CASE REPORT

Frederick T. Zugibe,[1] M.D., Ph.D.; James T. Costello;[2] Mark K. Breithaupt;[2] Eduardo Zappi,[2] M.D.; and Burton Allyn,[2] M.D.

The Confined Space-Hypoxia Syndrome

REFERENCE: Zugibe, F. T., Costello, J. T., Breithaupt, M. K., Zappi, E., and Allyn, B., **"The Confined Space-Hypoxia Syndrome,"** *Journal of Forensic Sciences*, JFSCA, Vol. 32, No. 2, March 1987, pp. 554-559.

ABSTRACT: Two meter readers of a local water company were found dead in an underground water meter pit. Studies revealed a decrease in oxygen and an increase in carbon dioxide in the pit as a result of aerobic microorganisms present in the pit. Such an atmosphere may be rapidly fatal to the unwary worker who frequents such an environment. It is of paramount importance that this occupational hazard be recognized so that preventative measures may be established. We propose that the term "Confined Space-Hypoxia Syndrome" be adopted to all such confined space accidents occurring in water meter pits, tanks, holds of ships, mines, underground storage bins, and so forth, resulting frcm oxygen-deficient atmospheres. A series of recommended preventative procedures is included.

KEYWORDS: pathology and biology, Confined Space-Hypoxia Syndrome, death

The bodies of two male meter readers, ages 37 and 42, were found lying face up at the bottom of a water meter vault in 10 in. (25 cm) of muddy water. The men were scheduled to read the commercial meter about 7 h before being found in the vault. A heavy froth was noted around the mouths and minimal abrasive injuries were noted on the foreheads of both men.

Scene

The meter vault is 12 ft (3.6 m) long, 7 ft (2.1 m) wide, and 6 ft (1.8 m) high, and the opening into the vault measured 2 by 3 ft (0.6 by 0.9 m) and had been covered before the incident (Fig. 1). A metal ladder facilitates entry into the concrete vault (Fig. 2). Organic material was present in the 10 in. (25 cm) of muddy water on the bottom, and the walls contained "moldy" areas. The meter vault is located in a shopping center and was so positioned that it could serve as a collection depot for seepage of runoff or other water. Since

Presented at the 38th Annual Meeting of the American Academy of Forensic Sciences, New Orleans, LA, 10-15 Feb. 1986. Received for publication 24 March 1986; accepted for publication 27 May 1986.

[1]Chief medical examiner, Rockland County, Pomona, NY, and adjunct associate professor of pathology, Columbia University College of Physicians and Surgeons, New York, NY.

[2]Senior medical investigator, medical investigator, pathologist, and assistant medical examiner, respectively, Rockland County Medical Examiner's Office, Pomona, NY.

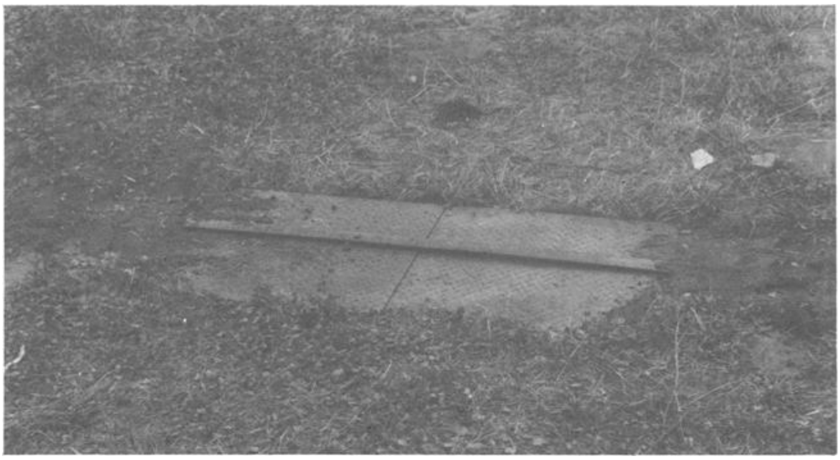

FIG. 1—*Water meter vault shown covered.*

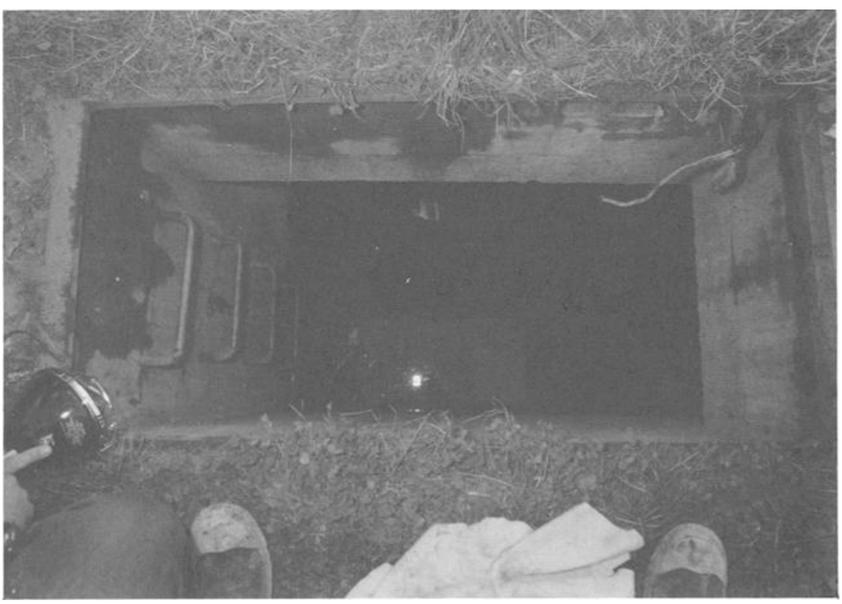

FIG. 2—*Open water meter vault; note water in bottom.*

garbage disposal facilities were present in the shopping center, it was deduced that organic material could easily contaminate the vault via the runoff.

Autopsy

Significant autopsy findings included marked pulmonary edema with hemorrhagic, frothy fluid oozing from the cut surfaces, and hemorrhagic congestion in both of the deceased. The lungs together weighed 1600 g in one individual and 1200 g in the other. The mastoid air cells showed some hemorrhagic changes. Microscopic sections of the lungs revealed the presence of homogeneous material in the alveolar spaces. Small hematomas were noted on both sides of the forehead.

Air Quality Testing

The vault was sealed after samples were taken for initial testing and tested again 1 week later and 30 days later. Samples taken before sealing the pit revealed oxygen levels that averaged 19%, carbon dioxide levels averaging 0.9%, no evidence of combustible gases, no evidence of methane, and no hydrogen sulfide. A week after sealing the pit, the oxygen level averaged about 15%, the carbon dioxide 2.5%, there were slight traces of combustible gases, and no evidence of methane or hydrogen sulfide.

Other Tests

Samples of the muddy water and reconstituted water samples of the dried mud, both of which were taken from the bottom of the vault at the time of the incident, were studied microscopically about three months after the incident to determine if any microorganisms were present. Live mounts were prepared with and without vital staining and evaluated under the light and phase microscope. Smears were made and stained with the gram stain. Numerous protozoa of various species and other unidentified microorganisms were present, but only rare microorganisms with features of algae species were noted. Many of the protozoa showed motility, varying from slow pseudopodic movements in some to a rapid undulating motion in the flagellated species. The gram stain revealed numerous positively stained, elongated bacilli, some negatively stained short bacilli, and both gram negative and positive cocci in clusters and chains. The almost total absence of algae species is consistent with the findings of the decreased oxygen concentrations and increased carbon dioxide, since algae are simple plants that use carbon dioxide and produce oxygen.

Discussion

A *confined space* is defined as an enclosure with limited openings for ingress and egress, which was the potential for dangerous atmospheric contamination, and which is not intended for continuous occupancy. The types of contamination include, but are not limited to, any combination of oxygen deficiency, explosive or flammable atmospheres, and concentrations of toxic substances. The National Institute for Occupational Safety and Health (NIOSH) classifies confined spaces into three categories [*1*]:

Confined Space Class A refers to a confined space that presents a situation that is immediately dangerous to life or health. The criteria are: the oxygen concentration must be 16% or less; the minimum concentration of a combustible gas or vapor in air which will ignite if an ignition source is present (LFL) must be 20% or greater; or the concentration of toxic substance is immediately dangerous to health or life (IDLH).

Confined Space Class B includes confined spaces that have the potential for causing injury and illness if preventive measures are not used, but which are not immediately dangerous to life and health. The oxygen concentration is in the range of 16.1 to 19.4%; the LFL is 10 to 19%; or the concentration of toxic substance is greater than contamination level (below the IDHL).

Confined Space Class C refers to a confined space in which the potential hazard would not require any special modification of the work procedure. The oxygen concentration is between 19.5 and 21.4%, the LFL is 10%, or the concentration of toxic substances is below the contamination level of the toxic agent.

The danger that lurks in poorly ventilated confined spaces is frequently not realized by the unwary individual. This is particularly true in industry, where workers such as meter readers must enter underground vaults to perform routine duties. The worker may have entered the same vault without incident on numerous occassions and then suddenly dies without any warning.

In this case, the meter had been read up to the prior month without incident. An analysis of the atmosphere in the vault at the outset only revealed a slight decrease in oxygen from the norm outside the vault to about 19% and a slight rise in carbon dioxide. The oxygen value was certainly not low enough and the carbon dioxide level not high enough to cause sudden collapse and death in two otherwise healthy adults. After the vault had been sealed for about one week, the oxygen level at the bottom of the vault was found to be as low as 15% and the carbon dioxide level increased from 0.7 to 2.5%. No discernible methane or hydrogen sulfide was detected. These values may have been depleted even further at the time of accident, although even an oxygen level of 15% and carbon dioxide of 2.5% would render an individual unconscious.

The U.S. Public Safety and Health (USPSH) NIOSH [*1*] indicates that an oxygen concentration of 16% or less is immediately dangerous to life. Moreover, the oxygen values compare with the oxygen values of 14.4% found in the water meter vault in the Melvindale, Michigan incident that took the lives of two Detroit Water Department Inspectors [*2*].

The circumstances in the Michigan case were almost identical; the men were found floating in 1 ft (0.3 m) of water in the water meter vault, just as the men in this case were found. The typical fish mouth frothing, lung findings, and hemorrhage in the mastoid air cells in our two cases suggested a drowning etiology. The depleted oxygen and elevated carbon dioxide obviously induced sudden unconsciousness, and the men subsequently drowned in the 10 in. (25.4 cm) of water.

Regardless of whether the cause of death in this type of case was directly due to the depleted oxygen and increased carbon dioxide or from drowning before succumbing to this atmosphere, the cause of death in both instances would be either directly or indirectly due to the hypoxia. Even if the water level was lower, or if the victims fell onto a ledge following the initial phase of hypoxia, they would soon succumb to the hypoxic environment. The presence of numerous protozoa and the numerous bacteria in the muddy waters containing organic material would account for the decreased oxygen and increased carbon dioxide. Seepage of water runoff (particularly where garbage may be present) contains organic material and organisms. Protozoa and aerobic bacteria utilize the oxygen and give off carbon dioxide and possibly some methane gas during the decomposition process. Fermentation of vegetable materials cause an increase in carbon dioxide with a depletion of oxygen.

We propose the term *Confined Space-Hypoxia Syndrome* (CSHS) to all such confined space deaths occurring in water meter pits, tanks, holds of ships, mines, underground storage bins, and so forth, resulting from oxygen-deficient atmospheres. During the hearings of the Occupational Safety and Health Review Commission [*3*] regarding this mishap, Dr. Y.-M. Rho of the New York Medical Examiner's Office proposed the term Acute Stagnant Air Syndrome [*3*]. He later suggested the term Stagnant Manhole Air Syndrome.[3] Both terms, however, were found to be unsatisfactory because the term *stagnant* refers only to *a lack of flow or motion* and says nothing about the composition of the air.

The air in this case involving the two meter readers was regularly stagnant, but only became oxygen deficient after the vault became wet and contaminated with organic material containing microorganisms. The air was stagnant for a long time before these deaths, yet meter readers regularly entered the vault and read the meter without incident. Oxygen deficiency can also result from the consumption of oxygen by welding, cutting, heating, and brazing activities in confined spaces, from chemical reactions such as the formation of rust

[3]Y.-M. Rho, personal correspondence, 24 March 1980.

on exposed surfaces of confined spaces, from absorption of oxygen by products stored in a tank such as activated charcoal which markedly decreases the oxygen level in a tank, and from displacement by another gas such as nitrogen, helium, and argon. Our proposed term Confined Space-Hypoxia Syndrome or CSHS encompasses all confined spaces with oxygen-deficient atmospheres.

Other types of confined space hazards that should not be included under the CSHS [3,4] are:

(1) flammable atmospheres from enriched oxygen, vaporization of flammable liquids, chemical reactions, combustible dusts, and so forth;

(2) toxic atmospheres arising from stored products as chemicals released from decomposing organic products such as hydrogen sulfide (H_2S), from the accumulation of toxic fumes from welding or brazing of metals in closed spaces such as cadmium, from the buildup of carbon monoxide formed from chemical reactions, work activities, incomplete combustion of organic substances or decomposition of organic matter, and from toxic solvents as halogenated hydrocarbons, paints, paint thinners and cleaning solvents, and

(3) irritant or corrosive atmospheres that contain chlorine, hydrochloric acid, sulfuric acid, nitrogen dioxide ammonia, sulfur dioxide, benzene, carbon tetrachloride, ethylchloride, and so forth.

Recommendations

Much of the information used in developing the following recommendations have been compiled from a number of sources [1-6]. Before any confined space is entered, a qualified person must test the atmosphere to determine if any hazards to life or health are present and to determine what procedures to follow and what type of protective equipment is required to protect the individual or individuals entering the confined space. Although many confined space hazards are not part of the Confined Space-Hypoxia Syndrome, the procedures that must be followed encompasses all confined space hazards, since there may be no way to know which type might be present in the enclosure. *Emphasis, however, is placed on the procedures for handling oxygen-deficient atmospheres.*

1. No entry should be permitted in Class A, Class B, or Class C spaces without a permit which certifies that all hazards have been evaluated, and corrective procedures have been taken to insure the safety of the person or persons entering the space.
2. All personnel must undergo a training course to be made aware of the hazards of confined spaces and to be instructed in emergency entry and exit procedures, use of applicable respirators, first aid procedures, and protective clothing.
3. All personnel that are to enter Class A and B spaces must undergo a physical examination to detect any significant medical problems that would preclude working in confined spaces. The exam must test for visual, audiological, and smelling deficits.
4. Proper safety clothing and safety equipment must be available depending on the circumstances. The usual hard hats, safety goggles, safety boots, and protective clothing should be worn by anyone entering a confined space. A trained person must be present outside and above the confined space and must be in constant communication with the person entering the space. The person must be trained in the use of and must have in readiness safety equipment including safety harnesses, lifelines, self-contained breathing apparatus, first aid supplies, and breathing apparatus in case of an emergency.
5. Before anyone enters a vault or tank, the atmosphere must be tested through a small opening or by lifting the cover just enough to insert a probe to determine the percentage of oxygen, the LFL of any combustible or explosive gases or vapors, and the concentration of hydrogen sulfide, methane, and other toxic substances. If unsafe readings are afforded, then various levels from the top to the bottom of the space should be tested. The instruments used

FIG. 3—*Demonstration of blower-utilized ventilation of confined space.*

in testing must be appropriately calibrated according to the instructions of the manufacturer.

6. No personnel must be permitted to enter the space if the oxygen level is found to be less than 19.5% or greater than 25%, if the atmosphere is above 10% of the LFL, or if the concentration of toxic substances cannot be kept within permissible levels as referenced in authoritative references (NIOSH Registry of Toxic and Chemical Substances, industrial hygiene guides, and so forth).

7. If the oxygen level is less than 19.5%, the confined space must be adequately ventilated, depending on the capacity of the blower used (Fig. 3). The oxygen level must be tested again following ventilation. When a safe level is attained, the space must be continuously ventilated or appropriate audible monitors for oxygen deficiency and combustible gases must be in operation before entry by personnel.

If the confined space contains a flammable atmosphere above the LFL, the space must be purged with inert gases to remove the flammable substance, followed by ventilation with air to decrease the chances of combustion.

Since there is a wide range of toxic substances that can occur in confined spaces, appropriate procedures to purge the space must be utilized depending on the particular substance.

8. If a confined space must be entered when the atmosphere is oxygen deficient in the Class A or B range, or when toxic gases or vapors are present, such as in an emergency situation the person entering the space must wear an appropriate self-contained breathing apparatus, a body harness attached to rescue equipment. There must also be another person stationed on top outside the space with appropriate breathing apparatus and first-aid supplies in readiness.

References

[*1*] "Criteria for a Recommended Standard-Working in Confined Spaces," Report PB80-183015, U.S. National Institute for Occupational Safety and Health, 1979.

[*2*] "Preventing Confined Space Accidents," *Michigan's Occupational Health*, Vol. 22, Michigan Department of Public Health, Aug. 1977, pp. 1-8.

[*3*] *Secretary of Labor v. Spring Valley Water Co., Inc.*, OSHRC Docket 79-3222, U.S. Occupational Safety and Health Review Commission, 3 March 1980.

[*4*] "American National Standard Safety Requirements for Working in Tanks and Other Confined Spaces," Report ANSI Z117.1, American National Standards Institute, Inc., 26 Aug. 1977.

[5] "Safety Gudelines—Confined Space Entry," Report SG 1015-0, Orange and Rockland Utilities, Inc., 30 April 1980.
[6] "Deaths Associated with Liquid-Manure Systems—United States," *CDC Veterinary Public Health Notes*, U.S. Public Health Centers for Disease Control, April 1981, pp. 34-37.

Address requests for reprints or additional information to
Frederick T. Zugibe, M. D.
Chief Medical Examiner
Rockland County Health Center—Bldg. A
Pomona, NY 10970