates act as a cooling mechanism, lower flow rates reduce the cooling effect.

However, there are additional aspects to flow control, aspects that have important patient and facility safety implications.

The Issue

The principal source of oxygen for chamber compression, and constant flow, is the hospital's bulk liquid oxygen (LOX) system. This oxygen is stored in a super-cooled and liquefied form. As it is transferred, on demand, to the hospital, it is converted into a usable gas, via an associated vaporizing system. Having boiled off from a liquid, this resulting gas is essentially dry. It contains little to no moisture.

While a dry gas has the benefit of minimizing corrosive damage to system valving and piping, it has potentially adverse effects on hyperbaric safety. A dryer atmosphere promotes a greater accumulation of static electricity. A resulting static electrical discharge may generate sufficient energy to cause ignition of volatile substances (hydrocarbon-based oils and lotions, alcohol-prepped materials, hydrocarbon contaminated air, etc.).

Key Operational Issues

1) Under routine operations, as the rate of gas flow through the chamber is decreased the chamber atmosphere's relative humidity increases. This effect is the result of a greater accumulation of the patient's evaporative moisture loss within the chamber. This is a good thing.

2) If the patient complains of being cool, slow the rate of oxygen flow. Don't provide additional blankets. This is all too frequently the action taken, yet it represents an increasing safety hazard. Should a fire occur within the chamber, more fuel is available. This could represent the difference between a fire entirely contained within the chamber versus a fire that results in catastrophic failure of the chamber, and potential damage to the entire facility, and its staff.

3) If a patient complains of being too warm:
   i. Cover them with a sheet rather than a blanket.
   ii. Compress the chamber at a slow rate of descent, in order to limit the effect of compression on heat production.
   iii. Titrate chamber flow increases rate for optimal comfort, rather than opting for the widest setting, 0.1, and it above proves insufficient.
   iv. Maintain the hyperbaric facility temperature within a range of 68-72°F.

4) If a patient complains of being too cold:
   i. Close the exhaust valve.
   ii. If this isn't sufficient, switch the sheet out for a blanket.

5) Get into the habit of observing the oxygen flow setting upon arrival at the sickest treatment pressure. Don't find yourself in a position where a treatment is underway, and you do not know, even fairly the flow setting.

Bottom Line

Know the flow rate at all times. Optimize it for patient comfort.

Reading Assignment

Wood JB: **Static Electricity.** Hyperbaric Facility Safety: A Practical Guide, ed Washington?, 1999:somethingsomething

Inadequate fire safety plan

One of several chambers Naval Hospital Central Jakarta, Indonesia

Fire & "explosion" > 4 deaths

3 pts. 1 physician

room filled with smoke > several occupants hospitalized (2 remained so at 7 days)

Operator…

"tried using water deluge system but too late"

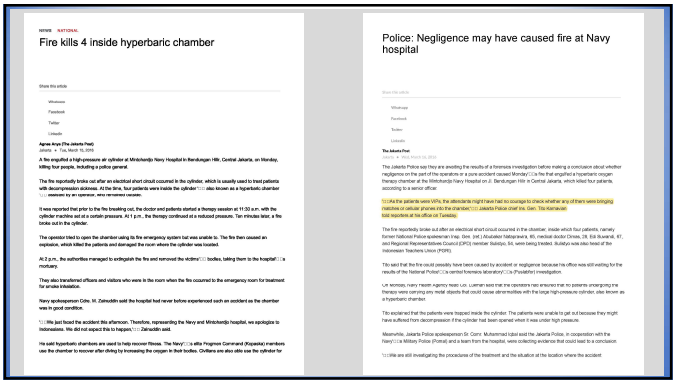
"failed to activate deluge system"

"deluge system inoperable"

"deluge system activated but inadequate to extinguish flames"

Hospital declared…

"It had complied with strict operating procedures"



NEWS NATIONAL

Fire kills 4 inside hyperbaric chamber

Police: Negligence may have caused fire at Navy hospital

Unanticipated factors

Fire in the Multiplace Hyperbaric Chamber

B. A. Youn, D. Gordon, C. Moran, and B. Brown

Youn B, *et al.* J Hyperbaric Med 1989;4(2)

Multiplace chamber at 2.0 ATA

- *2 inside attendants*
- *4 patients; 3 adults, 1 4-wk-old*

SOP microwave warming of blankets

- *some pediatric, all neonates*

Cotton blanket warmed for 2.5 mins. high setting

Scorched (ironed shirt) smell upon removal

Examined by unfolding several times
- *nothing untoward/not unduly hot*

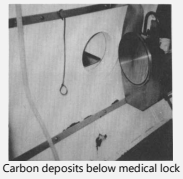
Compressed in medical lock

Upon receipt into chamber IA noticed 2 brown spots
- *blanket immediately developed open flame*

IA attempted to reinsert into lock

Chamber deluge activated…*twice*

Burned 100% cotton blanket



Carbon deposits below medical lock

Pts switched to air breathing

Poor visibility resulted in second deluge

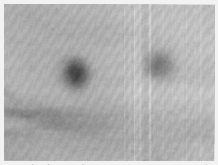
All occupants uneventfully decompressed

Pts counseled & monitored; 3 inpts.

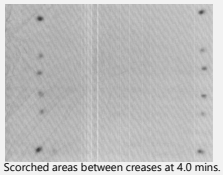
All eventually completed their HBO courses

Tested microwave warming 2.5-4.0 mins.

Scorching not obvious unless blanked fully opened



Scorched areas between creases at 2.5 mins.



Scorched areas between creases at 4.0 mins.