NFPA No.
# 328M

*File: 30 Series*
*Flammable Liquids*



## Flammable Liquids and Gases in

# MANHOLES, SEWERS

June

**1956**

Twenty-five Cents*



NATIONAL FIRE PROTECTION ASSOCIATION
International
60 Batterymarch St., Boston 10, Mass.

5M-6-56 R. S.

*Discount for quantities

Printed in U.S.A.

# National Fire Protection Association

INTERNATIONAL

Executive Office: 60 Batterymarch St., Boston 10, Mass.

The National Fire Protection Association was organized in 1896 to promote the science and improve the methods of fire protection and prevention, to obtain and circulate information on these subjects and to secure the cooperation of its members in establishing proper safeguards against loss of life and property by fire. Its membership includes nearly two hundred national and regional societies and associations (list on outside back cover) and more than sixteen thousand individuals, corporations and organizations. Anyone interested may become a member; membership information is available on request.

This pamphlet is one of a large number of publications on fire safety issued by the Association including periodicals, books, posters and other publications; a complete list is available without charge on request. All NFPA standards adopted by the Association are published in six volumes of the **National Fire Codes** which are re-issued annually and which are available on an annual subscription basis. The standards, prepared by the technical committees of the National Fire Protection Association and adopted in the annual meetings of the Association, are intended to prescribe reasonable measures for minimizing losses of life and property by fire. All interests concerned have opportunity through the Association to participate in the development of the standards and to secure impartial consideration of matters affecting them.

NFPA standards are purely advisory as far as the Association is concerned, but are widely used by law enforcing authorities in addition to their general use as guides to fire safety.

## Definitions

The official NFPA definitions of shall, should and approved are:

SHALL is intended to indicate requirements.

SHOULD is intended to indicate recommendations, or that which is advised but not required.

APPROVED refers to approval by the authority having jurisdiction.

Units of measurements used here are U. S. standard. 1 U. S. gallon = 0.83 Imperial gallons = 3.785 liters.

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# Flammable Liquids and Gases in Manholes, Sewers

(NFPA No. 328M—1956)

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 accepted by the National Fire Protection Association on June 6, 1956. At one step of its development there was a joint sub-committee of the two NFPA Committees which met to assure joint thinking on a difficult problem.

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.

The material in this informative report should prove most useful to the many industries confronted with this problem as well as to various governmental agencies.

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*Serving in a personal capacity. †Not a voting member.

# 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 warning 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 are flammable, 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 disulphide and ammonia. Calcium carbide will react with water to produce acetylene which is flammable.

Sewage Gases in Sewers and Drains: Sewage gas results from the fermentation or decomposition of organic matter. These gases can be produced when organic matter has settled as a solid in sewer lines caused by flat grades, crevices, sumps or obstructions where consistent flow of sewage is lacking, or as the result of bacterial action on wood or other organic material immersed in water. These flammable gases are principally methane, hydrogen sulfide and hydrogen and, on the basis of present evidence, they seldom reach explosive concentrations in sewers and drains. However, when they are mixed with other flammable liquids and gases present in sewers, explosive conditions may occur.

Flammable Liquids: Flammable cleaning solvents and compounds washed down drains by industrial and domestic users may be the media from which flammable vapors originate. Hydrocarbon liquids such as gasoline and kerosene in industrial plants, service station and garage wash racks are often sent to sewers and drains either accidentally or because there is no easier method of disposal. Any leaking underground tank containing flammable liquids such as a service station's underground gasoline tanks, may be a source of flammable vapors in underground structures.

Petroleum Pipeline Products: Liquid petroleum products beneath public streets and rights-of-way. These pipelines may be and liquefied petroleum gases, are conveyed by pipelines installed exposed to the same sources of physical damage as fuel gas pipes and these sources of damage are discussed in detail later. If any of these pipelines should fail, the escaping liquids and gases may penetrate substructure walls or rise to the street surface. Liquids may be washed into drains or enter the ventilating openings in the manhole covers of underground structures. Escaping liquid petroleum products may evaporate in the ground, penetrate the surrounding ground, or may enter a confined space to produce a flammable mixture.

Penetration of Structures by Gases: Flammable gas products present in the subsoil enter conduits, sewers, drains or basements because underground structures constructed of cement, concrete, brick or vitreous tile generally are not built to be impervious to gas. If a flammable gas or liquid is present in the soil, there is some likelihood that it may penetrate an adjacent underground structure. Gas may frequently enter the subsurface sections of buildings through or around any underground conduits that penetrate the substructure walls, and through abandoned gas lines that have not been capped or sealed. The distance that gas can move through manmade underground structures, while theoretically unlimited, has in practice been found to be limited but unpredictable.

Electric Circuit Oil Switches and Oil Insulated Transformers: This equipment is frequently installed in a street vault and electrical failures will occasionally result in an explosion. The action of protective devices in shutting off current is usually very fast, being of the order of two seconds or less. This has the effect of limiting the explosion, if one does occur, to the vault in which the failure occurs. However, when the vault is adjacent to or within a large structure, such an explosion may result in heavy damage.

**Damage to Underground Lines.**

Corrosion: One type of corrosion which occurs in gas lines and petroleum pipelines is where the soil composition and resistance is such that electric current from the development of local action cells can flow readily from anodic areas on the pipe surface through the soil to the cathodic areas on the same pipe. Such soil conditions may be due to acid or alkali content, organic matter, variations of water or oxygen content, soil type, or the presence of certain bacteria in the soil. Corrosion may also occur as a result of chemical reaction between the pipe and surrounding soil. Electrolysis is another cause of corrosion in utility gas pipe and petroleum pipelines. Stray direct-current electric currents originate from two sources: 1. Direct-current electric railways and trolley lines using rails to carry return currents. 2. Industrial plant direct current machinery using the ground as a return conductor. Underground pipes may pick up stray currents from cross connections with other structures carrying current. These currents may not be destructive where they enter the piping system. However, drainage of these stray currents to the ground may cause corrosion at these points of discharge. Current drainage from these underground lines is controlled as effectively as possible by installation of drainage bonds and reverse-current switches, but the effect of these bonds and switches is mitigated by changes in railway traffic, alterations in underground structures, and damage to rail or drainage bonds. Under such situations the electric current may discharge from pipelines to ground, and if not detected and corrected, the pipe wall may be eventually penetrated.

Structural Failures: The allocation of insufficient space for the installation of underground structures may, in some situations, result in the encasing of gas and flammable liquid pipes in the walls of ducts and subsequently constructed masonry vaults. Such pipes from vaults under certain conditions may be fractured. Flood washouts, earthquakes and landslides may cause the dislocation and movement of ground and are often responsible for pipe fractures. Rupture of water mains due to corrosion, electrolysis or structural failure may in turn cause washout of soil that supports gas and flammable liquid pipes. Lacking support, these pipes may fracture.

Excavating: Contractors doing excavation work often encounter gas and flammable liquid pipes, and even though aware of their presence, workmen may unintentionally damage the pipe resulting either immediately or ultimately in a leak. Damage such as this is not always reported and often repairs are attempted by the party responsible for the physical damage which later may prove to be inadequate.

### Unsafe Practices.

Before washing spilled petroleum products from street surfaces into drains or sewers, which may be a potentially dangerous action and often is an unlawful practice, other disposal means should be considered such as mopping up with sand, rags or mops. If, in an emergency, no alternative is available, disposal into a drain or sewer should be done only on the decision of a qualified person, after the Chief of the Fire Department has been notified.

Disastrous consequences may result from the thoughtless or deliberate dumping into drains of waste products which are either directly flammable or which by reaction with organic matter in sewers may produce a flammable mixture. Though the presence of a flammable material may be detected, its source often is difficult to determine.

## PROTECTIVE PRACTICES.

The adoption of protective measures which will detect the presence of flammable products in manholes and vaults, and provide the means to prevent the accumulations of gas within the explosive range, should reduce the incidence of explosions in underground structures. Such a defensive procedure is necessary because of the difficulty of eliminating the flammable material at its source.

Numerous sources of ignition may be found in underground structures. The operators of underground structures by eliminating the use of flames in suspected areas may materially reduce the number of ignitions. Experience has shown, though, that fire and explosion incidence can best be reduced by the elimination of flammable vapors from the atmosphere of the underground structure. It is all but impossible to remove all ignition sources.

Considering the diversity of contributory causes for flammable products in underground structures, protective practices should be designed to reduce to a minimum the quantity of flammable vapors. Where such vapors are found to be present, a complete purge of the manhole or vault atmosphere should be made and the source of the flammable vapors eliminated. Manholes and vaults should be ventilated by forced draft when necessary to prevent concentrations of these vapors within the explosive range. After complete ventilation of the underground structure, the atmosphere should be tested with a combustible gas indicator before entering and before any hot work is performed. A positive reading on the combustible gas indicator does not necessarily mean that the toxicity hazard has been eliminated. Adequate ventilation should be maintained and periodic gas analysis of the atmosphere during any such work should be made.

There are a number of instruments that can be used to detect unsafe atmospheres found in underground structures. They should be used to determine the characteristics of any questionable situation.

Oxygen: A safe practical method of testing an atmosphere for oxygen deficiency is by means of the flame safety lamp, or the oxygen deficiency indicator which is an adaptation of the flame safety lamp. Conventional flame safety lamps should never be used to test an atmosphere which is suspected of containing hydrogen or acetylene. Similarly the oxygen deficiency indicator should be used only in safe atmospheres. The flame of the lamp is extinguished when the oxygen content of the atmosphere is less than approximately 16 per cent. Such an atmosphere is considered hazardous to human life. There are other instruments that give a direct reading of oxygen deficiency or excess. One dependable instrument of this type operates on the basis of the paramagnetic quality of oxygen.

Carbon Monoxide: This gas in concentrations greater than 0.10 per cent by volume results in unconsciousness in little more than an hour and death in four hours. Further increases in concentration reduce this time element. Its effect is to displace oxygen in the blood stream. Several instruments have been developed for the quick detection of carbon monoxide. Those capable of detecting the smallest concentrations considered hazardous are the carbon monoxide tester (palladium-molybate complex) and the carbon monoxide indicator.

Hydrogen Sulfide: This flammable and toxic gas is colorless and has an odor resembling rotten eggs. It is toxic in concentrations in excess of 0.002 per cent by volume. Continued exposure will paralyze the olfactory nerves. The hydrogen sulfide detector will detect the low toxic concentrations of this gas.

Fuel Gases and Vapors from Flammable Liquids: Combustible gas indicators are available in a number of different types to meet the requirements of the specific use to which they may be applied. The three most common types are (a) an "All Purpose" instrument suitable only for the detection of flammable gases such as natural gas, manufactured gas, hydrogen and acetylene and all vapor air mixtures associated with fuel oils, gasoline including leaded gasoline, alcohols and acetones. This instrument indicates the presence of these gases and vapors only. (b) A specific instrument is available for use on the specific gas or vapor-air mixture for which it is calibrated, such as natural gas, manufactured gas, hydrogen or acetylene. Such an instrument is usually calibrated in the range of zero to slightly above the lower explosive limit of the specific gas or vapor. This instrument is not an all purpose instrument and is designed for use only on the gas or vapor on which it is calibrated. (c) A specific instrument is utilized principally by gas utilities for use in pinpointing leaks in underground mains and services. This instrument must be calibrated on the specific gas being sampled, i.e., natural or manufactured gas and has a scale range of zero to 100 per cent gas. A portable combustible gas indicator is also available for operation in explosive atmospheres.

Periodic surveys with instruments should be made of the atmosphere of all water, gas and electric underground structures for the presence of flammable vapors. The frequency of such surveys will depend upon the previous experience and the potential hazard.

Liquefied petroleum gases and utility gases are odorized to facilitate detection unless the gas possesses a distinctive odor to the extent that its presence is readily detectable or where the odorant would serve no useful purpose as a warning agent. Utility gases should be odorized in accordance with Paragraph 861 of Section 8 of the ASA B31.1 Code for Pressure Piping and Liquefied Petroleum Gases in accordance with Section B.1 of NFPA Standards on Liquefied Petroleum Gases, No. 58. Experience has shown that odorants can be absorbed in traveling through the soil.

Volatile flammable liquids may have accidentally entered a drainage system because of a spill or other emergency. Steps should be taken to minimize the hazard by exhausting the vapors with blowers or exhaust fans driven by explosionproof motors and by pumping out the liquid with pumps equipped with explosionproof motors. Floor drain openings into buildings in the area of the spill and for some distance downstream should be checked for escape of vapors. Water should be placed in any dry traps to seal them. Copious quantities of water should be used to flush any flammable liquid through the system quickly and to dilute it, if miscible with water.

Prior to laying a pipeline, a suspected electrolysis area should be examined rather than to explore for leakage after piping has been damaged. Where electrolysis or corrosive soil conditions are known, owners of pipelines that carry flammable products through such soil should take measures to arrest electrolysis or corrosion. Protective measures against corrosion should be taken in cooperation with other owners of nearby underground structures which would be adversely affected by unilateral action. If damage is suspected, surveys may be made; by testing all available underground structure street openings with combustible gas indicators, by noting the condition of vegetation, by pressure drop tests, by soapsuds testing on exposed pipe and fittings and by bar test surveys. The bar test survey requires extra care to prevent damage to underground structures.

Service stations with underground tanks of gasoline, may be a source of leakage of flammable liquids. When a service station tank is found to be leaking, its contents should be removed immediately. When such a tank is taken out of service, abandoned or removed, the procedures described in NFPA No. 30-F, Abandonment or Removal of Underground Tanks, should be followed.

The functional purpose of underground structures as well as the design require different procedures for the elimination of flammable gases, though the means of detection are similar. Where flammable products may have originated within the structure, as in sanitary sewers or electric vaults, the elimination of the cause is a distinctly different problem, than if the flammable product entered the structure from the outside.

Sewers and drains should be periodically flushed and cleaned to prevent deposits of organic material and slime growth. Periodic inspections should be made of industrial plants to prevent the discharge into sewers of waste that might produce explosive gases due to physical or chemical impurities, high temperatures, alkalinities or acidities.

Periodic checks should be made of protective equipment in underground electric systems. Efforts should be made to prevent the overloading of cables and to avoid arcing conditions that may be causing the source of flammable gas by the breakdown of insulation. Fusing and arcing should be prevented, too, because it furnishes a source of ignition. The efficiency of all rail bonds on tracks of electrified railway systems should be checked to insure that the potential gradient of the rail system is at a minimum.

## SUMMARY.

A review of all the factors relating to the problem of explosive hazards in underground structures, together with an analysis of causes of explosions, indicates that flammable material may at some time be present during the life of an underground structure.

Control procedures and education are the proper approaches to the problem. Effective control cannot be maintained unless the various utilities involved, the administrative bodies of cities and others cooperate in an adequate safety program.

Utility companies should adopt a definite program to minimize the amount of lost and unaccounted for gas. It should be recognized that only part of "the lost and unaccounted for gas" is due to pipeline leakage.

Utility companies should maintain an adequate inspection program for the detection of leaks at street openings. This can best be accomplished by the use of combustible gas indicators, vegetation surveys, and other methods. Periodic inspection and testing of key equipment should be conducted with reasonable frequency as a part of regular maintenance operations. Such a distribution piping maintenance program could be carried out in accordance with the requirements of Paragraph 852 of Section 8 of the ASA B31.1 Code for Pressure Piping.

Inactive gas services and mains should be abandoned in accordance with the applicable parts of Paragraph 852 of Section 8 of the ASA B31.1 Code for Pressure Piping.

Automatic or manually operated drains in industrial piping should be designed so as not to discharge their product into underground structures.

Owners and operators of underground pipelines carrying flammable liquids should maintain an adequate inspection program for the detection of escaping flammable liquids.

The Recommended Good Practices for Bulk Liquid Loss Control in Service Stations published by the American Petroleum Institute will be of value to operators of service stations.

An in-service training program for all employees whose occupation is associated with underground structures will teach them to recognize the presence of fire and toxic hazards, and oxygen deficiencies and teach them how to take proper precautions against such possibilities.

Administrative bodies of some cities have established a program to control or prevent the discharge into sewers and drains of all products likely to result in flammable atmospheres in vaults and manholes.

Administrative bodies of cities should adopt an ordinance which would require a contractor before starting construction or excavation work (1) to obtain a permit, (2) to notify the owner of adjacent underground structures in writing of his intention to start work, and (3) to obtain from the owner the exact information on the location of the underground structures and pipes containing flammable products. All agencies having underground structures should be prepared to furnish contractors with exact information on the location of such underground structures. This permit should prohibit the contractor from interference with the above mentioned pipes without giving prior notice to the owner or operator.

All agencies having underground structures should be prepared to furnish contractors with the record of the locations of such adjacent structures or furnish a man who knows the location of these pipes. In the event the exact location of any underground structure is not known, the contractor should make a physical inspection of the entire right-of-way of the proposed trench by employing underground detecting devices and visual inspection of adjacent structures.

Apart from direct damage to piping, contractors should take extra precautions to avoid damage to corrosion protecting coatings, anodes, electrodes, bonding facilities and related devices. If these are disturbed or damaged, the owner of the structures should be notified before backfilling the excavation. Care should be taken in all excavations in which wire or metal is found, even though these are not immediately adjacent to a pipeline. They may be part of the protective system.

Administrative bodies of cities should require anyone conducting blasting operations to obtain a permit. The permit should not be granted until the owners of adjacent underground structures have been consulted. A model ordinance, NFPA No. 495-L 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. Lower | Upper | Specific Gravity of Liquid (Water=1) | Specific Gravity of Vapor (Air=1) |
|---|---|---|---|---|---|
| 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 | 0.62 | 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 | 13.5 | 14.5 | 1.73 | 3.27 |
| Methyl Chloride | Gas | 10.7 | 17.4 | 0.92 | 1.78 |
| Natural Gas* | Gas | 4.5 | 14.5 | .... | 0.65 |
| Petroleum Naphtha* | 20 | 0.9 | 6.0 | 0.75 | 3.75 |
| Producer Gas* | Gas | 14.1 | 95.6 | .... | 0.86 |
| Propane | Gas | 2.2 | 9.5 | .... | 1.56 |
| Toluene | 40 | 1.4 | 6.7 | 0.87 | 3.14 |
| Water Gas*(Carbureted) | Gas | 5.5 | 46.2 | .... | 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 eyewitness 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.