UNDERSEA AND HYPERBARIC MEDICAL SOCIETY
CHAMBER EXPERIENCE AND MISHAP DATABASE REPORT FOR 1923 - 1998

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Introduction

The chamber accidents in this survey include, hyperbaric chambers, hypobaric chambers, diving bells, recompression chambers, caisson airlocks, and space capsules worldwide.

Presented here are data from the Undersea and Hyperbaric Medical Society's Chamber Experience and Mishap Database[1] which is a retrospective study of accidents which have been recorded worldwide through 1998. In this report, incidents are reported whether the accident caused the chamber to be incapacitated or if an injury or fatality resulted.

Objectives

The objectives of this survey are multiple. A major point is to emphasis the information which can be learned from these tragic mishaps in order to increase the safe use of chambers, while at the same time putting into perspective the strong safety record of the associated industries.

Methods

A database was developed by the Safety Committee of the Undersea and Hyperbaric Medical Society (UHMS) called the Chamber Experience & Mishap Database. This database allows information to be gathered from both contemporary and historical experiences. This means that each subsequent report may update data from years and years ago. Such was the case recently when data was added from China and Russia. Presently the data are compiled in Microsoft Access.

Database Guidelines - To share information regarding accidents is extremely important, in order to learn and do better in the future. As Santayana said, " Those who ignore the lessons of history are doomed to repeat them." However, many choose not to share or would like to remain anonymous. This is to be respected. Therefore, the Safety Committee developed guidelines for the publication of information. The guidelines are as follows:

1. Aggregate information is compiled and presented in a comprehensive manner as data.
2. Data are compiled and maintained anonymously, unless -
    a. Details are published elsewhere.
    b. The principles agree to release the information.
3. The UHMS Safety Committee is liable for the accuracy of information only to the degree it is provided.
4. The Database will include historical and current information.

Classification of data - Information in the Undersea and Hyperbaric Medical Society Safety Committee's Chamber Experience and Mishap Database has been divided into three simple classes which are further subdivided into sub classes.

Type Facility - The type of facility is industry specific, using the intent of use as criteria by which the accident is classified. The sub classes of the type facilities are:

Hyperbaric - The accident occurred in a chamber using high pressure for the administration of oxygen or other gases for therapeutic purposes.

Diving - The accident occurred in a chamber used for diving operations.
Hypobaric - The accident occurred in an altitude or space craft environment.

System - The system defines the type chamber in which the accident occurred.
Multiplace - The chamber is capable of taking many persons to increased pressure.
Monoplace - The chamber is capable of taking only a single person to increased pressure.
System - The chamber support system, such as piping, compressor, or hatch.
Hypobaric - The chamber is capable of taking many persons to reduced pressure, as in that of an altitude chamber or space craft.
Bell - The chamber is used for work or extraction from increased pressure, generally underwater.

Cause - The cause of the accident, that which an investigation determined to be the basis of the death or injury.
Fire - The injury or death was caused by fire.
Pressure - The injury or death was caused by pressure differential.
Other - The injury or death was caused by something other than fire or pressure.

Results

The first recorded accident in the Chamber Experience and Mishap Database is that from a Cunningham chamber dated from 1923, that accident did not result in either death or injury. Used outside the hospital in the cold environment of Kansas City, gas burners were placed under the chamber to heat the chamber. The heat rose enough one day to start smoldering and smoking. The occupants were escorted out without incident, however, it was recorded as the first hyperbaric chamber accident. Since that accident, there have been a total of 113 incidents which resulted in 135 deaths and 50 injuries over 75 years. In the first 44 years, 1923 to 1967, there were 15 incidents, a rate of 0.34 incidents per year. After 1967 that rate increased to an average of 3.2 incidents per year. This includes hyperbaric chambers, hypobaric chambers, diving bells, and space craft. (Figure 1) Concomitant increases in the number of injuries and deaths followed the increase in incidents. (Figure 2) It should be pointed out that the number of deaths has far out paced the number of injuries during this period. This is not only because of the large number of multiplace chambers involved (48), but the number of fires (81). In the United States, the National Fire Protection Association (NFPA) published in 1969 a Manual on Fire Hazards in Oxygen-Enriched Atmospheres and later in 1970 a Standard for Hyperbaric Facilities. These manuals, which are updated and reviewed regularly, are primarily responsible for there never being a fire related death in a clinical hyperbaric chamber in the United States.

Figure 1:

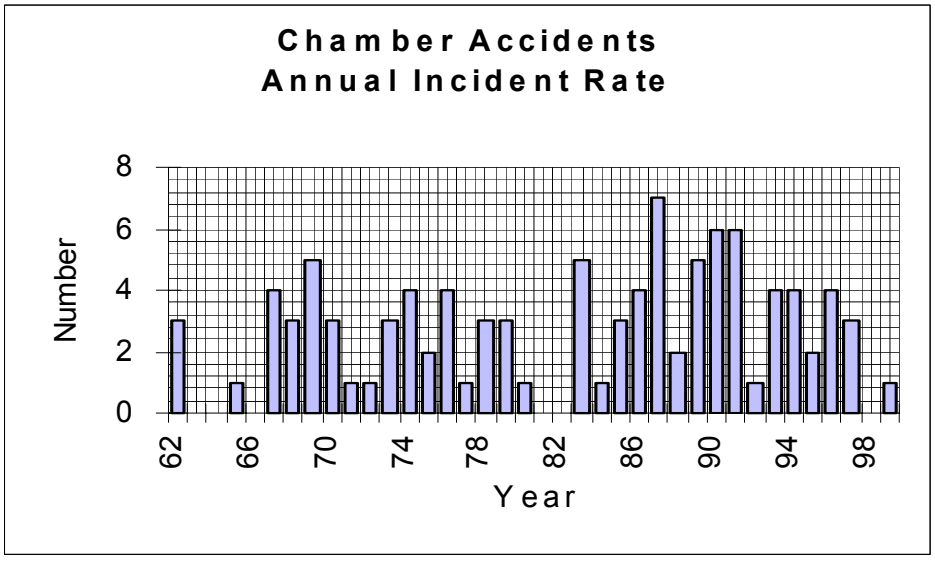
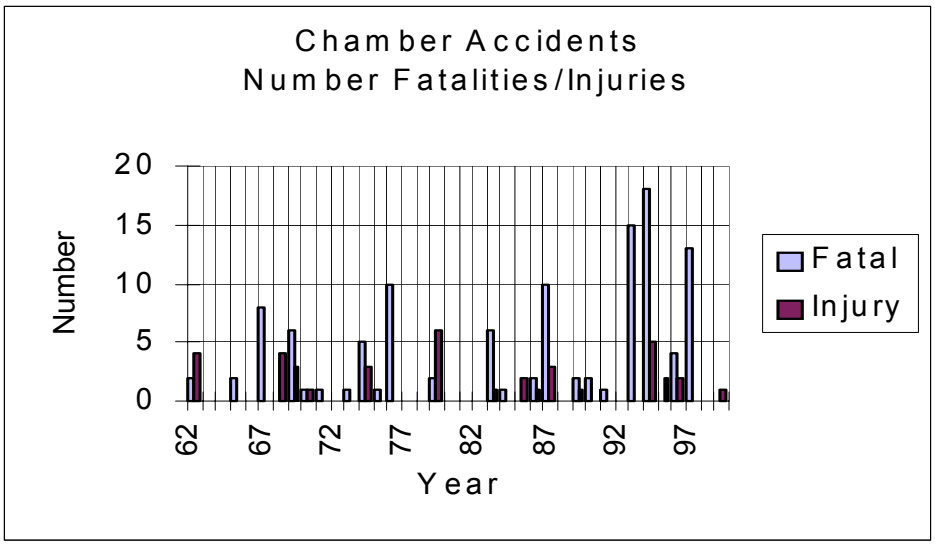


Figure 2:

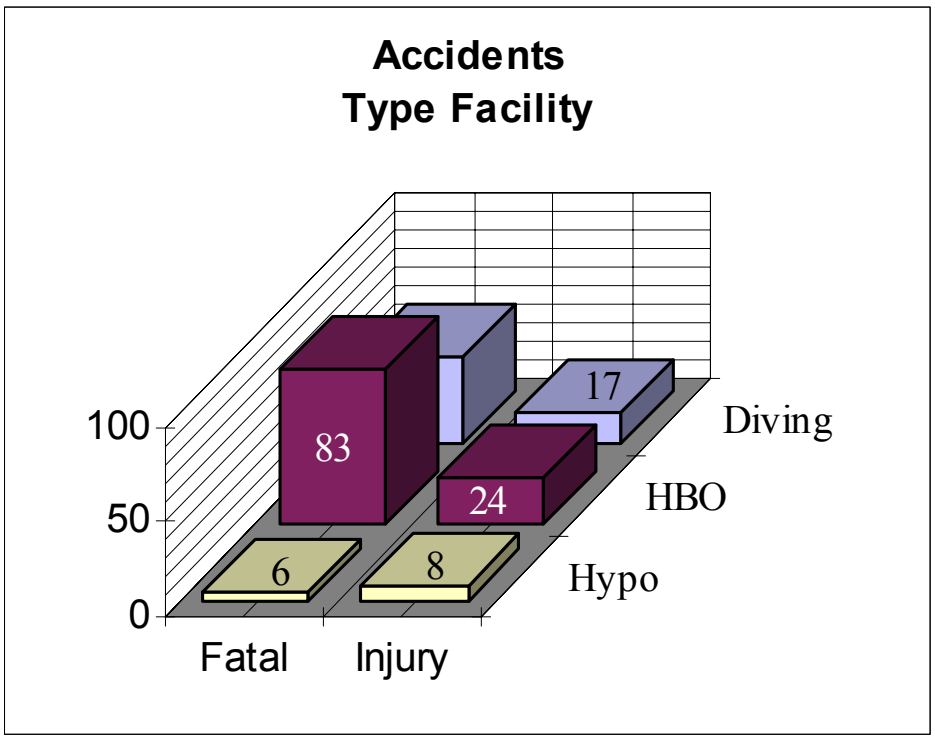


While estimates could be made, regarding the number of treatments, dives, research studies, and altitude exposures, they would simply be estimates, as data are not available. Data are available, however, regarding the number of chambers worldwide. (Table 1) These data, available in 1995 change significantly as the number of uses and practitioners increases.

Discussion - The Chamber Experience and Mishap Database contains as much information as can possibly be collected from research and reports. (Form 1) Data included here is Type Facility, System, and Cause only. Location and demographic information is omitted to maintain anonymity.

TYPE FACILITY (Figure 3)

Figure 3:



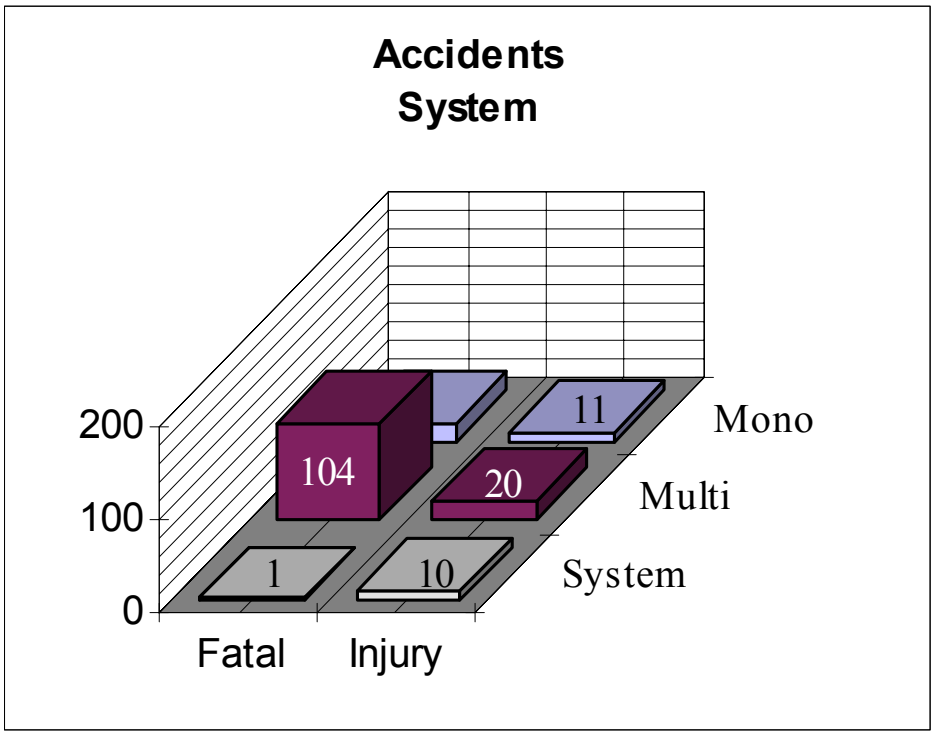
Hyperbaric chambers - Hyperbaric chambers have the largest number of incidents (61/54%), fatalities (83/61.5%), and injuries (24/48%). (Table 2) Examining the data more closely it would appear that clinical hyperbaric chambers have a disproportionate percentage of fatalities and injuries. The major cause of hyperbaric chamber deaths and injuries is fire (40/65.5%) with pressure contributing less (13/21.3%). (Table 3)

Diving chambers - The bulk of the accidents in the diving industry occurred from 1945 through 1985 with a hiatus until 1997. In 1997 an off shore diver, who entered a chamber to decompress with only a bathing suit and "ditty bag" decided to light up a cigarette while decompressing on oxygen. Off shore diving facilities do not require NFPA Standards, therefore there was no deluge system to extinguish the fire. Diving accidents contributed to less than half the number of incidents (43/38%) and one third the number of fatalities (46/34.1%) while it was an even contributor to the number of injuries (18/36%). (Table 2) Two thirds of the fatalities were from fires (32/66.7%), while one third of the injuries were from pressure (10/33.3%). (Table 3)

Hypobaric chambers - Hypobaric facilities, have not had an accident resulting in death since 1967, or injury since 1980. Altitude chambers are used ostensibly in the military for flight personnel, this use has an excellent track record of only nine accidents (9/8%), 6 fatalities (6/4.4%), and 8 injuries (8/16%). (Table 2) Virtually all of the accidents in altitude chambers were the result of fire. (Table 3)

SYSTEMS (Figure 4)

Figure 4:



Multiplace chambers - The multiplace chamber edges the monoplace chamber out as the major contributor to the number of accidents (50/44.3%), but is the unheralded leader in number of deaths (105/77.8%), while injuries are fewer (23/46%). (Table 2) Perhaps this is because, not only do these chambers hold more occupants, but it is more difficult to remove personnel in a crisis. Multiplace chambers had a wider distribution of cause than monoplace chambers with fire ahead of pressure accidents by a significant margin (35/68.6%) and pressure contributing less, (11/21.5%). (Table 3) Another factor in the large number of deaths in multiplace chambers is that when one person inside a multiplace chamber makes a mistake, many pay the price. Over the years there have been four instances where children have been give toys that create sparks as they were entering hyperbaric chambers. Three episodes were in monoplace chambers, where the children where only the victims. However, one multiplace chamber compressed with oxygen was ignited when one of the eight inside caused a spark with the friction toy. Fires have occurred in multiplace chambers from faulty wiring, light bulbs, blankets over light bulbs, and even an operator opening the chamber with a lighted cigar in his mouth.

Monoplace chambers - The monoplace chamber, compressed with oxygen, requires special attention during patient preparation and operation. The major number of chambers around the world are monoplace chambers, never the less, the accident rate is low (24/21.3%), even the number of deaths is below average (19/14.1%), and the number of injuries is low (13/26%). (Table 2) The sobering fact is that for the most part each was a single accident and almost all deaths were by fire (20/83.3%). (Table 3) Monoplace chamber operators must be vigilant, because it is so easy to become complacent. Listed here are a few examples intended to reinforce operator diligence.

1. A physician noted a toy in the hands of a child inside the chamber, he asked how much longer the child would be inside for his treatment. When informed, "Only ten minutes" he told the operator to continue. It was only minutes after this that the child ignited the toy and the chamber.

2. An outpatient taken from home to a monoplace to be treated was allowed to keep his blanket. Under the blanket was a hand warmer (the fourth hand warmer to be implicated in accidents) which ignited the chamber some time into the treatment. With the bulky blanket as fuel, the fire accelerated rapidly increasing pressure beyond the release tension of the tie rods holding the chambers metal hatches on. With the release of these hatches, the patient and his wife were killed.

3. Unconfirmed reports have implicated the patient themselves in at least two instances. One in the home environment where matches were found inside the chamber used by the patient to treat themselves. The author has experienced seeing a suicide patient attempt to secret a cigarette lighter into the chamber after being arrested for murder.

4. An operator left a mother by the bedside to read to their child. When the mother saw materials inside ignite she attempted to open the chamber to remove her child. Frantically attempting to open the chamber without success, she called on the personnel across the hall. They too were unable to open the chamber. Twenty minutes later the operator returned to find the accident.

5. One of the best examples of chamber operators allowing patients to intimidate them and usurp their authority was in an accident where an unconscious diver was brought into a monoplace facility to be treated by his insistent buddies. The buddies demanded the patient be treated right then! Without delay for normal procedures, the operator placed the patient into the chamber in the clothes he was wearing. Once pressure was reached, the patient regaining consciousness and calmly reached in his pocket, removing a cigarette and lighting it, killing himself and injuring the operator.

6. Monoplace chambers used concurrently with ionizing radiation for radiation therapy have been responsible for at least three injuries when the chamber burst and decompressed explosively.

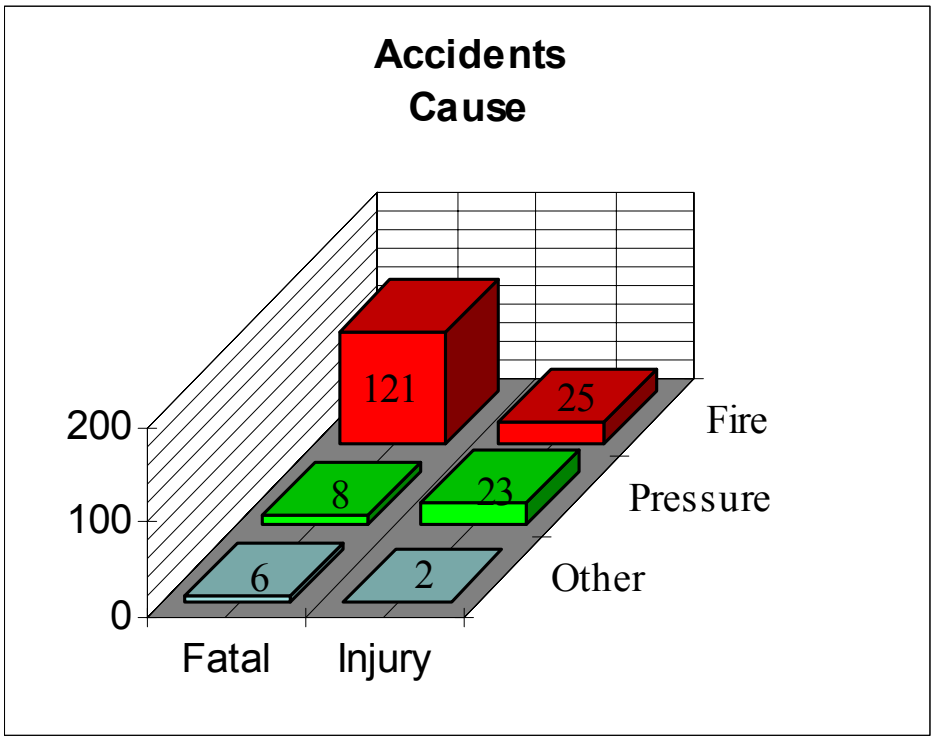
Systems - Systems accidents cause no deaths, and only a few injuries (7/14%). (Table 2) The distribution of fire accidents (19/63.3%), compared to pressure accident (9/30%) is significant. (Table 3) These are cases where a hatch or device is not secured properly and sudden pressure exposure results in violent movement of the device. In one case, amputating the legs of an operator standing in the wrong place. In older multiplace chambers, medical locks were a particular hazard. Another device which repeatedly has cause fires in systems is the quick opening ball valve in oxygen lines. It alone has been responsible for at least six accidents.

Altitude chambers - Altitude chamber accidents were primarily research accidents while researching the correct oxygen mixture for space travel and altitude exposure. It was after the Apollo accident in which three astronauts were burned during flight preparation, followed three days later with an accident at Brook AFB, that the space program ceased using 100% oxygen at reduced atmospheric pressure. All of the deaths and/or injuries in reduced pressure chambers were from fires. (Table 3)

Diving bells - Most of the accidents in diving bells involved training and welding. In one case the student was practicing welding inside the bell with increased oxygen without following the procedure of stripping to bathing suit, immersing in water, and having outside support. Two of the three accidents were fires (2/66.7%). (Table 3)

CAUSE (Figure 5)

Figure 5:



Fire – The overwhelming cause of deaths in chambers is fire (121/89.6%). (Table 2) Death might be from asphyxiation rather than burns, but it is still a result of the fire. Sheffield et al presented a 73 year analysis of fires in chambers, which iterates 17 case reports of accidents.[3] It can be said that chambers, designed and built to today's standards are safe. The fire risk is from items brought into the chamber. This might be the occupants, the occupant's personal belongings, monitoring or research equipment, recording equipment or even maintenance equipment. Often critical care equipment used for patient care takes precedence over fire risk.

Pressure – Pressure accidents in chambers are lower in fatalities (13/9.6%), but as high as fires when causing injury (20/40%). (Table 2) Often we think the pressure we are dealing with in hyperbaric chambers is low pressure. Perhaps it is compared to pressure in gas cylinders, however, even a slight deviation in pressure can result in deadly consequences. Perhaps the best known pressure accident is the Hanover incident. At this facility technicians changed the pressure gauges during a maintenance procedure. The console gauges were changed from gauges reading feet of seawater to gauges reading meters of seawater. The operator, unaware of the change, compressed the patients to roughly three times the normal operating pressure. Upon decompression the patients complained of decompression sickness like symptoms. Sending three of the patients away, the physician and a patient were sent back down in the same chamber. The operator was still unaware of the change in pressure gauges. After a treatment for decompression sickness which was thought to be at normal treatment depth, the patient and physician died upon ascent. The other three patients died in local hospital from decompression sickness. A dramatic pressure related accident happened when a diver, decompressing in a saturation chamber, flushed the toilet upon which he was sitting at the same time the outside operator opened the valve to clean the toilet. The resulting pressure differential caused the diver to lose the major portion of his large and small intestines.

Other – Other is a category used for those unusual cases which do not fit in the other groups. Cases involving decompression sickness or other problems not directly related to over pressure are placed in this category. Three accidents (9/7.9%) resulted in 1 death (1/0.7%). (Table 2) A case in point is an accident which occurred in Florida. After a reduction in force of most of the chamber personnel, a nurse was compressed in the morning to treat a routine wound care patient. After decompressing from that dive, the nurse was asked to be compressed again to treat an arterial gas embolism patient. Upon decompressing to 30 feet during treatment, approximately five hours into the treatment, the nurse complained of chest pain. She was immediately brought to the surface and sent home, where she died one hour later from the "chokes".

Summary

Incidents occurring in or around chambers are minimal compared to many other occupational hazards. In 1997, a very bad year for chamber accidents, there were three accidents resulting in 13 deaths and no injuries worldwide. That same year, there were, just in the United States, 43 catastrophic fires resulting in 216 deaths, 94 of those were fire fighters.[4] In 1996 there were 171 fire related deaths in the state of Florida and 2,900 nation wide.[2] However, without proper diligence and careful adherence to safety rules, accidents are going to occur in our industry. Coding and Standards agencies and practitioners should concentrate their efforts in making our occupation as safe as possible. The first chamber related fire death in the United States could result in the rapid demise of hyperbaric medicine. Should this happen, it would be unfortunate for the patients served by Hyperbaric Medicine.

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Table 1:

HYPERBARIC CHAMBERS WORLDWIDE			
Country	**Monoplace**	**Multiplace**	**Total**
Russia			1,100
Japan	668	55	723
United States	500	175	675
Italy			74
England			29
Cuba			27
Germany			24
Canada			12
Brazil			9
Norway			6
Australia			7
Sweden			5
Israel			4
Spain			2
Egypt			1
Singapore			1

From International Affairs Conference UHMS meeting, West Palm Beach, FL, 1995 Hideyo Takahashi, M.D., Ph.D. presiding.

Table 2:

INCIDENT SUMMARY						
Item	**Incidents**		**Fatalities**		**Injuries**	
Type Facility	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Hyperbaric	61	54.0	83	61.5	24	48.0
Diving	43	38.0	46	34.1	18	36.0
Hypobaric	9	8.0	6	4.4	8	16.0
System						
Multiplace	50	44.3	105	77.8	23	46.0
Monoplace	24	21.3	19	14.1	13	26.0
System	30	26.5	0	0.0	7	14.0
Altitude	6	5.3	6	4.4	7	14.0
Bell	3	2.6	5	3.7	1	2.2
Cause						
Fire	81	71.7	121	89.6	28	56.0
Pressure	23	20.4	13	9.6	20	40.0
Other	9	7.9	1	0.7	2	4.0
TOTAL	**113**		**135**		**50**	

Table 3:

CAUSE SUMMARY (INCIDENTS)						
Item	**Fire**		**Pressure**		**Other**	
Type Facility	**Number**	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Hyperbaric	40	65.5	13	21.3	8	13.2
Diving	32	66.7	10	33.3	1	0.0
Hypobaric	9	100	0	0.0	0	0.0
System						
Multiplace	35	68.6	11	21.5	5	9.8
Monoplace	20	83.3	2	8.3	8.4	0.0
System	19	63.3	9	30.0	2	6.7
Altitude	6	100.0	0	0.0	0	0.0
Bell	2	66.7	1	33.3	0	0.0

Form 1: (no longer in use)

EXPERIENCE & MISHAP DATABASE
REPORT FORM

Date:	Time:	Day of Week:
Location:		Type Hospital:
Address:		Type Clinic:
City	State:	Country:

Type Facility			**Chamber/System**				
HBO	Diving	Hypobaric	Multiplace	Monoplace	System	Altitude	Bell

Cause			Number Injuries	Years of Operation
Fire	Pressure	Other	Number Fatalities	Compression Gas
Ignition Source			Cause of Death	

Type Equipment	Model	Manufacturer

Reporter		Telephone
Address	FAX	E-Mail
City	State	Country
Role		

Victims				
Name	Age	Sex	Marital Status	Occupation