NATIONAL TRANSPORTATION SAFETY BOARD

PIPELINE ACCIDENT REPORT

MISSOURI PUBLIC SERVICE COMPANY

CLINTON, MISSOURI

DECEMBER 9, 1972

NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D.C. 20591
REPORT NUMBER: NTSB-PAR-74-3

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The report contains Pipeline Safety Recommendations P-74-16 through P-74-27.

16. Abstract
This report describes and analyzes a gas explosion and fire which occurred on December 9, 1972, in downtown Clinton, Mo. Gas had leaked into a building from a cracked cast-iron main located behind the building. Missouri Public Service Company personnel arrived at the site of the reported leak 50 minutes before the explosion. Eight persons died, and seven others were injured.

The National Transportation Safety Board determines that the probable cause of the explosion was the ignition of gas that had leaked from a cast-iron main cracked by a combination of soil stresses and railroad vibration, which applied a bending force to the pipe in an area weakened by graphitization.

Contributing to the explosion were the failure of the gas company to shut off the flow of gas to the leak site and the inadequate efforts of the gas-company personnel to prevent the ignition of the leaking gas detected in the building.

The report contains recommendations to the Office of Pipeline Safety of the Department of Transportation, the American Society of Mechanical Engineers Gas Piping Standards Committee, and the Missouri Public Service Company. They concern emergency response, shutoff valve operation, and prompt detection of system failures.

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Natural Gas Explosion, Cast-Iron Main, Pipeline Shut-down Delay, Natural Gas Leak, Telemetering, Graphitization, Pipeline Safety Standards, Migration of Gas

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FOREWORD

The accident described in this report was determined to be a major accident by the National Transportation Safety Board under criteria established in the Safety Board's regulations.

This report is based on facts obtained from an investigation conducted by the Safety Board. Cooperation during the investigation was received from the Office of Pipeline Safety, the Missouri Public Service Commission, and the Missouri Public Service Company.

The conclusions, the determination of probable cause, and the recommendations herein are those of the Safety Board.

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MISSOURI PUBLIC SERVICE COMPANY CLINTON, MISSOURI DECEMBER 9, 1972

SYNOPSIS

At 5:05 p.m. on Saturday, December 9, 1972, a gas leak in an office building in downtown Clinton, Mo., was reported to the Missouri Public Service Company (MPS). The outside temperature was near $0^{o}F$. An MPS serviceman arrived at the scene at 5:15 p.m., confirmed the presence of gas in the building, turned off the gas boiler, and requested that his supervisor --the district engineer-- come to the scene. After the supervisor arrived, he and the serviceman determined that the gas was leaking into the building from the outside. This was confirmed when they inspected behind the building in the alley which contained a 4-inch high-pressure cast-iron main. At 6:06 p.m., as the MPS men were returning to their vehicles to summon a repair crew, the building exploded violently. The building was demolished and an adjacent building was damaged structurally and partially collapsed. Fires started in both buildings. About an hour later, the adjacent building collapsed further, and two women trapped in the building and five men who were attempting their rescue were killed. One other person, the manager of the office building, was killed in the accident, and seven others were injured. The fires continued out of control for about 6 hours.

The National Transportation Safety Board determines that the probable cause of the explosion was the ignition of gas that had leaked from a cast-iron main cracked by a combination of soil stresses and railroad vibration, which applied a bending force to the pipe in an area weakened by graphitization.

Contributing to the explosion were the failure of the gas company to shut off the flow of gas to the leak site and the inadequate efforts of the gas-company personnel to prevent the ignition of the leaking gas detected in the building.

FACTS

The Accident

At 4:40 p.m., on Saturday, December 9, 1972, the recording chart at the town border station through which the Missouri Public Service Company

(MPS) supplied Clinton, Mo., with gas registered a large, unexpected increase in the flow of gas. MPS, however, was unaware of the increase, because the station was unmanned.

Shortly after 4:40, a woman whose photographic studio was on the first floor of an office building on South Main Street in Clinton told the building manager that she smelled gas. At 5:05 p.m., the building manager reported the odor of gas to MPS. An MPS serviceman, on call at his home, was dispatched. When he arrived at 5:15 p.m., the serviceman was taken by the building manager and the woman to the back of the first floor of the building where an odor was detected. The serviceman, however, did not know whether the odor was gas. After unsuccessfully searching for a source of the odor, such as a sewer vent, the three persons went to the basement, where they detected slight odors of gas at different locations. The serviceman returned to his truck and called the dispatcher on the radio to request that his supervisor, the district engineer, be dispatched. The district engineer was called at 5:30 p.m. and left for the scene.

The serviceman returned to the basement with a combustible-gas indicator and other equipment. He soap tested the piping in the basement, but did not find any leaks. He then checked the cracks in the basement stonewall with his indicator and got full-scale readings of the lower explosive limit (LEL) 1/ in both the east and the north walls. Readings taken in the basement atmosphere did not indicate any gas. After he completed taking the readings, the serviceman shut off the gas supply at the furnace and made sure that all flames, including pilot lights, were out.

At 5:45 p.m., the district engineer arrived and was briefed by the serviceman. Additional indicator tests showed a half-scale reading of the LEL at a crack in the north wall and a full-scale reading at a crack in the east wall. Because the gas appeared to be coming from the rear wall, the district engineer went outside with the serviceman to check behind the building. (See Figure 1.) As soon as they reached the back of the building, they could smell the gas and hear it hissing around the edge of some fenceposts about 5 feet from the building.

The district engineer realized that the leak was on the main and returned to the front of the building to his car to call for a repair crew. Although the engineer believed that the leak required immediate repair, he did not believe that the building was in imminent danger and did not consider shutting off the main valves. He intended to bring a crew to the scene, determine whether the gas was leaking from a large break, and take whatever steps were required to stop the leak.

1/ About 4.5 percent natural gas in air.

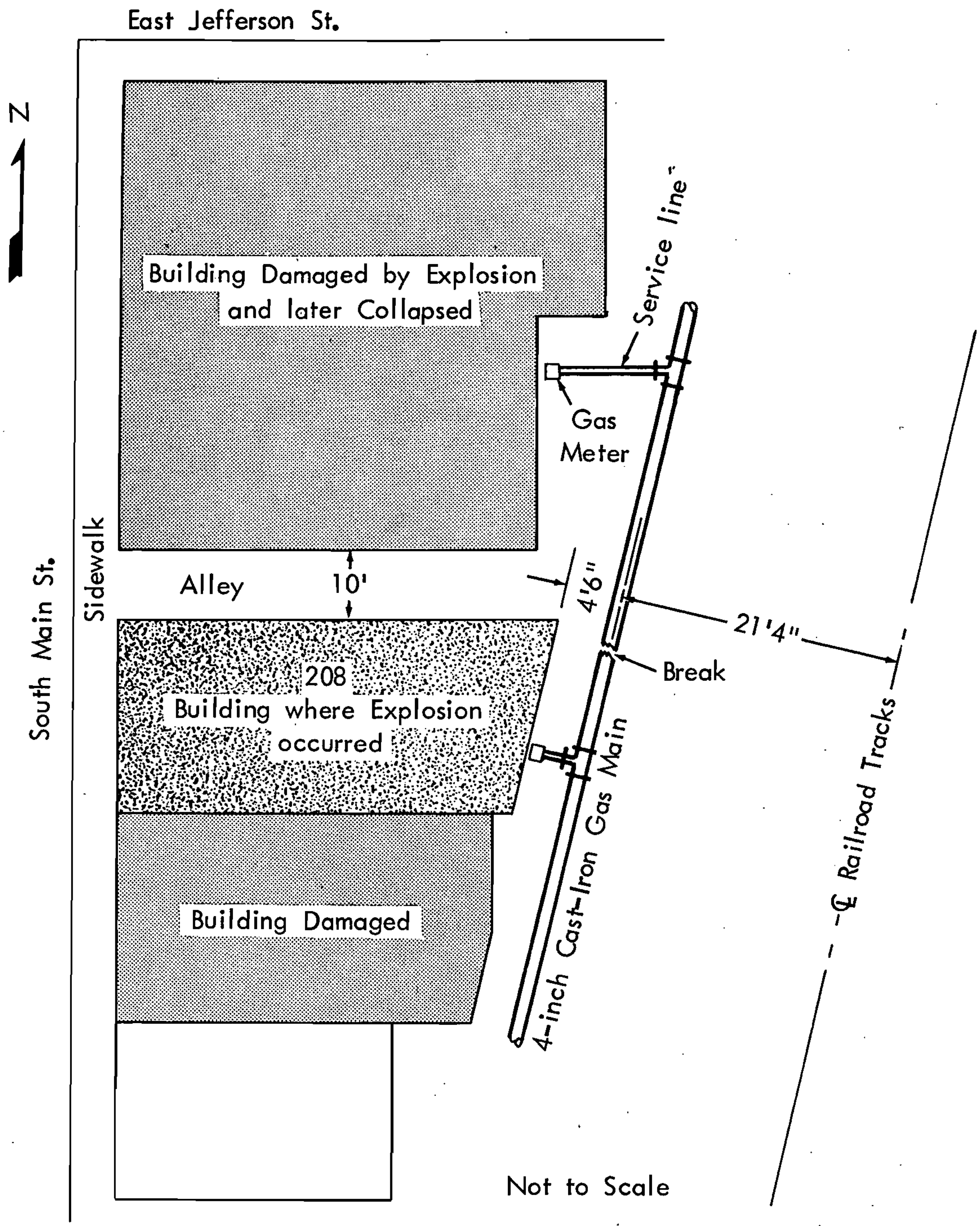

Figure 1. Accident site.

The serviceman also returned to the front of the building, where his truck was parked, to get some equipment. He saw the building manager, who was the single remaining occupant of the office building, in the doorway and told him that he could go home, since the leak had been found. At 6:06 p.m., as the building manager stepped inside the door and the serviceman went to his truck, the building exploded violently.

The building was demolished by the explosion; a neighboring building to the north, which was separated from the office building by a 10-foot-wide alley, was damaged structurally and was partially collapsed. (See Figure 2.) Windows were shattered in a 3-square-block area.

The building manager was apparently trapped inside the office building. Two women were trapped in a clothing shop on the first floor of the neighboring building. (See Figure 3.) A small fire which started in the rear of the office building began to grow in intensity and spread to the neighboring building. Two additional explosions reportedly occurred between 7 and 7:15 p.m. Shortly after 7 p.m., the north building collapsed further, and the two trapped women and five men attempting their rescue were killed. By that time, both buildings were burning intensely. (See Figure 4.)

Additional MPS crews were sent to the leak site, along with maps which showed valve locations in the accident vicinity. At 6:30 p.m., one crew turned off Valve #1 on East Jefferson Street east of South Main Street. (Figure 5 shows the locations of the valves at the leak site.) Simultaneously, a second crew was trying to locate and turn off Valve #3 on Washington Street. The search for this valve lasted nearly an hour. The valve, however, was covered by 8 to 10 inches of gravel and frost, and the crew did not have a jackhammer. For that reason, the crew could not locate Valve #3 and had to move instead to Valve #2 on Water Street. They turned off the valve on Water Street at 7:45. Thus, valves on both sides of the leak site were finally shut off 2 hours 40 minutes after the leak report and 1 hour 40 minutes after the explosion. Closing these valves affected gas service to 17 customers.

Only Valve #2 was listed as an emergency valve. Valve #1 was quickly located because it had been serviced shortly before the accident in conjunction with routine maintenance work. The MPS personnel at the leak site did not know of the existence of Valve #4, located in the alley next to the office building, because the MPS maps which had been sent did not clearly show the valve.

Eighteen fire departments from surrounding communities and Whiteman Air Force Base responded to the call for assistance. The fire continued out of control for about 6 hours. The Missouri National Guard assisted police in patrolling the area and assisted firemen in clearing debris and searching for victims.

Figure 2. Rear of office building in which the initial explosion occurred (shown on left) and neighboring building north across the alley (shown on right).

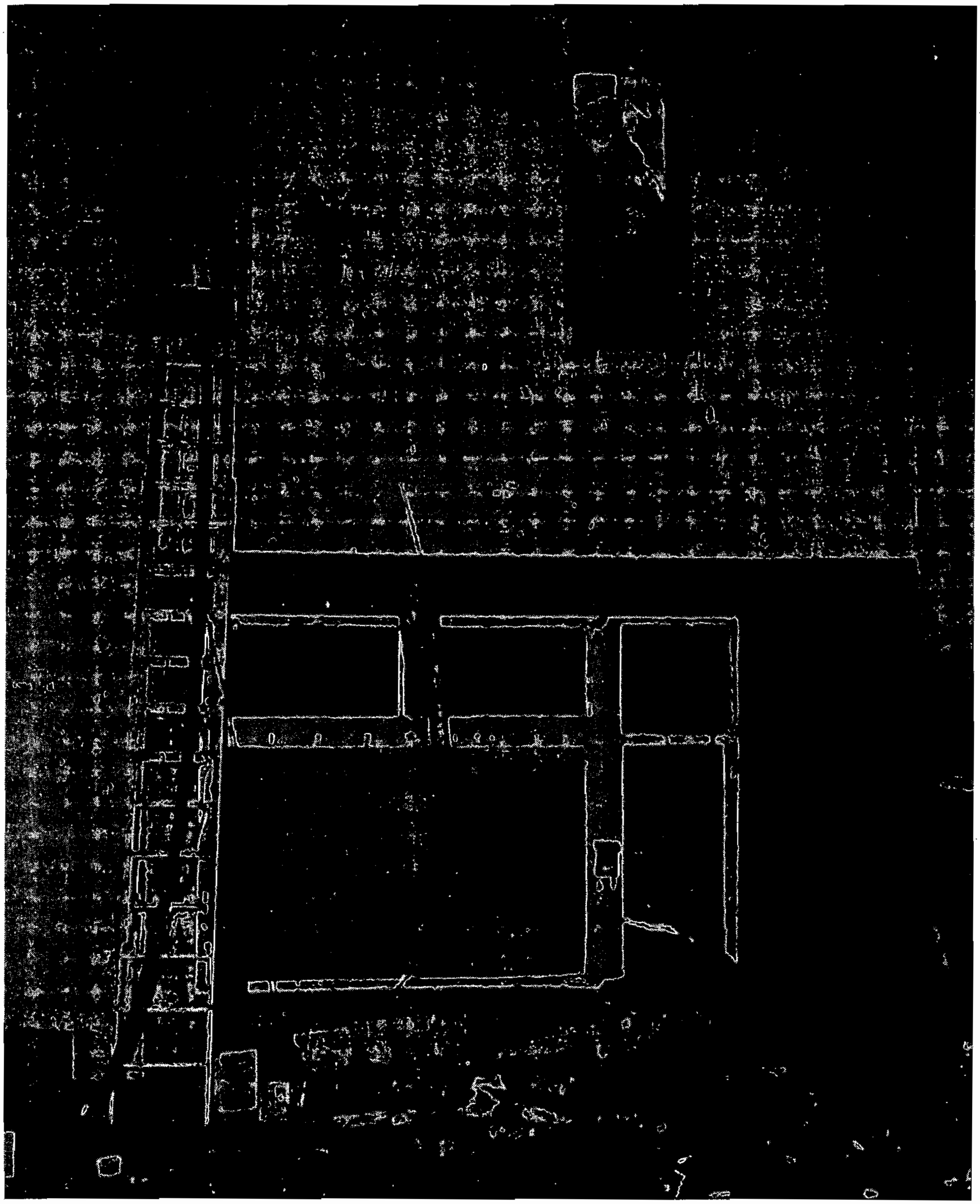

Figure 3. Firemen attempting to rescue two women trapped in the structually damaged building north of the office building.

Figure 4. Building north of the office building at the height of the fire.

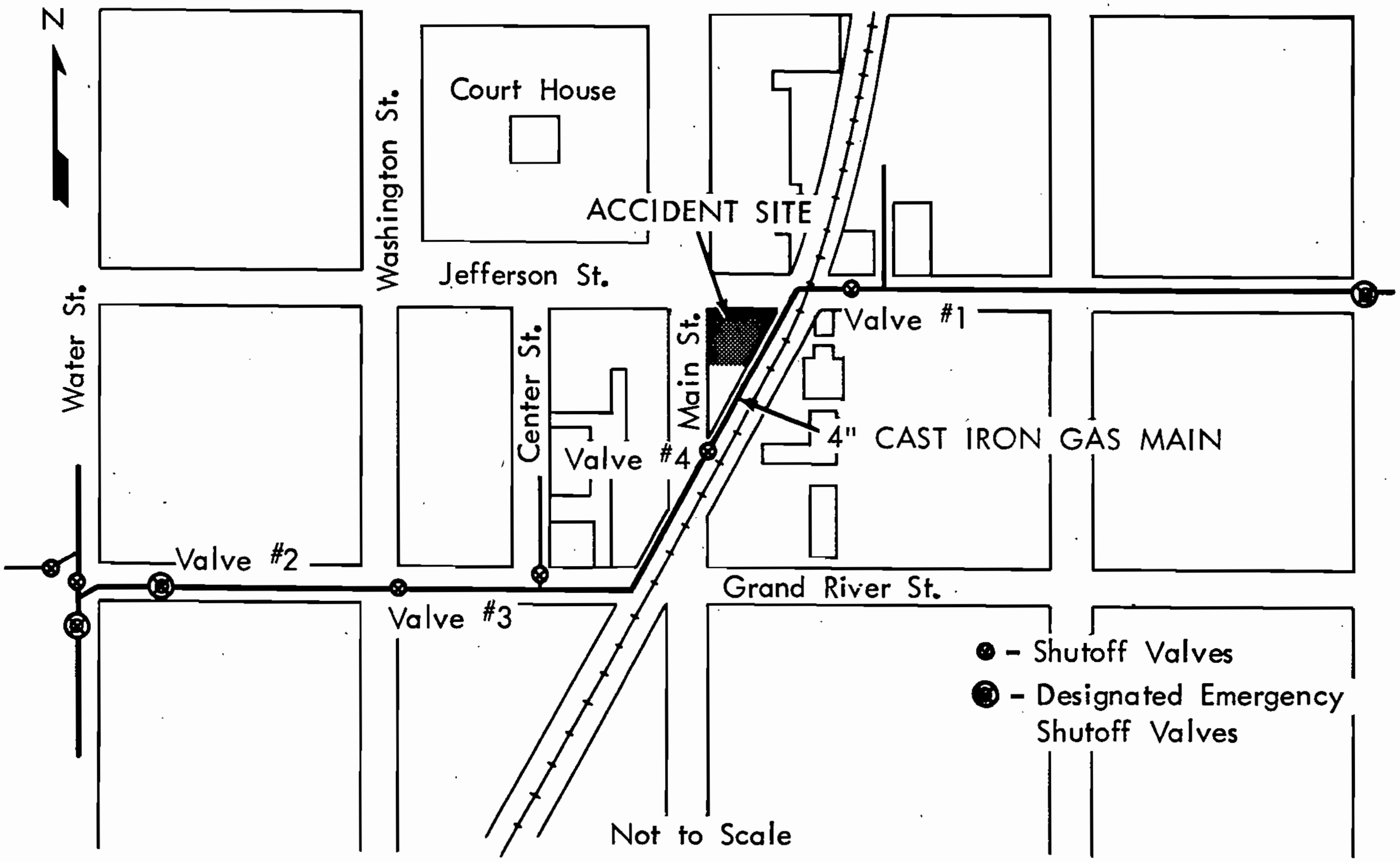

Figure 5. Valve locations at the accident site.

The morning after the accident, the 4-inch cast-iron main behind the building was uncovered. The main was cracked, had pulled apart about 1/5 inch, and was misalined about 1/3 inch. 2/ (See Figure 6.)

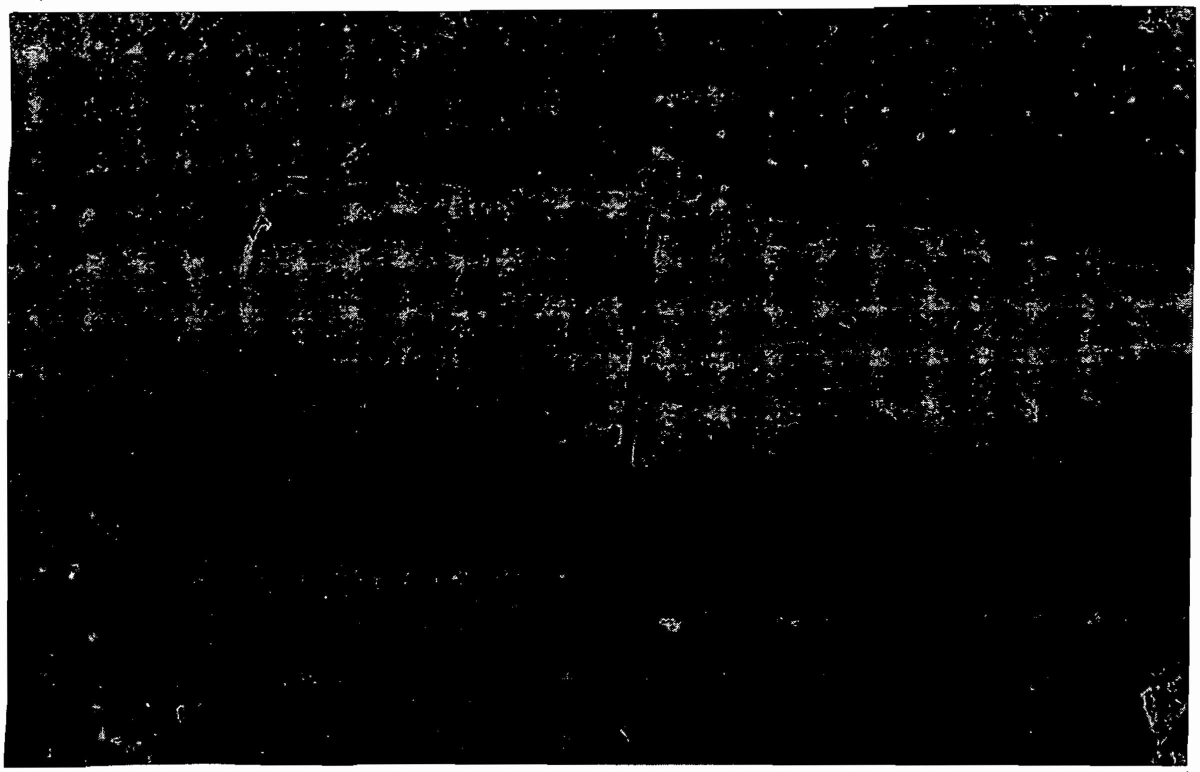

Figure 6. Failed section of 4-inch cast-iron gas main. Notice the separation and misalinement of the pipe.

Accident site

The building in which the gas leak was first detected was located at 208 South Main Street, south of East Jefferson Street, at the southeast corner of the Clinton town square. It was a three-story brick building with a sandstone and mortar basement wall and was constructed before the turn of the century. The second building involved in the accident was a two-story brick structure north of the first building. Both buildings housed commercial businesses.

2/ Shortly after the explosion, when the riser pipe to the meter behind the office building was separated, the recording chart at the town border station showed another sharp increase in gas flow. The flow returned to normal when the Water Street valve was closed at 7:45 and the leak was isolated from the rest of the gas-distribution system.

A 4-inch cast-iron main, operated at 17 psig, was located in an open space 4½ feet behind the office building. The main was installed in 1958 and was 2 feet below the surface at the point of fracture. A service line that supplied the boiler in the office building at 208 South Main entered the building 10 feet south of the fracture.

The gas-distribution system for Clinton, which serviced 3,300 gas customers, consisted of high- and low-pressure mains, mostly cast-iron, ranging from 10 inches to 2 inches in diameter.

The town border station was supplied by a 10-inch gas main operated at pressures ranging from 40 to 65 psig. The main transported gas from a transmission pipeline operated at 150 to 175 psig. The town border station contained a 6-inch orifice meter to measure the gas flow and two pressure-controlled parallel regulators, one 3 inches and the other 4 inches in diameter. During the winter, gas was received at the station at about 65 psig, measured, and reduced in pressure to about 17 psig. Gas at this pressure fed the high-pressure distribution system. Nine district regulators reduced the pressure to supply the low-pressure system. A recording chart that was changed daily registered the flow rate and the inlet pressure to the town border station. Another recording gauge registered the pressure in the low-pressure system. The only data, however, telemetered to MPS' offices concerned the high-pressure transmission pipeline.

There were 245 main shutoff valves, 34 of which were designated key or emergency valves which may be necessary for the safe operation of the system, as required by Federal standards.

A main track of the Missouri-Kansas Texas Railroad Company (MKT) ran through Clinton in the open space behind the buildings involved in the accident. The track was 19 feet from the gas main, which was within the railroad right-of-way. The train speed limit for this section of track was 35 mph. On the day of the accident, three northbound and two southbound trains passed the accident site. One of the southbound trains passed shortly after 4:35 p.m. The crews of two of the northbound trains, one which passed at 6:08 p.m. and the other at 6:10 p.m., reported seeing the explosion and the fire. Although witnesses reported that some of the trains' cars appeared to be burning, MKT reported no damage to its equipment.

Weather and Soil Conditions

The temperature at the Kansas City, Mo., International Airport, 70 miles northwest of Clinton, was 65°F, about 13°F above normal, a week before the accident. At that time, the temperature started to fall and averaged 21°F below normal during the week before the accident. On the evening of the accident, the temperature was reported to be near 0°F in

Clinton, and the top 6 to 8 inches of the ground was frozen and covered by about 1 to 2 inches of hard-packed snow.

Analysis of soil samples taken at different locations at and near the main indicated that the backfill in the area was made up of cinders, soil and gravel, organic material, and some glass. 3/ The percentages of the different materials at the various locations were as follows:

Breakdown of Backfill in Accident Area

Location	Soil/Gravel	Cinders	Glass	Organic 1/ Material
Surface:	Percent	Percent	Percent	Percent
Over main 2/	83	15	2	13.0
-- 6' east of main --	19	80	1	16.8
6 feet east of main:				
1 foot deep --	14	85	1	19.7
2 feet deep --	5	93	2	22.2

1/ Organic material was removed from each sample before the sample was analyzed. For this reason, the first three columns add up to 100 percent.

2/ This sample contains fill soils not native to the site placed at that location during backfill after the accident.

The analysis report stated that:

"All samples contained vegetation and are loamy.
[The two surface samples] supported vegetation growth as evidenced by active growth.
The high percentage of organic materials would tend to allow for compaction and settling. However, much of this effect would be offset by the high percentage of cinders. The high percentage of cinders would tend to cause a corrosive condition."

Although the samples near the pipe indicated a high percentage of cinders, MPS representatives present when the pipe was uncovered after the accident stated that the pipe was bedded in clay. Corrosiveness tests were conducted by an MPS consultant on a soil sample taken 3 feet east of the break. It was the opinion of the MPS consultant that the soil in the area of the pipe was not unduly corrosive.

3/ Soil tests conducted by Heath Consultants, Inc.

Damage

As a result of the accident eight persons died, and seven were injured. The office building manager's body was found in the east end of the basement of the office building. The office building and the neighboring building to the north were destroyed. A building adjoining the office building to the south was damaged and was subsequently razed.

Applicable Standards

Applicable Federal safety standards in effect at the time of the accident are contained in 49 CFR 192. The Federal standards had been adopted by the Missouri Public Service Commission as State standards. Certain requirements of the standards which are pertinent to the accident are cited below.

Each operator is required by 49 CFR 192.615, Emergency plans, to:

"(a) Have written emergency procedures;
(b) Acquaint appropriate operating and maintenance employees with the procedures."

Section 192.751, Prevention of accidental ignition, states:

"Each operator shall take steps to minimize the danger of accidental ignition of gas in any structure or area where the presence of gas constitutes a hazard of fire or explosion, . . ."

The 1973 edition of the ASME Guide for Gas Transmission and Distribution Piping Systems, a guide to provide "how to" information to conform to the Federal standards, has material on this subject, but it deals primarily with repair of pipelines that are outside buildings. It does, however, recommend the use of explosion-proof flashlights and prohibits smoking and open flames where the possible leakage or presence of gas constitutes a hazard of fire or explosion.

Section 192.741 of 49 CFR concerns requirements for telemetering and recording gauges at pressure-limiting and regulator stations. A distribution system supplied by more than one district pressure regulating station must be equipped with either telemetering or recording pressure gauges to indicate the gas pressure in the district. For systems supplied by one regulating station only, the operator shall determine the necessity of installing either telemetering or recording gauges by considering, among other things, number of customers, pressures, and capacity. The section also requires inspection of regulator equipment and correction of unsatisfactory operating conditions if abnormally high or low pressures are indicated. There are no requirements for the telemetering or recording of gas flow rates.

Concerning the location and maintenance of valves, 49 CFR 192.181(a) requires that high-pressure distribution systems have valves spaced to reduce the time to shut down any section of main in an emergency. Section 192.747 requires that valves necessary for the safe operation of a distribution system must be checked and serviced at least once a year.

Pertinent MPS Procedures

During normal working hours, MPS gas servicemen and crews were dispatched by the district engineer's office. On weekends and after normal business hours, requests for service were received by the MPS electric-load dispatcher 4/ on duty, who would contact a serviceman on call. A district engineer was also on call during off-duty hours, as were maintenance crews. The serviceman on call possessed a valve key but did not have the records which showed the location of the valves. He could operate valves, however, under the supervision of the district engineer. The district engineer on call did not have a valve key or the valve records in his possession. To obtain the valve records, the district engineer or the serviceman would have to return to MPS' offices to review appropriate records. The maintenance crews had the valve keys and the necessary records to locate and operate valves.

MPS had an emergency plan which covered actions to be taken in response to an interruption of gas supply to any of the communities it served. The plan did not cover investigation of gas leaks or action to be taken if only part of MPS' facilities failed.

The serviceman who was initially dispatched to investigate the leak report had not been given any formal training by MPS. He was, however, an experienced employee who had worked for MPS for 26 years and had served as an apprentice under another serviceman.

Tests and Research

Pipe analysis. The section of main containing the crack was removed and sent to the Midwest Research Institute for analysis. Assistant Professor Donald R. Askeland of the University of Missouri participated in the tests. His report stated that:

> "The two halves of the pipe fit closely together at the fractured surfaces except at the top of the pipe. A small sliver of material appeared to be missing from this region. This area of the fractured surface was deeply corroded more than 75% through the wall thickness, beginning at the outside surface. This soft

4/ The main duties of the electric-load dispatcher involve surveillance of the electric load in various parts of the electric distribution system and do not involve dispatching personnel.

corroded area, where the sound metal was very thin, appears to be the location at which failure began. Then the crack propagated in both directions towards the bottom of the pipe. The crack appeared to alter direction at the bottom of the pipe since the two cracks did not quite meet, resulting in an abrupt jog in the fracture path."

Although no deep areas of corrosion were observed on the fractured surface, except at the top of the pipe, numerous other areas of corrosion appeared on the outer surface of the two sections. Further evidence of the widespread corrosion was noted at two random cuts through the south half of the pipe.

The report concluded:

"The properties and the structure of the cast iron pipe are typical of centrifugally cast iron pipe and meet the specifications of the A.S.A., at least as far as can be determined using the nonstandard hardness test, ring test, and bend test. Failure of the pipe was not due to poor quality of the original cast iron pipe.

However, the pipe was badly corroded in local areas with a particularly deep area at the fractured surface. While the properties of the metal itself were adequate, the reduction of the thickness of the sound or uncorroded metal at various locations in the pipe would reduce the capacity of the pipe to withstand heavy loads."

The cover letter transmitting the report stated:

"Failure almost certainly occurred because deeply corroded areas reduced the load-bearing capacity of the various stresses acting on the pipe."

These findings are similar to those of the National Bureau of Standards (NBS) in other cast-iron pipe failures. A summary of NBS cast-iron metallurgical test results was included in the Board's report of the pipeline accident which occurred in Atlanta, Ga., on August 31, 1972. 5/

Vibration tests. Vibrations were measured at the accident site on December 15 and 16, 1973, by a consulting engineering firm from Illinois. The tests were conducted to determine the magnitude of vibration and strain to which the gas main was subjected as a result of the passage of nearby trains. Based on the results of the tests, the consultant concluded that if the section of pipe in which the fracture occurred was as

5/ National Transportation Safety Board, Atlanta Gas Light Company, Atlanta, Georgia, August 31, 1972, NTSB-PAR-73-3.

strong as normal cast-iron pipe, the train vibrations were not responsible for the fracture, nor were they sufficiently intense to contribute to the fracture.

Electric-resistance strain gauges were applied to the gas main 44 feet north of the point of fracture to measure vibration on the pipe in undisturbed soil. In addition, vibration transducers were mounted near the strain gauges as well as 2 feet from the point of fracture.

The consultant reported that some vibration was caused in the gas main by sources such as flat wheels and wheels' passing joints. The magnitude of each vibration depended on the load carried by the wheel. The vibrations lasted from 3 to 4.5 seconds per locomotive or car. A train consisting of 2 locomotives and 34 freight cars thus caused a vibration which lasted 2 minutes 40 seconds and consisted of a series of impacts, with each impact consisting of oscillations of decreasing amplitude.

The speed of the trains which passed through the accident site during the vibration tests ranged from 6.3 to 10 mph. During normal train operations, considerably higher speeds were observed. The maximum vibrations generated by the trains during these tests were a particle velocity of 0.14 in/s and a displacement of 0.00065 inch. (The diameter of a human hair is 0.00300 inch.) Vibrations of such intensities would not normally be considered sufficient to fracture or affect detrimentally a normal cast-iron gas main.

The strains in the pipe recorded during the vibration tests were less than two one-millionths of an inch. Strains of these magnitudes are negligible in determining the strength of normal cast-iron pipe. The stresses and strains extrapolated to higher train speeds (10 to 60 mph) also represent a very small proportion of the strength of the pipe (less than 1 percent).

Breakage of Cast-Iron Pipe

The general problem of the breakage of cast-iron gas mains was discussed in detail in the Atlanta, Ga., pipeline accident report referenced above. 6/ The report, which basically outlined work that has been done to pinpoint causes of cast-iron breakage, also described one type of corrosion (graphitization) in cast-iron failures and methods and programs to prevent future breaks. The report recommended action to reduce the hazards to the public from cast-iron breaks through programs of replacement and repair of sections of cast-iron that might be susceptible to breakage because of their location or size. Such factors as soil conditions and stability, external loads, diameter, and gas pressure were to be considered.

6/ NTSB-PAR-73-3.

In response to the Board's recommendations, guidelines to help pipeline operators set up these programs are being developed by the American Society of Mechanical Engineers (ASME) Gas Piping Standards Committee.

ANALYSIS

Emergency Response

The MPS serviceman was at the scene 50 minutes before the explosion, and the district engineer was at the scene 25 minutes before the explosion. Both of these men detected the odor of gas and also determined with gas-detection instruments that it was entering through the basement wall. Nevertheless, the district engineer (the supervisor) did not consider shutting off main valves to stop the flow of gas to this section of main even after he confirmed that the gas was leaking from the main.

In at least five recent pipeline accidents (including this accident) on which the Safety Board has issued reports, the pipeline operator's personnel were at the leak site from 10 minutes to more than 90 minutes before any explosions occurred. 7/ In each case, there should have been sufficient opportunity to prevent an accident. In none of the cases, however, was the flow of gas turned off, and in four, nearby buildings were not checked for the presence of gas before the explosions. As a result of these accidents, 19 persons died.

Some pipeline operators have recently reevaluated their methods of training emergency personnel and the adequacy of their written procedures to cope with emergencies. Because every employee will not act the same way in an emergency situation, simulated emergencies have been conducted by some operators to test emergency procedures and determine how different people react in emergencies. As a result of such tests, a pipeline operator may decide not to use certain workmen for emergencies.

In this accident, the source of ignition could not be determined positively. However, when the serviceman told the manager of the office building that the leak had been found and that the manager would no longer be needed, the building manager probably went back into the building and turned off the lights. This could have triggered the explosion.

Although the serviceman acted correctly in turning off the gas-burning appliances to eliminate sources of ignition, neither he nor the district engineer cautioned the building manager about operating electric switches. However, most buildings have a master switch which could be used to cut off power for the entire building, if the atmosphere is

7/ Annandale, Va., Report No. NTSB-PAR-72-4; Lake City, Minn., NTSB-PAR-73-1; Atlanta, Ga., NTSB-PAR-73-3; North Richland Hills, Texas, NTSB-PAR-72-3.

non-explosive at that point. In addition, in many cases, an outside electric meter can be unplugged.

MPS Procedures, Industry Guidelines, and DOT Standards

Written guidelines or procedures were not available to the MPS employees at the scene. MPS' emergency procedures, which basically cover only a large interruption of gas supply, were incomplete. Other "emergency" conditions should have been covered, e.g., the failure of a part of its facilities or the detection of explosive gas mixtures inside buildings. The lack of any formal leak-investigation training was also a factor in this accident.

The problem of emergency plans and guidance for employees dispatched to an emergency was reviewed in the Board's report of the Annandale, Va., accident. 8/ In that report, the Board recommended that the ASME Gas Piping Standards Committee develop guidelines to assist pipeline operators in preparing their emergency plans. The recommendation stressed that the plans should indicate the action to be taken by the first gas company employee who arrives at the scene. The Committee is currently working on such guidelines.

In response to the report, the Department of Transportation indicated that when the Federal standards were initially developed, the Office of Pipeline Safety (OPS) decided to include requirements for operating and maintenance plans and emergency plans in a general way. Then, as OPS gained experience, more comprehensive plans would be developed. OPS initially recognized that more detailed requirements would be needed in these areas, but did not have the expertise to develop such requirements in the time available to publish the basic standards. Through its monitoring activities and its training programs with industry and State agencies, OPS has gained considerable insight into what can or cannot be accomplished by the operators. OPS had indicated that with this recent additional knowledge, OPS expects to be able soon to propose new rules for clarifying the intent of the requirements for operating, maintenance and emergency plans. DOT further indicated that the forthcoming regulations would give industry a clearer understanding of what is required to improve operating safety and also to satisfy the recommendations of the Safety Board.

Pipe Failure and Gas Migration

The separation and misalinement of the pipe at the point of failure indicated that the pipe was under considerable tension. This tension probably resulted from soil settlement and soil movement over the years and from compaction caused by the movement of the trains.

8/ NTSB-PAR-72-4.

The ability of the pipe to withstand bending stresses steadily decreased as the graphitization of the pipe continued. The large number of cinders in the soil surrounding the pipe created a highly corrosive environment. (The widespread corrosion of the pipe does not corroborate the MPS consultant's opinion that the soil in the area of the pipe was not unduly corrosive.) This weakening, which resulted from corrosion, combined with existing soil stresses and the vibration from the passing train, created a condition which resulted in the pipe's failure. Although tests showed that the train vibrations would have had little effect on normal cast-iron pipe, this pipe could not be considered normal, since up to 75 percent of its wall thickness had been attacked by corrosion. A series of impacts from a passing train (made more severe by the frozen condition of the soil) could have been the final load needed to initiate the failure of the pipe. A southbound train had passed the accident site a few minutes before the increased flow of gas registered on the recording chart.

Most of the 17-psig gas escaping from the break could not vent to the atmosphere because the frozen surface acted as a lid and forced the gas to migrate underground to the place it entered the building through cracks in the stone foundation wall.

Operation of Valves in Emergencies

The MPS representatives at the scene before the explosion were not in a position to expeditiously shut off main line valves to stop the flow of gas to the leak, even if such an action had been decided upon. Although the serviceman had a valve key, neither he nor the district engineer knew the location of the valves. A trip to the MPS office to obtain such information would have taken additional time. Furthermore, the electric-load dispatcher relaying messages for the gas operations on weekends did not have access to these records.

After the explosion, MPS crews arrived at the scene to turn off the valves to isolate the leak. They did not proceed to the designated emergency valves, which are inspected more frequently and are probably more readily accessible. Instead, they attempted to locate and operate the valves closest to the leak site. One valve was located and operated quite quickly, but the second, covered by frost and gravel, could not be found. The crew searched for this valve for an hour. Even after this delay, it was necessary to proceed to an emergency valve located farther away from the leak to shut down the failed section.

There is no direct evidence to explain why MPS did not initially attempt to use the emergency valves. Generally, reluctance to operate designated emergency valves stems from a desire to interrupt service to as few customers as possible, especially when the outside temperature is $0^{o}F$. However, in an emergency, rapid shutdown is essential, and valves designated for emergency use should be the primary valves considered. They should not be considered as a last resort.

Thus a paradox exists. On one hand, operators select only a percentage of the valves in a system as emergency valves, because Federal regulations require frequent inspection of these valves. On the other hand, when an emergency occurs, the operators attempt to use valves closer to the leak. Since these valves do not obtain the same inspection and maintenance as the emergency valves, the chance of locating them promptly and finding them in operable condition is less than exists for emergency valves.

MPS did not have a preplanned shutdown procedure to isolate any section of its piping system. The use of such a procedure would have reduced the shutdown delay. Also, if the failed section had been shut down before the explosion, the accident might have been prevented.

The Safety Board recommended in the Annandale, Va., accident report that all operators be required to prepare preplanned shutdown procedures. The problem of designation of emergency valves was discussed in the Safety Board's report of the Lake City, Minn., accident. 9/ In that report, the Board urged OPS to include requirements which express clearly the intent of OPS concerning the number and location of emergency valves. The Board also asked the ASME Gas Piping Standards Committee to develop guidelines to be used by distribution pipeline operators in designating the location of emergency valves to assure a minimum time to shut down a section of main in an emergency. OPS indicated that a current study is considering the number and location of emergency valves, and that OPS would evaluate the data and take appropriate action. The Gas Piping Standards Committee reported that the recommended guidelines would be developed.

Monitoring the Pipeline System

Although Federal standards require that gas pressures in distribution systems be recorded or telemetered, the standards do not require that a pipeline operator be able to discover a sudden problem. Reviewing a recorded pressure chart removed from a station the day after the accident might show what happened, but would be of no use at the time of the emergency. Furthermore, telemetering pressure is only a partial solution, since in many cases, the gas flow rate must be known to permit discovery of a problem.

Regulators are generally controlled by a set pressure or a set flow rate. Under pressure control, if conditions downstream change, the regulator changes the flow in order to maintain the pressure. In this acci-

9/ NTSB-PAR-73-1

dent, since the regulator was pressure controlled, in order to maintain the pressure at the set level after the main cracked, the regulator automatically sharply increased the flow rate.

Since the information contained on the recording chart at the town border station was not telemetered to an MPS office, MPS was not aware of a problem in its distribution system. When the system compensated for the failure by maintaining pressure, the hazard caused by the leak increased.

As a practical matter, many distribution operators, although not required to do so, telemeter pressure and flow-rate information to a central office as an aid in meeting load requirements. A high/low alarm system is usually operated for each station. If the pressure or the flow rate increases beyond preset limits, an alarm sounds. Whether a problem, such as a broken main, can be detected by this kind of system depends largely on the magnitude of the failure.

The type of information that should be telemetered for safety purposes will vary with the type of system. If a regulator is pressure controlled, a problem downstream will generally be more readily detected from changes in flow rate rather than pressure. If a regulator is flow controlled, pressure changes will be more significant. Federal regulations do not make this distinction.

Complex distribution systems make it impractical and uneconomical to telemeter information from every monitoring point, since many problems, including system failures, might not be detected. Telemetering, however, is probably the best means of detecting leaks in a relatively small distribution system with only one gas feed.

The Federal requirement for single-feed systems is vague. Operators of relatively small single-feed systems do not have to install telemetering or recording gauges. The requirement, however, also permits operators of large single-feed systems supplying hundreds of customers or even entire towns to omit telemetering or gauges, and thus to rely on local detection of heavy leaks to provide warning. In addition, and probably more critical, is the option between gauges and telemetering. Gauges can provide a warning if a regulator station is staffed so that a problem can be promptly detected. 10/ Most stations today are not staffed.

MPS thus was not violating any Federal standard by not telemetering the pressure and flow-rate data to a staffed location. MPS, however, was not able to detect major problems in its system. The indication of

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10/ The New York State Public Service Commission recently ordered the Central Hudson Gas and Electric Corporation to install pressure and volume recording guages at a station serving a distribution system where failures were suspected. The Commission ordered that the data be telemetered to a central office for 24-hour monitoring.

the break appeared on the recording guage 1 hour 20 minutes before the explosion. If this had been promptly detected and considered along with the reported gas leak, the situation probably would have been handled differently and the accident might have been prevented.

CONCLUSIONS

1. The actions taken by MPS after MPS confirmed the presence of leaking gas in the basement did not prevent the explosion.

2. The gas which exploded in the office building at 208 Main Street leaked from a cracked high-pressure cast-iron gas main and entered the building through cracks in the east basement wall.

3. The MPS emergency procedure was incomplete, because it covered the interruption of gas service to entire communities only and did not cover hazardous emergencies of lesser scope.

4. Even though certain valves were designated for use in emergency situations, MPS did not attempt to operate them initially, but instead closed them only after other non-emergency valves closer to the break could not be located. This increased the delay in shutting off the flow of gas to the break and defeated the purpose of emergency valves.

5. The practice by MPS of not providing valve keys and valve location information to all field personnel increased the time required to shut off the flow of gas.

6. The Federal safety standard in 49 CFR 192.741 concerning telemetering of distribution-system pressures is vague and inconsistent. It does not require sufficient information to permit an operator to detect failures in his system promptly.

7. The Federal pipeline safety standards do not define an emergency and do not offer adequate guidance to operators concerning the areas which should be covered in emergency procedures.

8. Although the Federal safety standards in 49 CFR 192.181 and .747 require designation and maintenance of valves to shut down a section of main in an emergency, there is no requirement that these designated valves be operated first.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of the explosion was the ignition of gas that had leaked from a cast-iron main cracked by a combination of soil stresses and railroad vibration, which applied a bending force to the pipe in an area weakened by graphitization.

Contributing to the explosion were the failure of the gas company to shut off the flow of gas to the leak site and the inadequate efforts of the gas-company personnel to prevent the ignition of the leaking gas detected in the building.

RECOMMENDATIONS

The National Transportation Safety Board recommends that:

1. The Office of Pipeline Safety of the Department of Transportation:

   (a) Revise 49 CFR 192.741 to require pipeline operators to telemeter gas pressure or flow data in such a way as to insure prompt warnings of significant system failures shown by pressure or flow changes. The type and location of the data points should be considered on an individual basis and should include single-fed systems serving substantial numbers of customers. (Recommendation No. P-74-16)

   (b) Define what constitutes an emergency and provide clarification of the requirements of emergency procedures under 49 CFR 192.615, Emergency plans. (Recommendation No. P-74-17)

   (c) Require that designated emergency valves be the valves closed initially when a section of main is required to be isolated in an emergency. (Recommendation No. P-74-18)

2. The American Society of Mechanical Engineers Gas Piping Standards Committee:

   (a) Develop guidelines for the use of telemetering on gas distribution systems so that system failures can be promptly detected. (Recommendation No. P-74-19)

   (b) Expand the guidelines on the prevention of accidental ignition, to provide for more comprehensive guidance to pipeline operators when gas is detected in buildings and structures. The guidelines should include such subjects as ventilation of structures, prohibition of electrical switch operation, and occupant evacuation. This work should be coordinated with the guidelines currently being developed concerning the action to be taken by the first gas company employee arriving at the scene of an emergency. 8/ (Recommendation No. P-74-20)

3. The Missouri Public Service Company:

(a) Expand its emergency procedures to include the actions to be taken in all types of emergencies. (Recommendation No. P-74-21)

(b) Install telemetering equipment at the Clinton and other town border stations, so that system failures can be promptly detected. (Recommendation No. P-74-22)

(c) Expand its formal training program to provide employees who respond to reported leaks with the knowledge and techniques required to assist them in handling emergency situations. (Recommendation P-74-23)

(d) Take remedial action to reduce the possibility of breakage of cast-iron mains. This action should include replacement of those sections of cast-iron main susceptible to failure. (Recommendation P-74-24)

(e) Develop a sectionalizing program of its high-pressure distribution system so that preplanned procedures are available to isolate any section of its system in an emergency. (Recommendation No. P-74-25)

(f) Train and equip all appropriate radio-equipped field personnel (including electric servicemen) to locate and operate main line valves in emergencies. (Recommendation No. P-74-26)

(g) Provide valve location and other necessary information to dispatchers in radio contact with servicemen, supervisors, and repair crews, so that emergency efforts can be expeditiously coordinated. (Recommendation No. P-74-27)

8/ See NTSB Recommendation P-72-48 contained in NTSB-PAR-72-4.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JOHN H. REED
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ LOUIS M. THAYER
Member

/s/ WILLIAM R. HALEY
Member

Isabel A. Burgess, Member, was absent and did not participate in the adoption of this report.

February 27, 1974

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