Building Explosion and Fire
Silver Spring, Maryland
August 10, 2016

Accident Report

NTSB/PAR-19/01
PB2019-100722

National
Transportation
Safety Board

NTSB/PAR-19/01
PB2019-100722
Notation 58957
Adopted April 24, 2019

Pipeline Accident Report

Building Explosion and Fire
Silver Spring, Maryland
August 10, 2016

National
Transportation
Safety Board

490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2019. ***Building Explosion and Fire, Silver Spring, Maryland, August 10, 2016*****. NTSB/PAR-19/01. Washington, DC.**

Abstract: On August 10, 2016, at 11:51 p.m. eastern daylight time, a 14-unit apartment building, located at 8701 Arliss Street, in Silver Spring, Montgomery County, Maryland, partially collapsed due to a natural gas-fueled explosion and fire. The explosion and fire also heavily damaged an adjacent apartment building which shared a common wall with building 8701. As a result of this accident, 7 residents died, 65 residents were transported to the hospital, and 3 firefighters were treated and released from the hospital. The investigation focused on the following safety issues: the location and inspection of service regulators within a structure; the inspection of the gas meter assembly; the notification of the natural gas odor to Washington Gas Light Company; and the detection of natural gas through odorants and methane. As a result of this investigation, the National Transportation Safety Board (NTSB) makes new safety recommendations to the Pipeline and Hazardous Materials Safety Administration; the Public Service Commission of Maryland, the Commonwealth of Virginia State Corporation Commission Division of Public Utility Regulation, and the Public Service Commission of the District of Columbia; the International Academies of Emergency Dispatch; the International Code Council; the National Fire Protection Association; the Gas Technology Institute; and Washington Gas Light Company.

National Transportation Safety Board
Records Management Division, CIO-40
490 L'Enfant Plaza, SW
Washington, DC 20594
(800) 877-6799 or (202) 314-6551

NTSB publications may be purchased from the National Technical Information Service. To purchase this publication, order product number PB2019-100722 from:

National Technical Information Service
5301 Shawnee Rd.
Alexandria, VA 22312
(800) 553-6847 or (703) 605-6000
http://www.ntis.gov/

Contents

Figures

Tables

Abbreviations and Acronyms

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ATF	US Bureau of Alcohol, Tobacco, Firearms and Explosives
BSI	British Standards Institution
CFD	computational fluid dynamics
CFH	cubic feet per hour
CFR	*Code of Federal Regulations*
COMAR	*Code of Maryland Regulations*
DOT	US Department of Transportation
ECC	Montgomery County Emergency Communication Center
EPA	US Environmental Protection Agency
GAO	US Government Accountability Office
GTI	Gas Technology Institute
IAED	International Academies of Emergency Dispatch
ICC	International Code Council
IFGC	*International Fuel Gas Code*
LEL	lower explosive limit
LP	liquified petroleum
MAOP	maximum allowable operating pressure
MCFRS	Montgomery County Fire and Rescue Service
MCPD	Montgomery County Police Department
NCSL	National Conference of State Legislatures
NFPA	National Fire Protection Association

NFPA 54	*National Fuel Gas Code*
NPS	nominal pipe size
NTSB	National Transportation Safety Board
OTD	Operations Technology Development
PHMSA	Pipeline and Hazardous Materials Safety Administration
PSC	Public Service Commission of Maryland
psig	pounds per square inch, gauge
RMD	residential methane detectors
RSPA	Research and Special Programs Administration
SCFH	standard cubic feet per hour
UEL	upper explosive limit
UL	Underwriter's Laboratories
WC	water column
WG	Washington Gas Light Company
WSSC	Washington Suburban Sanitary Commission

Executive Summary

On August 10, 2016, at 11:51 p.m., eastern daylight time, a 14-unit apartment building, located at 8701 Arliss Street, in the unincorporated community of Silver Spring, in Montgomery County, Maryland, partially collapsed due to a natural gas-fueled explosion and fire.

The explosion and fire also heavily damaged an adjacent apartment building, 8703 Arliss Street, which shared a common wall with building 8701.

As a result of this accident, 7 residents died, 65 residents were transported to the hospital, and 3 firefighters were treated and released from the hospital. The damage from the accident exceeded $1 million.

The following are safety issues in this accident:

- the location and inspection of service regulators within a structure
- the inspection of the gas meter assembly
- the notification of the natural gas odor to Washington Gas Light Company
- the detection of natural gas through odorants and methane

The National Transportation Safety Board determines that the probable cause of the explosion in building 8701 of the Flower Branch apartment complex was the failure of an indoor mercury service regulator with an unconnected vent line that allowed natural gas into the meter room where it accumulated and ignited from an unknown ignition source. Contributing to the accident was the location of the mercury service regulators where leak detection by odor was not readily available.

1. Factual Information and Analysis

1.1 The Accident

On August 10, 2016, at 11:51 p.m., eastern daylight time, a 14-unit apartment building, located at 8701 Arliss Street, in the unincorporated community of Silver Spring, in Montgomery County, Maryland, partially collapsed due to a natural gas-fueled explosion and fire.[1] (See figure 1.)

Figure 1. The accident location, 8701 Arliss Street, before the August 10, 2016, explosion. (Photograph from Google Earth, dated November 2015.)

The explosion and fire also heavily damaged an adjacent apartment building, 8703 Arliss Street, which shared a common wall with building 8701. (See figure 2.)

[1] All times mentioned in this report are eastern daylight time, unless otherwise specified.

Figure 2. Buildings 8701 (right-center) and 8703 (left) Arliss Street, Silver Spring, Maryland, after the explosion and fire. (Photograph provided by the Public Service Commission of Maryland.)

As a result of this accident, 7 residents died, 65 residents were transported to the hospital, and 3 firefighters were treated and released from the hospital.[2] The damage from the accident exceeded $1 million.

1.2 Accident Site and Property Description

Buildings 8701 and 8703 Arliss Street were part of the Flower Branch Apartments, a 26-building complex that was constructed in 1955. (See figure 3.) The apartment complex was managed by Kay Management, a real estate management and development company.

[2] Some of the injuries reported included respiratory problems from smoke inhalation and injuries from falling or burns.

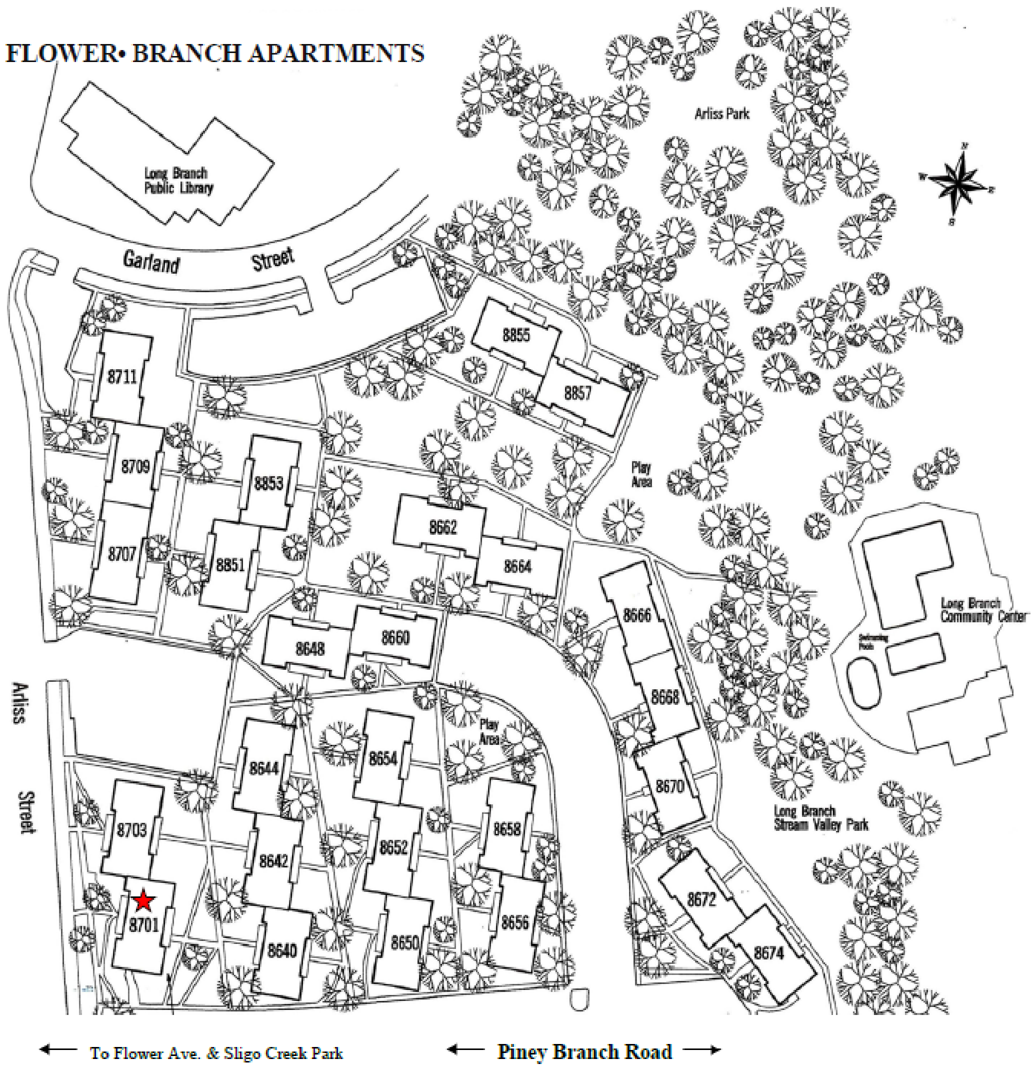

Figure 3. Layout of the Flower Branch apartment complex. Building 8701 is identified by a red star. (Graphic provided by Kay Management.)

Building 8701 Arliss Street was a four-level structure with a basement and three floors. Four apartments were located on each of the upper three levels. The basement/terrace level consisted of one apartment, a meter room, a storage room, and a property management and rental office. (See figure 4.)

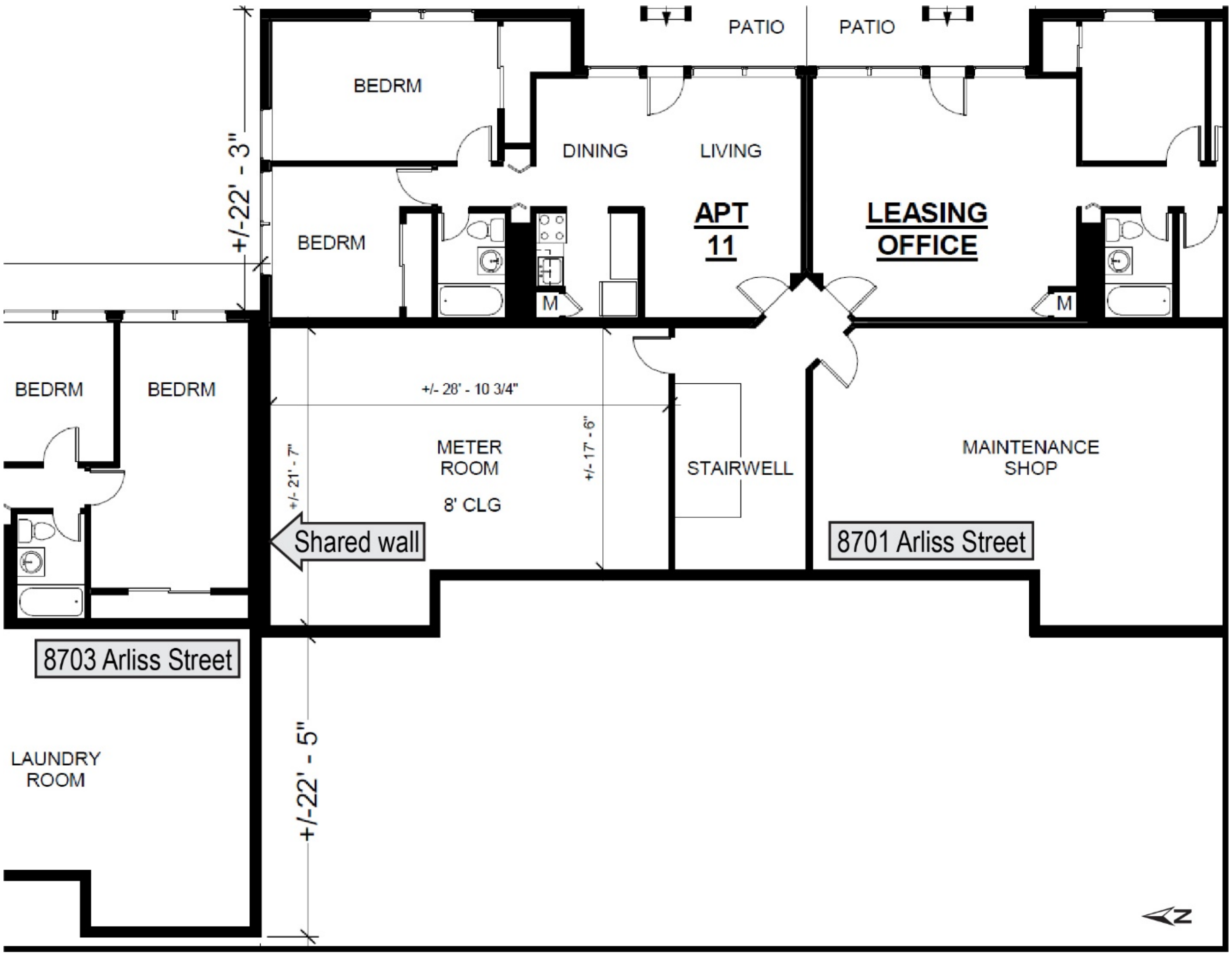

Figure 4. A plan for the basement/terrace floor for 8701 Arliss Street and the shared-wall portion of 8703 Arliss Street. (Graphic provided by Kay Management.)

According to Washington Gas Light Company's (WG) construction and service records for 8701 Arliss Street, between the years of 1955 and 1969 the natural gas main along Piney Branch Road that supplied this address was a medium-pressure main constructed of 6-inch inside diameter wrapped steel. The service line from the main that supplied 8701 Arliss Street was 2-inch nominal pipe size (NPS) wrapped steel, connected to a 1-inch NPS inlet pipe and a 1-inch outlet pipe after the service regulators.[3] The main had a maximum allowable operating pressure (MAOP) of 25 pounds per square inch, gauge (psig) and the operating pressure at the time of the explosion was between 20 and 22 psig.[4] This line had been servicing the address for over 60 years until the explosion on August 10, which severed a portion of the service line. The service line construction was completed on May 31, 1955, and the installation of the natural gas meters and regulators was completed on June 15, 1955. The gas main and service line were buried about 3 feet below the surface. The 2-inch service line ran along the front of the apartment buildings, including 8701 Arliss Street. On September 25, 1969, the service line was relocated about 80 feet and disconnected

[3] NPS is nominal pipe size as defined the American Society of Mechanical Engineers (ASME) B36-10M-2018 standards for wrought steel pipe (ASME 2018).

[4] *MAOP* refers to how much pressure the walls of the pipeline may safely hold in normal operations.

from the 6-inch medium-pressure wrapped steel main on Piney Branch Road. The service line was then connected to a 4-inch medium-pressure wrapped steel main that ran along Arliss Street.

1.2.1 Gas Meter/Utility Room

The gas meters were located in the meter room in the basement of 8701 Arliss Street on the north facing wall. The gas meter assembly included 15 meters that served 13 apartments, and maintenance and management offices.[5] The electric meter panel and a commercial-grade gas water heater were positioned about 6 feet away from the gas meter assembly. The room was also used for equipment and supply storage. At the time of the accident, it contained supplies and equipment needed for maintenance.[6]

The meter room had restricted access and only two windows: one enclosed with glass and the other covered with a piece of wood with two small holes for ventilation. The room was secured by a knob lock, a vertical deadbolt lock, and was armed with an alarm system.[7] Only Kay Management staff and Montgomery County Fire and Rescue Service (MCFRS) responders were authorized access to the meter room. In February 2016, the lock to the meter room was changed; however, Kay Management had not placed a copy of the new key in the MCFRS Knox Box, located on the premises.[8]

1.3 The Investigation

1.3.1 Gas Odor Leak Calls

Prior to the accident, several residents of buildings 8701 and 8703 reported to investigators that they smelled gas in the weeks and months leading up to the explosion. One resident reported that he smelled natural gas after returning from work around 11:30 p.m. on August 10. While he was taking out the trash, around 11:50 p.m., he smelled a gas odor in the stairwell and walked down to the basement to locate the source. He told National Transportation Safety Board (NTSB) investigators that he found the odor became stronger as he walked into the basement and he could hear a hissing noise from behind the locked doors of the meter room. He said that he planned to call 9-1-1 to report the gas odor after he finished taking out the trash. However, before he could report the leak, as he walked back from the community trash containers about 120 feet away, the explosion occurred.[9]

[5] The management office was an apartment converted for business purposes.

[6] Kay Management provided an inventory list for the meter room in 8701 Arliss Street.

[7] According to the US Bureau of Alcohol, Tobacco, Firearms and Explosions (ATF) Origin and Cause report, the knob lock was locked, and the vertical dead bolt was not locked, prior to the explosion. For more information, see "ATF Report" in NTSB Docket DCA16FP003.

[8] A *Knox Box* system is an access box for fire departments to use in the event of an emergency to enter structures or areas that are deemed difficult. This is required under National Fire Protection Association (NFPA) 1, which is a comprehensive fire code that the State of Maryland has adopted by reference in its Fire Prevention Code.

[9] For more information, see "Interview transcript with Resident A" in NTSB Docket DCA16FP003.

1.3.2 Previous Gas Odor Calls

Between September 2015 and June 2016, Kay Management received six gas odor calls from residents of 8701 Arliss Street.[10] Members of its maintenance staff said that when they investigated, they either did not detect gas through their gas-detection equipment or would report that the painting of apartments was causing the smell. MCFRS fire personnel responded to an odor call at building 8701 on July 25, 2016. According to interviews with Flower Branch residents and employees from Kay Management, residents in the building typically called either the management company or 9-1-1 to report gas odors. WG has no record of responding to or receiving any notifications of gas odor calls from 8701 Arliss Street in the 5 years prior to the accident.

The same resident who detected the natural gas odor on the night of the explosion had called 9-1-1 on July 25, 2016, to report a strong smell of natural gas both outside and inside of building 8701. The resident told the 9-1-1 operator that the strongest smell of natural gas was detected on the first level of the apartment building. The 9-1-1 operator told the resident not to turn on anything that could create an ignition source, and to evacuate himself and others out of the building. Neither the resident nor the 9-1-1 operator contacted the gas company.

On July 25, 2016, MCFRS fire personnel arrived at building 8701 around 10:20 p.m. They approached the building using a calibrated four-gas multimeter.[11] Residents directed the fire personnel to the main hallway of the first floor, where no combustible gas readings or natural gas odors were detected. Although one responder reported smelling "something," it did not register on his detection equipment. The fire personnel proceeded through the apartment building, checking inside occupied apartments and underneath doors of unoccupied apartments. The fire personnel moved to the basement to test the storage and meter rooms but were unable to gain access to the meter room because the locks had recently been changed and the new key was unavailable. The fire personnel wedged the top of the doors open but detected no gas. MCFRS departed at 10:33 p.m. because they did not detect any gas readings throughout the building.[12] The Kay Management property manager was not notified of the odor leak call and only learned of it after a conversation with a resident days later.[13] There are no records of additional conversation between Kay Management and MCFRS regarding the July 25 odor complaint.

1.3.3 Emergency Response

On August 10, 2016, at 11:52 p.m., the MCFRS Emergency Communication Center received a 9-1-1 call reporting the explosion and fire. Buildings 8701 and 8703 Arliss Street were evacuated by two Montgomery County Police Officers who were within 1,000 feet from them

[10] For more information, see "Operations – Kay Management (All Work Orders 08-01-15 thru 08-25-16)" in NTSB Docket DCA16FP003.

[11] *Four-gas multimeters* are devices that measure the atmosphere for the following four parameters: oxygen concentration (in percentage O_2), flammability (in percentage of lower explosive limit [LEL]), carbon monoxide concentration (in parts per million), and hydrogen sulfide concentration (in parts per million).

[12] For more information, see "Reg. Oversight – MCFRS Statements on July 25, 2016, incident" and "Interview of Montgomery County Fire and Rescue Lieutenant" in NTSB Docket DCA16FP003.

[13] For more information, see "Interview of Manager of Flower Branch Apartments-Errata" in NTSB Docket DCA16FP003.

when the explosion occurred. MCFRS dispatched units to the accident scene at 11:54 p.m., and the first unit arrived at 11:58 p.m. to begin rescue and fire suppression efforts.[14] Residents of nearby apartment buildings within the complex voluntarily evacuated themselves.

The MCFRS Emergency Communication Center called WG at 12:08 a.m. on August 11, 2016. Within an hour of the initial notification, WG personnel arrived on scene and shut off the 4-inch diameter main supplying gas to the five apartment buildings along Arliss Street, and the MCFRS responders extinguished the fire shortly thereafter.

The NTSB concludes that the postexplosion responses by both MCFRS and WG were prompt and adequate.

1.3.4 Postaccident Gas Leak Surveys and Odorant Testing

NTSB investigators arrived on scene the morning of August 11, 2016. WG pressure tested the main, which held pressure, indicating there was no leak.[15] Soil bar hole tests were conducted within 3 hours of the accident in areas adjacent to the main and the 2-inch service lines in the front and back of buildings 8701 and 8703 detected no gas readings.[16] Building 8701's gas regulator vent line, which is a pipe that directs the natural gas away from the building and into the atmosphere in case of an over-pressure scenario, was also tested and showed no obstruction in the vent line.

Overseen by the Public Service Commission of Maryland (PSC), WG performed postaccident odorant testing at two different regulator stations in Silver Spring, Maryland, and odorant levels were found compliant with Pipeline and Hazardous Materials Safety Administration (PHMSA) regulations that require natural gas to be odorized and detected at 1/5th (or 20 percent) of the lower explosive limit (LEL).[17] This safety feature is required for all distribution lines. The State of Maryland has a more stringent requirement for odorant levels, which must be detectable at 1/10th (10 percent) of the LEL.[18] The testing indicated that the levels also complied with the *Code of Maryland Regulations* (*COMAR*) requirement. At the Flower Branch complex, the natural gas service lines were also tested for odorant levels and met the regulatory limits.[19]

---

[14] For more information, see "Survival Factors" in NTSB Docket DCA16FP003 for detailed event chronology and emergency response activities.

[15] The operating pressure of the gas line that feeds into apartment buildings 8701 through 8711 Arliss Street was measured to be 20 psig.

[16] (a) *Soil bar hole* tests measure the amount of odorant in soil. (b) For more information, see "PSC Pipeline Incident Investigation Report" in NTSB Docket DCA16FP003.

[17] *Odorant tests* measure the amount of substances that have been added to gas provide a distinctive smell to ensure regulatory safety requirements are met.

[18] Title 49 *Code of Federal Regulations* (*CFR*) 192.625 and *Code of Maryland Regulations* (*COMAR*) 20.55.09.06.

[19] For more information, see "Operations–DCA16FP003-OPS-Odorant Monitoring-1" in NTSB Docket DCA16FP003.

1.3.5 Fire and Arson Investigations

During the incident, MCFRS requested the assistance of the US Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF). The ATF National Response Team responded to investigate the source of the explosion and assist in locating the tenants of buildings 8701 and 8703. ATF conducted several interviews with residents in the days immediately following the explosion. Both agencies concluded their field investigation on August 17, 2016. They found no data to support the presence of explosives or a clandestine drug laboratory. In its report, ATF concluded that the explosion was caused by a release of natural gas in the meter room of 8701 Arliss Street and excluded all other potential causes.[20]

The meter room of building 8701 had several potential natural gas ignition sources, including open-flame ignition sources, such as burners on the water heater. Furthermore, electrical equipment installed in the room could have produced electrical arcing (NFPA 2014).

1.3.6 Explosion Damage and Evidence

ATF documented and collected data to analyze the migration of the debris that projected from the explosion. Debris from building 8701 was found as far as a parking lot 300 feet away. The surrounding walls of the meter room on the north, south, and east sides were blown out and into other apartments or adjacent rooms. The west wall of the meter room, which was below ground level and backed by soil outside the building, did not appear to have any damage. The subsonic pressure wave from the explosion also blew out windows from the apartment in the basement of building 8701. Vehicles parked within the line of sight of the front entrance to building 8701 were severely damaged due to explosion debris. Vehicles parked farther away from building 8701 were found with significantly less or no damage.

The stairwell/hallway door to the meter room was the only door to have blown away from its respective room, compared with the other stairway/hallway doors in building 8701 that had separated from the frame and blown into their respective rooms. Also, according to the ATF report, the concrete floor that separated the meter room and the above first-floor apartments had blown upward and flipped over onto itself, which eliminated the scenario that an explosion could have occurred above the meter room.[21] Fire, heat, and structural damage in building 8703 was most severe along the shared wall of the northwest quadrant of building 8701 and decreased in severity farther away from the meter room. The shared north wall of the meter room blew away from the meter room and into an apartment in building 8703. During the field inspection of the meter room, an unconnected union of the vent line to the lower mercury service regulator was also found.

The victims of the explosion were found in the apartments closest to the meter room in buildings 8701 and 8703. Autopsy reports identified the cause of death for each of the victims from either impact from the explosion or from exposure from the intense heat. Based on the pattern

[20] (a) ATF referred to the natural gas as "fugitive" in its report. (b) For more information, see "ATF Report" in NTSB Docket DCA16FP003.

[21] For more information, see "ATF Report" in NTSB Docket DCA16FP003.

of debris and the location of the victims, the NTSB concludes that the explosion radiated from the meter room, where the gas meter assembly was located.

1.3.7 Gas Service to the Flower Branch Apartment Complex

Building 8701 received natural gas from a distribution system owned and operated by WG, that also delivers natural gas to more than 1 million residential, commercial, and industrial customers throughout Washington DC, and surrounding regions in Maryland and Virginia.[22] WG is required to comply with regulations from the US Department of Transportation (DOT), Title 49 *Code of Federal Regulations* (*CFR*) Part 192, and *COMAR* Title 20, Subtitle 55. In Maryland, WG is periodically audited and inspected by the PSC to monitor compliance with both federal and state regulations.

WG is required to service and maintain gas lines up to the outlet of the meter, also known as “jurisdictional piping.” All piping past the meter outlet to the appliances in the apartment, or “house lines,” are the responsibility of the property owners or the owners’ designee, such as Kay Management, who install, operate, and maintain those lines in accordance with county regulations. The local authority over Flower Branch Apartments is Montgomery County, which used the 2015 edition of the *International Fuel Gas Code*, as well as the 2015 *Plumbing and Fuel Gas Code* of the Washington Suburban Sanitary Commission (WSSC) at the time of the incident (ICC 2015) (WSSC 2015).[23]

[22] For more information, see https://www.washingtongas.com/about/company-profile. (Accessed August 26, 2016).

[23] Washington Suburban Sanitary Commission is a water and wastewater utility that oversees water and sewer pipelines in Prince George’s and Montgomery counties in Maryland.

2 Safety Issues

2.1 Introduction

The NTSB identified the following safety issues in the investigation of this accident: (1) use of natural gas service regulators; (2) inspection of the gas meter assembly; (3) notification of the gas odor to Kay Management, WG, and MCFRS; and (4) detection of natural gas through odorants and methane.

2.2 Gas Meter Assembly Inspection

NTSB focused on the gas service equipment and appliances in the meter room because the ATF's investigation ruled out all other potential fuel sources in the room and the evidence indicates that the explosion originated in the meter room. During the inspection of the basement level of building 8701, NTSB investigators found burned and damaged components of the gas meter assembly, which included the mercury service regulators. A detailed inspection revealed that the vent line connection to the upper mercury service regulator was fractured below the coupling/union assembly, and the lower mercury pressure regulator was not connected to the regulator vent line at the coupling/union assembly, as shown in figure 5.[24]

[24] A union assembly is similar to a coupling and serves as an attachment between two external threaded pipes and nipples. For more information, see "Materials Laboratory Factual Report No. 16-097" in NTSB Docket DCA16FP003.

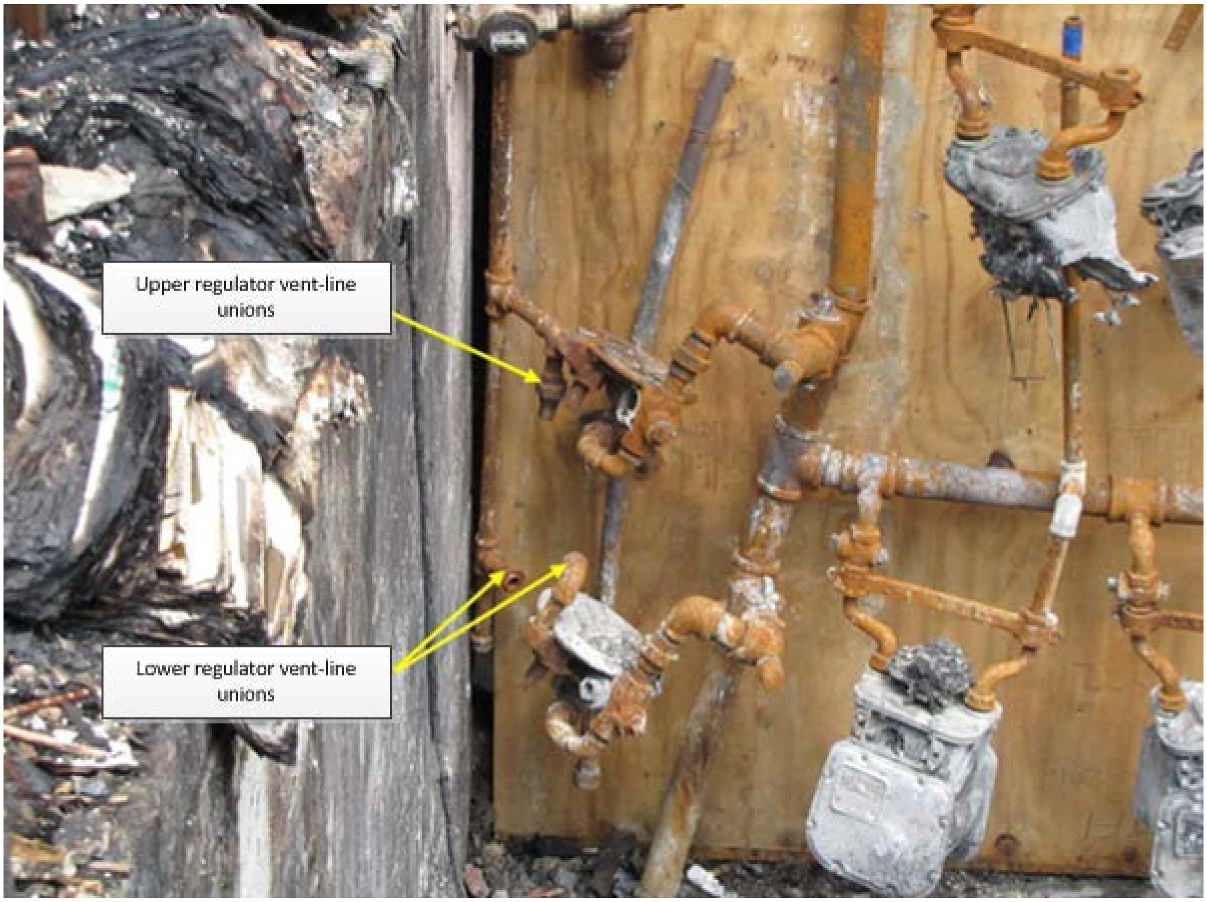

Figure 5. Portions of mercury service regulators and gas meters in building 8701 showing heat/fire/explosion damage and the unconnected lower regulator vent line.

ATF reconstructed the natural gas meter rack, piping, electric meters, and water heater. The gas meters on the upper row of the meter rack near the regulators showed significant fire and heat damage, particularly when compared with the gas meters farther away from the point of the explosion at the west wall. (See figure 6.) The water heater showed significant fire and heat damage and was found in the northeast quadrant of the meter room, about 6 feet from the nearest customer gas meter. The water heater was placed by ATF at its pre-explosion location.

Figure 6. Building 8701 after debris removal and ATF reconstruction. The first two gas meters (designated with a yellow arrow) show substantially more heat/fire damage than other meters. (Photograph provided by ATF.)

2.3 Service Regulators

2.3.1 Service Regulator Overview

Service regulators are installed to a meter inlet to control the gas pressure into a building. They reduce the high pressure used to transport natural gas through the delivery system to the lower pressures used in homes and businesses. As a safety feature, regulators include a relief valve that opens if the pressure of the regulated gas exceeds a specified pressure and the excess gas is vented to the outside atmosphere.

Until the mid-1970s, some natural gas regulators included a reservoir, which is a cup-like feature, filled with mercury. In such regulators, the mercury, which remains liquid at room temperature, would serve as a liquid trap on the relief valve. If the gas pressure in the system was too high, it would push the mercury aside, enabling the gas to pass through a vent and escape safely outside of the building. In nonmercury service regulators, a spring mechanism with a diaphragm is used as the safety relief valve.

According to WG, the regulators installed in building 8701 were also installed in all 26 buildings of the Flower Branch apartment complex between 1955-1956.[25] The two mercury service regulators and their associated piping in building 8701 will be referred to in this report as the "upper" and "lower" service regulators. Based on similar installations in other nearby Flower Branch apartments, it appears the lower regulator was installed about 2 feet above the floor, as seen in figure 7.

[25] (a) For more information, see "Operations – DCA16FP003 – Mercury Regulator Removal and Replacements" in NTSB Docket DCA16FP003. (b) In the 1940s and 1950s, WG installed mercury service regulators manufactured by Reynolds Gas Regulator Company, which is no longer in business. (c) The gas regulators from building 8701 were marked "I-M-30," which, according to WG, indicated they were a Reynolds Model 30, and were equipped with a 1/4-inch orifice. The same regulators also contained a metal tag indicating a 1955 manufacture date. (d) Although some of these regulators were in the buildings in the Flower Branch apartment complex in 2016, they have all now been removed and replaced.

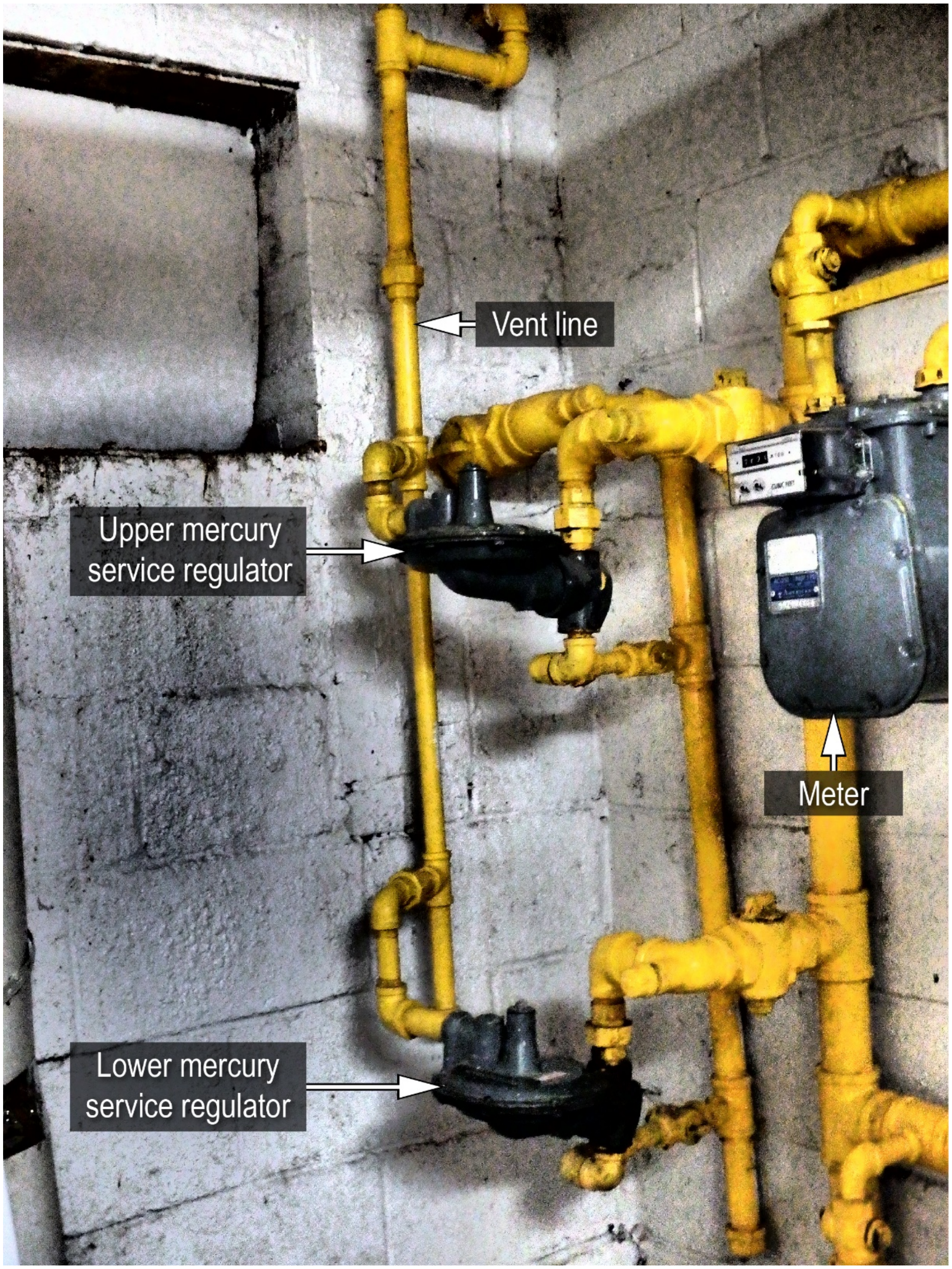

Figure 7. Exemplar configuration of a mercury service regulator assembly in a similar Flower Branch apartment building.

Figure 8 shows a close-up photograph of an exemplar mercury-filled service regulator.

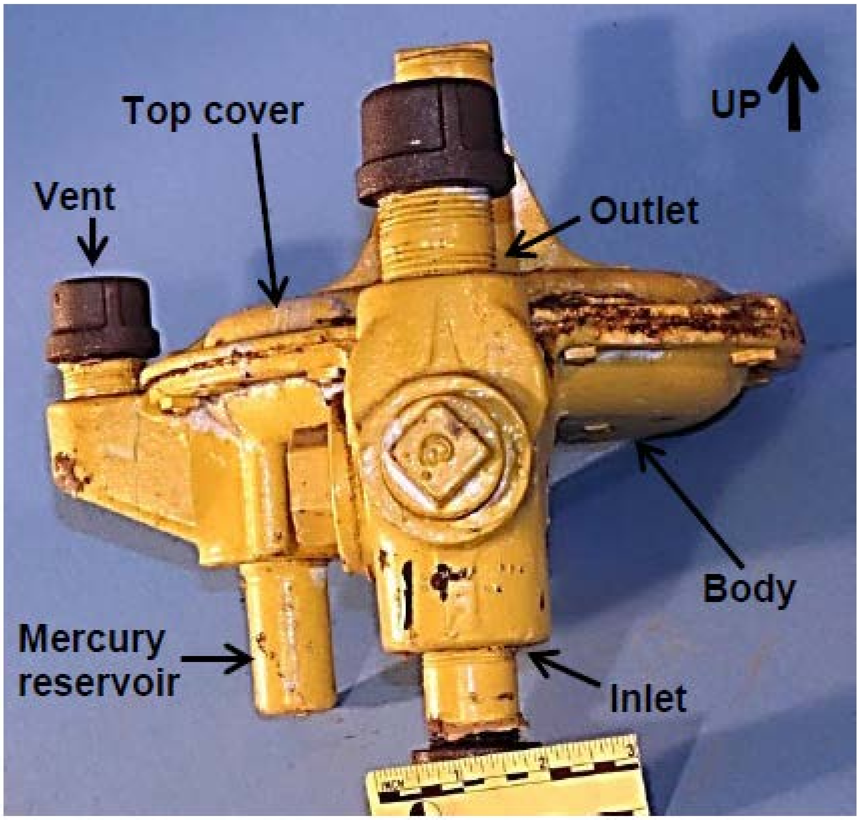

Figure 8. Exemplar mercury service regulator taken from a nearby Flower Branch apartment building.

Figure 9 shows a cross sectional image of the same regulator. A mercury service regulator consists of the following moving internal parts:

1. Spring used to adjust the natural gas delivery pressure.

2. Leather diaphragm and metal diaphragm plate serve as the pressure-sensing elements and translate pressure into a force to counterbalance the force of the spring.

3. Valve seat (also referred to as a disc) provides a positive shutoff under no-flow conditions.

4. Linkage that transmits the motion of the diaphragm to the valve seat.

5. Orifice is the passageway where pressure is reduced as distribution gas flows.

6. Mercury cup to store a specified amount of mercury for overpressure protection.

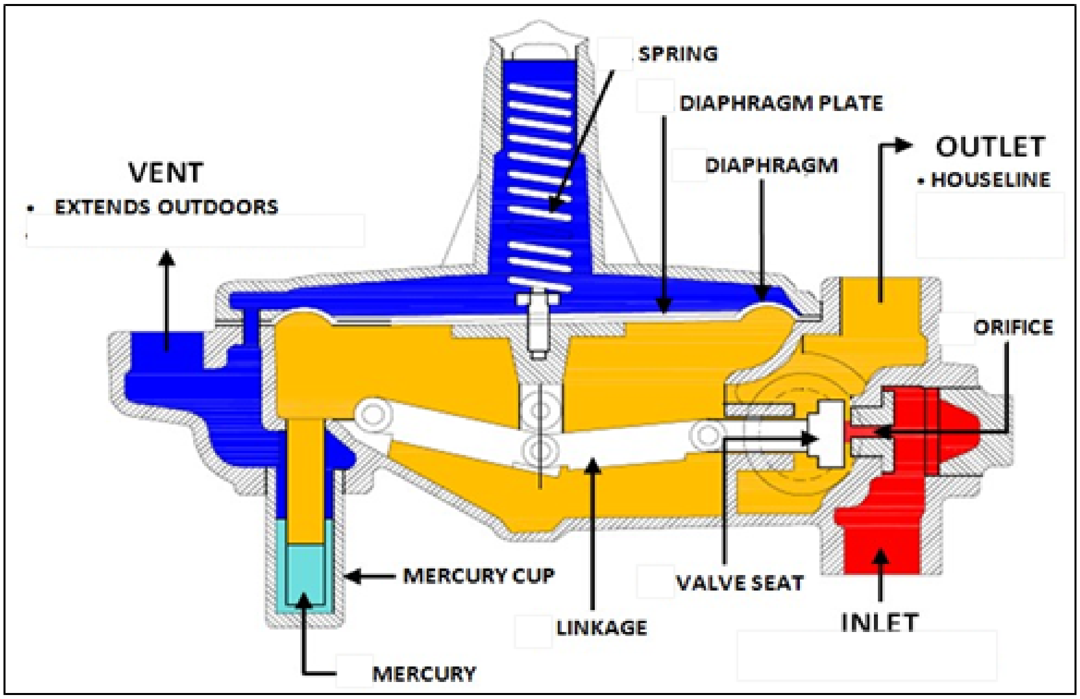

Figure 9. Cross sectional image of a mercury service regulator. (Diagram provided by WG.)

In general, the gas regulator assembly operates as shown in figure 9. Under normal operations, gas enters the regulator through the inlet and flows out of the outlet to the gas meter and customer line. The size of the gap between the orifice and valve seat determines the amount of gas that passes through the outlet. The size of the orifice also has a bearing on the outlet pressure, but the size is predetermined prior to installation and remains fixed throughout the service life.

When there is no downstream demand for gas, the valve seat presses against the orifice, and gas does not flow downstream. When downstream demand for gas increases (such as when customer gas appliances are turned on), the pressure under the diaphragm decreases. This action causes the diaphragm to move downward and the linkage to pivot so that the valve seat moves away from the orifice, resulting in the gap between the orifice and valve seat.

As the valve seat moves away from the orifice, gas flow into the regulator increases. Eventually, the downstream demand will decrease (fewer appliances are used or decreased usage), and the pressure under the diaphragm will increase. This causes the valve seat to move closer to the orifice and results in a reduced gas flow. The inlet pressure for the Flower Branch gas service was 20 psig and the pressure downstream of the mercury service regulator ranged between 5 and 7 inches of water column (.20 -.25 psig).[26]

Mercury service regulators operate at a predetermined pressure set point. When the pressure in the regulator exceeds its pressure set point, excess gas will flow through the mercury and exit to the vent, which is often referred to as an overpressure or venting event. Gas vents outside the building into the atmosphere through a vent line. As gas exits the vent line, the houseline pressure stabilizes. A malfunctioning valve seat and orifice seal, a perforated diaphragm,

[26] *Inches of water column* is a unit of pressure measurement for gas appliances.

and insufficient mercury can all lead to a venting event. Section 2.3.7 will discuss the rate of gas flowing out of the vent under these three failure scenarios.

2.3.2 NTSB Materials Laboratory Examination of the Mercury Service Regulators

NTSB investigators recovered the gas regulator assembly from the basement of 8701 Arliss Street and sent it to the NTSB Materials Laboratory in Washington, DC, for an examination.[27]

Figure 10 is a photograph of an approximate reconstruction of the preaccident configuration of the service regulators, service line, pipeline to the meters, and vent line. The white and yellow arrows pictured show the direction of the gas flow through the service line during normal operation; the blue arrows show the direction of the gas flow under an over-pressure scenario through the vent line.

[27] For more information, see “Materials Laboratory Factual Report 16-097” in NTSB Docket DCA16FP003.

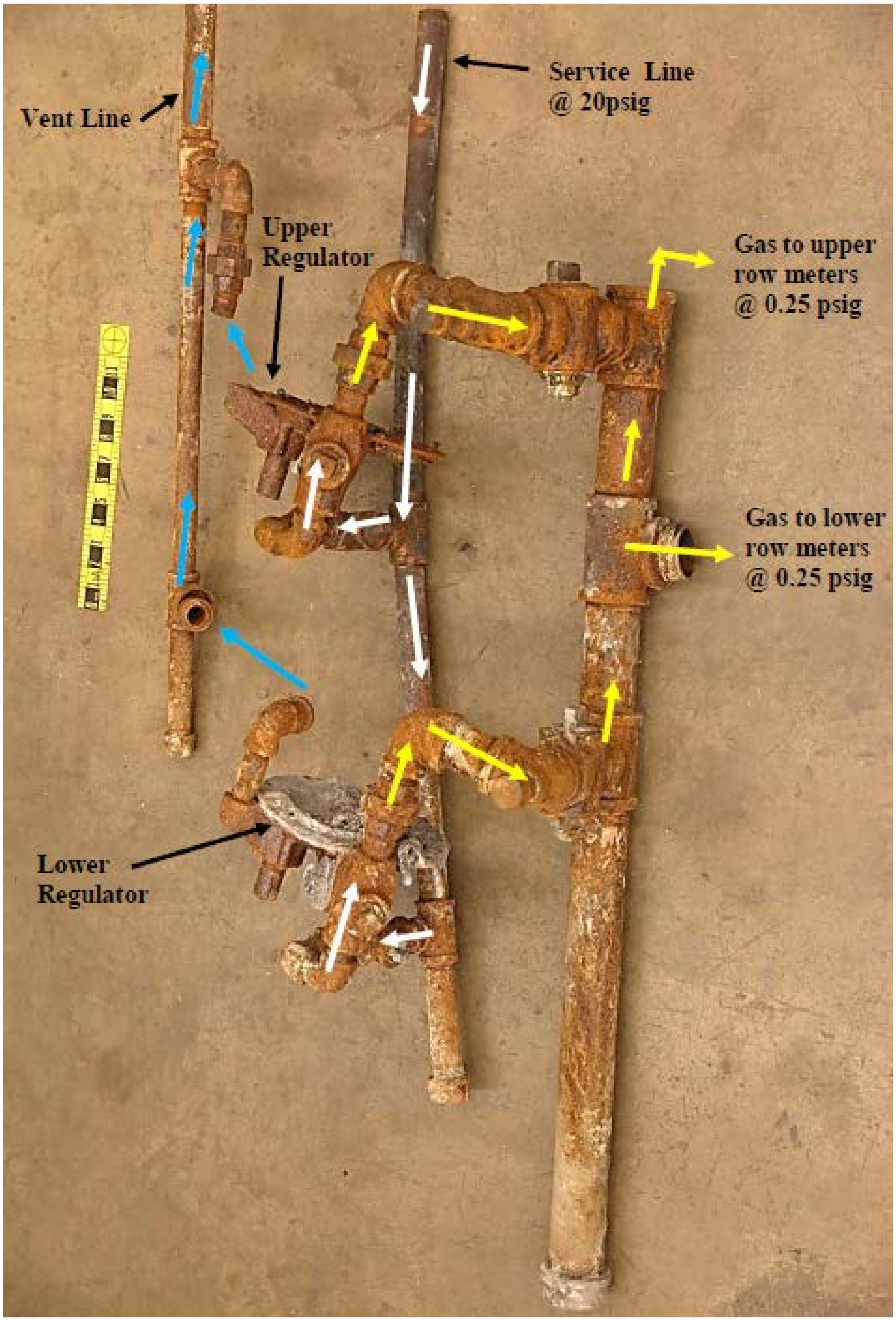

Figure 10. Mercury service regulators, service line, jurisdictional pipeline, and vent line after the accident.

Investigators from the NTSB Materials Laboratory performed a compositional alloy analysis on the mercury service regulators from the affected buildings and determined that the body was made from a ferrous alloy, and the top cover and metal tags were made from an aluminum alloy. The melting temperature of a typical aluminum alloy is about 1,220°F

(Moses 1978). The top cover and 2-inch diameter plug for the upper and lower gas regulator assemblies were both melted from exposure to heat from the fire.[28] Based on this observation, the temperature in the general area of the gas regulator assemblies reached at least 1,220°F. This also explains why mercury was not found in the reservoir cups of the upper and lower gas regulator assemblies. Mercury exists as a liquid at room temperature and has a boiling point of about 674°F, where it evaporates. The mercury most likely evaporated as a result of heat exposure from the fire.

The two regulators that serviced building 8701 were connected to one vent line, but each regulator had its own union assembly. A union assembly is made up of three components: an internal threaded nut, an insert, and a mating external threaded socket. Figure 11 shows a photograph of the lower regulator union assembly parts before cleaning. The separation was between the internal threaded nut (on the left) and the external threaded socket (on the right) of the lower assembly.

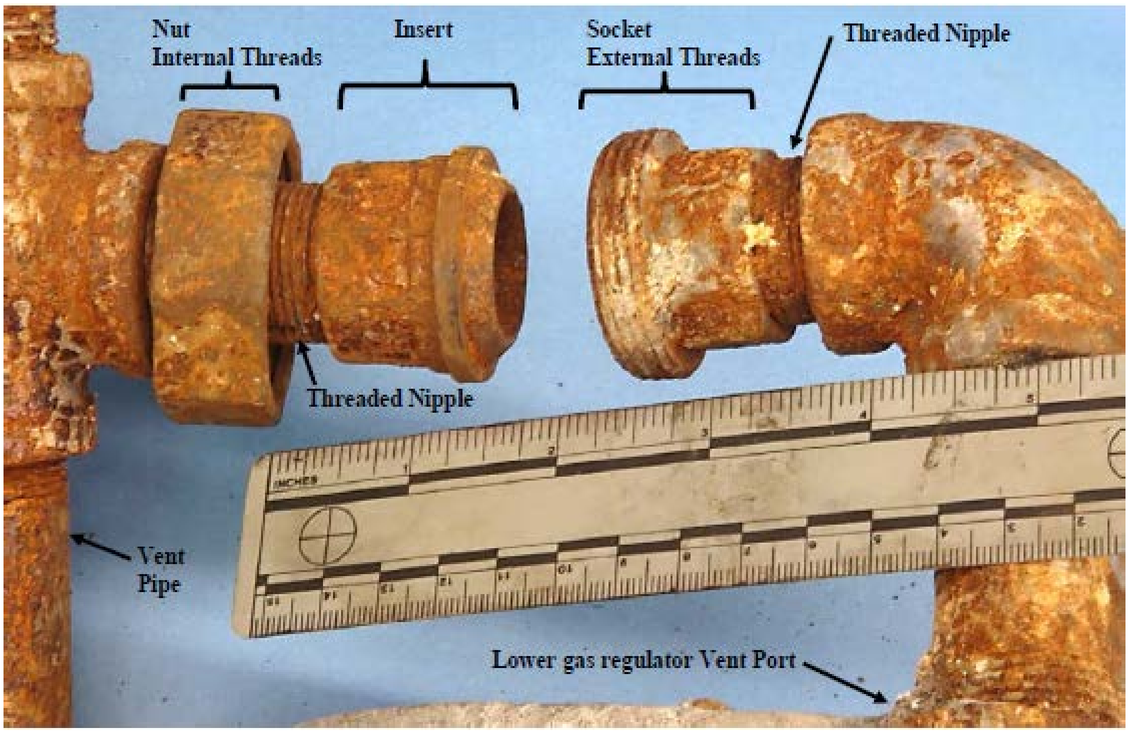

Figure 11. Photograph of the lower regulator union assembly parts (before cleaning).

2.3.3 Upper Regulator Union Assembly

The vent port of the upper regulator contained internal threads. (See figure 12-C.) An external threaded nipple and union assembly were separated from the vent port of the upper regulator and the bottom end of the threaded nipple showed evidence of bending deformation relative to the length of its axis. (See figure 12.) The bending deformation was in the general direction as indicated by the arrow in figure 12-A. The first four internal threads on the vent port,

[28] *Plug* is an access panel that allows for the service or inspection of the orifice and disc (valve seat). It is located on one side of the regulator.

as shown in figure 12-C, showed thread damage that coincided with the damage observed on the nipple. (See figure 12-B.) The observed damage is consistent with the damage that could occur if the threaded nipple was forcefully pulled out of the mating regulator vent port.

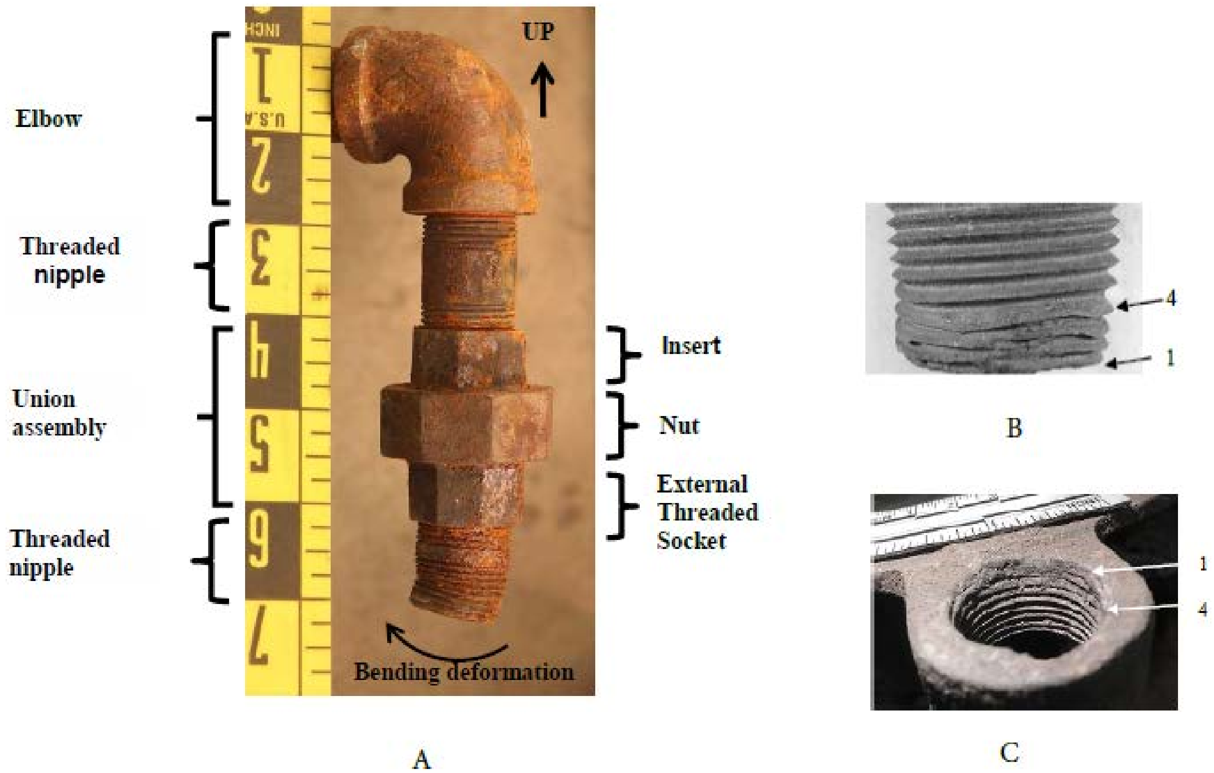

Figure 12. A photograph of the exposed external threaded nipple from the upper regulator union assembly.

NTSB investigators felt a slight looseness between the nut and insert portion when trying to disconnect the union assembly between the nut and the external threaded socket; however, the union assembly could not be rotated by hand. (See figure 12-A.) This indicated that the hermetic seal between the ball portion of the union external socket and the nut was broken.[29] This was confirmed by a pressure test of the union assembly, which showed a leak at the nut and external thread on the socket. The damage to the hermetic seal likely occurred from the force of the explosion or intense heat exposure from the fire.

Therefore, the NTSB concludes that the upper mercury service regulator was most likely connected to the vent line through the threaded nipple and union assembly prior to the explosion in building 8701 and the regulator likely became separated from the vent line due to forces of the explosion or from the building collapse.

[29] *Hermatic seal* refers to something so tightly closed that no air or gas can enter or escape.

2.3.4 Lower Regulator Union Assembly

The separation of the union assembly for the lower regulator was between the external threaded socket and internal threaded nut. The external threaded socket was attached to the regulator vent port by an elbow and threaded nipple; and the mechanical connections between them were firm. The union insert was connected to the vent line by a threaded nipple and a pipe tee; and the mechanical connections between them were also firm.

Figure 13 shows the union assembly components after cleaning. The external threads of the socket contained two dents; and the crown portion of the first two full external threads of the socket showed minor deformation.[30] The external threaded socket showed no evidence of major deformation. On one side of the nut, the crown portion of the first three internal threads showed evidence of minor metal flow deformation; and NTSB investigators observed similar deformation on an isolated area of only one thread on the diametrically opposite side. When mating threads are pulled apart by force, fracture or deformation by shear of the threads can also be expected.[31] However, NTSB investigators observed no evidence of deformation or fracture of the threads in the nut and corresponding mating threads on the socket (compare figures 12 and 13 for thread damage). Had the force of the explosion, falling debris, or a building collapse caused the disconnection of the lower union assembly, there would be evidence of mechanical damage or deformation through a significant portion of the engaged threads, as seen with the threaded nipple for the upper regulator union assembly.

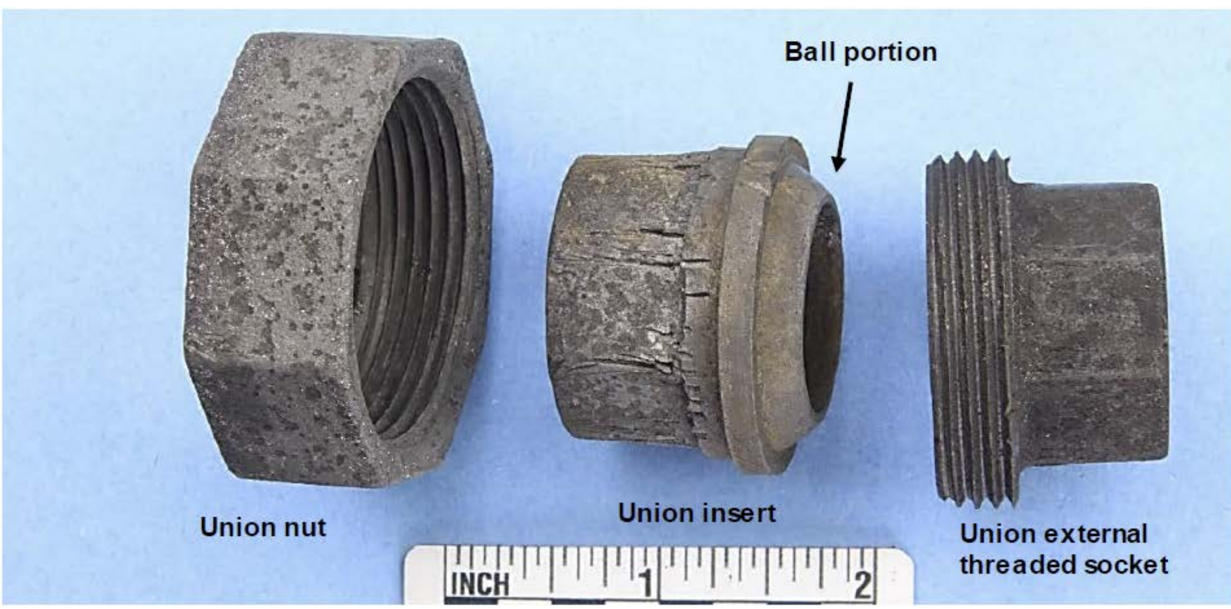

Figure 13. Photograph of the disassembled union assembly for the accident lower gas regulator after cleaning.

[30] *Crown* is the tip portion of a thread.
[31] *Shear stress* occurs in mechanical components when coplanar forces are applied.

Therefore, the NTSB concludes that the external threaded socket of the lower mercury service regulator union most likely was not threaded to the nut and, therefore, the lower mercury service regulator was not connected to the vent line prior to the explosion.

2.3.5 Vent Line Inspection Practices

Records for the 5 years prior to the accident show that WG gas technicians had visited the meter room at 8701 Arliss Street for different service calls on six occasions.[32] In that time, WG gas technicians visited the building twice to turn on gas service, which includes inspecting the mercury regulator.[33]

WG written procedures required that a mercury service regulator be tested each time the associated meter was set, reset, or changed. This procedure called to ensure that the vent line was clear of debris and could appropriately direct the gas to the atmosphere during an overpressure event. Part of the procedure for this test included disconnecting the vent line at the union, but did not include verifying the line was reconnected. Although this procedure made no distinction between single-family and multifamily structures, WG technicians told NTSB investigators that this testing was, in practice, generally performed only on single-family homes. For multifamily structures, such as apartment buildings, WG technicians only performed visual tests for debris and the outdoor venting of lines.[34] They did not check whether or not lines were connected properly.

The NTSB concludes that without a requirement that technicians verify the connection of vent lines for indoor service regulators, such vent lines could inadvertently be left open following service work. Therefore, the NTSB recommends that WG revise its procedures and field forms to require technicians to verify the integrity of vent lines following the testing of indoor service regulators throughout the WG network.

2.3.6 Examination and Exclusion of Gas Appliances in the Meter Room

The only gas appliance in the meter room of building 8701 was the 81-gallon, natural gas-fueled water heater that was installed on July 2, 2012.[35] Kay Management maintenance staff visually examined it every Monday to ensure it functioned properly through one on-off cycle. A Kay Management maintenance engineer last inspected the water heater 2 days prior to the explosion and found it to be in working order.

The water heater had an electronic pilot-light ignition. The main burner and pilot gases would cut off during the off cycle when the tank water reached the preset temperature setting on the thermostat. The main burner would not ignite if the pilot sensor did not first sense stable pilot ignition. Changes in inlet gas pressure, negative air pressure into the ignition control module, and the presence of a corrosive material/environment are all conditions that could activate the pilot sensor and cause the pilot not to ignite. However, the pilot sensor could not detect flammable

[32] WG records for meter room activity for 8701 Arliss Street.
[33] WG turned on gas service for 8701 Arliss Street on September 27, 2012, and July 7, 2014.
[34] For more information, see "Interview of Williams Meter Employee" in Docket DCA16FP003.
[35] The water heater was State Water Heaters model SBD81-199-NE.

vapors and, therefore, it would allow the water heater to initiate operation and continue to operate in the presence of flammable vapors.

In a postaccident examination, NTSB investigators observed that nearly half of the water heater was covered with a U-shaped pattern of thermal damage. Visual examination of the water heater by investigators showed no evidence of bulging or significant body deformation.[36] (See figure 14.)

Figure 14. Hot water heater at the accident scene after the explosion. (Photograph provided by ATF.)

In addition, a length of gas piping, which included the gas shut-off valve, was still attached to the water heater. All the recovered piping associated with the water heater was heavily oxidized, consistent with heat exposure, and all piping connections were found to be attached and threaded completely. The recovered gas piping to the water heater had a full-diameter, through-thickness fracture at the end of the section where the piping connected to the inlet on the gas control valve assembly, near the bottom of the water heater. Figure 15 shows the main burner assembly and pipe segment that separated from the gas control valve assembly. The fractured end of the pipe segment

[36] For more information, see "Materials Laboratory Report 16-100 Hot Water Heater" in NTSB Docket DCA16FP003.

showed evidence consistent with an overstress separation.[37] Therefore, the NTSB concludes that the gas piping to the water heater was most likely separated at the control valve due to overstress forces resulting from the explosion. Furthermore, the NTSB concludes that the water heater did not fail prior to the explosion and was not the source of the natural gas release in the meter room.

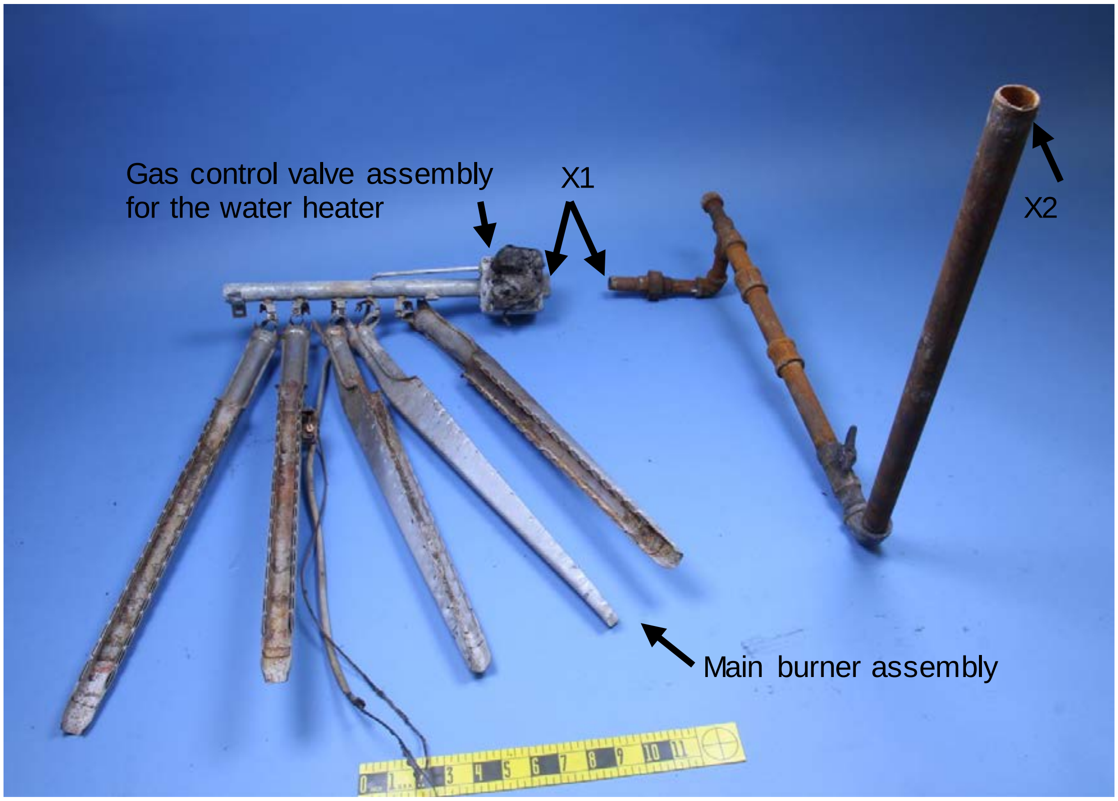

Figure 15. The main burner assembly, including the separated pipe and the gas control valve assembly. The arrows labeled X1 and X2 indicate the pipe segment fractures at the threaded portion.

2.3.7 Mercury Service Regulator Testing

The mercury service regulators sustained significant damage in the accident and could not be functionally tested. Instead, the NTSB field tested mercury service regulators similar to the ones damaged in the accident at the WG facility in Springfield, Virginia.[38] The testing included regulator failure scenarios such as a complete loss of mercury in the reservoir, a malfunctioning valve seat and orifice seal (valve seat obstruction), and a perforated diaphragm.[39] The flowrates of

[37] For more information, see "NTSB Materials Laboratory Factual Report No. 18-008" in NTSB Docket DCA16FP003.

[38] Detailed information on the testing can be found in "Washington Gas NTSB Party Submission re Building Explosion Fire" in NTSB Docket DCA16FP003.

[39] The exemplar gas regulator assembly was disassembled from another residence in the Flower Branch apartment complex.

the mercury service regulators were measured under different loads, such as no houseline demand and low-load houseline demand, and failure modes.

Valve seat obstruction failure testing was performed to measure the venting that followed a small disruption at the regulator seal between the valve seat and the orifice seal. Table 1 shows the results.

Table 1. Valve seat obstruction failure test data.

Houseline Demand	Relief or Houseline Pressure (w.c.)	Relief Flowrate through Vent Line (CFH)
No houseline demand	8 – 8.5 inches	165
Low-load houseline demand	7 – 7.5 inches	51

Investigators also tested the response of the regulator system to a diaphragm tear, a "wide-open" failure where the valve seat pulled away from the orifice, allowing gas to freely flow around the seat, into the houseline, and out of the vent line. During the testing, the vent lines were metered with AC-250 diaphragm meters, which were necessary for flowrate determination. (See table 2.) However, the meters did act as a slight restriction within the vent line. Meters are never present on vent lines within an actual installation; with them removed, the houseline pressure within a shut-in system dropped to 1.5 psig.[40]

Table 2. Diaphragm tear failure test data for a torn upper regulator.

Houseline Demand	Houseline Pressure (psig)	Relief Flowrate Top Vent (SCFH)[a]	Relief Flowrate Bottom Vent (SCFH)[a]	Combined Flowrate (SCFH)
No houseline demand	1.75	1,170	1,020	2,190
Low-load houseline demand	1.6	1,020	900	1,920

[a] The vent lines were metered with AC-250 diaphragm meters. These meters were necessary for flowrate determination; however, they did act as a slight restriction within the vent line. Meters are never present on vent lines within an actual installation. With the meters removed, the houseline pressure within a shut-in system dropped to 1.5 psig.

Investigators found through testing where mercury was completely removed from the reservoir, the average mercury service regulator leakage rate through the vent piping was 331 standard cubic feet per hour (SCFH). This calculated average leakage rate was for testing exemplar regulators 1, 2, and 3, and excluded exemplar regulator 4.[41] Table 3 shows details on the loss of mercury failure testing for each exemplar service regulator.

[40] *Houseline pressure* is the natural gas pressure of the gas line leading into the home that connects the gas appliances.

[41] Exemplar regulators 1, 2, and 3 were Reynolds Model 30 mercury service regulators and exemplar regulator 4 was a Schlumberger Model B-39 nonmercury service regulator.

Table 3. Loss of mercury failure test data.

Exemplar Regulator	System Pressure (psig)	Ambient Temperature (°F)	Leakage through Vent, observed Q_{obs} (CFH)	Pressure Downstream of Rotameter, P_{act} (psig)	Flow through Vent corrected Q_{corr} (SCFH)
1	20.1	61	197	11.8	344
2	20.5	64	163	18.9	320
3	20.5	65	184	13.4	330
4	20.4	65	260	2.4[a]	360

[a] A B-39 regulator seat was removed during testing, representing a system failure mode not expected in the field.

In addition, investigators pumped gas into the exemplar mercury service regulators at 20 psig—the same inlet pressure of the Flower Branch apartment complex—and observed how they functioned under different load demands of gas. During the field testing, NTSB investigators heard gas forcefully exiting the vent. This corroborated interview statements of a resident who heard a "weeping" or hissing noise outside the basement on the day of the accident, and WG and contractor service technicians who reported that when a mercury service regulator begins to fail and venting gas, that type of noise is heard and a gas odor can be detected. The NTSB concludes that the audible hissing noise heard by a resident, the evidence of past mercury service regulator failures, the pre-existing unconnected vent line union, and the lack of evidence of any pre-existing anomalies in the gas piping or gas appliances indicate that a failed mercury service regulator was the most likely source of the natural gas release in the meter room of building 8701. Discussion of past mercury service regulator failures is found in section 2.3.9.

2.3.8 Natural Gas Accumulation in the Meter Room of Building 8701

Natural gas is composed mostly of methane, with lesser amounts of nitrogen, ethane, and propane, and traces of butane, pentane, hexane, carbon dioxide, and oxygen.[42] Gas companies add an odorant, such as methyl mercaptan, as a safety measure so it can be easily detected by smell if there is a leak.[43] The flammability range for natural gas has an LEL of 3.9 percent to 4.5 percent, and an upper explosive limit (UEL) of 14.5 percent to 15 percent. Natural gas can be explosive if it is in a confined area, if the concentration of gas is between the LEL and UEL, and an ignition source is present (NFPA 2017).

The NTSB completed a study report using a computational fluid dynamics (CFD) model to estimate the time for natural gas released from a failed mercury service regulator to create an atmosphere in the meter room with a concentration sufficient to support an explosive event (NTSB 2018a). The mercury service regulator failure mode selected for the model was the "valve seat obstruction," as described in section 2.3.8. The CFD model simulated two different cases using the data from the valve seat obstruction failure testing. (See table 1.) One case assumed that there was no demand for gas by the building appliances (no house load) and, therefore, the service regulator had a constant vent leakage rate of 165 SCFH. The other case assumed a 165 SCFH leakage rate and periodic demand for gas by the water heater, during which time the service

[42] For more information on the composition of the gas at the Flower Branch Complex, see "Gas Composition on August 10, 2016 to Flower Branch Complex (Silver Spring, MD)" in NTSB Docket DCA16FP003.

[43] *Methyl mercaptan* is a colorless gas with a strong odor similar to that of rotten eggs.

regulator vent leak would reduce to zero. The water heater was assumed to be active 20 minutes of every hour. WG provided gas composition analysis and the concentration for LEL for the gas being delivered to the Flower Branch apartments on the day of the accident. The LEL was reported to be 4.78 percent, which was used in the model. The general configuration of the meter room can be seen in figure 16.

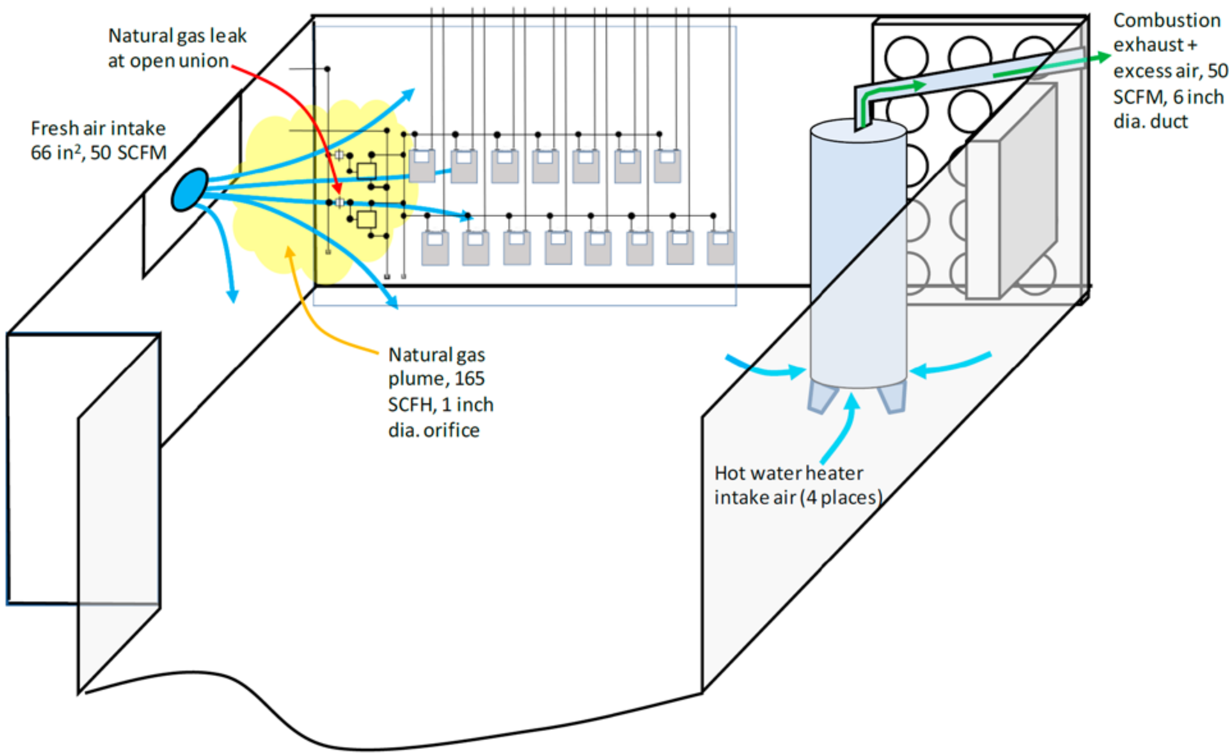

Figure 16. Three-dimensional visualization of the meter room.

According to the time stamp of the alarm records, the last maintenance person locked the meter room at 8:42 p.m., and the explosion occurred at 11:51 p.m. There were no reports of gas odors by residents or maintenance crew at or before 8:42 p.m. The next person to detect a gas odor was a resident of building 8701 who arrived home about 30 minutes before the explosion. Therefore, the natural gas had about 3 hours to accumulate to its explosive range.

Both cases of the scenario representing the valve seat obstruction failure of the mercury service regulator yielded a buoyant natural gas leak that began filling the meter room from the top down. In the case where the gas leak was continuous, a gas concentration greater than LEL formed between the ceiling and 48 inches above the floor within the first hour. In the low-leakage rate case where the gas leak was interrupted by the water heater’s operation, a gas concentration greater than LEL formed between the ceiling and 48 inches above the floor within the first hour and a half.[44] The mercury service regulator failure scenario for the low leakage rate case reached LEL

[44] The average concentration of the gas in the room, from the ceiling to the floor, measured at about 12-inch increments, reached LEL in 1 hour and 54 minutes when the leak was continuous and 2 hours 40 minutes when the leak was being interrupted.

in the timeframe established in the investigation, and the other failure modes with higher leakage rates would result in shorter time frames to support an explosive event.

Therefore, the NTSB concludes that a low leakage rate of venting natural gas from a mercury service regulator with an obstructed orifice, and other regulator failure scenarios with higher leakage rates, could have allowed the gas concentration to build up to an explosive atmosphere in the meter room between 8:42 p.m. and the time of the explosion at 11:51 p.m.

2.3.9 Mercury Service Regulator Replacement

As of December 2018, WG has replaced about 175,000 mercury service regulators in total and has about 125,000 mercury service regulators still in service throughout its system.

Within WG's *Operations and Maintenance Manual* were specific procedures for mercury service regulators. In addition, it specified conditions which required the mercury service regulators to be replaced:

- The regulator has "blown" or is weeping gas through the vent.
- The regulator is being tested and fails the functional and lock-up test, or malfunctions.[45]
- The system is being uprated to a MAOP above 25 psig.
- The service is being replaced.
- The connecting piping is being altered or replaced, making it practical to change the regulator.
- The regulator is scheduled for removal (WG 2016).

Mercury is a metal that is toxic to human health when exposed through inhalation or ingestion. When released into the environment, mercury may evaporate and become an invisible, odorless, toxic vapor. Between October 2011 and September 2016, WG replaced 12,174 mercury service regulators in their system. Of those, 11,182 mercury service regulators were replaced to mitigate potential environmental risks. The US Environmental Protection Agency (EPA) issued a recommended management practice for the safe removal of mercury containing devices, such as mercury service regulators in May 2011 (EPA 2011). The design of mercury service regulators include materials such as leather diaphragms and rubber valve seats that are subject to age-related deterioration. The remaining 992 regulators were replaced due to performance failure identified by service technicians.[46] Of those, 631 were caused by venting and 293 were caused by mercury leaking out of the reservoir. Venting or a leaking body connection was found to be the cause of failure in 63 percent of the mercury service regulators and mercury blew out of the reservoir in about 30 percent of the failed mercury service regulators. Although WG identified a leaking or

[45] These tests examine the functionality of the service regulators to ensure it does not exceed its set pressure or leak gas.

[46] In this report, WG technicians include both permanent WG and contract employees.

torn diaphragm as another possible failure, it was not recorded for any of the mercury service regulator failures found in their system.

Furthermore, while reviewing WG field records for 8701 Arliss Street, NTSB investigators discovered erroneous entries identifying mercury service regulators as nonmercury service regulators.[47] WG did not review field entry forms to ensure data entry accuracy and did not have a system-wide master list identifying the location of each mercury service regulator. The NTSB concludes that WG relied on unvalidated information to determine the location and condition of mercury service regulators. Therefore, the NTSB recommends that throughout the WG network, WG implement an audit program to verify the data on the service forms used to determine the location and condition of mercury service regulators to ensure the accuracy of this safety-critical data. In addition, the NTSB recommends that following WG's successful completion of Safety Recommendation P-19-009, PSC, the Commonwealth of Virginia State Corporation Commission Division of Public Utility Regulation, and the Public Service Commission of the District of Columbia audit and verify the performance of WG's mercury service regulator replacement program, including its recordkeeping.

2.3.10 Location of Natural Gas Service Regulators

Mercury service regulators, along with all types of natural gas service regulators, must comply with 49 *CFR* Part 192, which is under the authority of PHMSA. In the regulation, they are classified as "service regulators" and defined as a "device on a service line that controls the pressure of gas delivered from a higher pressure to the pressure provided to the customer. A service regulator may serve one customer or multiple customers through a meter head or manifold."[48]

PHMSA regulations include minimum requirements for the location, protection, and installation of service regulators. Service regulators must be installed in a "readily accessible location and be protected from corrosion and other damage" and be located "as near as practical to the point of service line entrance."[49] Service regulators must have vents that "terminate outdoors" and vent "into the atmosphere and away from any opening into the building." If located outside, the regulators also must be protected from damage from flood or vehicle traffic.[50]

The service regulators in building 8701 were located inside the basement and were connected to an outside vent line. When the mercury service regulator failed on August 10, the excess natural gas flow was not properly vented to the outside because of the unconnected union assembly from the lower service regulator. The natural gas accumulated in the basement until it reached its explosive range and ignited from one of the many possible ignition sources in the room.

The NTSB concludes that the failure of a service regulator, combined with an unconnected vent line, poses a significant threat to people and property with little warning. In particular, the risk of mercury service regulator failure is increased because of their age. Therefore, the NTSB recommends that WG establish a time frame with specific dates and milestones for the replacement

[47] WG 5-year service records from October 2011 to September 2016 for 8701 Arliss Street.
[48] Title 49 *CFR* 192.3, "Definitions."
[49] Title 49 *CFR* 192.353, "Customer meters and regulators: Location."
[50] Title 49 *CFR* 192.355, "Customer meters and regulators: Protection from damage."

of its mercury service regulators throughout the WG network that recognizes the need to expedite this program and that prioritizes multifamily dwellings where mercury service regulators are located inside the property. In addition, the NTSB recommends that the PSC, the Commonwealth of Virginia State Corporation Commission Division of Public Utility Regulation and the Public Service Commission of the District of Columbia oversee the replacement process for the mercury service regulators that WG has in service.

Many dwellings that use natural gas have meters and service regulators outdoors, so that should a regulator fail, the gas release is directed into the atmosphere and does not accumulate to explosive levels inside a structure. However, in many multifamily structures, including the buildings of Flower Branch apartments, service regulators are indoors, but isolated and inaccessible to residents. The NTSB concludes that had service regulators been located outside building 8701, the explosion would not have occurred because gas would have vented to the atmosphere and dissipated. The NTSB recommends that PHMSA require that all new service regulators be installed outside occupied structures. Additionally, the NTSB recommends that PHMSA require existing interior service regulators be relocated outside occupied structures whenever the gas service line, meter, or regulator is replaced. In addition, multifamily structures should be prioritized over single-family dwellings. In addition, the NTSB recommends that WG install all new service regulators outside occupied structures. Further, the NTSB recommends that WG relocate existing interior service regulators outside occupied structures whenever the gas service line, meter, or regulator is replaced. In addition, multifamily structures should be prioritized over single-family dwellings.

2.4 Natural Gas Odor Notification

2.4.1 Kay Management

Kay Management staff reported that when residents applied for a rental apartment, they would provide a “move-in package” to the new tenants. This included documents such as a copy of their application, parking rules, permits, an amenity sheet, and floor plan. Residents were verbally told that that if they had any problems, such as a gas odor or an appliance that is not working, to call the 24-hour emergency number for Kay Management. Residents were provided a telephone number for WG, but only for starting new gas service for their apartment. The package did not provide any written guidance on how to report a gas odor to WG.

Kay Management provided in-house training to its maintenance staff to detect a gas leak in an apartment. They were instructed to use a TIF gas detector to search for a leak after receiving a gas odor call from a resident.[51] If staff members did not find a leak, they would continue to test other apartments and rooms within the building. If gas was detected in the apartment, staff members were instructed to check to see if they could make a quick repair, such as replacing a knob on a gas stove or relighting the pilot light. The staff members may also do a soap test, if

[51] TIF Instruments is an electronics company that develops leak detection instruments and lab technology for field service technicians.

needed, to determine the source of the leak.[52] If they were unable to do the repair, they would schedule an appointment with a plumbing contractor who was certified to repair house lines. If the plumbing contractor determined that the issue was not because of the house line, but a jurisdictional line, the plumbing contractor would report the issue to Kay Management that would then call WG.[53]

2.4.2 Washington Gas

WG is required by PHMSA to have a public awareness plan to keep the public and local emergency responders aware of pipeline operations and related safety issues in the event of a gas leak or fire.[54] Specifically, the company periodically mails information to its customers, such as a pamphlet sent with monthly billing statements. In the event of a gas leak, the WG website directs individuals to first call 9-1-1 and then WG. In addition, the company maintains a Gas Operations Dispatch Center, staffed by trained personnel, that receives notification of gas-related emergencies and immediately dispatches the closest service technician to the reported leak site. WG procedures require that leaks and emergency orders be given priority over nonemergency work and calls off-duty employees to perform additional work if the emergency exceeds the capacity of personnel on duty.

WG technicians have expertise with gas infrastructure and are generally equipped with instruments and detection methods that could identify methane at lower concentrations. WG procedures require that when an odor complaint is received, technicians conduct a leak investigation. When that occurs, the technician will not leave the area until the potential leak is "investigated, graded, and/or repaired, or until confirming that there is not a gas leak." If the technician cannot gain access to the area of the suspected inside leak, the gas is required to be turned off and a reasonable effort made to obtain access. If this cannot be accomplished, the technician is to leave a contact card for the customer and notify dispatch that the gas is turned off (WG 2016).

Had WG been notified of the July 25 odor complaint, they likely would have investigated further to confirm a natural gas leak and take steps to stop it if one occurred.

2.4.3 Montgomery County Fire and Rescue Services

MCFRS has a specific policy and procedure for responding to natural gas incidents. The procedure states that after a rescue unit is dispatched to a natural gas incident, a unit officer confirms there is a gas leak and classifies it as either a "major" or "minor" leak, based on its severity.[55] Examples of a major leak would be one that has migrated throughout an occupied structure, health care facility, or high occupancy structure with high life-hazard risks or a leak from

[52] (a) A *soap test* is a method in which a soap solution is used to detect leaks. It is commonly used in the gas industry. (b) For more information, see interview transcripts of maintenance personnel for the Flower Branch apartment complex for Kay Management employees in NTSB Docket DCA16FP003.

[53] For more information, see the interview transcript of the president of Kay Management in NTSB Docket DCA16FP003.

[54] Title 49 *CFR* 192.616, "Public awareness."

[55] According to MCFRS, a *major leak* is "a natural gas leak with an imminent threat of life safety," and a *minor leak* is "a leak not believed to pose an imminent threat of life safety," and that does not involve a fire.

a transmission (nonodorized) supply pipeline. Under MCFRS guidelines, the incident commander is then required to establish a Level II Command and “request additional resources as needed.” In addition, the guidelines state that gas personnel are to be considered the “expert natural gas resource officer (MCFRC 1996).”

When a leak is confirmed, the incident commander sets up a hot zone and restricts the area to fire service personnel in full protective turnout equipment and eliminates all ignition sources within that zone. Fire personnel then checks all occupancies in the immediate vicinity for the presence of natural gas and, if present, evacuates the occupants and ventilates the structure. The minor gas leak procedure includes a provision for the gas company technician to report to the incident commander upon arrival.

However, the MCFRS policy and procedure did not specify how and when to notify the gas company. The NTSB believes the applicable gas company should be notified after responders have been notified whenever a member of the public calls 9-1-1 to report a gas odor or a gas leak. In this particular situation, those calls were received by the Montgomery County Emergency Communication Center (ECC), which used specific protocols for their dispatchers. The ECC used *Protocol-60 Gas Leak/Gas Odor (Natural and LP [liquified petroleum] Gases)* when receiving a 9-1-1 call for a gas odor/leak (IAED 2014). The ECC purchased its protocols from Priority Dispatch, a research company that provided products and training for emergency call-taking centers. Priority Dispatch worked in conjunction with the International Academies of Emergency Dispatch (IAED), who authored the *Protocol-60 Gas Leak/Gas Odor (Natural and LP Gases)* protocol. However, *Protocol-60 Gas Leak/Gas Odor (Natural and LP Gases)* did not direct the dispatcher to contact the gas company during a gas odor/leak call. The NTSB concludes that had WG been notified of the gas odor call on July 25, 2016, a service technician may have had the opportunity to enter the meter room of building 8701, identify the unconnected vent line, and remedy the situation, potentially preventing the gas release and explosion that occurred on August 10, 2016. Therefore, the NTSB recommends that the IAED revise *Protocol-60 Gas Leak/Gas Odor (Natural and LP Gases)* to direct dispatchers to notify the gas company when any odor call is received.

2.5 Odorant and Methane Detection of Natural Gas

2.5.1 Odorant Detection

Natural gas regulations that have required the addition of odorant to natural gas distribution pipelines were first promulgated by DOT in 1970 (*Federal Register*, 1970, 13247). Because these gas systems are situated primarily in populated areas, the odorant can act as an early warning of a gas release to prevent an explosion and fire. In the United States, all odorants contained sulfur because of its unique odor that when detected could be associated with natural gas. Pipeline operators selected a blend of a sulfur-based odorants that were the most appropriate for their pipeline network. Odorant was the primary safety feature that members of the public relied upon to detect a natural gas release (GAO 2018).

However, soon after the odorant regulations were issued, the Research and Special Programs Administration (RSPA) observed problems with the odorization practices, the effectiveness of commercial odorants in use, as well as odorant fading, and commissioned a study by the Institute of Gas Technology to study these issues.[56] RSPA was particularly concerned about odor fading because a number of uncontrolled releases of natural gas went undetected, leading to explosions and fires that caused severe injury, death, and extensive property damage (RSPA 1975). The study noted that odorant could be stripped from natural gas through the adsorption or absorption on pipeline walls, particularly new main pipelines; oxidation by the presence of iron oxide and traces of oxygen; and adsorption through the soil.[57] The study recommended a solution for odorant fade in new pipelines by applying coatings to the internal surface of gas mains to prevent odorant adsorption. However, the study did not find a solution to address odorant adsorption through soil, and the study recommended "research efforts for developing an odorant blend that will have better soil penetration characteristics."

In subsequent years since the RSPA study was published, government, industry, and academia have researched the issue of odorant fade. In 1998, the DOT Transportation Safety Institute recommended that gas companies develop odorization programs which would consist of odorant selection criteria, method of injection, and verification of odor intensity (Bull 1998). That same year, a chemical company, Elf Atochem North America, Inc., proposed that companies use different mercaptans blended with sulfide components as an alternate odorant with effective soil penetrability. Additionally, various odorant blends have been studied and distinguished by their physical and chemical properties, which reflect their resistance to oxidation and ability to pass through soil (Usher 1999). Despite these proposed solutions, PHMSA regulations do not address methods for mitigating odorant fade when natural gas migrates through soil. Furthermore, NTSB continues to recognize odorant fade as a contributing factor in many gas pipeline accidents.

Appendix B contains examples of 20 accidents between 1971 and 2018 where natural gas had either migrated from an outside leak or within a structure and accumulated to dangerous concentrations leading to explosions, fires, fatalities, injuries, and severe property damage. NTSB identified within those investigations whether gas odorant played a significant role in warning the occupants about the presence of gas in buildings. In some cases, the occupants smelled gas but failed to report the odor due to a lack of awareness about the dangers of natural gas. In some cases, gas odor was not detected by the occupants of the building in time for them to evacuate before the explosion occurred, despite the odorant levels being compliant with regulatory requirements. In several of these cases, the NTSB cited odorant fade due to soil adsorption as a contributing factor.

Since the Pipeline Safety Improvement Act of 2002 was signed into law, gas companies have been required to educate the public through public information programs on the hazards of natural gas and specifically outline steps for public safety in the event of a pipeline release.[58]

[56] (a) Before PHMSA was created in 2004, RSPA was the entity within the DOT responsible for regulating the pipeline industry. (b) The Institute of Gas Technology was founded in 1941 at the Illinois Institute of Technology. In 2000, the Institute combined with the Gas Research Institute to form the Gas Technology Institute.

[57] *Adsorption* is the process by which a material such as a gas, liquid, or solute, adheres to the surface of another material that is a solid or liquid. *Absorption* is the process in which a material is dissolved by another material, such as a liquid or solid.

[58] Section 5 of the Pipeline Safety Improvement Act of 2002 requires gas companies to have a public education program to advise affected municipalities, school districts, businesses, and residents of pipeline facility locations.

However, as illustrated in this accident, as well as some of the accidents discussed in appendix B, public awareness programs do not guarantee that gas odors will be appropriately reported.

Kay Management and WG staff provided information to residents of the Flower Branch apartment complex on what to do if they detect gas odors. They were supposed to contact both WG and the fire department. However, only one call was made to authorities—the call was made only to the fire department—regarding the odor, despite several residents attesting to noticing the odor for several weeks prior to the accident.

While olfactory senses can provide warning of a gas leak, they cannot be relied upon in every situation as a primary means of detecting the presence of hazardous gas concentrations. As illustrated in a 2016 document from the British Standards Institution (BSI), the European standard for combustible gas detectors, EN 50244, states that most people may be able to detect gas odors at very low levels of 2 percent LEL or less; however, this can depend on an individual's sensitivity to the odor, medical conditions, and the phenomena of olfactory fatigue (BSI 2016).[59] Although in many cases, gas odorants effectively warn about the presence of gas leaks, too often personal decisions to report gas leaks and evacuate buildings are connected to the intensity by which individuals are able to smell gas odors. PHMSA odorant requirements rely on a person with a "normal sense of smell" and assumes that when the odor is detected, there is adequate time to evacuate, identify, and resolve the leak before the gas accumulates to explosive levels.[60] However, as demonstrated by many NTSB investigations, gas odorant does not always provide sufficient warning of gas leaks and hazardous conditions and, under certain conditions, a gas leak can go undetected. For instance, in many multifamily structures gas regulators are located in locked rooms, basements, or other areas that are not readily accessible to residents. Therefore, the NTSB concludes that the use of gas odorants alone does not effectively mitigate the risk of death and injuries caused by gas system leaks, such as the undetected leak that occurred at the Flower Branch apartment complex.

2.5.2 Methane Detection

The seven fatalities in the August 10 explosion were residents located in apartments in buildings 8701 and 8703, closest to the basement meter room. Had there been an alarm to warn of a natural gas release, residents, especially those closest to the meter room, could have been notified earlier to evacuate to a safe place away from the building, without relying on someone to smell gas odors to identify the hazard. The NTSB concludes that had methane detectors been installed at the Flower Branch apartment complex, an alarm would have alerted residents to a gas release on either July 25, 2016, or August 10, 2016, reducing the potential and consequences of a natural gas explosion.

The NTSB has recommended previously that "gas detectors" be required to provide early warning of gas leaks in buildings. NTSB first issued this recommendation as a result of an investigation into a gas explosion that occurred in a commercial building in New York City,

---

[59] *Olfactory fatigue* is when a person's sense of smell adapts to an odor after prolonged exposure and is unable to recognize the smell temporarily.

[60] According to 49 *CFR* 192.625 (a), "Odorization of gas," "a combustible gas in a distribution line must contain a natural odorant or be odorized so that at a concentration in air of one-fifth of the lower explosive limit, the gas is readily detectable by a person with a normal sense of smell."

New York, on April 22, 1974 (NTSB 1976). Building personnel had smelled gas odors in the basement, but the explosion occurred before the gas could be shut off, injuring 70 people. The report noted that many commercial buildings were required to have smoke or heat detectors placed in strategic interior locations; therefore, it seemed logical for similar requirements to be adopted for installing gas detectors. As a result of this investigation, the NTSB recommended the US Department of Housing and Urban Development (HUD) to:

> Investigate the practicality and the availability of gas vapor detection instruments for installation at strategic locations in buildings. Based on the results of this investigation, recommend guidelines to appropriate State and local government agencies for regulations for the installation of gas detection instruments in buildings. (P-76-12)

HUD responded that gas detectors were technically possible, but the agency did not believe they were practical at the time. HUD responded that it would continue to review developments in the field and would reevaluate their position “when a practical, cost effective natural gas detection system is developed.”

NTSB made a similar safety recommendation from the investigation of a gas explosion and fire that occurred in a retirement home in Allentown, Pennsylvania, on June 9, 1994 (NTSB 1996). Workers hit a gas service line while performing excavation work; gas entered the home and ignited. Although workers and residents inside the home smelled gas and reported it to the gas company, they did not evacuate before the explosion occurred. The NTSB investigation found that the performance and cost-effectiveness of gas detectors had improved in the 20 years since Safety Recommendation P-76-12 was issued. Therefore, the NTSB recommended in Safety Recommendation P-96-16 that HUD:

> Evaluate the safety benefits of using gas detectors in buildings approved by the Department for Federal rent subsidies as a means of providing building occupants and local emergency-response agencies with early notice of released natural gas within buildings; require that gas detectors be used in buildings in which the Department has determined that a gas detector would be cost effective and beneficial. (P-96-16)

For 5 years, HUD did not respond to this safety recommendation. In July 2001, HUD declined to implement the recommendation because it claimed that it did not have the statutory authority and that gas detection should be required in the National Fire Code.[61] The NTSB classified this safety recommendation as *Closed—Unacceptable Action*.

Currently, methane gas or combustible gas alarms are not required by federal or state regulations, nor are they required in building or fire codes for residential occupancies. While smoke and carbon monoxide alarm requirements have been incorporated into many state regulations, methane detection alarms have not been widely adopted due to initial reservations regarding the reliability of the technology (NCSL 2018). Although some states and cities have considered requiring the use of this technology because of their own major natural gas incidents,

[61] Letter from HUD to NTSB, July 19, 2001.

the proposed bills or state regulations have not been implemented. It is unlikely that these proposals will be enacted until the devices perform more reliably and there is adequate industry guidance for both performance and installation. For example, legislation has been proposed in the New York Assembly that would require all temporary and permanent dwellings in the state to install an operable combustible gas detector. Further, it would require that the detector be wirelessly connected to the gas company. This legislation, A 2913, also requires gas companies to annually publish a report of gas leaks broken down by county. A 2913 has been referred to the Assembly Governmental Operations Committee, but the committee has not taken any action on the proposal.[62] New York City went further and enacted a local law that revised its housing maintenance and building codes to require the installation of natural gas detection devices once an industry standard has been developed.[63]

Operations Technology Development (OTD), a membership-controlled partnership of natural gas distribution companies that studies new technologies, is currently researching methane detection technology in residential occupancies (OTD 2018).[64] OTD initiated the Residential Methane Detectors (RMD) program, which is currently being overseen by one of its members, the Gas Technology Institute (GTI). Other members, such as WG, are also providing funding for the program. The program began in 2014 and involves researching and testing commercially available methane detectors, evaluating consumer behavior for adoption of the technology, and reviewing and developing industry standards for the installation and maintenance of methane detectors.

OTD presented the RMD program at a PHMSA Research and Development forum in November 2016 (Wiley 2016). At these forums, representatives from academia or industry proposes projects and PHMSA will follow with a solicitation for projects that aligns with its research interests. However, PHMSA rejected the proposal and did not follow with a solicitation for research on residential methane detection after the OTD program was presented. Therefore, the RMD program has remained an industry-funded effort.

The RMD program evaluated commercially available metal oxide semiconductor methane detectors that sound an alarm when gas concentrations exceed a specified set-point. In December 2017, the RMD program completed its pilot testing phase of various commercially available methane detectors using a nationally recognized testing laboratory (OSHA 2018).[65] As documented in a GTI report, the devices were tested under different conditions such as extreme temperatures and humidity, exposure to multiple chemicals, different detection limits for methane (5 percent, 10 percent, and 25 percent LEL), and reduced voltage supply (GTI 2017). The program found many commercially available methane detectors are not reliable and may be subject to false alarms because of interference with household chemicals or exposure to extreme temperatures and

[62] New York State Senate Bill A2913, https://www.nysenate.gov/legislation/bills/2019/A2913, Accessed April 9, 2019.

[63] New York City Council, Local Law 157, Int 1100-2016, http://legistar.council.nyc.gov/LegislationDetail.aspx?ID=2576426&GUID=D9EE7190-AF91-411D-A017-8305FF6D6F0D&Options=Advanced&Search. Accessed November 5, 2018.

[64] OTD is a member-driven, not-for-profit organization that identifies, selects funds, and oversees research projects that are intended to improve safety, reliability, and operational efficiency in the gas utility industry.

[65] OSHA certifies a private-sector organization that meets the legal requirements under 29 *CFR* 1210.7 to perform testing and certification of procedures using consensus-based testing standards.

humidity. The next stages in the RMD program involve additional testing that is expected to be completed in 2018, and also a placement study to develop a scientific rationale for recommendations on where to best locate the residential methane detectors inside buildings.

One natural gas company, Consolidated Edison Company of New York, is participating with a consortium of gas companies in the testing phase of the RMD program.[66] The company officially began a pilot program to install 9,000 units in New York City in November 2018.[67] The detectors trigger an alarm when a leak is detected at 10 percent LEL and communicates directly to the gas company's emergency response center, that dispatches a technician and notifies the local fire department. The alarm also has a voice-activated message that alerts residents to evacuate and to call 9-1-1.

To address methane detector reliability, the RMD program has identified an existing industry standard, the American National Standards Institute (ANSI)-approved, product standard by the Underwriter's Laboratories, UL 1484 *Safety for Residential Gas Detectors*, which covers electrically operated gas detectors that detect both propane and methane in residential occupancies and recreational vehicles (UL 2016). This standard currently permits alarms to operate at a detection limit of 25 percent of the LEL for methane, or 5 percent volume of air, which is the limit where most commercially available alarms are set. The RMD program advocates lowering this detection limit to 10 percent LEL for methane so that the alarms will provide earlier notification of a gas release. Industry standards in other countries, such as Great Britain, have established lower detection limits for natural gas detection alarms to provide early notification. The British standard sets visual indicators and audible alarms for combustible gases to operate at "a volume ratio above 3 percent LEL and below 20 percent LEL (BSI 2009)."

The RMD program's ongoing research and development of new and existing technology is intended to resolve the uncertainties with methane detection. However, once the technology is established, standards will need to be developed to ensure the proper installation, maintenance, and testing requirements, including effective and safe detection limits. The NTSB concludes that the development of a national code that establishes methane-detection performance criteria and requires the technology to be installed in residential and commercial buildings with natural gas service would provide a redundant means of leak detection to supplement the use of odorants.

In the United States, the National Fire Protection Association (NFPA) and the International Code Council (ICC) are nationally recognized standard-setting bodies for both building and fire codes, as well fuel gas codes such as the *International Fuel Gas Code* (*IFGC*) (ICC 2015) and the *National Fuel Gas Code* (*NFPA* 54) (NFPA 2018). The *IFGC* and *NFPA 54* provide minimum safety requirements for the design and installation of fuel gas piping systems in homes and other nonindustrial buildings, though, neither of them requires methane detection alarms. These codes are adopted across the nation and incorporated either in state or local regulations. They also apply

[66] As a result of the natural gas-fueled building explosion and fire in East Harlem, New York City on March 12, 2014, the New York State Public Service Commission agreed as part of the settlement to the Consolidated Edison Company that the company provide improvements for detection and response to gas leaks, which included remote methane detection equipment.(NTSB 2015).

[67] (a) Letters from Consolidated Edison Company to the New York State Public Service Commission, January 3, 2017, and July 2, 2018; (b) "PSC Announces $25.5 Million East Harlem Settlement," press release, July 12, 2018.

to gas service pipelines entering structures, which is under the jurisdiction of the local authority and the responsibility of the owner to implement. For example, at the Flower Branch apartment complex, the gas service piping after the gas meter is regulated by Montgomery County, which has adopted the WSSC Code that incorporates by reference the 2015 International Fuel Gas Code.[68]

The NTSB concludes that the scope of *NFPA 54*, *IFGC*, and their widespread adoption by local authorities appear to be the most appropriate standards for requiring methane detector alarms, with local jurisdictions enforcing the requirements and making them feasible. Therefore, the NTSB recommends that, in coordination with NFPA and ICC, the GTI work to develop standards for methane detection systems for all types of residential occupancies in both the *IFGC* and the *National Fuel Gas Code*, *NFPA 54*. At a minimum, the provisions should cover the installation, maintenance, placement of the detectors, and testing requirements. Further, the NTSB recommends that, in coordination with GTI and ICC, the NFPA revise the *National Fuel Gas Code*, *NFPA 54* to require methane detection systems for all types of residential occupancies with gas service. At a minimum, the provisions should cover the installation, maintenance, placement of the detectors, and testing requirements. Lastly, the NTSB recommends that, in coordination with GTI and NFPA, the ICC incorporate provisions in the *IFGC* that requires methane detection systems for all types of residential occupancies with gas service. At a minimum, the provisions should cover the installation, maintenance, placement of the detectors, and testing requirements.

[68] Currently, the WSSC Plumbing and Fuel Gas Board is considering a proposal to adopt the 2018 *IFGC*.

3 Postaccident Actions

Since the explosion, WG has taken a number of initiatives involving safety messaging when a release of natural gas is suspected, including:

- Distributing 10,000 door-hanging signs in multiple languages communicating the importance of calling the gas company upon smelling natural gas to multifamily buildings in Montgomery County, Maryland, that have gas service.
- Continuing to work closely with local fire departments in the Washington, DC, region on improving communications to ensure WG is alerted each time the jurisdiction received notice of a possible odor of natural gas.
- Developing a plan for a coordinated response with local first responders when a possible odor of natural gas is detected.

In addition, WG is planning equipment improvements, including:

- Installing new service regulators to the exterior of 8701 Arliss Street and any new multifamily dwelling construction projects in the Flower Branch apartment complex, reducing the risk of high gas flow releasing into the interior of the buildings.
- Simultaneously replacing all legacy multimeter sets with old service lines and moving them to the exterior of the building.

Furthermore, WG has installed thermal safety valves in all new and replaced metered facilities, which shut off the flow of gas in the event of a structure fire, reducing further damage from an incident.[69]

[69] Detailed information on the testing can be found in "Washington Gas NTSB Party Submission re Building Explosion Fire" in NTSB Docket DCA16FP003.

4 Conclusions

4.1 Findings

1. The postexplosion responses by both Montgomery County Fire and Rescue Service and Washington Gas Light Company were prompt and adequate.

2. Based on the pattern of debris and the location of the victims, the explosion radiated from the meter room, where the gas meter assembly was located.

3. The upper mercury service regulator was most likely connected to the vent line through the threaded nipple and union assembly prior to the explosion in building 8701 and the regulator likely became separated from the vent line due to forces of the explosion or from the building collapse.

4. The external threaded socket of the lower mercury service regulator union most likely was not threaded to the nut and, therefore, the lower mercury service regulator was not connected to the vent line prior to the explosion.

5. Without a requirement that technicians verify the connection of vent lines for indoor service regulators, such vent lines could inadvertently be left open following service work.

6. The gas piping to the water heater was most likely separated at the control valve due to overstress forces resulting from the explosion.

7. The water heater did not fail prior to the explosion and was not the source of the natural gas release in the meter room.

8. The audible hissing noises heard by a resident, the evidence of past mercury service regulator failures, the pre-existing unconnected vent line union, and the lack of evidence of any pre-existing anomalies in the gas piping or gas appliances indicate that a failed mercury service regulator was the most likely source of the natural gas release in the meter room of building 8701.

9. A low leakage rate of venting natural gas from a mercury service regulator with an obstructed orifice, and other regulator failure scenarios with higher leakage rates, could have allowed the gas concentration to build up to an explosive atmosphere in the meter room between 8:42 p.m. and the time of the explosion at 11:51 p.m.

10. Washington Gas Light Company relied on unvalidated information to determine the location and condition of mercury service regulators.

11. The failure of a service regulator, combined with an unconnected vent line, poses a significant threat to people and property with little warning.

12. Had service regulators been located outside building 8701, the explosion would not have occurred because gas would have vented to the atmosphere and dissipated.

13. Had Washington Gas Light Company been notified of the gas odor call on July 25, a service technician may have had the opportunity to enter the meter room of building 8701, identify the unconnected vent line, and remedy the situation, potentially preventing the gas release and explosion that occurred on August 10.

14. The use of gas odorants alone does not effectively mitigate the risk of death and injuries caused by gas system leaks, such as the undetected leak that occurred at the Flower Branch apartment complex.

15. Had methane detectors been installed at the Flower Branch apartment complex, an alarm would have alerted residents to a gas release on either July 25, 2016, or August 10, 2016, reducing the potential and consequences of a natural gas explosion.

16. The development of a national code that establishes methane-detection performance criteria and requires the technology to be installed in residential and commercial buildings with natural gas service would provide a redundant means of leak detection to supplement the use of odorants.

17. The scope of *National Fire Protection Association 54*, *International Fuel Gas Code*, and their widespread adoption by local authorities appear to be the most appropriate standards for requiring methane detector alarms with local jurisdictions enforcing the requirements and making them feasible.

4.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the explosion in building 8701 of the Flower Branch apartment complex was the failure of an indoor mercury service regulator with an unconnected vent line that allowed natural gas into the meter room where it accumulated and ignited from an unknown ignition source. Contributing to the accident was the location of the mercury service regulators where leak detection by odor was not readily available.

5 Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations:

To the Pipeline and Hazardous Materials Safety Administration:

> Require that all new service regulators be installed outside occupied structures. (P-19-001)

> Require existing interior service regulators be relocated outside occupied structures whenever the gas service line, meter, or regulator is replaced. In addition, multifamily structures should be prioritized over single-family dwellings. (P-19-002)

To the Public Service Commission of Maryland, the Commonwealth of Virginia State Corporation Commission Division of Public Utility Regulation, and the Public Service Commission of the District of Columbia:

> Following Washington Gas's successful completion of Safety Recommendation P-19-009, audit and verify the performance of Washington Gas's mercury service regulator replacement program, including its recordkeeping. (P-19-003)

> Oversee the replacement process for the mercury service regulators that Washington Gas has in service. (P-19-004)

To the International Academies of Emergency Dispatch:

> Revise *Protocol-60 Gas Leak/Gas Odor (Natural and Liquified Petroleum Gases)* to direct dispatchers to notify the gas company when any odor call is received. (P-19-005)

To the International Code Council:

> In coordination with the Gas Technology Institute and the National Fire Protection Association, incorporate provisions in the *International Fuel Gas Code* that requires methane detection systems for all types of residential occupancies with gas service. At a minimum, the provisions should cover the installation, maintenance, placement of the detectors, and testing requirements. (P-19-006)

To the National Fire Protection Association:

> In coordination with the Gas Technology Institute and the International Code Council, revise the *National Fuel Gas Code, National Fire Protection Association 54* to require methane detection systems for all types of residential occupancies with gas service. At a minimum, the provisions should cover the

installation, maintenance, placement of the detectors, and testing requirements. (P-19-007)

To the Gas Technology Institute:

In coordination with the National Fire Protection Association and the International Code Council, work to develop standards for methane detection systems for all types of residential occupancies in both the *International Fuel Gas Code* and the *National Fuel Gas Code, National Fire Protection Association 54*. At a minimum, the provisions should cover the installation, maintenance, placement of the detectors, and testing requirements. (P-19-008)

To Washington Gas Light Company:

Throughout the Washington Gas network, implement an audit program to verify the data on the service forms used to determine the location and condition of mercury service regulators to ensure the accuracy of this safety-critical data. (P-19-009)

Revise your procedures and field forms to require technicians to verify the integrity of vent lines following the testing of indoor service regulators throughout the Washington Gas network. (P-19-010)

Establish a time frame with specific dates and milestones for the replacement of mercury service regulators throughout the Washington Gas network that recognizes the need to expedite this program and that prioritizes multifamily dwellings where mercury service regulators are located inside the property. (P-19-011)

Install all new service regulators outside occupied structures. (P-19-012)

Relocate existing interior service regulators outside occupied structures whenever the gas service line, meter, or regulator is replaced. In addition, multifamily structures should be prioritized over single-family dwellings. (P-19-013)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ROBERT L. SUMWALT, III
Chairman

EARL F. WEENER
Member

BRUCE LANDSBERG
Vice Chairman

JENNIFER HOMENDY
Member

Report Date: April 24, 2019

Vice Chairman Bruce Landsburg filed the following concurring statement.

Board Member Statement

Vice Chairman Bruce Landsberg filed the following concurring statement on April 25, 2019. Chairman Robert L. Sumwalt, III and Member Earl Weener joined in this statement.

While concurring with the report, I believe there is an education opportunity for first responders, property owners, and code enforcement personnel. This tragedy might have been prevented had the Montgomery [County] Fire Department had access to the meter service room on July 25th, as required by the fire code.

Because Kay Management had changed the lock in February 2016, and failed to provide a key to the fire department, the first responders were unable to gain access, despite the report of gas odor. They pried the top of door partially open to insert a gas detector probe but no gas was noted and they decided not to pursue it further. Neither Washington Gas nor Kay Management was notified.

As noted in the Board meeting, the concentration of gas mixtures, air currents, odorant concentration, and sensitivity of various measuring devices all affect the ability to detect the presence of gas. From the NTSB Report,"Between September 2015 and June 2016, Kay Management received six gas odor calls from residents of 8701 Arliss Street. Members of its maintenance staff said that when they investigated, they either did not detect gas through their gas-detection equipment or would report that the painting of apartments was causing the smell. During this period, MCFRS fire personnel responded to an odor call at building 8701 on July 25, 2016. According to interviews with Flower Branch residents and employees from Kay Management, residents in the building routinely called either the management company or 9-1-1 to report gas odors."

As a result, perhaps several opportunities to prevent the explosion were missed. While the Board declined to make a recommendation, the various trade associations and publications should offer a case study of this accident to code enforcement, first responder, and building management organizations. Maintaining access to rooms having gas meters or appliances is not only required by code, it is essential to safety. Likewise building management and maintenance personnel should understand the seriousness of such reports, especially when repetitive and take appropriate action.

First responders must have immediate access to such places. If for any reason they are unable, building management must be reachable 24/7 to provide immediate access - No exceptions! Further, first responders must immediately seek to gain access with building management, especially when inspecting closed spaces containing gas equipment within multi-family buildings.

A placard/sign should be placed adjacent to the lockbox or entrance providing an emergency phone number and a notice that when keys or combinations are changed, that they must be placed in the lockbox.

First responder training should include scenarios recreating this circumstance, so crews know how to respond when this situation is invariably repeated. It cannot be said with certainty that had the first responders gained access to the meter room on July 25th the accident would have been prevented, but it might have. Given the loss of life and property, both looking backward and forward, this seems like a very small and easily accomplished action.

6 Appendix

6.1 Appendix A: The Investigation

The National Transportation Safety Board (NTSB) was notified around 2:00 a.m. on August 11, 2016, of an explosion and fire at the Flower Branch apartment complex in Silver Spring, Maryland. A team of seven, including an investigator-in-charge, investigators, representatives from Transportation Disaster Assistance, and an attorney from the office of General Counsel, launched to the scene later that morning.

Parties to the investigation included the Pipeline and Hazardous Materials Safety Administration (PHMSA), Public Service Commission of Maryland (PSC), Montgomery County Fire and Rescue Service (MCFRS), Montgomery County Police Department (MCPD), and Washington Gas (WG).

6.2 Appendix B: Sample of 20 NTSB Investigations of Residential and Commercial Building Pipeline Accidents Between 1971 and 2018

a. On October 4, 1971, in Fort Worth, Texas, a house exploded and burned when gas ignited and exploded inside the home as a resident tried to light her gas stove. The resident sustained major burns to over 50 percent of her body. Natural gas had migrated from an improperly installed plastic service saddle-tapping nipple connection into the house, which ultimately failed, and load stresses from the operation of heavy construction equipment over the connection and heavy rainfall that caused the soil to exert pressure on the pipe (NTSB 1972).

b. On March 24, 1972, in Annandale, Virginia, a contractor backhoe snagged a 2-inch steel gas main. Gas company personnel arrived 40 minutes later and started searching for the break but did not shut off the gas, check for gas in the nearby houses, or call emergency responders. About 20 minutes later, gas had leaked from the main and into the houses. One house exploded, and then a few minutes later two other homes exploded and burned, killing three and injuring one. A number of residents had smelled gas in their houses, but only one reported it to the gas company (NTSB 1972a).

c. On April 22, 1973, in El Paso, Texas, an explosion occurred at a 15-unit apartment complex, killing seven people and injuring eight. Residents had smelled gas odor the day before the explosion but had not alerted the fire department or the gas company. The educational materials provided by the gas company on procedures to follow in case of a gas leak contributed to the problem because they were only printed in English and were sent to an area that housed a primarily Latino population. In addition, no emergency number was provided on the materials. The gas leak had occurred from a broken cast-iron reducer and also from two corrosion leaks from the gas main (NTSB 1974).

d. On December 2, 1973, in Charleston, West Virginia, a gas explosion occurred at a single-family home, followed by an intense fire that killed three people and injured two. The fire was initially extinguished by the local fire department and the gas was shut off, but another fire rekindled from the gas-saturated soil. The NTSB determined the probable cause of the explosion and fire was an accumulation of natural gas that had released from two corroded holes of a gas main, which had migrated into the house and ignited. Residents in the home had smelled a slight odor the day before the accident, but did not report it to the gas company or fire department. The natural gas was tested and found to have met the federal requirements for odorant level. The NTSB contributed the odor fade to filtering of the odorant through the soil and olfactory fatigue (NTSB 1974a).

e. On April 22, 1974, in New York City, New York, an explosion occurred at a commercial building, injuring 70 people. The NTSB determined that the probable cause of the accident was a rupture of an overpressure hydropneumatics tank which rocketed upward and tore an overhead gas service line, which allowed an uncontrollable flow of gas into the building, which ignited and exploded. Personnel who went into the basement to check on the water smelled a gas odor, but the building exploded before the gas could be shut off. The NTSB issued a recommendation to the US Department of Housing and Urban Development to require gas vapor detection instruments for installation at strategic locations in buildings (NTSB 1976).

f. On January 10, 1976, in Fremont, Nebraska, a natural gas main failed due to contraction caused by cold weather that caused the pipe to pull out of its compression coupling and release gas. The gas seeped into a hotel, eventually accumulating and igniting, causing an explosion and fire that killed 20 and injured 39 people. The gas company had received multiple odor calls an hour before the explosion occurred. The gas technicians responded but could not identify the leak in time. An evacuation order was issued about 20 minutes before the explosion, but that was not sufficient time for everyone to leave the building (NTSB 1976a).

g. On December 15, 1977, in Lawrence, Kansas, a natural gas main pulled out of a compression coupling which was jointed to a steel gas main. Natural gas released and migrated through the stone foundation walls of a three-story apartment building and an adjacent bakery, which then accumulated and ignited. The result was an explosion and fire that killed two residents and injured three. One of the employees of the bakery had smelled a gas odor, but did not call the gas company (NTSB 1978).

h. On June 28, 1982, in Portales, New Mexico, a natural gas explosion killed five people and injured one person in a single-family home. The natural gas release was caused by a failed service line that had been damaged from earlier excavation work for the local telephone company over a month before the accident occurred. Between the time of the excavation work and the explosion, no one had detected gas and did not report it. The natural gas was tested and found to have met the federal requirements for odorant level. At that time there was high rainfall in the region. The NTSB concluded that the odorant compounds in the gas were absorbed in the surrounding soil where the gas leaked from the service line. Soil samples were taken and supported this conclusion (NTSB 1983).

i. On September 25, 1984, in Phoenix, Arizona, an intense natural gas-fed fire destroyed two apartments in an apartment building, killing five residents and injuring seven. The probable cause of the accident was the weakening of a plastic main that failed and released natural gas that migrated through the soil and under two apartments, where it accumulated and ignited by a gas pilot light of a furnace. Prior to the accident, residents smelled gas, but failed to report it to the gas company (NTSB 1985).

j. On December 6, 1985, in Derby, Connecticut, a natural gas explosion and fire destroyed a restaurant, killing 6 people and injuring 12 inside. Also, one passerby and one firefighter were also injured. Gas had released into the restaurant from a broken gas main that migrated into the basement of the restaurant and ignited and exploded. Restaurant personnel and patrons detected the gas odor, but did not report it to the gas company of the fire department prior to the accident (NTSB 1986).

k. On June 9, 1994, in Allentown, Pennsylvania, a natural gas explosion occurred at a retirement home. Excavation work was being performed outside the home when a natural gas service line was hit. The fugitive gas flowed underground, passed through an opening in the building foundation, and migrated to other floors. Eventually the gas accumulated and ignited, causing an explosion, killing 1, and injuring 66. Workers and residents inside the home smelled gas and reported it to the gas company, but did not complete the evacuation before the explosion occurred. The NTSB recommended to the US Department of Housing and Urban Development to evaluate the safety benefits of using gas detectors and to require an approved device in buildings similar to the retirement home (NTSB 1996).

l. On October 17, 1994, in Waterloo, Iowa, an explosion and fire occurred at a neighborhood tavern, killing six, severely injuring one, and causing several minor injuries. The NTSB determined that the service pipeline had failed due to stress intensification that was primarily caused by shifting soil settlement at a connection to a steel main. The service pipeline had poor resistance to brittle cracking. Odorant levels were tested and found in compliance with federal requirements (NTSB 1998).

m. On July 7, 1998, in South Riding, Virginia, a house exploded, killing one and injuring three others. The accident was caused by the failure of a gas service line to the home that had been located too close to an electrical service line that overheated and arced. The uncontrolled release of gas accumulated into the basement and ignited. The owner of the house did not smell gas before going to bed, which was about 2 hours before the explosion occurred. A resident located 150 feet away smelled gas 30 minutes before the explosion, investigated, and called the gas company when he could not locate the source. Minutes later, the explosion occurred (NTSB 2001).

n. On December 13, 2005, in Bergenfield, New Jersey, an apartment building exploded after natural gas migrated into the building from a damaged distribution service pipeline due to nearby excavation work that was being performed the same day. The building exploded while contractors and gas company service technicians were working to shut off the gas. Three residents were killed and five were injured. Although some residents smelled gas, people remained in the building because there was no evacuation order (NTSB 2007).

o. On March 5, 2008, in Plum Borough, Pennsylvania, an explosion and fire occurred at a single-family home, killing one person and severely injuring a child. The NTSB determined that the gas distribution pipeline had been damaged from excavation work from years before which created corrosive conditions, causing the pipe to fail. No one smelled gas 30 minutes prior to the explosion, and the gas was thought to have migrated through a porous backfill of a new sewer line and accumulated rapidly in the house with little warning to residents. Odorant levels were tested and found in compliance with both federal and state requirements (NTSB 2008).

p. On December 24, 2008, in Rancho Cordova, California, an explosion and fire occurred at a house, killing one person and injuring five others, including a utility employee and one firefighter who were hospitalized. The NTSB determined that the main pipeline had inadequate wall thinning that allowed gas to leak from a mechanical coupling that was installed 2 years before the accident. Residents had smelled gas prior to the accident and called the gas company. Although the gas company personnel were in the process of locating the leak, they did not promptly evacuate the residents and the public. The delayed response contributed to the accident (NTSB 2010).

q. On December 17, 2013, in Birmingham, Alabama, a two-story duplex at a public housing project exploded when natural gas in an apartment ignited, killing one resident and injuring three others. Residents said they had smelled gas outside the surrounding apartments earlier in the night but reported that it was only a faint smell and they did not notify the fire department. The NTSB determined that the probable cause was the accumulation of natural gas released from a corroded main that cracked from tree root growth. The NTSB report noted that when odorized natural gas passes through the soil, it can absorb and deplete the odorant from the gas (NTSB 2016).

r. On March 12, 2014, two adjacent multi-occupancy, five-story buildings in Manhattan, New York City, were destroyed by a natural gas-fueled explosion and fire, killing 8, injuring more than 50 people, and displacing over 100 families from their home. The NTSB found that a defective fusion joint at the service tee allowed natural gas to leak from the gas main and migrated into the building where it ignited. During postaccident interviews, residents reported smelling gas the evening prior, but did not report it to the gas company (NTSB 2015).

s. On August 2, 2017, the NTSB investigated a school building in Minneapolis, Minnesota, that was destroyed by a natural gas explosion, killing two individuals and injuring nine. At the time of the explosion, two workers were installing new piping to support the relocation of gas meters from the basement of the building to the outside. As gas company employees were removing the existing piping, a natural gas line pressure opened, releasing gas into the basement. A school maintenance worker smelled the natural gas and went to the basement meter room where the gas company employees had been working. He exited the basement, announcing over his handheld radio there was gas in the building and that everyone should evacuate immediately.

However, less than 1 minute later, the building exploded. At the time of this report, this investigation is still open (NTSB 2017).

t. On February 21, 2018, in Dallas, Texas, a natural gas-fueled explosion occurred at a single-family home, killing a 12-year old juvenile and injuring four other family members. The family reported they had not smelled any natural gas prior to the explosion. At the time of this report, this investigation is still open (NTSB 2018).

References

ASME (The American Society of Mechanical Engineers). *Welded and Seamless Wrought Steel Pipe.* ASME B36.10M-2018. (New York: ASME).

Bull, David, 1998. *[Title] 49* CFR *§ 192.625: Odorization: A Matter of Protection*. White paper. April 1998. (Washington, DC: US Department of Transportation, Transportation Safety Institute).

BSI (British Standards Institution). 2009. *Electrical apparatus for the detection of combustible gases in domestic premises. Part 1*. "Test methods and performance requirements." (London: BSI).

----. 2016. *Electrical apparatus for the detection of combustible gases in domestic premises. Guide on the selection, installation, use and maintenance*. EN50244. (London: BSI).

EPA (US Environmental Protection Agency). 2011. *Before You Tear it Down, Get the Mercury Out.*(https://www.epa.gov/sites/production/files/2015-10/documents/before_you_tear_it_down.pdf.), accessed September 5, 2018.

FR (*Federal Register*). 1970. Vol. 35, no. 161 (August 19).

GAO (US Government Accountability Office). 2018. *Gas Pipeline Safety: Stakeholders and Officials' Views of Federal Odorizing Requirements.* GAO-18-409. (Washington, DC: GAO).

GTI (Gas Technology Institute). 2017. *Residential Methane Detector Program, Phase II*. Prepared for Operations Technology Development. (Des Plaines, Illinois: GTI).

IAED (International Academies of Emergency Dispatch). 2014. *Protocol-60 Gas Leak/Gas Odor (Natural and Liquified Petroleum Gases)*. (Salt Lake City, Utah: IAED).

ICC (International Code Council). 2015. *International Fuel Gas Code*. (Washington, DC: ICC).

MCFRC (Montgomery County Fire and Rescue Commission). 1996. *Policy and Procedure*, "Natural Gas Incident Response." No. 25-07. (Rockville, Maryland: MCFRC).

Moses, Alfred J., 1978. *Practicing Scientist's Handbook*. (New York: Van Nostrand Reinhold Company).

NCSL (National Conference of State Legislatures). 2018. "Carbon Monoxide Detector Requirements, Laws and Regulations." (http://www.ncsl.org/research/environment-and-natural-resources/carbon-monoxide-detectors-state-statutes.aspx), accessed November 5, 2018.

NFPA (National Fire Protection Association). 2017. *Guide for Fire and Explosion Investigations*. Section 10.2.1, "Natural Gas." *NFPA 921*. (Quincy, Massachusetts: NFPA).

----. 2018. *National Fuel Gas Code*. *NFPA 54*. (Quincy, Massachusetts: NFPA).

NTSB (National Transportation Safety Board). 1972. *Lone Star Gas Company, Fort Worth, Texas, October 4, 1971*. PAR-72/05. (Washington, DC: NTSB).

----. 1972a. *Washington Gas Light Company, Natural Gas Explosion, Annandale, Virginia, March 24, 1972.* PAR-72/04. (Washington, DC: NTSB).

----. 1974. *Southern Union Gas Company, El Paso, Texas, April 22, 1973.* PAR-74/02. (Washington, DC: NTSB).

----. 1974a. *Columbia Gas of West Virginia, Inc., Charleston, West Virginia, December 2, 1973.* PAR-74/04. (Washington, DC: NTSB).

----. 1976. *Consolidated Edison Company Explosion, New York, New York, April 22, 1974.* PAR-76/02. (Washington, DC: NTSB).

----. 1976a. *Nebraska Natural Gas Company, Pathfinder Hotel Explosion and Fire, Fremont, Nebraska, January 10, 1976.* PAR-76/06. (Washington, DC: NTSB).

----. 1978. *Kansas Public Service Company, Inc. Explosion and Fire, Lawrence, Kansas, December 15, 1977.* PAR-78/04. (Washington, DC: NTSB).

----. 1983. *The Gas Company of New Mexico Natural Gas Explosion and Fire, Portales, New Mexico, June 28, 1982*. PAR-83/01. (Washington, DC: NTSB).

----. 1985. *Arizona Public Service Company Natural Gas Explosion and Fire, Phoenix, Arizona, September 25, 1984*. PAR-85/01. (Washington, DC: NTSB).

----. 1986. *Northeast Utilities Service Company Explosion and Fire, Derby, Connecticut, December 6, 1985.* PAR-86/02. (Washington, DC: NTSB).

----. 1996. *UGI Utilities, Inc., Natural Gas Distribution Pipeline Explosion and Fire, Allentown, Pennsylvania, June 9, 1994*. PAR-96/01. (Washington, DC: NTSB).

----. 1998. *Fire and Explosion, Midwest Gas Company, Waterloo, Iowa, October 17, 1994.* PAB-98/02. (Washington, DC: NTSB).

----. 2001. *Natural Gas Explosion and Fire, South Riding, Virginia, July 7, 1998.* PAR-01/01. (Washington, DC: NTSB).

----. 2007. *Natural Gas Service Line Break and Subsequent Explosion and Fire, Bergenfield, New Jersey, December 13, 2005*. PAB-17/01. (Washington, DC: NTSB).

----. 2008. *Natural Gas Distribution Line Break and Subsequent Explosion and Fire, Plum Borough, Pennsylvania, March 5, 2008*. PAB-08/01. (Washington, DC: NTSB).

----. 2010. *Explosion, Release, and Ignition of Natural Gas, Rancho Cordova, California, December 24, 2008*. PAB-10/01. (Washington, DC: NTSB).

----. 2015. *Natural Gas-Fueled Building Explosion and Resulting Fire, New York, New York, March 12, 2014.* PAR-15/01. (Washington, DC: NTSB).

----. 2016. *Pipeline Accident Brief: Birmingham Public Housing Gas Explosion, Birmingham, Alabama, December 17, 2013.* PAB-16/01. (Washington, DC: NTSB).

----. 2017. *Preliminary Report: Pipeline: Gas Explosion Destroyed Minnehaha Academy, Minneapolis, Minnesota, August 2, 2017.* DCA17MP007. (Washington, DC: NTSB).

----. 2018. *Preliminary Report: Natural Gas-Fueled Explosion of Residence, Dallas, Texas, February 23, 2018.* PLD18FR002. (Washington, DC: NTSB).

----. 2018a. *Materials Laboratory Study Report.* 18-039S. (Washington, DC: NTSB).

OSHA (Occupational Safety and Health Administration). 2018. "OSHA's Nationally Recognized Testing Laboratory (NRTL) Program." (https://www.osha.gov/dts/otpca/nrtl/index.html), accessed November 5, 2018.

OTD (Operations Technology Development). 2018. "Strengthening North America's Energy Infrastructure." (https://www.otd-co.org/about/Pages/default.aspx), accessed November 5, 2018.

RSPA (Research and Special Programs Administration). 1975. *Study of the Properties of the Numerous Odorants and Assessment of their Effectiveness in Various Environmental Conditions to Alert People to the Presence of Natural Gas*. (Washington, DC: US Department of Transportation, RSPA).

UL (Underwriter's Laboratories). 2016. *Standard for Residential Gas Detectors*. (Northbrook, Illinois: UL).

Usher, M.J., 1999. *Odor Fade – Possible Causes and Remedies*. White paper. (Philadelphia, Pennsylvania: Elf Atochem North America, Inc. and London: CGA Gas Measurement School).

WG (Washington Gas). 2016. *Operations and Maintenance Manual*. Revision 27. (Washington, DC: WG).

Wiley, K. 2016. "Methane Detection Projects." Presentation to the Pipeline and Hazardous Materials Safety Administration Research and Development Forum, November 16, 2016, Cleveland, Ohio.

WSSC (Washington Suburban Sanitary Commission). 2015. *Plumbing and Fuel Gas Code*. (Laurel, Maryland: WSSC).