Atmos Energy Corporation Natural Gas-Fueled Explosion
Dallas, Texas
February 23, 2018

Accident Report

NTSB/PAR-21/01
PB2021-100901

National Transportation Safety Board

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Notation 64964
Adopted January 12, 2021

Pipeline Accident Report

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

National Transportation Safety Board. 2021. *Atmos Energy Corporation Natural Gas-Fueled Explosion, Dallas, Texas, February 23, 2018*. Publication Type NTSB/PAR-21/01. Washington, DC: NTSB

Abstract: On February 23, 2018, at 6:38 a.m. local time, a natural gas–fueled explosion occurred at 3534 Espanola Drive, Dallas, Texas. The residence sustained major structural damage, but when first responders arrived on scene at 6:44 a.m., they observed no smoke or fire. Four family members were injured, and one was killed in the explosion. Following the explosion, National Transportation Safety Board (NTSB) investigators located a through-wall crack in the 71-year-old natural gas main that served the residence. In the 2 days before this explosion, two gas-related incidents occurred on the same block at houses that were served by the same natural gas main, each resulting in significant structural damage and burn injuries to one occupant. The first occurred on February 21, 2018, at 5:49 a.m., and resulted in one injury involving second-degree burns and significant structural damage to 3527 Durango Drive. The second incident occurred on February 22, 2018, at 10:21 a.m., and resulted in one injury involving second-degree burns and significant structural damage to 3515 Durango Drive. As a result of this investigation, the NTSB issued new safety recommendations to the Pipeline and Hazardous Materials Safety Administration, the Railroad Commission of Texas, the Dallas Fire-Rescue Department, Atmos Energy Corporation, and the Gas Piping Technology Committee. The NTSB is also reiterating safety recommendations to the International Code Council, the National Fire Protection Association, and the Gas Technology Institute.

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Abbreviations and Acronyms

AGA	American Gas Association
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
Atmos	Atmos Energy Corporation
BCI	Bryant Consultants, Inc.
CFM	cubic feet per minute
CFR	*Code of Federal Regulations*
CGI	combustible gas indicator
DFR	Dallas Fire-Rescue Department
DIRT	Damage Information Reporting Tool
DOT	U.S. Department of Transportation
EDS	energy dispersive spectroscopy
GPTC	Gas Piping Technology Committee
hazmat	hazardous materials
HAZWOPER	Hazardous Waste Operations and Emergency Response
HMCRP	Hazardous Materials Cooperative Research Program
HMRT	Hazardous Materials Response Team
HUD	US Department of Housing and Urban Development
HVAC	heating, ventilation, and air conditioning
IC	incident commander
ICC	International Code Council
IFGC	International Fuel Gas Code

IG	inspector general
IM	integrity management
IM Plan	Distribution Risk and Integrity Management Plan
LEL	lower explosive limit
MAOP	maximum allowable operating pressure
MNOPS	Minnesota Department of Public Safety, Office of Pipeline Safety
NFPA	National Fire Protection Association
NFPA 54	National Fuel Gas Code
NRC	National Response Center
NTSB	National Transportation Safety Board
O&M	operations and management
OQ	operator qualifications
OSHA	Occupational Safety and Health Administration
PHMSA	Pipeline and Hazardous Materials Safety Administration
ppm	parts per million
psig	pounds per square inch gauge
PSMS	Pipeline Safety Management System
RMLD	remote methane leak detector
RRC	Railroad Commission of Texas
RSPA	Research and Special Programs Administration
SEM	scanning electron microscopy
SME	subject matter expert
SOP	standard operating procedure
TAC	Texas Administrative Code
TCFP	Texas Commission of Fire Protection

TRB	Transportation Research Board
UEL	upper explosive limit
USACE	US Army Corps of Engineers
U.S.C.	*United States Code*
USCB	US Census Bureau

Executive Summary

On February 23, 2018, about 6:38 a.m. local time, a natural gas-fueled explosion occurred at 3534 Espanola Drive, Dallas, Texas, injuring all five occupants, one fatally. The one-story two-bedroom residence sustained major structural damage. Following the explosion, National Transportation Safety Board investigators located a through-wall crack in the 71-year-old natural gas main that served the residence and positive gas measurements leading from this crack to the residence.[1]

In the 2 days before this explosion, two gas-related incidents occurred on the same block at houses that were served by the same natural gas main, each resulting in significant structural damage and burn injuries to one occupant.[2] The first occurred on February 21, 2018, at 5:49 a.m., and resulted in one injury involving second-degree burns and significant structural damage to 3527 Durango Drive. The second incident occurred on February 22, 2018, at 10:21 a.m., and resulted in one injury involving second-degree burns and significant structural damage to 3515 Durango Drive.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the explosion at 3534 Espanola Drive was the ignition of an accumulation of natural gas that leaked from the gas main that was damaged during a sewer replacement project 23 years earlier and was undetected by Atmos Energy Corporation's investigation of two related natural gas incidents on the 2 days prior to the explosion. Contributing to the explosion was Atmos Energy Corporation's insufficient wet weather leak investigation procedures. Contributing to the severity of the explosion was Atmos Energy Corporation's inaction to isolate the affected main and evacuate the houses. Contributing to the degradation of the pipeline system was Atmos Energy Corporation's inadequate integrity management program.

[1] (a) For more information, see the factual information and analysis sections of the report. Additional information about the accident investigation can be found in the public docket for the accident (NTSB case number PLD18FR002) by accessing the Accident Dockets link for the Docket Management System at www.ntsb.gov. For more information on our safety recommendations, see the Safety Recommendation Database at www.ntsb.gov. (b) *Through-wall crack* refers to a crack that extends between the inner- and outer-diameter of a pipe; the commodity cannot leak from a crack in the pipe until it extends through the wall.

[2] Throughout this report, the term "explosion" is used to refer to the explosion at 3534 Espanola Drive, whereas the term "incident" is used to refer to the earlier events at 3527 Durango Drive and 3515 Durango Drive. The term "incident" is used in accordance with Title 49 *Code of Federal Regulations* 831.40(a)(2) and does not indicate that these events meet the Pipeline and Hazardous Materials Safety Administration's definition of incident in Title 49 *Code of Federal Regulations* 191.3.

Safety Issues

This report focuses on the following safety issues:

- **Incident investigation.** Neither the Dallas Fire-Rescue Department nor Atmos Energy Corporation identified the causes of the two incidents that occurred in the days immediately preceding the explosion. Dallas Fire-Rescue Department arson investigators and Atmos Energy Corporation technicians did not effectively investigate, communicate, or collaborate to determine the cause of either incident. Further, Atmos Energy Corporation did not gather enough evidence to determine if gas migrated from their piping and fueled the first two incidents.

- **Leak investigations and repairs.** Atmos Energy Corporation dedicated significant resources to its response following the second incident, finding 13 leaks determined to present an existing or probable future hazard. However, none of its employees questioned the integrity of the system. As a result, Atmos Energy Corporation did not take appropriate action to secure the safety of the area and its residents. This was attributed, in part, to inadequate procedures for performing leak investigations in wet weather conditions.

- **Methane detection.** Although Atmos Energy Corporation added odorant to its gas distribution system in a manner consistent with Pipeline and Hazardous Materials Safety Administration regulations, none of the residents at any of the affected homes smelled gas. Although odorant can act as an early warning of a gas release to prevent an explosion and fire, it is known to become depleted if it travels through soil.

- **Incident reporting.** Incident reporting requirements mandated by the Pipeline and Hazardous Materials Safety Administration rely on the judgement of the operator to determine whether an incident resulted from a leak in their system and do not specify the level of investigation necessary to make the determination. While operators have an option to report events that may have been caused by their system, Atmos Energy Corporation relied on an incomplete investigation to support its position not to report the first two incidents.

- **Integrity management.** Although Atmos Energy Corporation's integrity management program was generally consistent with regulatory requirements and industry practice, the program did not adequately evaluate and address the risk of its 71-year-old system. This failure to adequately address risk was illustrated by the 26 leaks determined to present an existing or probable future hazard in the area around the explosion, as well as the additional 740 leaks found in northwest Dallas in the weeks that followed.

Findings

- None of the following were factors in the explosion: (1) ongoing maintenance activities; (2) overpressurization of the gas distribution system; (3) materials used for the construction of the gas main and external coating; and (4) natural gas composition.

- The natural gas main was damaged by mechanical excavation equipment, likely when the sanitary sewer lateral was replaced in 1995.

- A circumferential crack in the main propagated through the pipe wall prior to the first incident, allowing natural gas to leak into the surrounding environment for an extended period.

- Soil absorbed and depleted the natural gas odorant, eliminating the opportunity for occupants to detect it.

- Natural gas leaking from Atmos Energy Corporation's cracked gas main in the alley behind 3534 Espanola Drive migrated through the soil and into the house where it was ignited by an unknown source.

- Dallas Fire-Rescue Department's initial misclassification of the first incident delayed the sharing of information that could have helped Atmos Energy Corporation identify the origin of the leak.

- Had the Dallas Fire-Rescue Department's arson investigators been adequately trained on natural gas systems, their investigation findings may have provided more timely and accurate assistance to Atmos Energy Corporation in locating the source of the gas leak.

- Timely pressure testing of the customer piping by Atmos Energy Corporation could have eliminated potential sources of the gas leaks and helped focus their efforts on outside leak detection to locate the damaged and leaking gas system piping more quickly.

- Atmos Energy Corporation did not adequately investigate the first two gas-related incidents that occurred at 3527 and 3515 Durango Drive.

- Damage to the structure involved in the first incident on 3527 Durango Drive was consistent with a fuel gas/air mixture explosion, which was most likely caused by natural gas that migrated from underneath the structure.

- Fuel gas was involved in both incident homes; there was insufficient evidence to exclude natural gas from Atmos Energy Corporation's system from either incident, evidence of leaks present prior to the first two incidents occurring, and the probability of two or three structure fires/explosions occurring independently on the same block during the same week is very low. Therefore, the two prior incidents that occurred on

the same block on subsequent days and the explosion at 3534 Espanola Drive were all likely related.

- Limitations of the equipment and procedures due to the wet weather conditions on the ability of Atmos Energy Corporation to reliably detect the presence of leaked gas during its response to the first two incidents, and the number and severity of leaks identified following the first two incidents and prior to the explosion, should have prompted Atmos Energy Corporation to shut down or isolate the pipeline.

- Had Atmos Energy Corporation pressure tested the main in the alley behind the first two incident homes on February 21 or 22, it could have found that the main did not hold pressure, spurring additional protective actions that could have prevented the fatal injury at 3534 Espanola Drive.

- Atmos Energy Corporation's wet weather leak investigation procedures were insufficient given the known limitations of its equipment.

- The assistance of the Dallas Fire-Rescue Department's Hazardous Materials Response Team, particularly after the second incident, could have enhanced Atmos Energy Corporation's leak investigation.

- Had methane detectors been installed at the residences located on Durango and Espanola Drives, an alarm would have alerted residents to a gas release, reducing the potential for and consequences of the resulting natural gas fires and explosions.

- The lack of official reporting of the first two incidents by Atmos Energy Corporation delayed the response from regulatory authorities, the Railroad Commission of Texas and the Pipeline and Hazardous Materials Safety Administration.

- The Pipeline and Hazardous Materials Safety Administration does not provide clear requirements regarding the level of investigation necessary to determine whether an event is subject to its reporting requirements, potentially resulting in the underreporting of natural gas incidents.

- If Dallas Fire-Rescue Department reported the first two incidents in a timely manner, it could have prompted further investigation or regulatory oversight prior to the explosion.

- The high number of leaks observed in northwest Dallas after the explosion were due to the degradation of Atmos Energy Corporation's gas distribution system, not sudden, unanticipated geologic loadings.

- Atmos Energy Corporation did not adequately consider or mitigate against threats that were degrading its pipeline system, the likelihood of failure associated with these threats, or the potential consequences of such a failure as required by gas distribution integrity management requirements.

- While Atmos Energy Corporation's periodic leak survey methodology and frequency complied with the minimum state and federal requirements, it did not identify the degraded system that was found after the explosion.

Recommendations

New Recommendations

To the Pipeline and Hazardous Materials Safety Administration:

- Expand incident reporting requirements in Title 49 *Code of Federal Regulations* Part 191 so that events that may meet the definition of "incident" are immediately reported to the National Response Center even when the source of the natural gas has not been determined. (P-21-1)

- Evaluate industry's implementation of the gas distribution pipeline integrity management requirements and develop updated guidance for improving their effectiveness. The evaluation should specifically consider factors that increase the likelihood of failure such as age, increase the overall risk (including factors that simultaneously increase the likelihood and consequence of failure), and limit the effectiveness of leak management programs. (P-21-2)

- Assist the Railroad Commission of Texas in conducting the audit recommended in Safety Recommendation P-21-4. (P-21-3)

To the Railroad Commission of Texas:

- With assistance from the Pipeline and Hazardous Materials Safety Administration, conduct a comprehensive audit of Atmos Energy Corporation's incident reporting practices; policies and procedures for responding to leaks, fires, explosions, and emergency calls; and integrity management programs. (P-21-4)

To the Dallas Fire-Rescue Department:

- Revise the continuing education requirement for your arson investigators to include training on building fuel gas systems. (P-21-5)

- Revise your procedures to require gas monitoring after the occurrence of a gas-related structure fire or explosion. (P-21-6)

- Develop and implement a formal process to alert appropriate local, state, and federal agencies of potential systemic safety issues that should be investigated further. (P-21-7)

To Atmos Energy Corporation:

- Provide initial and recurrent training to Dallas Fire-Rescue Department arson investigators and firefighters on the local natural gas distribution system and associated hazards. (P-21-8)

- Develop and implement more rigorous inside leak investigation requirements in response to fires and explosions when gas involvement cannot be excluded, including clear guidance on pressure testing and inside gas measurements and the potential need to return to the property after firefighters have departed. (P-21-9)

- Develop a clear procedure to coordinate with local emergency responders when investigating all fires and explosions that may be gas related to conclusively determine whether your system can be excluded as a potential contributor, and collecting the necessary evidence to support the conclusion of your investigations. (P-21-10)

- Revise your policies and procedures for responding to leaks, fires, explosions, and emergency calls to address the challenges caused by wet weather conditions. The revised policies and procedures should include: (1) leak investigation methods that are reliable in wet weather; (2) leak investigation procedures that assess all viable gas migration paths; (3) criteria for when to shut down or isolate gas distribution systems and pressure test main and service lines; and (4) an alternate safe response such as evacuation when reliable leak investigations are not possible due to wet weather or other circumstances. (P-21-11)

- Without delay, assess your integrity management program, paying particular attention to the areas identified in this investigation, and revise the program to appropriately consider: (1) threats that degrade a system over time, and (2) the increased risk that can result from factors that simultaneously increase the likelihood and consequence of failure. (P-21-12)

To the Gas Piping Technology Committee:

- Develop additional guidance that identifies steps gas distribution operators can take to safely respond to leaks, fires, explosions, and emergency calls, considering the limitations due to wet weather conditions, that includes: (1) criteria for when to shut down or isolate gas distribution systems, pressure test main and service lines, and begin evacuations; (2) leak investigation methods that are reliable in wet weather; (3) require an alternate safe response, such as an evacuation when reliable leak investigations are not possible due to wet weather; and (4) leak investigations that assess all viable gas migration paths, including granular backfill and crawlspaces. (P-21-13)

- Develop guidance that identifies steps that gas distribution operators can take to ensure that their gas distribution integrity management program, at a minimum, appropriately considers: (1) threats that degrade a system over time, and (2) the

increased risk that can result from factors that simultaneously increase the likelihood and consequence of failure. (P-21-14)

Previously Issued Recommendations Reiterated in this Report

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)

  This recommendation is currently classified "Open—Acceptable Response."

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)

This recommendation is currently classified "Open—Acceptable Alternate Response."

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)

This recommendation is currently classified "Open—Acceptable Response."

1. Factual Information

1.1 Synopsis

On February 23, 2018, at 6:38 a.m. local time, a natural gas–fueled explosion occurred at 3534 Espanola Drive, Dallas, Texas.[1] The residence sustained major structural damage, but when first responders arrived on scene at 6:44 a.m., they observed no smoke or fire. Four family members were injured, and one was killed in the explosion. Following the explosion, National Transportation Safety Board (NTSB) investigators located a through-wall crack in the 71-year-old natural gas main that served the residence.[2]

In the 2 days before this explosion, two gas-related incidents occurred on the same block at houses that were served by the same natural gas main, each resulting in significant structural damage and burn injuries to one occupant.[3] The first occurred on February 21, 2018, at 5:49 a.m., and resulted in one injury involving second-degree burns and significant structural damage to 3527 Durango Drive. The second incident occurred on February 22, 2018, at 10:21 a.m., and resulted in one injury involving second-degree burns and significant structural damage to 3515 Durango Drive. (See figure 1.)

[1] All times in this document are local time unless otherwise noted.

[2] *Through-wall crack* refers to a crack that extends between the inner- and outer-diameter of a pipe; the commodity cannot leak from a crack in the pipe until it extends through the wall.

[3] (a) Throughout this report, the term "explosion" is used to refer to the explosion at 3534 Espanola Drive, whereas the term "incident" is used to refer to the earlier events at 3527 Durango Drive and 3515 Durango Drive. The term "incident" is used in accordance with Title 49 *Code of Federal Regulations* (*CFR*) 831.40(a)(2) and does not indicate that these events meet the Pipeline and Hazardous Materials Safety Administration's (PHMSA) definition of incident in 49 *CFR* 192.3. (b) For more information, see the factual information and analysis sections of this report. Additional information about the accident investigation can be found in the public docket for this accident (NTSB case number PLD18FR002) by accessing the Accident Dockets link for the Docket Management System at www.ntsb.gov. For more information on our safety recommendations, see the Safety Recommendation Database at www.ntsb.gov.

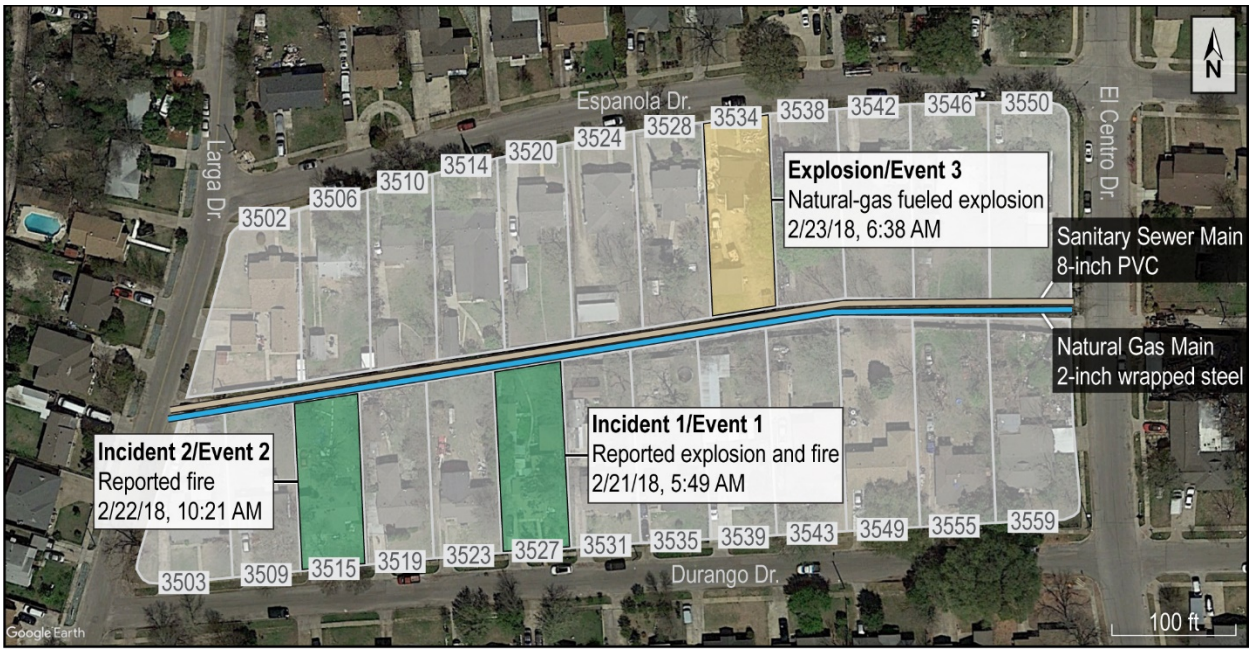

Figure 1. Location of explosion, preceding incidents, and shared utilities.

1.2 Background

Atmos Energy Corporation (Atmos), headquartered in Dallas, Texas, is an independent, publicly held natural gas distribution company. At the time of the accident, Atmos served more than 3 million distribution customers in over 1,400 communities. Atmos employed about 4,600 people and also managed company-owned natural gas pipeline and storage assets.

Atmos's distribution operations were divided into six divisions serving eight states, encompassing about 69,000 miles of distribution pipeline: Colorado-Kansas, Kentucky/Mid-States, Louisiana, West Texas, Mississippi, and Mid-Tex.

This accident occurred on assets within Atmos's Mid-Tex Division, which was formed when Atmos acquired distribution and transmission assets from TXU Gas Company in 2004. Atmos managed proprietary pipeline and storage assets, including one of the largest intrastate natural gas pipeline systems in Texas.

1.3 Narrative

On Friday, February 23, 2018, at 6:38 a.m., the Dallas Fire-Rescue Department (DFR) Communications Division dispatcher received several 911 calls reporting an explosion at 3534 Espanola Drive, Dallas, Texas. The greatest structural damage occurred at the northwest corner of the house, where its exterior walls were blown outward and the roof had partially collapsed. The east and south walls of the house were displaced outward as well. Two family members reported hearing a popping noise in the general area of the kitchen the night before the explosion; however, none of the occupants reported smelling gas odors.

Atmos crews, who were already in the area repairing leaks, heard the explosion and began evacuating the neighborhood. DFR arrived minutes later and together they evacuated a 2-block area. DFR expanded the evacuation area three times after its initial evacuation as the investigation progressed to nearby residences, the Stephen C. Foster Elementary School, and 60 single-family homes east of the explosion site. In total, the evacuation involved about 300 single-family homes, 250 apartment units, and 600 students. The evacuation was lifted on February 24, 2018, at 3:30 p.m.

Following the explosion, NTSB investigators located a through-wall crack in the 2-inch diameter gas main that was installed in 1946 in the alley behind 3534 Espanola Drive. Further examination found the crack originated from a dent in the main that was situated beneath a 6-inch diameter sanitary sewer lateral that had been installed in 1995 and was within 0.5 inches of the gas main.[4] NTSB investigators also found five gouges in the pipe wall along a 22-inch length of the gas main near the dent. The natural gas leak rate was estimated based on NTSB's laboratory testing to be between 8 and 14 cubic feet per minute (CFM) at the operational pressure range of the system of 17 to 45 pounds per square inch, gauge (psig). The occupants of the houses where the earlier incidents occurred did not report smelling gas odorant immediately prior to those incidents. DFR estimated damages to the three homes was about $220,000. All three homes were later demolished.

1.4 Events Leading Up to the Explosion

Between February 20 and February 22, 2018, a nearby weather station recorded 6.14 inches of precipitation.[5] While this was the record 3-day rainfall for the month of February since 1940, higher recordings had been observed during other times of the year, including late October and late November 2015. The temperature ranged from 34° to 52°F on the days the incidents and explosion occurred.

All three affected houses were built in the late 1940s with a frame construction, pier and beam foundation, a crawlspace, and no basement. The three houses shared an unpaved alley which contained the sanitary sewer main and natural gas main that served the houses.

The sanitary sewer had been originally installed in the 1940s and was replaced by the City of Dallas in 1995.[6] The sanitary sewer main and laterals had an embedment of crushed stone and granular material. The polyvinyl chloride sewer lateral pipes for homes on the south side of the unpaved alley extended over the natural gas main.

[4] A *sanitary sewer lateral* is a pipe that connects a home's plumbing to the city's sanitary sewer system.

[5] As discussed in sections 1.9.1 and 1.9.2, Atmos policies and procedures include provisions for performing gas leak surveys and leak investigations in wet weather conditions.

[6] The sanitary sewer main and lateral replacement project was performed by a City of Dallas contractor who was supervised by a sanitary sewer construction inspector from the City of Dallas Water Department. The contractor was required to replace the sewer laterals that extended between the sewer main and the property line of each home in the alley.

The natural gas main that served the three affected houses was installed in 1946 and had a maximum allowable operating pressure (MAOP) of 55 psig.[7] The service regulator reduced the pressure to about 0.25 psig. All components downstream of the service regulator, including the service meter and customer piping, were operated at a pressure of about 0.25 psig. The coated steel main was cathodically protected by sacrificial anodes and the natural gas was odorized.[8] The natural gas composition was determined through gas sample analysis.[9]

Atmos told NTSB investigators that the "fires" that occurred at 3527 and 3515 Durango Drive showed no evidence they were caused by a release of gas from its pipeline and, therefore, were not considered reportable "incidents" as defined by Title 49 *Code of Federal Regulations* (*CFR*) Part 191.[10] Atmos e-mailed a courtesy notification to the Railroad Commission of Texas (RRC) on the evening of February 22, 2018, but did not provide telephonic notice to the RRC or immediate notice to the National Response Center (NRC).[11] Atmos also did not file an incident report with the Pipeline and Hazardous Materials Safety Administration (PHMSA). A timeline of the events is shown in figure 2.

[7] NTSB investigators reviewed the operating pressure data for the gas main for the period between 2016 through the time of the explosion in 2018; all pressure measurements reviewed were below the MAOP. The operating pressure in the 2 days before the explosion ranged from 17-45 psig.

[8] (a) *Cathodic protection* is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell. A simple method of protection connects the metal to be protected to a more easily corroded "sacrificial metal" to act as the anode. The sacrificial metal then corrodes instead of the protected metal. For structures such as long pipelines, where passive galvanic cathodic protection is not adequate, an external direct current electrical power source is used to provide sufficient current. (b) Title 49 *CFR* Part 192, Appendix D, "Criteria for Cathodic Protection and Determination of Measurements," requires, in part, that cathodically protected steel structures have a negative voltage of at least 0.85 volts. Atmos records indicated a negative voltage of at least 0.85 volts over the last 10 years. (c) Atmos provided documentation of odorant tests for the 5 years prior to the explosion, which indicated that the natural gas odorant was "readily detectable," as required. The gas odorization test after the explosion confirmed that the odorant was "readily detectable."

[9] Atmos provided results from an analysis of gas samples for the 6 months prior to the explosion, and indicated that all measurements were within an acceptable range.

[10] E-mail from Atmos to NTSB, April 22, 2020.

[11] (a) RRC is the agency that regulates the oil and gas industry, gas utilities, pipeline safety, safety in the liquefied petroleum gas industry, and surface coal and uranium mining for the State of Texas. (b) Through certification by PHMSA, the Pipeline Safety department of the RRC inspects and enforces the pipeline safety regulations for intrastate gas distribution pipeline operators in Texas.

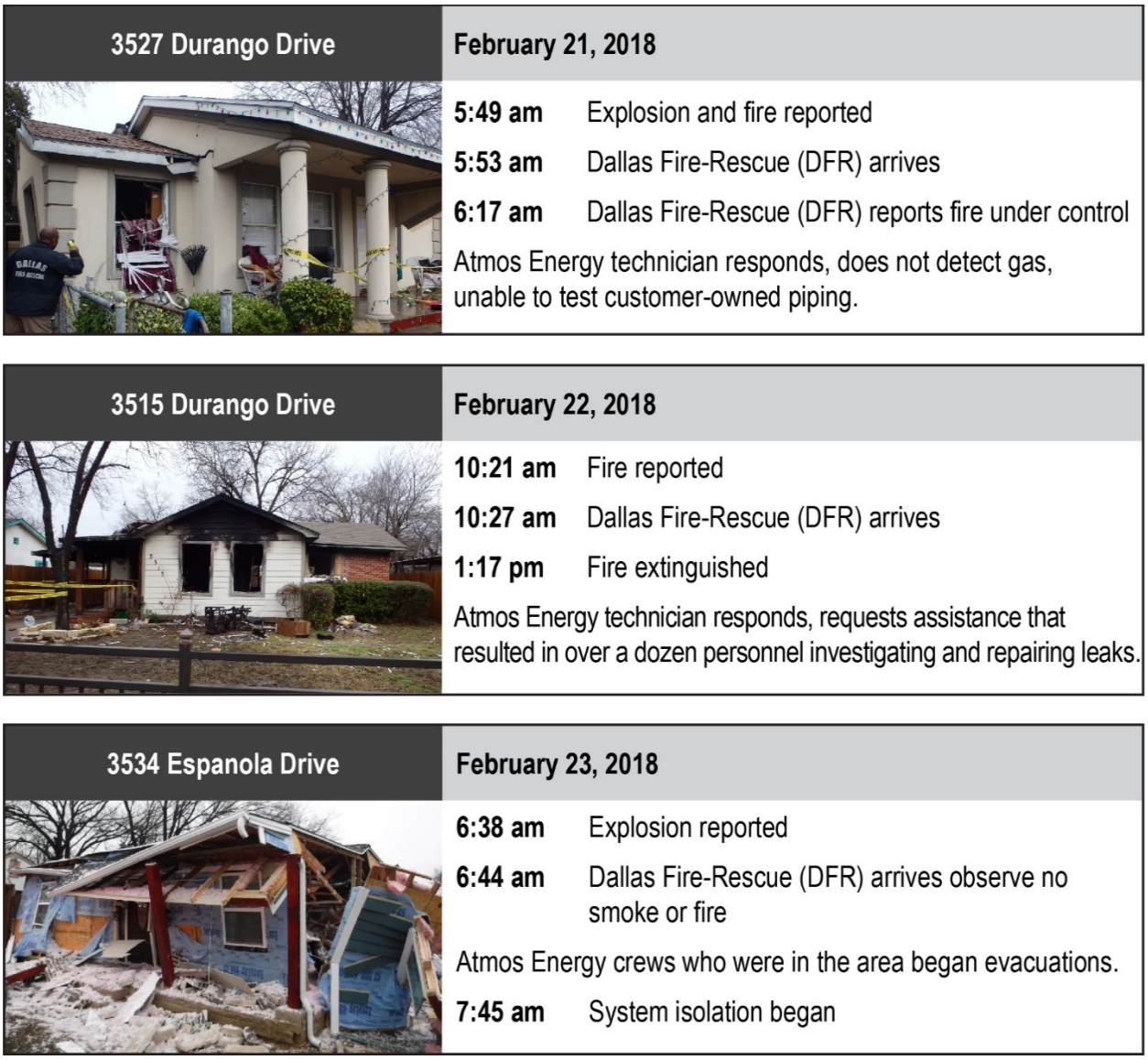

Figure 2. Timeline of the events leading up to the explosion. (Photos courtesy of DFR.)

1.4.1 3527 Durango Drive Incident

On February 21, at 5:49 a.m., DFR dispatch received multiple 911 calls for a structure fire at 3527 Durango Drive. The callers reported that a house "exploded," and smoke was coming out. The first responding engine company arrived at 5:53 a.m. and observed fire at the back of the house. One of the firefighters observed that the roof was not involved in the fire but had been blown off. The firefighter said that he noticed that glass was broken outside of the house and sheetrock had been knocked down from the interior of the house onto the floors. At 5:59 a.m., the firefighter turned off the gas supply at the meter behind the house and requested a gas and electric utilities response. The DFR safety officer said that he noticed the left façade appeared pushed out. While firefighters were working, the safety officer noticed flames were coming from under the floor of the house (crawlspace) and firefighters had to pull a board off the

back of the house and place a firehose nozzle under the floor to extinguish it. The fire was reported under control by 6:17 a.m.

An Atmos service technician arrived on scene soon after the fire was extinguished. He learned from the firefighters that they had turned off the gas. The technician proceeded to the rear of the property with his combustible gas indicator (CGI) to examine the gas meter. He told NTSB investigators that he did not recall looking at the CGI during this time, but it would have sounded an alarm had it detected any gas. When he reached the gas meter, he confirmed that the gas was off and found it undamaged. The service technician told NTSB investigators that he was unable to pressure test the customer piping because of safety concerns related to reactivating natural gas service while the firefighters were present.[12]

The service technician performed one bar hole test near the meter without inserting his bar hole probe all the way into the hole and detected no gas.[13] He told NTSB investigators that he did not want to place his bar hole probe into the hole because the ground was already saturated with water which could damage the sensor. He was not able to perform additional bar hole tests because the soil was too saturated with water. The technician told NTSB investigators that he would have performed multiple bar hole tests had the soil had been dry. Moreover, the alley behind the house was muddy and largely saturated with water. Due to the wet conditions, the technician surveyed above the top of the soil with his CGI, including along the 2-inch gas main in the alley. While surveying, he was also looking for bubbles emerging from the water, which can be indicative of gas. He neither saw bubbles, nor obtained any positive gas readings with his CGI.

The service technician told NTSB investigators that he spoke with a DFR arson investigator who told him that the fire was gas-related and probably came from inside the house, likely originating from the back part of the house where the heaviest damage was observed. The Atmos service technician told NTSB investigators that he could not evaluate the arson investigator's determination because he could not run a test on the customer piping. The technician consequently documented that the gas leak originated from the customer piping and that the bar hole test was negative. He was present at the scene for about 25-30 minutes and did not smell gas at any time while at the property.

The initial DFR fire investigation report indicated that the origin was in or around a gas heater which was located in the restroom in the rear addition to the house. On March 2, 2018, the homeowner who had been injured in the incident reported to DFR arson investigators that he heard a popping noise about 2:00 a.m. on the night of the fire. He said later that morning that he heard a noise coming from the heating, ventilation, and air conditioning (HVAC) unit, went to adjust the thermostat, and noticed the heat was not working. He then entered the attic to

[12] (a) Atmos's customer piping test procedure required the technician to measure pressure losses on the customer piping. According to Atmos, the technician was following procedures and was not required to return to this location to conduct a pressure test. (b) A *pressure test* or *pressure drop test*, is used to determine if an isolated segment of pipeline loses pressure due to leakage. The test segment is isolated, pressurized (typically with air or gas), and then monitored for pressure losses for a predetermined period of time.

[13] The term *bar hole test* describes a gas measurement technique in which a hole is made in the ground, a bar hole probe is inserted into the hole, and a gas measurement is made (typically for 45 seconds).

investigate and found the cover that normally sits in front of the pilot light was on the ground next to the unit and the pilot light was out. When he replaced the cover the pilot light reignited and he was thrown back, causing second-degree burns. DFR updated its fire investigation report, indicating that the occupant was thrown back from the HVAC unit exploding and classifying the incident as "undetermined."

1.4.2 3515 Durango Drive Incident

On February 22 at 10:21 a.m., the homeowner at 3515 Durango Drive reported a fire in his kitchen. Responding firefighters arrived at 10:27 a.m. Upon arrival, the DFR incident commander (IC) observed large amounts of smoke coming from the south and west sides of the residence. He also saw a fire on the north and west side of the structure. During firefighting operations, he ordered the roof to be ventilated to control the spread of the fire. At 11:40 a.m., DFR requested Atmos to respond. The fire was extinguished in about 3 hours.

A DFR arson investigator interviewed the homeowner who reported that he was alone in the kitchen when the fire started. He indicated that he was boiling water on the range top when he noticed flames from the range turning red and growing out of control. The burner then flashed over him, resulting in second-degree burns. The arson investigator learned that the range was only a year old and had no previous problems.[14]

The DFR fire investigation report stated that the fire originated in the kitchen on or adjacent to the range. It further stated that the fire traveled vertically to the attic, igniting nearby cabinets and surrounding structural members, resulting in significant fire and smoke damage and total loss of the structure. The DFR fire investigation report classified this incident as "undetermined."

The DFR fire investigation report also indicated that a neighbor from 9621 Larga Drive voluntarily provided a statement that she had been experiencing issues with her gas service lately and told the arson investigator that she also observed red flames from her range. The neighbor told arson investigators that she contacted Atmos Energy on February 19, 2018, and asked if there were any gas issues in the neighborhood. The dispatcher told her Atmos Energy was unaware of any issues.

1.4.3 Atmos Energy Response Following Second Incident

On February 22, 2018, a service technician was the first Atmos employee to respond to the fire at 3515 Durango Drive. On arrival, he confirmed that DFR had already turned off the gas at the meter.

The DFR IC told the service technician that the fire started in the kitchen at the gas range and that another gas-related incident had occurred the previous day at 3527 Durango Drive. The service technician was asked to investigate what was going on. He then contacted an Atmos

[14] No recalls or reports were found for this range model on the US Consumer Product Safety Commission website.

supervisor who dispatched two operations supervisors and a distribution operator. Atmos's response ultimately involved over a dozen personnel, including the director of operations, an operations manager, survey specialists, and construction crews.

Atmos's leak detection efforts began at 3515 Durango Drive. The service technician said that the customer's piping was not testable because of the fire damage. The service technician conducted bar hole testing around the house and found no evidence of gas. However, he found the soil conditions to be wet, and many bar holes had filled with water. Furthermore, he told NTSB investigators that in such circumstances, he usually puts his CGI probe as close to the hole as possible without getting it wet, to mitigate this issue.[15]

The service technician could not bar hole test the riser because there was too much standing water puddled there.[16] Atmos procedures indicated that, if the soil was saturated with water, a visual inspection should be performed to look for water bubbles. He observed bubbles in the water at the service riser, however, CGI surveying over the top of the water near the riser did not result in any positive gas readings.

Atmos technicians returned to 3527 Durango Drive to perform additional bar hole tests. These tests, which included a perimeter around the foundation of the house, did not indicate the presence of natural gas. Technicians also conducted bar hole testing throughout the alley. Testing locations were spaced about 5 feet apart from Larga Drive to the east until and including the area behind 3539 Durango Drive. However, the technicians found the testing difficult due to the muddy, wet soil conditions. The service technician told investigators that some of the bar holes they created filled with water. He described their work process as "kind of bar holing, kind of surveying." Technicians also checked the accessible sewer boxes in the alley. This sewer testing near 3515 Durango Drive indicated the presence of gas at first, but the measurements were not sustained. The results of the Atmos employee bar hole testing and surveying are shown in figure 3.

Three natural gas leaks were found in the block surrounding the site prior to the explosion and one was found on an adjacent street. Of the two leaks classified as Grade 2 in the alley behind the affected houses, one was located behind 3519 Durango Drive and the other was located behind 3524 Espanola Drive.[17] Technicians found a 52 percent by volume gas reading near the residence at 3519 Durango Drive and repaired the service line. Technicians found

[15] Atmos policies and procedures include provisions for performing gas leak surveys and leak investigations in wet weather conditions. See sections 1.9.1 and 1.9.2 for additional information.

[16] *Riser* refers to a pipe which connects the underground piping to above-ground piping and facilities, including the meter and the house. The term *service riser* is used interchangeably with the term gas meter riser.

[17] Leaks are classified into one of three grade categories. (1) Grade 1: A leak that represents an existing or probable hazard to persons or property that requires immediate repair or continuous action until the conditions are no longer hazardous. (2) Grade 2: A leak that is recognized as being nonhazardous at the time of detection, but justifies scheduled repair based on probable future hazard. (3) Grade 3: A leak that is nonhazardous at the time of detection and can be reasonably expected to remain nonhazardous.

multiple positive gas readings near the residence at 3524 Espanola Drive. Technicians found a gas leak on the customer piping at 3531 Durango Drive and shut off gas service to the property.[18]

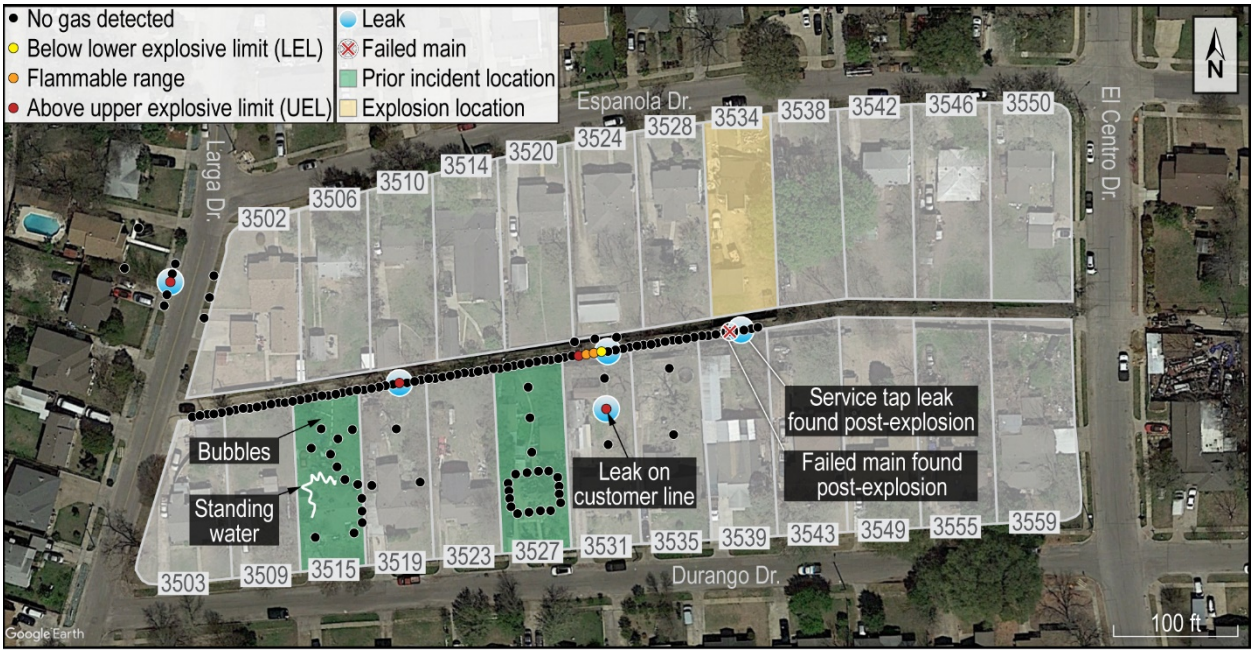

Figure 3. Gas measurements taken in the block surrounding the site prior to the explosion.

As part of Atmos's response, two survey specialists were directed to conduct a special leak survey.[19] Although the two survey specialists worked independently of each other, they coordinated their survey plans. Both survey specialists used a remote methane leak detector (RMLD) to detect gas above ground, even though they were aware that the RMLD was not recommended for use in wet weather conditions. If gas was detected with the RMLD, a CGI was used to pinpoint the location of the gas leak.

One survey specialist told NTSB investigators that he asked his supervisor how he was supposed to survey in the "pouring down rain." He said that his supervisor told him to "use your RMLD and do the best job you can."

Both survey specialists found that there was a significant amount of standing water in the area that presented challenges in locating the precise location of a leak with a CGI. Their ability to perform a bar hole test was limited because some locations were either underwater or the probe hole would fill up with water before they had an opportunity to take a gas measurement. Atmos leak reports indicated that the conditions would not permit a bar hole test at five locations.

[18] This portion of the system the responsibility of the customer; it is not regulated by PHMSA or the RRC and is not owned by Atmos.

[19] Atmos employs "special" leak surveys as a tool for operational purposes such as supplementing leak investigations.

While conducting a leak survey using his RMLD in the alley behind the two incident and the explosion houses, one survey specialist reported finding what he believed to be gas indications in the alley. He reported his finding to two operations supervisors, one of whom interpreted the RMLD readings as false positives. The operations supervisor, therefore, decided not to order additional bar hole testing. He noted other technicians had already performed bar hole testing in the area and did not detect any gas.

The operations manager told NTSB investigators that if service technicians felt the conditions were unsafe, they were empowered to take actions they felt necessary, including turning off a customer's gas service.[20] The technician would likely first contact and discuss the situation with a supervisor if it involved shutting off gas to an entire neighborhood. Neither survey specialist had been concerned about the integrity of the main.[21]

In total, Atmos identified four leaks classified as Grade 1 and nine leaks classified as Grade 2 in an 8-block area around the 3500 block of Espanola Drive prior to the explosion. (See figure 4.) Of those, Atmos had completed repairing all four Grade 1 leaks and two of the Grade 2 leaks before the explosion occurred on the morning of February 23.[22] An Atmos operations supervisor told NTSB investigators that excessive rain rendered the repair work difficult. He said that it was challenging to dig in the alley, and it was not possible to bring a truck with a pump into the alley because it would have gotten stuck. He said that the workers had to try to scoop water out with a bucket and that they were "trying…[to repair gas leaks] against all odds."

The director of operations told NTSB investigators that he was not alarmed by these leaks and was comfortable that service technicians had performed the necessary surveys and addressed any leaks that required immediate attention. He said that he was not concerned that the weather conditions would have affected the service technician's equipment accuracy or prevented them from performing survey work.

[20] Around mid-day on February 22, the operations manager and director of operations became aware of the first two incidents and began gathering additional details from an offsite location.

[21] Based on the investigation and information gathered by the service technicians, survey specialists, and construction crews, the operations manager believed there was nothing that suggested a hazardous situation existed that required them to turn the gas off to the neighborhood.

[22] All six repairs were made on coated steel, with five of those repairs being made on service lines. Atmos attributed four of the repaired leaks to a thread leak and two leaks to ground movement.

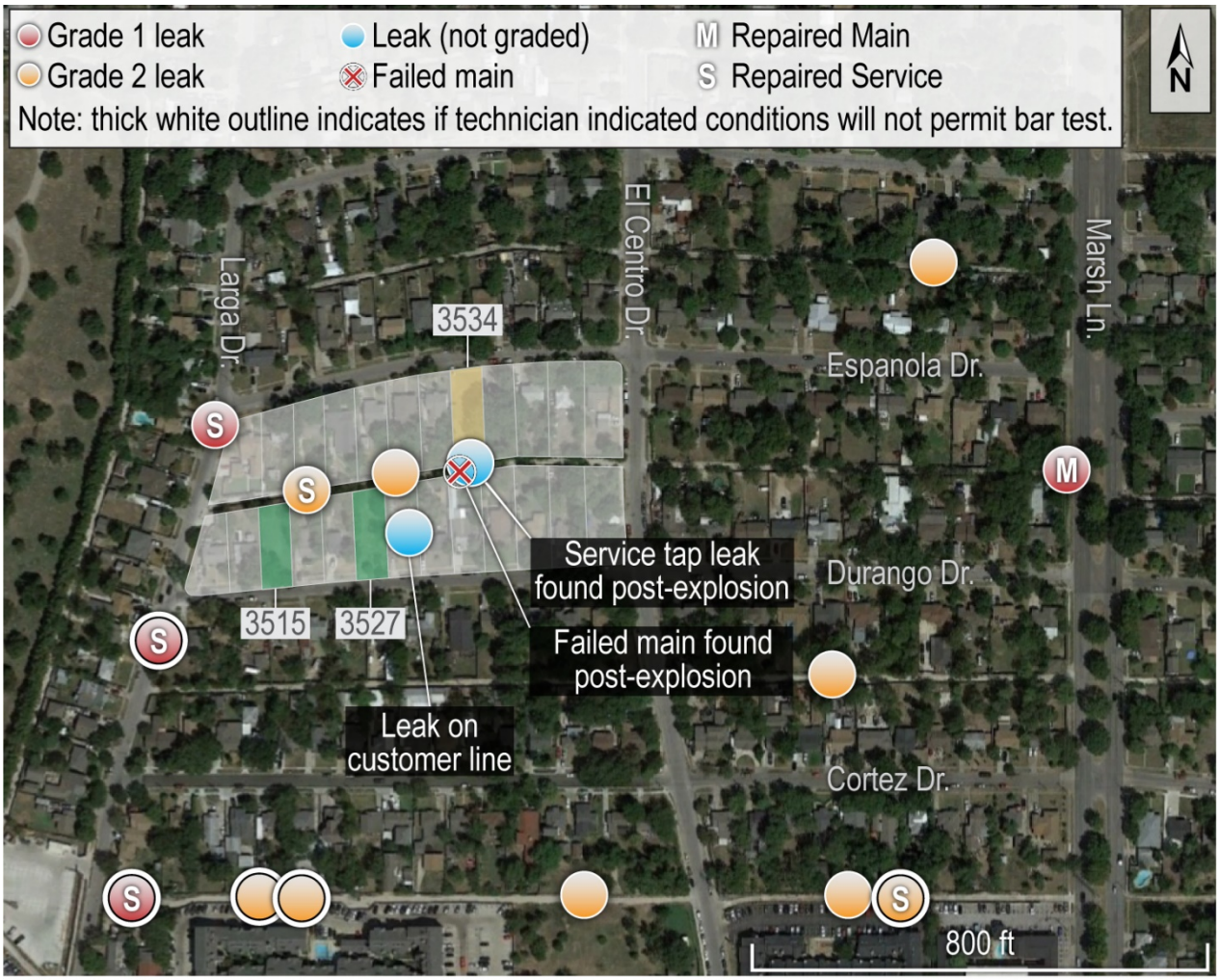

Figure 4. Leaks identified prior to the explosion.

1.5 Emergency Response to 3534 Espanola Drive

Following the natural gas explosion that occurred at 3534 Espanola Drive at 6:38 a.m. on February 23, 2018, the DFR dispatch center received multiple reports of the explosion.[23] At 6:44 a.m., first responders arrived, assessed the scene, and reported no smoke or fire but major structural damage to the home. The family had just moved into the recently remodeled home about 1 month prior to the explosion.

Atmos crews, who were already in the area surveying and repairing leaks (as described above), heard the explosion and began evacuating the neighborhood. Within minutes, emergency

[23] A foundation inspector who evaluated the house where the explosion occurred (3534 Espanola Drive) observed the foundation of the home had experienced a significant amount of differential settlement and lateral movement. He reported that highly plastic clay soils, typically found in the Dallas-Fort Worth area, can distress structures over time due to expansion and contraction caused by seasonal moisture changes. The foundation of the explosion house was repaired and then inspected by the City of Dallas in 2017.

response vehicles arrived on scene. The Atmos operations supervisor saw the damaged home, but no smoke or fire. He observed that the front of the house appeared to be falling in. The operations supervisor contacted the Atmos operations manager and the director of operations, who told him to evacuate the Durango and Espanola side of the 3500 block. With the assistance of a firefighter, Atmos crews evacuated the 2-block area, going door-to-door advising residents to evacuate and not to start cars or turn on lights. Following the evacuation, the director of operations instructed the operations supervisor to isolate gas mains in the area.

Meanwhile, firefighters assessed the situation and requested emergency medical response for the injured family members. The DFR IC was aware of the two recent fires in the neighborhood and considered how wide of an area to evacuate. The first evacuation included a 2-block area designated as "Exclusion Zone 1."[24] An Atmos operations supervisor responded to the initial command post, which was established near 3534 Espanola Drive. The Atmos operations supervisor continued to update the IC on the company's efforts to isolate the gas system.

Five DFR arson investigators inspected the damaged home, however, they did not enter the structure under safety advisement of the DFR IC. Other arson investigators interviewed family members who reported hearing "popping" noises earlier that night but were unable to determine what was causing the sound. They did not smell any gas prior to the explosion. The three family members who were located in bedrooms at the time of the explosion did not sustain significant physical injury. However, two family members located in the living room toward the front of the house sustained severe injury, including the one fatality. The DFR fire investigation report, which is found in the NTSB docket for this investigation (PLD18FR002), classified the explosion as "undetermined."

Following the evacuation of the 2-block area, Atmos technicians continued to perform leak surveys in the surrounding neighborhood. DFR requested evacuation guidance from Atmos and subsequently expanded the evacuation by several blocks, which was completed by about 10:00 a.m. (Exclusion Zone 2). DFR deployed a hazardous materials (hazmat) coordinator to the Stephen C. Foster Elementary School to monitor for gas; he detected none. Nonetheless, by 1:30 p.m., DFR evacuated the school as a precaution (Exclusion Zone 3). A fourth evacuation was issued for an additional 60 single-family homes east of this area (Exclusion Zone 4). In total, the DFR evacuated about 300 single-family homes, two apartment buildings (250 units), and a school (about 600 students). Figure 5 shows the Exclusion Zones.

[24] This was not a mandatory evacuation, which can only be issued by a county judge. Mandatory evacuations are required for high-risk security scenarios and also in times when residents are not compliant. This was not needed for the February 23 house explosion because residents were willing to evacuate.

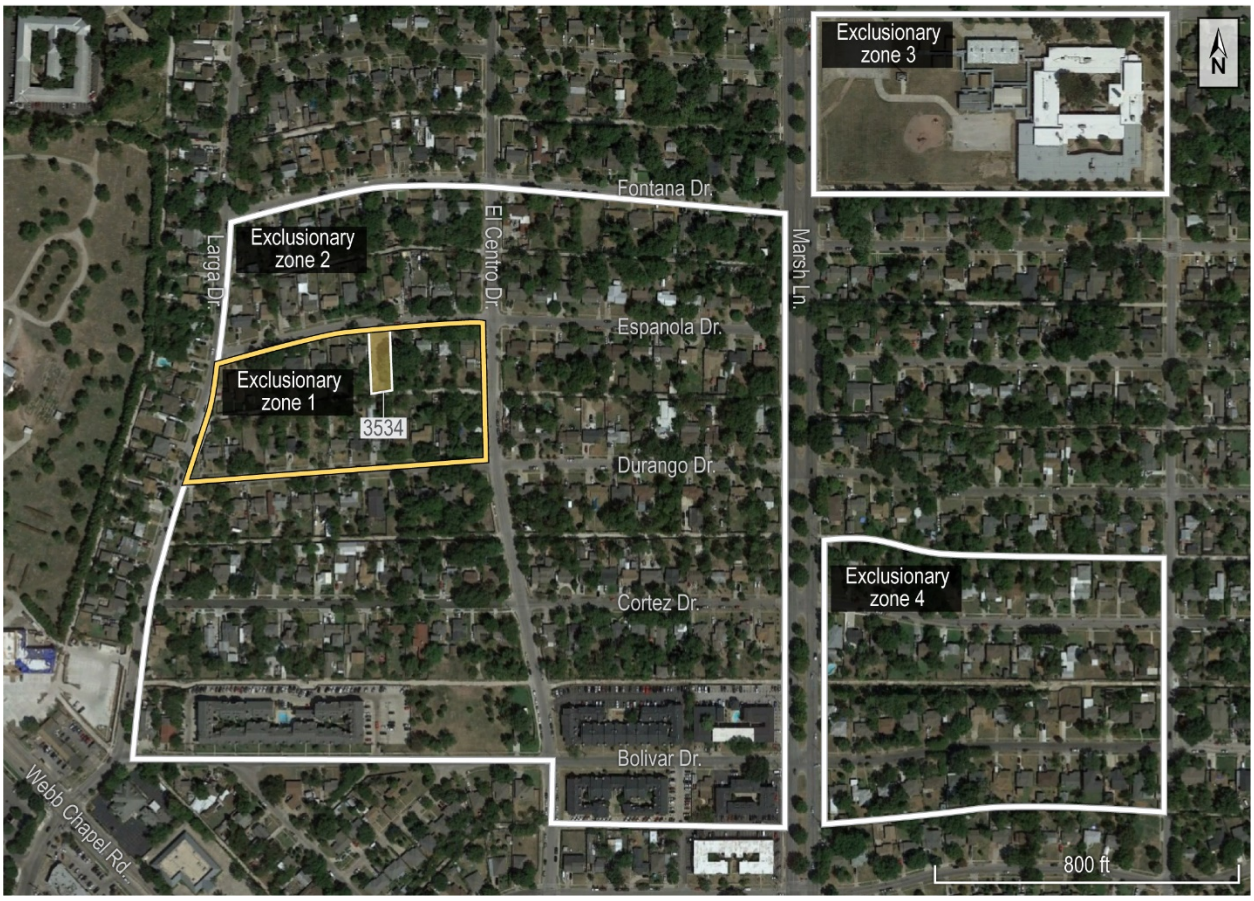

Figure 5. Dallas Fire-Rescue map of the four exclusionary zones after the February 23 explosion. (Map courtesy of Google.)

DFR cleared the incident scene at 7:00 a.m. on February 24. However, DFR maintained a presence at the command post in the event further evacuations were necessary while Atmos conducted leak surveys. At about 3:30 p.m. on February 24, Atmos publicly announced that the evacuation in the four exclusion zones had been lifted.

1.6 System Isolation and Pipe Segment Replacement

Atmos isolated the gas distribution system through a series of staged system isolations with gas service being disconnected throughout the immediate neighborhood. System isolation began about 7:45 a.m. on February 23 and was completed that evening. On the afternoon of February 23, Atmos decided to replace all mains and service lines in the isolation area.[25]

Atmos continued performing special leak surveys over an expanded area after the explosion. The Atmos Energy vice president of technical services told NTSB investigators that, after these surveys discovered an unusual number of leaks, the company decided to isolate a

[25] The isolation area included piping in the alley and along Larga Drive within the special leak survey area from February 22, 2018, as shown in figure 6.

9-block area, in part, based on pipe material type and vintage. In the area shown in figure 6, technicians found nine leaks they classified as Grade 1 and 17 leaks they classified as Grade 2.[26] Of these 26 leaks, 11 were not excavated to determine the cause since the system was being replaced; six were attributed to stripped threads; two were attributed to corrosion; two were attributed to ground movement; and one was attributed to each of the following causes: gasket/O-ring, excessive strain, weld (steel), third-party damage, and other.

[26] Figure 6 shows the special leak survey area from February 22. After the explosion at 3534 Espanola Drive, additional leak surveys were performed. Grade 1 and 2 leaks that were found after the explosion are highlighted by a white dashed line in figure 6.

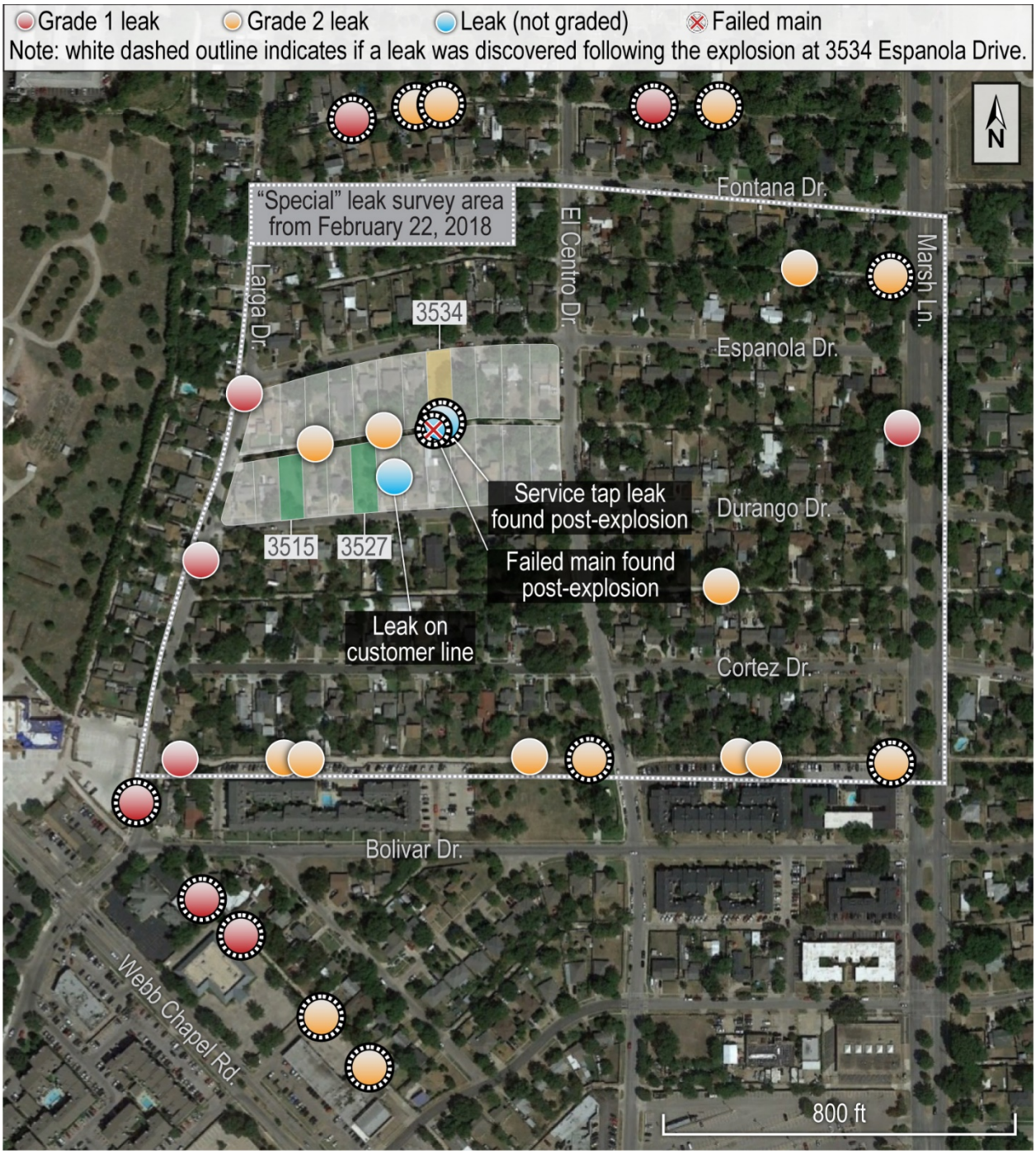

Figure 6. Leaks identified as Grade 1 or 2 and prior to system replacement.

On the afternoon of February 24, 2018, Atmos completed leak testing in the west Dallas neighborhood bounded by Gaspar Drive to the north, Larga Drive to the west, Almazan Drive to the south and Marsh Lane to the east. However, Atmos indicated natural gas service to this area had to be disconnected to ensure the safety of the residents. Atmos announced that they had about 40 contract crews replacing 2.5 miles of pipe throughout the area. Atmos indicated that

natural gas services would be restored following the installation of the new main and service lines.[27]

Between February 23, 2018, and March 1, 2018, Atmos continued performing special leak surveys over an expanded area and worked with DFR to evacuate additional areas in northwest Dallas.[28] On March 1, 2018, Atmos announced in a letter to its customers that it would be conducting a planned outage, temporarily disconnecting natural gas service to about 2,800 homes in northwest Dallas.[29] The public statement advised that the outage was necessary to replace Atmos's natural gas distribution system after "recent extraordinary rains and unique geological conditions in the area have caused unprecedented system performance." The Atmos statement added that the action was not being taken because of any imminent emergency or danger.

In a July 2, 2018, letter to the RRC, however, Atmos stated that the March 1 outage was in direct response to the leak activity in northwest Dallas. Moreover, Atmos told NTSB investigators that "the extraordinary measure was taken after a period of intensive leak surveying and monitoring of system performance," and that:

> Atmos Energy engaged a geoengineering firm to understand the potential cause for the sudden and unexplained leaks and assist in developing a response. The preliminary findings of the geoengineering firm indicate that the area in question contains dissimilar geological formations in close proximity which were impacted by the historic rain fall. The different characteristics of these formations—and resulting movement of one formation relative to the other, together with many other contributing factors—likely caused longitudinal forces to be added to the system that could not have been readily detected, predicted, anticipated, or foreseen.

In a July 12, 2018, letter to the RRC, Atmos attributed the increase in the number of leaks reported by the division that included the explosion and incident sites for that 6-month period to "abnormal, sudden, and unexplained leak activity within a defined geographic area in northwest Dallas." Atmos further indicated that it hired a geotechnical engineering firm that indicated that "unique conditions…caused ground movement that put unanticipated longitudinal forces" on its pipeline system. On July 25, 2018, Atmos issued a public statement that its leak investigations "revealed that in less than a week's time, our system experienced multiple times the number of leaks experienced in each of the previous three years over this area."

[27] Gas restoration began on February 26, 2018, and continued on a rolling basis as the system was replaced.

[28] Leak survey areas that extended beyond the area shown in figure 6 were not considered to be within the scope of the NTSB's investigation of the explosion but are discussed in section 2.7.

[29] The City of Dallas reported that gas restoration was completed on May 11, 2018 (http://www.dallascitynews.net/resident-support-evacuations-northwest-dallas).

1.7 Examinations After the Explosion

1.7.1 On-site Integrity Tests

On February 23, 2018, Atmos performed a pressure test of the customer piping at 3534 Espanola Drive from the outlet of the meter to the riser near the house.[30] The customer piping was pressurized with air at 0.25 psig and held for 10 minutes, passing the pressure test.[31]

On February 24, 2018, Atmos pressure tested the main and service lines that supplied the impacted homes with natural gas. All service lines were disconnected and isolated just upstream of the service regulator. The full test segment extended from behind 3503 Durango Drive to behind 3559 Durango Drive. Excavations were completed and the main was cut and capped to perform the pressure test. The main and service lines did not hold pressure.

Additional pressure tests were completed between February 26, 2018, and March 7, 2018, in various phases to locate the point of failure. The pressure tests were performed at a pressure of 25 psig for 30 minutes or more and resulted in the identification of three leaks at the following locations:

1. The threads of the service tee assembly in the alley behind 3524 Espanola Drive.
2. The main directly under the sewer lateral in the alley behind 3539 Durango Drive.
3. The service tee assembly in the alley behind 3539 Durango Drive.

Sections of Atmos's pipeline system pertaining to leaks 1 and 2 was removed and sent to the NTSB Materials Laboratory in Washington, DC for further evaluation.

During pressure testing and associated excavation activities, NTSB investigators noticed a change in soil color and a sulfur smell at an excavation site behind 3539 Durango Drive. The soil characteristics changed at a depth of about 1-2 feet. The odor became stronger and the discoloration more apparent with continued excavation to the east toward the 3539 Durango Drive sewer lateral. No soil discoloration or sulfur smell was observed around the main east of the 3539 Durango Drive sewer lateral. The sewer lateral was estimated to have a clearance from the top of the gas main to the bottom of the sewer lateral of about 0.5 inch. When the natural gas main was pressurized and soap tested, NTSB investigators heard an air release and saw visible soap bubbles on the main at the 3539 Durango Drive lateral crossing.[32] (See figure 7.) After cleaning, a dent and circumferential crack were identified on top of the pipe directly under the sewer lateral. Substantial coating damage and an adherent concrete-like substance were found on

[30] The customer natural gas piping was found to be disconnected near the riser to the house after the explosion.

[31] The integrity of the customer piping was later confirmed by a pressure test performed by Atmos and supervised by the RRC on March 2, 2018. This pressure test was performed from the outlet of the meter to the house riser using a hand pump. The test was held for at least 30 minutes at 0.25 psig after an initial 30 minutes of 0 pressure to establish a baseline.

[32] *Soap test* or *bubble leakage test* refers to a leak detection method where soap water or other foam-forming solutions are applied to exposed piping to determine whether a leak exists.

the main. Coating damage was evident across about 25 inches of pipe, mostly concentrated on the top of the pipe in the area directly beneath and to both sides of the sewer lateral.

Figure 7. Crack in natural gas main at 3539 Durango Drive sewer lateral crossing. (Courtesy of Atmos.)

Depth of cover measurements were taken at several locations where the natural gas main was exposed. The measured depth of cover of the natural gas main varied, ranging from 43 to 58 inches. The depth of cover of the sanitary sewer main at the connection to the 3539 Durango Drive sewer lateral was 75 inches. The depth of cover at the gas main and sewer lateral crossing were about 32 inches to the top of sewer lateral sand, 42 inches to the top of sewer lateral, and 49 inches to top of the gas main.[33]

[33] The cover requirements outlined in 49 *CFR* 192.327 say that "each buried main must be installed with at least 24 inches of cover unless specific exceptions apply."

1.7.2 On-site Gas Measurements

Several CGI gas measurements were taken following the explosion, as shown in figures 8 and 9.[34] The highest gas reading observed at each measurement location in the backyard of 3534 Espanola Drive are shown in figure 9. The approximate location of leaks found by Atmos following the second incident as well as by NTSB investigators during integrity testing after the explosion are also indicated in the figures.

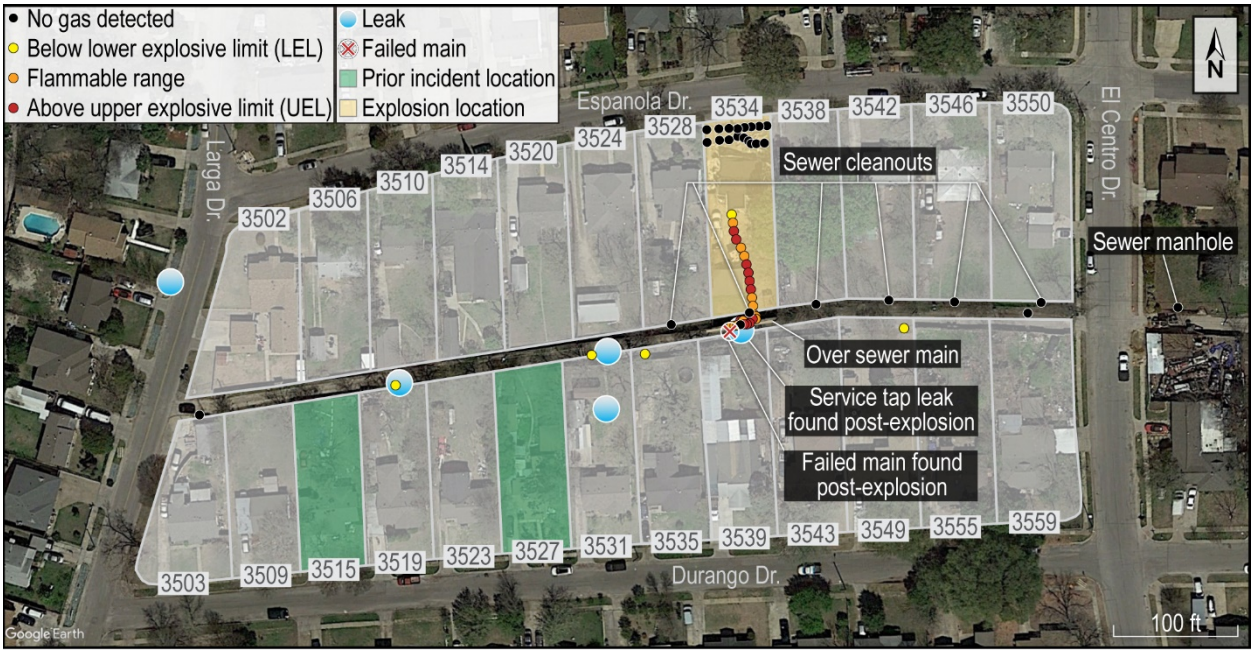

Figure 8. Gas measurements taken in the block surrounding the site after the explosion.

[34] Gas measurements in the backyard were taken on the day of the explosion and again 8 days later. Weather conditions varied over this time.

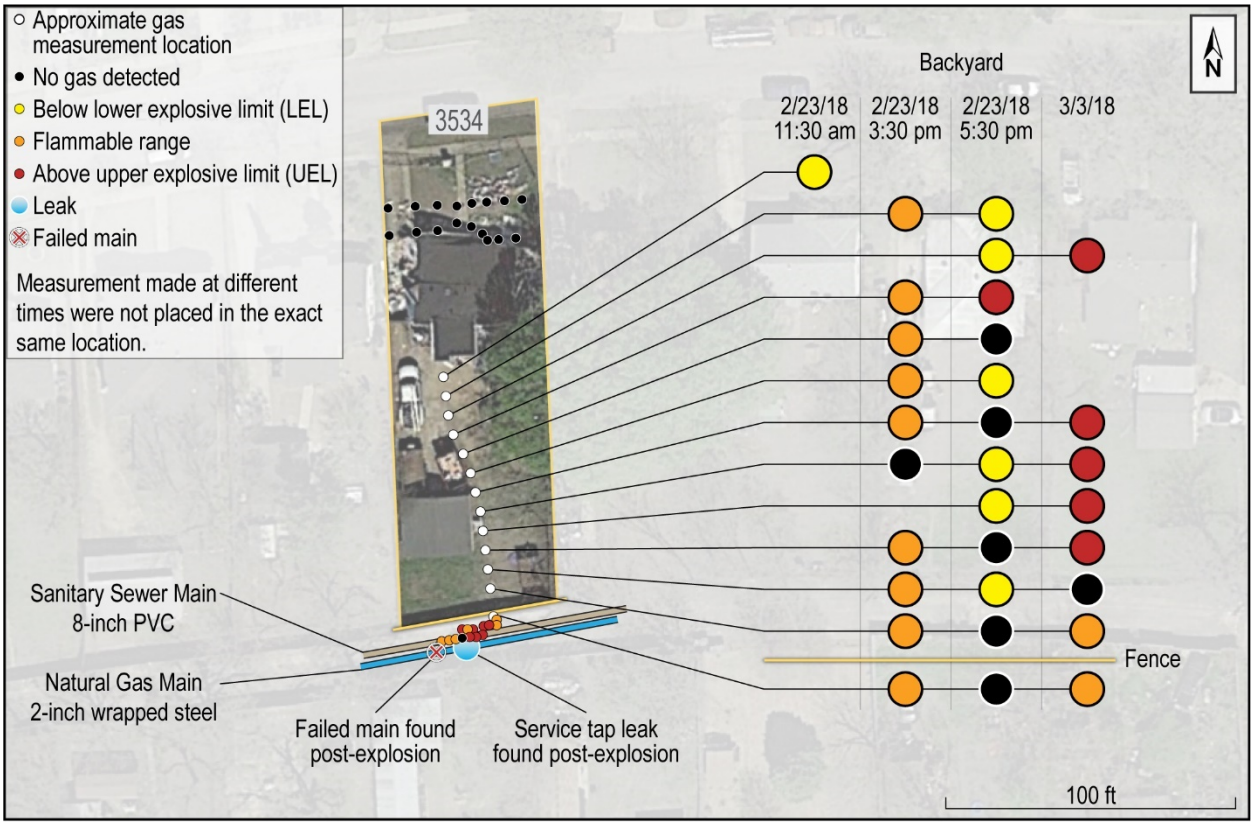

Figure 9. Gas measurements taken on and near the property after the explosion.

1.7.3 Gas Odorization Testing

The RRC conducted a gas odorization test on February 23, 2018, at four test points near the affected residences and found the natural gas odorant to be "readily detectable," as required.[35]

1.7.4 Gas Regulator Testing

The service regulators from the three affected houses (3527 and 3515 Durango Drive and 3534 Espanola Drive) were tested after the explosion. The independent testing laboratory indicated that all three regulators properly locked up when the flow was shut off and they all relieved pressure when the downstream pressure exceeded the internal relief set points.[36] The testing laboratory determined that all downstream set points were within the expected range for a residential natural gas regulator. A copy of this report appears in NTSB docket PLD18FR002.

[35] According to 49 *CFR* 192.625(a), "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."

[36] *Lock up* refers to the service regulator function of shutting off flow when there is no demand for gas.

1.7.5 NTSB Testing

Two segments of the 1946-vintage steel natural gas main that was installed in the alley behind the affected houses were examined by the NTSB Materials Laboratory. One 10-foot long segment included the crack found behind 3539 Durango Drive. The other 3-foot long segment included the service tee assembly from behind 3524 Espanola Drive. The gas main had an outer diameter of 2 3/8 inch and a wall thickness of about 0.15 inch.

1.7.5.1 Examination of Cracked Gas Main

Visual examination of the gas main segment from behind 3539 Durango Drive revealed the top surface of the gas main coating was damaged in four locations, as evidenced by missing pieces of the coal tar enamel spiral wrap indicated by brackets “D”, “C”, “B”, and “A” in figure 10.

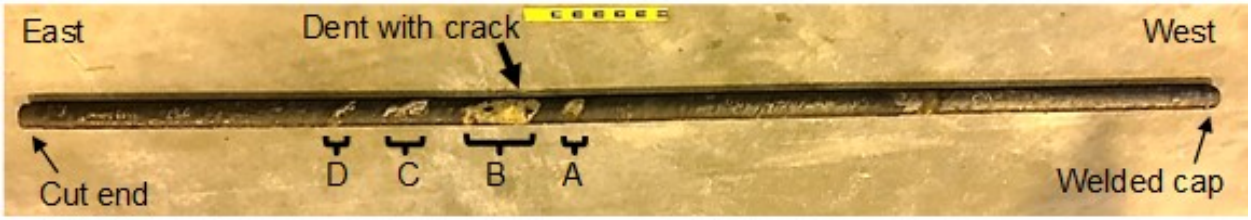

Figure 10. Natural gas main recovered near 3539 Durango Drive sewer lateral crossing.

The exposed surface of the gas main in the four locations of coating damage was covered with a hard, compacted, adherent deposit that had formed on the exposed pipe surfaces. The circumferential crack intersected the dent. (See figure 11.) The dent was about 0.46-inch deep and about 1.4 inches in diameter. The crack occurred within one of the coating damage areas. The pipe had a slight downward bow with the greatest vertical deformation in the general area of the dent with the crack.

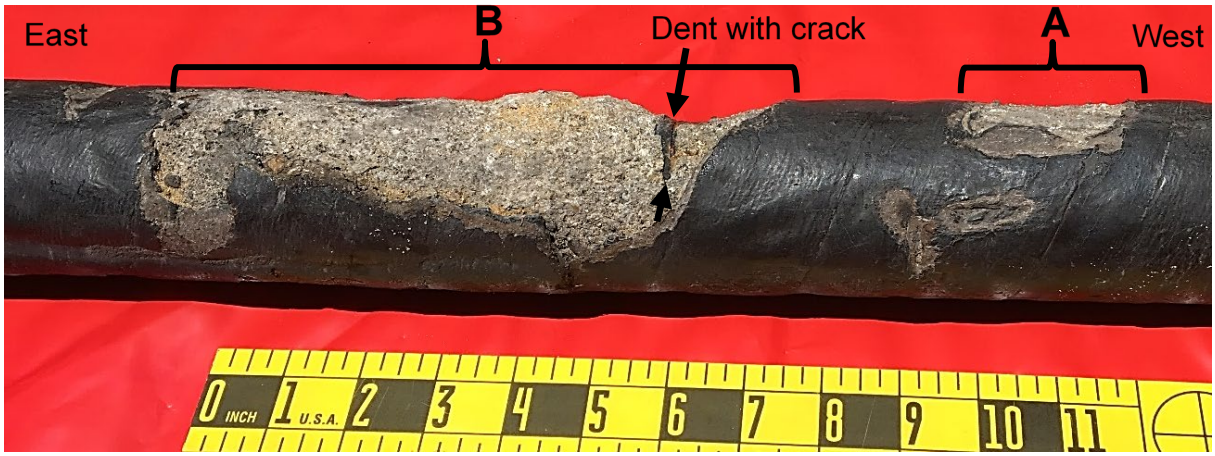

Figure 11. Side view of the damaged natural gas main showing the dent with a crack.

NTSB investigators identified five major diagonally oriented pipe wall gouges along the 10-foot length of the gas main. The five major gouges are indicated in figure 12 as "A1," "B1," "C1," "C2," and "D1." There was at least one major gouge within each of the four coating damage areas, along with evidence of several other minor gouges. The gouges exhibited evidence of metal flow deformation, consistent with a gouge that started on the south and ended at the north. The gouges had round profiles and lengths that ranged between 0.9 inch and 1.8 inches, widths that measured between 0.13 and 0.25 inch, and depths that ranged between 0.007 and 0.018 inch.

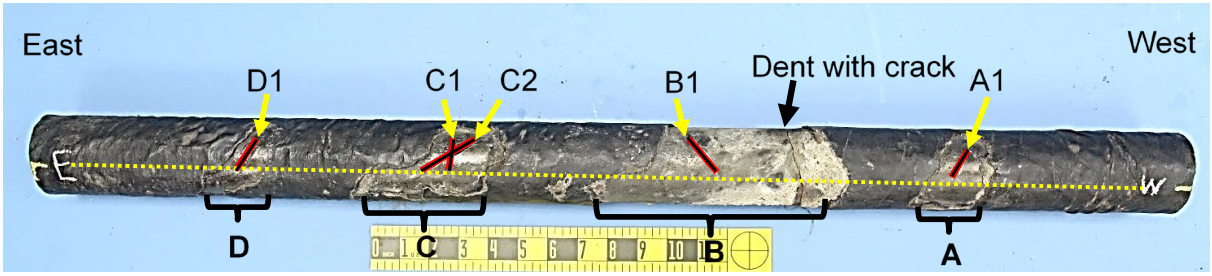

Figure 12. Top surface of the natural gas main showing the five major gouges.

Figure 13 shows the crack and dent in the top side of the main in region "B," after removing hard deposits from the surface in areas outside of the dent and exposing a gouge, indicated as "B1." A smaller dent, about 0.25-inch diameter, was found in the area indicated by arrow "B2."

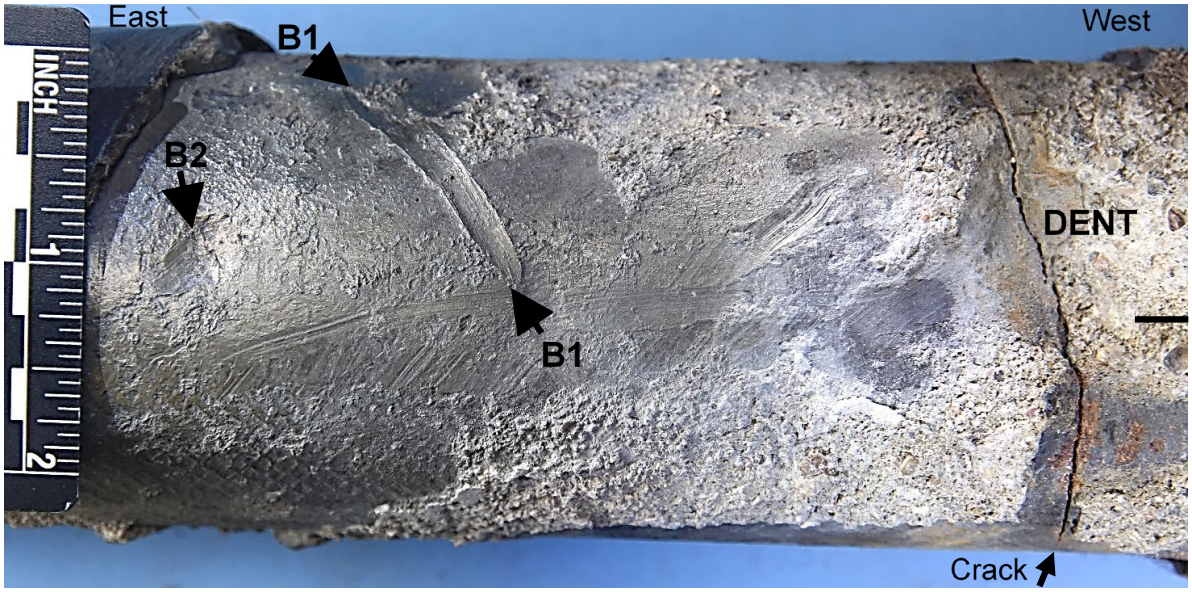

Figure 13. Crack and dent on top surface of natural gas main after removing surface deposits.

A microscope examination of the west face of the fracture revealed evidence of ratchet marks that emanated from multiple origins at the outer dent surface. There was a 20 percent reduction in wall thickness at the area of the dent. The crack propagated from the bottom of a

dent though the wall thickness and extended circumferentially to the approximate axial centerline of the pipe. (See figure 14.) The fracture surface exhibited moderate corrosion product deposits.

The fracture face at two isolated areas contained barely visible black regions adjacent to the dent on the external surface, in the areas indicated by regions "S1" and "S2" in figure 14. The remaining portion of the fracture surface exhibited a lighter orange-brown corrosion deposit. The black regions extended between the outer surface and as deep as about 0.07 inch below the surface, to the approximate areas indicated by black dashed lines in figure 15. The black regions appeared similar to thumbnail-like patterns. Scanning electron microscopy (SEM) also revealed the fracture surface contained cleavage fracture features that were pitted. The cleavage fracture features extended the entire length of the crack.

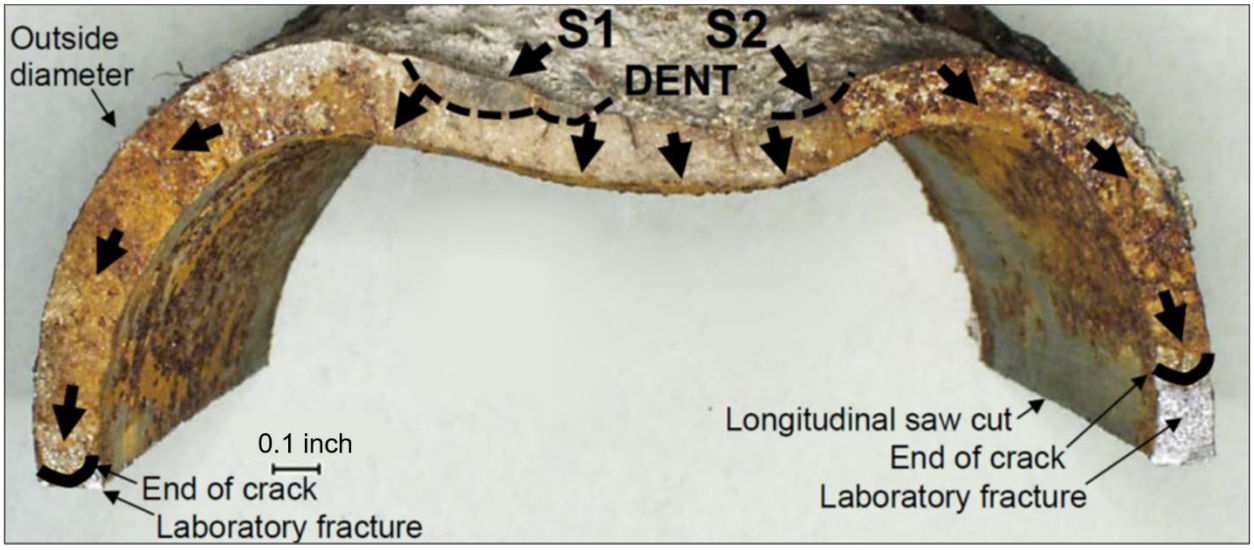

Figure 14. West face of pipe fracture after separating mating faces of circumferential crack.

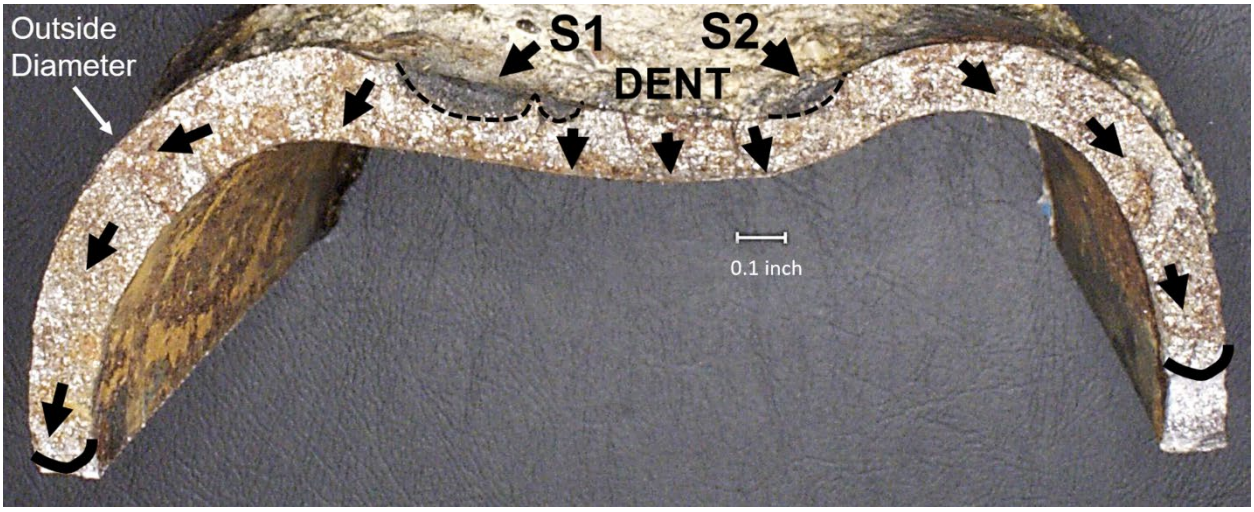

Figure 15. West face of the pipe fracture, after cleaning procedure.

X-ray diffraction analyses of a sample of a hard deposit removed from a gouge revealed evidence of calcite (calcium carbonate).[37] Energy dispersive spectroscopy (EDS) analysis of the hard deposits revealed they contained major elemental peaks of calcium, and evidence of oxygen, silicon, iron, carbon, magnesium, sulfur, potassium, titanium, aluminum, manganese, and zinc. The EDS spectrum from the fracture face prior to cleaning contained elemental peaks that were similar to those found on the hard deposit, whereas, the EDS spectrum of the dark (black) regions adjacent to the dent contained elemental peaks of iron, oxygen, and carbon.

Cross section examination of the gas main revealed the pipe was seamless. Chemical analysis of the pipe material was consistent with Seamless Bessemer Grade C material in accordance with the 1945 edition of American Petroleum Institute (API) Standard 5L (API 1945).[38] Tensile tests showed that the measured ultimate tensile strength, yield strength, and elongation values were consistent with Seamless Bessemer Grade C pipe material.[39] The measured pipe diameter of 2.4 inches and thickness of 0.167 inch were within API 5L specifications.

Chemical analysis of a pipe sample from the gouge area showed a hydrogen content of 6 parts per million (ppm) that was nearly twice the hydrogen content for a pipe sample that was removed from an area that was covered with a coal tar wrap coating.[40]

1.7.5.2 3524 Espanola Drive Gas Main Segment, Tee, Service Line, and Riser

NTSB investigators examined a second segment of the same gas main on which was attached a tee assembly, service pipe, and service riser that was recovered from behind 3524 Espanola Drive. (See figure 16.) The base portion of the tee assembly was welded to the gas main. A 103-inch length of polyethylene service pipe was attached to the steel tee.

[37] In cathodic-protected pipe, the cement like deposits that build up in exposed portions of the pipe are referred to as a calcareous deposit. The impervious calcareous deposits provide protection against corrosion. A calcareous deposit is a layer typically consisting of a mixture of calcium carbonate and magnesium hydroxide.

[38] The 1945 edition of API Standard 5L was consulted because it was the edition that was in effect at the time the gas main was installed in 1946.

[39] In the 1960s, the manufacture of steel pipe using the Bessemer process was discontinued. By 1970, Bessemer steel was dropped from API Standard 5L.

[40] Electrochemical reactions can occur on the exposed steel surface of cathodic-protected pipeline that result in liberation of hydrogen. The hydrogen can adsorb on the exposed steel surface and diffuse into the steel resulting in embrittlement and hydrogen-assisted cracking.

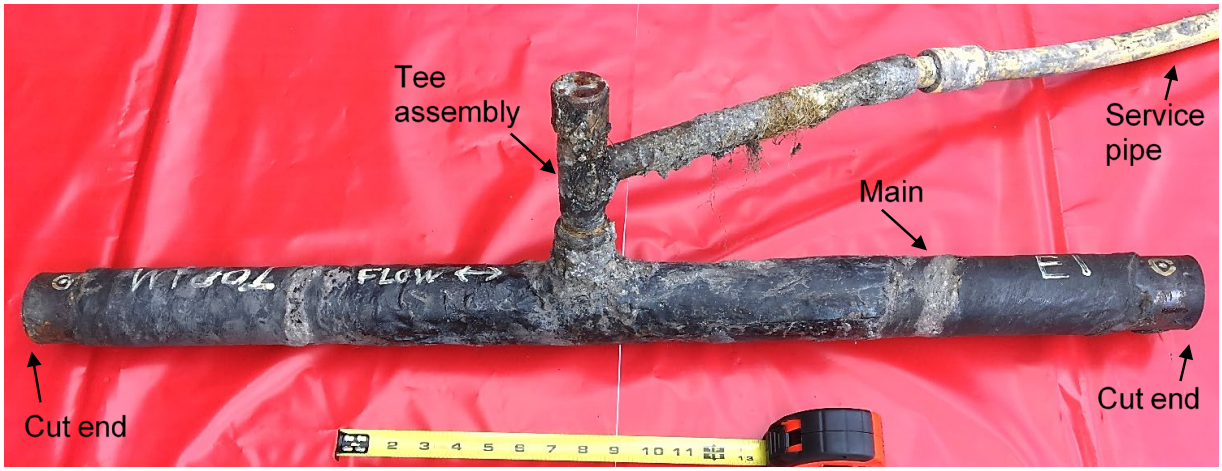

Figure 16. Natural gas main, with service line recovered from behind 3524 Espanola Drive.

Visual examination found no evidence of a crack in either the service pipe, tee assembly, service riser, or gas main segment. The outer wall of the 0.75-inch service pipe was marked with an indication that Performance Pipe manufactured it on June 3, 1997, from medium-density polyethylene. The measured diameter and thickness of the main and service pipe were within the specified size.

1.7.5.3 Laboratory Pressure Tests

The 10-foot segment of the main with the circumferential crack was pressurized to determine the leak rate. NTSB investigators attempted to pressurize the pipe to 55 psig, the MAOP of the pipe, but this was not possible because of air flowing out of the crack. The operational pressure range of the system in the days prior to the explosion was between 17 and 45 psig. Based on the pressure-testing data, this calculates to a natural gas leak rate of between 8 and 14 CFM.

A 3-foot segment of the steel main with a steel tee assembly and polyethylene service pipe located behind the dwelling at 3524 Espanola Drive was also pressurized to determine the leak rate. A 0.2 CFM flow rate was observed when the pressure reached 55 psig. A soap solution revealed that the tee assembly was leaking in the area below the cap and at the base of the tee assembly.

1.7.6 Soil Testing

Geotechnical reports were prepared by two organizations following the explosion. Atmos Energy retained a geotechnical engineering firm, Bryant Consultants, Incorporated (BCI). BCI was retained to assist Atmos in determining a potential cause of the sudden and unexplained leaks in a defined area in northwest Dallas in the days leading up to Atmos's planned system outage on March 1, 2018, and assist in developing a response. The NTSB contracted the US Army Corps of Engineers (USACE) to develop a government geotechnical report to evaluate the technical accuracy of the preliminary geotechnical assessment report provided by BCI.

1.7.6.1 Bryant Consulting Soil Study

BCI completed a preliminary geotechnical assessment report, dated February 28, 2018, that described the presence of two geologic formations, the Eagle Ford and Austin Chalk, underlying a defined area in northwest Dallas. The report states that the close proximity of these two formations creates a geological hinge point where the land generally to the west of Marsh Lane may move more relative to the land to the east of Marsh Lane where more uniform and stable soil and moisture conditions are generally encountered. The report further suggests that the recent extended period of rain had likely exacerbated this movement and that these forces caused unanticipated external loadings on Atmos's piping system. No specific evidence or test data were cited in the preliminary geotechnical assessment report.

Following its preliminary assessment, BCI performed an in-depth analysis of this area in northwest Dallas, which Atmos stated corroborated the preliminary assessment findings.[41] According to Atmos, BCI collected dozens of core samples and conducted subsurface geological testing throughout the area that refined existing geological maps of the area. BCI presented Atmos with a project summary of this work but did not produce another written report. Atmos told NTSB investigators that BCI was not engaged to investigate or draw conclusions regarding the events of February 21 through 23, 2018, and did not perform any testing within the 3500 block of Durango and Espanola Drives.[42]

1.7.6.2 US Army Corps of Engineers Soil Study

The USACE produced a report, *Atmos Pipeline Assessment, Dallas, Texas,* dated April 2019, evaluating the technical accuracy of the BCI preliminary geotechnical assessment report.[43] The USACE reported that based on the site-specific borings, drilled as part of the subsurface investigation, there is only one geologic formation, the Eagle Ford Shale, underlying the explosion site. Moreover, based on the laboratory test results described in its report, USACE concluded that the plasticity characteristics and swell potential (relative change in volume to be expected with changes in moisture content) of the subsurface materials within the explosion block are highly uniform. Though uniform, USACE observed that the subsurface soils in the explosion block are high plasticity clays, the swell potential of which significantly increases as subgrade moisture content increases. The USACE indicated that the clay swells when saturated with water and shrinks on drying, and the associated movement tends to distress the structures constructed on top or within these formations, such as buried piping. The USACE indicated that the magnitude of force exerted on piping systems is proportional to the plasticity of the soil and the variability of the moisture content within the soil.

[41] E-mail from Atmos to NTSB, April 22, 2019.
[42] E-mail from Atmos to NTSB, April 22, 2019.
[43] The USACE report can be found in the docket for this accident (NTSB case number PLD18FR002) by accessing the Accident Dockets link for the Docket Management System at www.ntsb.gov.

1.7.7 Incidents at 3527 and 3515 Durango Drives

Although this investigation focused on the explosion at 3534 Espanola Drive, NTSB investigators also gathered available information related to the incidents at 3527 Durango Drive and 3515 Durango Drive as described below.

1.7.7.1 Customer Piping at 3527 and 3515 Durango Drives

Pressure testing of the customer piping at 3527 Durango Drive was performed by the homeowner's representative and observed and documented by Atmos's representative on March 24, 2018. The testing found no leaks on the system or on any of the appliances.[44]

Furthermore, pressure testing of the customer piping at 3515 Durango Drive was conducted on March 15 and 20, 2018, by a licensed master plumber with 39 years of experience. Photographs from this testing indicated a pressure drop on the system from 0.27 psig to 0.22 psig over a period of about 7 minutes. The master plumber noted three gas appliances in the home (gas range, water heater, and HVAC) and the only damage to the gas piping that he found was to a flex connector that was disconnected from the range.[45]

1.7.7.2 Damage to 3527 Durango Drive

The structure at 3527 Durango Drive consisted of the original home, constructed in 1948, and an addition, which included a bedroom and restroom that was constructed around 2013. Damaged areas of the home included the roof, exterior of the structure, and interior of the home.

The roof of the original structure had bulges, areas of displaced shingles, and several holes. Portions of the roofline were buckled, sagged, and displaced from its original position. Portions of the exterior siding were detached from the sheathing on two sides. The exterior wall on the west side of the original home was displaced outward and detached from the roof, roof vent, and both windows.

The rear wall of the addition exhibited missing strips of siding, sections of missing roof edging in the lower corner of the exterior wall, and a hole that extended into the interior. The remaining exterior sheathing of the rear wall of the addition bowed outward.

Thermal damage was largely confined to the addition, areas adjacent to the addition, and the attic. The interior of the addition was destroyed by fire. The bedroom adjacent to the addition and the adjoining hallway sustained thermal damage.

The sewer line, located under the addition, was found separated at the elbow after the incident. There was thermal discoloration on the exterior of the piping, particularly the elbow. The soil beneath the piping appeared to have been disturbed.

[44] E-mail from Atmos to NTSB, May 1, 2020.
[45] This range had been removed from kitchen after the incident.

In the attic, the roof rafters, decking, and other wooden structural members located near the HVAC exhibited light surface charring and soot. The ceiling of the living room, located immediately below the HVAC unit, had collapsed downward into the room below exposing the wooden ceiling joists which appeared undamaged and exhibited no exposure to heat or fire.

The gas range and hot water heater appeared to have no fire-related damage. The HVAC unit had thermal damage and soot on three sides of the unit. The interior of the HVAC also sustained thermal damage. There was light soot on the interior surfaces and most of the wiring had melted insulation. On the interior of the access panel, the labels and diagrams appeared to be undamaged. There appeared to be no fire-related damage to the gas bathroom heater which had been installed in the original home (not the addition) prior to the incident.

1.7.7.3 Damage to 3515 Durango Drive

The structure at 3515 Durango Drive was constructed in 1948. The interior of the structure was destroyed by fire. Most of the interior walls and ceiling were missing, and the exposed structural joists were fire damaged.

On the west side of the residence, adjacent to the kitchen, the upper third of the exterior wall under the carport sustained fire damage to the upper third of the wall. There was fire damage to the siding at the southwest corner. Glass panes were missing from the two windows and the upper portion of the frame was covered in soot. The section of siding between them had some charring and soot. The siding was missing to the left of the left window. The siding anchors appear still attached to the exterior sheathing. The siding below this area was intact and undamaged. Glass fragments were embedded in exterior fencing slats next to the carport.

The northwest corner of the structure sustained fire damage that extended from the corner to the center of the exterior wall. The exterior wall in this area was largely missing with only vertical fire-damaged structural supports remaining. The roof was buckled and sagging, and portions of the roof were missing.

The gas range had soot over all exposed exterior surfaces. There was thermal damage to the backsplash and control panel. The metal panels on either side of the control panel were discolored and warped. All plastic components were melted.

1.8 Prior Leak History

Atmos leak data for the impacted area indicated that the 2-inch main in the alley behind the affected houses had no history of leaks in the 10 years prior to this explosion. According to historical records, Atmos identified one leak on this main in the last 25 years. That leak was permanently repaired in 1997.[46] There were several leaks on the service lines that tied in to the 2-inch main during the past decade.

[46] On June 19, 1997, a leak was identified at 3559 Durango Drive and classified as Grade 2. The leak was reported to be permanently repaired on December 11, 1997.

The 25 service lines connected to the natural gas main in the alley behind the affected houses were originally installed with wrapped steel between 1947 and 1950. Thirteen of these original service lines had been replaced with plastic service lines between 1994 and 2018. Two of the replaced service lines had been replaced again with plastic service lines between 2017 and 2018.

Prior to the explosion, Atmos had most recently completed leak surveys in the area of the explosion on and March 21, 2014, and March 7, 2017. Atmos organized leak surveys by geographical regions referred to as map sheets. The map sheet where the explosion occurred included an area of about 8 blocks near the explosion site. During the 2017 survey, Atmos identified three leaks it classified as Grade 2. No leaks were identified in this area during the 2014 survey. In both leak surveys, the technicians used a vehicle-mounted infrared optical gas-detection system and a hand-held RMLD. When necessary, technicians used a CGI to pinpoint leaks, often in combination with a bar hole test when the leak was suspected to be below surface.

In addition to the three leaks that were identified through Atmos's 2017 leak survey, two additional leaks reported by customers occurred in the year prior to the first incident. The leak at 3514 Espanola Drive was reported on September 17, 2017, classified as Grade 1, and repaired on the same day. The second leak at 3527 Durango Drive was reported on January 1, 2018. The customer complained about a gas smell at the meter. The responding Atmos technician found an above-ground leak on the service regulator and a Grade 2 below-ground leak near the service riser. The customer-owned natural gas line was also pressure tested and passed. Atmos replaced the service regulator on January 1, 2018, and the service line on January 29, 2018.

Between January 1, 2013, and February 22, 2018, in the 2-mile radius surrounding the explosion site, Atmos repaired 443 leaks, excluding leaks that occurred as a result of third-party damage, over about 155 miles of main (2.86 repaired leaks per mile of main). During the same time period, Atmos repaired 9,256 leaks in the City of Dallas, excluding leaks that occurred as a result of third-party damage, over about 3,245 miles of main (2.85 repaired leaks per mile of main).

1.9 Atmos Policies and Procedures

Atmos employed a variety of policies, procedures, specifications, and practices in the operation of its distribution systems. These included a requirement for continuous surveillance, as specified in 49 *CFR* 192.613. Atmos's Operations and Management (O&M) Manual stated that all employees are expected to visually monitor the company's facilities on an ongoing basis and report any concerns that are identified to their immediate supervisor. Atmos's O&M Manual stated that anytime a pipeline is found to be damaged or deteriorated to the point that a section of pipe becomes unsafe, immediate measures should be employed to determine the hazard, the extent of hazard, protect life, and protect property.

In addition, the Atmos O&M Manual described its damage prevention program, required under 49 *CFR* 192.614. The damage prevention program was designed to prevent damage to underground facilities caused by excavation and other construction activities. The program addressed notifying excavators and the public about the program, receiving location requests,

contacting excavators, and marking the pipeline. Furthermore, Atmos's Construction Procedures Manual described procedures for pipeline locating and marking.

The Atmos O&M Manual included additional requirements addressing gas leak surveys, emergency response plans, and gas distribution pipeline IM.

1.9.1 Gas Leak Surveys

At the time of the explosion, Atmos had been surveying the alley where the explosion occurred every 36 months.[47] The manual indicated that use of flame ionization equipment, optical methane detectors, RMLD, and other approved methods were acceptable.

The O&M Manual also required that: (1) all leakage surveys were to be conducted using calibrated leak detection equipment in accordance with the manufacturer's instructions; (2) indications of underground leakage would be confirmed by subsurface gas surveys using CGI; (3) all indications of natural gas leakage would be investigated and evaluated in an appropriate timeframe; and (4) leaks would be classified into one of three grade categories (Grade 1, Grade 2, or Grade 3).

The O&M Manual also provided guidance related to conducting leak surveys during wet weather conditions for regulatory compliance purposes. For example, the manual indicated that the survey technician may go to a known leak to validate if conditions were conducive for a quality surface gas detection survey. The O&M Manual further noted that if the survey technician believed environmental conditions were not favorable to perform a quality leak survey, then the survey should not be conducted. The O&M Manual also stated that "water-saturated soil may prevent the use of a CGI," but noted that the survey technician should visually inspect for the presence of gas, which could be observed by water bubbles or vapors when the use of survey equipment was not possible.

The O&M Manual indicated that a subsurface gas detection investigation should be used to determine the extent of a suspected leak. The subsurface survey included performing bar hole tests near the gas line, including over service tees, main line valves, and couplings. To pinpoint the leak and determine the migration pattern, the manual called for probe holes to be placed in all directions, including perimeters of structures, service lines, and mains, until readings of 0 percent gas are reached using a CGI. The manual stated if gas was detected, the survey technician should also use a CGI to bar hole test at the "service riser, tap, main(s) in all directions…water meter and both sides of the driveway along with the perimeter of the structure and the adjacent structures on the property…accessible sewer vents on and around the structure…storm sewer outlets…accessible storm drains, manholes, and sanitary sewer outlets in the area."

The user's manual for the Atmos Energy RMLD equipment described the instrument as being capable of detecting methane leaks from a remote distance because it used laser technology known as tunable diode laser absorption spectroscopy. The manual suggested that

[47] (a) As stated in section 1.8, the last known survey of the alley was performed on March 7, 2017. (b) RRC required Atmos to perform leak surveys at least every 3 calendar years, as discussed in section 1.10.2.

this made it possible to detect leaks along the sight line. The user's manual stated that the RMLD operated under a variety of environmental conditions including cold or hot weather and light rain. The RMLD System Specifications indicated a nominal detection distance of 100 feet, an operating temperature of 0° to 122°F, and humidity of 5-95 percent relative humidity, noncondensing. The user's manual further indicated that several conditions could occur that would cause the algorithm to give a detection indication, including overly strong returns due to strong reflectors, such as "water droplets."

In addition to the periodic leak surveys conducted in accordance with 49 *CFR* 192.723, Atmos also employed "special" leak surveys conducted in general accordance with its O&M manual. These special leak surveys were not intended for regulatory compliance purposes and were used as a tool for operational purposes such as supplementing leak investigations. Accordingly, Atmos permitted a special leak survey to be used under conditions (such as wet weather) that would not be chosen for a compliance leak survey.

1.9.2 Emergency Response Procedures

At the time of the explosion, Atmos had several procedures that addressed regulatory requirements promulgated in 49 *CFR* 192.605 and 192.615, including its emergency operating and fire response procedures.

Atmos's procedures for responding to gas emergencies were contained in its O&M Manual and directed responding employees to first determine the nature and extent of the hazard before taking necessary protective actions. The procedure also stated that if required, the gas system in the affected area of the emergency should be isolated or shut down by using system maps that identify the location of valves, regulator stations, and size of piping. The rest of the procedure listed reporting requirements for each of the states where Atmos had natural gas operations.

Atmos's fire response procedure was contained in its service procedure manual. The procedure was to be used by employees who were dispatched to the scene of a structural fire and called for the technician to first make the area safe for employees and the public. After assessing the situation, the technician had to complete a full leak investigation when access to premises was allowed and practical. The technician had to also notify the supervisor and/or Atmos dispatch of any fire deemed reportable.[48] The procedure specified that appropriate personnel should determine if further evidence collection and investigation was needed and followed applicable state and federal reporting procedures.

The company's leak investigation procedures were also contained in its service procedure manual. The procedures included provisions for investigating leaks that were reported to be inside or outside of a building.

For inside leak investigations, the preliminary investigation could include a visual observation for excess consumption on the meter, abnormal appearance of vegetation, odor of

[48] Reportable events met the criteria defined in 49 *CFR* Part 191.

natural gas, and any other sign that could indicate the presence of a natural gas leak. The procedure required technicians to turn off the meter prior to entering structure if a hazardous condition was observed. The technician then was to enter the structure and complete a customer piping test if access to the premises was allowable and practical. The procedure directed the technician to contact a supervisor if unusual circumstances were encountered. However, if the customer was not at home during the investigation, the meter was to be turned off and secured and an outside leak investigation was to be performed.

For outside leak investigations, the procedure called for the technician to conduct a leak search with approved leak detection equipment around the perimeter of the structure and any adjacent structures on the property, and bar hole test the riser. This procedure also advised that water-saturated soil could affect the accuracy of leak detection equipment. If surface conditions were not favorable, Atmos technicians were to follow its wet weather leak investigations procedure. The wet weather leak investigations procedure stated that service technicians should visually inspect and perform multiple bar hole tests as necessary, while looking for water bubbles and vapors to determine if gas is present. For outside leak investigations, the customer piping test procedure was also to be conducted if needed. If natural gas was detected but the source was unknown, the procedure called for a supervisor to be contacted.

1.9.3 Gas Distribution Pipeline Integrity Management Program

Atmos's Distribution Risk and Integrity Management Plan (IM Plan) provided procedures to implement its IM program and to comply with 49 *CFR* Part 192 Subpart P, Gas Distribution Pipeline Integrity Management and Title 16 *Texas Administrative Code* (TAC) 8.206, Risk Based Leak Survey Program.

The scope of Atmos's IM Plan included mains, service lines, and related facilities (such as service regulators or company-owned meters). Atmos developed a statistical risk-evaluation methodology for its distribution systems that was built through an iterative process based on leakage history. Atmos's risk model considered the following categories of threats to each gas distribution pipeline: corrosion, natural forces, excavation damage, other outside-force damage, material or welds, equipment failure, operations, and other concerns that could threaten the integrity of its pipeline. The natural-force damage threat considered whether ground movement could result in a leak for all pipe material types.

Atmos gathered information about its distribution infrastructure from existing records of design, construction, O&M activities, and subject matter expert (SME) input. They also collected data to support its IM Plan in conjunction with normal construction and O&M activities. Atmos noted in its IM Plan that information should be gathered to identify environmental factors that could increase the potential for leakage or cause leaking gas to migrate to an area where it could create a hazard.

Atmos used a commercially available software-based risk assessment tool to support its risk analysis. Segments of mains were risk-ranked every year based on a risk score that combined estimates of the likelihood and consequence of failure. Factors such as the number of leaks and coating condition were used to estimate the likelihood, while factors such as line pressure and population density were used to estimate the consequences of failure. The risk

model did not explicitly consider the age of the pipeline segments but grouped them into failure categories based on similar attributes, such as material and coating. At the time of the explosion, this risk assessment did not consider the risk contribution of service lines. Atmos considered the risk of service lines through a parallel internal modeling effort.

Atmos identified relative high-risk segments based on risk scores and SME identification. The segment of main in the alley behind the affected houses was not considered relative high risk or subject to accelerated action such as increased leak survey frequency or scheduled replacement. Similarly, Atmos told NTSB investigators there were no more relative high-risk segments in the evacuation area of about 300 homes or the about planned outage area of about 2,800 homes than in any other typical area.

1.10 Regulatory and Municipal Requirements

Federal pipeline safety statutes allow for states to assume safety authority over intrastate natural gas pipelines and hazardous liquid pipelines through certifications and agreements with PHMSA under Title 49 *United States Code* (*U.S.C.*) 60105 and 60106. To participate in PHMSA's pipeline safety and underground natural gas storage programs, states must adopt the minimum federal pipeline safety regulations; however, states may pass more stringent state regulations for intrastate pipeline safety through their state legislatures.

Through certification by PHMSA Office of Pipeline Safety, RRC inspects and enforces the pipeline safety regulations for intrastate gas distribution pipeline operators in Texas. The gas distribution system in the area around the explosion was subject to federal and state regulations promulgated by PHMSA and the RRC, as well as Atmos internal procedures. The Atmos-owned portion of the system, including the main and service lines which ended at the outlet of the service meter, was regulated by PHMSA and the RRC. All piping downstream of the outlet of the service meter was the responsibility of the customer.

1.10.1 PHMSA Regulatory Requirements

Federal pipeline safety regulations are found in 49 *CFR* Parts 190-199. PHMSA regulations in 49 *CFR* Part 191, requires an operator to provide immediate notice to the NRC following an incident if it meets any of the following criteria:[49]

- An event that involves a release of gas from a pipeline that results in one or more of the following consequences:
    - A death, or personal injury necessitating in-patient hospitalization;
    - Estimated property damage of $50,000 or more, including a loss to the operator and others, or both, but excluding the cost of gas lost; or

[49] Throughout this report, immediate notice and immediate reporting are used consistently with PHMSA regulatory requirements in 49 *CFR* 191.5(a), which states that notice should be provided at the earliest practicable moment following discovery, but no later than 1 hour after confirmed discovery.

  - Unintentional estimated gas loss of three million cubic feet or more.

- An event that is significant in the judgment of the operator.

If such an event occurs, the operator is also required to submit a PHMSA Incident Report as soon as practicable but not more than 30 days after detecting the incident. Supplemental reports are required if additional information is obtained after the report is submitted.

The following PHMSA requirements in 49 *CFR* Part 192 are relevant to this investigation:

- Title 49 *CFR* 192.605, *Procedural Manual for Operations, Maintenance, and Emergencies*, requires, in part, that each operator has a manual of written procedures for operations, maintenance, and emergency response. Under section 192.605(e), gas operators are required to establish procedures for surveillance, emergency response, and accident investigation.

- Title 49 *CFR* 192.613, *Continuing Surveillance*, requires, in part, that each operator have a procedure for continuing surveillance of its facilities to determine and take appropriate action concerning changes in class location, failures, leakage history, corrosion, substantial changes in cathodic protection requirements, and other unusual operating and maintenance conditions.

- Title 49 *CFR* 192.615, *Emergency Plans*, which requires that each natural gas operator have "established written procedures to minimize the hazard resulting from a gas pipeline emergency." At a minimum, the procedures must address notification, identification and classification of events that require immediate response by the operator, as well as adequate means of communication between local emergency response authorities.

- Title 49 *CFR* 192.617, *Investigation of Failures*, which requires that each operator establish procedures for analyzing accidents and failures for the purpose of determining the causes of the failure to be able to "minimize the possibility of a recurrence."

- Title 49 *CFR* 192.723, *Distribution systems: Leakage surveys*, requires each operator to conduct periodic leakage surveys with leak detector equipment as frequently as necessary, but at least once every 5 calendar years at intervals not exceeding 63 months.

- Title 49 *CFR* Part 192 Subpart P, *Gas Distribution Pipeline Integrity Management* (IM), prescribes minimum requirements for an IM program. The required elements of an IM plan: knowledge; identify threats; evaluate and rank risk; identify and implement measures to address risks; measure performance, monitor results, and evaluate effectiveness; periodic evaluation and improvement; report results.

1.10.2 RRC Regulatory Requirements

The RRC requirements for intrastate gas distribution systems are codified in TAC Title 16, "Economic Regulation," Part 1, "Railroad Commission of Texas," Chapters 8, "Pipeline Safety Regulations" (16 TAC Chapter 8). RRC requirements adopt 49 *CFR* Parts 191 and 192 by reference.

RRC imposes additional requirements for intrastate gas distribution operators working in the State of Texas. Some of these more restrictive requirements are applicable to the gas distribution system in the area where the explosion occurred, including:

- Title 16 *TAC* 8.206, "Risk-Based Leak Survey Program," which requires, in part, that each operator has either a prescriptive or risk-based program for leak surveys. At the time of the accident, the piping in the area around the accident was leak surveyed under Atmos's prescriptive program. The prescriptive program requires the operator conduct leak surveys no less frequently than every 3 calendar years at intervals not exceeding 39 months for the natural gas distribution system in the Walnut Hills neighborhood.

- Title 16 *TAC* 8.210, "Reports" which require a telephonic report at the earliest practical moment for any even that meets the definition of an incident in 49 *CFR* 191.3.

1.10.3 DFR Procedures and Training

DFR has several standard operating procedures (SOP), including one for responding to structure fires and one for responding to natural gas leaks. The structure fire SOP calls for the first truck to "control utilities" as one of its tactical considerations but does not require natural gas monitoring.

In contrast, the natural gas leak SOP calls for firefighters to monitor for gas. If gas is detected at 10 percent by volume of the lower explosive limit (LEL), firefighters are to evacuate the structure, shut off the gas at the meter, open doors and windows to ventilate the structure, continue to monitor for gas until the hazard no longer exists, and request the gas operator to respond, "if needed."[50] This SOP called for every fire engine to carry a two-gas monitor to test the atmosphere for carbon monoxide and natural gas. DFR reported having two-gas monitors on the fire engines; however, they indicated to NTSB investigators that they were not available during the response to the February 21-23 incidents because they were in the process of upgrading their gas detection technology.

DFR firefighters are trained to detect the presence of natural gas using combustible gas indicators. All DFR firefighters are trained to operations level in accordance with Occupational Safety and Health Administration (OSHA) Hazardous Waste Operations and Emergency Response (HAZWOPER) standard 29 *CFR* 1910.120, which is defined in the regulation as a

[50] The lower explosive limit was 5 percent natural gas in air by volume.

response in "a defensive fashion without actually trying to stop the release." DFR firefighters are also trained in the core competencies of NFPA 472, Operations Level.

In addition, the DFR has a Hazardous Material Response Team (HMRT) to respond to hazardous material incidents. The HMRT uses combustible gas indicators and photoionization detectors for identifying flammable atmospheres. However, the natural gas leak SOP only requires the HMRT to respond if requested by the IC. The DFR ICs for the February 21-23 incidents did not request HMRT support. On February 23, 2018, after learning of the second and third incidents, the hazmat coordinator dispatched himself to assist in the incident response.

DFR HMRT has a continuing education training requirement of 20 hours per year. The DFR hazmat coordinator told NTSB investigators the HMRT attended training with Atmos periodically but not every year. The DFR hazmat coordinator last attended training with Atmos the month before the incident in January 2018. The DFR firefighters that were not part of the HMRT, as well as one arson investigator, told NTSB investigators they never had any prior training with Atmos on natural gas emergencies.

In Texas, arson investigators must be certified by completing a Texas Commission of Fire Protection (TCFP)-approved class and examination and maintain certification by completing 20 hours of continuing education each year. All arson investigators involved in the first two incidents and explosion were certified and had completed on-the-job training.

DFR told NTSB that natural gas concerns found during a fire incident would be forwarded to the City of Dallas Building Inspection Division. However, this practice was not documented in any DFR SOP. The fire investigation reports from February 21 through February 23 were not sent to any other DFR division or City of Dallas municipal department.

1.11 Actions After the Explosion

1.11.1 Regulatory Actions After the Explosion

Following the explosion, the RRC amended its regulations as described below:[51]

- *TAC* 8.209(h) was revised to require operators to replace 8 percent of its highest risk pipe identified in its IM plan annually. It previously required operators to replace 5 percent of its highest risk pipe annually.

- *TAC* 8.210(f) was added, requiring the RRC to retain state records regarding a pipeline incident in perpetuity.

- *TAC* 8.210(a)(1) was revised to require telephonic incident reporting no later than 1 hour following confirmed discovery.

[51] Title 39 *Texas Administrative Code* Parts 209 and 210.

- *TAC* 8.210(a)(2) was added, specifying information that must be provided following an incident when the information is known by the operator.

On March 27, 2018, the RRC began an evaluation of Atmos concerning the explosion. The RRC noted the following items during its evaluation:

- Atmos procedures and information from the manufacturer stated the RMLD equipment was not to be used in sustained wind or wind gusts above 15 mph. The RMLD was not capable of registering a reading above those wind speeds due to inadequate gas plume to measure.

- Atmos procedures and information from the manufacturer stated the RMLD equipment was not to be used in wet conditions. Water present in the area can refract the laser signal and cause the RMLD to not work.

- Atmos procedures stated that when needing to bar hole to find underground leaks that the bar holes should be placed as close as practicable to the main.

- Atmos personnel stated that with a few exceptions all leak survey technicians used the RMLD during leak surveys.

- Atmos did not provide a method or tool to measure wind speeds for the last scheduled leak survey in the area of the failed section on March 7, 2017. Local weather conditions of that day gathered at the nearby Love Field airport showed wind gusts exceeding 15 mph.

- Leak surveys using the RMLD conducted on February 22, 2018, in the alleyway of Espanola and Durango were conducted in wet conditions.

- The main in the alleyway of Espanola and Durango had a depth of 4 feet. All bar holes made for gas leak testing did not reach the depth of the main.

1.11.2 Atmos Actions After the Explosion

Following the explosion, the Atmos Vice President of Pipeline Safety told NTSB investigators that it has initiated or completed several initiatives across ten categories, including:

- **Damage prevention.** Atmos audited more of its third-party line locating services to determine what actions could be taken to further reduce the risk of third-party excavation damage. The company modified its "Watch and Care" program to require additional follow-up communication with excavators who have called in a line locate ticket. It also began marking the location of newly installed pipe and associated facilities to bring immediate visibility to its location while facilities map records are updated. It established new reporting metrics to better evaluate the performance of its damage prevention program. The company implemented a Damage Prevention Ambassador Program that encouraged employees to proactively visit excavation sites to provide damage prevention materials to excavators and ensure proper 811

notification. The company is working to develop the LocusView mobile app system by the end of 2020, which will allow distribution pipeline construction crews to transmit detailed data on new installations to the Atmos geographic information management systems. To date, over 700 construction crews (internal and contractors) are using LocusView. The company has also developed safety mascots and ambassadors Gus the Gopher and Rosie the Skunk to engage customers and the public in remembering to call 811 before digging and using the five senses to detect natural gas.

- **Pipeline Safety Management Systems (PSMS).** After the explosion, Atmos accelerated the implementation of PSMS by updating its initial self-assessment and engaging its industry third-party expert to perform an enterprise-wide PSMS assessment and gap analysis. It added a director-level resource to support its accelerated PSMS implementation effort.

- **Procedures.** Atmos updated its leak survey and leak investigation procedures to include mandatory 911 notification and the establishment of a safety perimeter when a hazardous condition is discovered.

- **Training.** To enhance its training curriculum, Atmos developed online leak survey refresher training for all employees possessing leak survey operator qualifications (OQ). In 2019, it also developed a 1-week leak survey refresher training class for all employees whose primary job responsibilities included leak surveying. The training consisted of classroom instruction, a review of procedures, hands-on training by equipment vendors, discussion of weather-related conditions, and industry case studies. Additionally, every operations supervisor has completed a new 1-week hands-on Operations Supervisor Boot Camp course to gain a better understanding of processes and equipment.

- **Leak survey.** To enhance its leak survey program, Atmos created a dedicated work group within the division that included the area surrounding the explosion and incident sites to support and monitor leak survey activity. Supplemented by third-party resources, Atmos closely monitored its system in the Dallas-Fort Worth area through more frequent leak surveys than required by state and federal regulations. The company purchased mobile leak detection units equipped with advanced sensors for its Texas operations, with additional units to be purchased over time.

- **Risk factors.** To better address geological and climatological threats, Atmos included geological risk factors in its 2019 risk analysis for the division that included the explosion and incident sites. It also initiated a review of geological and climatological threats across all states where the company operates.

- **Research and development.** Atmos participated in collaborative efforts through its partnership with the Gas Technology Institute to develop residential methane detectors, leak survey sensors and technology, and damage prevention tools and practices.

- **System modernization.** Atmos has committed to replacing about 5,000 to 6,000 miles of distribution and transmission pipe in the next 5 years and replacing all remaining cast-iron pipe by the end of 2021.

- **Quality management.** Atmos deployed an electronic inspection application to its internal and third-party inspectors to enhance consistency in inspection and quality management processes. It implemented an automated interface between its OQ program and its work management system.

- **Data analysis.** Atmos implemented advanced data analytics tools that provide faster and more precise results than manual processes. It implemented visualization technology tools that can provide near real-time graphical representation of data to assist operations and compliance leaders in its decision making.

1.11.3 DFR Actions After the Explosion

Following the explosion, DFR reported that it has made or plans to make a number of improvements in communication, response procedures, equipment, and training. A summary of these initiatives includes:

- **Increased communication between DFR and Atmos.** Recent meetings have focused on building relationships, as well as the discussion and review of on-scene operating procedures. Atmos has provided training sessions, allowing DFR to learn at its facilities and from its personnel about gas-related emergencies. Although the implication is that this will be an ongoing initiative, DFR did not provide additional information regarding the effort moving forward.

- **Response policies and procedural changes.** Based on a caller's description of a gas emergency, DFR dispatchers previously only had two incident types to choose from. DFR expanded incident type coding to ensure dispatchers can correctly code gas-related incidents to provide a better representation of what responders can expect to find once they arrive at a scene.

- **Updated SOPs.** DFR updated its policies to include acceptable and expected response actions during gas leak responses. New and notable action descriptions were included, such as: "Standby for Suppression," "Evacuation Assessment and Assistance," "Traffic Management," "Utility Control," and "Air Monitoring." Finally, a policy still in review includes a step-by-step notification process to ensure that DFR communicates with the responsible agencies when an emergency is believed to have occurred because of a gas leak.

- **First responder hazardous materials training and equipment.** With the assistance of Atmos, DFR added new four-gas monitors for distribution to all battalion chief vehicles so that DFR's initial responders on-scene to gas leaks can use the same monitors for gas detection as its HMRT and Atmos technicians. DFR has also issued new single-gas detectors to all engine and truck companies, which are more reliable and simpler to use and calibrate than previous models.

- **Additional hazardous materials training.** DFR developed a curriculum plan that includes a combination of computer-based training and in-person classes delivered by the HMRT. The curriculum has a section dedicated to training dispatchers and giving them a plan to follow based on the responses of the caller to create the most effective initial response with the flexibility to increase the response as needed.

- **Enhanced policies, procedures, and training in the areas of technical review and explosion dynamics training.** Since these incidents, the arson division has implemented the practice of routine after-action technical reviews, that include a constructive critique of the written reports and performance of all fire investigators who were involved with an incident. A strong focus is placed on examining an investigator's reasoning and conclusions and ensuring that they are supported by the evidence obtained on scene through a thorough, compliant investigation.

- **Enhanced arson division training.** DFR plans for investigators to improve their abilities to respond to explosions that originate from utility lines and residential or commercial appliances by requiring training certified by the International Association of Arson Investigators.

2. Analysis

2.1 Introduction

This accident occurred when a natural gas-fueled explosion at 3534 Espanola Drive, Dallas, Texas, injured all five occupants, one fatally, and caused significant structural damage to the residence. In the 2 days before this explosion, two gas-related incidents occurred at houses on the same block that were served by the same natural gas main, each resulting in one injury involving second-degree burns and significant structural damage to the affected residences.

This analysis discusses the explosion and following safety issues:

- Condition of the natural gas main at the time of the explosion. (See section 2.2.)
- Inadequate investigation of the two incidents that preceded the explosion limited responding personnel's ability to ensure safety. (See sections 2.3 and 2.4.)
- Response to the first two incidents focused on expanding leak investigations and repairs instead of securing the safety of the area. (See section 2.5.)
- Residents were not alerted to the presence of natural gas in their homes prior to explosive concentrations accumulating. (See section 2.6.)
- The first two incidents were not reported through official channels in a timely manner, inhibiting participation by appropriate local, state, and federal entities. (See section 2.6.1 and 2.6.2.)
- Atmos's integrity management program did not require preventative action prior to widespread performance degradation. (See section 2.7.)

Having completed a comprehensive review of the circumstances that led to the explosion, the investigation established that the following factors did not contribute to its cause:

- **Ongoing maintenance activities.** Following the incident at the second house, 3515 Durango Drive, Atmos recognized the need for significant resources and sent them to the neighborhood in a timely manner. Immediately prior to the explosion, Atmos was repairing its gas distribution system in the neighborhood where the explosion occurred. The investigation found no evidence that the ongoing maintenance activities and repairs that were completed prior to the explosion negatively impacted the system.
- **Overpressurization of the gas distribution system.** NTSB investigators reviewed the operating pressure data for the natural gas main for the period between 2016 through the time of the explosion in 2018; all pressure measurements reviewed were below the MAOP (55 psig). The service regulators for the three affected homes were

tested by an independent laboratory following the explosion and determined to be functioning properly within an acceptable tolerance.

- **Materials used for the construction of the gas main and external coating.** The gas main was constructed from steel that met the chemical composition and tensile properties specified by API 5L Standard at the time of construction in 1945. The main was covered with a coal tar enamel wrap that typically was used for protecting a steel main.

- **Natural gas composition.** Atmos tested the natural gas composition for the 6 months prior to the explosion through periodic gas sample analysis, which was confirmed to be within its acceptance threshold.

Thus, the NTSB concludes that none of the following were factors in the explosion: (1) ongoing maintenance activities; (2) overpressurization of the gas distribution system; (3) materials used for the construction of the gas main and external coating; and (4) natural gas composition.

2.2 Condition of the Natural Gas Main

The 2-inch diameter steel natural gas main had been in service for about 71 years at the time of the explosion. There were 25 service lines that connected the natural gas main to the residences on this block. After the explosion, the main and service lines were pressure tested to 25 psig, revealing three leaks, two on service line tees and one on the main itself. Excavations were completed to expose and evaluate all three leaks. The leaking portion of the natural gas main and one service tee were sent to the NTSB Materials Laboratory in Washington, DC, for examination.

A sanitary sewer main that also served the three houses was located just north of the natural gas main in the unpaved alley. The sanitary sewer main and laterals were originally installed in the 1940s and replaced by City of Dallas contractors in 1995. The drawings that were used during the 1995 sanitary sewer replacement project included the location of the natural gas main and a caution to contact Lone Star Gas Company (since acquired by Atmos) 48 hours prior to construction at the telephone number provided. Based on the construction drawings, it is likely that the excavation crew was aware of the relative proximity of the natural gas main to the construction activities and the potential hazard presented if the natural gas main was damaged. Nonetheless, the leak in the natural gas main was found about 0.5-inches below one of the sanitary sewer laterals.

Evaluation of the leaking portion of the natural gas main revealed that the top surface was dented, and the external protective coating was missing in the dented region. This portion of the main was covered in calcareous deposits. Denting and gouging damage on the top side of a pipeline typically occurs when personnel operating construction equipment dig above a buried pipe. The size of the gouge marks found on the top side of the gas main are consistent with gouges made by construction equipment, such as a tooth, located in front of the bucket portion of a backhoe. Although safe excavation practices typically require methods necessary to prevent damage to underground natural gas pipelines such as hand digging, impact stresses caused by a

handheld shovel would not have been severe enough to cause the gouging and dent damage that was found on the natural gas main. The exact date of the original sewer construction, around 1946, was not determined. As a result, information was not available to indicate if the construction of the natural gas and sanitary sewer systems was coordinated. Therefore, the NTSB concludes that the natural gas main was damaged by mechanical excavation equipment, likely when the sanitary sewer lateral was replaced in 1995.

In the time since this natural gas main was damaged, the NTSB published the safety study *Protecting Public Safety Through Excavation Damage Prevention* (NTSB 1997). This safety study discussed the prevalence of third-party damage and the significant risk it presents to public safety. In this study, the NTSB highlighted the importance of people who are excavating fully understanding the one-call notification process, including requirement for hand digging near underground facilities.[52] Additionally, pipeline industry stakeholders have increased their focus on third-party damage prevention, largely through participation in the Common Ground Alliance (CGA) initiatives.[53]

A crack extended from the bottom of the dent through the wall thickness progressing circumferentially to the approximate axial centerline of the pipe. Ratchet marks on the fracture surface indicated that the fracture initiated from multiple origins on the outer surface of the main at the bottom of the dent. The fracture surface exhibited corrosion product deposits and revealed two thumbnail-type cracks from the outer surface of the pipe at the dent bottom into the pipe wall. The thumbnail cracks were darker in color, consistent with preexisting oxidation deposits. The remaining portion of the fracture surface exhibited a lighter orange-brown corrosion deposit, consistent with deposit products that formed at a later point. SEM examination after removal of the corrosion deposits revealed that the fracture progressed in transcrystalline cleavage, consistent with a Mode I fracture beginning at the origin and propagating circumferentially though the pipe wall, arresting at about the pipe centerline.[54]

The circumferential orientation of the crack is consistent with an externally applied bending force on the pipe such that the pipe surface within the dent was in tension. The darker-colored thumbnail cracks were the first to occur. Later, the remaining portion of the fracture progressed from the thumbnail cracks. The cleavage fracture morphology, the tension bending stress at the bottom of the pipe dent, and the presence of adequate dissolved hydrogen in the steel (6 ppm of hydrogen was measured) is consistent with hydrogen-induced cracking. Since the pipe was cathodically protected and the external spiral-wrapped coal tar coating was missing

[52] One-call systems allow the public to make a single telephone call (or online request) a few days prior to digging to notify all affected utility operators with just one communication. Since 2007, the nationwide call-before-you-dig telephone number has been 811.

[53] CGA was established in 2000 with a mission of preventing damage to underground utility infrastructure and protecting those who live and work near these assets. CGA launched the Damage Information Reporting Tool (DIRT) in 2003 to provide a database of voluntarily submitted data about underground damage and near-miss reports. CGA publishes Best Practices: The Definitive Guide for Underground Safety and Damage Position and DIRT Analysis and Recommendations annually. There are over 200 CGA member organizations, including Atmos.

[54] As defined in fracture mechanics, *Mode I* refers to an opening mode where the crack surfaces separate in tension as the crack propagates.

in the dented region, the dented region could charge with hydrogen, embrittling the steel over time.[55]

The internal surface of the pipe adjacent to the crack exhibited moderate corrosion product scale, consistent with moisture intrusion over time. The surface of the crack also contained evidence of calcareous deposit buildup. Hence, the circumferential crack was present for an extended period rather than occurring immediately preceding the time of the explosion, preceding the fires that occurred in the other two neighborhood homes.

Based on the observations, the circumferential crack initiated at the bottom of the dent forming two thumbnail cracks which arrested. At a later point, the balance of the circumferential crack propagated from the thumbnail cracks, driven by a hydrogen-induced cracking mechanism. The crack most likely formed before the calcareous deposit developed. However, given the above observations, it is not possible to further define the exact timeline of the crack formation process. Therefore, the NTSB concludes that a circumferential crack in the main propagated through the pipe wall prior to the first incident, allowing natural gas to leak into the surrounding environment for an extended period.

Soil has a tendency to absorb and deplete odorant from natural gas as has been identified in several NTSB investigations. (See section 2.5.) While testing after the explosion confirmed the presence of adequate levels of odorant, observations by residents, employees working near the explosion location, and NTSB investigators indicated that the natural gas odorant had been depleted after the natural gas leaked from the cracked main.

Atmos took gas measurements after the explosion on February 23, 2018, that indicated the presence of gas along a path between the alley and the residence involved in the explosion. NTSB investigators later confirmed the presence of gas along a path between the cracked main and the residence, obtaining readings as high as 43 percent by volume of natural gas in air over the sewer main 12 days after natural gas had been isolated in this area in response to the fatal explosion.[56] (See figure 9.)

Natural gas generally vents to the atmosphere when unconstrained because its density is less than that of air. However, environmental factors such as significant amounts or extended periods of rainfall can cause leaking gas to migrate to an area where it could create a hazard. Industry guidance from the American National Standards Institute (ANSI) and the Gas Piping Technology Committee (GPTC) recognizes that, "A high water table, tidal effects, or excessive moisture from rain may inhibit venting of the gas to atmosphere" (ANSI/GPTC 2018). Soil gas permeability decreases with an increase in soil moisture because there is less void volume available. Thus, gas can accumulate and migrate because of the low permeability layers. By contrast, gas travels more easily through granular materials, such as gravel and crushed rock as there is higher interconnected void volume. This phenomenon was observed in the NTSB

[55] In steel pipe protected by cathodic protection, an electrochemical reaction can occur at the exposed gouge area of the pipe that results in evolution of hydrogen. The hydrogen can be absorbed by the metal and can embrittle the wall of the pipe.

[56] The explosive range for methane is 5-15 percent by volume in air; 43 percent by volume is above the upper explosive limit.

investigation of an explosion and fire that occurred in Bowie, Maryland, on June 23, 1973 (NTSB 1974).[57] Under dry conditions, gas from an active leak may find a path to vent from the ground and disperse in the atmosphere without accumulating to explosive concentrations. Gas vented in this manner would not fuel an explosion or fire. However, when the pathway to the surface becomes obstructed (less permeable), lateral gas migration increases. Extensive rain prior to the explosion resulted in the soil in the explosion area becoming saturated with water. Wet ground conditions inhibited venting of natural gas from the cracked main to the atmosphere.

The sewer main and laterals had been installed with an embedment of crushed stone and granular material that extended from the cracked main, to the property line of each house along this alley. At the 3534 Espanola Drive property line, the sewer lateral connected to the customer-owned sanitary sewer, which provided a potential path for gas to migrate to the home. The customer-owned portion of the sewer system and the customer-owned gas line, both of which traversed the property underground from the alley to the home, had been replaced during a remodeling project in 2017. The process of excavation disturbs and loosens soil, generally resulting in newly placed soil and backfill being more porous than native soil. Thus, there were two potential gas migration paths that extended from the crack to the residence: (1) along the embedment of the sanitary sewer main, laterals, and customer piping; and (2) along the natural gas main, service line, and customer piping. While natural gas could have migrated along a portion of each or both of these paths, several measurements after the explosion indicated the presence of gas over the sanitary sewer main.

NTSB investigators pressurized the cracked main in the Materials Laboratory after it was excavated and calculated the leak rate based on observed and extrapolated data. The leak rate for natural gas was between 8 and 14 CFM at the operational pressure range of the system in the days prior to the accident (17–45 psig). The actual leak rate may have differed from that measured in the laboratory due to constraints from the surrounding soil and the actual bending load acting on the pipe. In laboratory tests, the flow rate at 55 psig from the cracked main was over 50 times that of the 3524 Espanola Drive service tee, suggesting that the cracked main was the dominant source of natural gas in the alley behind the house where the explosion occurred.

Once gas reached the foundation of the home, gas intrusion could have been driven by several factors, including: the relatively dry and more permeable soils in the crawlspace, the tendency for natural gas to rise in air, temperature differentials, wind loading, and pressure gradients. As pressure differentials develop, gas can migrate both vertically and laterally and be drawn up to the soil surface or into a building's interior space. While the actual path of gas migration into the interior of the home could not be determined after the explosion, the positive gas readings near the foundation of the home and the resulting explosion demonstrate that natural gas did enter the home and accumulate to explosive concentrations.

In summary, the observations made by investigators during excavations and testing after the explosion indicate that gas leaked from a crack in Atmos-owned piping and was depleted of

[57] In the Bowie, Maryland, investigation, the NTSB indicated that gas flowed from the leak and accumulated in the porous sand and gravel which was covered by less permeable "clayey" materials which sealed off trapped gas when they became wet and relatively impermeable due to heavy rains in the 2 days before the accident.

odorant as it propagated through the soil. This is the likely source of the gas that was discovered in the soil in the backyard of the residence. Gas then accumulated in the house until it exceeded the lower explosive limit and was ignited by an unknown source. The NTSB concludes that soil absorbed and depleted the natural gas odorant, eliminating the opportunity for occupants to detect it. In addition, the NTSB concludes that natural gas leaking from Atmos's cracked gas main in the alley behind 3534 Espanola Drive migrated through the soil and into the house where it was ignited by an unknown source.

2.3 Investigation of the Two Incidents that Preceded the Explosion

Atmos and DFR investigated each of the two gas-related incidents that occurred in the days prior to the fatal explosion. Neither the DFR arson investigators nor Atmos identified the causes of these incidents.

2.3.1 DFR's Investigation of the First Two Incidents

While DFR's initial response to the first two incidents was consistent with industry and National Fire Protection Association (NFPA) guidelines, it did not take steps necessary to locate the fuel source following either incident as recommended (NFPA 2020). Pinpointing the location of a natural gas leak requires the expertise of a specialist who is trained in this area, such as a gas operator's service technician. Industry guidance states that "investigation of building fuel gas incidents can be an extremely complicated, technical, scientific, and potentially dangerous task requiring specialized knowledge, training, and experience" (NFPA 2020a).[58]

In each of the first two incidents, DFR arson investigators were dispatched to the scene to investigate the origin and cause. The fire investigation reports for those incidents both concluded that the fire originated from or around a gas-fueled appliance. The arson investigators made those conclusions based on physical evidence as well as occupant and responding firefighter testimony.

The DFR arson investigators responsible for investigating the first incident at 3527 Durango Drive initially concluded that the fire originated near a gas heater when it exploded, causing major damage to the back of the house Arson investigators verbally conveyed this determination to the Atmos technician, indicating that the cause was most probably an interior gas leak. This information likely influenced the Atmos technician's investigation because the Atmos technician relied on the DFR investigator's assessment and did not gather enough information to complete an independent assessment. Consequently, the technician was only present at the scene for about 30 minutes and left after conducting a single bar hole test to look for an indication of subsurface gas. The fire investigation report referred to a gas heater in the restroom in the back of the house, in an addition that had been constructed around 2013. However, NTSB found no evidence that a gas heater was present in the addition of the home at the time of the explosion. Based on their interview of the homeowner following the explosion on

[58] *Fuel gas* is any one of a number of fuels that under ordinary conditions are gaseous. Although natural gas is a common fuel gas, it is not the only one.

March 2, the arson investigators concluded that the origin of the first incident was the HVAC unit located in the attic of the home, not a gas heater in the addition.

The DFR arson investigators responding to the second incident at 3515 Durango Drive concluded that the fire originated in the kitchen near the range. When arson investigators learned that both the homeowner and a neighbor had experienced unusual flames from their ranges, and another gas-related incident occurred the previous day at nearby 3527 Durango Drive, they could have considered the possibility that there was an issue with the gas distribution system. NFPA 921 states that "once it has been determined that a fuel gas system has influenced the way a building has burned, either as a fuel source, as an ignition source, as both a fuel and ignition source, or by providing additional fire spread, the gas system should be analyzed. This analysis should provide information as to the manner of and extent to which the fuel gas system may have been involved in the origin or cause of the fire or explosion" (NFPA 2020a). However, the DFR arson investigators did not consider warning signs of a larger issue with the gas distribution system.

The DFR arson investigator's initial misclassification of the first incident and not considering potential issues with gas distribution system as a potential cause prompted the NTSB to evaluate the arson investigator's training and qualifications. Qualifications to become an arson investigator require, among other things, a fire investigator certification. Specifically, for natural gas, the TCFP curriculum lists building fuel gas systems as a covered subject and requires the investigator-in-training to identify common fuel gas system components and other common appliances. The investigator-in-training must also be able to explain fuel gas system leakage, pressure testing, flow rate and pressure, and underground migration. The curriculum appears to provide a good foundation in fire investigation topics and principles, including the relevant aspects of natural gas hazards in building fuel gas systems which an investigator will likely come across since natural gas is a common fuel used in residential, commercial, and industrial buildings.

Nevertheless, this topic was only covered in the initial certification. The continuing education requirement for arson investigators did not include building fuel gas systems. Moreover, the arson investigators had never received gas systems training from Atmos.

Regular training and awareness of the local natural gas systems is important to understanding how to investigate fire or explosion incidents involving natural gas and ultimately prevent the occurrence of future accidents. The Transportation Research Board published Hazardous Materials Cooperative Research Program (HMCRP) *Report 14: Guide for Communicating Emergency Response Information for Natural Gas and Hazardous Liquids Pipelines*, which provides guidance to improve collaboration between local emergency responders and pipeline operators when responding to pipeline incidents. The report notes that:

> Although pipeline operators maintain sophisticated systems for monitoring pipeline flows and pressures and detecting leaks, incident experience suggests that small leaks may not be initially detected through these control systems. Even in cases of significant releases, direct observation by the public, pipeline personnel or contractors, and public emergency responders accounts for well over one-half

> of all first reports of releases…The timely ability to identify a pipeline emergency is the most important step in the incident management process (TRB 2014).

The HMCRP report also notes that pipeline emergencies can be inherently complex events that extend beyond the response phase of an incident. The report recommends, among other things, that emergency responders learn about pipelines in their service area and pipeline operators learn about local emergency response. While arson investigators are not the initial emergency responders on scene, they play a key role when responding to gas-related fire or explosion incidents by assisting the pipeline operator in locating gas leaks by communicating important information about the circumstances of the incident.

DFR arson investigators discovered key information, as discussed above and in sections 1.4.1 and 1.4.2, about the circumstances of the first two incidents that could have assisted the service technicians in determining if a leak was occurring from Atmos's pipeline. The NTSB concludes that DFR's initial misclassification of the first incident delayed the sharing of information that could have helped Atmos identify the origin of the leak. The NTSB concludes that had the DFR arson investigators been adequately trained on natural gas systems, their investigation findings may have provided more timely and accurate assistance to Atmos in locating the source of the gas leak. Therefore, the NTSB recommends that Atmos provide initial and recurrent training to DFR arson investigators and firefighters on the local natural gas distribution system and associated hazards. Additionally, the NTSB recommends that DFR revise the continuing education requirements for its arson investigators to include training on building fuel gas systems.

2.3.2 Atmos's Investigation of the First Two Incidents

Atmos procedures direct their employees responding to the scene of a structural fire to perform a full leak investigation—including an inside and outside leak investigation—and then determine the need for further investigation.

2.3.2.1 Inside Leak Investigation

The Atmos technicians responding to each incident did not pressure test the customer piping because of the presence of firefighters. Consistent with Atmos expectations, the responding technicians did not wait until the firefighters departed to access and test the customer piping, nor did they indicate plans to return to the residences. Thus, Atmos did not obtain testing data about the performance of the customer piping and appliances that would have been critical for determining the sources of the gas leaks.

Though the copresence of gas distribution company employees and firefighters at gas-related fire and explosion scenes is expected, Atmos procedures do not direct technicians to wait to perform the customer piping pressure testing or return once the building is accessible. However, if a customer reports an inside leak that does not involve a fire or explosion, the premises would generally be accessible, and the technicians would test the customer piping and appliances. This strategy is not commensurate with the potential safety significance because gas-related fires and explosions can present a significant safety hazard or precede a more significant accident. Technicians should respond to fires and explosions that may be gas-related

with at least as much rigor as a reported inside leak. It is critical that technicians conduct pressure testing when the cause of an incident cannot otherwise be determined.

If the customer piping is damaged, it may not be possible to test some or all of it. However, the absence of valid data should not bias technicians toward the assumption that the critical system failure occurred on the customer's side of the piping system. Rather, the only implication of a shortage of critical information is that more data is needed.

In addition, Atmos's inside leak investigation procedures do not incorporate GPTC recommendations that call for sampling the atmosphere of the crawlspace for the presence of combustible gases (ANSI/GPTC 2018).

In situations such as the incidents at 3515 and 3527 Durango Drive where the responding technicians were unable to determine what led to the fires/explosion, it may be necessary after firefighters have departed to dispatch a technician to return to a property. The technician would then test the customer piping or perform additional evaluations to conclusively determine the cause of a gas-related incident. Though it is not always possible to identify the exact cause of gas-related accidents, more rigorous investigation processes would lead to a higher success rate. The NTSB concludes that timely pressure testing of the customer piping by Atmos could have eliminated potential sources of the gas leaks and helped focus their efforts on outside leak detection to locate the damaged and leaking gas system piping more quickly. Therefore, the NTSB recommends that Atmos develop and implement more rigorous inside leak investigation requirements in response to fires and explosions when gas involvement cannot be excluded, including clear guidance on pressure testing and inside gas measurements, and the potential need to return to the property after firefighters have departed.

2.3.2.2 Outside Leak Investigation

The Atmos service technician said that he did not make multiple bar holes to test for subsurface gas leaks in response to the February 21, 2018, incident at 3527 Durango Drive because of the wet weather. This conflicted with Atmos's procedures which called for performing multiple bar hole tests when water-saturated soil may affect the accuracy of leak detection equipment. Atmos's procedures do not describe where such additional bar holes are to be made when the area of interest cannot be tested (such as because of standing water), nor do the procedures describe how such efforts would yield usable data. The service technician had years of experience, and there is no evidence to contradict his assertion that additional bar hole testing was not possible in the water-saturated soil that was present during his exterior leak investigation.

With the techniques employed under such conditions, subsurface gas migration could have gone undetected. This, combined with the absence of any pressure-testing data, resulted in the service technician not having enough data to determine whether a failure on Atmos's system or the customer's piping and appliances fueled the explosion.

During the Atmos response to the second incident on February 22, 2018, at 3515 Durango Drive, service technicians could not use their typical procedures at several locations on the property to conduct bar hole testing. At some of these locations, the service

technicians were able to employ a modified procedure by testing for gas above (instead of within) the bar hole. At other locations, bar hole testing was not possible because of puddled water; instead, the responding technician tested for gas above the water. Gas generally disperses more quickly in these open atmospheres compared to dry bar holes. However, the presence of water makes it more difficult to obtain valid data.

The same environmental factors that impede bar hole testing can also cause gas to migrate to an area where it could create a hazard and inhibit venting of the gas to atmosphere. If the gas is migrating underground and not venting, the CGI probe may correctly indicate that there is no gas at the measurement location, while gas continues to migrate laterally. Wet weather conditions inhibited Atmos's ability to determine the cause of the first two incidents and also affected the expanded leak investigations as discussed in section 2.4.

2.3.2.3 Determining the Need for Further Investigation

Atmos procedures state that "appropriate personnel" should determine whether further evidence collection and investigation is needed. Following the investigation of the two incidents, Atmos dedicated significant resources to the response in the affected neighborhood, but these efforts did not focus on determining whether the gas-related incidents involved a release of gas from Atmos's portion of the system. They did not return to the incident sites to test the customer piping or obtain additional CGI measurements along potential gas migration paths after these first two incidents. Critical data could have been gleaned, for example, from testing the backfill around the sewer main, and the crawlspaces at both incident locations. Even after excavation revealed a crack in their piping near 3534 Espanola Drive, Atmos did not consider either of the first two incidents to be related to their piping. Because the first two incidents were reported to be gas-related, additional actions could have been taken by Atmos to ensure safety and determine if its piping was involved. More thorough investigations, including pressure testing, would have yielded critical data suggestive of a gas leak originating outside of the residences. For example, if Atmos had pressure tested the customer piping at the first two incident homes as soon as it was safe to do so, the data could have more promptly redirected gas leak detection efforts to Atmos-owned piping where leaks were ultimately discovered. The NTSB concludes that Atmos did not adequately investigate the first two gas-related incidents that occurred at 3527 and 3515 Durango Drive. Thus, the NTSB recommends that Atmos develop a clear procedure to coordinate with local emergency responders when investigating all fires and explosions that may be gas related to conclusively determine whether its system can be excluded as a potential contributor and collecting the necessary evidence to support the conclusion of its investigations.

2.3.3 NTSB's Evaluation of Causal Factors for the First Two Incidents

The NTSB examined available information from several sources to evaluate whether the first two incidents were related to the explosion at 3534 Espanola Drive.

The incident at 3527 Durango Drive was initially reported as an explosion, as later confirmed by the NTSB's condition of the structure after the explosion. Although some of the damage to the structure, such as the hole on the east side of the addition and the missing glass windowpanes, can be attributed to firefighting and overhaul procedures, the damage found in the

rest of the structure is not consistent with a typical house fire or firefighting and overhaul procedures.[59] Pushed out walls and exterior siding separated and detached from anchors are consistent with blast pressure wave damage. A blast pressure wave is not created during a typical structure fire (NFPA 2020). The damage observed at 3527 Durango Drive is consistent with a low-order explosion.[60] One source of this type of explosion is the ignition of a fuel gas-air mixture such as natural gas in air. Although residential explosions can also occur due to other sources (leaking flammable liquids, propane gas cylinders), DFR did not find evidence of other potential incident causes.[61]

The homeowner entered the attic to find out why his HVAC had shut off and replaced the HVAC pilot light cover but did not report smelling gas odorant.[62] This likely initiated a relight of the pilot light, igniting gas accumulated within the attic. In addition, contrary to the arson investigator's final report, photographs after the incident confirmed that the HVAC sustained thermal damage but had not exploded. The thermal damage to the HVAC indicated that it was located within the accumulated gas. Therefore, the HVAC was the most likely ignition source for the gas/air mixture inside the structure at 3527 Durango Drive.

After the incident, all customer-owned gas lines, including those for the gas appliances, were tested for leaks. Because no leaks were found, the customer's appliances, including the HVAC system, and piping were excluded as potential sources of gas. Therefore, the most likely source of gas was from outside the structure at 3527 Durango Drive.

The DFR safety officer observed flames coming from under the floor of the addition and said that a firehose stream was directed under the floor to extinguish the flames.[63] No evidence of visible fuel sources, such as accumulated combustibles, were observed in this area after the incident. Therefore, the most likely fuel source for this fire reported under the floor of the addition, was accumulated natural gas from subsurface migration.

The fire damage in the attic was less severe than the damage to the relatively new addition and adjacent areas. The fire damage exhibited in these areas indicated that the fuel concentration was higher in this section, making this the most likely entry pathway for the gas to have come into the house. Also, the soil disruption likely occurred during the construction of the addition. Disrupted soil has additional void spaces, allowing for gas to migrate more easily into

[59] *Overhaul* is a firefighting term involving the process of final extinguishment after the main body of the fire has been knocked down. It is the process of searching for hidden fire extension on a fire scene by opening walls, ceilings, voids, and partitions to check for fire extension within a structure.

[60] A *low order explosion* describes an explosive event where the blast pressure front moves slowly, displacing or heaving (rather than shattering) objects in its path, such as pushed out or displaced walls or bowed-out structures.

[61] The sewer line, located under a bathroom in the addition, was found separated at the elbow after the incident. In a close-up photograph of this area, the soil underneath the elbow appears disturbed. No evidence of long-term discharge into the crawlspace was observed. Therefore, it is likely that this separation occurred during the incident.

[62] Soil has a tendency to absorb and deplete odorant from natural gas. For more information, see section 2.5.

[63] Many pier and beam homes are constructed with crawlspace vents which can increase circulation within a crawlspace when open. The location and status of the vents in the crawlspace of 3527 Durango Drive could not be verified. However, crawlspace vents are intended for moisture control, not hazardous material ventilation. In fact, recent research suggests that crawlspace vents are not sufficient for moisture control in many cases. (Ref: https://www.advancedenergy.org/crawlspaces/).

this section of the structure as compared to the original home. Gas from outside 3527 Durango Drive likely entered the structure through the new addition before spreading up into the attic.

Therefore, the NTSB concludes that damage to the structure involved in the first incident on 3527 Durango Drive was consistent with a fuel gas/air mixture explosion, which was most likely caused by natural gas that migrated from underneath the structure.

Damage to the structure at 3515 Durango Drive, was most severe at the west and north sides, particularly near the corner of the structure around the carport. The kitchen was in this area and was most likely the originating location of the fire.

There was evidence that natural gas may have been present in this home immediately prior to the incident, including the homeowner's testimony, non-fire-related damage to the home, and a statement from a neighbor indicating that she was having difficulty with her natural gas range 3 days prior to this incident. Investigators found no evidence of other fuel sources in the fire origin area, such as accumulated combustibles.

The homeowner's description of flames that grew out of control while he was boiling water suggested that a fuel gas/air mixture may have been present in the home. While this testimony is consistent with a fuel gas environment, it could not be confirmed by physical evidence due to the subsequent damage. Damage to the west side of the home, including missing siding was not consistent with a typical structure fire. The siding anchors appeared still attached to the exterior sheathing with no sign of thermal damage. The damage to the siding is consistent with blast pressure wave damage and is not typical of a structure fire (NFPA 2020). This is the only area of the structure that exhibited this type of damage. The rest of the structure sustained severe thermal damage that would have destroyed any other signs of blast pressure damage. However, firefighting efforts and overhaul procedures could not be completely ruled out as the cause for this damage. Therefore, the nature of the structural damage not related to the fire could not be confirmed.

While structural fires do generate some overpressure due to the generation of combustion gases from burning material, those pressures are insufficient to project glass shards any significant distance. Glass fragments were embedded in exterior fencing slats next to the carport which is not consistent with a typical structure fire.

A nearby resident who lived on 9621 Larga Drive stated that she had contacted the gas company a few days prior to the fire at 3515 Durango Drive (second incident) because of an issue with her gas range. She reported that when she turned on her stove, instead of the expected blue, the burner flames were red. She stated that the gas company representative she spoke to told her there were no problems with the gas service in her neighborhood and that everything was normal. Due to the similarity in flame color outside the normal flame color during optimal operation, this event is not insignificant even though the cause of the unusual flame color went undetermined.[64] The gas range had been working well prior to the incident and no repairs had been done on the appliance. The occupant stated that he had not smelled gas inside the residence

[64] Red, orange, or yellow flames from a gas range can be an indication of a fuel gas/air mixture issue or the presence of contaminants.

prior to the incident. Although the gas range could not be tested due to the incident-related damage, investigators found no obvious signs of failure or malfunction during the visual examination. However, due to the damage to the structure and to the gas range, neither the range nor any other potential cause could be completely excluded.

Additionally, the homeowner's testimony, the non-fire-related damage observed on the structure at 3515 Durango Drive, and the related unusual gas range event reported by a neighbor are not consistent with an appliance-related fire. Therefore, the involvement of natural gas in this incident could not be excluded.

The first incident was likely fueled by natural gas that migrated to the house from outside the structure and, while the cause of the second incident could not be confirmed, there was evidence that fuel gas existed within the second incident home prior to the second incident. Nonetheless, testing after the incident revealed that the customer piping at both residences performed adequately.

Several leaks were found on Atmos's gas distribution system following the second incident, including four leaks in the alley behind the incident homes. There was also one leak on a nearby home customer line. Therefore, there was evidence that fuel gas existed within both homes prior to the first two incidents and involvement of natural gas from Atmos's natural gas distribution system could not be excluded.

According to the NFPA and the US Census Bureau (USCB), about 363,000 home structure fires occur annually in the almost 140 million housing units in the nation. (NFPA 2019 and USCB n.d.). This corresponds to a rate of about one structure fire per 20,055 housing units per week. It is very unlikely that two or three fires/explosions occurred on the same block in the same week independently. By contrast, if a structure fire/explosion results from a common cause, the likelihood of a second or third structure fire/explosion on the same block could be much higher. Common cause failures can occur due to common initiating events such as weather conditions or leaks that feed multiple locations or other dependencies.

The NTSB concludes that fuel gas was involved in both incident homes; there was insufficient evidence to exclude natural gas from Atmos's system from either incident, evidence of leaks present prior to the first two incidents occurring, and the probability of two or three structure fires/explosions occurring independently on the same block during the same week is very low. Therefore, the two prior incidents that occurred on the same block on subsequent days and the explosion at 3534 Espanola Drive were all likely related.

2.4 Leak Investigations and Repairs Prior to the Explosion

After the second incident occurred on February 22, 2018, Atmos maintenance crews responded, performed a leak survey, and repaired their highest-priority leaks. Atmos expanded the scope of its testing throughout the day and continued to locate other leaks within its system. Atmos supervisors effectively communicated with management during this response, and the operations manager and the director of operations also remained in contact throughout the response as necessary.

Despite the resources Atmos deployed and its belief that all leaks were being identified and properly addressed, Atmos did not take appropriate action to prevent the fatal explosion.

The NTSB referenced PHMSA's regulations and industry guidance to assess how closely Atmos's response after the second incident followed its recommendations for emergency response. PHMSA requires each operator to establish written procedures to minimize the hazards resulting from a gas pipeline emergency. Overall, Atmos's response following the second incident was generally consistent with industry guidelines. For instance, it determined that an immediate response was necessary, and quickly sent personnel to assess the situation. However, Atmos did not take more extensive actions—such as "evacuating and preventing access to the premises" or an "emergency shutdown and pressure reduction"—prior to the explosion at 3534 Espanola Drive (ANSI/GPTC 2018).

Atmos chose to address the potential hazard by immediately sending personnel and equipment to the neighborhood to mitigate the risks by attempting to detect and repair significant gas leaks. However, their efforts were hindered by weather conditions. Both the technicians and management knew that their equipment was not recommended for wet weather. Atmos's technicians attempted to complete their assigned tasks despite these known limitations. Furthermore, Atmos allowed special leak surveys to be performed in wet weather conditions known to negatively affect survey quality when they were supplementing leak investigations. While there was not a wet weather leak survey procedure, Atmos's surveys were to be conducted in general accordance with Atmos's O&M Manual. While such methods are the general practice for the gas industry, they are not reliable during wet weather conditions.

Excessive water in some areas prevented technicians from following standard bar hole testing procedures. When needed, the technicians took readings above ground, a method that could not detect gas that remained underground. Ultimately, bar hole testing conducted following the second incident revealed the presence of gas in the alley behind the incident houses. Yet, at no time did Atmos's bar hole testing detect the presence of subsurface gas in the alley directly behind the house involved in the explosion. Two leaks were found in this area after the explosion—the catastrophic leak associated with the crack in the main behind 3534 Espanola Drive and the less significant leak at the service tee to 3539 Durango Drive.

One survey specialist found positive gas readings down the alley on the 3500 block between Espanola and Durango Drives with his RMLD that were interpreted by an operations supervisor as false positives; these readings did not contribute to locating the cracked gas main. While Atmos field employees were attempting to complete their assigned tasks in challenging conditions, the environmental constraints could not be overcome with the equipment they were issued and processes they were following.

Atmos's decision-making following the two incidents was based on incomplete and inaccurate information gathered at the scene. Had Atmos fully considered the limitations of its technicians' equipment in the existing environmental conditions, and the prospect that they might not be able to accurately detect and locate gas leaks, its response after the second incident should have been to shut down pipeline operations to the neighborhood rather than trying to find and repair the leaks. The NTSB concludes that limitations of the equipment and procedures due to the wet weather conditions on the ability of Atmos to reliably detect the presence of leaked

gas during its response to the first two incidents, and the number and severity of leaks identified following the first two incidents and prior to the explosion, should have prompted Atmos to shut down or isolate the pipeline.

Though shutting down a portion of the system to pressure test the main would have been a significant effort, this testing would have demonstrated that the main did not hold pressure. As evidenced by the testing on February 24, 2018, these initial test results could have been available the same day. With this additional information, Atmos would have had reason to suspect that natural gas from its system existed within the incident houses. Accordingly, this may have prompted Atmos to test the atmosphere within neighboring houses and perform necessary protective actions, such as evacuations. Therefore, the NTSB concludes that had Atmos pressure tested the main in the alley behind the first two incident homes on February 21 or 22, it could have found that the main did not hold pressure, spurring additional protective actions that could have prevented the fatal injury at 3534 Espanola Drive.

The weather conditions and associated equipment limitations were known and expected, but Atmos's procedures did not contain clear guidance on how its technicians were to overcome these challenges. The heavy rainfall received in the 2 days before the explosion was not unprecedented in the region. However, it is unlikely that Atmos had to engage in extensive bar hole testing during infrequent excessive rains. When a leak or incident occurs during wet weather, a reliable approach for detecting the leak must be available for the responding employees.

According to industry guidance, five leak survey and test methods are available to detect leaks. They include the: surface gas detection survey, subsurface gas detection survey, vegetation survey, pressure drop test, and bubble leakage test. However, this guidance also notes that moisture can affect the results of the three survey methods. The pressure drop and bubble leakage tests are not affected by wet weather conditions. The pressure drop test requires the test section to be isolated and the bubble leakage test requires the entire test section to be exposed (ANSI/GPTC 2018).

No pressure drop tests were conducted on February 21 or 22, 2018. However, Atmos did pressure test the main and service lines the day after the fatal explosion and the segment did not hold pressure. The most significant leak found during testing after the explosion was from a crack that had existed on the main prior to the first incident occurring.

Pressure testing the main is an involved process for detecting a leak as it requires isolating and pressurizing the test segment. However, it would be the least involved of the two methods provided in the industry guidance that are not susceptible to moisture. Neither the GPTC nor Atmos guidance specified the circumstances which warrant pressure testing of the main.

As demonstrated by gas measurements taken after the explosion, the backfill around the sanitary sewer main was a viable gas migration path. However, neither Atmos procedures nor GPTC specifically identified sewer embedment, commonly constructed of granular material, as potential gas migration paths that require investigation. Had Atmos required its technicians to

perform bar hole testing over the sanitary sewer main, the technicians may not have reached the depth of the embedment with the equipment that was available to them.

Several options could have been taken to secure the safety of the area following the first and second incidents. For example, Atmos could have shut down pipeline operations and pressure tested its system or could have evacuated the area. However, neither the industry guidance in ANSI/GPTC Z380.1 nor Atmos procedures specified the circumstances which warrant these actions. Therefore, the NTSB concludes that Atmos's wet weather leak investigation procedures were insufficient given the known limitations of its equipment.

Thus, the NTSB recommends that Atmos revise its policies and procedures for responding to leaks, fires, explosions, and emergency calls to address the challenges caused by wet weather conditions. The revised policies and procedures should include: (1) leak investigation methods that are reliable in wet weather; (2) leak investigation procedures that assess all viable gas migration paths; (3) criteria for when to shut down or isolate gas distribution systems and pressure test main and service lines, and (4) an alternate safe response such as evacuation when reliable leak investigations are not possible due to wet weather or other circumstances.

Similarly, the NTSB recommends that GPTC develop additional guidance that identifies steps gas distribution operators can take to safely respond to leaks, fires, explosions, and emergency calls, considering the limitations due to wet weather conditions, that includes: (1) criteria for when to shut down or isolate gas distribution systems, pressure test main and service lines, and begin evacuations; (2) leak investigation methods that are reliable in wet weather; (3) require an alternate safe response, such as an evacuation when reliable leak investigations are not possible due to wet weather; and (4) leak investigations that assess all viable gas migration paths, including granular backfill and crawlspaces.

Because DFR firefighters are dispatched to calls regarding natural gas odor complaints, they are trained to use CGIs to detect the presence of natural gas. All DFR firefighters are trained to operations level in accordance with Occupational Safety and Health Administration (OSHA) Hazardous Waste Operations and Emergency Response (HAZWOPER) standard 29 *CFR* 1910.120, which is defined in the regulation as a response in "a defensive fashion without actually trying to stop the release." Responding firefighters' roles are limited to confirming if a natural gas hazard exists and if it does, they are to take defensive measures to protect people and property.

After extinguishing the structure fires that occurred following the first two incidents, the responding firefighters left the scene and did not perform gas monitoring. The DFR procedures for responding to structure fires or natural gas leaks did not stipulate that gas monitoring be performed after a structure fire that may have been caused by the ignition of natural gas. While firefighters isolated one possible source of leak by shutting off the gas at the meter, there are still other paths for natural gas to migrate into the house. Therefore, monitoring the air inside or outside the house for combustible gas is needed to ensure the safety of the area. The firefighters relied solely on Atmos to perform this gas monitoring.

DFR's HMRT members are trained to first responder technician level, also in accordance with OSHA's HAZWOPER standard. In the State of Texas, a firefighter trained as a hazardous material technician "assumes a more aggressive role than a first responder at the operations level, in that the Hazardous Materials Technician will approach the point of release."[65] They are also certified in accordance with NFPA 472 and the Texas Commission on Fire Protection. In addition to this, the DFR HMRT also received periodic training on natural gas from Atmos. However, the DFR HMRT was not requested to respond after the second incident or the explosion. In response to gas-related fires and explosions in which the cause cannot be readily determined, having the presence of the DFR HMRT team would provide additional support to the gas operator's leak investigation. In addition, if there was a need for an evacuation, the gas company would be able to coordinate easily with the DFR HMRT that would be present.

The NTSB concludes that the assistance of the DFR HMRT, particularly after the second incident, could have enhanced Atmos's leak investigation. Industry guidance recommends that the initial response take immediate steps to protect the public from the dangers of an explosion or fire and to mitigate those hazards. Gas monitoring would be an appropriate action to take to ensure those hazards are mitigated during a response to a gas-related fire. Therefore, the NTSB recommends that DFR revise its procedures to require gas monitoring after the occurrence of a gas-related structure fire or explosion.

2.5 Methane Detection

Odorant is the primary safety feature that members of the public rely upon to detect a natural gas release (GAO 2018). Because these gas distribution 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. However, when odorized natural gas passes through the soil from a leaking supply pipe, the soil can absorb and deplete the odorant from the gas (Tenkrat and others 2010). This phenomenon has been recognized since at least 1974 when the NTSB published a report which cited "lack of odor in the leaked gas when it reached the houses and the atmosphere" as a contributing cause (NTSB 1974).

Atmos added odorant to its gas distribution system in a manner that was consistent with PHMSA regulations, and yet none of the residents smelled gas prior to the incident. This is the expected response for natural gas that migrates a sufficient distance through soil, and is consistent with observations made during integrity tests after the explosion where the odor was apparent near the crack, but not noted at other excavation locations despite high methane gas readings.

Many NTSB investigations have demonstrated that gas odorant does not always provide sufficient warning of gas leaks and hazardous conditions, including:

- The June 28, 1982, natural gas explosion that killed five people and injured one in a single-family home in Portales, New Mexico. The natural gas release was caused by a failed service line that had been damaged from excavation work for the local

[65] Title 37 *TAC* 453.1.

telephone company over a month before the accident occurred. Between the time of the excavation work and the explosion, no one had detected gas. 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).

- The March 5, 2008, natural gas explosion and fire that killed one person and severely injured a child in a single-family home in Plum Borough, Pennsylvania. The NTSB determined that the gas distribution pipeline had been damaged from excavation work years prior 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 the porous backfill of a new sewer line and accumulated rapidly in the house with little warning to residents. Odorant levels were tested and found to be in compliance with federal requirements (NTSB 2008).

As part of the investigation of the August 10, 2016, natural gas explosion and fire of an apartment building in Silver Spring, Maryland, the NTSB analyzed 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 2019). The 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 of these 20 cases, as in the three events in Dallas in February 2018, gas odor was not detected by the occupants in time for them to evacuate before the explosion occurred, despite the odorant levels being compliant with regulatory requirements. In several of the 20 cases, the NTSB cited odorant fade due to soil adsorption as a contributing factor. Based on this analysis, the NTSB concluded that the use of gas odorants alone does not effectively mitigate the risk of death and injuries caused by gas system leaks (NTSB 2019).

The residents at 3534 Espanola Drive did not smell gas and were not alerted by DFR or Atmos officials of the potential hazard at any point before the explosion occurred. Likewise, none of the residents at either of the first two incident houses smelled gas prior to the incidents.

Finally, had there been an alarm to warn of a natural gas release, residents could have been notified earlier to evacuate to a safe place away from the residence, without relying on someone within the house to smell gas odors or an outside party to notify them of the hazard. The NTSB concludes that had methane detectors been installed at the residences located on Durango and Espanola Drives, an alarm would have alerted residents to a gas release, reducing the potential for and consequences of the resulting natural gas fires and explosions.

For 45 years, the NTSB has recommended that methane detectors be required to provide early warning of gas leaks. As a result of its investigation of an April 22, 1974, natural gas explosion in a commercial building in New York City, New York, on April 19, 1976, the NTSB issued Safety Recommendation P-76-12 to the US Department of Housing and Urban Development (HUD) (NTSB 1976). The investigation 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.

> 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 also said that it would continue to review developments in the field and would reevaluate its position "when a practical, cost effective natural gas detection system is developed."

The NTSB made a similar recommendation as a result of the investigation of a June 9, 1994, natural gas explosion and fire in a retirement home in Allentown, Pennsylvania (NTSB 1996). The NTSB's 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 issued Safety Recommendation P-96-16 to 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. The NTSB classified this safety recommendation *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. In the United States, the NFPA and the International Code Council (ICC) are nationally recognized standard-setting bodies for both building and fire codes, as well as fuel gas codes such as the International Fuel Gas Code (IFGC) and the National Fuel Gas Code (NFPA 54). 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 to gas service pipelines entering structures, which is under the jurisdiction of the local authority and the responsibility of the owner to implement.

In the investigation of the Silver Spring explosion and fire, the NTSB concluded that the scope of NFPA 54, and IFGC, and their widespread adoption by local authorities appeared to be

the most appropriate standards for requiring methane detector alarms, with local jurisdictions enforcing the requirements and making them feasible. (NTSB 2019) Therefore, the NTSB recommended that the ICC (Safety Recommendation P-19-6), the NFPA (Safety Recommendation P-19-7), and the Gas Technology Institute (Safety Recommendation P-19-8) work to develop standards for methane detection systems for all types of residential occupancies in both the IFGC and NFPA 54. At a minimum, the provisions should cover the installation, maintenance, placement of the detectors, and testing requirements.[66] In a November 13, 2020, update, the ICC reported that the NFPA has begun development of NFPA 715: *Standard for the Installation of Fuel Gases Detection and Warning Equipment*, a stand-alone standard specifically for residential gas detection devices and systems. Once final, that standard could be referenced in the National Fuel Gas Code (ANSI Z223.1/NFPA 54) and/or the ICC's IFGC. The issues addressed by that standard could also be addressed through the International Building Code, International Fire Code, International Residential Code, or the International Existing Building Code, which include similar requirements for smoke/fire alarms and carbon monoxide alarms.

Had an effective methane detector been installed in the house at 3534 Espanola Drive, the residents likely would have been alerted to the dangerous levels of gas before the explosion occurred. Thus, the current accident again shows the importance of implementing effective methane detectors, as the NTSB has been recommending for 45 years. Therefore, the NTSB reiterates Safety Recommendations P-19-6, -7, and -8.

2.6 Incident Reporting

Timely incident reporting can make the difference between life and death when there is an active gas leak. It provides appropriate stakeholders with the information they need to perform their incident response functions which support the identification, analysis, and evaluation of pipeline safety problems, and facilitate the development of practical solutions to pipeline safety challenges. Despite these benefits, the first two incidents were not sufficiently reported.

2.6.1 Atmos Incident Reporting

According to PHMSA regulations, a natural gas distribution incident requires immediate notice to the NRC if it involves a "release of gas from a pipeline" and meets specified consequence criteria, or if it is "significant in the judgment of the operator." If such an event occurs, the operator is also required to submit a PHMSA Incident Report as soon as practicable but not more than 30 days after detecting the incident. The operator is also required to supplement the report if additional information is obtained after the report is submitted.

Atmos submitted a notice to the NRC and a PHMSA Incident Report following the explosion, reporting an "unintentional release of gas" that caused an explosion at 3534 Espanola Drive. Atmos also submitted a Pipeline Safety Incident Notification to the RRC following the

[66] Safety Recommendations P-19-6 and P-19-8 are currently classified *Open—Acceptable Response,* and Safety Recommendation P-19-7 is classified *Open—Acceptable Alternate Response.*

explosion and provided a timeline of the gas operator's actions following the explosion, noting that the natural gas main did not hold pressure.

Although gas distribution operators have the option to report incidents that may involve a release from their pipeline, Atmos did not submit a notice to the NRC or a PHMSA Incident Report for either of the first two incidents. After the second incident, Atmos notified the RRC by email, indicating they were monitoring a situation involving two separate leak investigations where fires had occurred, and which measured gas was potentially involved. Atmos did not follow up with a formal PHMSA Incident Report. Atmos asserted that "there is no evidence" that these incidents involved a release of gas from its pipeline and submitted leak survey data collected on scene while responding to the first two incidents to support its position. This perspective implies there was sufficient evidence to exclude the involvement of natural gas from Atmos's system—there was not.

As state pipeline safety programs must adopt federal regulations, the RRC adopted the federal definition of a reportable natural gas incident. However, states do have the option to adopt more stringent regulations for intrastate pipelines.[67] Following the explosion, the RRC amended its regulations, the reporting requirements continue to rely on PHMSA's definition of an "incident." As a result, the RRC's regulatory changes would not be expected to result in additional reporting if a similar sequence of events occurs in the future. Nonetheless, state regulators cannot be expected to oversee an operator's determination or response if they are not notified through official channels.

By choosing not to report the first two incidents in a timely manner, Atmos did not provide the regulatory authorities, RRC and PHMSA, proper notice that would have allowed them to provide oversight to the response following the first or second incident. Although the courtesy notification did provide some notice, courtesy e-mails typically do not receive the urgent attention of an official incident report and are not provided with the same degree of timeliness. Had they been alerted through proper channels, regulatory authorities could have encouraged or required Atmos to take a different approach in response to the first two incidents to ensure public safety. The NTSB concludes that the lack of official reporting of the first two incidents by Atmos delayed the response from the regulatory authorities, RRC and PHMSA.

Industry guidance lists factors that pipeline operators can use to determine whether an event is "significant" and could be a reportable incident such as:

1) Rupture or explosion

2) Fire

3) Loss of service

[67] The Minnesota Department of Public Safety, Office of Pipeline Safety (MNOPS) has more stringent reporting requirements than PHMSA for intrastate natural gas pipelines. In addition to those events required to be reported by PHMSA, MNOPS requires telephonic notification if a release results in other consequences, such as "any media attention" or "unintentional fire or explosion" (MNOPS 2016).

4) Evacuation of people in the area

5) Involvement of local emergency response personnel

6) Degree of media involvement (ANSI/GPTC 2018).

Several of these items (such as explosion, fire, local emergency response, and media involvement) occurred during the first two incidents. Atmos, however, relied solely on its leak investigation data to determine that these incidents were not reportable. Pipeline operators are not required by PHMSA to consider the six recommended items when evaluating a reportable incident. Instead, PHMSA requirements rely on the "judgement of the operator" to determine if an event involves a release of gas from their pipeline or is otherwise significant.

The NTSB concludes that PHMSA does not provide clear requirements regarding the level of investigation necessary to determine whether an event is subject to its reporting requirements, potentially resulting in the underreporting of natural gas incidents. Therefore, the NTSB recommends that PHMSA expand incident reporting requirements in 49 *CFR* Part 191 so that events that may meet the definition of "incident" are immediately reported to the NRC even when the source of the natural gas has not been determined.

2.6.2 DFR Incident Reporting

After the second gas incident occurred, the DFR fire investigation reports for the two incident homes did not indicate a possible gas distribution issue in the area that needed to be further investigated. NFPA 921 states that "Pertinent information should be reported in a proper form and forum to help prevent recurrence" (NFPA 2020). DFR has no formal policy in place to direct investigators on which events to elevate; therefore, its current process for elevating events is not effective. The DFR fire chief appeared to have recognized the unusual circumstances of having two fires/explosions in close proximity of time and space and requested Atmos investigate to determine the cause. Recognizing the unusual circumstances, DFR could have also reported these incidents to other relevant DFR divisions or City of Dallas departments. The NTSB concludes that if DFR reported the first two incidents in a timely manner, it could have prompted further investigation or regulatory oversight prior to the explosion. Therefore, NTSB recommends that DFR develop and implement a formal process to alert appropriate local, state, and federal agencies of potential systemic safety issues that should be investigated further.

2.7 Integrity Management

Following the explosion, Atmos expanded its special leak surveys. In the area around the explosion, Atmos found 26 leaks that it classified as Grade 1 or Grade 2.[68] (See figure 6.) Of the leaks that were excavated by Atmos to determine the cause, the predominant cause was stripped threads (40 percent), followed by corrosion (13 percent), and ground movement (13 percent).

[68] Two additional leaks were found in the alley behind the affected houses by NTSB investigators during pressure testing after the explosion, as discussed earlier in this report.

In addition to the leaks discussed above, Atmos reported to the RRC that it found 264 leaks between February 23 and February 28, 2018, and 1,001 leaks in March 2018 that it classified as Grade 1 or Grade 2 in Dallas.[69] Of these leaks, 741 were reported to be located within the area in northwest Dallas, shown in figure 17. Atmos reported that these northwest Dallas leaks primarily occurred on service lines (543 or 73 percent) and primarily involved coated steel (640 or 86 percent). Of these leaks that were excavated by Atmos to determine the cause, the predominant cause was stripped threads (270 or 38 percent), followed by gasket/O-ring (146 or 21 percent), corrosion (112 or 16 percent), and ground movement (45 or 6 percent).[70]

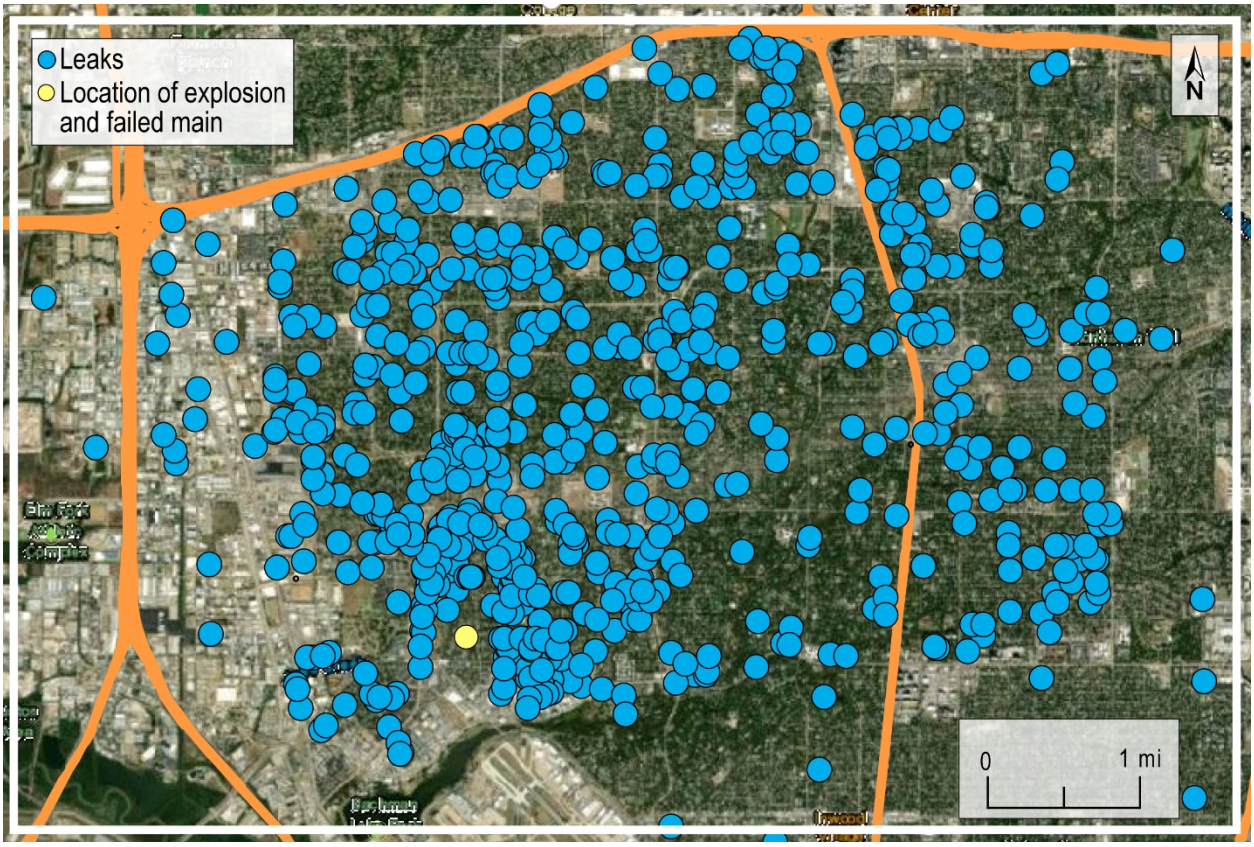

Figure 17. Leaks identified as Grade 1 or Grade 2 which were beyond the scope of this investigation.

The large number of leaks around the explosion site prompted further evaluation of PHMSA's Gas Distribution Pipeline Integrity Management (IM) requirements as they pertain to Atmos's system in the affected area. The PHMSA Gas Distribution Pipeline IM requirements were promulgated in 2009 to "enhance safety by identifying and reducing pipeline integrity

[69] This data is available to the public from the RRC upon request; however, the 28 leaks that were within the scope of this accident investigation were excluded from RRC reporting. The docket for this investigation includes both sets of data for reference. Data was filtered to include leaks reported to be both in the City of Dallas and the County of Dallas.

[70] Atmos did not excavate 38 of these leaks in northwest Dallas to determine their cause.

risks (*Federal Register* 2009, 63905)." These requirements were noted to be responsive to recommendations from the DOT's Inspector General (IG). The DOT IG issued a report in 2004 recommending that the PHMSA Office of Pipeline Safety require operators of natural gas distribution pipelines to implement some form of pipeline integrity management or enhanced safety program with the same or similar integrity management elements as hazardous liquid and natural gas transmission pipelines (RSPA 2004).[71] The DOT IG recognized that natural gas distribution pipelines cannot be internally inspected, but noted that other elements can be readily applied to this segment of the industry, including but not limited to: a process for continual integrity assessment and evaluation; an analytical process that integrates all available information about pipeline integrity and the consequences of failure; and repair criteria to address issues identified by the integrity assessment and data analysis.

The DOT IG indicated that this recommendation was needed, in part, because natural gas distribution pipelines were not achieving the DOT's strategic safety goal to reduce the number of transportation-related fatalities and injuries. The DOT IG indicated that accidents in natural gas distribution pipelines had resulted in more fatalities and injuries than hazardous liquid and natural gas transmission lines combined.

Although the Gas Distribution Pipeline IM requirements became effective August 2011, operator data that is reported to and maintained by PHMSA continues to show that natural gas distribution pipeline accidents result in more fatalities and injuries than hazardous liquid and natural gas transmission lines combined. In fact, a review of significant accidents and incidents reported to PHMSA indicates that 310 of the 406 fatalities or injuries (76 percent) that occurred on pipeline systems from 2000 through 2004 occurred during gas distribution incidents. The same information from 2014-2018 indicates that 319 of the 380 fatalities or injuries (84 percent) occurred during gas distribution incidents (PHMSA 2020).

The basic principle underlying IM is that "operators should identify and understand the threats to their pipelines and apply their safety resources commensurate with the importance of each threat" (*Federal Register* 2009, 63905). PHMSA has indicated that gas distribution pipelines tend to leak rather than rupture and that it is important for distribution IM programs to focus on identifying and addressing the conditions that can cause leaks, as well as managing leaks effectively when they do occur. PHMSA further indicated that, although compliance with ANSI/GPTC Z380.1 is not required, operators who follow these guidelines will comply with the requirements of the rule (PHMSA 2015).

The NTSB did not evaluate the cause of the 26 Grade 1 and Grade 2 leaks that Atmos identified around the explosion site, nor, as discussed above, did the NTSB evaluate the cause of the 741 Grade 1 and Grade 2 leaks found in northwest Dallas following the accident. While there are several possible causes that could have led to or contributed to the number of leaks, Atmos's data indicate that the predominant cause was stripped threads, followed by gasket/O-rings, and corrosion. These failure causes are typically associated with threats that can be predicted, such as installation errors or system degradation. However, Atmos's statistical risk evaluation did not

[71] The DOT IG report can be found in the docket for this accident (NTSB case number PLD18FR002) by accessing the Accident Dockets link for the Docket Management System at www.ntsb.gov.

identify the segment of main in the alley of the 3500 block of Espanola Drive and Durango Drive as relative high risk nor did it identify the about 300 home evacuation area or the about 2,800 home planned outage area as relative high risk.

Federal regulations specify that operators must determine the relative importance of each threat and estimate and rank the risks posed to its pipeline. This evaluation must consider each applicable current and potential threat, the likelihood of failure associated with each threat, and the potential consequences of such a failure. Following the explosion, Atmos indicated that the large number of leaks near the explosion site was "abnormal, sudden, and unexplained." As mentioned in section 1.7.6, Atmos hired a consulting company, BCI, that developed a preliminary assessment report, which contended there were two different geological formations underlying this region in northwest Dallas. The report stated that the recent extended period of rain "caused unanticipated external loadings" on Atmos's piping system. According to Atmos, following the release of the preliminary assessment report, BCI obtained data that corroborated this theoretical model, and BCI presented a project summary. However, BCI did not produce another written report. Thus, its findings and underlying data are not available for analysis. Additionally, there was no explanation provided for why Atmos attributed such a low percentage of leaks to ground movement.

The NTSB contracted with the USACE to evaluate the technical accuracy of BCI's preliminary assessment report (USACE 2019). The USACE found that the subsurface materials underlying the explosion block are highly uniform and there was no evidence of unanticipated external loading. Despite five leaks being discovered on its system on the explosion block, Atmos maintained that its consultant's evaluation of the area around and encompassing the explosion block was valid, but not specific to the location evaluated by the USACE.

The USACE observed that the swell potential of the clay soil found in this area can distress structures on top of or within the soil. This phenomenon was observed during the NTSB investigation of an accident that occurred in 1971 in the North Richland Hills area (about 22 miles west of 3534 Espanola Drive) on Lone Star Gas Company's system (since acquired by Atmos). In that investigation, the NTSB observed that the dense clay soil had exerted stresses on the pipe through the years every time rain saturated the soil sufficiently to cause it to swell, eventually breaking the embrittled pipe and allowing gas to escape. The rain-saturated soil prevented the escaping gas from dissipating to the air above and caused the gas to flow laterally into more porous, graveled soil under a driveway.

Significant rains preceded the current explosion, and it is possible that the hydrological conditions resulted in additional loadings on Atmos's pipeline system. However, significant rains are expected in this area and there was no evidence of other buried infrastructure failing at unusually high rates. Further, the predominant Atmos-determined failure causes are associated with system degradation rather than ground movement. The USACE observed that soil shrink and swell cycles distress buried structures. The NTSB previously investigated a nearby gas explosion which involved a failure that was attributed to distress from soil shrink and swell cycles, and a foundation inspector indicated that the foundation of the explosion house had

degraded, noting distress from high plasticity clay soils.[72] Therefore, the NTSB concludes that the high number of leaks observed in northwest Dallas after the explosion were due to the degradation of Atmos's gas distribution system, not sudden, unanticipated geologic loadings.

Pipeline operators with robust IM practices are expected to anticipate such threats to their piping infrastructure and apply their safety resources accordingly. The American Society of Mechanical Engineers (ASME) B31.8S, *Managing System Integrity of Gas Pipelines*, a nonmandatory code that "documents principles and processes embodied in integrity management" does not specifically discuss threats associated with additional loading that could occur due to periodic heavy rain; the category that includes "heavy rains" is specific to extreme loading (ASME 2010). However, ANSI/GPTC Z380.1 and PHMSA Form F7100-1.1 indicate that "natural force damage" includes "heavy rains/floods" and all water-related natural force causes. Industry guidance on identifying threats provides questions to help operators determine the applicability of threats to their system. The questions regarding natural force damage focus on extreme loading scenarios (such as landslides or earthquakes) and do not provide an indication that expected rainfall events should also be treated as a threat (ANSI/GPTC 2018).

In addressing the likelihood of failure, age is generally recognized as a strong indicator of performance. However, gas distribution operators are not explicitly required to assess the age of their pipeline in the likelihood of failure evaluation. Instead, PHMSA regulations state that "an operator may subdivide its pipeline into regions with similar characteristics (such as contiguous areas within a distribution pipeline consisting of mains, services and other appurtenances; areas with common materials or environmental factors), and for which similar actions likely would be effective in reducing risk." Similar to the approach described in federal regulations, Atmos grouped its assets into failure families based on asset attributes, such as material and coating.

Nonetheless, reliability refers to the probability that a system will function as expected for a predetermined amount of time when exposed to actual operating conditions. As the "predetermined amount of time" increases, systems tend to degrade and the reliability decreases. Moreover, increasing failure rates have been observed in older gas distribution infrastructure that have certain attributes (PHMSA 2020). The increasing failure rate typically occurs toward the end of life and accelerates the rate by which the reliability decreases. This behavior is typically attributed to cumulative degradation that occurs in the system over its service period. Trending failure rates by system age can reveal degrading performance.

A degrading trend can be observed from records for the 25 service lines that were installed on the 3500 block of Espanola and Durango Drives. No service lines were replaced between 1950 and 1994; all of the original service lines survived for at least 44 years, demonstrating high reliability. Beginning in 1994 until the day prior to the explosion, after 44 to 71 years of service, more than half of the service lines were replaced.

To address the consequence of failure, or the extent of potential damage if the problem is not mitigated, industry guidance provides examples of factors that may be considered in the evaluation of potential consequences. These factors include: the population (rural or residential),

[72] The foundation of the explosion house was repaired and inspected by the City of Dallas in 2017.

pipe diameter, and operating pressure (ANSI/GPTC 2018). Atmos considered several factors in its risk analysis, which were consistent with industry guidance.

Neither Atmos nor the GPTC addressed the potential for rain to result in an increase in potential consequences. In cases where rain presents a threat, its tendency to increase consequences can be particularly damaging because the capability to mitigate the threat is reduced. This explosion demonstrated that rain can increase the potential consequences by: (1) inhibiting the operator's ability to gather useful natural gas measurement data, (2) inhibiting venting, and (3) increasing the tendency of natural gas to migrate laterally where it could be stripped of odorant and create a hazardous condition. These factors were recognized and discussed in the ANSI/GPTC Z380.1, but only in areas not specific to gas distribution pipeline IM. When the likelihood and consequence portions of the risk equation are correlated, the risk can be significantly higher. Risk increases associated with reduced mitigative capability were not considered by Atmos's gas distribution pipeline IM evaluation or discussed in the industry guidance.

The NTSB concludes that Atmos did not adequately consider or mitigate against threats that were degrading its pipeline system, the likelihood of failure associated with these threats, or the potential consequences of such a failure as required by gas distribution integrity management requirements.

Therefore, the NTSB recommends that Atmos without delay, assess its IM program, paying particular attention to the areas identified in this investigation, and revise the program to appropriately consider: (1) threats that degrade a system over time, and (2) the increased risk that can result from factors that simultaneously increase the likelihood and consequence of failure.

Similarly, the NTSB recommends that the GPTC develop guidance that identifies steps that gas distribution operators can take to ensure that their gas distribution IM program, at a minimum, appropriately considers: (1) threats that degrade a system over time, and (2) the increased risk that can result from factors that simultaneously increase the likelihood and consequence of failure.

GPTC guidance describes leak management programs as an important risk management technique used by natural gas distribution operators to maintain the integrity of their distribution systems. This guidance identifies five basic elements of an effective leak management program:

- Locate the leaks in the distribution system
- Evaluate the actual or potential hazards associated with these leaks
- Act appropriately to mitigate these hazards
- Keep records
- Self-assess to determine if additional actions are necessary to keep people and property safe

The first step of an effective leak management program is locating leaks in the system, typically through leak surveys and leak investigations. Leak surveys are performed at frequencies determined by the operator. The guidance indicates that the frequencies may be based on the type of gas transported, environmental conditions, the operator's knowledge of the distribution system, and regulatory requirements.

The leak survey frequency is an important aspect of the leak management program. Leak surveys provide an indication of the leaks that may be present at the time they are performed but provide no information on leaks that may occur in the future. While the operator may discover or be alerted of leaks through various activities, such as maintenance or odor complaints, these strategies for locating leaks serve to supplement the leak surveys and are not expected to consistently locate all potentially hazardous leaks. For example, if the gas migrates through the soil to a residence, the odorant may be stripped from the natural gas and the resident would not have a reason to alert the operator.

The limitations of Atmos's leak management strategy were evidenced by the high number of leaks that were present in the area around the explosion site. Therefore, the NTSB concludes that while Atmos's periodic leak survey methodology and frequency complied with the minimum state and federal requirements, it did not identify the degraded system that was found after the explosion. Therefore, the NTSB recommends that PHMSA evaluate industry's implementation of the gas distribution pipeline IM requirements and develop updated guidance for improving their effectiveness. The evaluation should specifically consider factors that increase the likelihood of failure such as age, increase the overall risk (including factors that simultaneously increase the likelihood and consequence of failure), and limit the effectiveness of leak management programs.

This investigation highlighted specific aspects of Atmos's pipeline safety program that could be enhanced to improve public safety. Therefore, the NTSB recommends that the RRC with assistance from PHMSA, conduct a comprehensive audit of Atmos's incident-reporting practices; policies and procedures for responding to leaks, fires, explosions, and emergency calls; and IM programs.

The NTSB also recommends that PHMSA assist RRC in conducting the audit recommended in Safety Recommendation P-21-4.

3. Conclusions

3.1 Findings

1. None of the following were factors in the explosion: (1) ongoing maintenance activities; (2) overpressurization of the gas distribution system; (3) materials used for the construction of the gas main and external coating; and (4) natural gas composition.

2. The natural gas main was damaged by mechanical excavation equipment, likely when the sanitary sewer lateral was replaced in 1995.

3. A circumferential crack in the main propagated through the pipe wall prior to the first incident, allowing natural gas to leak into the surrounding environment for an extended period.

4. Soil absorbed and depleted the natural gas odorant, eliminating the opportunity for occupants to detect it.

5. Natural gas leaking from Atmos Energy Corporation's cracked gas main in the alley behind 3534 Espanola Drive migrated through the soil and into the house where it was ignited by an unknown source.

6. Dallas Fire-Rescue Department's initial misclassification of the first incident delayed the sharing of information that could have helped Atmos Energy Corporation identify the origin of the leak.

7. Had the Dallas Fire-Rescue Department arson investigators been adequately trained on natural gas systems, their investigation findings may have provided more timely and accurate assistance to Atmos Energy Corporation in locating the source of the gas leak.

8. Timely pressure testing of the customer piping by Atmos Energy Corporation could have eliminated potential sources of the gas leaks and helped focus their efforts on outside leak detection to locate the damaged and leaking gas system piping more quickly.

9. Atmos Energy Corporation did not adequately investigate the first two gas-related incidents that occurred at 3527 and 3515 Durango Drive.

10. Damage to the structure involved in the first incident on 3527 Durango Drive was consistent with a fuel gas/air mixture explosion, which was most likely caused by natural gas that migrated from underneath the structure.

11. Fuel gas was involved in both incident homes; there was insufficient evidence to exclude natural gas from Atmos Energy Corporation's system from either incident, evidence of leaks present prior to the first two incidents occurring, and the probability of two or three structure fires/explosions occurring independently on the same block during the same

week is very low. Therefore, the two prior incidents that occurred on the same block on subsequent days and the explosion at 3534 Espanola Drive were all likely related.

12. Limitations of the equipment and procedures due to the wet weather conditions on the ability of Atmos Energy Corporation to reliably detect the presence of leaked gas during its response to the first two incidents, and the number and severity of leaks identified following the first two incidents and prior to the explosion, should have prompted Atmos Energy Corporation to shut down or isolate the pipeline.

13. Had Atmos Energy Corporation pressure tested the main in the alley behind the first two incident homes on February 21 or 22, it could have found that the main did not hold pressure, spurring additional protective actions that could have prevented the fatal injury at 3534 Espanola Drive.

14. Atmos Energy Corporation's wet weather leak investigation procedures were insufficient given the known limitations of its equipment.

15. The assistance of the Dallas Fire-Rescue Department's Hazardous Materials Response Team, particularly after the second incident, could have enhanced Atmos Energy Corporation's leak investigation.

16. Had methane detectors been installed at the residences located on Durango and Espanola Drives, an alarm would have alerted residents to a gas release, reducing the potential for and consequences of the resulting natural gas fires and explosions.

17. The lack of official reporting of the first two incidents by Atmos Energy Corporation delayed the response from the regulatory authorities, the Railroad Commission of Texas and the Pipeline and Hazardous Materials Safety Administration.

18. The Pipeline and Hazardous Materials Safety Administration does not provide clear requirements regarding the level of investigation necessary to determine whether an event is subject to its reporting requirements, potentially resulting in the underreporting of natural gas incidents.

19. If Dallas Fire-Rescue Department reported the first two incidents in a timely manner, it could have prompted further investigation or regulatory oversight prior to the explosion.

20. The high number of leaks observed in northwest Dallas after the explosion were due to the degradation of Atmos Energy Corporation's gas distribution system, not sudden, unanticipated geologic loadings.

21. Atmos Energy Corporation did not adequately consider or mitigate against threats that were degrading its pipeline system, the likelihood of failure associated with these threats, or the potential consequences of such a failure as required by gas distribution integrity management requirements.

22. While Atmos Energy Corporation's periodic leak survey methodology and frequency complied with the minimum state and federal requirements, it did not identify the degraded system that was found after the explosion.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the explosion at 3534 Espanola Drive was the ignition of an accumulation of natural gas that leaked from the gas main that was damaged during a sewer replacement project 23 years earlier and was undetected by Atmos Energy Corporation's investigation of two related natural gas incidents on the 2 days prior to the explosion. Contributing to the explosion was Atmos Energy Corporation's insufficient wet weather leak investigation procedures. Contributing to the severity of the explosion was Atmos Energy Corporation's inaction to isolate the affected main and evacuate the houses. Contributing to the degradation of the pipeline system was Atmos Energy Corporation's inadequate integrity management program.

4. Recommendations

4.1 New Recommendations

To the Pipeline and Hazardous Materials Safety Administration:

Expand incident reporting requirements in Title 49 *Code of Federal Regulations* Part 191 so that events that may meet the definition of "incident" are immediately reported to the National Response Center even when the source of the natural gas has not been determined. (P-21-1)

Evaluate industry's implementation of the gas distribution pipeline integrity management requirements and develop updated guidance for improving their effectiveness. The evaluation should specifically consider factors that may increase the likelihood of failure such as age, increase the overall risk (including factors that simultaneously increase the likelihood and consequence of failure), and limit the effectiveness of leak management programs. (P-21-2)

Assist the Railroad Commission of Texas in conducting the audit recommended in Safety Recommendation P-21-4. (P-21-3)

To the Railroad Commission of Texas:

With assistance from the Pipeline and Hazardous Materials Safety Administration, conduct a comprehensive audit of Atmos Energy Corporation's incident-reporting practices; policies and procedures for responding to leaks, fires, explosions, and emergency calls; and integrity management programs. (P-21-4)

To the Dallas Fire-Rescue Department:

Revise the continuing education requirements for your arson investigators to include training on building fuel gas systems. (P-21-5)

Revise your procedures to require gas monitoring after the occurrence of a gas-related structure fire or explosion. (P-21-6)

Develop and implement a formal process to alert appropriate local, state, and federal agencies of potential systemic safety issues that should be investigated further. (P-21-7)

To Atmos Energy Corporation:

Provide initial and recurrent training to Dallas Fire-Rescue Department arson investigators and firefighters on the local natural gas distribution system and associated hazards. (P-21-8)

Develop and implement more rigorous inside leak investigation requirements in response to fires and explosions when gas involvement cannot be excluded, including clear guidance on pressure testing and inside gas measurements and the potential need to return to the property after firefighters have departed. (P-21-9)

Develop a clear procedure to coordinate with local emergency responders when investigating all fires and explosions that may be gas related to conclusively determine whether your system can be excluded as a potential contributor, and collecting the necessary evidence to support the conclusion of your investigations. (P-21-10)

Revise your policies and procedures for responding to leaks, fires, explosions, and emergency calls to address the challenges caused by wet weather conditions. The revised policies and procedures should include: (1) leak investigation methods that are reliable in wet weather; (2) leak investigation procedures that assess all viable gas migration paths; (3) criteria for when to shut down or isolate gas distribution systems and pressure test main and service lines; and (4) an alternate safe response such as evacuation when reliable leak investigations are not possible due to wet weather or other circumstances. (P-21-11)

Without delay, assess your integrity management program, paying particular attention to the areas identified in this investigation, and revise the program to appropriately consider: (1) threats that degrade a system over time, and (2) the increased risk that can result from factors that simultaneously increase the likelihood and consequence of failure. (P-21-12)

To the Gas Piping Technology Committee:

Develop additional guidance that identifies steps gas distribution operators can take to safely respond to leaks, fires, explosions, and emergency calls, considering the limitations due to wet weather conditions, that includes: (1) criteria for when to shut down or isolate gas distribution systems, pressure test main and service lines, and begin evacuations; (2) leak investigation methods that are reliable in wet weather, (3) require an alternate safe response, such as an evacuation when reliable leak investigations are not possible due to wet weather, and (4) leak investigations that assess all viable gas migration paths, including granular backfill and crawlspaces. (P-21-13)

Develop guidance that identifies steps that gas distribution operators can take to ensure that their gas distribution integrity management program, at a minimum, appropriately considers: (1) threats that degrade a system over time, and (2) the increased risk that can result from factors that simultaneously increase the likelihood and consequence of failure. (P-21-14)

4.2 Previously Issued Recommendations Reiterated in this Report

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)

This recommendation is currently classified "Open—Acceptable Response."

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)

This recommendation is currently classified "Open—Acceptable Alternate Response."

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)

This recommendation is currently classified "Open—Acceptable Response."

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ROBERT L. SUMWALT, III
Chairman

BRUCE LANDSBERG
Vice Chairman

JENNIFER HOMENDY
Member

MICHAEL GRAHAM
Member

THOMAS B. CHAPMAN
Member

Date: January 12, 2021

Member Jennifer Homendy filed the following concurring statement.

Board Member Statement

Board Member Jennifer Homendy filed the following concurring and dissenting (in part) statement on January 19, 2021.

I want to first thank staff and my colleagues for all their hard work on this investigation and in developing the findings, recommendations, and probable cause that were unanimously adopted at our January 12, 2021, Board Meeting. I believe, if implemented, these recommendations will prevent similar tragedies and injuries and save lives.

Respectfully, however, I disagree with Finding 6 and do not believe it should be in the final report. Finding 6 states, "Dallas Fire Rescue Department's initial misclassification of the first incident delayed the sharing of information that could have helped Atmos Energy Corporation identify the origin of the leak."

The emphasis in that finding is on Dallas Fire-Rescue's (DFR) initial misclassification of the first incident and its role in delaying Atmos Energy Corporation's (Atmos) response. I do not believe that DFR misclassified the incident. DFR initially responded to a call on a structure fire on February 21st and followed all their protocols for a structure fire response, including shutting off gas to the home. This also included contacting Atmos to have a technician respond to the scene so that Atmos could confirm that natural gas to the home was shut off and determine whether there was a natural gas leak. DFR also requested that an arson investigation team respond to the scene.

According to the head of Dallas Fire-Rescue Prevention and Investigation Bureau, while on scene, the job of the arson investigator is to interview witnesses and document the scene. This is the very beginning of the investigation process and no definitive conclusions are made during this period.

As stated in interview transcripts (see interviews with Dallas Fire-Rescue Arson Investigators 'D' and 'E'), when the two arson investigators arrived on scene, they were unable to obtain access to the area of the home where the fire occurred due to safety concerns, so their initial investigation focused on sketches of the home, photos, and interviews of the residents and neighbors. The resident who suffered serious injuries had been taken to the hospital, and, as I understand it from my conversation with the Director of our Office of Railroad, Pipeline, and Hazardous Materials Investigations, there was a language barrier between the outside arson investigator and the victim's 15-year-old son. As a result, the arson investigator was led to believe that there was a gas heater inside the home that exploded. It wasn't until March 2, after all three incidents occurred, that the arson investigators were able to interview the victim, which enabled them to determine there was no gas heater in the home and that the ignition source of the fire and explosion was the HVAC system.

As stated in interviews, it was still a preliminary investigation at the scene, much like our investigations, and required additional work to rule out accidental causes, such as an electrical fire, as mentioned in the interview of Dallas Fire-Rescue Arson Investigator 'D'. Like many of

our investigations, investigations take time, and when you don't have a key witness at the scene, that makes identifying a final classification in a report difficult. In fact, in interviews, Dallas Fire-Rescue Arson Investigator 'E' stated, "Well on this one because we weren't able to go in, we ruled it undetermined. If we don't put our – if we can't put our eyes on it, we can't make a sound judgment on exactly what happened. All we could do is go off the witnesses' testimony, utilizing those sketches and photos that we have."

This is consistent with National Fire Protection Association 921, *Guide for Fire Explosion Investigations:* "The use of a systematic approach often will uncover new factual data for analysis, which may require previous conclusions to be reevaluated." So, it is expected that the cause could change during the course of the investigation, much like our investigations. I'll note that our agency didn't initially believe the first two incidents were related to the third until we got deeper into the investigation.

I, therefore, disagree with the finding that it was "DFR's initial misclassification" that delayed the sharing of information that could have helped Atmos identify the origin of the leak. It's worth noting that none of the entities interviewed were asked specifically about such a delay.

The fact is, it was Atmos's responsibility to <u>independently</u> determine whether there was a gas leak. In fact, the Atmos senior service technician who had responded to the February 21 incident stated that he was told it was "probably gas related". Our investigators asked, "With it being gas related, would you have considered it that it could possibly have migrated up the line from, say, the main or the service line?" His response was, "Well I didn't pick up nothing in the detections, that we found – that I found out there anywhere." Upon further questioning, he stated he "would have performed additional bar holding or surveying" had he detected something.

The Atmos technician stated he could not enter the house and test the gas line because it would have been a danger to the fire personnel inside the house. Instead, he performed one bar hole test and surveyed for a gas leak and found nothing. He stayed on scene for 25 to 30 minutes and did not return, but should have to conduct more testing, given that there was a gas leak at the home weeks earlier, which Atmos had a record of. The technician stated that more bar hole testing was not possible due to the wet weather, which corresponds directly to our probable cause on Atmos's inadequate wet weather procedures.

The issue here is not that DFR misclassified the incident, but that Atmos failed to conduct additional and adequate testing, independent of DFR, and failed to have procedures in place to ensure the reliability of testing in wet weather conditions.

Thank you for the opportunity to share my views, and again I appreciate all the work of the staff and my colleagues leading up to the board meeting.

Appendixes

Appendix A. The Investigation

The National Transportation Safety Board (NTSB) was notified on the morning of February 23, 2018, that a single-family residence explosion occurred in the 3500 block of Espanola Drive, Dallas, Texas. Later, on the evening of February 23, 2018, the NTSB was notified that a second house had exploded in the days prior to the explosion. The NTSB launched an investigator-in-charge, and two team members to investigate the explosion.

Parties to the investigation included the Pipeline and Hazardous Materials Safety Administration, the Railroad Commission of Texas, Dallas Fire-Rescue Department, and Atmos Energy Corporation.

Appendix B. Consolidated Recommendation Information

Title 49 *United States Code* (*U.S.C.*) 1117(b) requires the following information on the recommendations in this report.

For each recommendation—

(1) a brief summary of the Board's collection and analysis of the specific accident investigation information most relevant to the recommendation;

(2) a description of the Board's use of external information, including studies, reports, and experts, other than the findings of a specific accident investigation, if any were used to inform or support the recommendation, including a brief summary of the specific safety benefits and other effects identified by each study, report, or expert; and

(3) a brief summary of any examples of actions taken by regulated entities before the publication of the safety recommendation, to the extent such actions are known to the Board, that were consistent with the recommendation.

To the Pipeline and Hazardous Materials Safety Administration:

Expand incident reporting requirements in Title 49 *Code of Federal Regulations* Part 191 so that events that may meet the definition of "incident" are immediately reported to the National Response Center even when the source of the natural gas has not been determined. (P-21-1)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.6.1. Atmos Incident Reporting. Information supporting (b)(1) can be found in section 2.6.1. Atmos Incident Reporting; (b)(2) is not applicable; and (b)(3) is not applicable.

Evaluate industry's implementation of the gas distribution pipeline integrity management requirements and develop updated guidance for improving their

effectiveness. The evaluation should specifically consider factors that increase the likelihood of failure such as age, increase the overall risk (including factors that simultaneously increase the likelihood and consequence of failure), and limit the effectiveness of leak management programs. (P-21-2)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.7. Integrity Management. Information supporting (b)(1) can be found in section 2.7. Integrity Management; (b)(2) can be found in section 2.7. Integrity Management; and (b)(3) is not applicable.

Assist the Railroad Commission of Texas in conducting the audit recommended in Safety Recommendation P-21-X. (P-21-3)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.3.2. Atmos's Investigation of the First Two Incidents (including subsections), section 2.3.3. NTSB's Evaluation of Causal Factors for the First Two Incidents, section 2.4. Leak Investigations and Repairs Prior to the Explosion, section 2.6.1. Atmos Incident Reporting, and section 2.7. Integrity Management. Information supporting (b)(1) can be found in section 2.3.2. Atmos's Investigation of the First Two Incidents (including subsections), section 2.3.3. NTSB's Evaluation of Causal Factors for the First Two Incidents, section 2.4. Leak Investigations and Repairs Prior to the Explosion, section 2.6.1. Atmos Incident Reporting, and section 2.7. Integrity Management; (b)(2) can be found in section 2.7. Integrity Management; and (b)(3) is not applicable.

To the Railroad Commission of Texas:

With assistance from the Pipeline and Hazardous Materials Safety Administration, conduct a comprehensive audit of Atmos Energy Corporation's incident reporting practices; policies and procedures for responding to leaks, fires, explosions, and emergency calls; and integrity management programs. (P-21-4)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.3.2. Atmos's Investigation of the First Two Incidents (including subsections), section 2.3.3. NTSB's Evaluation of Causal Factors for the First Two Incidents, section 2.4. Leak Investigations and Repairs Prior to the Explosion, section 2.6.1. Atmos Incident Reporting, and section 2.7. Integrity Management. Information supporting (b)(1) can be found in section 2.3.2. Atmos's Investigation of the First Two Incidents (including subsections), section 2.3.3. NTSB's Evaluation of Causal Factors for the First Two Incidents, section 2.4. Leak Investigations and Repairs Prior to the Explosion, section 2.6.1. Atmos Incident Reporting, and section 2.7. Integrity Management; (b)(2) can be found in section 2.7. Integrity Management; and (b)(3) is not applicable.

To the Dallas Fire-Rescue Department:

Revise the continuing education requirements for your arson investigators to include training on building fuel gas systems. (P-21-5)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.3.1. DFR's Investigation of the First Two Incidents. Information supporting (b)(1) can be found in section 2.3.1. DFR's Investigation of the First Two Incidents; (b)(2) is not applicable; and (b)(3) is not applicable.

Revise your procedures to require gas monitoring after the occurrence of a gas-related structure fire or explosion. (P-21-6)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4. Leak Investigations and Repairs Prior to the Explosion. Information supporting (b)(1) can be found in section 2.4. Leak Investigations and Repairs Prior to the Explosion; (b)(2) is not applicable; and (b)(3) is not applicable.

Develop and implement a formal process to alert appropriate local, state, and federal agencies of potential systemic safety issues that M-MG should be investigated further. (P-21-7)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.6.2. DFR Incident Reporting. Information supporting (b)(1) can be found in section 2.6.2. DFR Incident Reporting; (b)(2) is not applicable; and (b)(3) is not applicable.

To Atmos Energy Corporation:

Provide initial and recurrent training to the Dallas Fire-Rescue Department arson investigators and firefighters on the local natural gas distribution system and associated hazards. (P-21-8)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.3.1. DFR's Investigation of the First Two Incidents. Information supporting (b)(1) can be found in section 2.3.1. DFR's Investigation of the First Two Incidents; (b)(2) is not applicable; and (b)(3) is not applicable.

Develop and implement more rigorous inside leak investigation requirements in response to fires and explosions when gas involvement cannot be excluded, including clear guidance on pressure testing and inside gas measurements, and the potential need to return to the property after firefighters have departed. (P-21-9)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.3.2.1. Inside Leak Investigation. Information supporting (b)(1) can be found in section 2.3.2.1. Inside Leak Investigation; (b)(2) is not applicable; and (b)(3) is not applicable.

Develop a clear procedure to coordinate with local emergency responders when investigating all fires and explosions that may be gas related to conclusively determine whether your system can be excluded as a potential contributor, and collecting the necessary evidence to support the conclusion of your investigations. (P-21-10)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.3.2. Atmos's Investigation of the First Two Incidents (including subsections), section 2.3.3. NTSB's Evaluation of Causal Factors for the First Two Incidents. Information supporting (b)(1) can be found in section 2.3.2. Atmos's Investigation of the First Two Incidents (including subsections), section 2.3.3. NTSB's Evaluation of Causal Factors for the First Two Incidents; (b)(2) is not applicable; and (b)(3) is not applicable.

> Revise your policies and procedures for responding to leaks, fires, explosions, and emergency calls, to address the challenges caused by wet weather conditions. The revised policies and procedures should include: (1) leak investigation methods that are reliable in wet weather; (2) leak investigation procedures that assess all viable gas migration paths; (3) criteria for when to shut down or isolate gas distribution systems and pressure test main and service lines; and (4) an alternate safe response such as evacuation when reliable leak investigations are not possible due to wet weather or other circumstances. (P-21-11)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4. Leak Investigations and Repairs Prior to the Explosion. Information supporting (b)(1) can be found in section 2.4. Leak Investigations and Repairs Prior to the Explosion; (b)(2) is not applicable; and (b)(3) is not applicable.

> Without delay, assess your integrity management program, paying particular attention to the areas identified in this investigation, and revise the program to appropriately consider: (1) threats that degrade a system over time, and (2) the increased risk that can result from factors that simultaneously increase the likelihood and consequence of failure. (P-21-12)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.7. Integrity Management. Information supporting (b)(1) can be found in section 2.7. Integrity Management; (b)(2) is not applicable; and (b)(3) is not applicable.

To the Gas Piping Technology Committee:

> Develop additional guidance that identifies steps gas distribution operators can take to safely respond to leaks, fires, explosions, and emergency calls, considering the limitations due to wet weather conditions, that includes: (1) criteria for when to shut down or isolate gas distribution systems, pressure test main and service lines, and begin evacuations; (2) leak investigation methods that are reliable in wet weather; (3) require an alternate safe response, such as an evacuation when reliable leak investigations are not possible due to wet weather; and (4) leak investigations that assess all viable gas migration paths, including granular backfill and crawlspaces. (P-21-13)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.4. Leak Inspections and Repairs Prior to the Explosion. Information supporting (b)(1) can be found in section 2.4. Leak Inspections and Repairs Prior to the Explosion; (b)(2) is not applicable; and (b)(3) is not applicable.

> Develop guidance that identifies steps that gas distribution operators can take to ensure that their gas distribution integrity management program, at a minimum, appropriately considers: (1) threats that degrade a system over time, and (2) the increased risk that can result from factors that simultaneously increase the likelihood and consequence of failure. (P-21-14)

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in section 2.7. Integrity Management. Information supporting (b)(1) can be found in section 2.7. Integrity Management; (b)(2) is not applicable; and (b)(3) is not applicable.

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