III. CONFINED SPACE HAZARDS

Overview and Magnitude of the Problem

(a) Overview

The hazards encountered and associated with entering and working in confined spaces are capable of causing bodily injury, illness, and death to the worker. Accidents occur among workers because of failure to recognize that a confined space is a potential hazard. It should therefore be considered that the most unfavorable situation exists in every case and that the danger of explosion, poisoning, and asphyxiation will be present at the onset of entry.

Before forced ventilation is initiated, information such as restricted areas within the confined space, voids, the nature of the contaminants present, the size of the space, the type of work to be performed, and the number of people involved should be considered. The ventilation air should not create an additional hazard due to recirculation of contaminants, improper arrangement of the inlet duct, or by the substitution of anything other than fresh (normal) air (approximately 20.9% oxygen, 79.1% nitrogen by volume). The terms air and oxygen are sometimes considered synonymous. However, this is a dangerous assumption, since the use of oxygen in place of fresh (normal) air for ventilation will expand the limits of flammability and increase the hazards of fire and explosion.

Hazardous conditions to be discussed in this Chapter include: Hazardous Atmospheres (flammable, toxic, irritant, and asphyxiating), and General Safety Hazards (mechanical, communications, entry and exit, and physical).

An estimation of the number of workers potentially exposed to confined spaces would be difficult to produce. A report prepared under contract for NIOSH [1] shows that the rate of confined space related injuries in the shipbuilding and repair industry is 4.8%. Projected on a national level, 2,448 accidents per year may be attributed to the hazards of working in confined spaces in this single industry. The Bureau of Labor Statistics shows that the Standard Industrial Classification (SIC) 373, Shipbuilding and Repair Industry, has a 23.9% injury rate. Based on this injury rate 5% of all accidents in the Shipbuilding and Repair Industry occur while working in and around confined spaces. Because of the lack of data it is not possible at this time to project this proportion of confined space related injuries to other industries [2]. Based on the total working population of selected specific SIC codes, and a rough estimate of the percentage of each category who may work in confined spaces at some time, NIOSH estimates that millions of workers may be exposed to hazards in confined spaces each year.

(b) Types of Confined Spaces

Confined spaces can be categorized generally as those with open tops and with a depth that will restrict the natural movement of air, and enclosed spaces with very limited openings for entry [3]. In either of these cases the space may contain mechanical equipment with moving parts. Any combination of these parameters will change the nature of the hazards encountered. Degreasers, pits, and certain types of storage tanks may be classified as open topped confined spaces that usually contain no moving parts. However, gases that are heavier than air (butane, propane, and other hydrocarbons) remain in depressions and will flow to low points where they are difficult to remove [4]. Open topped water tanks that appear harmless may develop toxic atmospheres such as hydrogen sulfide from the vaporization of contaminated water [5]. Therefore, these gases (heavier than air) are a primary concern when entry into such a confined space is being planned. Other hazards may develop due to the work performed in the confined space or because of corrosive residues that accelerate the decomposition of scaffolding supports and electrical components.

Confined spaces such as sewers, casings, tanks, silos, vaults, and compartments of ships usually have limited access. The problems arising in these areas are similar to those that occur in open topped confined spaces. However, the limited access increases the risk of injury. Gases which are heavier than air such as carbon dioxide and propane, may lie in a tank or vault for hours or even days after the containers have been opened [6]. Because some gases are odorless, the hazard may be overlooked with fatal results. Gases that are lighter than air may also be trapped within an enclosed type confined space, especially those with access from the bottom or side.

Hazards specific to a confined space are dictated by: (1) the material stored or used in the confined space; as an example, damp activated carbon in a filtration tank will absorb oxygen thus creating an oxygen deficient atmosphere [7]; (2) the activity carried out, such as the fermentation of molasses that creates ethyl alcohol vapors and decreases the oxygen content of the atmosphere [8]; or (3) the external environment, as in the case of sewer systems that may be affected by high tides, heavier than air gases, or flash floods [9].

The most hazardous kind of confined space is the type that combines limited access and mechanical devices. All the hazards of open top and limited access confined spaces may be present together with the additional hazard of moving parts. Digesters and boilers usually contain power-driven equipment which, unless properly isolated, may be inadvertently activated after entry. Such equipment may also contain physical hazards that further complicate the work environment and the entry and exit process.

(c) Reasons for Entering Confined Spaces

Entering a confined space as part of the industrial activity may be done for various reasons. It is done usually to perform a necessary function, such as inspection, repair, maintenance (cleaning or painting), or similar operations which would be an infrequent or irregular function of the total industrial activity [10].

Entry may also be made during new construction. Potential hazards should be easier to recognize during construction since the confined space has not been used. The types of hazards involved will be limited by the specific work practices. When the area meets the criteria for a confined space, all ventilation and other requirements should be enforced.

One of the most difficult entries to control is that of unauthorized entry, especially when there are large numbers of workers and trades involved, such as welders, painters, electricians, and safety monitors.

A final and most important reason for entry would be emergency rescue. This, and all other reasons for entry, must be well planned before initial entry is made and the hazards must be thoroughly reviewed. The standby person and all rescue personnel should be aware of the structural design of the space, emergency exit procedures, and life support systems required.

Hazardous Atmospheres

Hazardous atmospheres encountered in confined spaces can be divided into four distinct categories: (a) Flammable, (b) Toxic, (c) Irritant and/or Corrosive, and (d) Asphyxiating.

(a) Flammable Atmosphere

A flammable atmosphere generally arises from enriched oxygen atmospheres, vaporization of flammable liquids, byproducts of work, chemical reactions, concentrations of combustible dusts, and desorption of chemicals from inner surfaces of the confined space.

Alther [11] reported on a case involving workers in an enriched oxygen atmosphere. Two men entered a newly constructed tank to repair a bulge which had formed after the flange of the manhole was welded to the tank. The planned repair procedure was to have two men enter the tank with a jack to force the flange of the manhole into place while a third worker heated the bulge from the outside. To accomplish this procedure the men had to close the manhole. To improve the air within the tank, oxygen used for welding was blown in through an opening. A worker on the outside noticed through the opening that the hair of one of the workmen inside was on fire. The cover was immediately removed and one of the workers managed to escape, his clothing was burning rapidly, the second worker had collapsed and remained unconscious inside. It became necessary to invert the tank to remove the unconscious workman. Both workmen who were doing the work inside suffered serious burns. One died a short time later; the second was hospitalized for several months. A rescuer in the operation was burned on the hands.

Investigation of the accident revealed the use of oxygen in place of normal air increased the flammability range of combustibles. Enrichment of the atmosphere with only a few percent of oxygen above 21% will cause an increase in the range of flammability, hair as well as clothing will absorb the oxygen and burn violently. Enriched oxygen atmospheres which expand the region of flammability could be the result of improper blanking off of oxygen lines, chemical reactions which liberate oxygen, or inadvertently purging the space with oxygen in place of air [11].

An atmosphere becomes flammable when the ratio of oxygen to combustible material in the air is neither too rich nor too lean for combustion to occur. Combustible gases or vapors will accumulate when there is inadequate ventilation in areas such as a confined space. Flammable gases such as acetylene, butane, propane, hydrogen, methane, natural or manufactured gases or vapors from liquid hydrocarbons can be trapped in confined spaces, and since many gases are heavier than air, they will seek lower levels as in pits, sewers, and various types of storage tanks and vessels [12,13]. In a closed top tank, it should also be noted that lighter than air gases may rise and develop a flammable concentration if trapped above the opening.

The byproducts of work procedures can generate flammable or explosive conditions within a confined space. Specific kinds of work such as spray painting can result in the release of explosive gases or vapors [14]. Table III-3 shows that approximately one-third of the events identified as "atmospheric condition" were the result of the victims performing activities that generated fumes or depleted the oxygen supply. The most common of these activities was welding in a confined space. Welding in a confined space was a major cause for explosions in areas that contained combustible gas [1].

Chemical reactions forming flammable atmospheres occur when surfaces are initially exposed to the atmosphere, or when chemicals combine to form flammable gases. This condition arises when dilute sulfuric acid reacts with iron to form hydrogen or when calcium carbide makes contact with water to form acetylene. Other examples of spontaneous chemical reactions that may produce explosions from small amounts of unstable compounds are acetylene-metal compounds, peroxides, and nitrates. In a dry state these compounds have the potential to explode upon percussion or exposure to increased temperature. Another class of chemical reactions that form flammable atmospheres arise from deposits of pyrophoric substances (carbon, ferrous oxide, ferrous sulfate, iron, etc) that can be found in tanks used by the chemical and petroleum industry. These tanks containing flammable deposits, will spontaneously ignite upon exposure to air [15].

Combustible dust concentrations are usually found during the process of loading, unloading, and conveying grain products, nitrated fertilizers, finely ground chemical products, and any other combustible material. It has been reported that high charges of static electricity, which rapidly accumulate during periods of relatively low humidity (below 50%), can cause certain substances to accumulate electrostatic charges of sufficient energy to produce sparks and ignite a flammable atmosphere [14]. These sparks may also cause explosions when the right air or oxygen to dust or gas mixture is present.

Desorption of chemicals from the inner surfaces of a confined space is another process that may produce a flammable atmosphere. This is often a natural phenomenon in which the partial pressure at the interface between the surfaces and the stored chemical is radically reduced. For example, after liquid propane is removed from a storage tank the walls of the vessel may desorb the remaining gas from the porous surface of the confined space.

Dorias [16] reported on an explosive gas-air mixture in a horizontal cylindrical container (1000 m3), which had contained liquid propane. The cylinder was emptied to check for stress cracking. The space was to be filled with water to expell the gas, and drained so it could automatically fill with normal air. The container was presumably filled full of water and drained. The gas analysis of the resulting space showed an explosive gas-air mixture. The procedure of filling with water and draining was repeated and the test results were the same, an explosive gas-air mixture. To speed up the process, a man climbed into the cylinder and sprayed the interior with water for 3 hours, and allowed the interior to air dry. On the 4th day, a mechanic entered the tank and prepared the areas to be inspected for stress. Following this, a man entered the tank with a test device and a Katel lamp (220 volts not of an explosion-proof design). There was a sudden explosion and flame streamed out of the entry manhole. The man who was testing the atmosphere suffered severe injuries from which he died 6 days later. Investigation of the events revealed that the tanks were filled only 50% full the first time and only 80-90% full the second time. Therefore, it was concluded the space was never thoroughly emptied of all gas. Reconstruction of the operation showed that the spraying operation did not remove all the propane, and left a gas-air mixture of approximately 5% propane by volume, an extremely explosive condition [16].

(b) Toxic Atmospheres

The substances to be regarded as toxic in a confined space can cover the entire spectrum of gases, vapors, and finely-divided airborne dust in industry [17]. The sources of toxic atmospheres encountered may arise from the following:

(1) The manufacturing process (for example, in producing polyvinyl chloride, hydrogen chloride is used as well as vinyl chloride monomer which is carcinogenic).

(2) The product stored (removing decomposed organic material from a tank can liberate toxic substances such as H_2S).

(3) The operation performed in the confined space (for example, welding or brazing with metals capable of producing toxic fumes).

Zavon [18] reported, in 1970, that four employees of a local utility were repairing a water meter in an underground vault 18 feet x 6 feet x 5 feet with an opening 24 inches in diameter. To make the repairs, it was necessary to cut 26 cadmium plated bolts with an oxygen propane torch. Two men worked in the vault with one man cutting and the other standing beside him. Neither man wore a respirator and no ventilation was provided. Two other men remained on the surface. During the cutting of the bolts with the oxygen propane torch, a "heavy blue smoke" filled the vault. This smoke was exhausted after the cutting was completed.

The 56-year-old man who had cut the bolts died 17 days after exposure. He became nauseated shortly after the job and was seen by his family physician the next day for fever (102-103 F), chest pain, cough, and sore throat. On the 4th day following the incident he was in greater distress and was hospitalized. Death occurred in 2 weeks and was attributed to massive coronary infarction and corpulmonale. The 29-year-old assistant complained of chills, nausea, cough and difficulty in breathing. He was treated for pneumonia and made a slow recovery. A reenactment of the work demonstrated that the exposure to cadmium was well above the threshold limit value of "0.1 mg/m3" [18]. Symptoms attributed to cadmium poisoning include: severe labored breathing and wheezing, chest pain, persistent cough, weakness and malaise, and loss of appetite. The clinical course is similar in most cases. The injured frequently are well enough to work the day after exposure, but their conditions deteriorate until approximately the 5th day. At this point, the exposed worker will either get much worse or begin to improve [19].

Toxic gases may be evolved when acids are used for cleaning. Hydrochloric acid can react chemically with iron sulfide to produce hydrogen sulfide [20]. Iron sulfide is formed on the walls of cooling jackets when only several parts per million sulfide are in the water used in the cooling process. As an example, 5 men were overcome while cleaning a heat exchanger using a hydrochloric acid solution [20].

Another area where the hydrogen sulfide hazard exists is in the tanning industry. Lime pits used in the process of removing hair from the hides contain in addition to lime, a 1% solution of sodium sulfate (Na_2SO_4). Acid dichromate solution is also used in the tanning process. If these two solutions (sodium sulfate and acid dichromate) are combined accidentally, hydrogen sulfide (H_2S) will be produced. One such incident occurred when several unused pits at a tannery were being cleaned. Sludge had formed on the bottom of the pit due to drainage from the hides when they had been treated with lime and acid dichromate. When men entered the pit to clear the drain line, they were overcome. Because of the high specific gravity of hydrogen sulfide, the gas formed by the sodium sulfide-dichromate reaction had settled in the pit, and when the sludge was stirred the released gas overcame the workers. In this instance, 5 men became unconscious and two died [21]. The particular hazard associated with hydrogen sulfide at higher concentrations is due to its physiological effect of anesthetizing the olfactory nerves and can also cause a loss of reasoning, paralysis of the respiratory system, unconsciousness, and death [22,23].

During loading, unloading, formulation, and production, mechanical and/or human error may also produce toxic gases which are not part of the planned operation.

Toxic solvents, which present problems [24], such as trichloroethylene, methyl chloroform, and dichloromethane, are used in industry for cleaning and degreasing. Acrylonitrile, infrequently used, has been encountered as an ingredient in a protective coating applied to tank interiors [17].

Trichloroethane and dichloroethane are widely used in industry as cleaning solvents because they are among the least toxic of the chlorinated aliphatic hydrocarbons. These solvents have been used as a replacement for carbon tetrachloride and trichloroethylene [25-27].

In a case report by Hatfield and Maykoski [28] trichloroethane, also known as methyl chloroform was substituted for trichloroethylene because of the high toxicity of the latter. A radiator and metal tank repairman was involved in an aircraft tip tank cleaning and assembly operation. The technique of cleaning the interior of the tanks varied among workers. Some workmen would moisten a pad with solvent and would hand wipe the metal surfaces by reaching through an opening on the end of the tank; some would use pads on the end of a shaft, while others would climb inside and clean. One particular worker would saturate a pad with solvent and lower himself head first into the down-tilted tip of the tank and clean as fast as possible. This worker was found with his legs protruding from the upper end of the 450 gallon tank and was unresponsive. He was removed immediately and was given artificial respiration until a physician arrived and pronounced him dead.

Reconstruction of the fatal accident revealed the concentration of methyl chloroform in the tank had reached 62,000 ppm. The workers assumed that since the new cleaning solvent was less toxic than the one previously used, there was less danger. However, the new cleaning solvent, methyl chloroform, is a potent anesthetic at 30,000 ppm, which was less than half the concentration level in the worker's breathing zone.

The compatibility of materials must be considered when structural members and equipment are introduced in confined spaces. The previous history of the confined space must be carefully evaluated to avoid reactions with residual chemicals, wall scale, and sludge which can be highly reactive. One such case was reported in May of 1968, when an aluminum ladder was used for entry into a chemical evaporating tank which had contained aqueous sodium arsenite ($Na AsO_2$ H_2O) and sodium hydroxide (NaOH). The aluminum reacted with the $NaAsO_2$ and the NaOH to liberate hydrogen, which in turn reacted with the arsenic to form arsine [29]. Other cases of incompatability arise from the use of chemical cleaning agents. The initial step in chemical cleaning usually is the conversion of the scale or sludge into a liquid state which may cause poisonous gases to be liberated. In 1974, several employees who were cleaning a boiler tank prior to repairing a leak used a cleaning fluid, Vestan 675. The cleaning action caused the release of ammonia fumes that were not properly exhausted. The men were hospitalized with severe chest pains, but recovered [29].

Another hazardous gas that may build up in a confined space is carbon monoxide (CO). This odorless colorless gas that has approximately the same density of air is formed from incomplete combustion of organic materials such as wood, coal, gas, oil, and gasoline [30]; it can be formed from microbial decomposition of organic matter in sewers, silos, and fermentation tanks. Carbon monoxide is an insidious toxic gas because of its poor warning properties. Early stages of carbon monoxide intoxication are nausea and headache. Carbon monoxide may be fatal at 1000 ppm in air, and is considered dangerous at 200 ppm, because it forms carboxyhemoglobin in the blood which prevents the distribution of oxygen in the body.

Carbon monoxide (CO) is a relatively abundant colorless, odorless gas, therefore, any untested atmosphere must be suspect. It must also be noted that a safe reading on a combustible gas indicator does not ensure that CO is not present [14]. Carbon monoxide must be tested for specifically. The formation of CO may result from chemical reactions or work activities, therefore, fatalities due to CO poisoning are not confined to any particular industry. There have been fatal accidents in sewage treatment plants [8] due to decomposition products and lack of ventilation in confined spaces. Another area where CO results as a product of decomposition is in the formation of silo gas in grain storage elevators [8]. In another area, the paint industry, varnish is manufactured by introducing the various ingredients into a kettle, and heating them in an inert atmosphere, usually town gas, which is a mixture of carbon dioxide and nitrogen. In one accident report, a maintenance engineer entered a kettle that had been vented for 12-24 hours to check a blocked sampling tube. He was found dead some time later. Death was due to carbon monoxide poisoning. Investigation into the inert gas supply system revealed that the CO content of the town gas was over 1% (10,000 ppm), and that there were minor faults in the protective valves into the kettle so that a small leak was occurring. The employee had entered an atmosphere of reduced oxygen partial pressure containing CO and had succumbed before he could save himself [21]. In many cases CO poisoning occurs because of poor work practices.

In welding operations, oxides of nitrogen and ozone are gases of major toxicologic importance, and incomplete oxidation may occur and carbon monoxide can form as a byproduct [31]. One such case, documented in the Pennsylvania Occupational Injury Files of 1975, involved an employee who was overcome by carbon monoxide while welding inside a copper heat-treating oven with the door partially closed.

Another poor work practice, which has led to fatalities, is the recirculation of diesel exhaust emissions [32]. Tests have shown that although the initial hazard due to exhaust toxicants may be from increased CO_2 levels (or depleted O_2), the most immediate hazard to life processes is CO [33]. Increased CO levels can only be prevented by strict control of the ventilation or the use of catalytic convertors.

(c) Irritant (Corrosive) Atmosphere

Irritant or corrosive atmospheres can be divided into primary and secondary groups. The primary irritants exert no systemic toxic effects because the products formed by them on tissues of the respiratory tract are non-irritant, and other irritant effects are so violent as to obscure any systemic toxic action. Examples of primary irritants are chlorine (Cl_2), ozone (O_3), hydrochloric acid (HCl), hydrofluoric acid (HF), sulfuric acid (H_2SO_4), nitrogen dioxide (NO_2), ammonia (NH_3), and sulfur dioxide (SO_2). A secondary irritant is one that may produce systemic toxic effects in addition to surface irritation. Examples of secondary irritants include benzene (C_6H_6), carbon tetrachloride (CCl_4), ethyl chloride (CH_3CH_2Cl), trichloroethane (CH_3CCL_3), trichloroethylene ($CHClCCl_2$), and chloropropene (allyl chloride-CH_2CHCH_2Cl) [34].

Irritant gases vary widely among all areas of industrial activity. They can be found in plastics plants, chemical plants, the petroleum industry, tanneries, refrigeration industries, paint manufacturing, and mining operations [17].

Prolonged exposure at irritant or corrosive concentrations in a confined space may produce little or no evidence of irritation. This has been interpreted to mean that the worker has become adapted to the harmful agent involved. In reality, it means there has been a general weakening of the defense reflexes from changes in sensitivity, due to damage of the nerve endings in the mucous membranes of the conjunctivae and upper respiratory tract. The danger in this situation is that the worker is usually not aware of any increase in his exposure to toxic substances [17].

(d) Asphyxiating Atmosphere

The normal atmosphere is composed approximately of 20.9% oxygen and 78.1% nitrogen, and 1% argon with small amounts of various other gases. Reduction of oxygen (O_2) in a confined space may be the result of either consumption or displacement [35].

The consumption of oxygen takes place during combustion of flammable substances, as in welding, heating, cutting, and brazing. A more subtle consumption of oxygen occurs during bacterial action, as in the fermentation process. Oxygen may also be consumed during chemical reactions as in the formation of rust on the exposed surface of the confined space (iron oxide).

The number of people working in a confined space and the amount of their physical activity will also influence the oxygen consumption rate.

A second factor in oxygen deficiency is displacement by another gas. Examples of gases that are used to displace air, and therefore reduce the oxygen level are helium, argon, and nitrogen. Carbon dioxide may also be used to displace air and can occur naturally in sewers, storage bins, wells, tunnels, wine vats, and grain elevators. Aside from the natural development of these gases, or their use in the chemical process, certain gases are also used as inerting agents to displace flammable substances and retard pyrophoric reactions. Gases such as nitrogen, argon, helium, and carbon dioxide, are frequently referred to as non-toxic inert gases but have claimed many lives [36]. The use of nitrogen to inert a confined space has claimed more lives than carbon dioxide. The total displacement of oxygen by nitrogen will cause immediate collapse and death. Carbon dioxide and argon, with specific gravities of 1.53 and 1.38, respectively, (air = 1) may lie in a tank or manhole for hours or days after opening [36]. Since these gases are colorless and odorless, they pose an immediate hazard to health unless appropriate oxygen measurements and ventilation are adequately carried out.

In a report by the Ontario (Canada) Health Department, an underground oil storage tank which required cleaning, had been blanketed with nitrogen to prevent oxidation of the oil. The man assigned to clean the tank dropped an air hose into the tank before entering. As he reached the bottom of the ladder, he passed out. His helper outside the tank went in to help and feeling faint, left without getting the man out. He went to get assistance from a nearby maintenance shop. Three men came to the tank and climbed down and all were overcome. Finally, after about 20 minutes, all four men were recovered with the help of the fire department. The only reason that there were no fatalities was that an airline in the tank was blowing air into the vicinity of the fallen workers [37].

Oxygen deprivation is one form of asphyxiation. While it is desirable to maintain the atmospheric oxygen level at 21% by volume, the body can tolerate deviation from this ideal. When the oxygen level falls to 17%, the first sign of hypoxia is a deterioration to night vision which is not noticeable until a normal oxygen concentration is restored. Physiologic effects are increased breathing volume and accelerated heartbeat. Between 14-16% physiologic effects are increased breathing volume, accelerated heartbeat, very poor muscular coordination, rapid fatigue, and intermittent respiration. Between 6-10% the effects are nausea, vomiting, inability to perform, and unconsciousness. Less than 6%, spasmatic breathing, convulsive movements, and death in minutes [12,38].

In discussing oxygen and what constitutes an oxygen deficient atmosphere from a physiologic view, one must address the concept of partial pressures. At sea level the normal atmospheric pressure for air (20.9% O_2 + 78.1% N_2 + 1% Ar + trace amounts of various inert gases) is 14.7 psi or 760 mm Hg absolute. The partial pressure of O_2 (PO_2) at sea level will be approximately 160 mm Hg. The concept of partial pressures is that in any mixture of gases, the total gas pressure is the sum of the partial pressures of all the gases [39].

The PO_2 in ambient air can be decreased by a reduction in the O_2 level at constant pressure or by maintaining the percentage of O_2 constant and decreasing the total atmospheric pressure as in the case at high altitudes.

It is important not only to know the O_2 percent by volume, but to understand the relationship of O_2 to altitude and the concept of partial pressure. For example, 20.9% O_2 in air at sea level constitutes a greater PO_2 than 20.9% O_2 at 5,000 feet because the total atmospheric pressure at 5,000 feet is less. As the PO_2 in the atmosphere drops, the volume of air required to maintain a PO_2 of 60 mm Hg in the alveolar space of the lungs increases. A PO_2 below 60 mm Hg in the alveolar space is considered oxygen deficient [39].

Absorption of oxygen by the vessel or the product stored therein is another mechanism by which the PO_2 may be reduced and result in an oxygen deficient atmosphere. For example, activated carbon, usually considered as an innocuous material free of occupational hazard and toxicity, was responsible for two fatalities in a carbon filtration tank. Damp activated carbon absorbs oxygen and has been known to decrease the oxygen level from 21% to 4% in a closed vessel [7].

Montgomery et al [7] reported on two fatalities caused by the use of activated carbon in a water filtration vessel, (12.5 feet in diameter and 17 feet high). The space was newly constructed, filled halfway with granular carbon in a slurry form (water medium), the water was drained off through a bottom drain, and the tank was closed off to protect it from the weather. The next morning two workers entered the filtration vessel to perform necessary adjustments to the carbon bed and the interior sprinkler mechanism. When the workmen failed to appear at lunch time, they were found dead on the carbon bed. However, a rescuer entered the tank without any type of respiratory protection and with no ill affects. Tests of the atmosphere revealed no cause of death, the oxygen level was 21%, hydrocarbon and hydrogen sulfide tests were negative.

The investigation of the fatalities revealed the following: the tank was re-closed and re-opened the following day. No toxic gases were found; however, the oxygen level had dropped from 21% to 12% by volume. Other vessels checked at this location which had been closed for several weeks revealed the oxygen level was down to 2%.

In summary, it was discovered that dry carbon would not reduce the oxygen level significantly. Damp activated carbon, however, supposedly an innocuous material and free from toxicity, contributed to the death of two workers as a result of selective absorption of oxygen in a confined space with no ventilation.

General Safety Hazards

(a) Mechanical

If activation of electrical or mechanical equipment would cause injury, each piece of equipment should be manually isolated to prevent inadvertent activation before workers enter or while they work in a confined space. [12,40]. The interplay of hazards associated with a confined space, such as the potential of flammable vapors or gases being present, and the build-up of static charge due to mechanical cleaning, such as abrasive blasting, all influence the precautions which must be taken.

To prevent vapor leaks, flashbacks, and other hazards, workers should completely isolate the space [41]. To completely isolate a confined space the closing of valves is not sufficient. All pipes must be physically disconnected or isolation blanks bolted in place [5]. Other special precautions must be taken in cases where flammable liquids or vapors may re-contaminate the confined space. The pipes blanked or disconnected should be inspected and tested for leakage to check the effectiveness of the procedure. Other areas of concern are steam valves, pressure lines, and chemical transfer pipes. A less apparent hazard is the space referred to as a void, such as double walled vessels, which must be given special consideration in blanking off and inerting.

(b) Communication Problems

Communication between the worker inside and the standby person outside is of utmost importance. If the worker should suddenly feel distressed and not be able to summon help, an injury could become a fatality. Frequently, the body positions that are assumed in a confined space make it difficult for the standby person to detect an unconscious worker [10]. When visual monitoring of the worker is not possible because of the design of the confined space or location of the entry hatch, a voice or alarm-activated explosion proof type of communication system will be necessary [15].

Suitable illumination of an approved type is required to provide sufficient visibility for work in accordance with the recommendations made in the Illuminating Engineering Society Lighting Handbook.

(c) Entry and Exit

Entry and exit time is of major significance as a physical limitation and is directly related to the potential hazard of the confined space. The extent of precautions taken and the standby equipment needed to maintain a safe work area will be determined by the means of access and rescue. The following should be considered: type of confined space to be entered, access to the entrance, number and size of openings, barriers within the space, the occupancy load, and the time requirement for exiting in event of fire, or vapor incursion, and the time required to rescue injured workers [41].

(d) Physical

The hazards described in this section include non-chemical, physiologic stressors. These include thermal effects (heat and cold), noise, vibration, radiation, and fatigue while working in a confined space.

(1) Thermal Effects

Four factors influence the interchange of heat between man and his environment. They are: (1) air temperature, (2) air velocity, (3) moisture contained in the air, and (4) radiant heat [42,43]. Because of the nature and design of most confined spaces, moisture content and radiant heat are difficult to control. As the body temperature rises progressively, workers will continue to function until the body temperature reaches 38.3 - 39.4 C. When this body temperature is exceeded, the workers are less efficient, and are prone to heat exhaustion, heat cramps, or heat stroke [44]. In a cold environment certain physiologic mechanisms come into play, which tend to limit heat loss and increase heat production. The most severe strain in cold conditions is chilling of the extremities so that activity is restricted [42]. Special precautions must be taken in cold environments to prevent frostbite, trench foot, and general hypothermia.

Protective insulated clothing for both hot and cold environments will add additional bulk to the worker and must be considered in allowing for movement in the confined space and exit time. Therefore, air temperature of the environment becomes an important consideration when evaluating working conditions in confined spaces.

(2) Noise

Noise problems are usually intensified in confined spaces because the interior tends to cause sound to reverberate and thus expose the worker to higher sound levels than those found in an open environment. This intensified noise increases the risk of hearing damage to workers which could result in temporary or permanent loss of hearing. Noise in a confined space which may not be intense enough to cause hearing damage may still disrupt verbal communication with the emergency standby person on the exterior of the confined space. If the workers inside are not able to hear commands or danger signals due to excessive noise, the probability of severe accidents can increase [42].

(3) Vibration

Wholebody vibration may be regarded as a "generalized stressor" and may affect multiple body parts and organs depending upon the vibration characteristics. Segmental vibration, unlike wholebody vibration, appears to be more localized in creating injury to the fingers and hands of workers using tools, such as pneumatic hammers, rotary grinders or other hand tools which cause vibration [42].

(4) General/Physical

Some physical hazards cannot be eliminated because of the nature of the confined space or the work to be performed. These hazards include such items as scaffolding, surface residues, and structural hazards. The use of scaffolding in confined spaces has contributed to many accidents caused by workers or materials falling, improper use of guard rails, and lack of maintenance to insure worker safety. The choice of material used for scaffolding depends upon the type of work to be performed, the calculated weight to be supported, the surface on which the scaffolding is placed, and the substance previously stored in the confined space.

Surface residues in confined spaces can increase the already hazardous conditions of electrical shock, reaction of incompatible materials, liberation of toxic substances, and bodily injury due to slips and falls. Without protective clothing, additional hazards to health may arise due to surface residues.

Structural hazards within a confined space such as baffles in horizontal tanks, trays in vertical towers, bends in tunnels, overhead structural members, or scaffolding installed for maintenance constitute physical hazards, which are exacerbated by the physical surroundings. In dealing with structural hazards, workers must review and enforce safety precautions to assure safety.

Rescue procedures may require withdrawal of an injured or unconscious person. Careful planning must be given to the relationship between the internal structure, the exit opening, and the worker. If the worker is above the opening, the system must include a rescue arrangement operated from outside the confined space, if possible, by which the employee can be lowered and removed without injury

Statistical Data

Accidents in confined spaces, like all others, are required by Federal regulations to be reported only if medical attention or loss of time from work, or death is involved. Some states and workers' compensation carriers have slightly more stringent requirements, but none require the reporting of incidents which can be considered near misses. The report by Safety Sciences prepared under contract for NIOSH [1] tended to show that fatalities occurred more frequently in confined spaces. For example, death by asphyxiation would be reported; however, if an employee experienced shortness of breath or dizziness, but managed to escape the confined space, and was not treated by a physican, this would probably not be a reported case.

The criteria used in selecting cases was based on the definition published in the Federal Register 42:213, November 4, 1977 and specific circumstances likely to be found on injury and fatality records.

Table III-1 shows the number of "events", injuries, and fatalities from each data source. "Events" refers to the number of separate occasions in which one or more confined space-related injuries or illnesses occurred [1].

Table III-2 shows the number of events, injuries and fatalities obtained for each of the 15 basic accident and illness types which are described in Appendix 4 of this document. A total of 276 confined space related events were identified, which resulted in a total of 234 injuries and 193 fatalities. The table shows that the most hazardous conditions in a confined space are a result of atmospheric related events [1].

Table III-3 shows the number of events by SIC code for each of the 15 confined space-related accident and illness types [1].

TABLE III-1

NUMBER OF CONFINED SPACE-RELATED CASES OBTAINED BY DATA SOURCE

Data Source	Approx. No. of Cases Reviewed	No. of Events	No. of Injuries	No. of Fatalities
1. First Reports from Previous NIOSH Study 1974-75	20,000	67	66	1
2. OSHA 36's 1976-77	6,000	132	130	143
3. Equifax, Inc. "Occupational Death Reports" 8/76-12/76	1,700	41	2	49
4. Shipbuilding and Repair Cases 1976-77	750	36	36	0
Totals	28,450	276	234	193

Safety Sciences, San Diego, California - 1977 [1]

TABLE III-2

ACCIDENT AND ILLNESS TYPE
CONFINED SPACE (CS)

Ref. No.	Accident and Illness Type	Events	Injuries	Fatalities
1	Atmospheric Condition in CS	80	72	78
2	Explosion or Fire in CS	15	49	15
3	Explosion or Fire at Point-of-Entry to CS	23	20	32
4	Electrocution or Electrical Shock	11	2	9
5	Caught In/Crushing of CS	10	3	10
6	Trapped in Unstable Materials in CS	16	0	16
7	Struck by Falling Objects in CS	15	1	14
8	Falls (while in CS; not into CS)	27	26	1
9	Ingress/Egress of CS	33	30	3
10	Insufficient Maneuverability in CS	15	15	0
11	Eye Injury in CS	10	10	0
12	Contact with Temperature Extreme in CS	7	4	3
13	Noise in CS	1	1	0
14	Vibration in CS	1	1	0
15	Stress from Excess Exertion in CS	12	0	12
Totals		276	234	193

Safety Sciences, San Diego, California - 1977 [1]

TABLE III-3

CONFINED SPACE EVENTS BY SIC CODE AND ACCIDENT/ILLNESS TYPE

SIC	Name of Industry	*1	*2	*3	*4	*5	*6	*7	*8	*9	*10	*11	*12	*13	*14	*15
01	Agricultural Products - Crops	4			1		1	1								1
02	Agricultural Products - Livestock						1									
07	Agricultural Services						1									
09	Fishing, Hunting, and Trapping		1													
13	Oil and Gas Extraction	6	1					1		1						
15	Building Construction	2		2	2			1			3					1
16	Construction Other Than Building Construction	6		3				1		2			1			3
17	Construction - Special Trade Contractors	8	4		1			1		1	3					2
20	Food and Kindred Products	1	1	1	1	2	2	1	3	1						1
23	Apparel			3												
24	Lumber and Wood Products, Except Furniture	1		3						1						
25	Furniture and Fixtures	1														
26	Paper and Allied Products	1							3	1	1	2	1			
28	Chemicals and Allied Products	8	2	2	2				1		1					1
29	Petroleum Refining and Related Industries		1													
30	Rubber and Misc. Plastic Products	1								2						
31	Leather and Leather Products	1			1											
32	Stone, Clay, Glass, and Concrete Products					1	3		1	2						
33	Primary Metal Industries	1		1		1		1	3	1	1	2	1			
34	Fabricated Metal Products, Ex. Machinery and Transportation Equip.	4			1		1	1			1					1

TABLE III-3 (CONTINUED)

CONFINED SPACE EVENTS BY SIC CODE AND ACCIDENT/ILLNESS TYPE

SIC	Name of Industry	*1	*2	*3	*4	*5	*6	*7	*8	*9	*10	*11	*12	*13	*14	*15
35	Machinery, Except Electrical	2	1	1				2	2		1	1				
36	Electrical and Electronic Equip.	1			1				1	1						
37	Transportation Equip.	3	2	1					2	4	1		1		1	1
3731	Shipbuilding	4			1	1			8	13	7	1		1		
38	Measuring, Analyzing, and Controlling Instruments; Photographic, Medical, and Optical Goods; Watches and Clocks					1		1								
42	Motor Freight Transportation and Warehousing	3	1				3	1								
44	Water Transportation	3						1					1			
45	Transportation by Air	1						1								
47	Transportation Services	1		1												
48	Communication	3														
49	Electric, Gas, and Sanitary Services	3		1			1									
50	Wholesale Trade - Durable Goods	1		2		4			1							
51	Wholesale Trade - Nondurable Goods	1		2			1	1								1
54	Food Stores								1				2			
55	Auto Dealers and Gas Stations								1							
58	Eating and Drinking Places									1						
59	Misc. Retail						1									
65	Real Estate	1														

TABLE III-3 (CONTINUED)

CONFINED SPACE EVENTS BY SIC CODE AND ACCIDENT/ILLNESS TYPE

SIC	Name of Industry	*1	*2	*3	*4	*5	*6	*7	*8	*9	*10	*11	*12	*13	*14	*15
70	Hotels, Camps, and Other Lodging Places	1														
73	Business Services	1														
75	Automotive Repair		1	1												
76	Misc. Repair Services	1		2												
82	Educational Services	1														
91	Executive, Legislative, and General Government	1														
93	Public Finance, Taxation, and Monetary Policy	1														
	Unknown	1														

*1 - Atmospheric Condition
*2 - Explosion or Fire
*3 - Explosion or Fire at Point-of-Entry
*4 - Electrocution or Electrical Shock
*5 - Caught In/Crushing
*6 - Trapped in Unstable Materials
*7 - Struck by Falling Objects
*8 - Falls
*9 - Ingress/Egress
*10 - Insufficient Maneuverability
*11 - Eye Injury
*12 - Contact with Temperature Extreme
*13 - Noise
*14 - Vibration
*15 - Stress from Excess Exertion

Safety Sciences, San Diego, California - 1977 [1]

IV. DEVELOPMENT OF THE STANDARD

Previous Standards

The basis for most of the previous standards were safety codes designed for specific industrial activities, and dealt with areas such as open surface tanks, welding and cutting, and the pulp and paper, and shipping industries.

The most recent standard published on confined spaces is the 12-year effort compiled by the American National Standards Institute, Z117.1-1977. Despite the effort, the ANSI standard does not address the vitally important areas of training of personnel and specific recommendations for the safety equipment required in a confined space. All personal protective equipment is referenced to different ANSI Standards, which are broad based and do not address the specific problems of confined spaces.

The ANSI Standard also accepts the use of tagging as a reliable method of locking out a potentially hazardous situation. The tagging system as a substitute for locking out all lines or pipes, or de-energizing systems of a confined space does not provide sufficient protection to the worker against accidental activation.

The ANSI Standard does mention the use of life lines; however, the only recommendation is for their use in an oxygen deficient atmosphere.

The General Industry Safety and Health Standards of the Occupational Safety and Health Administration (OSHA) address safety in confined spaces in over 50 different sections of 29 CFR 1910. The defining parameters of a confined space as given in the OSHA regulations are: (1) limited means of exit, (2) a space subject to accumulation of toxic or flammable contaminants or, (3) one where an oxygen deficient atmosphere may develop. It includes but is not limited to such spaces as storage tanks, process vessels, bins, boilers and open top spaces more than 4 feet in depth. This is essentially the same definition used to establish the scope of this recommended criteria. However the "Classification of open-surface tank operation" (1910.94(d) (2) (i-ii)) differs from the classification system proposed in this document. This proposed classification system is intended to apply to all confined spaces and is based upon the evaluation of several additional parameters. Such a classification will allow the application of a wider range of safety measures and ease the enforcement of the OSHA regulation. The confined space classification system was designed to create a focal point by drawing together over 140 references in the OSHA standards. For example, the use of life lines in all confined spaces, has been addressed in this document and a solution to their excessive use has been proposed. The two documents agree on many areas of good work practices, such as the use of standby personnel, blanked-off lines, and main shutoff valves. Another area of agreement is the acceptance of 19.5% as the minimal oxygen level for safe work practice. There are some areas of the OSHA regulations that appear to accept tagging as a sufficient measure to ensure against opening of valves or energizing equipment during entry or while working in confined spaces. The proposed standard is more stringent in that only locking-out, blanking-off or disconnection are acceptable.

Canadian [45] and Australian [46,47] regulations and standards on confined space entry were reviewed. The Canadian Standard uses a hazard evaluation report, which appears to be a condensed form of the recommended permit system. The Canadian Standard also relies on the qualified person to make decisions for entry and necessary precautions for working in and for making emergency escape. A minimum safe level of oxygen for entry is not stated, only what is considered an oxygen deficient atmosphere (less than 17% by volume). The Australian Standard, which comes under the Factories' Regulations, states the confined space shall be emptied and flushed of hazardous substances and be ventilated with fresh air before entry. The Australian Standard is concerned primarily with entry and exit, not with isolation or safe oxygen level. The Australian Standard does; however, refer to a competent person similar to the qualified person for testing the atmosphere for flammable level. Other countries [14,48-50] published guidelines or standards for entering and working in confined spaces. Many of those reviewed follow recommendations similar to the Australian and Candadian standards. Therefore, it would be redundant to make a lengthy comparative list of standards. The state standards reviewed [8,12,51-54] and those from industry [40,55-68] were also closely evaluated. The number of references involved prohibits the citing of each one, although valuable concepts were obtained.

Basis for the Recommended Standard

Workers who enter and work in confined spaces are confronted with many potentially hazardous conditions. The hazards can range from an oxygen deficient atmosphere or liberation of a toxic agent, to mechanical equipment accidentally energized. The hazardous atmospheres that can be encountered in a confined space are; flammable, toxic, irritant and/or corrosive, and asphyxiation. These atmospheric conditions are discussed in Chapter III, along with cited accident cases to emphasize the hazards involved with confined space entry.

The limited statistical data available on accidents and injuries directly related to confined spaces indicate a very high mortality level. This disproportionately high mortality level for the number of reported accidents and injuries could be the result of inadequate reporting methods, as not reporting a near miss with death, or data collection systems failing to list a confined space as a causative or other factor in traumatic accidents. In the accident and injury cases tabulated for this document, atmospheric conditions in confined spaces were responsible for the most frequent accident type in terms of events and number of persons killed or injured [1].

The work practices section in Chapter I of the recommended standard was developed after extensive review of published literature, [2,11,15-17,31,33,36,55-92] the current Federal, State, and local applicable codes, [8,12,51-54,93-101], international codes or recommendations [3,45-50,102], and site visits to facilities where working in confined spaces is part of the industrial activity.

(a) Testing and Monitoring

Prior to entry into a confined space, workers should know the space's potential hazards. Deaths have occurred because a presumably safe space was not tested prior to initial entry [7,13]. The various tests to be performed prior to entry shall include tests for flammability, toxic agents, oxygen deficiency, and harmful physical agents. Specific instruments are required for testing the atmosphere for flammability, oxygen deficiency, carbon monoxide, and physical agents. For example, combustible gas indicators are designed for the purpose of measuring the concentration of flammable gases, and will not measure or indicate the presence of carbon monoxide at toxic levels, conversely a carbon monoxide detector is designed for the measurement of carbon monoxide only. It should be noted that combustible gas indicators respond differently to different flammable hydrocarbons and should be calibrated for the specific contaminant if known. The flammability measurement may be erroneous if the oxygen level is less or greater than normal atmospheric concentrations. Therefore, it is recommended that the oxygen level be determined prior to flammability testing to make any necessary corrections in the flammability measurement.

When the materials may form a combustible dust mixture, special precautions must be taken to prevent an explosive atmosphere from developing. There are numerous instruments available for measuring airborne dust concentrations; however, none appear to have automatic alarm systems and would require constant personal monitoring. The only practical approach to the control of combustible dusts is to eliminate the hazard by preventive measures, such as, (1) engineering controls, (2) good housekeeping, (3) elimination of ignition sources, (4) isolation of dust producing operations and, (5) training and education of the employees.

The oxygen deficiency measuring instrument is designed to measure the volume of oxygen present, usually scaled with a range of 0.0-25%. If the percentage of oxygen in a confined space atmosphere is less than 19.5% or greater than 25%, special precautions, as determined by the qualified person, shall be taken. In accordance with OSHA Safety and Health Standard 29 CFR Part 1910 and other references [12,33,51,76,87], a minimum oxygen level of 19.5% has been adopted for worker safety. The upper oxygen limit has been set at 25% because an increase above this level will greatly increase the rate of combustion of flammable materials [11].

Continuous and/or frequent monitoring becomes necessary in cases where the work being performed within the confined space has the potential of generating toxic agents [4,5,14,54,58,64,74,81,83,84,86,87]. Data collected for NIOSH by Safety Sciences [1] shows that in 28 out of 80 accident events, the toxic gas or oxygen deficiency was not in the confined space at the time of entry, but was either generated by the work occurring in the space, or by gas being unexpectedly admitted into the confined space after the worker had entered. In these cases, only continuous and/or frequent monitoring would be a possible countermeasure.

(b) Medical

Medical requirements for workers who might enter a confined space should take into consideration the increased hazard potential of confined spaces. In this setting, the workers must rely more heavily upon their physical, mental, and sensory attributes, especially under emergency conditions. Workers should be evaluated by competent medical personnel to insure that they are physically and mentally able to wear respirators under simulated and actual working conditions. Because of the additional stress placed on the cardiopulmonary system, some pathologic conditions, such as cardiovascular diseases or those associated with hypoxemia, should preclude the use of respiratory protective devices [101].

In areas where the hazard potential is high, a person certified in CPR and first aid should be in attendance. Since irreversible brain damage can occur in approximately 4 minutes in an oxygen deficient atmosphere, it is essential that resuscitation attempts occur within that time [102].

(c) Safety Equipment and Clothing

Many cases of accidental dermal exposure, respiratory distress, and traumatic injury due to falling objects have occurred in confined spaces; therefore, a general safety standard should address the problem of whole body protection [3]. Another area of concern is the use of life lines in all confined spaces. Part of the recommended standard should be an evaluation of the confined space to define when life lines shall be used and when a safety belt with D rings for attaching life lines would be sufficient [12,14,17,53,58,61,73,93,97,103,104].

(d) Training

Training of employees for entering and working in confined spaces is essential because of the potential hazards and the use of life saving equipment. To insure worker safety, the training program should be especially designed for the type of confined space involved and the problems associated with entry and exit. If different types of confined spaces are involved, this will require additional training. Areas that should be covered in an effective training program are:

1. Emergency entry and exit procedures
2. Use of applicable respiratory equipment
3. First Aid and Cardio-Pulmonary Resuscitation (CPR)
4. Lockout procedures
5. Safety equipment use
6. Rescue drills
7. Fire protection
8. Communications

Training of employees should be done by the qualified person or someone knowledgeable in all relevant aspects of confined space entry, hazard recognition, use of safety equipment, and rescue [3,33,53,58,63,68,84,90,97].

For training to be effective, classroom sessions, on-the-job training, or simulated conditions, appear to be the most satisfactory methods. Classroom sessions should include all applicable Federal, state, and local regulations that govern the specific industrial activity in which the employee will be working, as well as the hazards of a confined space (physical and chemical). The training guidelines in Chapter V can be used as a format for additional classroom activity. On-the-job training should be closely supervised until the employee has a complete understanding of all potential hazards. Testing of the employee should take place to evaluate the person's competency and determine if retraining is necessary.

(e) Work Practices

(1) Purging and ventilation - poor natural ventilation is one of the defining parameters of a confined space, therefore purging and mechanical ventilation must be closely evaluated when safe work practices are developed for entering and working in confined spaces. Purging is the initial step in adjusting the atmosphere in a confined space to acceptable standards (PEL's, LEL's, and LFL's). This is accomplished either by displacing the atmosphere in the confined space with fluid or vapor (inert gas, water, steam and/or cleaning solution), or by forced air ventilation. According to the literature [11] 20 air changes should bring the atmosphere in the confined space into equilibrium with the external environment.

After purging, one establishes general and/or local exhaust ventilation to maintain a safe uncontaminated level. Guidelines for establishing ventilation rates are referenced in the ANSI Standard Z9.2-1972 [105] and NIOSH Recommended Industrial Ventilation Guidelines [106]. In addition, other information applicable to the special problems of confined spaces must be considered such as the Occupational Safety and Health Standard 29 CFR 1915.31(b) [31,45,69,107-109]. Entering into an inert atmosphere is one of the most hazardous activities associated with working in a confined space. Work in an inert atmosphere is usually performed by employees of companies who specialize in this because of the high degree of training and expertise needed to perform inert entry operations safely. The scope of this document deals with the necessary precautions but does not cover the specialized training for entry into a confined space containing an inert atmosphere [11,106].

(2) Isolation/Lockout/Tagging - a review of the statistical data provided to NIOSH [1] demonstrated an obvious need for lockout procedures. The use of tags, while valuable for identification and/or information purposes, appears to have been inadequate in preventing accidents. A review of the literature has shown that proper isolation and lockout procedures are more effective than tagging [5,6,12,45,55,57,61,64,88,103].

(3) Cleaning - decontaminating a space by cleaning is necessary to provide for worker safety. However, it must be recognized that the cleaning process itself can generate additional hazards. Continuous and/or frequent monitoring is required during this process to determine that flammable mixtures and hazardous concentrations of contaminants are adequately diluted before safe entry can be made [3,5,15,20,48,49,59,61,79,80,91].

(4) Equipment and tools - the literature reviewed [15,58,63,64,109], has shown the potential for explosion is greatly increased when explosion proof equipped tools and equipment are not used or improperly maintained. Also the potential for electrocution is increased when low voltage or ground fault circuit interrupters are not used.

(5) Permit System - the inherent dangers associated with a confined space clearly indicate the need for strict control measures of employees and equipment. The literature has shown [50,52,55,56,63,69,77,86,88,90] that the use of a permit system is a very effective method of attaining control. The permit provides written authorization for entering and working in confined spaces, clearly states all known or potential hazards, and identifies the safety equipment required to insure the safety of the worker.

(6) Entry and Rescue - the potential hazards associated with a confined space must be evaluated prior to entry. These hazards would include the following: oxygen level, flammability characteristics, toxic agents, and physical hazards ie, limited openings and communications. To simplify entry and rescue it would appear logical to set up a classification table for easy reference. The literature reviewed [5,12,51,63,69,76] has provided necessary information to set up an entry classification table and allow for flexibility in the selection of personal protective equipment.

It is essential that well planned rescue procedures and the proper use of personal protective equipment be followed. The literature and data reviewed have shown a very poor record in successful rescue efforts. Spontaneous reaction instead of well planned and executed rescue procedures has led to multiple fatalities in confined spaces. In 19 of the 25 cases in which rescue was attempted, the rescuers were injured or killed. These cases resulted in 13 deaths and 30 injuries to rescuers, even though only 5 victims were successfully saved. One particular case resulted in injury to 15 rescuers; however, they were successful in saving 3 lives [1]. Therefore, the standby and/or rescue team shall be properly equipped and trained in all aspects of rescue.

(7) Recordkeeping - from a review of the limited data available (no SIC code for confined spaces) and the information collected from the plant site visits on accidents in confined spaces, it is apparent that recordkeeping systems must be changed to identify areas where accidents occur, so that underlying causes can be determined. The records to be kept by the employer should contain such information as employee name, age, training, job description, number of years on the job, accident location and severity, underlying causes, and action taken to insure future worker safety.