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Residential Buildings and Gas-Related Explosions

E. F. P. Burnett, N. F. Somes and E. V. Leyendecker

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

June 1973

Final Report

Prepared for
Office of Policy Development and Research
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

RESIDENTIAL BUILDINGS AND GAS-RELATED EXPLOSIONS

by

Eric F. P. Burnett,* Norman F. Somes

and

Edgar V. Leyendecker

Structures Section

Structures, Materials, and Life Safety Division

Center for Building Technology

ABSTRACT

The findings of an analysis of available statistics concerning the frequency of gas-related explosions in residential buildings are presented. The study was confined to incidents involving piped gas systems as they affect residential and commercial buildings. Though due regard has to be taken of the limitations inherent in the available statistics, it is concluded that in the USA the probability of occurrence of an explosion capable of causing significant structural damage could be 2.2 per million housing units per year.

Key Words: Building; explosion; frequency; gas; gas industry; progressive collapse; risk; statistics; structure.

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* Guest Worker from the University of Waterloo, Ontario, Canada, October 1971 to April 1972.

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1. Introduction

Since 1968 there has been growing international concern that buildings, particularly multistory residential buildings, may be subjected to loading conditions not normally considered in design, i.e. abnormal loadings. In that year there occurred the much-publicized collapse of apartments at Ronan Point in England (see figure 1). In this 22-story building of precast concrete panel construction, collapse was triggered by an accidental explosion of gas that leaked from the connection of a gas range located in an apartment on the 18th floor.

A Commission of Inquiry Report [1][1/] and subsequent studies revealed a number of deficiencies in existing codes and standards, particularly as they applied to multistory construction. In the United Kingdom interim criteria for the appraisal and strengthening of existing buildings and the design of new structures were quickly implemented. Several other countries in Europe introduced additional design criteria to deal explicitly with the risks exposed by the Ronan Point incident.

While Ronan Point was of precast concrete panel construction, there is no basis for assuming that other forms of multistory

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1/ Figures in brackets designate literature references listed at the end of the report.

Figure 1 Ronan Point Apartment Building after the collapse, with a second identical building in the background. Reproduced from [1].

construction are free from the potentially disastrous effects of abnormal loading. This point has been demonstrated by a number of incidents in recent years e.g. the collapse [2] of an 11 story load-bearing masonry apartment building in Barcelona, Spain, as the result of an explosion. Allen and Schriever [3] have attempted to summarize other recent incidents of progressive collapse, particularly those occurring in North America in recent years.

In November 1971, the US Department of Housing and Urban Development requested the National Bureau of Standards to make a study of all aspects of abnormal loading and the problem of progressive collapse. A discussion of the recognized sources of abnormal loading is given elsewhere [4]. Several of these types of loading are considered to occur frequently enough to warrant particular attention. The domestic gas explosion is one of these. In an attempt to assess the probability of gas-related explosions that might be structurally significant, a study of relevant US data was initiated. This report is confined to explosive incidents involving piped gas systems insofar as they affect residential and commercial buildings.

2. Background to the Problem - The Distribution and Use of Gas

It has been reported [5] by the American Gas Association (AGA) that there are more than 915,000 miles of gas pipeline within the continental USA. This total is composed of approximately 288,000 miles [6] of pipeline in gathering and transmission[2/] systems and approximately 627,000 miles [6] of pipeline involved in the subsequent distribution of gas. Since the gathering and transmission systems occur largely in rural or non-built-up areas, it is with gas distribution systems that this study is primarily concerned. It is significant that within the gas distribution system, gas leaks occur at an annual rate of 1 per 1.1 mile of gas line; i.e., a total of more than 560,000 leaks in 1972. More than 300,000 of these leaks occurred as a consequence of normal wear and tear; i.e., corrosion, fatigue, material failure, etc. Leaks are reported [6] to occur with comparable frequency in both the mains and service lines. About two-thirds of all leaks were associated with the pipeline itself, the remainder being associated with the fittings and other attachments.

Including both single and multiple dwelling units, almost 34,700,000 housing units in the USA used gas for house heating in 1970 [5]. It is also estimated [5] that natural gas serves about 55 percent of all housing units as a fuel for residential space heating. Of all new customers for gas house heating in 1970, 37 percent were conversions to a gas service system. Because a single customer, meter, or furnace may involve more than one dwelling unit these figures may

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2/ Appendix 1 contains a definition of terms commonly used by the Gas Industry.

not be fully representative of the total number of dwelling units to which gas is supplied.

The Gas Appliance Manufacturers Association indicated [7] that as of December 1970 there were: 39,840,400 gas domestic ranges in use (as opposed to 35,534,00 electric) and 31,964,300 gas water heaters in use (as opposed to 20,232,000 electric). Based on the number of gas ranges in use and the 1970 total housing stock of 67,711,029 housing units, it appears that approximately 59 percent of all dwelling units have gas supplied to them. The AGA estimates that, including appliance usage, natural gas is supplied to upwards of 60 percent of the total residential market.

A gas-related explosion occurs as a consequence of a leak and the accumulation of gas. Considering the number of miles of distribution pipeline, the number of leaks, and the proportion of the population served directly with gas, it is quite possible that gas service system explosions constitute a structural hazard for buildings. That a gas related explosion can and does occur in buildings that are in the neighborhood of a distribution line but are not directly served by gas, suggests that gas explosions may be a structural hazard for the majority of buildings in built-up or urban areas wherever a gas distribution system exists.

3. Current Statistics

The most common forms of gas distributed by pipeline are natural gas (principally methane), manufactured gases, liquefied petroleum gas (propane and butane), and mixed gas (usually manufactured plus natural or liquefied petroleum gas). In terms of residential consumption in 1970, 98.5 percent of all gas utility customers used natural gas [5] and for all practical purposes the data for natural gas may be considered to be representative of the industry.

Irrespective of the specific cause of the explosion, there are three categories of structurally relevant gas related explosions; i.e, (1) explosions that occur within the individual dwelling or useable unit; (2) explosions that occur within the building but not in a dwelling unit or habitable area of the building - this category would include an explosion in a boiler room or in a laundry facility; and (3) explosions that occur outside the building but are so located or of such a magnitude that the structural integrity of the building would be affected.

Ideally, the probability, severity, and the consequences of each type of explosive incident should be evaluated. To assess the probability, relative structural significance, and risk, it would be useful to know the types of building involved; i.e., single family, row housing, office building, and in particular, multi-unit apartment buildings. Unfortunately, the available statistics are somewhat limited and those that do exist were gathered for a purpose that had little, if any, concern for the actual nature and magnitude of the explosion and its structural implications. The two principal sources of information on the gas industry are the AGA and the Office of Pipeline Safety of the US Department of Transportation (OPS). Information from each of these sources is evaluated in the following sections.

3.1 American Gas Association

A prime source of information is the summary of the research report "Public Safety and Gas Distribution" [8] prepared for the American Gas Association by Arthur D. Little Inc., dated December 1967. This was a survey of the gas distribution industry in which 140 companies and systems, representing 83.3 percent of all gas distribution meters, participated. The report provides yearly averages for gas-related incidents over the 10-year period 1957-66. Yearly averages of incidents involving payment of compensation are based on the 7-year period 1957-1963. Both in terms of the time periods and the number of companies involved, this survey constitutes the most comprehensive, if not the only, study of the overall safety of the gas distribution industry within the continental USA. Obviously, either the original data or the report itself would be invaluable in any study of gas-related incidents. However, the AGA said the full report could not be released because it contained confidential material from member companies and the raw data of the 1967 study had since been routinely destroyed by the consultants.

Table 1 was assembled from information contained in the summary report prepared by A. D. Little Inc. It is evident that in each year of the survey an average of 1,508 gas explosions occurred; 329 required monetary reparation. A total of 151 (i.e., 60 percent of 253) explosions involved payment of more than $1,000. It is recognized that only a proportion of these explosions could have been severe enough to cause structural damage, but unfortunately, there is no record of:

1. the relative proportion of personal and property damage;
2. the numbers and types of buildings involved;
3. the relative severity of each of the incidents involving payment greater than $1,000.
4. whether gas was supplied to the building

Presumably very few, if any, of the explosions incurring payment of less than $1,000, were likely to have caused significant structural damage. In order to evaluate a probability based upon the AGA statistics, it will be assumed that only one building was involved in each of the 151 incidents and that each suffered significant structural damage.

OPS figures for 1971 [6] indicate that of the total number of reported explosions, 50 percent occurred in residential buildings and 7 percent in commercial buildings. The remainder occurred largely in manholes, regulator pits, etc., and it is unlikely that these involved reparation in excess of $1,000. Furthermore, it is unlikely that the remainder involved the gas company in claims for payment since in most instances these incidents probably occurred on or within gas company property. Accordingly, it will be presumed that 50/57, namely 87.5 percent of the 151 incidents; i.e., 131, were likely to have involved residential buildings. In 1960 the occupied housing stock in the US totaled 58,314,784 units [9]. According to the American Gas Association approximately 32,530,200 of these units were supplied with gas. All things being equal, the probability of occurrence of an explosion must be greater for users of gas than for non-users. However, it is also evident that gas can accumulate and explosions do occur in buildings not serviced or supplied with gas. Therefore, the probability of a gas-related explosion should be determined for both the user and the non-user of gas. Unfortunately the available estimate of 131 structurally significant explosions in residential units cannot be separated into user and non-user categories. If it were to be presumed that all 131 explosions occurred in dwelling units supplied with gas then, for users of gas, the annual probability of occurrence of a structurally significant gas-related explosion is 131/32,530,200 x 100 = .000403 percent or 4.0 structurally significant explosions per million dwelling units per year.

Since (i) the figure of 131 includes a number of non-user explosions and (ii) gas distribution networks exist in most if not all urban areas, a more representative figure would be the annual probability of occurrence of a structurally significant gas-related explosion in any residential unit i.e.

$$131/58,314,784 \times 100 = .00022 \text{ percent}$$

or 2.2 structurally significant explosions per million dwelling units per year.

During the period 1957-1963, the average annual natural gas sales to residential customers totaled 300×10^8 therms. In terms of energy, the annual rate of structurally significant gas-related explosions is 0.44 for every 1×10^8 therms of gas supplied. If all gas-related explosions and the total amount of natural gas sales (905×10^8 therms) are considered, the probability of explosion could be 1.67 explosions per 1×10^8 therms per year.

3.2 Office of Pipeline Safety

In accordance with the provisions of the Natural Gas Pipeline Safety Act of 1968, a nationwide reporting system for gas-related incidents was initiated in 1970 by the Office of Pipeline Safety. Detailed reports are required of individual incidents that involve one or more of the following criteria:

1. caused a death or a personal injury requiring hospitalization;
2. required any segment of transmission pipeline to be taken out of service;
3. resulted in gas igniting;
4. caused estimated damage to the property of the operator, or others, or both, of a total of $5,000 or more;
5. required immediate repair and other emergency action such as evacuation of a building, blocking off an area, rerouting of traffic to protect the public;
6. were deemed significant but did not meet the criteria 2, 3 or 4.

All gas companies with more than 100,000 customers (over 85% of the total number of gas customers) are required to submit reports within 20 days of the incident. Records for 11 months of 1970 and the whole of 1971 are publicly available [6]. Since the standard of response was somewhat better in 1971 than in 1970 and because the 1970 records do not cover the whole year, only the 1971 figures will be considered here.

During 1971, a total of 164 explosions in distribution systems and 11 explosions in transmission systems were reported in individual leak reports. Eighty-three of these explosions involved residential type buildings (houses, apartments, etc.)

and at least 38 of these could have been of structural significance since either a fatality, serious injury or extensive property damage was reported. Similarly, 12 gas-related explosions occurred in commercial or educational buildings, and of these, at least 4 were structurally significant. The majority of the remaining 69 explosions were either industrial or construction incidents and often occurred in manholes, compressor stations, etc.

Whereas the AGA reported that over the 10-year period 1957-1966, the annual average number of explosions was 1,508 and of these 329 involved reparation of some sort, the OPS has recorded a total of 175 for 1971. Possible reasons for this variation are as follows:

1. The OPS restricts itself to distribution and transmission systems; i.e., the safety of all pipeline facilities up to and including the customer's meter. While it appears that some incidents that occur downstream of the meter are reported, the statistical requirements of OPS do not extend past the meter between the primary gas distribution system and the appliances or services and their internal distribution systems. As table 2 demonstrates, the majority of all incidents, but not necessarily all significant incidents, occur after or downstream of the meter.

2. Whereas the A. D. Little survey recorded all explosive incidents (it has here been presumed that only those requiring reparation of more than $1,000 were structurally significant)

the OPS reporting criteria are somewhat different. For example, criterion (2) does not include the taking of any segment of distribution pipeline out of service; criterion (4) places a lower limit on total property damage of $5,000; while criteria (5) and (6) are both open to various interpretations.

On the other hand the criteria for reporting incidents to the OPS should insure that most significant incidents are reported, irrespective of the source of the leak and the location of the appropriate meter. At the very least, the figure of 38 structurally significant gas-related explosions should permit the evaluation of a lower bound criterion applicable to residential construction. The 1970 Census of Housing [10] gives the total number of units as 67,711,029. Accordingly, a lower bound estimate of the annual probability of incidence of a structurally significant gas-related explosion in any dwelling unit is

$$\frac{38}{67{,}711{,}209} \times \frac{100^{*}}{85} \times 100 = .000066 \text{ percent}$$

or 0.66 explosions per million dwelling units per year.

To emphasize that this figure is very much a lower bound estimate, it is instructive to refer to the accident report in Appendix 2 which records how one explosive incident destroyed 13 houses and fire damaged 93 others. Furthermore, if only

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* OPS Statistics (Individual Leak Reports) only cover 85 percent of the gas distribution industry.

the proportion of dwelling units served with gas approximately 42,259,000 according to the A.G.A.) were to be used, then the value for this probability would be approximately

$$\frac{38}{42,259,200} \times \frac{100}{85} \times 100 = .000106 \text{ percent}$$

or 1.06 structurally significant explosions per million dwelling units per year.

At present, the AGA and OPS statistics conflict. Of the two, the AGA statistics appear to be the more representative since:

1. they apparently cover all incidents, both upstream and downstream of the meter in distribution systems,
2. they represent a 10-year average whereas the first complete year of OPS statistics is 1971.

4. Implications

Four values for the probability of occurrence of structurally significant gas-related explosions involving residential type buildings have been determined. The most reliable and representative of these is the AGA based figure of 2.2 structurally significant (assuming damage in excess of $1,000 indicates significance) gas-related explosions per million dwellings where the total number of gas-related explosions has been related to the total number of dwelling units. In the United Kingdom (UK) the figure 3.3 explosions per million dwellings is often quoted [1] as being representative of the ten-year period 1957-66. However this figure involves only those gas-related explosions that occur in dwelling units supplied with gas i.e. the probability of a gas user being subjected to a gas-related explosion. If the total number of dwelling units (approximately 18 x 10^6 [1]) were used instead, then the related probability is approximately 2.2 per million dwellings. Since the number of gas-related explosions involving residential non-users of gas has not been included, this figure is obviously on the low side. Comparison of British and American figures is therefore difficult but it is evident that they are of similar orders of magnitude and that the probability of a gas-related explosion in the US is not as great as in the UK.

It should be noted that for the United Kingdom, Taylor and Alexander have reported [11] that about 18 percent of all gaseous explosions caused significant structural damage. If this percentage were applied to the 1508 US explosive incidents, the resulting number, 271, is greater than the 151 incidents reported to the AGA involving payments of more than $1,000.

That US practice with regard to the distribution and use of gas is relatively safer than that in the UK is further borne out by the fact that for the period 1957-1963 the US had 1.67 explosions per 1 x 10^8 therms per year while in the UK for 1966, the comparable figure was 2.1 explosions per 1 x 10^8 therms. In the UK, possibly as a result of the process of conversion from the use of manufactured to natural gas, the rates for 1969 and 1970-1971 are 5.0 and 6.5 per

1 x 10^8 therms respectively [12].

Subsequent to the Ronan Point failure in 1968, the British appear to have gathered the most comprehensive statistics regarding gas-related explosions and buildings. As table 3 demonstrates, the incidence of explosions from liquids (e.g., gasoline, adhesives, etc.) and liquefied petroleum gas (e.g., butane, methane) in domestic buildings is relatively high. However, the probability of structural damage is much lower than that for piped gas and presumably a similar situation prevails in North America.

Where individual single-family dwellings are concerned, the probability of incident may be considered to be proportional to the risk. When multi-unit dwellings are involved, the probability of structural damage is the same for all individual dwelling units, but the probability of damage to the building, and hence the possibility of structural collapse, is much greater. For a 100-unit apartment building and a service life of 50 years, the equivalent risk of a structurally significant explosion occurring during the lifetime of the building supplied with gas is therefore proportional to 1.67 percent in the UK. Since the probability of a (piped) gas-related explosion in a dwelling unit in a multistory residential building not served with gas is very small the actual probability of a gas-related explosion in a multistory dwelling unit served by gas is less than that in a similar single family residential unit. It is therefore very difficult to predict accurately the susceptibility of a multistory residential building to gas explosion in the US. It would appear that for a 100 unit building the equivalent risk is less than 2.0 percent

$$\frac{4.0 \times 100 \times 50 \times 100}{1{,}000{,}000} = 2.0\%$$

and greater than 1.1 percent.

$$\frac{2.2 \times 100 \times 50 \times 100}{1{,}000{,}000} = 1.1\%$$

On the basis that service systems are apparently slightly safer in the US than in the UK a figure of 1.5 percent would appear to be a reasonable estimate of the probability of an explosion in a representative apartment building over its service life in the United States.

In addition to previously stated qualifications, these numbers should be qualified to some extent because the proportion of gas appliances per unit in multi-unit dwellings is most probably less than the proportion of gas serviced units in single-family residences. On the other hand, many apartment-type buildings will have common utility systems; i.e., water heating, central heating plant, etc., serviced by gas. In addition, more multiple dwelling units are being supplied with gas and, given the relative economy of natural gas, these proportions are likely to increase. Certain practices such as internal distribution systems operating at high pressure or service rooms located on the roof with a high pressure gas supply, may increase the volume of gas that is released into a given space in a given amount of time in the event of a leak. This increased volume of gas may increase the potential severity of any resulting explosion. It follows that if gas service systems constitute a structural hazard then this applies equally to multi-unit dwellings and the probability of a serious explosive incident is likely to increase in the future.

5. Conclusions

Though due regard has to be taken of the limitations inherent in the available statistics, it is concluded that in the USA the probability of occurrence:

1. Of an explosion capable of causing significant (assuming damage in excess of $1,000 indicates significance) structural damage could be on the order of 2.2 per million housing units per year.
2. Of an explosion capable of causing significant structural damage in a hundred unit apartment building during a 50-year service life could be on the order of 1.5 percent.

Acknowledgements

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Table 1. Gas-Related Incidents, Their Nature, Annual Incidence and Consequence [8]

NATURE OF INCIDENT	10 YEAR AVERAGE		7 YEAR AVERAGE - 1957-63 INCLUSIVE				
	INCIDENT REPORTED		INCIDENTS INVOLVING PAYMENT[1]		SIZE OF PAYMENT		
					>$1,000	<$1,000 >$ 25.	< $25.
	NUMBER	%	NUMBER	%	%	%	%
EXPLOSION	1508	12.8	329	13.3	60	10	4
FIRE	1835	15.6	274	11.1	36	9	7
PRODUCTS OF COMBUSTION	1228	10.4	109	4.4	7	5	3
UNIGNITED GAS	3118	26.5	1498	60.7	12	66	69
FLASHBACK	4122	35.1	217	8.8	6	9	11
OTHER	344	2.9	167	6.8	3	7	8
		103.3[2]		105.1[2]	124[2]	106[2]	102[2]
TOTAL NUMBER OF INCIDENTS	11753		2466		253[3] / 10.3%[4]	1607[3] / 65.1%[4]	606[3] / 24.6%[4]

1 Total Payments by Gas Company exclusive of Company repair costs.

2 Some incidents may involve more than one of the listed phenomena.

3 Some incidents may have been involved in more than one of the listed phenomena.

4 Percent of the total number (2466) of incidents.

Table 2: Relative location of the cause of the various gas-related incidents in a typical year. [8]

	10 YEAR AVERAGE		7 YEAR AVERAGE	
LOCATION OF BASIC CAUSE OF INCIDENT	TOTAL NUMBER OF INCIDENTS		TOTAL NUMBER OF INCIDENTS INVOLVING PAYMENT	
	NUMBER	%	NUMBER	%
BEFORE OR AT THE METER I.E., UPSTREAM	3,122	26.5	1,780	72.1
AFTER THE METER I.E., DOWNSTREAM	8,296	70.6	639	25.9
OTHER	335	2.9	47	2.0
TOTAL NUMBER OF INCIDENTS PER YEAR	11,753	100	2,466	100

Table 3. The Number of Explosions and their Probability of Occurrence in Domestic Buildings in the UK for the Period 1957-1966 [1]

Explosions 10 years 1957-66	1. Total of explosions reported	2. Explosions that caused structural damage		3. Explosions that caused structural damage and could have occurred in Multi-story blocks		4. Explosions that caused severe structural damage and could have occurred in multi-story blocks	
Source	Number	Number	Risk	Number	Risk	Number	Risk
1. Manufactured Gas	747	393	3.3	393	3.3	152	1.3
2. Liquids, (e.g., spilled gasoline, methylated spirit, adhesives)	298	72	0.4	36	0.2	7	0.0
3. Liquefied Petroleum Gas (e.g., methane, butane)	96	71	0.4	30	0.2	21	0.1
4. Other and Unknown	748	251	1.4	45	0.3	13	0.1
5. Total of All Sources	1889	787	5.5	504	4.0	193	1.5

Appendix 1

Definitions

The following definitions are consistent with those used in the gas industry [8]

British Thermal Unit (Btu.): The amount of heat required to raise the temperature of one pound water one degree Fahrenheit under stated conditions.

Conversion to Natural Gas: Changing the gas service to ultimate customers from gas other than natural gas to natural gas, including adjustments of consumers' appliances to perform satisfactorily with natural gas.

Distribution Company: Company which obtains the major portion of its gas operating revenues from the operation of a retail gas distribution system, and which operates no transmission system other than incidental connections within its own system or to the system of another company. For the purposes of A.G.A. statistics, a distribution company obtains at least 95 percent of its gas operating revenues from sales to ultimate customers and classifies at least 95 percent of mains (other than service pipe) as distribution.

Manufactured Gas: A gas obtained by destructive distillation of coal, or by the thermo-decomposition of oil, or by the reaction of steam passing through a bed of heated coal or coke. Examples are coal gases, coke oven gases, producer gas, blast furnace gas, blue (water) gas, carbureted water gas.

Natural Gas: A naturally occurring mixture of hydorcarbon and nonhydrocarbon gases found in porous geologic formations beneath the earth's surface, often in association with petroleum. The principal constituent is methane.

Pressure, Gauge, (PSIG): Pounds per square inch above atmospheric pressure.

Service Line: The pipe which carries gas from the main to the customer's meter.

System:

Distribution: Generally, mains, services, and equipment which carry or control the supply of gas from the point of local supply to and including the sales meters.

Low Pressure: A system in which the gas pressure in the mains and services is substantially the same as that delivered to the customer's appliances; ordinarily a a pressure regulator is not required on individual service lines.

High Pressure: A system which operates at a pressure higher than the standard service pressure delivered to the customer; thus, a pressure regulator is required on each service to control pressure delivered to the customer. Sometimes this is referred to as Medium Pressure.

Field and Gathering: A network of pipelines (mains) transporting natural gas from individual wells to compressor station, processing point, or main trunk pipeline.

Transmission: Pipelines (mains) installed for the purpose of transmitting gas from a source or sources of supply to one or more distribution centers, or to one or more large volume customers, or a pipeline installed to interconnect sources of supply. In typical cases transmission lines differ from gas mains in that they operate at higher pressures, are longer, and the distance between connections is greater.

Therm: A unit of heating value equivalent to 100,000 British thermal units (Btu).

NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D. C. 20591
PIPELINE ACCIDENT REPORT

MOBIL OIL CORPORATION
HIGH-PRESSURE NATURAL GAS
PIPELINE
Houston, Texas
September 9, 1969

I. SYNOPSIS

At 3:40 p.m. on September 9, 1969, a 14-inch pipeline carrying natural gas at a pressure of more than 780 p.s.i.g. ruptured in a newly constructed residential subdivision 3¼ miles north of Houston, Texas. The escaping gas created a duststorm-like condition and sounded like a jet engine. Electric and telephone utility servicemen working in the area, with the help of local residents, immediately commenced to evacuate all residents in the vicinity of the rupture. About 8 to 10 minutes later, the escaping gas exploded violently. Thirteen houses, ranging from 24 feet to 250 feet from the rupture, were destroyed by the blast. The leaking gas caught fire and continued to burn to heights of 125 feet for 1½ hours until valves on either side of the leak were closed by Mobil workmen dispatched to the valve locations. The fire abated at that time, but some gas burned for another 5 hours. In all, 106 houses were damaged and property damage was estimated at $500,000. Miraculously, there were no deaths, but nine people were injured, two seriously.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of the accident was the rupturing of a length of pipe along a weak zone in the electric resistance weld, made when the pipe was manufactured in 1941, due to the subjecting of the pipeline to pressures higher than ever before experienced.

Contributing causes to the rupture were: (1) the setting of the regulators to control the gas pressure at levels higher than the maximum allowable operating pressure permitted by the American Standards Association Code for Pressure Piping, and higher than the pressure to which the pipeline was tested, (2) the lack of any written procedures for making the tie-in, (3) the failure of Federal or State regulations to limit the maximum operating pressure.

Contributing to the extent of the damage was the delay in shutting down the pipeline after the rupture occurred.

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The findings of an analysis of available statistics concerning the frequency of gas-related explosions in residential buildings are presented. The study was confined to incidents involving piped gas systems as they affect residential and commercial buildings. Though due regard has to be taken of the limitations inherent in the available statistics, it is concluded that in the USA the probability of occurrence of an explosion capable of causing significant structural damage could be 2.2 per million housing units per year.

17. KEY WORDS (Alphabetical order, separated by semicolons)
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