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FLAMMABLE, COMBUSTIBLE LIQUIDS & GASES IN

MANHOLES, SEWERS, AND SIMILAR UNDERGROUND STRUCTURES

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Recommended Practice for the Control of

Flammable and Combustible Liquids and Gases in Manholes, Sewers, and Similar Underground Structures

NFPA 328-1982

1982 Edition of NFPA 328

This edition of NFPA 328, *Recommended Practice for the Control of Flammable and Combustible Liquids and Gases in Manholes, Sewers, and Similar Underground Structures*, was prepared by the Technical Committee on Tank Leakage and Repair Safeguards, released by the Correlating Committee on Flammable Liquids, and acted on by the National Fire Protection Association, Inc. on November 17, at its Fall Meeting in Toronto, Ontario, Canada. It was issued by the Standards Council on December 9, 1981 with an effective date of December 29, 1981 and supersedes all previous editions.

Changes other than editorial are indicated by a vertical rule in the margin of the page on which they appear. These lines are intended as an aid to the user in identifying changes from the previous edition.

Origin and Development of NFPA 328

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. This recommended practice was first adopted in 1956 and subsequent editions were published in 1964, 1970, and 1975.

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Recommended Practice for the Control of

Flammable and Combustible Liquids and Gases in Manholes, Sewers, and Similar Underground Structures

Foreword

Manholes, sewers and similar underground conduits have long been recognized as constituting areas where fire and explosion hazards of some severity may exist. The probability of an explosion within an underground space is dependent on two factors: (1) that the atmosphere contains a mixture of flammable vapor and air within the flammable range, and (2), that there be a coincident source of ignition. The severity of an individual explosion and its consequences are dependent on various factors. The possibility that any one explosion may result in a major catastrophe is always present.

This publication is limited to the control of hazards presented by flammable and combustible 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 publication is to give to enforcement officials, fire authorities, contractors and owners of underground structures guidance on problems involving flammable and combustible liquids and gases which may be found in underground structures.

Chapter 1 The Problem

1-1 General. With increasing congestion, and for aesthetic considerations, the trend in civic planning is 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.

1-2 Sources of Ignition.

1-2.1 The possibility of ignition of flammable gases or vapors which may collect in underground areas 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.

1-2.2 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.

1-2.3 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, automotive and other internal combustion engines, tar pots and pedestrian smokers.

1-2.4 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.

1-2.5 Static electricity may be a source of ignition and its accumulation 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 under pressure escapes from a pipe at high velocity. Particles of dust, scale, rust, or liquid droplets inside the pipe may become heavily charged with static when blown out by gas or vapor and, if they impinge on an insulated body, the body will accumulate the charge and a spark discharge may occur.

1-3 Sources of Flammable and Combustible Liquids and Gases.

1-3.1 The condition created by the existence of gases and vapors in underground structures can be grouped into two classes: (1) flammable and (2) injurious to life. The latter condition results from the toxic or suffocating properties of the gases or vapors. Some of these liquids and gases fall into both classes. While this publication deals primarily with the flammable limits associated with liquids and gases, some of which are listed in Appendix A, additional precautions may be required to protect against health hazards. An example is hydrogen sulfide, where the dangerous breathing concentration is only a small fraction of the lower flammable limit (LFL).

1-3.2 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.

1-3.3 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 relased 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 percent, 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 also a source of 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.

1-3.4 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.

1-3.5 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.

1-3.6 Chemicals. 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 disulfide and ammonia. Calcium carbide will react with water to produce acetylene which is flammable.

1-3.7 Sewage Gases. 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.

1-3.8 Flammable and Combustible Liquids. 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 occasionally sent to sewers and drains either accidentally or through negligence. Any leaking underground tank containing liquids, such as a service station's underground gasoline tanks, may be a source of flammable vapors in underground structures (*see NFPA 329, Underground Leakage of Flammable and Combustible Liquids*).

1-3.9 Petroleum Pipeline Liquids. Liquid petroleum and liquefied petroleum gases are conveyed by pipelines installed beneath public streets and rights-of-way. These pipelines may be 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.

1-3.10 Penetration of Structures by Gases. Flammable gas as present in the soil may 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, as may be produced by decaying organic matter, there is some likelihood that it may penetrate an adjacent underground structure. Particular attention should be paid to landfill sites developed by the depositing of garbage and trash. Gas from this source, primarily methane, may not have an odor. Gas may enter the subsurface sections of buildings through cracks or around any underground conduits that penetrate the substructure walls.

1-3.11 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 damage to the vault in which the failure occurs. However, when the vault is adjacent to or within a large struture, such an explosion may result in heavy damage.

1-4 Damage to Underground Lines.

1-4.1 Corrosion. One type of corrosion which occurs in gas lines and petroleum pipelines is where the soil composition and resistance are 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. Corrosion of this type can be controlled with cathodic protection.

1-4.2 Stray Currents. Another cause of corrosion in underground lines is stray electric currents originating from such sources as: direct current electric railways and trolley lines using rails to carry return currents; industrial plant direct current machinery using the ground as a return conductor; stray currents from cross connections with other structures carrying current; and leakage from foreign system cathodic protection rectifiers. These currents may not be destructive where they enter the piping system, but drainage of these stray currents to ground may cause corrosion at these points of discharge.

1-4.3 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 and combustible 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.

1-4.4 Excavating. Contractors doing excavation work often encounter gas and flammable and combustible liquid pipes, and even though aware of their presence, workers may unintentionally damage the pipe resulting either immediately or ultimately in a leak. Damage such as this is not always reported and often inadequate repairs are attempted by the party responsible for the physical damage.

1-4.5 Fire Damage. Fires in underground structures can result in spalling of concrete, destruction of protective linings and deterioration of other interior surfaces. Such damage, if extensive, may result in weakening the structure.

1-5 Unsafe Practices.

1-5.1 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 appropriate public authorities have been notified.

1-5.2 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 may be difficult to determine.

Chapter 2 Protective Practices

2-1 General.

2-1.1 The adoption of protective measures which will detect the presence of flammable materials in manholes and vaults, and provide the means to prevent the accumulations of gas or vapor 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.

2-1.2 Numerous sources of ignition may be found in underground structures. The operators of underground structures may materially reduce the number of ignitions by eliminating the use of flames in suspected areas. 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.

2-1.3 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 low 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.

2-1.4 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.

2-1.5 Oxygen. There are indicators that give a direct reading of oxygen concentration. Under no conditions should an area be entered, without self-contained breathing apparatus, unless it contains at least 19.5 percent oxygen.

2-1.6 Carbon Monoxide. This gas in concentrations greater than 0.10 percent 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-molybdate complex) and the carbon monoxide indicator.

2-1.7 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 percent by volume. Continued exposure will paralyze the olfactory nerves. The hydrogen sulfide detector will detect the low toxic concentrations of this gas.

2-1.8 Fuel Gases and Vapors from Flammable and Combustible 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 most common type is an "all-purpose" instrument suitable 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 gases and vapors in percent of the lower flammable limit (LFL). It must be calibrated, used, and maintained in accordance with the manufacturer's instructions. 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 percent gas. A portable combustible gas indicator is also available for operation in explosive atmospheres.

2-1.9 Periodic surveys with instruments should be made of the atmosphere in 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.

2-1.10 Liquefied petroleum gases and utility gases are odorized to facilitate detection unless the odorant would serve no useful purpose as a warning agent. Such purposes are relatively rare and practically all such gases distributed by underground pipelines are odorized. Experience has shown that odorants can be absorbed in traveling through the soil.

2-1.11 Volatile flammable liquids may enter 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 or combustible liquid through the system quickly and to dilute it, if miscible with water.

2-1.12 Underground tanks of flammable liquids may be a source of leakage. When a 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 Appendix B of NFPA 30, *Flammable and Combustible Liquids Code*, entitled Abandonment or Removal of Underground Tanks, should be followed.

2-1.13 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, alkalies or acids, unless the system is specifically designed for such materials.

2-1.14 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 forming flammable gas by the breakdown of insulation.

Chapter 3 Summary

3-1 General.

3-1.1 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 in 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.

3-1.2 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 Federal and State Pipeline Regulations.

3-1.3 Inactive gas services and mains should be abandoned in accordance with Federal and State Regulations.

3-1.4 Automatic or manually operated drains in industrial piping should be designed so as not to discharge their product into underground structures.

3-1.5 Owners and operators of underground pipelines carrying flammable and combustible liquids should maintain an adequate inspection program for the detection of escaping liquids.

3-1.6 Publication 1621, *Recommended Practice for Bulk Liquid Stock Control at Retail Outlets*, published by the American Petroleum Institute, will be of value to operators of service stations.

3-1.7 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.

3-1.8 Some public authorities 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.

3-1.9 Sewers and drains should be designed to ensure 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.

3-1.10 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.

3-1.11 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.

3-1.12 Close liaison should be established between the fire chief and industrial safety officials. Mutually approved procedures should be developed to cope with emergencies so that the fire fighters can act effectively in their line of duty.

3-1.13 All agencies having underground structures should be prepared to furnish contractors with the record of the locations of such adjacent structures or furnish a person 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 excavation by employing underground detecting devices and visual inspection of adjacent structures.

3-1.14 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.

3-1.15 Public authorities should:

(a) 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 materials. 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.

(b) 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. NFPA 495, *Explosives and Blasting Agents*, and the American Insurance Association's *Fire Prevention Code* contain additional information on this subject.

(c) 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.

(d) prohibit the encasement of pipes containing flammable materials within the constructed walls of new structures. This recommendation does not apply to piping entering buildings.

(e) 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 materials in the return electric circuit.

(f) promote cooperative efforts on the part of all organizations having underground facilities to reduce corrosion.

Appendix A

This Appendix is not part of the requirements of this NFPA document, but is included for information purposes only.

Properties of Some Flammable and Combustible Liquids and Gases Which Have Been Found in Underground Structures[1]

	Flash Point Closed Cup Deg. F	Flammable Limits in Air % by Vol. Lower	Upper	Specific Gravity of Liquid (Water = 1)	Vapor Density (Air = 1)
Acetone	-4	2.15	13.0	0.8	2.00
Acetylene	Gas	2.5	100.0	....	0.90
Ammonia	Gas	16.0	25.0	....	0.6
Benzene	12	1.3	7.1	0.9	2.8
Butadiene	Gas	2.0	12.0	.....	1.9
Butane	Gas	1.6	8.5	....	2.00
Carbon Disulfide	-22	1.3	50.0	1.30	2.60
Carbon Monoxide	Gas	12.5	74.0	...	1.0
Ethane	Gas	3.0	12.5	....	1.0
Ethyl Chloride	-58	3.8	15.4	0.9	2.2
Gas Oil*	150+	0.5	5.0	<1	..
Gasoline (Values vary for different grades of gasoline)	-45	1.4	7.6	0.8	3.-4.0
Hydrogen	Gas	4.0	75.0	....	0.1
Hydrogen Sulfide	Gas	4.0	44.0	.	1.2
Kerosene	100-162	0.7	5.0	<1	....
Methane	Gas	5.0	15.0	...	0.6
Methyl Bromide (Practically nonflammable)	Gas	10.0	15.0	....	3.3
Methyl Chloride	Gas	8.1	17.4	....	1.8
Natural Gas*	Gas	3.8	13.0	...	..
Petroleum Naphtha* (Petroleum Ether)	<0	1.1	5.9	0.6	2.5
Propane	Gas	2.1	9.5	...	1.6
Toluene	40	1.2	7.1	0.9	3.1

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

[1]Properties of other flammable materials can be found in NFPA 325M, *Properties of Flammable Liquids, Gases, and Volatile Solids.*

Appendix B

This Appendix is not part of the requirements of this NFPA document, but is included for information purposes only.

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.

Gasoline Spill into Sewer System — Wapello, IA — March 29, 1979.

This incident was a result of a gasoline spill from a tank truck while making a delivery to a gasoline service station. It was estimated that approximately 30 gal entered the sewer system. Explosions blew manhole covers off in a six-block area. Basements of buildings in a 20-block area were checked for possible fire. Two fires were discovered in basements and quickly extinguished by fire fighters. Fire fighting operations also consisted of opening hydrants in the affected area to flush the sewer system. Property damage to the sewer system and buildings was not reported.

Flammable Liquids in Sewer — Akron, OH — June 23, 1977.

Liquid chemicals used by a rubber products manufacturer were dumped into the city's sewer system intentionally by unknown persons. The chemicals consisted of 3,000 gal of petroleum naphtha, and smaller amounts of acetone and isopropyl alcohol. Multiple explosions occurred within a six-block area causing damage to two main streets and a playground. Source of ignition was not determined.

Fire fighting operations consisted of flushing the sewer system. There were no reported building fires. Damage was estimated at $300,000.

Gas in Manhole — Savannah, GA — June 1973.

An unknown gas had accumulated in a manhole and was ignited by a welder's torch. All the circuits in the manhole were de-energized by the explosion and the ensuing fire was extinguished by CO^2 extinguishers.

LP Gas Leak in Cave — Walthill, New Brunswick, Canada — January 24, 1973.

A leak in an underground LP-Gas installation seeped through the ground and into a cave. When a light switch was thrown, an explosion occurred that seriously injured two boys. The minor fire that followed was extinguished by the boys' father.

Flammable Liquids in Sewer — Peabody, MA — May 23, 1972.

Flammable liquids from an unknown source leaked into the sewerage system and ignited from a welding torch at the sewerage treatment building. The ensuing fire completely damaged the building.

Gasoline in Sewer — Nashville, TN — January 18, 1970.

Gasoline that had leaked from a bulk storage plant entered the sewer system and, eventually, the sewerage treatment plant, resulting in two explosions. The piping for the roof drain of a floating roof tank, which goes down inside the tank, had frozen and ruptured. Since the valve at the discharge end had been left open, gasoline flowed from that drain valve into the diked area surrounding the tank. The dike drain had also been left open, allowing the gasoline to flow out of the diked area into an open sewer connection nearby. The gasoline eventually made its way to the treatment plant, where the explosions occurred. It was estimated that 46,000 gal of gasoline entered the sewer system.

Gasoline in Sewer — Joliet, IL — July 2, 1969.

A series of sewer explosions in the downtown business district blew out manhole covers and many windows. Exposed buildings were also damaged by fires, and large chunks of concrete were torn from the wall of the Illinois Waterway. The explosions were caused by ignition of gasoline fumes in the sewer lines. The source of the gasoline was a storage tank on the premises of a bottling plant. Vandals had broken into the plant and stolen some motor oil and possibly some gasoline. The pump was found running, and it was estimated that 850 gal had entered the sewer system through a catch basin in the yard.

Gas in Tunnel — Manhattan, NY — January 3, 1969.

Explosion of gas leaking from a ruptured 100-ft section of a 16-in. main caused the roadbed of Delaney Street to buckle in many places over a three-block area. The ignition source was not determined. Escaping gas burned along the street, damaging parked cars and exposed buildings. All street and subway traffic was halted, including the Williamsburg Bridge. Occupants were evacuated from 35 fivestory tenement buildings. An unknown or forgotten 5-ft-diameter tunnel, two blocks long and containing a narrow-gage railroad track, was discovered under Delaney Street. Apparently the leaking gas had accumulated in the tunnel.

Gas Leakage in Manhole — New York, NY — October 15, 1968.

Eight fire fighters and Consolidated Edison workers were injured when a gas explosion and fireball erupted from a manhole at 42nd Street and Eighth Avenue. Subway and street traffic was snarled, and some buildings were evacuated. The accident was caused by ignition of gas leaking from a 2-in. pipe. Ignition source was not definitely established.

Electrical Fault — Seattle, WA — August 17, 1968.

Failure of three 13,000-volt power lines in a street vault caused fire and explosions. Power to secondary lines was knocked out, causing complete power failure over a 40-block area. One manhole cover was blown 12 stories high.

Transformer Vault — Arlington, VA — December 19, 1967.

Transformers serving a large bilevel shopping center were located in an underground vault. A loud explosion of unknown cause occurred, followed by twelve or more short explosions of variable intensity. The resulting fire was contained within the vault, although smoke and gases entered the stores and the truck tunnel that extended the full length of the shopping center. Transformers were the askarel type. The center's 54 stores were closed down for three hours.

Underground Transformer Vault — Alexandria, VA — February 23, 1967.

Two 32,000 volt transformers in an underground vault outside one of the stores of a shopping center exploded and burned when the 3,000 amp transformer protector failed. Fire fighters applied mechanical foam and then used Hi-X foam to extinguish the fire. Buildings were not damaged.

Gasoline in Sewer — Indianapolis, IN — December 8, 1966.

After heavy rainfall, a 6,000-gal gasoline tank in a service station under construction settled in the trench. The pipe connections broke, allowing about 1,000 gal of gasoline to flow into the storm sewer. Explosions occurred about 1½ miles downstream, rocketing steel manhole covers high in the air and causing severe damage to the sewer line. Ignition source was not definitely determined but might have been sparking from electric cables in the sewer chambers.