NATIONAL TRANSPORTATION SAFETY BOARD

SPECIAL STUDY OF

EFFECTS OF DELAY IN SHUTTING DOWN FAILED PIPELINE SYSTEMS AND METHODS OF PROVIDING RAPID SHUTDOWN

NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D. C. 20591

REPORT NUMBER NTSB- PSS-71-1

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Approved: DECEMBER 30, 1970

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DEPARTMENT OF TRANSPORTATION
NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20591

OFFICE OF
THE CHAIRMAN

February 2, 1971

Honorable John A. Volpe
Secretary of Transportation
400 Seventh Street, S. W.
Washington, D. C. 20590

Dear Mr. Secretary:

The National Transportation Safety Board has recently conducted a study entitled, "The Effects of Delay in Shutting Down Failed Pipeline Systems and Methods of Providing Rapid Shutdown."

In many recent pipeline accidents, a delay in promptly shutting down the failed pipeline system has magnified the effects of the accident. The study points out that by reducing the time between failure and shutdown, the accident effects can be minimized or eliminated. Equipment and procedures, which could have prevented the accidents discussed in the study if they had been employed, are currently available and in use by some pipeline operators on a limited basis. The study discusses in general terms some of the methods and types of equipment that are available to the industry at present to obtain rapid shutdown of failed facilities. The equipment is quite varied, ranging greatly in complexity and in cost.

Use of the rapid shutdown equipment and plans vary greatly within the gas and liquid pipeline industries, mainly because there are no industry guidelines or Federal requirements as to what constitutes a reasonable period of time between a failure and a shutdown.

The need for such Federal regulation is pointed out by the fact that the current regulations would not have prevented any of the tragic accidents referred to in the study.

The study also discusses the degree of security to be provided to the public.

On the basis of the study, the National Transportation Safety Board recommends that:

> The Office of Pipeline Safety of the Department of Transportation conduct a study to develop standards for the rapid shutdown of failed natural gas pipelines and work in conjunction with the Federal Railroad Administration to develop similar standards for liquid pipelines.

The purpose of the rapid shutdown is to reduce the amount of hazardous materials released, and any method which will quickly reduce the amount released should be considered.

The degree of security provided by the standards should also consider the relative hazard of the commodity, the size of the population-at-risk at points along the pipelines, and the potential damaging effects on property and the environment. Two special factors concerning the population-at-risk should be taken into account; namely, (1) that in most situations the risk is concentrated in the relatively small proportion of the population near pipelines, whereas the remainder of the population benefits with lesser risk from the use of the commodities, and (2) that the population-at-risk is often unaware of the hazard and therefore unable to escape it or guard against it, and is dependent upon the protection of the regulations. The risk to those near pipelines should not be appreciably greater than the risk to the remainder of the population. A substantially greater effort to protect those near pipelines should be provided than would be justified by balancing the cost of safety measures against the lives to be saved.

Sincerely yours,

John H. Reed

John H. Reed
Chairman

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INTRODUCTION

In almost all recent pipeline accidents, the delay in shutting down the failed pipeline system has resulted in an increased magnitude of catastrophe. Had the flow of gas or hazardous liquid been stopped soon after the initial rupture, the effects of many accidents would have been minimized or eliminated. With the ever increasing use of pipelines for natural gas and other hazardous materials and the proximity of these lines to expanding populated areas, it is imperative that systems and methods be developed and put to use which will provide for the rapid shutting down of failed pipeline systems.

The responsibility for pipeline safety is assigned to the Department of Transportation under two separate statutes. The Department of Transportation Act of 1966 assigned responsibility for liquid pipeline safety to the Secretary of Transportation, but vests this responsibility in the Administrator, Federal Railroad Administration (FRA). The Natural Gas Pipeline Safety Act of 1968 assigns responsibility for the safety of gas pipelines to the Secretary. The Office of Pipeline Safety was created within the Secretary's Office to carry out the mandates of this act. The FRA has never received budgetary authorization for staff for the liquid pipeline safety function. Staff support for this function was initially provided by the Office of Hazardous Materials, but more recently by the Office of Pipeline Safety.

The present or proposed Federal safety regulations for gas and liquid pipelines do not include standards requiring rapid shutdown of failed systems. Most operators of high-pressure gas and liquid pipeline systems now depend on the dispatching of authorized personnel to one or more valve locations to operate manually valves on the main lines to shut down or control these systems. Low-pressure gas mains generally do not have valves, and other very time-consuming methods are used for control of escaping gas.

The question arises as to what can be considered reasonable and practical standards for minimizing hazards by shutting down failed pipeline systems. In addition, what will be the costs of using these standards and what benefits will be derived? What groups are at risk? Who will be the beneficiaries, and who should bear the cost? Under what circumstances would the standards and guidelines developed be made retroactive, or should standards apply only to newly constructed or reconstructed systems? Another factor to be considered is how to repair a leaking line. Under what conditions should the gas or liquid be turned off before commencing to repair the leak? Or conversely, under what conditions can a repair be made while the main is under pressure? These are some of the questions that must be considered during development of standards and guidelines for rapid shutdown.

DISCUSSION OF RECENT ACCIDENTS

To illustrate the effects of delay in shutting off a failed pipeline system, a few recent accidents will be cited.

On May 29, 1968, a bulldozer working at the front of a children's nursery in Hapeville, Georgia, broke a 1-inch medium-pressure gas service line. The bulldozer operator reportedly was unable to locate the buried shutoff valve. In a few minutes, an explosion occurred in the nursery. The ensuing fire engulfed the frame dwelling. Nine people, including seven children, lost their lives. Three other children were seriously injured.

On the night of January 8, 1968, a City Water Bureau crew was repairing a water main in Reading, Pennsylvania. A backhoe struck a 3/4-inch medium-pressure gas service line but did not break the pipe at that spot. However, the service line was separated from the main which was about 14 feet away. About 2 hours later, an explosion occurred in a building near the break, demolished the two semidetached homes which comprised the structure and killed all nine occupants. More than an hour was required for the gas company to shut off the gas in the area.

On November 19, 1969, a contractor for a telephone utility installing underground cable ruptured a 10-inch gas pipeline near Vandyne, Wisconsin. This line was operating at a pressure of more than 750 p.s.i.g. at the time of the accident. Approximately 45 minutes after the rupture, the leaking gas ignited, killed one person and injured three others. All those killed or injured were employees of the contractor. Valves 1 mile and 8 miles on either side of the leak were subsequently closed, and the fire was extinguished approximately 3-1/2 hours after the initial rupture.

On June 1, 1968, near Coshocton, Ohio, an 8-inch pipeline carrying liquefied petroleum gas (propane) at a pressure of more than 750 p.s.i.g. ruptured because a landslide had pushed the line 21 feet from its original location. A propane vapor cloud more than a mile long and 100 to 400 yards wide eventually formed, filling the valley-like terrain. Four vehicles, driving into the cloud, stalled. It is reported that the cloud was ignited, as one of the drivers attempted to start his vehicle, about an hour and a half after the rupture.

The pumping stations on either side of the rupture were shut down by remote control from Houston, Texas, about 30 minutes after the break and an hour before the explosion. These stations were 54 miles upstream and 65 miles downstream of the rupture. However, product in the line between the two stations continued to escape. An employee of the pipeline operator was dispatched from his home about 50 miles from the rupture to close the manually operated main line valves located 5 miles upstream and 3 miles downstream of the break. These valves were not closed until about 2 hours and 2 hours and 20 minutes, respectively, after the explosion. The closing of the downstream valve finally isolated the break. Product in the line continued escaping and the fire continued for about 12 hours until all the vapors had burned. The last valve isolating the break was not shut off until 4 hours after the rupture of the pipeline.

The fire engulfed the more than a mile section which was covered by the vapor cloud, killing three occupants of the cars, injuring five others, and destroying or heavily damaging a barn and five outbuildings. A farm house was blistered by the heat, and some farm equipment was damaged. Seven vehicles were destroyed or damaged.

On December 5, 1968, an 8-inch liquefied petroleum gas (propane) pipeline ruptured at a point about 1-1/2 miles north of Yutan, Nebraska. The pressure at the point of the failure was calculated to be approximately 890 p.s.i.g. When the rupture occurred, a check valve north of the Platte River and approximately 3 miles downstream of the rupture prevented any backflow of product from the downstream side of the valve. Valves 2 miles downstream and 9 miles upstream were manually closed restricting the shut-in area to about 11 miles. This was accomplished approximately 1 hour after the rupture. Due to the conversion of liquid to vapor, product continued to flow from the ruptured pipeline. About 6 hours after the initial break and 5 hours after the closest valves to the rupture had been shut down, workmen approached the break area in order to plan the repair of the pipeline. Six men driving four vehicles reached a point approximately 140 feet from the break when a flash fire ignited, engulfing an area approximately 1,200 feet by 500 feet. Five men were killed and one was injured. The fire continued for about 5 hours until it burned out.

On January 13, 1969, in Lima, Ohio, a 22-inch pipeline carrying crude oil and operating at a pressure at approximately 850 p.s.i.g. ruptured, releasing an estimated 1,000 to 2,000 barrels of crude oil into the streets and sewers of the south side of Lima. The crude oil found its way through the sewers into the municipal sewage treatment plant where it was ignited, causing damage estimated at $200,000. While in the sewer system, the crude oil endangered a 110-square block area, requiring the evacuation of about 6,500 persons. In addition, three large industrial plants employing 2,000 persons were also evacuated. Oil reportedly flowed into the streets for about 2 hours after the break, covering the street from curb to curb at depths of 3 to 4 inches. The leakage of oil was completely stopped after a long section of pipe above the break had almost completely drained, about 7 hours after the break was reported.

In New York City, about 11 p.m., on January 3, 1969, a gas explosion erupted beneath a main downtown Manhattan Street, buckling the pavement for a distance of four blocks. The initial explosion was followed shortly by several more explosions, and fires along the path of the ruptured pavement. Three hundred families were evacuated from their homes. Fires continued to burn for more than 7 hours until the gas in the area could be shut off. Although the blast occurred in a densely populated and heavily traveled district, only seven persons were injured in the accident. The explosion disrupted traffic and forced the closing of the westbound lanes of a bridge leading from Brooklyn. Subway service was also disrupted. About 11 hours before the explosion took place, a utility crew had been sent to the scene to repair a gas leak which was causing a small fire in the roadway. The fire went out and was re-ignited by the repair crew several times. Workmen continued to search for the leak, and it was reported that the explosion occurred on one of the occasions the gas was being re-ignited. After the accident, it was determined that an abandoned tunnel or "pipe gallery" was located beneath the roadway. This tunnel was constructed 60 years ago to hold utility ducts and pipes, but it was never used and was subsequently sealed. Gas from leaking mains seeped into the tunnel, accumulating along its entire length, and was ignited, causing the blast. The problem of locating the source of the gas leakage was complicated by the multiplicity of interconnected mains in the area. This condition stems back to when gas service was first provided in Manhattan. The area was supplied by a number of companies, each with its own gas mains. Through the merger of these original companies, a condition of redundance of parallel mains on the same streets, some of which are almost 100 years old, now exists. Because of this multiplicity of mains, it was difficult to pinpoint the leaking gas. This problem also exists throughout Manhattan. For example, there are 2,675,000 feet of street but almost 6,000,000 feet of gas main in Manhattan. Another borough served by the same company in New York City has only about the same footage of gas main as street.

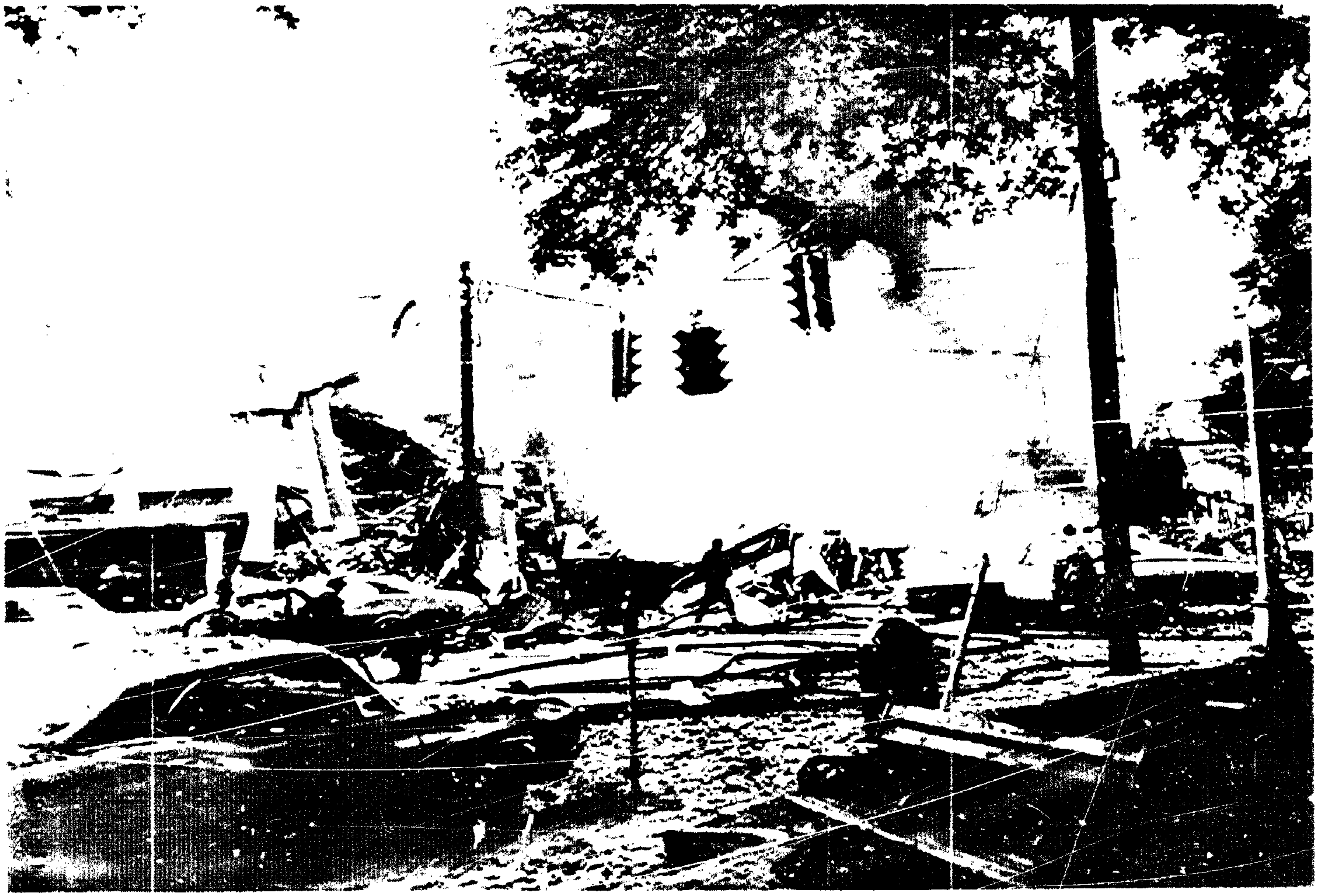
After the accident, it was necessary to shut off a number of mains to stop the fires. Having no other method available, the utility was required to use the stopper method. (An explanation of this method can be found on page 13.) Stoppers were used in five different locations on four separate gas mains, and the installation of each stopper required that pavement be opened and the main exposed by digging. This time-consuming process resulted in the extremely long delay of 7 hours in curtailing the flow of gas in the area. (See figure 1.)

Shortly after 3 p.m. on Saturday, January 24, 1970, a gas leak was reported by the owner of a jewelry store located on the main street of downtown Houma, Louisiana. A crew responding to the call determined that the leak was under the sidewalk located at the side of the jewelry store. Excavation equipment was brought to the scene, a hole was dug over the leak and an attempt was made to place a leak clamp on the cracked 2-inch cast iron

medium-pressure main. During the attempt to repair this leak, an explosion occurred taking the life of two utility workmen and one fireman at the scene. Twenty-eight other people were injured, and the shock of the blast badly damaged buildings adjacent to and across the street from the jewelry store which was demolished by the initial blast. The explosion rocked the downtown area and shattered windows up to five and six blocks away. Damage was estimated to be approximately $250,000. The main in question was a spur line which served only the building which housed the jewelry store that was demolished. An accessible valve which could have been used to shut off the supply of gas to this leak was located approximately 32 feet from the leak, but was never operated. The explosion occurred about 1 hour and 20 minutes after the leak was reported. After the explosion, the leaking gas started to burn, sending flames about 30 feet in the air. The fire continued until the valve was turned off, about 1 hour after the explosion. There was a delay in reaching the valve box because after the explosion, it was covered with debris from the demolished building. The valve was finally closed 2 hours and 20 minutes after the leak was reported. (See figure 2.)

On September 9, 1969, a 14-inch natural gas pipeline, which was being operated at more than 750 p.s.i.g. ruptured in a newly constructed residential subdivision north of Houston, Texas. About 8 to 10 minutes later, the gas, rushing from the 40-foot section of ruptured pipe, exploded violently. Thirteen homes were completely destroyed by the blast and ensuing fire, and 11 others were damaged. Because of prompt evacuation urged by local utility crews working in the area and local residents, there were no fatalities, but eight people were injured. Some of the newly constructed homes had been built within 25 feet of the almost 30-year-old pipeline. In order to shut off the supply of gas, workmen had to be dispatched to two valves, 1-1/2 and 8 miles from the rupture. The two valves required 90 minutes to shut down but some gas continued to burn for another 5 hours.

In Gary, Indiana, on June 3, 1969, a series of explosions and fires occurred in the natural gas distribution system serving a 16-square-block area. There were no fatalities, but nine residents and five firemen were injured. Seven houses were destroyed and 45 others damaged. Total property damage was about $350,000. High-pressure gas at 20 p.s.i.g. flowed into the low-pressure system when a separation valve was inadvertently opened. The erroneously operated valve remained open for only about 1 minute, but the high-pressure gas ruptured the diaphragm of the regulator supplying the low-pressure system. Since there were no relief devices or monitoring regulators at the regulator station, the high-pressure gas flowed unrestricted into the low-pressure system for about 30 to 45 minutes until the shutoff valve located in the regulator vault could be turned off. A delay of from 10 to 25 minutes was experienced because the first company employee who arrived at the regulator station could not lift the heavy steel covers of the vault and had to request assistance. The system continued at high pressure until the gas in the mains



was exhausted by flowing into the homes. This accident is covered in greater detail in a report issued by the Board in February 1970. 1/ Among the recommendation made in this report, eight were directed toward the prevention of problems of slowness in shutting down systems.

1/ NTSB Pipeline Accident Report of Low-Pressure Natural Gas Distribution System, Gary, Indiana, June 3, 1969; adopted December 4, 1969.

FEDERAL REGULATIONS

At the present time, regulations in effect for the natural gas industry are contained in the Code of Federal Regulations, Title 49 - Transportation; Part 190-Interim Minimum Federal Safety Standards for the Transportation of Natural and Other gas by Pipeline; Minimum Federal Safety Standards. Part 192 became effective on November 12, 1970. Part 190, the interim standards were revoked on that date, except for the provisions applicable to design, installation, construction, initial inspection and initial testing of new pipelines which will remain in effect until March 13, 1971.

The minimum standards make partial reference to some design features for shutdown of failed piping systems or the safe dissipation of gas resulting from a failed pipeline system. Section 192.179 of the regulations spells out the required spacing for valves and the location of valves for transmission lines. Sectionalizing block valves are required to be installed, according to location classifications of a pipeline based on population density and surroundings. In a location where buildings of four or more stories above ground are prevalent, each point on the pipeline must be within 2-1/2 miles of a valve. The required distance is extended in four steps to the requirement that each point on the pipeline must be within 10 miles of a valve for locations which have 10 or less buildings intended for human occupancy, in an area that extends 220 yards on either side of the center line of any continuous 1 mile length of pipeline. The class locations are described in section 192.5. Section 192.179 also requires that each sectionalizing block valve on a transmission line and the operating device used to open or close it must be readily accessible and protected from tampering and damage. It is also required that each section of transmission line between mainline valves have a blow down valve with adequate capacity to permit the transmission line to be blown down "as rapidly as practicable". Each blow down discharge is required to be located so that gas can be blown to the atmosphere without hazard. No guidelines or definitions of what is "as rapidly as practicable" are specified, and therefore this requirement is indefinite and difficult to enforce.

Section 192.181 dealing with distribution line valves requires that high-pressure distribution systems have valves spaced so as to reduce the time to shut down the section of main in an emergency. The spacing of the valves is determined by a number of factors including operating pressure, size of mains, and local physical conditions. A valve is also required to be installed on the inlet piping of each regulator station controlling the flow or pressure of gas in the distribution system. The valve must be a distance from the regulator station that is sufficient to permit the operation of the valve during an emergency that might preclude access to the station. Valves on mains installed for operating or emergency purposes are required to be placed in readily accessible locations so as to facilitate their operation in an emergency. The operating stem or mechanism must be readily accessible. Again, as in the case of transmission line valves the requirements are not specific and are thus difficult to enforce as definite safety controls.

Under part 190, the interim minimum Federal safety standards became those standards for each State, which the State had in effect on August 12, 1968. The majority of the States having standards, had those standards contained in the 1968 edition of the United States of America Standards B31.8 (B31.8) Gas Transmission and Distribution Piping Systems. The 1968 edition of USAS B31.8 was adopted for those states which did not have standards in effect on August 12, 1968. Section 846.21 of the 1968 edition of B31.8 mades the following statement concerning the location of automatic transmission valves " . . . this code does not require the use of automatic valves nor does the code imply that the use of automatic valves presently developed will provide full protection to a piping system. Their use and installation shall be at the discretion of the operating company." While the other requirements concerning transmission line valves of the minimum Federal Safety Standards effective November 12, 1970, are similar to those found in the B31.8 Code, the section stated above concerning the use of automatic valves has not been included in the new Federal standards.

The only reference in the Federal standard in relation to the use of automatic shutoff devices on distribution facilities is found in section 192.197. It permits the option of using an automatic shutoff device in conjunction with a service regulator to regulate and limit to the maximum safe value the pressure of gas delivered to a customer if the maximum actual operating pressure of the distribution system exceeds 60 p.s.i.g. Other devices can be used with the service regulator in lieu of an automatic shut-off device.

The standards do have requirements concerning automatic shutting down of compressor station facilities in the case of emergencies; however, this is only part of what is needed to achieve rapid shutdown and minimize loss in the entire system.

The review of the minimum Federal standards indicates that there are no meaningful requirements for any specific degree of rapid shutdown of failed systems, or for the control of the gas that has escaped from these failures. None of the natural gas accidents described earlier would have been better controlled by these requirements.

Sections pertinent to shutting down failed liquid systems were included in Federal regulations effective April 1, 1970. These regulations, covered in Part 195, Transportation of Liquids by Pipeline, of Title 49, issued by the Federal Railroad Administration, Department of Transportation, prescribed requirements for design, construction, operation, and maintenance of pipelines transporting liquids. The requirements for liquid pipelines are similar to those discussed above for gas pipelines. The regulations established the location requirements for valves. Under section 195.260 valves are required: (1) on the suction and discharge ends of pump stations so that station equipment could be isolated in the event of an emergency, (2) on pipelines entering or leaving a tank farm in the manner which permits isolation of the tank farm from other facilities, and (3) on pipeline systems at locations that will minimize damage from accidental product discharge. No requirements are established for minimum distances between main line valves as is done for gas pipelines. A maximum distance between valves of 10 miles was included in the proposed regulations, but omitted in the actual regulations. Valves are also required on lateral spur lines, on each side of water crossings more than 100 feet in width, unless the Federal Railroad Administrator finds in a particular case that valves are not justified, and on each side of a reservoir holding water for human consumption.

There is no requirement in this section for automatic operation or remote operation of valves. Section 195.262, which establishes requirements for pumping equipment, does require safety devices that would prevent ov pressuring of pumping equipment. This section requires devices for emer y shutdown for each pumping station. While the regulations require emergency shutdown devices for pumping stations, no such requirements are made for valves in main lines. These regulations would not have prevented the large scale fluid pipeline accidents involving propane at Coshocton, Ohio, or the crude oil accident at Lima, Ohio.

DISCUSSION OF METHODS AND EQUIPMENT FOR SHUTDOWN OF FAILED SYSTEMS

In every accident described in this review, the explosion and/or fire took place some time after the initial rupture of the pipe which allowed natural gas or other hazardous material to escape. The period between the rupture and ignition varied in each case. In the Hapeville, Georgia, accident it was only a few minutes, while in the Yutan case the period between rupture and ignition was 6 hours. For every one of the accidents cited, there are devices or equipment currently available which probably could have prevented the accident or greatly minimized its effect.

One such device is used on gas service lines to shut off automatically the supply of gas in case of a rupture or failure of the service line downstream of the device. This safety device is activated by an excess flow and automatically shuts off the gas at the device. It employs a small magnet and an alloy steel ball, which is the only moving part. Under normal operating conditions, the flow is not sufficient to move the ball away from the magnet. However, if the flow should drastically increase, indicating a rupture or failure of the service line, an unauthorized disconnection of the meter or other condition, the ball would move or be forced away from the magnet and shut off the supply of gas. These devices are usually installed on or at the point where the service line is connected to the main but they can be installed in any position in the service line. It is noted that this device requires an inlet pressure of approximately 2 1/2 p.s.i.g. to become operable, and cannot be utilized on low-pressure systems. If such a device had been installed on the service line supplying the Hapeville, Georgia, nursery, the accident would have been prevented.

A similar excessive flow shutoff device has been developed that can function on high and low-pressure services, but it has not as yet been marketed.

There are controls available and in use today that will automatically close main pipeline valves in the event of excessive drops in line pressure. Any short, sudden drop encountered during normal operation does not affect the controls. The controls are such that when the valve operates, it is closed within a matter of seconds. These controls are in use for valves in main lines on river crossings to protect against line breaks. They are also used on inlet piping to compressor and pump stations. Similar equipment is also available to operate valves remotely on command, or manually at the site.

There are automatic shutoff valves available for gas distribution systems. These valves can be set to shut off automatically the supply of gas when the pressure increases in a system. They can be used on low- and high-pressure systems. A valve of this type was installed on the service line to a school in Gary, Indiana, at the time of that accident. When the pressure increased in the system, this valve automatically shut down, avoiding any damage to the school itself. These valves are also known as security valves.

In order to reduce the time necessary to shut off a supply of gas in an emergency, a number of utilities have established programs to predetermine which valves would be required to be closed should a leak or emergency develop. The course of action is then preprogramed.

When a leak is reported, by referring to the prepared material, it can be determined which valves would have to be operated to isolate the leak, how large the area of shutdown would be, the number of customers in the area to be shutdown, and the number of servicemen necessary to shut off effectively all appliances and relight the same appliances once the necessary repairs have been made. The section to be isolated by the operation of the preprogramed valves involve approximately 1,800 customers, in the Long Island Lighting Company's plan. These sections are currently being reduced to about 900 customers. In order to effect a shutdown, it is still required that a company representative be dispatched to the location of the necessary valves with the proper equipment. Once arriving at the scene, he can then make the physical shutdown. The time required to accomplish the shutdown will vary considerably, depending on the location of the workmen required, time of day, and the day of the week. Among other things, many companies do not have properly equipped personnel on duty 24 hours a day. Thus, as was noted in a number of the accidents, personnel were called from their homes to proceed to the valves to shut off the supply of gas or liquid.

Because valves are not generally utilized on low pressure gas distribution systems, other methods have been necessary to control gas flows not only during emergency situations, but also for needed maintenance and system expansion work.

The main methods of shutting off or controlling the flow of gas in low-pressure mains that are not equipped with valves, consist of either a gas main bag, or a gas stopper, or both. A bag is a rubber balloon connected with a piece of rubber tubing so that it can be inflated. This bag is inserted through a small hole cut in the top of the main and inflated to stop the flow of gas. For use on intermediate pressure gas lines, a cylindrical bag of canvas may be utilized. This type of bag is inserted through a hole into the main and inflated with a hand pump. A gas stopper is made up of a flexible circular steel frame having a rubber-coated, canvas-type material stretched over the frame. When utilized, the frame is squeezed together and inserted through a hole in the main. The frame is then brought back into the circular shape and therefore forms a partition in the main, stopping the flow of gas. In certain instances, a bag and a stopper on either side of the leak would be used, or any combination of bags and stoppers might be utilized.

Naturally, in each instance of use of a bag or stopper an excavation must be made over the main, the main exposed and cleaned and a hole cut into the main.

To reduce the great amount of time needed to apply the bags and stoppers, other methods have been developed. One such method involves the pumping of grease directly into a low-pressure gas main on either side of a leak either through service pipes or by driving a bar into the main from the street surface. One drawback of this method is that the main and service lines, are left full of grease, and must therefore be replaced after the gas has been controlled. In addition, the grease method has proven effective only on low-pressure mains 8 inches in size and smaller. A second method recently developed by Philadelphia Gas Works uses urethane foam in the same manner as the grease was used. Foam chemicals are mixed together to generate a proper low-density foam which is inserted into the main either directly or through service lines. This froth foam forms a rigid product in a short period of time. Tests have been performed successfully on 20-inch mains at low pressure where flows were more than 100,000 cubic feet an hour. These tests indicate that the flow in a 20-inch main could be shut off in less than 3 minutes after foam is inserted into the main.

Equipment is also currently available to squeeze or pinch steel mains or services of small diameter. It is necessary to excavate and expose the pipe on both sides of a leak. The device is then placed around the main and hydraulically squeezed, stopping the flow of gas. This device cannot be used on cast iron mains or large diameter pipe. The flow of gas through plastic pipe can also be shut off by the pinching method.

The drastic and complicated nature of all these methods results from the fact that although needs arise to close valves, valves were not employed in the original design. Most of these methods require that the pipe be exposed by digging. The methods also involve varying degrees of risk to the workmen. They are applicable as "emergency" methods not so much in the safety sense, but for the maintenance reason that gas cannot be allowed to continue to flow during large scale repair operations.

Most automatic and remote controlled shutdown equipment in use today on high-pressure gas and liquid transmission systems is found at pumping and compressor stations, at delivery, metering, and regulating stations. The equipment is not generally placed on main lines. In addition to the safety aspects of the use of automatic and remote controlled equipment, the pipeline operators make frequent use of this equipment in their normal operations. Pumps and compressors are operated remotely as requirements change. Pressures and flows can be increased or decreased by remote control.

Automatic shutoff valves, also called "line break valves," are installed occasionally on gas transmission systems at major water crossings to provide for continuity of gas supply in the event of a rupture. Unlike liquid pipeline systems which generally deliver products to storage tanks for further delivery, gas pipelines generally provide gas to distribution companies for direct use by residential, commercial, and industrial gas consumers. While an interruption of liquid flow may be inconvenient, a loss of gas supply can have serious consequences. Shutting off a major supply pipeline could mean the loss of gas service to thousands of customers, if alternate sources of gas are not available. When two pipelines are utilized at the crossing of a body of water, the broken line could be automatically shut off in the event of an emergency, stopping the loss of gas and preserving continuous gas supply. If only one pipeline crossed the waterway and it ruptured, valves on either end of the water way would shut down, if equipped with such devices, and allow for use of the "line pack" gas (gas compressed in the pipeline) on either side of the break until an alternate feed could be turned on, if available. (This same "line pack" is a hazard when a failure occurs.) Automatic controls are used at water crossings, and not generally at other locations along the main line, because of the vulnerability of the line to damage, either from swift currents or anchors of ships using the waterway and the inaccessibility of the portion of line under water. Automatic shutoff valves are also used, but to a lesser extent, at other key points, such as main highway crossings. Columbia Gulf Transmission Co., in addition to utilizing line break valves at river crossing, also installs them on main lines to some major cities, such as Nashville, Tennessee.

A number of New England States required that automatic shutdown controls or "operators" be installed on all main line valves on Tennessee Gas Transmission Company's large diameter high-pressure transmission pipeline constructed about 15 years ago. These "operators" have not yet been called upon in an emergency to shut down a section of failed pipeline. It is also noted that the valves have never shut down unintentionally.

Liquid transmission pipelines do not generally utilize automatic shutoff valves on the main line. As previously noted, automatic and remotely controlled valves are found at pump stations and other installations. More use is made of check valves which stop liquid from flowing backward toward a break. However, there is equipment available, and in use on a Buckeye Pipe Line Company products line in New York City, which contains a combination of automatic shutoff valves and check valves which isolate automatically a section containing a break from the remainder of the system. After the line has been shut down in sections, pressure sensors then telemeter pressures to a control center so that it can be quickly determined which section contains the break. In addition, manually operated valves located every one-half mile can then be closed to further isolate a leak. Metering devices measures the amount of liquid entering and leaving the line. A computer compares the flows and, if any difference occurs, an alarm sounds. Pumps at the inlet station are automatically shut down, followed by the closing of the automatic valves located along the line as the pressure drops. The installation of this equipment was required by New York City officials.

Some gas distribution system operators can remotely control large regulator stations. Output of the regulators can be controlled, based on customer requirements. Valves can also be remotely activated to shut down the station completely, if necessary. Sensors are used to telemeter pressures and flow rates back to a central control point. Some installations even have remote equipment to detect gas leaks or fires.

Gas transmission pipelines are required to have blowdown valves in each section of pipeline. These valves are also found at compressor stations. On main lines, the blowdown valves are usually located on each side of a main line valve so that in an emergency, one entire section of main containing the leak and between two valves, can be rapidly reduced in pressure. In this manner, all of the gas in a section of main containing a rupture would not have to be dissipated at the leak location. As an example of the pressure reducing ability of these devices, one gas pipeline operator estimated that 1 mile of 30-inch transmission pipeline can be reduced from 650 to 0 p.s.i.g. in about 2½ minutes, utilizing a 16-inch relief valve with a 12-inch stack. However, these blowdown valves, like most main line valves, must be operated manually. Even in instances where the main valves can be automatically or remotely operated, the blowdown valves generally require manual operation.

In certain failures of liquid pipelines, suction pumping of the liquid out of the failed line has been employed. This method was used when a line was shut down after a leak was discovered near Jacksonville, Maryland, in September 1970. This leak led to an accident which will be covered by a separate Board report.

The cost of utilizing the equipment currently available varies greatly. The initial cost of the various devices is naturally a factor as is the question of whether the device will be installed on existing facilities or in conjunction with new construction. Costs will be considerably higher when these devices are not installed initially, but must be added to existing facilities. Some of the devices cost only a few dollars, while others such as a remotely controlled large diameter shutoff valve may cost upwards of $20,000.

THE PUBLIC-AT-RISK

The degree of security to be provided by pipeline regulations has sometimes been assessed by applying cost-benefit criteria. How much larger is the amount of loss to be prevented than the cost necessary to prevent this loss? This criterion is applicable to a situation when the benefits in reduced risk and the costs are shared within the same group. However, the risks and losses from pipeline accident exposure and the costs of hazard reduction are not within the same group.

Those at risk from pipeline accidents are sometimes employees of the system; more often they are members of the general population who happen to live near a pipeline, or to be near it by chance. These people may not benefit from a given type of pipeline transportation, even indirectly. At most, they benefit from the service only to the same degree as others in the population. These people do, however, carry the risk for the benefit of the rest of society. The benefitting groups in society are the natural gas or liquid fuel users and the profit making institutions which operate the lines. One way to equalize this risk would be to reduce it to zero, so that those near the pipeline have the same risk as those who benefit from the pipeline service. Alternatively, since it is not possible to reduce a risk to zero, funds could be employed to reduce the risk to a point well below what would be justifiable by requiring the benefits to match or exceed the costs. Those who are bearing the risk deserve to be protected by expenditures far beyond the dictates of cost-benefit.

Another factor in assessing the degree of security necessary is the frequent ignorance of the risk among those exposed. Pipelines are out of sight and out of mind. The children in the Hapeville, Georgia, nursery, the local people whose cars stalled in a propane cloud at Coshocton, Ohio, the residents at Reading, Pennsylvania, were all completely unaware of hazard and unable to take any action to avoid it. In the natural gas pipeline explosion at Houston, only the owners of the two houses nearest the pipeline were aware of the pipeline. Many people certainly take up residence near an established pipeline without knowing what, if anything, is there. Certainly, the majority have little appreciation of the scope of disaster which could occur, or realize that the risk will continue for hours after a failure occurs.

The fact that a person who is at risk does not know the nature of the risk or how to avoid it means that, as a practical matter, the degree of protection offered by the system design and operation must therefore compensate for the lack of the individual's assistance in self protection. Greater effort is therefore required to achieve this protection.

There are thus at least two major reasons for requiring costly efforts by these safety standards beyond the point of balance of costs against benefits. First, the risk applies disproportionately to persons near the pipeline who are exposed to the risk for the benefit of the rest of society. Second, the users of pipeline service and bystanders are often ignorant of the hazard and of means of avoiding it. These people are dependent upon the protection of the responsible and knowledgeable public regulatory agencies and private industry. These two factors are also found in other transportation modes, but they appear outstandingly important in pipeline transportation.

CONCLUSION

By reducing the time required to shut down a failed pipeline system to minimize the loss of material, the hazardous effects to the public, to persons working near a pipeline, and to property can be minimized or eliminated. Equipment and procedures are currently available which, if utilized, could drastically reduce the shutdown delay cited in the accidents discussed in this study.

Analysis of the accidents discussed earlier indicates that the losses which occurred would have been drastically reduced if the applicable, currently available device had been in use or if installed shutdown equipment had been promptly operated. Excessive flow shutoff devices would have prevented losses in the Hapeville, Georgia, and Reading, Pennsylvania, accidents. Automatic or remote controlled valves would have prevented or reduced losses in the Vandyne, Wisconsin, Coshocton, Ohio, Yutan, Nebraska, Lima, Ohio, and Houston, Texas, accidents. In the propane accidents, the vapor clouds would have been smaller, the clouds might not have igniced or, if they did, would have caused less damage. The loss of life and damage to property in the Houma accident could have been prevented by shutting off the supply of gas by use of a nearby valve prior to the attempt to repair a cracked main. A large proportion of the loss in these accidents was due to the inability or the failure to shut down rapidly, not to the original failure.

The Federal safety standards for gas and liquid pipelines do not include requirements for rapid shutdown. Neither the ANSI-B31.8 code which is the interim Federal satandard for gas pipelines, nor the ANSI-B31.4, the industry standard for liquid pipelines, covers the problem of rapid shutdown. Use of the many shutdown plans and equipment by the pipeline operators is varied because there are no industrywide guidelines or Federal Requirements, as to what constitutes a reasonable period of time between a failure and a shutdown, or what other steps may be taken to minimize loss. The situations and conditions which can be encountered are also variable. Naturally, different guidelines would be applicable for shutting down a failed pipeline running through a desert as compared to one beneath the streets of a heavily populated city. Consideration must also be given to the type of commodity being transported in the pipeline system. Natural gas pipelines can be blown down to the atomosphere in most instances because the gas is lighter than air and will dissipate readily. However, crude oil cannot be released as readily. Other problems must also be considered. Propane (LPG) travels through pipelines as a liquid, but vaporizes when it escapes from a leak or rupture. This vapor is heavier than air and will not dissipate as readily as natural gas.

In the above discussion, many of the methods and equipment used to shut down and control gas or liquid during and emergency have been mentioned. Much of the equipment and many of the methods and procedures used in controlling liquid or gas in emergencies are already available, have been in use for many years by pioneering groups in the industries and appear feasible for general application where warranted. The relatively inexpensive devices discussed in the report should be installed universally, and the more costly equipment installed at critical locations such as in populated areas. Line break valves might not be needed in open country but should be utilized on transmission lines in cities and other populated areas. New and better methods are needed, and technology is such that development of these new methods and devices can certainly be expected. This can be appreciated when it is recognized that the bag and stopper method of controlling gas in low-pressure mains is still the number one method in use throughout the country. One of the reasons that new methods and equipment have not been developed is that there are no definitions as to what constitutes a rapid shutdown, what is an emergency situation. There have been no analyses of the relative importance of avoiding shutdown and of avoiding hazard. The question of what conditions warrant shutdown and what condition of risk to the community justify various degrees of rapidity of shutdown is not analyzed in any published documents. Only a few discussions are found in the B31.8 code. When these matters have been analyzed and requirements published, pipeline operators, the manufacturers, and service corporations which sell products and services to the pipeline industry will be able to concentrate on developing more modern and efficient methods and equipment for shutting down failed systems, since a market would be available.

RECOMMENDATION

On the basis of this study, the National Transportation Safety Board recommends that:

> The Office of Pipeline Safety of the Department of Transportation conduct a study to develop standards for the rapid shutdown of failed natural gas pipelines and work in conjunction with the Federal Railroad Administration to develop similar standards for liquid pipelines.

The purpose of the rapid shutdown is to reduce the amount of hazardous materials released, and any method which will quickly reduce the amount released should be considered.

The degree of security provided by the standards should also consider the relative hazard of the commodity, the size of the population-at-risk at points along the pipelines, and the potential damaging effects on property and the environment. Two special factors concerning the population-at-risk should be taken into account; namely, (1) that the population is often unaware of the hazard, and therefore unable to escape it or guard against it, and (2) that in many situations the risk is concentrated in a relatively small proportion of the population near pipelines in order to achieve benefits for the remainder of the population. The risk to those near pipelines should not be appreciably higher than the risk to the remainder of the population. A substantially greater degree of security for those near pipelines should be provided than would be indicated by requiring that the cost of the safety measures be justified entirely by the lives to be saved.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD:

/s/ JOHN H. REED
Chairman

/s/ OSCAR M. LAUREL
Member

/s/ FRANCIS H. McADAMS
Member

/s/ LOUIS M. THAYER
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/s/ ISABEL A. BURGESS
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December 30, 1970.

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