

NATIONAL TRANSPORTATION SAFETY BOARD

PIPELINE ACCIDENT REPORT

WASHINGTON GAS LIGHT COMPANY

BOWIE, MARYLAND

JUNE 23, 1973

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NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C. 20591

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16. Abstract <p>This report describes and analyzes a gas explosion and fire which occurred on June 23, 1973, in Bowie, Maryland. Gas had leaked from a crack in a plastic service line. Three persons died and a fourth was injured.</p> <p>The National Transportation Safety Board determines that the probable cause of the accident was the ignition of gas that had leaked from a stress crack in a plastic service line. The pipe had cracked because an occluded particle had created a stress point and weakened the pipe.</p> <p>Contributing to the accident was the lack of odor in the leaked gas when it reached the houses and the atmosphere.</p> <p>The report contains recommendations to the Office of Pipeline Safety of the Department of Transportation, the Department of Housing and Urban Development, the American Society of Mechanical Engineers of the Gas Piping Standards Committee, the American Gas Association, and the National Fire Protection Association. They concern leaking gas migration through soils and into buildings, odorant adsorption by soils, use of new materials in piping systems, odorant testing, and plastic pipe.</p>			
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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 the 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 Federal Highway Administration, the Office of Pipeline Safety of the Department of Transportation, the Maryland Public Service Commission, the Prince George's County Fire Department, the City of Bowie, the Washington Gas Light Company, and the Phillips Petroleum Company.

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

TABLE OF CONTENTS

	<u>Page</u>
SYNOPSIS	1
FACTS	1
The Accident	1
The Accident Site	4
Description of Losses	7
Events Preceding the Accident	7
Weather Conditions	8
Tests and Surveys	8
Plastic Pipe Failure	11
Plastic Pipe	14
Odorization	16
Applicable Standards	18
ANALYSIS	20
Period of Leakage	20
Migration of Leaking Gas	21
General Problem of Migration of Leaking Gas	21
Pipe Failure	23
Odorization	24
Cause of January 1973 Fire	24
Use of New Materials	24
CONCLUSIONS	25
PROBABLE CAUSE	25
RECOMMENDATIONS	26
APPENDICES:	
Appendix A: Excerpts from the National Bureau of Standards Report of the Failure Analysis of a Polyethylene (PE) Natural Gas Service Line from Bowie, Maryland	29
Appendix B: Phillips' Comments Concerning the NBS Report and the NBS Answer to those Comments .	31

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Adopted: October 24, 1974

WASHINGTON GAS LIGHT COMPANY
BOWIE, MARYLAND
June 23, 1973

SYNOPSIS

Shortly after 8 a.m., on June 23, 1973, a series of explosions, followed by fire, occurred at 12321 Welling Lane in Bowie, Maryland. Three occupants of the house were killed, and a fourth was injured; the house was badly damaged. Houses in a five-block area were evacuated.

The high pressure plastic gas service line which supplied the house had been cracked. Geological tests showed that the leaking gas had migrated to the sand-gravel material under the area and formed a gas reservoir. The odorant in the gas had been adsorbed by the soil; and, therefore, the gas was not detectable by its odor.

The National Transportation Safety Board determines that the probable cause of the accident was the ignition of gas that had leaked from a stress crack in a plastic service line. The pipe had cracked because an occluded particle had created a stress point and weakened the pipe.

Contributing to the accident was the lack of odor in the leaked gas when it reached the houses and the atmosphere.

FACTS

The Accident

On June 23, 1973, shortly after 8 a.m., the ranch-style home at 12321 Welling Lane in the Whitehall Section of Bowie, Maryland, exploded. The explosion was followed by fire and thick black smoke. A second explosion occurred a few minutes later, and temporarily extinguished the fire. A short time later, fire shot out of the rear of the building. The house was occupied by a couple and their teenaged son and daughter. The son, who was in bed, heard a rumbling noise and screaming. He opened his bedroom door and saw his mother in the hallway with her clothing afire; his father instructed him to leave the house. The walls were on fire, and the heat was intense. The boy ran through the kitchen and into the family room. He attempted to leave the house through the sliding glass doors in the family room, but the doors had been blown out on to the patio, and the doorway was blocked by fire. He went through the utility room and to the garage, opened the garage door, and left the house. His

father was immediately behind him. The boy survived the fire, but his father died the following day.

The boy neither noted nor detected any odor of gas the night before the accident or the morning of the explosion. In the days and weeks before the accident, there had been no indications from other members of the family of gas odors.

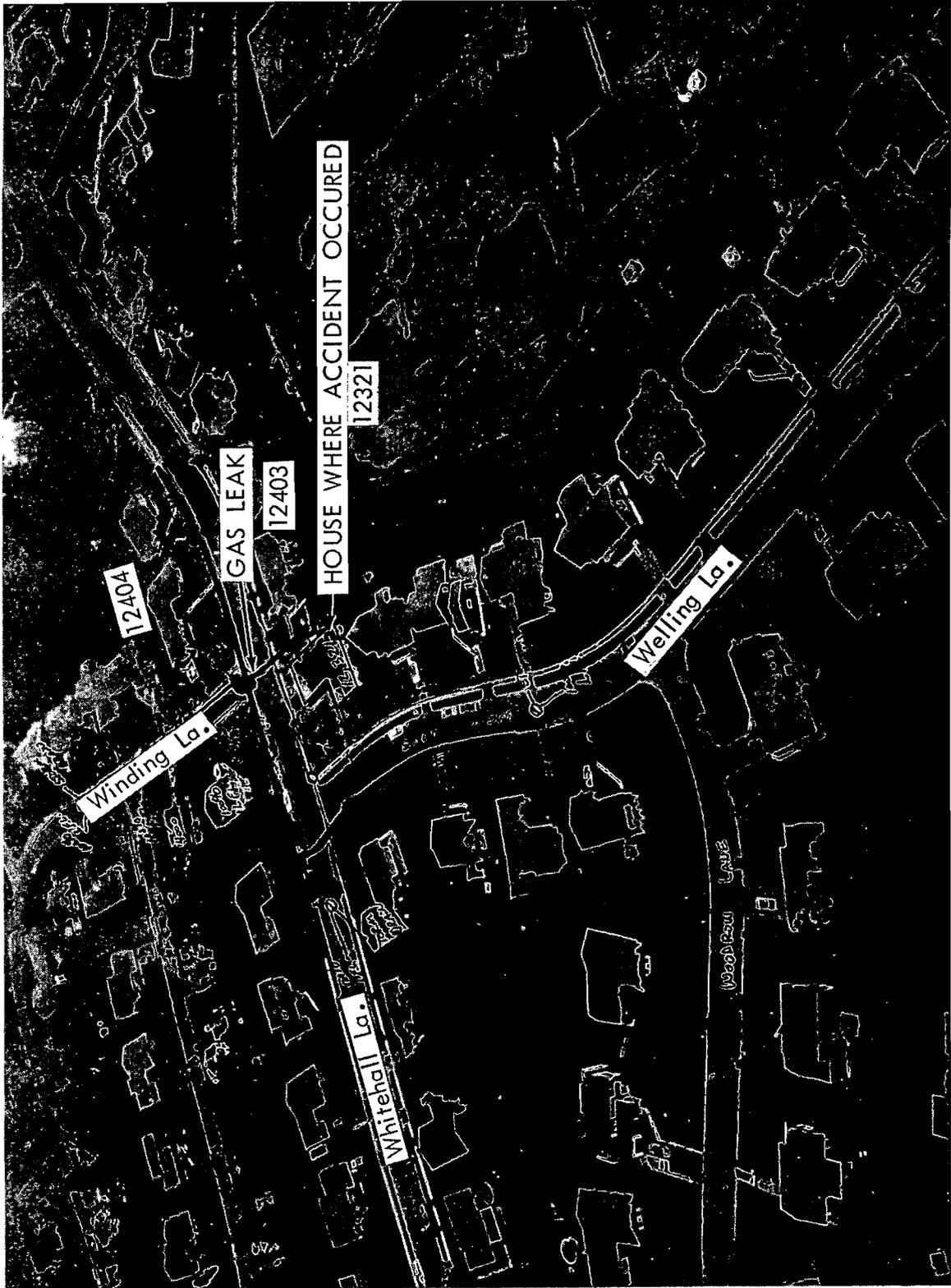
The fire department, in response to calls by neighbors, arrived within a few minutes, began fighting the fire, and attempted to rescue the occupants of the house. The mother and daughter, however, died in the burning house. The gas piping and meter located behind the house were separated from the house by the explosion, and a gas fire shot up from the ruptured piping. The valve at the meter was turned off by the fire department, which stopped the flow of gas that was feeding the fire.

At 8:50 a.m., the Washington Gas Light Company (WGL) was advised of the explosion, and a serviceman working in the area was dispatched; he arrived a few minutes later. At 9:40 a.m., the first WGL crew arrived and used combustible gas indicators. By this time, the fire had been extinguished, and the fire department and WGL personnel began to check other houses for gas. Other WGL personnel began to search for the leak.

Although the odor of gas was not noticeable, explosive mixtures of gas were detected in houses, water meter boxes, sewer manholes, storm sewers, and holes drilled in streets and on lawns. (See Figure 1.) By 10 a.m., 65 houses in a five-block area had been evacuated and ventilated. Between 11 and 11:30 a.m., the main electric and telephone facilities to the area were shut off. Gas meters on the outside of each of the houses in the area were turned off.

Additional WGL crews were called to the scene as the search for the leak continued. The $\frac{1}{2}$ -inch plastic gas service line to the house that exploded was squeezed off, cut, and capped at the curb. The service line from the curb to the two houses it served was air tested and found to be intact. Bar hole testing continued as WGL attempted to pinpoint the leak. WGL planned to close the main line valves to stop the flow of gas to the area if a hazard was found. Based on the continued testing, WGL supervisors in the field decided that no further hazard existed, and the main line valves were not turned off.

Shortly after 12 noon, a bar hole was drilled through the pavement above the location where the service line was connected to the main. Gas immediately blew up through the hole. WGL excavated down to the main and found a crack in the plastic service line, about 18 inches from its connection with the main. At 1 p.m., the line was cut and a compression coupled valve was positioned on the line, which stopped the flow of gas. Fire department and WGL crews continued to detect explosive concentrations of gas in several locations within the evacuated area. These



Prince George's County Fire Dep.
Figure 1. Aerial view of accident site showing explosive readings taken after accident.

locations included: Heating ducts in 12435 Winding Lane; bar holes around the water main and water service outside 12435 Winding Lane; the storm sewer along Whitehall Drive and Winding Lane; water meter pits in front of 12321 Welling Lane, 12435 Winding Lane, and 4000, 4002, and 4004 William Lane; and bar holes drilled in the intersection of Welling and Whitehall.

WGL continued to search for leaks, and combustible gas indicators continued to detect concentrations of gas throughout the area. A few small leaks on the packing glands of valves were located and stopped. However, no significant leaks were found. WGL began operations to draw the entrapped gas from the ground. The following morning, the residents of the evacuated houses, except for those of 12435 Winding Lane and 4000 William Lane, were permitted to return. Some traces of gas were still detected in those two houses, and those residents returned to their homes on June 25.

The Accident Site

The explosion occurred in a residential subdivision of Bowie, Maryland, constructed in 1965. Gas service was provided by a 6-in. steel main located on the east side of Whitehall Drive. The maximum allowable operating pressure for the main was 60 psig, but it was operating at 20 psig at the time of the accident. A $\frac{1}{2}$ -in. plastic branch service line supplied both 12321 Welling Lane and 12403 Whitehall Drive. (See Figure 2.) The plastic service line was Driscopipe Series 5,000, manufactured by Drilling Specialties, Inc.--a subsidiary of Phillips Petroleum Company (Phillips). The line, a schedule 40 pipe, was of high-density polyethylene Marlex TR212 resin and black. The main and service line were installed in the fall of 1965. On November 1, 1965, the service line was leak tested at 16-in. mercury for 5 minutes and was pressure tested at 100 psig for 15 minutes.

At that time, sketches were being used by WGL to show how the service connection to the main should be made. WGL practice was to use the same basic installation WGL had been using for copper tubing service lines, except that special service tees had to be made to complete the necessary connections. The $\frac{3}{4}$ in. x $\frac{3}{4}$ in. x $\frac{1}{2}$ in. compression outlet tee, which was required to connect the service line to the main, was not available commercially. WGL purchased the pipe and supplied it to a subcontractor, who installed the service line for the builder. The final connection of the service line to the main was made by WGL personnel. The service line was installed 40 in. below the ground, and in the process of coupling it to the steel main, the service line was bent slightly upward at a 30° angle. It was attached to a tee on the main by means of a standard compression coupling.

A $4\frac{1}{2}$ -inch-long aluminum pipe stiffener was used on the end of the plastic pipe that was placed in the compression coupling. (See Figure 3.)

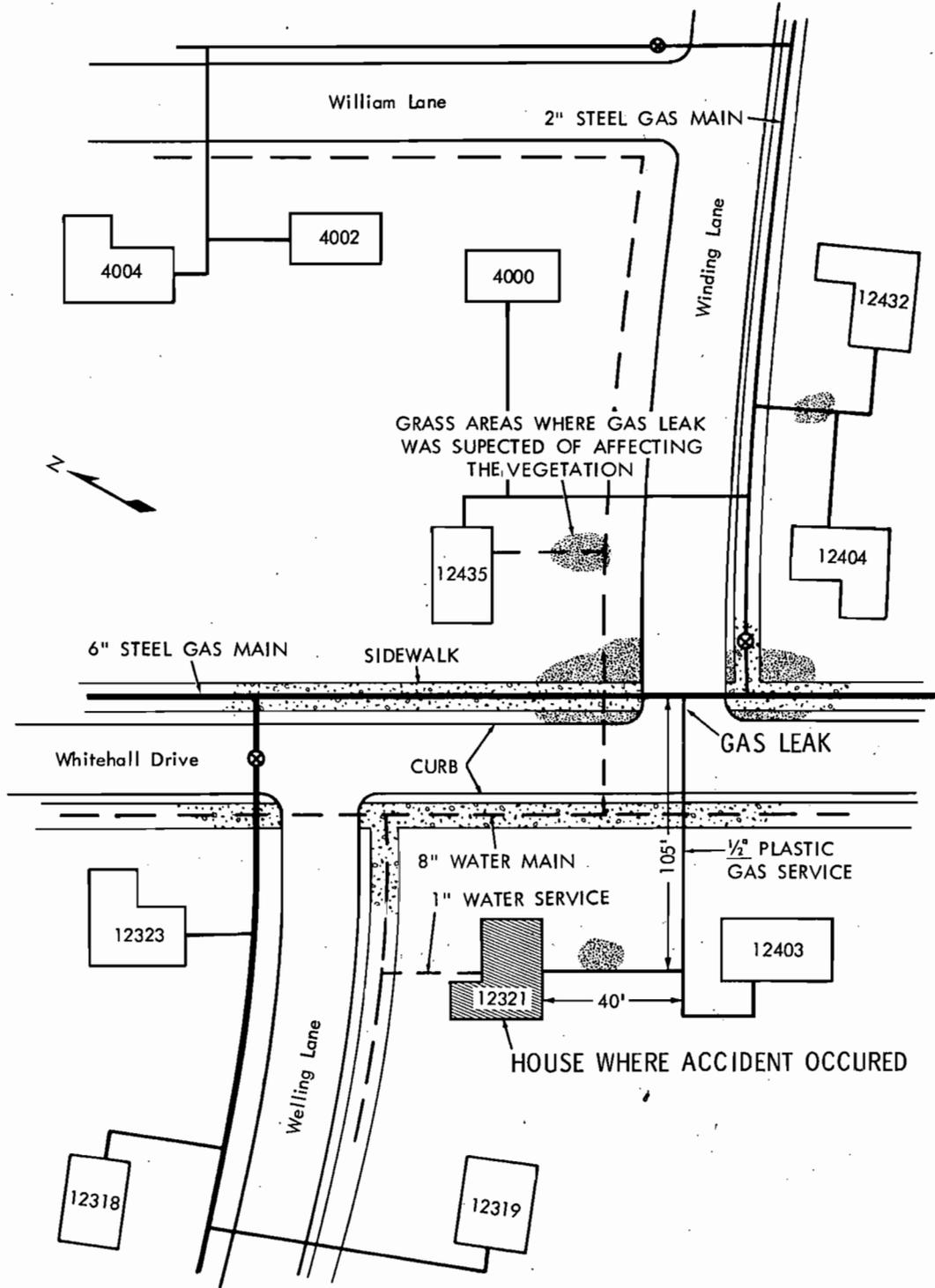


Figure 2. Accident site.

A meter, regulator, and shutoff valve were located at the back of each house where the service entered the building. There was no other shut-off valve on the service line. The service line sloped upward from the main to 12321 Welling Lane.

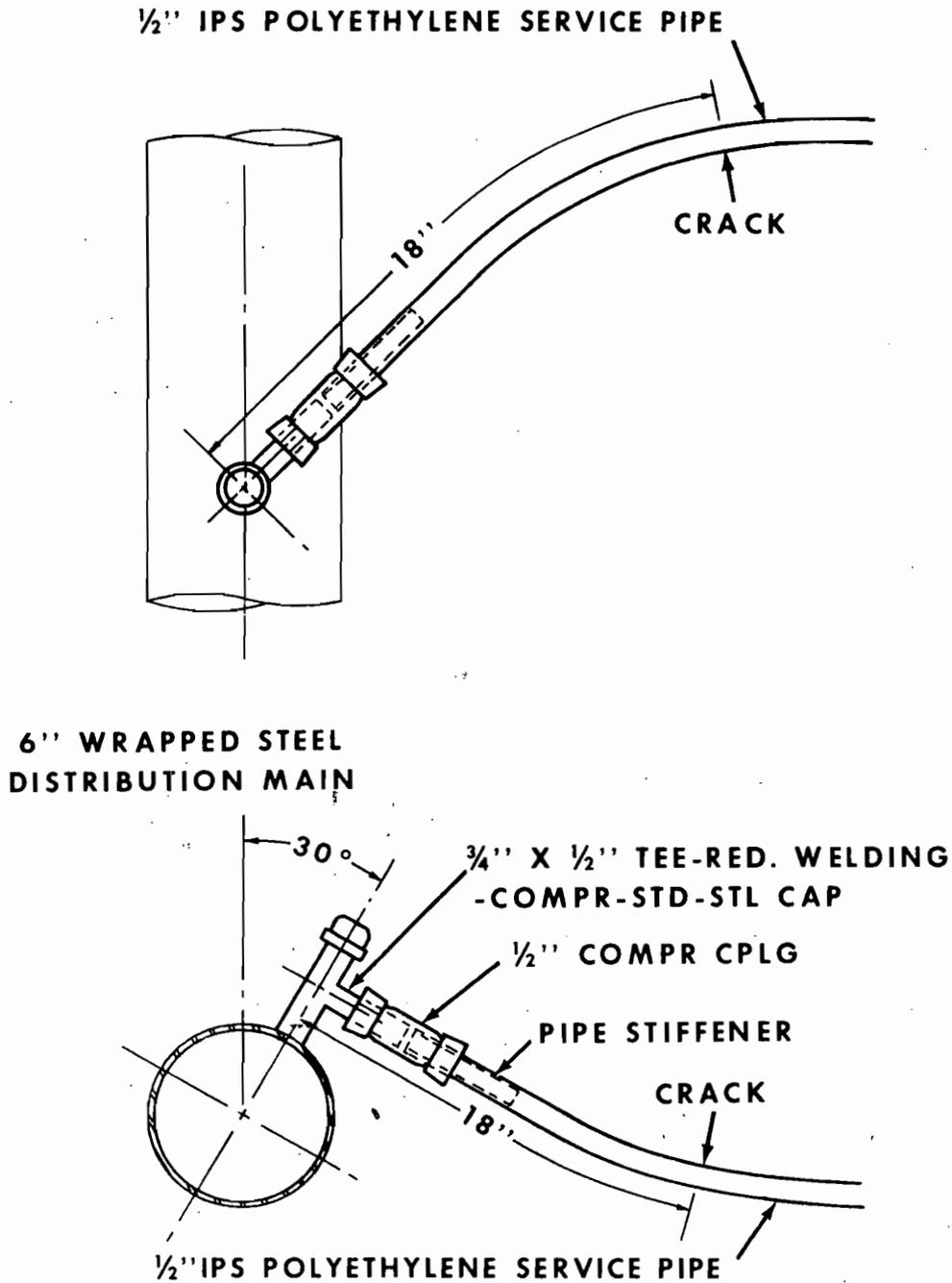


Figure 3. Plastic Service Connection to Steel Main

In the months following the installation, a paved street and sidewalks were installed. The steel main was then beneath the sidewalk on the side of the street opposite from 12321 Welling Lane. (See Figure 2.)

The house was a single-story, frame building with a shake and brick veneer front and an asphalt shingle roof. The house was built on a concrete slab placed on gravelly sand. The heating and air conditioning ducts were beneath the slab, and the registers were located in the floor of the house.

Description of Losses

A woman and her daughter died in the house; the father and son escaped from the house, but the father died from burns the following day. The son was burned, but survived.

The house was badly damaged by the explosion. The walls of the front bedroom, the family room, and the living room were pushed off the foundation. The sliding glass doors in the family room were blown out into the yard. The walls showed signs of heaving, and the upper areas of the building were burned. The greatest accumulation of gas appeared to be in the family room, since it showed signs of the highest pressures of the explosion venting process and the deepest and largest amount of wood charring. The property loss was estimated to be \$53,000.

Events Preceding the Accident

On January 19, 1973, 5 months before the accident, the resident of 12321 Welling Lane reported to the fire department a scorched area on the inside of an exterior garage wall at floor level. The fire department inspected, but could find no cause for the scorched area. No gas odors were detected and no tests were made with combustible gas indicators. The fire department concluded that the fire might have been caused by vapors from combustibles stored too close to the furnace.

No gas leaks had been reported to WGL from residents in the vicinity of the accident for at least 6 months before the accident. In 1973, WGL appliance servicemen had made nine service calls to houses within a two-block area of the accident to turn gas service on or off and to check appliances. In January and February 1973, WGL's maintenance crews were upgrading valve boxes in the area. The crews worked on eight valves in the area 7 days during the 2 months. Neither the servicemen nor the maintenance crews reported any gas odors.

In 1969 and 1971, WGL conducted vegetation surveys in the accident area. A similar survey was scheduled for the accident area later in 1973. In 1970 and 1972, a manhole survey was conducted during which all manholes, valve boxes, meter boxes, sewer, and street openings were checked

with a combustible gas indicator. No leaks were found in the area of the accident.

Weather Conditions

During the 2 days before the accident, 1.62 in. of rain were measured at the Baltimore-Washington International Airport (BWI). On June 21, the temperature varied from 68° to 90°F, on June 22, from 65° to 77°F, and on June 23, from 65° to 82° F. On June 23, the winds averaged 4.2 mph from the northwest with gusts to 14 mph.

The day a scorched area was reported to the fire department, 0.27 in. of rain, in thundershowers, was measured at BWI. The temperatures ranged from 34° to 62°F.

Tests and Surveys

Two days after the accident, holes were drilled in the concrete slab of the house, and readings of gas concentrations were taken beneath the slab and at other locations in and around the house. High, but varying, concentrations of gas (up to 66 percent gas in air) were detected at all locations. Soil samples were also taken.

Leakage Survey. On June 26, a leakage consultant inspected the accident area. He reported the presence of natural gas under the slab, in the heating ducts, and around the house. ^{1/} Explosive concentrations of gas were detected in bar holes throughout the area. The highest reading, 60 percent gas, was found over the gas service near the southwest corner of 12432 Winding Lane (See Figure 2.)

Grass and shrubbery at Winding Lane and Whitehall Drive appeared affected by gas leakage. Although natural gas is not toxic to vegetation, it does dry the soil and displaces oxygen. Vegetation behind 12321 Welling Lane (over the gas service), in front of 12435 Winding Lane (over the water service), and at 12432 Winding Lane (over the gas service) also showed symptoms of leaking gas. Combustible gas readings were detected in the same locations.

The consultant also reported that, although a gas sample taken over the gas service in front of 12432 Winding Lane held a 60-percent combustible gas reading, the sample did not have a discernible odor. However, gas odors did emanate from other openings over the mains and services in the area.

Geological Survey. To determine the reasons for the continued presence of residual gas in the ground, the Safety Board requested that

^{1/} Special Investigation for National Transportation Safety Board, Heath Consultants, Inc., Report No. 2-DC-104-SP-904.

the Federal Highway Administration (FHWA) investigate the geological conditions in the area. The FHWA reported 2/ that the 6-in. gas main and the 1-in. service line at the point of the leak were in relatively permeable soil under an almost impervious road pavement. The pavement subbase was underlain by sand in a silty, clayey matrix. Most of the materials at the site contained some clay, ranging up to 26 percent by weight of the material in the samples. The principal clay minerals were found to be kaolinite and montmorillonite. These materials are relatively permeable when dry, but may be nearly impermeable when wet. This complex was underlain by a rapidly permeable sand-gravel deposit.

These sand-gravel layers formed a gas reservoir which extended under the accident site, including the two houses (12321 Welling Lane and 12435 Winding Lane) in which combustible gas readings were detected. (See Figure 4.) The presence of the montmorillonite clay had a strong influence on the water and gas permeability of these soil formations. Montmorillonite easily adsorbs large volumes of water and swells to fill the pores in these sandy soils, making the soils less permeable to gas and water.

Research conducted at the Institute of Gas Technology 3/ has found that clay minerals such as kaolinite and montmorillonite will adsorb the low molecular weight sulfur compounds used as odorants in natural gas. Montmorillonite clay was the strongest adsorber of odorant compounds of all the materials in the study. (The three most abundant clays in the United States are montmorillonite, illite, and kaolinite.) The FHWA also reported that the gas escaping from pits and auger holes, dug for soil samples and gas purging, had no smell. The gas escaping from the boring under 12321 Welling Lane was odorless at concentrations up to 20 percent. At the same time, soils from 0-30 in. above and at the level of the gas pipe had a strong odor long after they had been aerated to zero gas content.

The FHWA reported that the gas leaked in 12321 Welling Lane did not flow through the utility trenches. Density tests show these trenches were filled with soil more compact than the soil adjacent to the gas line trenches. One low-density area was found in the water line trench, but fill on both sides of it was relatively dense.

When the gas readings persisted, WGL tested the mains and services in the area. The lines were taken out of service and tested with air. No leaks were found. WGL also injected freon gas into the mains and tested the bar holes to see if any new gas was leaking. The test was also negative.

2/ "Soil Investigation at Site of Gas Explosion, Whitehall Subdivision, Bowie, Maryland;" Jerome R. Blystone, Highway Research Engineer, Materials Division, Office of Research, Federal Highway Administration, Washington, D. C.

3/ "Soil Adsorption of Odorant Compounds," D. V. Kniebes, Institute of Gas Technology, Odorization Symposium, 1971. (Initial test results published in 1961.)

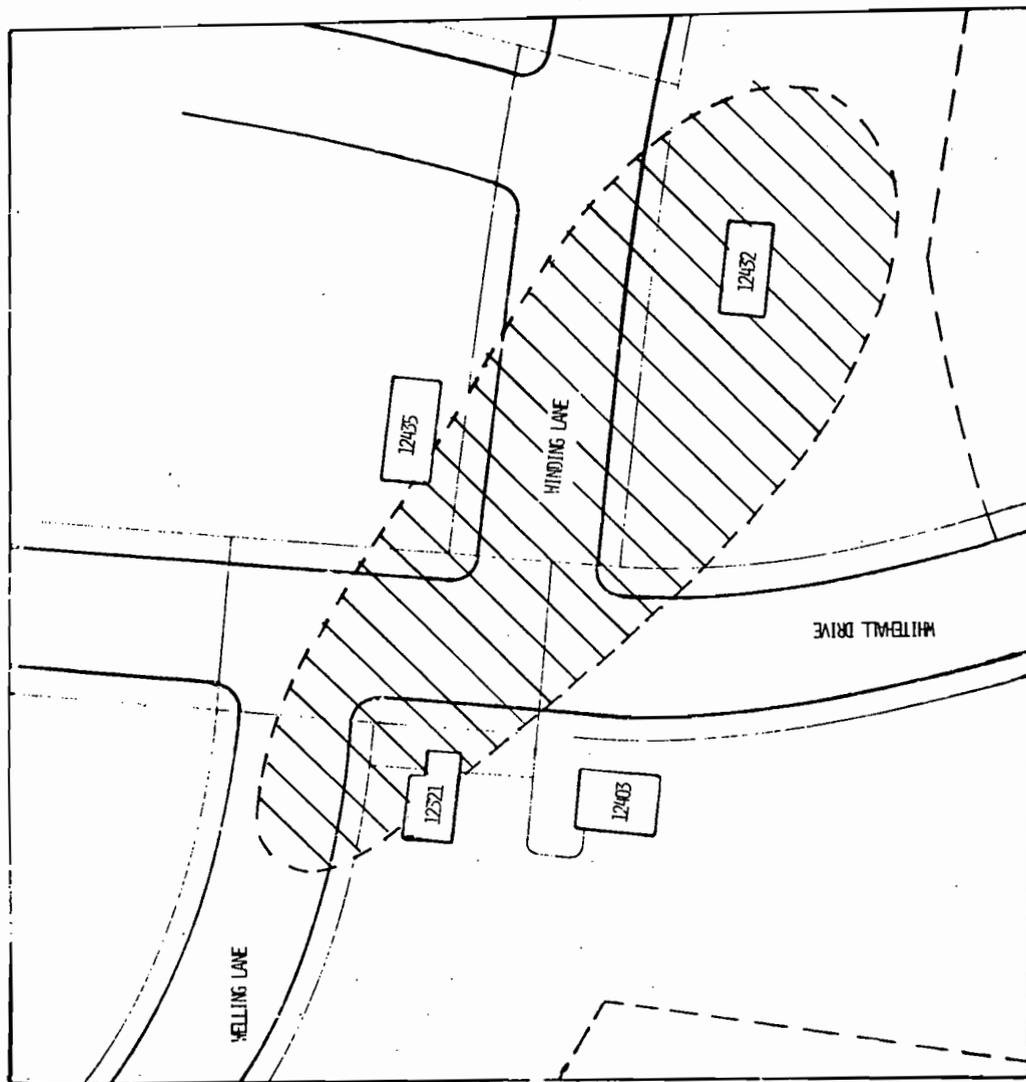


Figure 4. Location of gas reservoir -- indicated by hatching.

The fire department and WGL set up a monitoring system in which combustible gas indicator readings were taken at 184 locations in the area every hour. The frequency of readings was later reduced to every 2 hours. The test points were bar holes in streets, yards, water boxes, and manholes. For 2 months after the accident, WGL continued aspiration of the barholes using air compressors and ventilation of the strata through a number of open cuts made into gas and water trenches to a depth just below the pipe. Although gas concentrations decreased in the soil, the gas did not dissipate as quickly as expected.

Based on the discovery of the deep reservoir of gas, in August 1973, WGL drilled 17 4-in. venting holes to depths of 20 feet and inserted perforated plastic drain pipe. WGL developed a squirrel-cage fan to increase the suction on the vent holes. In addition, five 7-foot x 4-foot venting shafts, each 12 feet deep, were excavated. The fan-type aspirators were effective and shortened the time necessary to reduce the gas concentrations to acceptable levels.

By October 17, 1973, the tests at the bar holes, water boxes, and manholes were discontinued, and the venting shafts and six of the venting holes were backfilled. The remaining 11 venting holes were then monitored for 12 hours each day, between 7:30 a.m. and 7:30 p.m. (See Figure 5.) The fan aspirators were turned on whenever gas readings were obtained. The remaining vent holes were gradually backfilled, so by March 1974, two holes were being monitored three times a day and aspirated as required.

During the week of June 3, 1974 -- a year after the accident -- concentrations up to 40 percent gas were found around 12323 Whitehall Dr., across the street, and uphill from the house which exploded. Additional shafts were dug to help dissipate the gas in the reservoir. Heavy rains had fallen in the weeks and days before June 3, forcing gas still trapped in the reservoir to the surface. WGL was alerted to this problem by the homeowner who complained about dying vegetation.

Plastic Pipe Failure

The failed section of plastic pipe was analyzed by the National Bureau of Standards (NBS). The NBS found a 1.5-in. long, J-shaped crack in the pipe. (See Figure 6.) The pipe was found to be visibly flattened just beyond the end of the longitudinal portion of the crack.

Tests indicate that the density and melt index were normal. The density, melt index, and the absence of cracking or splitting of the pipe or lengthening of the nick in the flattening tests, were good indications that pipe compound had not deteriorated because of poor extruding or fabricating techniques or subsequent aging.

The wall thickness in the immediate area of the probable point of initiation of the crack was in compliance with manufacturer's specification

The section of pipe which contained the crack was cut open longitudinally to expose the inner wall. The following were observed: (1) The crack extended for an additional 1.25 in. longitudinally along the inner wall, although not in as straight a line as that on the outer pipe surface. (2) An occluded particle was embedded in the crack and protruded through the inner wall. The particle was located about 0.2 in. from the end of the curved portion of the crack. The protruding part

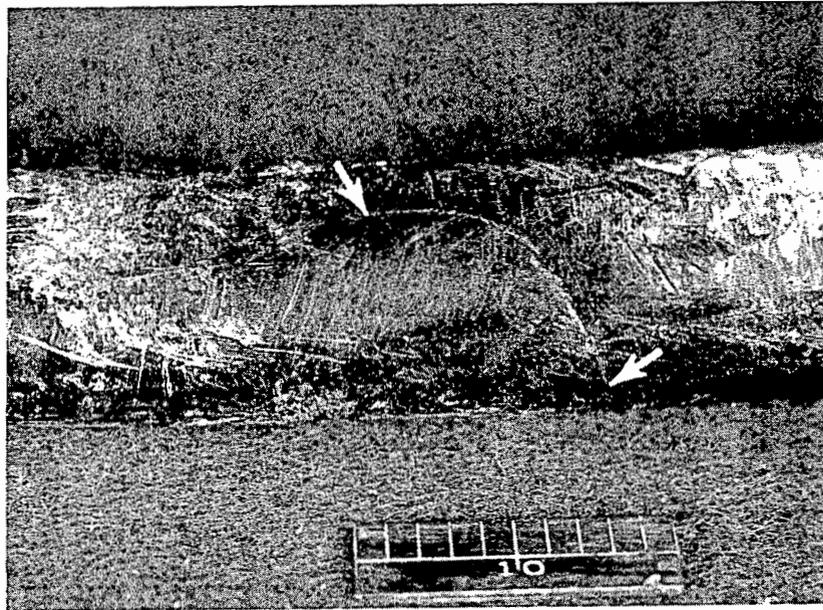


Figure 6. Closeup of crack with arrows showing extent of crack on the outer surface of the pipe.

of the particle was sharp to the touch and appeared to be firmly embedded in the crack. Under microscopic examination, the particle appeared to be a grain of sand. In addition, it was noted that some of the plastic had been extruded into the interior of the pipe, around the particle on both sides of the crack. The distortion of the inner wall surface caused by the displaced plastic material was somewhat greater along the inner side of the curvature of the crack. (See Figure 7.)

THE NBS concluded:

"From this investigation, it was concluded that the cause of failure appeared to be due to a stress crack initiated by the presence of an occluded particle, which acted as a stress point, in the inner wall of the pipe. All observations seemed to indicate that the particle became lodged in the wall during some stage of its fabrication, and that in acting as a stress point, weakened the pipe. The stress crack probably propagated to its final size as a result of exposure to a variety of possible forces on, and possibly within, the pipe wall.

"Evidence obtained by microscopic examination indicated the occurrence of a small leak through the pipe wall at a

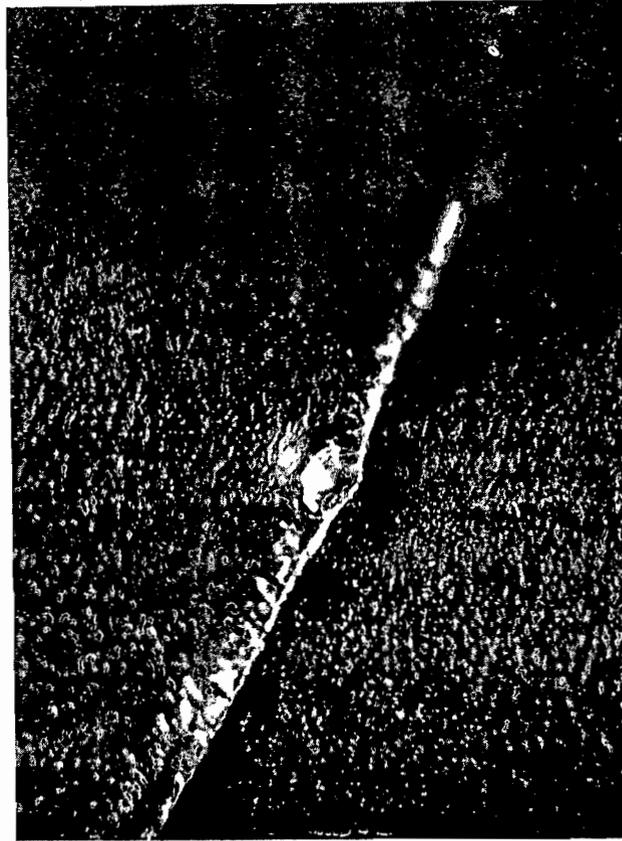


Figure 7. Illustration of the occluded particle in the crack in the inner wall of the pipe at 12X magnification.

point directly above the site of the occluded particle, and a second probable small leak that appeared to have been caused in part by the presence of the stress crack which had propagated along the inner wall from the site of the occluded particle. The full crack between, and extending slightly beyond these two sites, may have been very recent; and as far as final propagation through the outer surface of the pipe wall was concerned, may have been abrupt in nature." (See Appendix A.)

Plastic Pipe

Use of Plastic Pipe by WGL. -- In late 1964 and early 1965, the WGL group which tested the ½-in. Marlex TR212 plastic pipe, recommended that the pipe be considered acceptable for WGL's distribution system. It qualified its recommendation, pending further experience with the pipe, by limiting the use of Marlex to specific problem areas, such as those

encountered in sections of Bowie, Maryland, where highly corrosive soil conditions were prevalent.

By 1967, 600,000 feet of $\frac{1}{2}$ -in. Marlex plastic pipe was installed in the Bowie area. In 1968, WGL began to use a high-density, high-molecular weight plastic. Also in 1968, WGL began to use the medium-density PE2306 plastic for installing plastic systems using the heat fusion welding technique. The rate of increase in usage was governed by the rate at which construction crews could be trained in the new procedures and all WGL facilities could be converted to the change from metal to plastic services. A Plastics Manual was also developed by WGL to aid field personnel in the handling and installing of plastic pipe.

WGL indicated that it had never experienced a failure similar to the one which occurred in Bowie. It had, however, experienced numerous leaks in the plastic distribution system. For the 6-month period ending in April 1974, 600 leaks were reported in plastic service lines. Many of the leaks occurred at the point where the plastic service line was coupled to the metal compression coupling. These leaks resulted from a cold flow of the coupling gasket or from the plastic pipe itself. Plastic service lines have also broken at the point where the flexible pipe meets the more rigid main or meter riser. These breaks are shear and usually result from settlement because of poor backfilling. Other lines have broken where the pipe was bent during installation. Damage during excavation and other outside forces also caused many leaks.

The manufacturer of the pipe indicated that a break of this nature had never been reported to them by those gas utility companies who used their pipe. Phillips, the manufacturer of the plastic pipe, does not agree with the findings of the NBS. Phillips believes that a screen pack recommended for the extrusion operation would not have allowed a particle of the size found to pass through the extruder and into the pipe wall. The shape and orientation of the crack in the outside pipe wall, with regard to the direction of extrusion of the pipe, are contrary to established, well-known pipe stress failure phenomena resulting from a molded-in imperfection. Further, Phillips stated the particle was not encapsulated in the resin, which it would have been had it been molded into the pipe. Phillips believes that the pipe could have failed if it were first damaged by an external force before or during installation--during shipping, storing, preparing for installation, installing, or backfilling. Phillips also states that the occluded particle could have been introduced through the crack and was caught in the location where it was found.

Plastic Pipe Research. In June 1974, the Office of Pipeline Safety let a research contract containing various plastic pipe objectives. The objectives of the study are as follows:

"...to provide:

1. Criteria for the selection of the basic plastic material, manufacture of pipe and fittings, installation, and inspection of new systems.
2. Current information on joining techniques, methods of quality control and nondestructive testing of joints.
3. An evaluation of plastic pipe used in gas service, manufactured prior to and to other than a standard referenced in Part 192, and problems common to the use of such pipe.
4. Information concerning appropriate operation and maintenance procedures for current plastic piping systems.
5. A description of the common problems experienced in plastic piping systems and known solutions to those problems.

Odorization

WGL's Odorization Practices. WGL injects a gas odorant into its distribution system at Rockville, Md., and at Herndon, Va. The odorant is a blend of 80 percent tertiary butyl mercaptan and 20 percent dimethyl sulfide. The injection rate for the odorant varies seasonally between 1/2 and 3/4 pounds per million cubic feet of gas. Tests of the odor in the gas are made continuously throughout the distribution system at selected main valve locations. A wet chemical test is performed to measure the amount of mercaptan odorants in the gas, and an odorometer is used to determine the percentage of gas in air at which the odor of gas is readily perceptible. The gas for performing the tests is taken from the gage line connections located in valve boxes. The odor test point closest to the accident site was located about 1 mile away and was checked monthly. Tests made at that location from January to July 1973 are summarized below:

<u>Date</u>	<u>lbs/MMCF of Mercaptans</u>	<u>Percent Gas in Air Readily Perceptible</u>
Jan. 17	0.57	0.33
Feb. 2	0.15	0.35
March 9	0.94	0.19
March 29	0.61	0.22
April 19	1.10	0.18
May 17	0.93	0.31
June 11	0.05	0.11
June 23	No test made	0.48

On June 23, 1973, after the accident, the following odor test results were obtained:

<u>Location in Bowie</u>	<u>Percent Gas in Air Readily Perceptible</u>
Whitehall Dr. and Old Chapel Rd.	0.43
Welling Lane and Woodhaven Lane	0.26
Windover Turn and Winding Lane	0.21

Before the accident, WGL appliance servicemen would report any instances in which gas odors were not readily recognizable. Maintenance and repair crews would also report poor odor conditions for gas coming from piping in the street. Special odor tests were then conducted at valves in the area to determine the need for supplemental odorization. No attempt was made to determine the adequacy of gas odors for gas passing through soils.

After the accident, WGL changed its procedures to include checks on gas passing through soils. When odor problems were found, WGL conducted immediately leak tests in the area in an attempt to locate leaks not detectable by odor. The time between future leak surveys in these areas was also shortened.

In addition, WGL established a vegetation survey training program for all of its personnel who have occasion to visit its customers' premises (servicemen, meter readers, etc.). All suspected areas of vegetation damage are reported for followup by WGL. Obviously, this program can only be used during the growing season.

Gas Odorization Research. -- In its Gas Industry Research Plan 1974-2000, 4/ the American Gas Association specified all requirements for research on gas energy that are of major significance. With regard to gas odorants, two areas of research were identified: (1) The development of an improved odorant that would be effective at concentrations of 5 parts per million cubic feet or less, effective at 1/10 the concentration where it becomes objectionable, environmentally acceptable, and would cost about the same as current odorants. (2) A portable device capable of detecting odorants below human detection levels is needed. It would be used for sensing the odorant levels of gas entering a system, monitoring odorant addition, and checking for gas leaks. More than \$1.6 million will be needed for these two research efforts in the next 5 years.

In June 1974, the Office of Pipeline Safety let a state-of-the-art contract on odorants. The contract states:

"The purpose of this contract is to provide current state-of-the-art information relative to the odorization of natural gas. Comprehensive background information is to be developed on the present-day criteria for the selection of an odorant for various operating and

4/ M-20274, American Gas Association, Arlington, Va., January 1974.

system conditions. Also comprehensive background information is to be developed for the design, location, construction, operation, and maintenance of facilities required for odorization of natural gas and the handling, storage, and transfer of odorants. The physical and chemical characteristics of the various odorants and the advantages and disadvantages of each is to be presented. Investigation is to be made of research that has been done, is being done, or is proposed on gas odorization. This should include both foreign and domestic sources."

Based on the findings of the study and on the contractor's recommendations, OPS will consider making changes or additions to the Federal regulations or conducting further research and development that might be needed to improve the effectiveness of odorants and odorization equipment.

Applicable Standards

In 1965, when the gas distribution system was installed in the Whitehall section of Bowie, there were no Federal regulations concerning gas piping systems. Under the regulations of the Public Service Commission of Maryland, effective July 1, 1964, gas pipeline operators were required to comply with the current edition of the American Standard Code for "Gas Transmission and Distribution Piping Systems," ASA B31.8 (B31.8 Code). The 1963 edition was in effect in 1965, and the use of plastic pipe for the gas piping system was not covered. That edition included specifications for the use of steel, cast-iron, and copper pipe for mains and services.

The Code did have a specification for qualifying materials not covered. Paragraph 811.24 stated:

"Items of a type for which no standards or specifications are listed in this Code may be qualified by the user, by investigation, and tests (if needed) that demonstrate that the item of material or equipment is suitable and safe for the proposed service, and provided further that the item is recommended for that service from the standpoint of safety, by the manufacturer...."

The 1968 edition of the B31.8 Code was the first to include specifications for the use of plastic pipe. 49 CFR 192 does not include similar requirements for use of new material, but 192.53 does require that materials for pipe and components must be:

- "(a) Able to maintain the structural integrity of the pipeline under temperature and other environmental conditions that may be anticipated;

- (b) Chemically compatible with any gas that they transport and with any other material in the pipeline with which they are in contact; and
- (c) Qualified in accordance with the applicable requirements of this subpart."

There are no guidelines available in the ASME Guide for Gas Transmission and Distribution Piping Systems to provide more details, so that gas system operators can comply with the above requirements.

Specific requirements for use of steel, cast-iron, ductile iron, plastic, and copper pipe are stated in 49 CFR 192.55, 57, 59, and 61, respectively.

Concerning odorization practices, 49 CFR 192.625, Odorization of Gas, states in part:

- "(a) Combustible gases in mains and service lines must be odorized as provided in paragraphs (b) through (f) of this section.
- (b) The intensity of the odor of combustible gases must be such as to be readily detectable at concentrations of one fifth of the lower explosive limit.
- (c) Each operator shall conduct periodic sampling of combustible gases to assure the proper concentration of odorant in accordance with this section."

There are no guidelines in the ASME Guide concerning testing for proper odorant concentrations.

Concerning leakage surveys, 49 CFR 192.723, Distribution Systems, Leakage Surveys, and Procedures, states in part:

- "(b) The type and scope of the leakage control program must be determined by the nature of the operations and the local conditions, but it must meet the following minimum requirements:
 - (2) Leakage surveys of the distribution system outside of the principal business areas must be made as frequently as necessary, but at intervals not exceeding 5 years."

The ASME Guide contains a separate appendix on Gas Leakage Control Guidelines. These comprehensive guidelines provide criteria for the detecting, grading, and controlling of gas leakage.

Because of this accident and other recent accidents in Maryland, the Public Service Commission has revised its gas safety regulations. The major changes require gas leakage surveys of distribution systems outside of business areas, conducted by the hydrogen flame ionization (HFI) method or by the use of combustible gas indicators (CGI) and bar hole method, not less than once every 3 years. In addition, a leakage survey, by use of HFI or CGI equipment, is to be conducted within a customer's premises at appropriate locations, including atmosphere samples at all utility service entrances, by a company serviceman when he makes a service call at a customer's premises.

In regard to odorization, the new regulations require that the odorant level throughout the entire distribution system be such that gas will be detectable at 10 percent of the lower explosive limit. A review system is also to be established to keep track of areas where leaks were detected without the presence of odorant. Prompt leakage surveys conducted by HFI or CGI are required to determine the possible extent of the leakage area, and annual surveys are required of that area as long as the odorant adsorption condition exists.

On July 22, 1974, because of the potential dangers of residual gas remaining in the ground, new leaks, and odorant adsorption, the Maryland Public Service Commission directed WGL to install continuous gas detection and alarm devices within each residence in the residual gas area (about 12 homes). If the residual gas area should spread, devices will have to be installed in additional residences. WGL is also continuing to test for gas in the area and is using fan aspirators when gas is detected in the ground.

ANALYSIS

Period of Leakage

It could not be determined when the leak began, but several factors indicate that it existed for at least 5 months. The unexplained fire at 12321 Welling Lane in January was probably a result of leaking natural gas. The effects of the rainfall described above may have also occurred on that occasion since a thundershower occurred during the day. In addition, the lack of any new grass growth indicates that a gas leak existed at the beginning of the growing season.

The condition of the shrubbery also indicated that gas had been leaking for some time, because shrubbery can withstand greater concentrations of gas for longer periods than grass. The leakage rate was initially small, but increased as the crack in the plastic service line became larger.

Migration of Leaking Gas

The gas flowed from the leak and accumulated in the porous sand and gravel and formed a "gas reservoir." The formation was covered by less permeable clayey materials. (See Figure 8.) The heavy rainfall in the days before the accident had a dual effect. First, it caused the water table to rise, which reduced the volume of the gas reservoir and increased the pressure on the trapped gas. Second, the overlying material became wet and relatively impermeable, which sealed off the trapped gas. The increased gas pressure in the reservoir caused some of the gas in the sand and gravel layers to flow through the less permeable soil under the concrete slabs of the two houses; through their heat ducts; registers, and other openings in the slab; and into the houses.

Since the sulfur compounds in the odorant in the gas had been adsorbed by the clay minerals in the soil, the occupants of the houses were not aware of the hazard.

During dry weather, the roadways trapped gas in the base course and soils under the pavement. During wet weather, the roadway kept these materials dry so they acted as conduits and allowed gas from the leak to flow to the extreme areas of temporary gas concentrations.

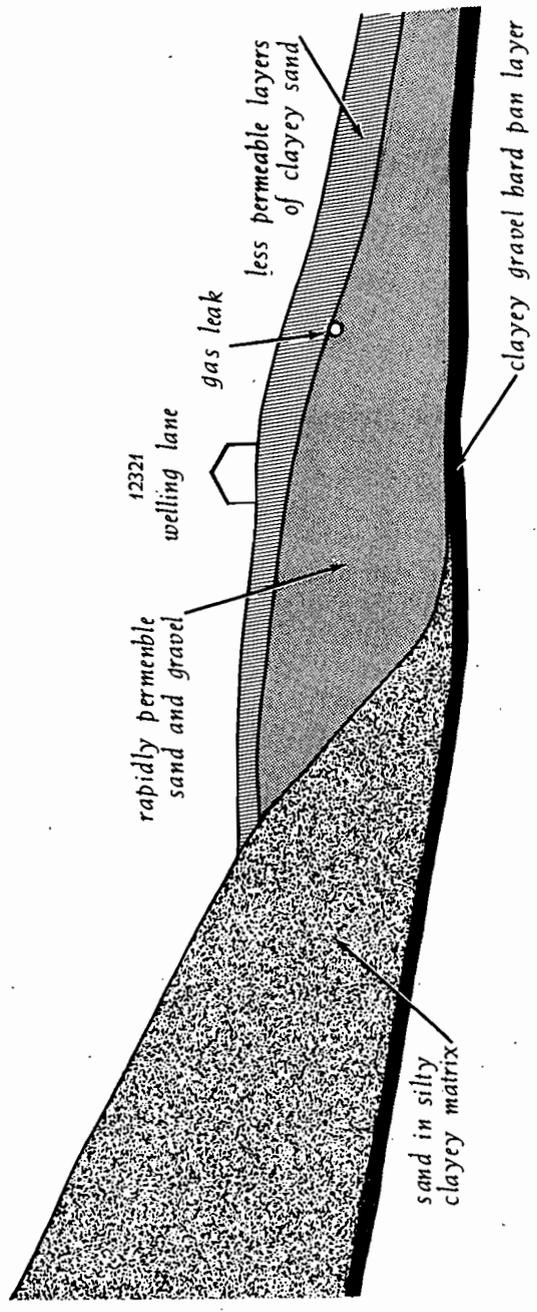
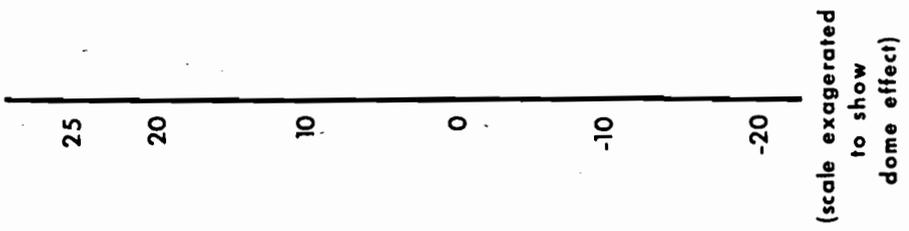
General Problem of Migration of Leaking Gas

In at least 10 recent pipeline accidents, on which the Safety Board has issued reports, gas escaping from underground leaks has entered buildings through porous floors, basement walls, spaces where pipes enter, and ventilation ducts. ^{5/} As a result of these accidents, including this accident, 40 people have died.

In its accident report on a gas explosion in Annandale, Va., the Safety Board recommended that the flow of natural gas through various basement wall materials and various types of construction be studied. The study was also to include effective methods of sealing the space around underground utility lines where they enter buildings. The recommendation, issued on February 2, 1973, was directed to the joint program for "Building Practices for Disaster Mitigation" which is administered by the National Science Foundation (NSF), the Office of Emergency Preparedness, and the National Bureau of Standards (NBS). To date, no research has been conducted or proposed.

In the same report, the Safety Board also discussed the flow of gas through various types of fill and recommended that the American Gas

^{5/} Annandale, Va., Report No. NTSB-PAR-72-4; Lake City, Minn., NTSB-PAR-73-1; Clinton, Mo., NTSB-PAR-74-3; El Paso, Texas, NTSB-PAR-74-2; Charleston, W. Va., NTSB-PAR-74-4; North Richland Hills, Texas, NTSB-PAR-72-3; Fort Worth, Texas, NTSB-PAR-72-5; Atlanta, Ga., NTSB-PAR-73-3; Coopersburg, Pa., NTSB-PAR-74-1.



- PROPERTIES OF SOIL FORMATIONS**
- 
BOTH WATER AND GAS COULD RAPIDLY FLOW THROUGH THESE DEPOSITS EASILY FILLED BY DIRECT DOWNWARD PERCOLATING WATER
 - 
RELATIVELY PERMEABLE WHEN DRY BUT MAY BE NEARLY IMPERMEABLE WHEN WET
 - 
RELATIVELY IMPERMEABLE WHEN WET

Figure 8. Cross section of accident site.

Association study the problem and recommended methods and types of fill for use during installation of underground utility lines.

The need for the recommended work on flow of natural gas through fill and buildings was reemphasized by the FHWA experiments and tests conducted at Bowie. One recommendation of the FHWA report deals with the use of clay barriers in utility trenches at intervals, particularly near the building, to stop the flow of leaking gas that might rapidly migrate in sand backfill. The American Gas Association responded that the recommendation would be considered; however, to date no research has been conducted or procedures formulated.

Pipe Failure

The manufacturer of the pipe, Phillips, does not agree with the pipe failure findings of the NBS. The NBS believes that the crack initiated from a particle lodged in the wall of the pipe during fabrication, while Phillips contends that the pipe was accidentally damaged sometime after fabrication and the particle entered the pipe wall as a result of this damage. The Board believes that the facts uphold the NBS findings.

Contrary to the manufacturer's statement, the particle was partially encapsulated, as best illustrated by the deformation of the inner pipe surface along the top of the particle. (See Figure 7.) NBS believes the particle was firmly embedded in the pipe wall, because the particle did not fall out initially, even though the pipe was subjected to severe mechanical vibrations when the crack was being cut open and because an NBS technician contacted the particle heavily enough to scratch his finger while rubbing it over the particle without dislodging it. The particle did fall out of the cavity when transverse cuts were made to open the crack, but this was attributed to the known poor adhesion of polyethylene to other materials, and the fact that the particle was partially embedded in each surface of the crack. The cavity on each of the two crack surfaces had discrete characteristics which indicated that the particle became occluded while the compound was still soft, as it would be during the initial extrusion of the pipe. In addition, the lack of any evidence of external mechanical damage does not support the manufacturer's contention that the outside of the pipe was first damaged and that the particle was then introduced through the crack.

The manufacturer stated that a 20/80/20 screen pack was recommended for use during extrusion of the pipe; there are no records available that show whether that size screen pack was actually used. If an undamaged 80-mesh screen had been used, the particle could not have passed through it, although the particle could have passed through a 20-mesh screen. The downstream side of the screen could have been contaminated during the assembly of the screen pack and/or in placing it in the extruder.

The NBS findings as to the origin of the crack indicate that the service line failed due to a series of events.

The occluded particle that became lodged in the pipe wall during fabrication acted as a stress concentration point. At some time after fabrication, possibly before or during construction, the pipe was flattened or kinked. Improper backfilling may have caused settlement and movement of earth surrounding the pipe. The stress created in the pipe wall from this movement, in addition to stress from the gas pressure in the pipe, was concentrated at the point where the particle was located, and caused the crack. The crack grew larger as forces increased or were repeated. The gas leakage increased as the crack increased.

The full comments made by Phillips concerning the NBS report and the NBS answer to those comments are included in Appendix B.

Odorization

Although Federal regulations require that the odor of combustible gas be readily detectable at concentrations of 1 percent gas in air, actual tests performed on WGL's systems show that the gas was usually detectable at much lower concentrations. However, these tests were performed on gas coming directly from the pipeline system and not that which had been subjected to conditions that would exist if gas escaped underground.

This and other odorization problems, such as olfactory fatigue, which was pointed out in the Board's Charleston, W. Va., report must be studied. 6/

Cause of January 1973 Fire

When the fire department investigated the small garage fire in January 1973, there was no reason to believe that the cause of the fire was leaking gas. However, after a thorough review of the January fire, the fire department believes that it might have been caused by an accumulation of natural gas which came into the house. The fire department has changed its procedures to require improved investigative techniques for similar situations, including the use of combustible gas indicators whether gas odors are detected or not.

Use of New Materials

Since there were no specifications for plastic pipe in the regulations when the plastic pipe was installed, WGL qualified the plastic pipe by testing the material in accordance with the general provisions of the B31.8 Code.

6/ Report No. NTSB-PAR-74-4.

Based on current Federal regulations, any new material could be used for the transportation of gas without OPS approval. In fact, OPS would not even have to be advised that a material not referred to in the regulations was being used.

Whereas the development and use of new and improved materials should not be discouraged, the regulations should require that OPS be advised when new materials are placed in service. To do so would give OPS the opportunity to evaluate the new material and, possibly, to add requirements similar to those covering currently used materials.

CONCLUSIONS

The National Transportation Safety Board concludes that:

1. The occluded particle found in the wall of the filed pipe became lodged in the wall during some stage of its fabrication.
2. The gas which leaked into 12321 Welling Lane and other houses in the area did not contain sufficient odorant to make the gas detectable.
3. The odorant compounds added to the gas by WGL were adsorbed by the surrounding soil when the gas leaked from the service line.
4. Whereas the data on the adsorption of the odorant compounds by certain types of soils have been known to the industry since 1961, no appreciable action has been taken to use this knowledge to assure proper odorant protection of the public in all parts of gas distribution systems.
5. There are not enough data available to determine whether occluded particles in plastic pipe pose a significant safety problem.
6. A vegetation survey, or some other type of leakage survey, during the months preceding the accident probably would have revealed a gas leak.
7. Under the current Federal regulations, any material could be used to transport natural or other gas by pipeline without the Office of Pipeline Safety's knowledge or approval.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of the accident was the ignition of gas that had leaked from a stress crack in a plastic service line. The pipe cracked because an occluded particle had created a stress point and weakened the pipe.

Contributing to the accident was the lack of odor in the leaked gas when it reached the houses and the atmosphere.

RECOMMENDATIONS

The National Transportation Safety Board recommends that:

1. The Office of Pipeline Safety of the Department of Transportation:
 - (a) Require pipeline operators who use materials not specifically covered in the Federal regulations to formally advise the Department of Transportation of its use. (Recommendation No. P-74-37)
 - (b) In its study of plastic pipe, determine whether occluded particles during extrusion are a significant safety problem, and, if so found, take necessary regulatory action to control that problem. (Recommendation No. P-74-38)
2. The Department of Housing and Urban Development:
 - (a) Study the flow of natural gas through various basement wall and floor materials and through various types of construction. The study should include effective methods of sealing the space around underground utility lines and ducts where they enter a building, and methods of permitting gas to escape in the open atmosphere when conducted to these entrance areas. (Recommendation No. 74-39)
3. The American Society of Mechanical Engineers Gas Piping Standards Committee:
 - (a) Develop guidelines to assist pipeline operators to maintain adequate public protection in areas where odorant adsorption by soil could occur. (Recommendation No. P-74-40)
 - (b) Develop guidelines for the sampling of combustible gases to assure proper concentrations of odorant as required by 49 CFR 192.625(f). (Recommendation No. P-74-41)
 - (c) Develop guidelines to assist pipeline operators in training meter readers and others who work at customers' premises to detect vegetation areas that might be an indication of gas leakage. (Recommendation No. P-74-42)
4. The American Gas Association:
 - (a) Give a high priority to the problem of soil adsorption of odorant compounds in its planned research to develop an improved odorant. (Recommendation No. P-74-43)

- (b) Give consideration to measuring the odorant level of gas escaping from underground leaks in its planned research on odorant monitoring. (Recommendation No. P-74-44)
- (c) Develop methods of testing soils to determine the potential effect on odorants. (Recommendation No. P-74-45)
- (d) Study the natural gas permeating and migration phenomena in various types of soil and under paved surfaces. Based on the results of this study, recommend the use of certain types of soil for pipeline backfill material that will aid in allowing leaking gas to vent to the atmosphere at the leak location with a minimum permeation or migration effect. (Recommendation No. P-74-46)

5. The National Fire Protection Association:

- (a) Advise firefighting personnel of the phenomenon of adsorption of gas odorant compounds by certain types of soils. They should be reminded of the need to use combustible gas indicators when attempts are being made to detect the presence of leaking gas. (Recommendation No. P-74-47)

6. The Washington Gas Light Company:

- (a) Continue its efforts at the accident site to dissipate the residual gas remaining in the ground.
- (b) Continue to monitor and test the affected homes in the area for the presence of gas until no further hazard from the residual gas is apparent. (Recommendation No. P-74-48)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JOHN H. REED
Chairman

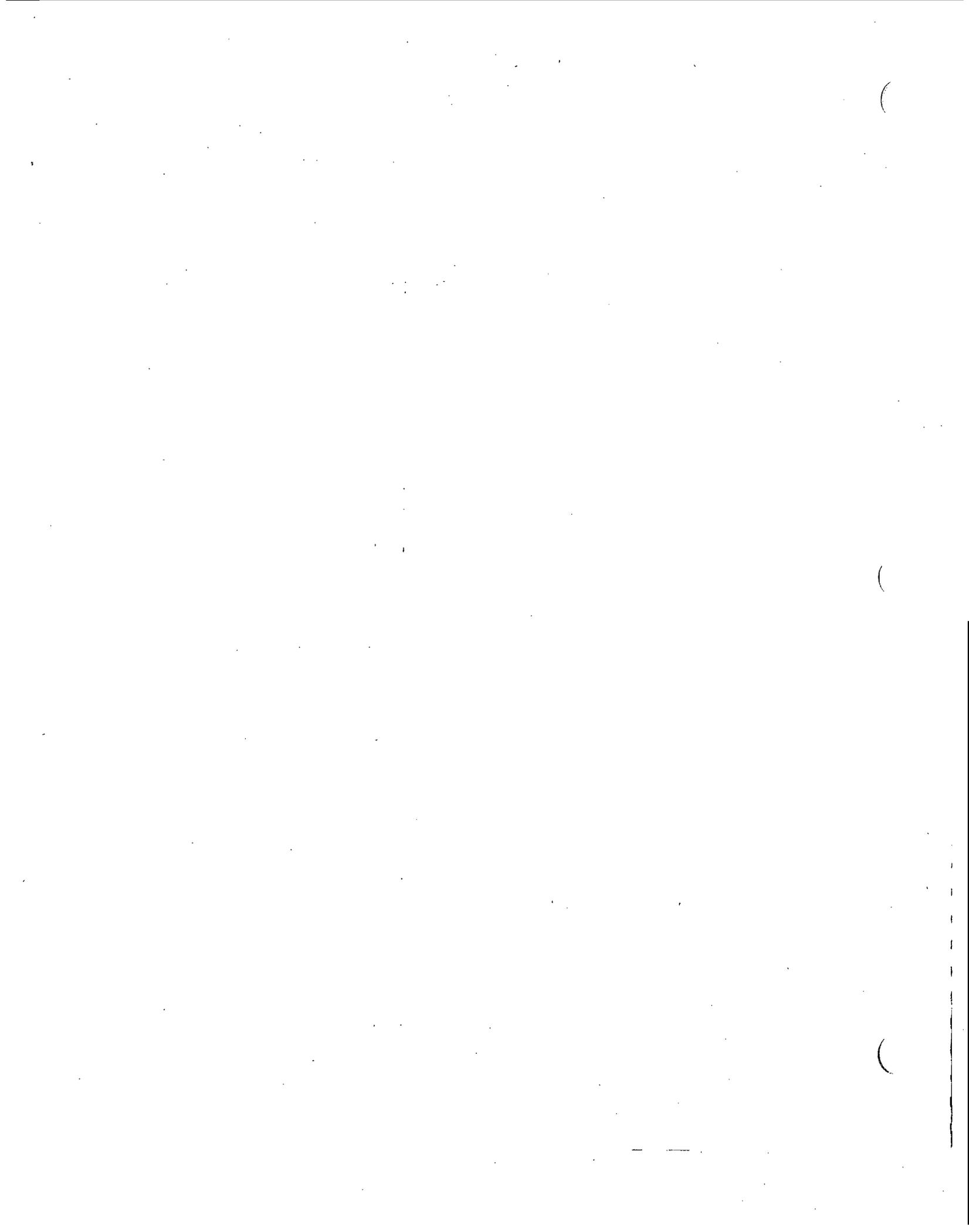
/s/ FRANCIS H. McADAMS
Member

/s/ LOUIS M. THAYER
Member

/s/ ISABEL A. BURGESS
Member

/s/ WILLIAM R. HALEY
Member

October 24, 1974



Appendix A

Excerpts from the National Bureau of Standards
Report of the Failure Analysis of a Polyethyl-
ene (PE) Natural Gas Service Line from Bowie,
Maryland

The NBS report noted that the basic pipe compound consisted of a carbon-black filled polyethylene-1-butene copolymer. Although the pipe was not so marked, the technical brochures supplied by the manufacturer indicated that it was in compliance with Commercial Standards CS197-60 and CS255-63 and was in compliance with type PE3306 plastic pipe as described in the latter standard. This code indicated that the pipe compound was produced from Type 3, Grade 3, high density polyethylene, resin and had a hydrostatic design stress rating of 600 psi for water at 23°C (73.4°F). This particular pipe was pressure rated for continuous use at pressures up to 190 psi for water and 95 psi with natural gas at 23°C (73.4°F).

Visual examination of the pipe disclosed a 1.5-inch-long crack in a modified "J" shape, with the stem of the "J" extending in a longitudinal direction of the pipe.

The longitudinal portion was on the order of 0.8 inches in length, with the remaining curved portion extending about an additional 0.2 inches in the longitudinal direction. The curved portion of the crack extended to a point where it was about 45 degrees to the transverse and longitudinal axes. The longitudinal section of the crack was located essentially on the inside of the bow.

The pipe was visibly flattened at a point just beyond the end of the longitudinal portion of the crack. At the point where the longitudinal portion began to curve, microscopic examination revealed the presence of a slight gap in the outer surface of the pipe. Preliminary tests indicated that this part of the crack seemed to have the highest leakage rate. This portion of the crack, measuring about 0.2 inches in length, was the only part of the crack in which there was an obvious separation of the two crack surfaces, in the outer surface of the pipe. Unfortunately, there was no way of determining whether this gap was present prior to exhumation of the section, or whether it occurred as a result of intentional attempts to straighten the section, e.g., to visually attempt to examine the interior of the pipe, by any of the several persons known to have had access to the pipe prior to its acceptance in the NBS laboratory.

The cracked section of pipe, in its received condition, was submitted to the NBS Fluid Meters Section, Mechanics Division, for air leakage tests. The pipe was pressurized to approximately 20 psig and maintained at that pressure for 30 minutes. The flow rate initially was measured at

2.31 cubic feet per minute, but increased to 2.82 cubic feet per minute after 30 minutes. The slight increase in flow rate was attributed to a possible slight straightening of the pipe.

After the crack was opened, the two surfaces of the crack were carefully examined by means of a stereo microscope over an approximate range of 12X to 60X magnification. The most significant points of interest were those areas including and surrounding the location of the occluded particle. At the point where the particle was located, each crack surface contained a discrete cavity. The one on the crack surface along the inner part of the curvature appeared to be slightly deeper than that on the opposite surface. However, each cavity seems to have rather discrete characteristics which would indicate, at the first approximation, the particle had become occluded while the pipe compound was still soft, i.e., during the initial extrusion of the pipe. One of the recommended procedures in the extrusion of this type of polyethylene pipe compound was that a 20/80/20 - mesh breaker screen pack be used in the extruder. Assuming this technique was used, the particle, if it had been a contaminant in the original pipe compound, would not have passed through an undamaged 80 - mesh screen, although it was small enough to pass through a 20 - mesh screen. However, this does not preclude the possibility of accidental contamination of the screen pack or extruder on the downstream side of the 80 - mesh screen. The inner wall of the pipe directly opposite the particle was carefully examined on the assumption that if the particle had gotten into the pipe during the installation, and was subsequently crushed with sufficient force to embed the particle into the pipe wall, that there should have been some visible damage on the opposite wall. No such damage was evident under microscopic examination. In addition, when a section of pipe was crushed, in a laboratory test, until the inner surfaces were in intimate contact, the specimen was permanently distorted out-of-round with respect to the specification requirements, a condition not observed in the immediate area of the occluded particle.

The sides of the crack above the particle extending to the outer pipe surface were examined for abrasion marks, such as could be expected to have been caused by the particle being forced into the crack from the outside. No such damage was observed. However, if such a situation had occurred, this would mean that the crack was already present when the particle was forced or fell into the crack. Since the site of the occluded particle was believed to be the obvious point of initiation of the stress crack, it would appear to have been too fortuitous for the stress crack to have been present and that the particle just happened to fall into and become lodged at this exact point. In addition, when the sample was received, there was no visible gap in the outer surface of the pipe wall through which the particle could have fallen. This portion of the crack was toward the inside of the bow in the pipe, and presumably could have been held closed by slight compressive forces at or near the outer surface of the pipe.

Above and around the particle cavity, the surfaces exhibited evidence of a brittle fracture of the type typically associated with stress cracking. One surface, in particular, was evenly coated with a rust-like stain, approximately 0.75 cm (0.3 inches) in width, surrounding the particle cavity and extending to the outer surface of the pipe wall. The opposing surface also exhibited staining, although not as evenly distributed over the entire surface, but also extending to the outer surface. As a result of observations it was concluded that the occluded particle created a stress point which later resulted in the formation of a stress crack extending through the pipe wall at that location. This crack presumably, because of the observed strains, occurred and resulted in the initial gas leak, at some extended period of time prior to the development of the crack to the size observed after the accident. The possible origin of a second gas leak was also observed. One possible assumption of its occurrence is that the crack propagated along the inner wall of the pipe, from the site of the occluded particle, and that a rupture at this point could have resulted from stresses in the pipe wall, since this site was located just within the area where the pipe began to be flattened out-of-round. Although the pipe wall was completely cracked through between the particle and the other site of stains, there were no stains that extended to the outer surface, although some staining of the sides of the crack were observed near the inner surface. This seemed to indicate that this portion of the crack, at least near the outer surface, was relatively recent. There were other random rust-like stains on the inner wall of the pipe, which indicated that their source, as well as those in the crack, could have been the nearby steel main.

Other potential sources of stress were noted as a result of the visual examinations. The flattened portion of the pipe was in the area where the inner wall was cracked. The outer wall contained a group of pits with embedded dirt and sand as though someone had stepped on the pipe. However, after noting comparable abrasions at various points around the circumference of the long section, where the pipe was not out-of-round, it was surmised that they may have been due to soil compaction, expansion and contraction or the like and that the flattening may have been due to straightening of the pipe. This assumes that the pipe was firmly held by the nearby compression fitting, and that flattening was not a fabrication defect. Such straightening could have produced tensile stresses near the outer surface in the cracked area. There was also the possibility that the flattened area was due to kinking of the pipe at some point in time prior to, or during, installation, a situation which could result in permanent out-of-roundness. The other observation was that both sections of pipe contained a pair of shallow, parallel grooves, along with the inner surface that were probably caused by the extruder die. Although both sections were bowed, these grooves were out of phase by about 90° with respect to their location and the direction of bowing. That is, one of the grooves was immediately adjacent to the occluded particle on the side towards the curved portion of the crack, and the

other somewhat closer to the curve, and both were located essentially along the inside of the bow in this section of pipe. Whereas, the two grooves in the long section were located along the side of the inner wall with respect to the bow. This indicated that the pipe had been twisted during installation, since the pipe is normally snaked back and forth along the bottom of the trench. If twisting occurred as a result of installation, then residual torsional stresses could also have been present in the crack area. Stresses due to either or both of these possibilities would be expected to decrease the resistance of the plastic to stress cracking.

Appendix B
Phillips Reply to NBS Findings



PHILLIPS PETROLEUM COMPANY
BARTLESVILLE, OKLAHOMA 74004 918 661-6600

CHEMICAL DEPARTMENT
Plastics Division—Technical Services and Development

August 1, 1974

NBS Failure Analysis No. 107
Gas Service Line from Bowie, Maryland

File: PEC-91-74

Mr. Barry M. Sweedler
Chief, Pipeline Safety Division
National Transportation Safety Board
Department of Transportation
Washington, D.C. 20591

Dear Barry:

With regard to the final report dated May, 1974, and further identified as NBSIR74-494, "Failure Analysis of a Polyethylene (PE) Natural Gas Service Line from Bowie, Maryland" (NBS Failure Analysis No. 107), (hereinafter called the "Report"), we would like to offer the following comments.

As stated in my letter to you, PEC-196-73, dated November 14, 1973, we do not agree with the conclusions "that the particle became lodged in the wall during some stage of its fabrication", (Report, page 8), for the following reasons:

1. The particle was not encapsulated in the resin, which would be the case if it was molded into the pipe. The report states that the particle protruded through the inner wall surface. I believe Mr. Toner would agree that the particle was very loosely held and was easily removed from its location. On the other hand, a particle that is present during extrusion is encapsulated by the resin and held firmly in place and would be very difficult to remove because the molten resin when cooled will shrink around the foreign particle. To demonstrate this we extruded pipe containing sand which had been deliberately added to the resin and samples were left with Mr. Toner and you at the meeting you held on November 20, 1973.
2. A screen pack is always used in a polyethylene extrusion operation. This is done to screen any foreign material from the resin as well as to help build up back pressure in the extruder which helps in mixing of resin. We recommend a screen pack of 20/80/20 mesh. Such a screen pack would not allow a particle of the size found to pass through the extruder and into the pipe wall. In fact, an 80 mesh screen will only allow the very finest sand particle (dust) to pass through.

Mr. Barry M. Sweedler
File: PEC-91-74
August 1, 1974
Page 2

3. The shape and orientation of the crack in the outside pipe wall, with regard to the direction of extrusion of the pipe, are contrary to established, well known pipe stress failure phenomena resulting from an imperfection. If the particle was extruded into the inside pipe wall and it became the point at which cracking began, the crack would have grown from the point of stress (occluded particle) parallel to the direction of extrusion. On the inside surface it did grow in this manner, i.e., "the crack extended for an additional 3.2 cm(1.25 in.) in the longitudinal direction along the inner wall, . . ." (Report, page 5). However, on the outside pipe surface, "the crack was approximately 3.8cm (1.5 inches) and in a modified 'J' shape, with the stem of the J extending in the longitudinal direction of the pipe." (Report, page 2). Examination of this section of the pipe shows that the hook of the J is transverse to the direction of extrusion. This transverse crack could not occur as a direct result of an occluded particle because all previous experience has shown that such stress cracks would be parallel to the direction of extrusion. Therefore, this transverse crack must have been caused by something other than the particle found on the inside pipe surface.

We also believe that the particle found in the pipe wall did not cause the pipe to fail for the following reasons:

1. The pipe which was made at our Sales Service Laboratory to demonstrate the appearance of pipe containing sand was put on test under pressure. The results are shown in Figure 1. At 140°F, five failure points were obtained between 120 and 1080 hours at hoop stresses of 1153 psi to 953 psi respectively. The best line through these points indicates absolutely no influence of the sand particles, and they were numerous.

The lack of influence of this added sand is shown at 140°F, a temperature considerably higher than the temperature of the installed gas line and at pressures 14 to 17 times the gas line pressure (the 20 psig line pressure is a hoop stress of 67 psi).

2. Although the report states the occluded particle was the point of initiation of the failure, just the opposite is highly probable and the particle could be incidental as far as the failure of the pipe is concerned. We believe the pipe could have failed by first being damaged by an external force before or during installation, i.e., during shipping, storage, preparation for installation, installation or back-filling. A quick blow from a sharp instrument could explain the "J" shaped cut on the pipe surface. This cut, having been started from the outside, could have grown under a torsional or bending stress which was applied when the pipe was installed. This type of stress is alluded to in the report. The occluded particle could have been introduced through this crack and was "caught" in the location where it was found. This would explain why it was so easily removed and was not encapsulated like the sand particles we deliberately added to pipe we subsequently tested (Figure 1).

Appendix B

Mr. Barry M. Sweedler

File: PEC-91-74

August 1, 1974

Page 3

Therefore, in conclusion, we do not believe the occluded particle was extruded into the pipe wall but that the pipe was accidentally damaged before, during or after installation. The particle entered the pipe wall as a result of this damage and the crack grew from this point of stress concentration caused by bending and/or torsional forces.

Very truly yours,



P. E. Campbell

Sales Service Laboratory

PEC:fc

Attachment

Appendix B



U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

September 26, 1974

Mr. Barry Sweedler
Chief, Pipeline Safety Division
National Transportation Safety Board
Washington, D.C. 20591

Re.: Comments from Phillips Petroleum on our report, NBSIR 74-494,
"Failure Analysis of a Polyethylene (PE) Natural Gas Service
Line from Bowie, Maryland (NBS Failure Analysis No. 107)"

Dear Barry:

We have read and evaluated the comments submitted to you on August 1, 1974, by Mr. Campbell of Phillips Petroleum concerning the above referenced report that we had submitted to your office.

These comments were generally the same as those that he had submitted earlier. In conducting our analysis and in the preparation of our report, we carefully weighed the validity of these earlier comments, but could not reconcile them to what we saw in the pipe sample, and our own past experience in conducting other failure analyses on plastics products.

In considering the comments in paragraph two of the letter, ours are as follows:

1. Although the sand particles deliberately added to the pipe samples submitted to us by the Phillips' Lab for evaluation all appeared to be encapsulated, the particle in our sample was only partially encapsulated. This is best illustrated by the deformation of the inner pipe surface along the top of the particle, Figure 3 of the report. When the 5-inch section of pipe, containing the crack, was cut in the longitudinal direction (Report, p. 5), we were obliged, because of the toughness of the plastic, to use an electric, scalloped-edge knife which operates like a band saw. This subjected the sample to severe mechanical vibration. After the embedded particle was photographed (Report, Figure 3) we suffered a minor scratch while rubbing our finger over the particle. Both of these incidences, we believe, indicate that the particle was firmly embedded in the pipe wall. Although the particle fell out of the cavity when the transverse cuts were made to open the crack (Report, p. 6), we attributed this to the known poor adhesion of polyethylene to other materials, and the fact that the particle was partially embedded in each surface of the crack. We attributed one possible reason for

the particle not being completely encapsulated to the possible accidental contamination on the downstream side of the 80-mesh screen in the 20/80/20-mesh screen pack (Report, p. 6), which could have occurred during the assembly of the pack and/or in placing it in the extruder.

2. There seems to be some misunderstanding about the configuration of the crack on the inner wall. The crack extended completely through the wall at all points along that portion visible on the outer wall (Report, Figure 2), including the curved portion in which the occluded particle was located. The extension of the crack on the inner wall was in the direction away from the curved section, i.e., to the left in Figure 2.

We agree that stress cracks usually propagate in the longitudinal direction in extruded PE pipe. However, we firmly believe, on the basis of our examination, that the occluded particle was the source of a stress point and that a stress crack propagated through the wall from this point to the outer wall of the pipe producing a semi-transverse crack in that area (Report, p. 8), and most likely was the initial point of leakage. Although the direction of the crack, at the point of the occluded particle, may be considered atypical, there are certain theoretical aspects concerning the morphology of the molded plastic that could account for this apparent anomaly.

Concerning the two points in paragraph three of the letter:

1. We did not imply that the presence of the occluded particle would have had any significant effect on the reduction of the hoop stress of the pipe, which was being subjected to a working pressure of about one-fifth of its design pressure for natural gas. However, we do believe that the presence of the particle would tend to weaken the pipe, by increasing its susceptibility to stress cracking, to the extent that on long term exposure to a variety of potential external stresses, some resulting from the installation technique and the proximity of the steel main, a stress crack could have been initiated at the point where the particle was located.
2. The section of pipe containing the crack was permanently bowed. The crack was generally located on the inside of the bow with the result that the crack surfaces on the outer wall were compressed together. Our microscopic examination conducted immediately after receipt of the pipe showed no evidence of a gap or separation of the crack surfaces on the outer wall. Assuming that the pipe had this same bowed configuration in its installed position we believe it would have been literally impossible for the particle to have fallen into the crack.

Appendix B

3. If you recall, at the meeting in which we first received the pipe, both you and Mr. Klem of the Prince Georges Fire Marshal's Office informed me that the pipe had been turned over to the P.G. Police Department who in turn submitted it to the FBI laboratory. They subsequently reported that there was no evidence of external mechanical damage. Our own examination of the sectioned crack surfaces corroborated that reported examination.

In general, we believe that Mr. Campbell's statements that the particle could not possibly have been molded into the pipe, and that the crack configuration was contrary to known "normal" failure modes are too dogmatic and inflexible. Accidents do happen, quality control does break down occasionally, and failures do not always follow the norm. We are most confident that our analysis correctly pinpointed the cause of failure, to the extent that we believe any other expert analyst would arrive at the same basic conclusions. In addition, unlike Mr. Campbell, we are, up to this point, the only one to have the advantage of microscopically examining all of the pertinent features of the stress crack and other visible artifacts associated with the failure.

We hope these comments will help reconcile the apparent differences between the conclusions in our report to those of the pipe manufacturer's representative.

Sincerely,



Samuel D. Toner
Consumer Product Systems Section