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Flammable Liquids*



Flammable Liquids and Gases in
MANHOLES, SEWERS

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Fifty Cents

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International

60 Batterymarch St., Boston 10, Mass.

National Fire Protection Association

International

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Flammable Liquids and Gases in Manholes, Sewers

NFPA No. 328M—1962

This revised edition of NFPA No. 328M supersedes the 1956 edition. This report was developed by the Sectional Committee on Maintenance and Repair, approved by the Committee on Flammable Liquids and the Committee on Gases and adopted at the 1962 NFPA Annual Meeting.

Sufficient case histories of fires and explosions in underground structures fully justify a careful review of the material contained within this report. The sources of flammable vapor-air mixtures in these locations, coupled with a study of unsafe practices and protective practices contained herein, certainly will indicate the desirability of utilizing the applicable corrective measures suggested in the summary of this report.

CHANGES IN 1962 EDITION

Only minor changes were necessary in this edition and include a new paragraph on "Fire Damage" and a clarification in the paragraph on "Refrigerant Gases". Other editorial changes include an updating of references.

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Control of Flammable Liquids and Gases in Manholes, Sewers and Similar Underground Structures.

Manholes, sewers and similar underground conduits have long been recognized by fire protection engineers as constituting areas where fire and explosion hazards of some severity may exist. Modern civilization, accompanied by the increase in number of gasoline service stations, solvent disposal operations, dry cleaning establishments, fuel gas production and distribution facilities, refrigeration plants, and many other industrial activities with potentially dangerous gas or vapor by-products makes the safe operation of underground structures more difficult each year.

The probability of an explosion within an underground space is dependent on two factors; one, that the atmosphere contains a mixture of flammable vapor and air within the flammable range, and two, that there be a coincident source of ignition. Explosions occur infrequently because the proper mixture and the source of ignition are not present at the same time. For example, in the City of Los Angeles, which had approximately 140,000 manholes and vaults within the metropolitan, suburban and county areas, routine gas detection surveys made over a fifteen year period prior to 1948 showed a total of over 9,000 vaults and manholes where the presence of flammable vapors was detected. In this period of time approximately 1,000,000 tests were made. The experience report indicated that an average of less than eight explosions occurred annually within the area.

The severity of an individual explosion and its consequences are dependent on various factors. There is always present the possibility that any one explosion may result in a major catastrophe.

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This report is limited to a study of the flammable liquids and gases found in manholes, sewers, vaults and similar underground structures. The underground structures include: Sanitary sewers, storm drains, water lines, fuel gas distribution systems, electric light and power conduits, telephone and telegraph communication lines, street lighting conduits, police and fire signal systems, traffic signal lines, refrigeration service lines, steam lines, and petroleum pipelines.

The term "underground structures" is not intended to include subways, tunnels and the substructural areas of buildings such as underground garages.

The purpose of this report is to give to enforcement officials, fire authorities, contractors and owners of underground structures guidance on problems involving flammable liquids and gases which may be found in underground structures.

THE PROBLEM.

With greater congestion today, the present trend in civic planning is directed toward the installation of all types of utility services beneath the street surface. This results in a continuous program of excavation and construction, with frequent damage to existing structures.

Sources of Ignition.

The possibility of flammable gases or vapors which may collect in underground areas being ignited is limited by certain fundamental conditions. The vapor must be mixed with sufficient air to make a flammable mixture, or it must be escaping into air at a point where a flammable mixture can be created. Heat of sufficient intensity to ignite the particular air-vapor mixture involved must be present at the place where a flammable mixture exists. Such heat may be caused by an open flame, an electric arc or spark, an incandescent heated particle, or a sufficiently heated hot surface.

The flammable limits of the gases and vapors which have been found in underground structures are listed in Appendix A. Flammable mixtures are formed when the concentration of these gases in air is between the minimum and maximum shown.

Flame: Any open flame is a potential source of ignition. These may be encountered in everyday work operations. Little control can be exerted over the casual sources of ignition when flammable vapors are escaping from or into underground structures. Such casual sources of ignition include burners and warn-

ing lanterns used by street surface maintenance crews, automobile exhausts, tar pots and pedestrian smokers.

Arcs: The heat of an electric arc occurring in electric underground structures may cause the distillation of insulating material producing flammable gases which in turn may be ignited by the arc itself when the proper air gas ratio is reached. This usually will occur when the arc reaches a manhole or vault after having started in a duct. Other gases or flammable vapors, if present, may also be ignited by such an arc.

Static: Static electricity may be a source of ignition and its generation is generally greatest in an atmosphere of low humidity. The hazard appears when static accumulates to the extent that a spark discharge may occur. Static electricity may be generated when a liquid or gas under pressure escapes from a pipe at high velocity into an atmosphere of low humidity. Particles of dust, scale, and rust inside the pipe may become heavily charged with static and, if they impinge on an insulated body, the body will accumulate the charge and a spark discharge may occur.

Sources of Flammable Liquids and Gases.

The contributory causes responsible for the presence of flammable liquids and gases in underground structures are not generally appreciated. Investigations over a period of years on reported cases of flammable vapors detected in sewers, drains, drainage canals and telephone and electric power vaults have disclosed a diversity of products within the structures. The condition created by the existence of these gases and vapors can be grouped into two classes: (1) flammable and (2) injurious to life. The latter condition results from the toxic, asphyxiating or suffocating properties of the gases or vapors. Some of these liquids and gases fall into more than one class. However, this study will be limited to those liquids and gases that are of a flammable nature (see Appendix A). The release of piped oxygen, which may be present in underground structures, will accelerate the combustion of any flammable vapor.

Natural Gas: Natural gas means gas which originated from naturally occurring gas or oil-bearing strata. In oil and natural gas producing areas, cracks and faults in the underlying strata or abandoned wells may permit gas to permeate the soil and enter underground conduits and vaults. Within the boundaries of some cities there are actively producing oil and gas fields and many of these underlie developed areas, residential and industrial, where underground structures are now installed.

Fuel Gas: Fuel gases include natural gas, liquefied petroleum gases, coke-oven gas, coal gas, oil gas, carbureted water gas, water gas, producer gas and blast-furnace gas. These gases, except liquefied petroleum gases, have specific gravities lower than that of air so that when released in an underground space they will tend to rise and diffuse rather rapidly above the point of leakage. These gases when mixed with air within certain limits produce flammable mixtures. Since the oxygen content of each of these gases when not mixed with air, is usually below 1.0 per cent, they may be classed as suffocating gases. With the exception of natural gas and liquefied petroleum gas, they are also highly toxic because of the high carbon monoxide content. Natural gas and other fuel gases as distributed by utility companies in underground pipes are an extensive source of potentially flammable gas. These pipes may be subject to damage caused by corrosion, electrolysis, structural failures and adjacent excavating. These causes are discussed in greater detail in later paragraphs of this section.

Refrigerant Gases: A number of the common refrigerants have varying degrees of flammability, for example, ammonia, methyl chloride, ethyl chloride, methyl bromide and ethyl bromide. With the exception of ammonia, all of these refrigerants in the vapor phase are heavier than air. Therefore, if they are released in large quantities in closed spaces, these heavy gases will flow downward into the lowest areas. Of these, only ammonia has a sufficiently strong odor in dilute concentrations to indicate its presence. Exposure to ammonia fumes may cause severe ammonia burns even at concentrations below the flammable limits. Liquid ammonia is often distributed through underground street pipes for refrigeration service in the business districts of many large cities. This system of pipes may be subject to the same exposure to physical damage as fuel gas pipes and petroleum pipelines.

Electric Cable and Other Insulating Material Gases: This source of flammable gas is practically limited to severely overloaded electric underground circuits. A breakdown of cable insulation will produce an electric arc. If the protective fuses do not operate promptly, this electric arc will continue. The heat of the arc may, by destructive distillation of cable insulation, (varnished cambric, rubber or paper), produce flammable gases containing hydrogen, carbon monoxide and hydrocarbons.

Chemical Products: Accidental spillage in chemical processing plants and disposal of waste chemical products through sewers by industrial plants may be potential sources or contributing causes for explosive conditions. Examples of such products are carbon

tures have been consulted. A model code, NFPA No. 495 may be found in Volume II, National Fire Protection Association's National Fire Codes or in Article 11 of the National Board of Fire Underwriters' Fire Prevention Code.

Administrative bodies of cities should require anyone razing buildings to obtain a permit. The permit should not be granted until the owners of underground structures in the area have been consulted.

Administrative bodies of cities should prohibit the encasement of pipes containing flammable products within the constructed walls of new structures. This recommendation does not apply to piping entering buildings.

Administrative bodies of cities should establish a procedure for connecting direct current electrical equipment to ground on the premises of the user. This is to prevent the inclusion, directly or indirectly, of underground pipes carrying flammable products in the return electric circuit.

Administrative bodies of cities can promote cooperative efforts on the part of all organizations having underground facilities to reduce corrosion.

Sewers and drains should be designed to insure proper cleansing velocities, proper ventilation, to prevent infiltration and to avoid the settling of heavy solids. Sewers and drains should be designed to minimize the danger of settlement and failure which in turn might break other adjacent underground structures.

Where ventilation of a vault or manhole is necessary, and mechanical ventilation cannot be provided, the manhole or vault should be designed (depending upon local conditions) so that effective natural ventilation for vapors or gases lighter than air can be obtained. Manholes for sewers should be regularly spaced to provide effective ventilation and explosion relief.

Every effort should be made to establish standard practice for the design, construction and maintenance of all underground structures with respect to the elimination of explosive hazards and the contributory causes.

Close liaison can be established between the fire chief and industrial safety officials. Between these individuals mutually approved procedures should be developed to cope with emergencies so that the firemen can act more effectively in their line of duty.

APPENDIX A.

PROPERTIES OF FLAMMABLE LIQUIDS AND GASES WHICH
HAVE BEEN FOUND IN UNDERGROUND STRUCTURES.

	Flash Point Closed Cup Deg. F	Flammable Limits in Air % by Vol.		Specific Gravity of Liquid (Water=1)	Specific Gravity of Vapor (Air=1)
		Lower	Upper		
Acetone	0	2.6	12.8	0.79	2.00
Acetylene	Gas	2.5	81.0	....	0.90
Ammonia	Gas	16.0	25.0	....	0.58
Benzene	12	1.4	7.1	0.88	2.77
Blast-furnace Gas*	Gas	35.0	74.0	....	1.01
Butadiene	Gas	2.0	11.5	....	1.87
Butane	-76	1.9	8.5	0.60	2.01
Carbon Disulphide	-22	1.3	44.0	1.30	2.64
Carbon Monoxide	Gas	12.5	74.0	....	0.97
Coke-oven Gas*	Gas	4.4	34.0	....	0.38
Ethane	Gas	3.0	12.5	....	1.04
Ethyl Chloride	-58	3.8	15.4	0.91	2.22
Gas Oil*	150	6.0	13.5	1.31	....
Gasoline (Values may vary for different grades of gasoline)	-45	1.4	7.6	0.75	3.-4.0
Hydrogen	Gas	4.0	75.0	....	0.07
Hydrogen Sulfide	Gas	4.3	45.0	....	1.18
Kerosene	100-165	0.7	5.0	1.0	....
Methane	Gas	5.3	14.0	....	0.55
Methyl Bromide	Gas	10.0	15.4	....	3.27
Methyl Chloride	Gas	10.7	17.4	....	1.78
Natural Gas*	Gas	3.8	13.0	....	0.65
Petroleum Naphtha*	20	0.9	6.0	0.75	3.75
Producer Gas*	Gas	20.0	80.0	....	0.86
Propane	Gas	2.2	9.5	....	1.56
Toluene	40	1.4	6.7	0.87	3.14
Water Gas*	Gas	7.0	72.0	....	0.68

*These flammable liquids and gases are mixtures and their properties may vary depending on the composition.

APPENDIX B.**Analysis of Causes of Explosions.**

A review of a number of explosions in underground structures is of considerable interest and is indicative of the seriousness of the hazards involved.

Inadequate Sewer Design — Andover, Ohio — August 10, 1955.

An explosion and fire in a combined restaurant and dairy store in this small farming community resulted in the loss of four buildings. The area had been subjected to a heavy rain and severe thunderstorm of about one hour's duration immediately preceding the explosion. The streets were flooded since the sewers had been unable to handle all the surface water. **The storm abated about 10 minutes before the explosion.** Conflicting eye-witness reports indicated that the restaurant-dairy was hit by lightning or collapsed as the result of an internal explosion and after initial explosion dense black smoke appeared from the kitchen area.

A complete survey of sewers, manholes, basements and gas lines by a utility company failed to indicate the presence of natural gas with a combustible gas indicator. Pressure testing of the salvaged gas service piping and meter failed to show evidence they were at fault. Finally, it was reasoned that since the storm and sanitary sewers in the area might be connected in some locations, and since many of the sanitary sewer manholes were sealed from road resurfacing operations, that flammable vapors from sources unknown had been trapped in the sanitary sewer lines.

Leakage in Distribution Piping Systems — Goldsboro, N. C. — April 12, 1954.

An explosion and fire in the business district was followed by a series of secondary lesser explosions at about 5-minute intervals in a nearby street sewer. Gas had entered one building through an abandoned gas pipe protruding into the basement and fire broke out within two or three minutes and burned for about two hours before it was extinguished.

A U. S. Bureau of Mines analysis showed that the gas at the explosion site was of the same composition as that distributed by the utility and consisted of a propane air mixture. It was also revealed that the community during the previous months had experienced three other explosions causing little damage. A survey in 1951 indicated that the utility sustained a loss as high as 38 per cent of the total gas fed into the system and at the time of the explosion the leakage had been reduced to 25 per cent. As a result of the fire the utility abandoned the underground system and converted all service to individual bottled gas units.

If the utility had followed up its "loss and unaccounted for gas" program by definite action and abandoned its services this explosion perhaps could have been avoided.

Leakage of Flammable Liquids or Gases Into Sewers — Cleveland, Ohio — September 11, 1953.

A tremendous underground explosion in a combination storm and sanitary sewer demolished 1.2 miles of pavement on West 117th Street killing one person and hospitalizing fifty-eight others. The blast threw manhole covers high into the air and broke out large chunks of concrete pavement some 20 feet by 10 feet in area. Gas mains and water lines were ruptured. A second blast occurred an hour later hurling more manhole covers into the air, but no one was hurt. At least 30 automobiles were heavily damaged or demolished in the blast. The catastrophe was thought to be due to the ignition of some flammable liquid or natural gas from local underground sources in the six-foot sewer line that ran beneath this street.

Improper Installation of New Underground LP-Gas Tank — Mattoon, Illinois — January 27, 1952.

A series of fires and explosions caused by the ignition of liquefied petroleum gas that had leaked from a buried 500-gallon tank caused damage of varying degrees to 18 buildings in a two-block mercantile area. The fire first occurred at the ground above the tank. The backs of several buildings within two blocks of the fire and all backing up to the same alley burst into flame a few minutes later and explosions occurred in others. Because of the fortunate time of occurrence, a Sunday, the stores were closed and there were no fatalities.

Later when the storage tank was dug up, a $\frac{3}{4}$ -inch threaded opening not equipped with a plug was found in the bottom of the tank through which liquefied petroleum gas had escaped into the surrounding earth. Gas is believed to have entered a storm sewer, telephone conduit tunnel and an abandoned central steam heating tunnel extending through the alley and to have spread by means of these ducts to the various buildings along the alley.

The lack of a plug on the underground tank indicates negligence on the part of the installer.

Gas Accumulation in a Confined Space — Brighton, New York — September 21, 1951.

Fires and explosions resulted in the loss of nineteen homes and serious damage to twenty-five additional buildings. The initial explosion, resulting from an accumulation of gas, took place in a regulator vault of the gas distribution system. The regulators, damaged by the force of the explosion,

opened wide and allowed high pressure gas to pass into a system designed to operate at a low pressure. This overloading resulted in numerous gas leaks within buildings which caused a series of explosions and fires in the affected area. The exact cause of the initial explosion within the regulator vault was never fully determined.

The problem of gas accumulations is one that is not always easy to overcome. Also adequate inspection of vaults should be maintained.

Gas Leakage into Sewer — Jefferson, Pa. — February 9, 1951.

This village located in one of the oldest natural gas fields in the United States was rocked by a series of explosions which wrecked six homes. The cause of the explosions was ignition of natural gas that had entered the various buildings through storm sewer connections. The source of the gas was a break in a wrinkle bend on a 16-inch gas line where it passed under a 24-inch terra cotta storm sewer. Directly over the break a 10-inch steel lateral sewer pipe had been cut into the storm sewer providing an easy opening for the gas to enter the storm sewer system. The fact that the earth was frozen several inches deep prevented gas from escaping readily through the ground.

Flammable Liquids in Sewers — Nitro, West Virginia — March 1, 1949.

An explosion and fire resulted from the ignition of flammable vapors at the rayon manufacturing plant of the American Viscose Corp. These vapors originated from waste flammable liquids in a 78-inch diameter sewer. As a result of the explosion 500 feet of the sewer collapsed and water from the sewer backed into the building and flooded 22 motors.

Gas Leakage into Various Underground Structures — Cleveland, Ohio — October 20, 1944.

The explosion and fire involved natural gas stored in insulated gas holders at less than 5 psi pressure and at -250 degrees F. The cylindrical tank of 150,000 cubic feet capacity failed releasing its liquefied contents into an industrial area. Ignition was almost immediate and flames soon caused an adjacent spherical tank of 100,000 cubic feet capacity to fail also. Burning liquefied natural gas flowed over the plant area and to adjacent properties. Gas accumulations in various sewers, underground electrical conduits, well-holes, basements and other depressions exploded repeatedly blowing manhole covers into the air, raising pavements, rupturing water mains and sewers and blowing out hundreds of windows. An industrial and residential area of 29 acres was completely consumed.

In regard to the underground part of this problem, substantial dikes would have been effective in preventing leakage into the underground structure.