Overpressurization of Natural Gas Distribution System, Explosions, and Fires in Merrimack Valley, Massachusetts September 13, 2018

Accident Report

NTSB/PAR-19/02
PB2019-101365

National Transportation Safety Board

NTSB/PAR-19/02
PB2019-101365
Notation 59529
Adopted September 24, 2019

Pipeline Accident Report

Overpressurization of Natural Gas Distribution System, Explosions, and Fires in Merrimack Valley, Massachusetts September 13, 2018

National Transportation Safety Board

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

National Transportation Safety Board. 2019. *Overpressurization of Natural Gas Distribution System, Explosions, and Fires in Merrimack Valley, Massachusetts, September 13, 2018*. Pipeline Accident Report NTSB/PAR-19/02. Washington, DC.

Abstract: On September 13, 2018, about 4:00 p.m. local time, a series of structure fires and explosions occurred after high-pressure natural gas was released into a low-pressure natural gas distribution system in the northeast region of the Merrimack Valley in the Commonwealth of Massachusetts. The natural gas distribution system was owned and operated by Columbia Gas of Massachusetts, a subsidiary of NiSource, Inc. Columbia Gas of Massachusetts delivers natural gas to about 325,000 customers in Massachusetts. One person was killed and 22 individuals, including three firefighters, were transported to local hospitals due to injuries; seven other firefighters incurred minor injuries. The fires and explosions damaged 131 structures, including at least 5 homes that were destroyed in the city of Lawrence and the towns of Andover and North Andover. Most of the damage occurred from fires ignited by natural gas-fueled appliances; several of the homes were destroyed by natural gas-fueled explosions. Fire departments from the three municipalities were dispatched to the fires and explosions. First responders initiated the Massachusetts fire-mobilization plan and received mutual aid from neighboring districts in Massachusetts, New Hampshire, and Maine. Emergency management officials had the electric utility shut down electrical power in the area, the state police closed local roads, and freight and passenger railroad operations in the area were suspended. Columbia Gas of Massachusetts shut down the low-pressure natural gas distribution system, affecting 10,894 customers, including some outside the area who had their service shut off as a precaution. The National Transportation Safety Board made new recommendations to the Pipeline and Hazardous Materials Safety Administration; the 31 states with an industrial exemption for natural gas infrastructure projects; the Commonwealth of Massachusetts Executive Office of Public Safety and Security; and NiSource, Inc.

The National Transportation Safety Board (NTSB) is an independent federal agency dedicated to promoting aviation, railroad, highway, marine, and pipeline safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable causes of the accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The NTSB makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

The NTSB does not assign fault or blame for an accident or incident; rather, as specified by NTSB regulation, "accident/incident investigations are fact-finding proceedings with no formal issues and no adverse parties … and are not conducted for the purpose of determining the rights or liabilities of any person." 49 C.F.R. § 831.4. Assignment of fault or legal liability is not relevant to the NTSB's statutory mission to improve transportation safety by investigating accidents and incidents and issuing safety recommendations. In addition, statutory language prohibits the admission into evidence or use of any part of an NTSB report related to an accident in a civil action for damages resulting from a matter mentioned in the report. 49 U.S.C. § 1154(b).

For more detailed background information on this report, visit the NTSB investigation website and search for NTSB accident ID PLD18MR003. Recent publications are available in their entirety on the Internet at the NTSB website. Other information about available publications also may be obtained from the website or by contacting:

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

NTSB publications may be purchased from the National Technical Information Service. To purchase this publication, order product number PB2019-101308 from:

National Technical Information Service, 5301 Shawnee Rd., Alexandria, VA 22312, (800) 553-6847 or (703) 605-6000, NTIS website.

NOTE: This report was reissued on November 7, 2019, with corrections to page 60 to remove NiSource employee information.
NOTE: This report was reissued on November 20, 2019, with corrections to page 30 and 31 to add a citation to Table 4.

Contents

Figures

Tables

Acronyms and Abbreviations

AGA	American Gas Association
ANSI	American National Standards Institutes
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
CFR	*Code of Federal Regulations*
CMA	Columbia Gas of Massachusetts
CoMIRS	Commonwealth of Massachusetts Interoperable Radio System
DPU	Massachusetts Department of Public Utilities
EOC	emergency operations center
ERP	emergency response plans
FMEA	failure modes and effects analysis
FOL	field operations leader
GIS	geographic information system
IC	incident commander
LFE	leader of field engineering
M&R	Measurement and Regulation
MAOP	maximum allowable operating pressure
MEMA	Massachusetts Emergency Management Agency
MOC	management of change
NG	National Grid United States
NCEES	National Council of Examiners for Engineering and Surveying
NSPE	National Society of Professional Engineers
NTSB	National Transportation Safety Board

ON	Operational Notice
OQ	operator qualification
P.E.	professional engineer
PHMSA	Pipeline and Hazardous Materials Safety Administration
PSAP	Public Safety Answering Points
psi	pounds per square inch
psig	pounds per square inch, gauge
PSMS	Pipeline Safety Management Systems
RP	Recommended Practice
RSPA	Research and Special Programs Administration
SCADA	Supervisory Control and Data Acquisition system
SCIP	Statewide Communications Interoperability Plan
SMS	safety management systems
w.c.	water column
WMS	work management system

Executive Summary

On September 13, 2018, about 4:00 p.m. local time, a series of structure fires and explosions occurred after high-pressure natural gas was released into a low-pressure natural gas distribution system in the northeast region of the Merrimack Valley in the Commonwealth of Massachusetts. The natural gas distribution system was owned and operated by Columbia Gas of Massachusetts, a subsidiary of NiSource, Inc. Columbia Gas of Massachusetts delivers natural gas to about 325,000 customers in Massachusetts. One person was killed and 22 individuals, including three firefighters, were transported to local hospitals due to injuries; seven other firefighters incurred minor injuries. The fires and explosions damaged 131 structures, including at least 5 homes that were destroyed in the city of Lawrence and the towns of Andover and North Andover. Most of the damage occurred from fires ignited by natural gas-fueled appliances; several of the homes were destroyed by natural gas-fueled explosions. Fire departments from the three municipalities were dispatched to the fires and explosions. First responders initiated the Massachusetts fire-mobilization plan and received mutual aid from neighboring districts in Massachusetts, New Hampshire, and Maine. Emergency management officials had National Grid United States (the electric utility) shut down electrical power in the area, the state police closed local roads, and freight and passenger railroad operations in the area were suspended. Columbia Gas of Massachusetts shut down the low-pressure natural gas distribution system, affecting 10,894 customers, including some outside the area who had their service shut off as a precaution.

The accident investigation focused on the following safety issues:

- Adequacy of natural gas regulations
- Project documentation
- Constructability review
- Project management
- Risk assessment
- Safety management systems
- Licensed professional engineer approval of natural gas projects
- Emergency response

The National Transportation Safety Board determines that the probable cause of the overpressurization of the natural gas distribution system and the resulting fires and explosions was Columbia Gas of Massachusetts' weak engineering management that did not adequately plan, review, sequence, and oversee the construction project that led to the abandonment of a cast iron main without first relocating regulator sensing lines to the new polyethylene main. Contributing to the accident was a low-pressure natural gas distribution system designed and operated without adequate overpressure protection.

1. Factual Information

1.1 Accident Synopsis

On September 13, 2018, about 4:00 p.m. local time, a series of structure fires and explosions occurred after high-pressure natural gas was released into a low-pressure natural gas distribution system in the northeast region of the Merrimack Valley in the Commonwealth of Massachusetts. The natural gas distribution system was owned and operated by Columbia Gas of Massachusetts (CMA), a subsidiary of NiSource, Inc. CMA delivers natural gas to about 325,000 customers in Massachusetts. The fires and explosions damaged 131 structures, including at least 5 homes that were destroyed in the city of Lawrence and the towns of Andover and North Andover. (See figure 1.) Most of the damage occurred from fires ignited by natural gas-fueled appliances; several of the homes were destroyed by natural gas-fueled explosions. Fire departments from the three municipalities were dispatched to the fires and explosions. First responders initiated the Massachusetts fire-mobilization plan and received mutual aid from neighboring districts in Massachusetts, New Hampshire, and Maine. Emergency management officials had National Grid United States (NG) (the electric utility) shut down electrical power in the area, the state police closed local roads, and freight and passenger railroad operations in the area were suspended. CMA shut down the low-pressure natural gas distribution system, affecting 10,894 customers, including some outside the affected area who had their service shut off as a precaution.

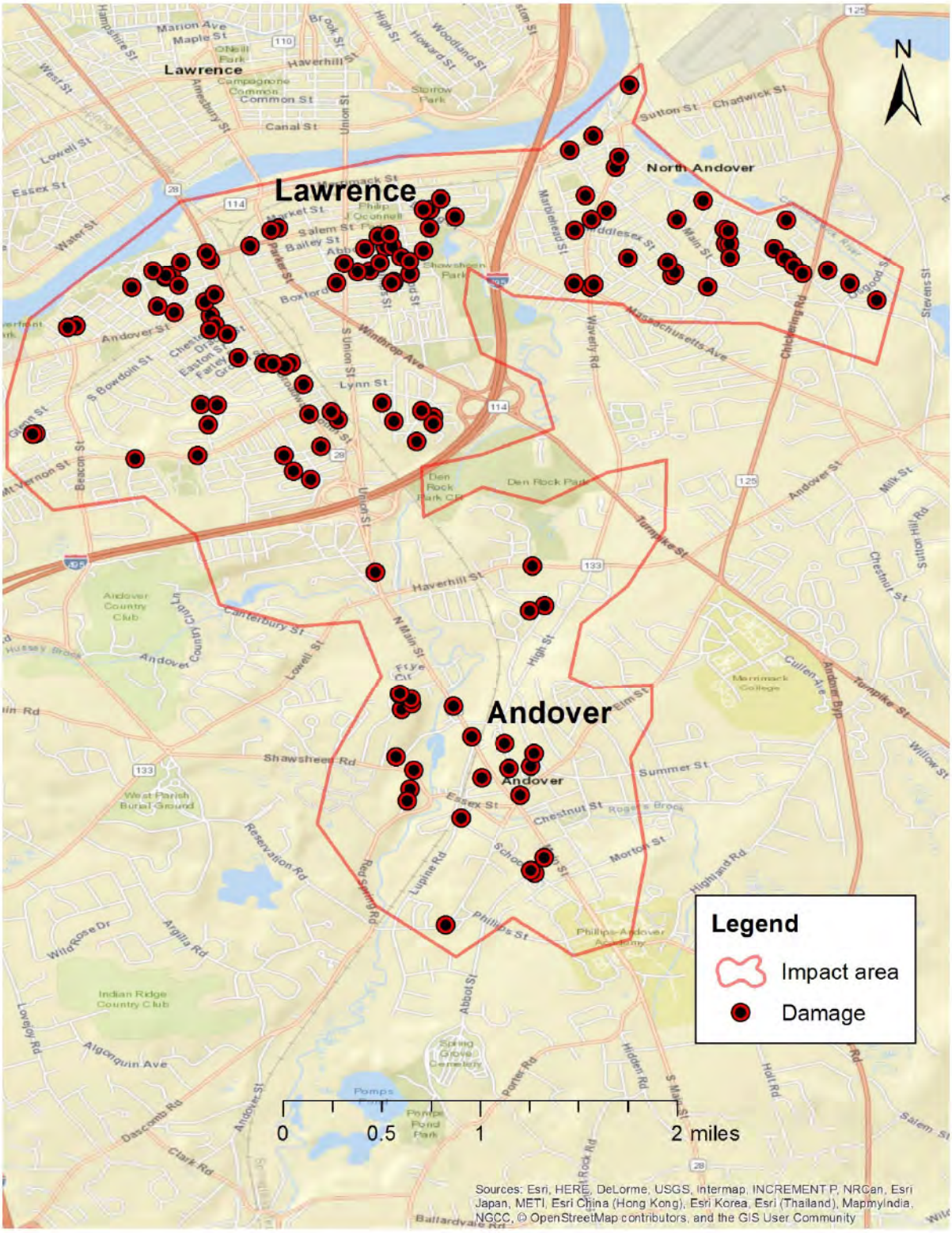

Figure 1. Map of the damaged structures in the area impacted by the overpressurization.

An 18-year-old male was killed when a home exploded, and the chimney fell onto the vehicle where he was sitting. (See figure 2.) Another person in the vehicle at the time of the

explosion was seriously injured, as was someone on the second floor of the house. In total, 22 people, including 3 firefighters, were transported to hospitals for treatment of their injuries. Injuries included respiratory injuries related to smoke inhalation from fires and musculoskeletal injuries from evacuating. Some people were transported to hospitals to maintain ongoing medical treatment that could not be continued in their homes because of the shutdown of natural gas and electricity and the evacuation of residents.

Figure 2. Remnants of house where the fatality and two severe injuries occurred.

1.2 Background

1.2.1 NiSource

NiSource, Inc. is an Indiana-based energy holding company whose subsidiaries are regulated natural gas and electric utility companies serving about 3.9 million customers in seven states.[1] Its natural gas distribution operations comprise about 60,000 miles of pipeline and include 732 low-pressure natural gas distribution systems. NiSource's Massachusetts subsidiary, CMA,

[1] NiSource is the successor to a corporation organized in 1987 under the name of Northern Indiana Public Service Company Industries, Inc., which changed its name to NiSource in 1999.

delivers natural gas to over 325,000 natural gas customers in southeastern Massachusetts, the greater Springfield area, and the Merrimack Valley.[2]

1.2.2 Feeney Brothers

CMA contracted with Feeney Brothers, a pipeline services firm, to work on a CMA project to replace an existing cast iron main with a polyethylene main.[3] About 7:00 a.m. on the day of the accident, a CMA construction coordinator, along with four employees of Feeney Brothers, arrived at Salem and South Union Streets in Lawrence, Massachusetts, to continue work on this project. The work they performed that day led to the overpressurization of the natural gas distribution system. All crewmembers were trained and qualified in accordance with the Pipeline Operator Qualification Rule, commonly known as OQ.[4] Following the accident, the contractor crewmembers, along with the CMA construction coordinator, were alcohol and drug tested in accordance with Title 49 *Code of Federal Regulations* (*CFR*) Part 199. The test results were negative for alcohol or other drugs.

1.2.3 Natural Gas Distribution Systems

Natural gas distribution systems deliver natural gas to customers for heating, cooking, lighting, and other uses. A basic distribution system has three elements: (1) natural gas mains that transport natural gas underground, (2) service lines that deliver natural gas from the mains to customers, and (3) meters that measure the quantity of natural gas used by each customer. Customer piping takes natural gas from the meter to customer's appliances where it is used. To minimize service interruptions, normal maintenance and natural gas distribution system upgrades are typically performed with the system operating.

Both low-pressure and high-pressure natural gas distribution systems are used to supply natural gas to customers. In a low-pressure natural gas distribution system, the natural gas in the mains is essentially the same pressure as the pressure provided to the customer's piping and used by the appliances. Natural gas is typically supplied to the mains from a high-pressure source through a regulator station that reduces the pressure to that required by the customers. The low-pressure natural gas distribution system in the Merrimack Valley was installed in the early 1900s with cast iron mains. The system used 14 regulator stations to supply natural gas to the mains and control pressure.[5] The regulator stations each contained two regulators in series—a worker regulator and a monitor regulator—each with a sensing line that feeds back the pressure in the main to the regulator, forming a redundant closed-loop control system. The worker regulator is the primary regulator that maintains the natural gas pressure, and the monitor regulator provides a redundant backup to the worker regulator. Each of the regulator stations reduced the natural gas

[2] Although CMA had internal guidance documents specifically for its employees, NiSource also had guidance documents that employees in all its subsidiaries were required to follow. In this report, guidance documents are identified accordingly.

[3] Feeney Brothers, a utility services firm headquartered in Dorchester, Massachusetts, was established in 1988 and employs over 700 employees and operates throughout Massachusetts, Connecticut, and New York.

[4] Title 49 *Code of Federal Regulations* (*CFR*) Part 192, Subpart N.

[5] *Regulator stations* house the worker and monitor regulators that are used to maintain natural gas pressure.

pressure from about 75 pounds per square inch gauge (psig) to 12 inches of water column (w.c.), about 0.5 psig, for distribution through the mains and delivery to customers.[6]

Since the regulator stations are the primary means of pressure control in the low-pressure systems, an overpressure condition in a natural gas distribution system could affect all customers served by the system. This is an inherent weakness of a low-pressure natural gas distribution system.

Figure 3 shows a typical arrangement for the low-pressure natural gas distribution system used in the Merrimack Valley before the accident.

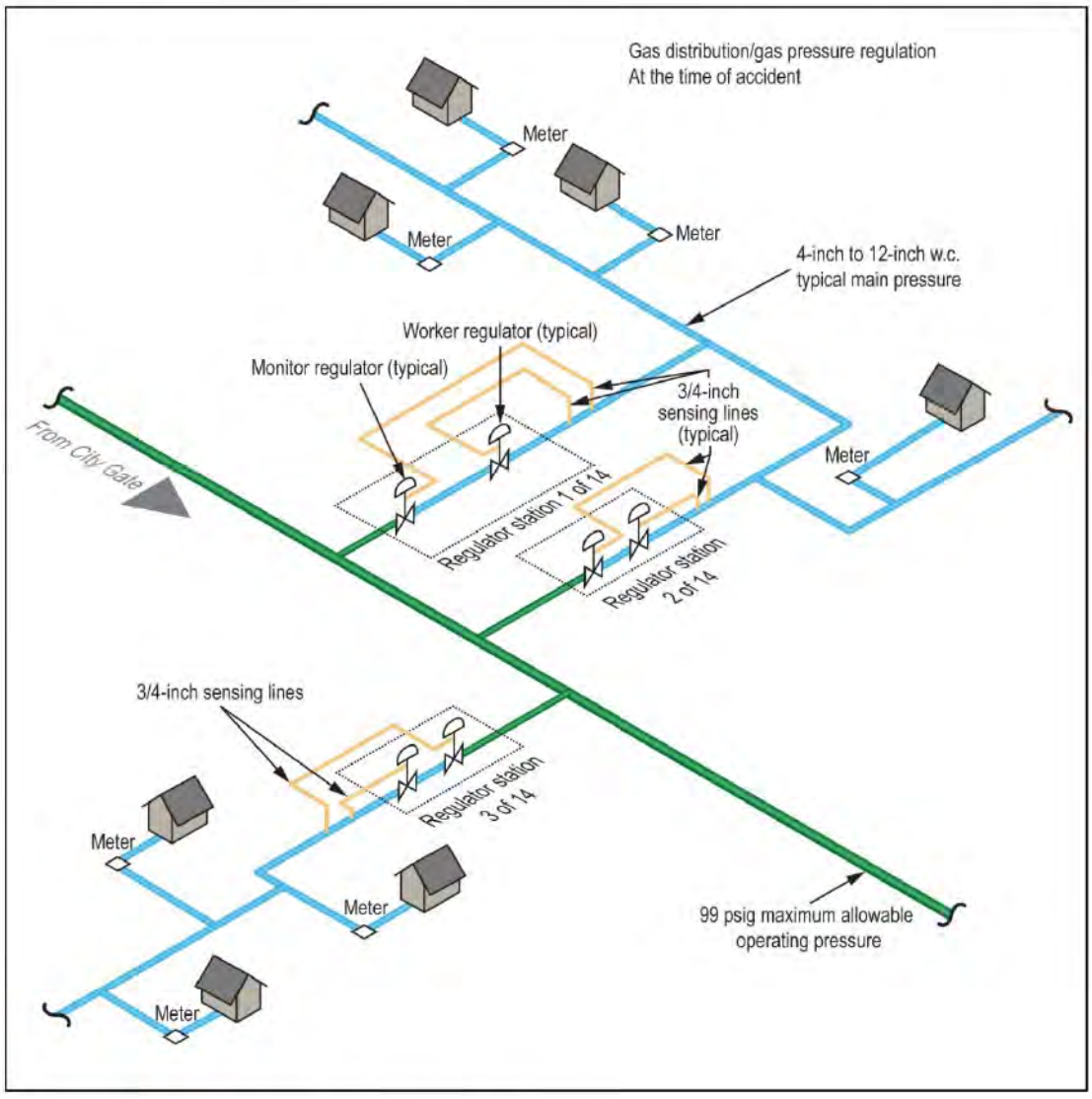

Figure 3. Typical configuration of the Merrimack Valley low-pressure natural gas distribution system.

[6] In the pipeline industry, it is customary to measure anything less than 1 psig in inches of water column. A measurement of 1 inch w.c. equals 0.0361 psig.

In a high-pressure natural gas distribution system, the natural gas pressure in the main is substantially higher than that required by the customer. A pressure regulator is installed at each meter to reduce the pressure. These regulators incorporate an overpressure protection device to prevent overpressurization of the customer's piping and appliances should the regulator fail. Additionally, excess flow valves are installed in the service line.[7] Because each customer's service in a high-pressure natural gas distribution system is protected by an excess flow valve and a pressure regulator, it is highly unlikely that an overpressure condition in the main would impact multiple customers. Figure 4 shows a typical high-pressure natural gas distribution system. This is the type of natural gas distribution system that was installed postaccident in the Merrimack Valley.

[7] An *excess flow valve* is a mechanical safety device installed on a gas service line to a residence or small commercial gas customer. In the event of damage to the gas service line between the street and the meter, the excess flow valve will minimize the flow of gas through the service line. Current federal regulations require a gas distribution company to install such a device on new or replacement service lines for single-family residences and certain multifamily and commercial buildings where the service line pressure is above 10 psig. See 49 *CFR* 192.383 for specific requirements.

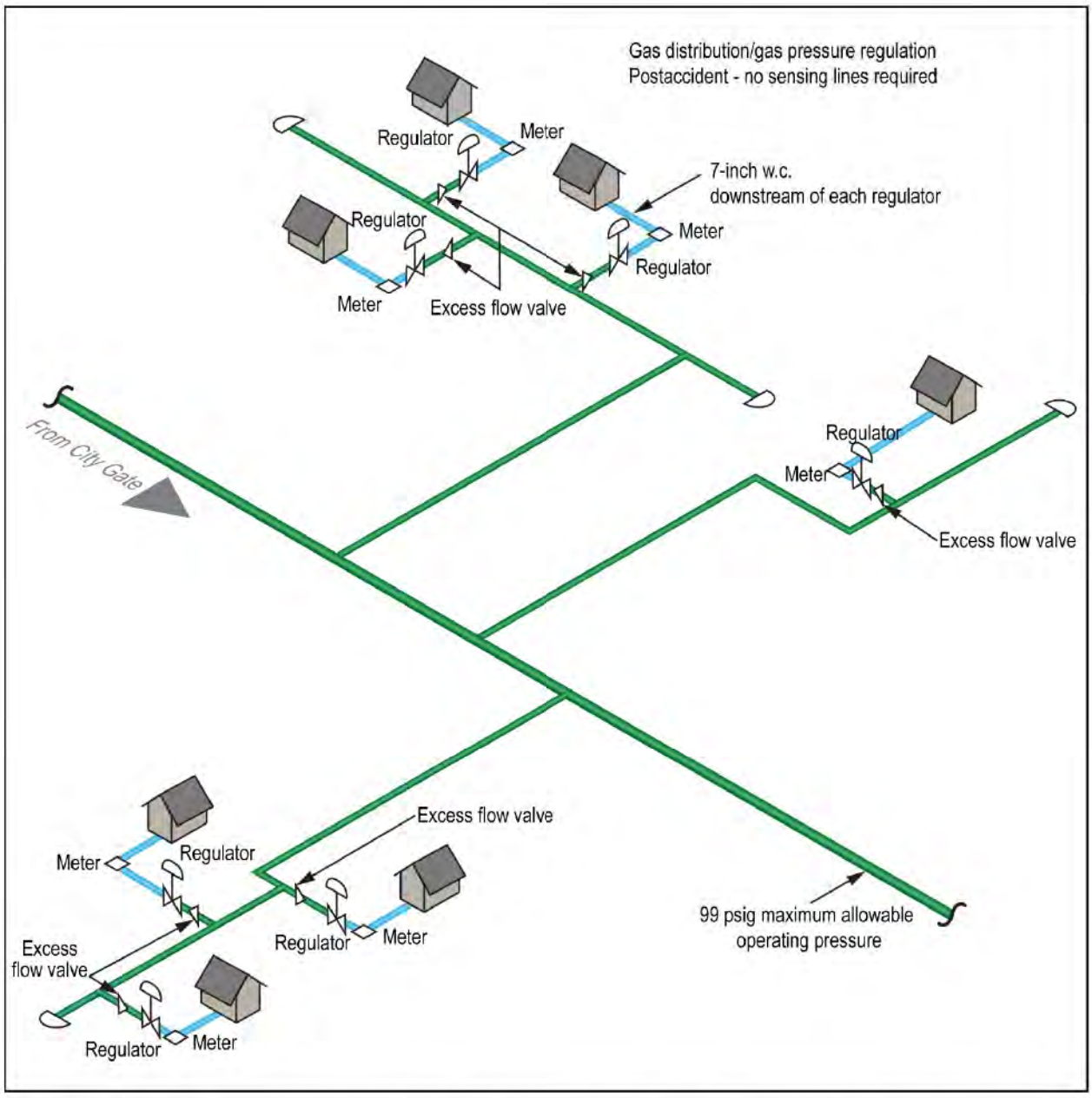

Figure 4. Typical configuration of high-pressure natural gas distribution system installed postaccident.

1.3 Events Preceding the Overpressure

About 7:00 a.m. on the day of the accident, a CMA construction coordinator, along with four employees of Feeney Brothers, arrived at Salem and South Union Streets in Lawrence, Massachusetts, to continue work on a CMA project to replace an existing cast iron main with a polyethylene main.

The crew completed the installation according to the CMA work plan, placed the new tie-ins into service, and isolated the existing cast iron main shortly before 4:00 p.m., by closing

valves on a 2-inch plastic bypass pipe between the cast iron and polyethylene mains.[8] The crew then cut the bypass pipe to abandon the cast iron main. (See figure 5.) In postaccident interviews, crewmembers said that within minutes of closing the valves and cutting the bypass, they observed the pressure gauge on the polyethylene main exceed the expected readings.[9] Furthermore, a fitting on the polyethylene natural gas main blew off into the hand of one of the workers. The crewmembers said that they responded quickly to plug the blowing natural gas, and they heard emergency vehicles in the neighborhood and observed smoke plumes in multiple directions within minutes.

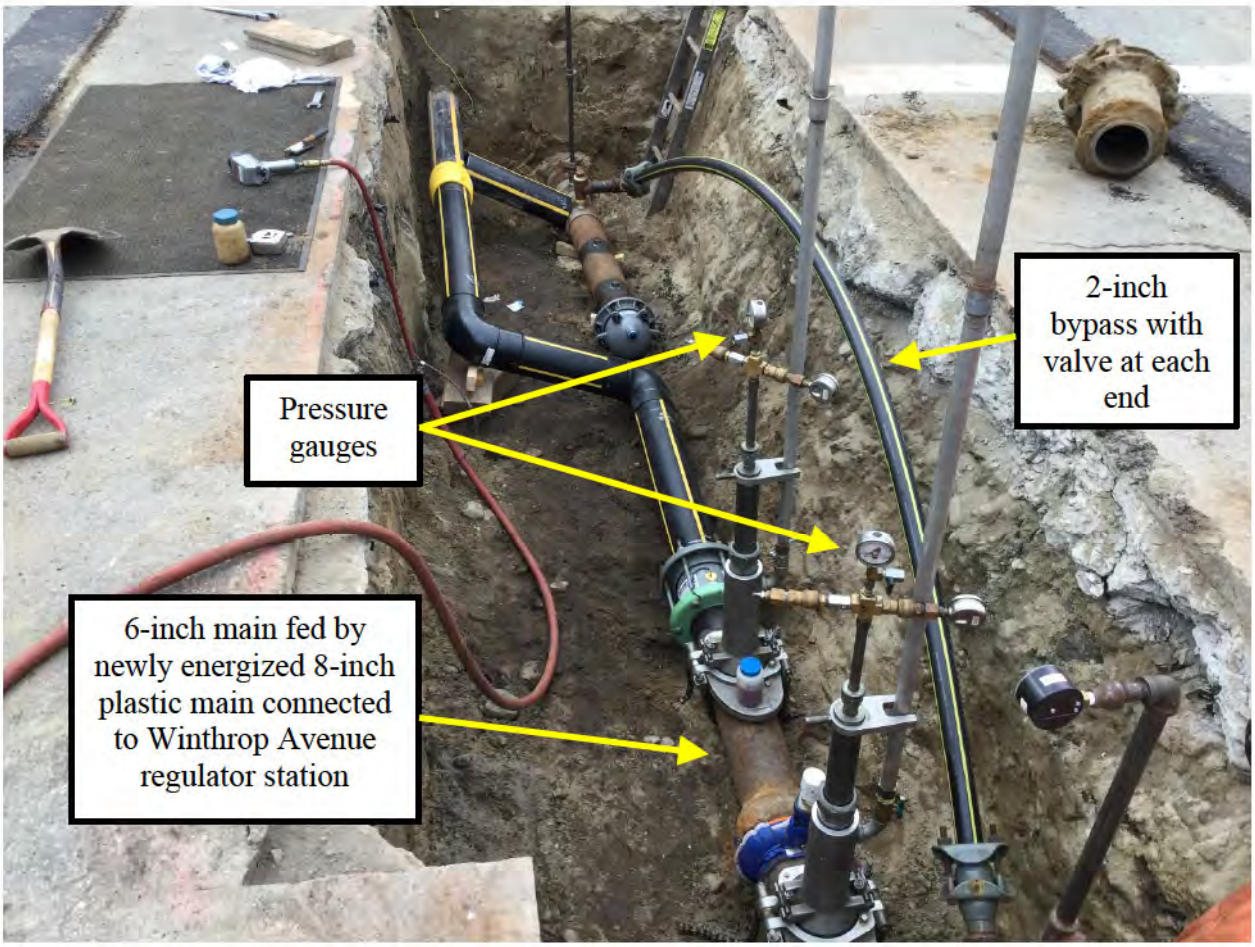

Figure 5. Salem Street tie-in for the South Union Street project (looking west). Photograph courtesy of Feeney Brothers.

At the Winthrop Avenue regulator station, about 0.5 mile south of the work area, the abandoned cast iron main was still connected to the regulator sensing lines providing input to the two pressure regulators used to control the system pressure.[10] (See figure 6.) Once the contractor

[8] A *tie-in* involves connecting new piping to existing piping. In this case, the main ran north and south while the branches ran east and west. When the main was replaced, the east and west branches needed to be tied into the new main.

[9] Supporting documentation referenced in this report can be found in the public docket for this accident, accessible from the NTSB Accident Dockets web page by searching PLD18MR003.

[10] *Sensing lines* are also called *control lines* or *static lines*.

crew isolated the cast iron main, the natural gas pressure began to drop in the cast iron main and in the regulator sensing lines. As the pressure dropped, the pressure regulators responded by opening further, increasing pressure in the natural gas distribution system. Since the Winthrop Avenue regulators no longer sensed system pressure, they fully opened, allowing high-pressure natural gas to be released into the low-pressure natural gas distribution system.

Figure 6. Location of September 13, 2018, tie-in and the Winthrop Avenue regulator station.

1.4 Emergency Response

1.4.1 Local and State Response

The overpressurization of the low-pressure natural gas distribution system in the Merrimack Valley impacted over 10,000 natural gas customers in three municipalities—Lawrence, North Andover, and Andover. The emergency call centers in these municipalities, known as public safety answering points (PSAP) began receiving 9-1-1 calls immediately following the overpressurization from residents and businesses reporting fires and explosions and requesting assistance.

Shortly after 4:00 p.m., the fire departments in Lawrence, North Andover, and Andover were inundated with emergency calls reporting structure fires and explosions. Within the first 30 minutes, all three fire departments had exhausted their list of mutual aid. The incident commanders (IC) from all three fire departments, who were either the fire chief or deputy chief,

told National Transportation Safety Board (NTSB) investigators they had never responded to a natural gas accident of this magnitude. Table 1 shows information on the local fire response from each of these municipalities.

Table 1. Local fire response.

Municipality	Time of notification	Number of stations	Number of responding firefighters	Number of injured firefighters
Lawrence	4:11 p.m.	6	124	4
Andover	4:19 p.m.	3	68	0
North Andover	4:13 p.m.	3	44	1

In Massachusetts, municipalities determine their own emergency radio communications and resources because Massachusetts Home Rule grants them the responsibility for the welfare of their residents.[11] The Commonwealth of Massachusetts Interoperable Radio System (CoMIRS) is a statewide network of connected but individually managed radio systems and dispatch networks that supports over 30,000 devices statewide. The Massachusetts State Police and North Andover use CoMIRS, but Lawrence and Andover do not.

Once the 10th alarm level was reached, a request to the Massachusetts Emergency Management Agency (MEMA) to activate the statewide Fire Mobilization Plan was triggered. The plan activated 15 task forces across the state, and over 180 fire departments and 140 law enforcement agencies responded to the scene.

Massachusetts State Police also responded to the affected area after receiving emergency calls. During the next 24 hours, they dispatched over 200 officers, which included detectives, members of the fire and explosion group, and crime-scene technicians. A total of 362 uniformed assets were deployed in the subsequent 4 days. They assisted in closing portions of Interstate 495, State Route 28, and State Route 114, and the police also escorted firefighters and technicians into the affected area.

Shortly after 4:00 p.m., the Massachusetts State Fire Marshal was notified of the natural gas events. Unified command was initiated and collaboratively operated by the Massachusetts State Fire Marshal and the director of MEMA and was staged in South Lawrence.[12]

About 5:20 p.m., NG received the first of several requests from CMA using a priority phone number to shut down electricity in the area to reduce sources that could ignite the released natural gas.

The mayor of Lawrence issued an evacuation order for areas south of the Merrimack River. The evacuation alert was issued over cell phones and media broadcasts to residents in the area. North Andover authorities issued a voluntary evacuation for all occupied structures with natural

[11] According to the National Association of Counties, *home rule* "gives local government the capability to shape the way it serves the needs of its constituency (Coester 2004)."

[12] In an IC system, a *unified command* is an authority structure in which the role of the IC is shared by two or more individuals, each already having authority in a different responding agency.

gas utility service, using local cable channels, the town website, and a citizen alert telephone system to send public service messages.[13] The Andover fire chief called for an evacuation using a citizen alert telephone system and social media, and instructed residents to turn off natural gas service meters if they knew how to and to evacuate if they did not feel safe or smelled natural gas. In total, over 50,000 residents were asked to evacuate following the overpressurization (MEMA 2018). Five centers were set up in the three municipalities to receive displaced people; four of the centers became overnight shelters and remained open for several days. Although residents were allowed to return to their homes in all three municipalities on September 16, 2018, 3 days after the accident, many were uninhabitable at that time. As explained in section 1.4.3, many residents were unable to live in their homes for several months after the accident.

1.4.2 Columbia Gas Response

On September 13, the NiSource Gas Systems Control monitoring center in Columbus, Ohio, received pressure alarms on its supervisory control and data acquisition (SCADA) system, which recorded a sudden increase of pressure in the Merrimack Valley low-pressure natural gas distribution system at 3:57 p.m. The SCADA capability was only able to monitor system pressures; it was unable to remotely control the natural gas system.[14]

The first SCADA high-pressure alarm activated at 4:04 p.m. for the South Lawrence regulator station, noting a pressure of 15.02 inches w.c.[15] A second high-pressure alarm activated for the Riverina SCADA pressure-monitoring center in Andover, noting a pressure of 16.94 inches w.c. at 4:05 p.m. The controller acknowledged both alarms and called the on-call technician for the CMA measurement and regulation (M&R) department at 4:06 p.m. A rate-of-change alarm was activated at 4:07 p.m., as well as a high-high pressure alarm at 4:08 p.m. for the Riverina station, which the controller acknowledged immediately.[16] At 4:16 p.m., the CMA on-call technician reported to the monitoring center that he saw smoke and explosions from a distance.

In response to the phone call from the SCADA center, the Lawrence technician called the M&R technicians about the alarms at 4:06 p.m. The M&R technicians immediately responded to perform field checks on the affected 14 regulator stations in the Merrimack Valley natural gas distribution system to identify and shut down any station that was feeding high-pressure natural gas into the system. At 4:30 p.m., one of the M&R technicians at the Winthrop Avenue regulator station heard a loud sound and recognized that a large quantity of natural gas was flowing through the regulators there. He adjusted the setpoint on the two regulators to reduce flow and isolated them. He noticed that the sound of the flowing natural gas began to decrease.

[13] The alert system automatically called every landline. Cell phones and private numbers had to be registered.
[14] The natural gas distribution system complies with all applicable regulatory requirements.
[15] Interviews with NiSource controllers defined a *high-pressure alarm* as elevated pressure in the system and *high-high pressure* is when the pressure in the system has reached its maximum allowable operating pressure (MAOP).
[16] A rate-of-change alarm is triggered by a rapid change in pressure.

A CMA field engineer and the CMA field operations leader (FOL) were at another construction site when they received notification at 4:18 p.m. to contact the CMA construction department, from whom they learned that fires were coming out of house chimneys.[17]

Due to traffic congestion, a police officer escorted the FOL toward the work site at Salem and South Union Streets. The FOL arrived around 5:08 p.m.[18] When the FOL arrived, the crewmembers told him they had confirmed the pressure in the entire low-pressure natural gas distribution system was in the normal range before removing the bypass. He then went to a home near the Salem and South Union Streets construction site and with the assistance of a pipefitter using a pressure gauge, found there was elevated pressure of 2.5 psi at 5:19 p.m. He then recommended to his supervisor, the Lawrence Operations Center manager, that CMA shut down the low-pressure natural gas distribution system.

After being designated as the CMA IC by the Lawrence Operations Center manager, the FOL then called the engineering department for the list of valves that needed closing to isolate and shut down the system. While waiting for this information, he requested all distribution crews to meet him at the work site at Salem and South Union Streets. The FOL assigned crews to regulator stations and directed them to verify with the engineering department the correct valve to close once they arrived at a regulator station. Once confirmed, they closed the valves. The FOL confirmed the closure of all valves at 7:24 p.m.

Low-low pressure alarms, indicating that the system was losing pressure, were received from the Riverina and South Lawrence SCADA pressure-monitoring points between 7:19 p.m. and 7:24 p.m., confirming the system was shutting down. At 7:43 p.m., the president of CMA declared a Level 1 emergency, in accordance with CMA's emergency response plan (ERP).[19]

Beginning at 8:39 p.m., the FOL sent pipefitters to different points in the system to take pressure readings to see if the pressure was dropping. About midnight, crews were dispatched to the affected areas in all three municipalities to assist the fire department personnel in shutting off meters and responding to fires, leak calls, and odor complaints. Locksmiths also were requested by CMA to provide technicians access to secured properties that needed to be checked for leaking natural gas.

On September 14 at 2:52 a.m., NiSource submitted a request to the Northeast Gas Association seeking mutual assistance from service technicians and supervisors from other natural gas companies. A total of 586 service technicians and 57 supervisors from 27 different natural gas companies responded to the area.

During the night, CMA's M&R department worked at the FOL's direction to confirm all regulator stations were locked in.[20] At 6:27 a.m., all 14 regulator stations were locked in and the

[17] A FOL primarily handles customer requests and responds to natural gas incidents and leaks.

[18] The location of the FOL was recorded by a global positioning system tracker in the NiSource system.

[19] *Level 1* is defined in NiSource's Emergency Manual as "Catastrophic Event-Which if not handled in an appropriate manner may dramatically impact NiSource's reputation, assets, or cause liability. Corporate Crisis Plan activated." Level 1 scenarios include a loss of a major natural gas facility or loss of critical natural gas infrastructure.

[20] *Lock in* refers to the inlet and outlet valves being completely closed and, as a result, there is no natural gas flowing in the regulator station.

low-pressure natural gas distribution system was confirmed shut down for 8,447 customers in the Lawrence, Andover, and North Andover areas. An additional 2,447 customers outside the immediate area had their natural gas shut off as a precaution.

1.4.3 Community Impact

Residents who were evacuated from the impacted area were allowed to return to their homes by 7:00 a.m. on September 16, 2018. However, restoration of residential natural gas and electricity required more time and involved multiple steps to coordinate the activities safely. CMA restored natural gas service to most customers in the impacted areas of Lawrence, North Andover, and Andover by December 16, 2018, 3 months after the accident.

On September 14, 2018, the governor of Massachusetts authorized Eversource Energy as the lead organization of the recovery process and to manage the restoration of the utility services in Andover, North Andover, and the portion of Lawrence that was south of the river (Commonwealth of Massachusetts 2018).[21] Between September 14 and September 16, 2018, NG coordinated with CMA and Eversource Energy to restore electrical power, following a required procedure to ensure that it was safe to re-energize homes without igniting any natural gas. As a precaution, the fire department sent assets to neighborhoods in case structure fires occurred when the electric service was turned on.

Until natural gas service was restored, many customers were without heat, hot water, and the service of other natural gas-fueled appliances such as stoves and clothes dryers. MEMA, the American Red Cross, and local officials set up a Recovery Resource Center to provide the communities with food and other support services. Also, NiSource and MEMA collaboratively set up an alternative housing program that relocated about 2,300 families to hotels, apartments, and trailers until they moved back into their homes (MEMA 2018).

1.5 Natural Gas Main Replacement Project

1.5.1 Scope

Beginning in 2016, CMA initiated an effort to replace 7,595 feet of low-pressure cast iron and polyethylene mains with 4,845 feet of low-pressure and high-pressure polyethylene mains on South Union Street and neighboring streets. The project was estimated to last 96 days, encompassing 12 different projects with two work crews, and the work scope included 93 service lines—65 service line replacements and 28 service line tie-ins. This was the first of the projects that involved abandoning the existing pipe. A work package, which included materials such as isometric drawings and procedural details for disconnecting and connecting pipes, was prepared for each of the planned construction activities. However, no package was prepared for the relocation of the Winthrop Avenue sensing lines from the cast iron main to the polyethylene main.

[21] Eversource Energy is an energy company that offers retail electricity, natural gas service, and water service to about 4 million customers in New England.

Figure 7 shows the area of the replacement of the natural gas main in South Lawrence along South Union Street with the cross-street tie-ins. The work on the day of the accident was at the north end of the project at Salem Street. The Winthrop Avenue regulator station is at the south end of the project.

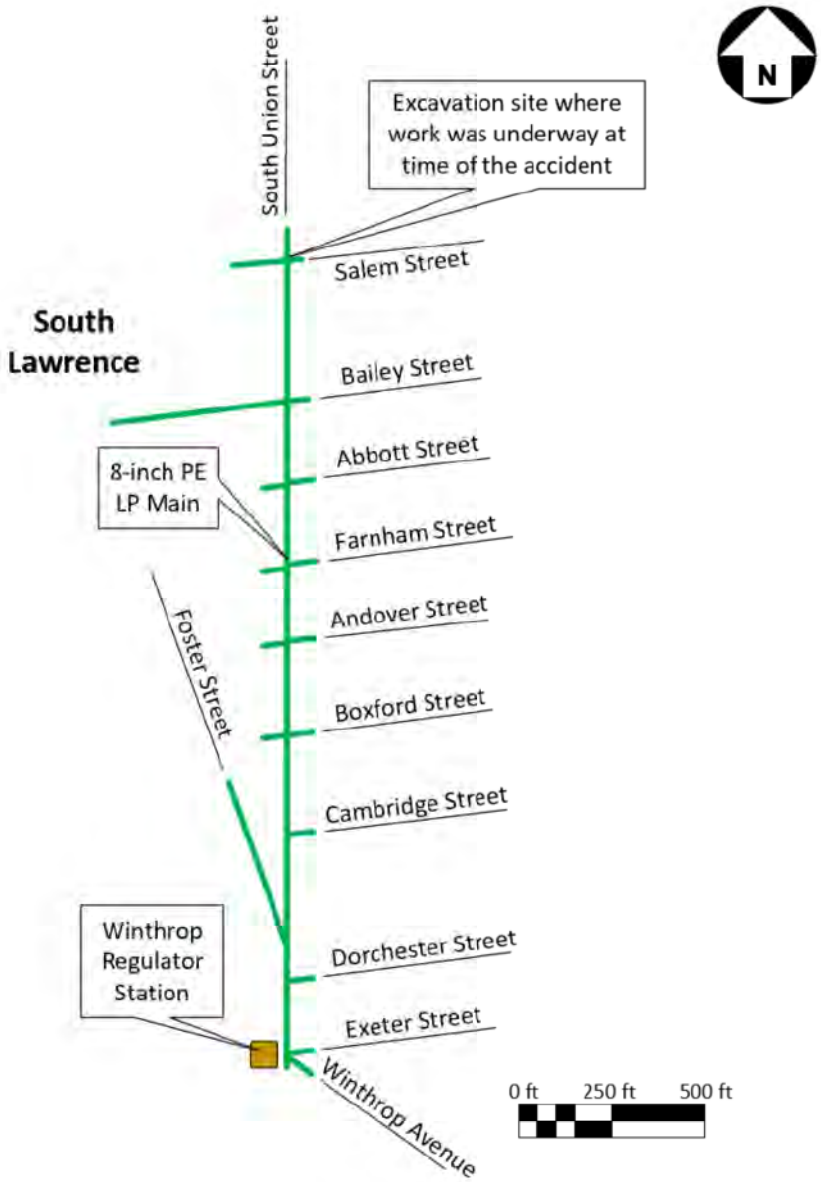

Figure 7. Areas along South Union Street with tie-ins impacted by the project.

The first stage of the project involved the installation of the polyethylene main, which was completed in late 2016. The regulator sensing lines at the Winthrop Avenue regulator station remained attached to the cast iron main, where they controlled natural gas flow through the

Winthrop Avenue regulator station into both the cast iron and polyethylene mains, which were connected in the low-pressure natural gas distribution system. (See figure 8.)

The city restrictions, due to paving in the area, delayed the South Union Street project for more than a year. Prior to the delay, CMA connected the polyethylene pipe to the distribution system, which allowed it to be monitored for pressure changes. The second stage of the project began in 2018 and involved installing the tie-ins to the polyethylene main and abandonment of the cast iron main. On the day of the accident, the sensing lines were still connected to the cast iron main and were functionally disconnected from the distribution system when the cast iron main was abandoned.

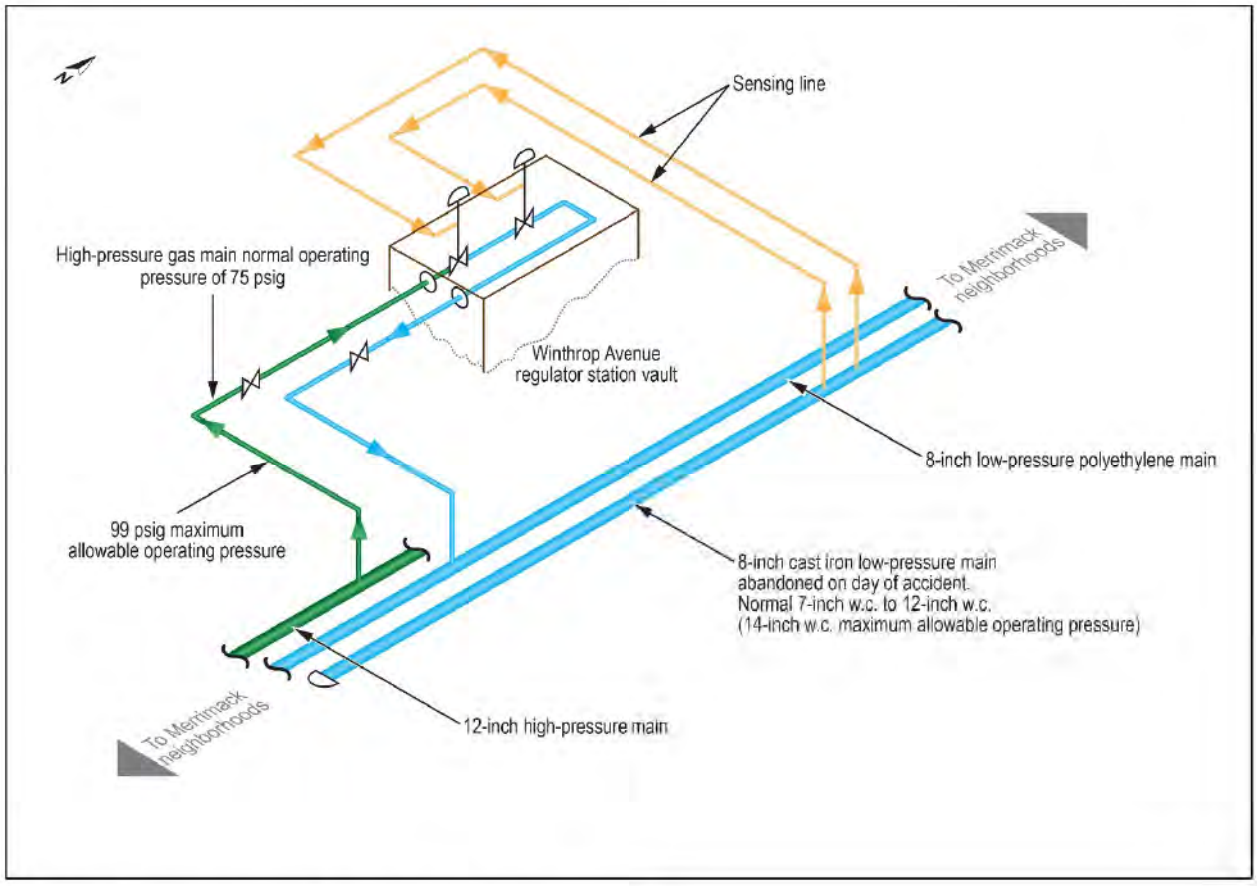

Figure 8. The Winthrop Avenue regulator station.

1.5.2 Project Reviews

CMA uses three types of documents that are found in a work package and that are used to control the workflow of a construction project. Once these documents were complete, they were submitted to engineering management for approval.

Table 2. Required CMA project workflow documentation.

Chronology	Title of document	Number of pages	Description
1	Capital Design Job Order Checklist	2	Details the individual steps and activities, accountabilities, and approvals performed and obtained by the field engineer during the project design and approval process.
2	Capital Project Execution Workflow	3	Provides the activity detail, handoffs, accountability, and approval that occurs throughout the construction process from the time a project is released until it is completed and submitted to the GIS Capital Closeout team for project closeout and mapping.
3	Constructability Safety Review	3	Documents a collaborative discussion between the project engineer and the construction leader to review the scope and details of a project before construction to identify and address potential obstacles to the execution of a project design.

Constructability reviews are a recognized and generally accepted good engineering practice for the execution of professional design services and are intended to provide an independent and structured review of construction plans and specifications to ensure there are no conflicts, errors, or omissions (Kirby and others 1989). Two constructability reviews of the South Union Street project were signed on March 1, 2016, and January 6, 2017. The second constructability review was signed again on December 14, 2017. The constructability review form had a required signature line for the engineering and construction departments and a signature line for M&R that was designated as optional. The constructability review forms for the South Union Street project did not include signature(s) for representatives from the M&R department.

Before the accident on September 13, 2018, the M&R department participation in constructability reviews was on a case-by-case basis. For example, if the project involved changing the design or location of a regulator station or installing or replacing a regulator, M&R would likely be involved in the constructability review and meetings in the field.

Postaccident review of the engineering work package and construction documentation for the project identified some omissions. Although CMA used its project workflow process to develop, review, and approve the engineering plans, the work package did not consider the existence of regulator sensing lines connected to the distribution lines that were slated to be abandoned within the scope of work. This omission was not identified by any of the CMA constructability reviews (NTSB 2018). In fact, none of the CMA workflow documents refer to natural gas distribution system pressure control nor do they refer to regulator control or sensing lines, and none of the documentation in the construction packages for the South Union Street project referred to sensing lines for regulator control. The 2018 constructability review document referenced pressure monitoring and stated that "if pressure rises/falls beyond these points, contact M&R."

1.5.3 Sensing Line Documentation

NTSB investigators spoke with an M&R department supervisor, who stated:

> Except for the newest stations, there's no, there is no, there is no drawings of control [sensing] lines. We frequently get asked to come out and help, you know, locators mark control lines. We can't really help them because we don't know where they are. Well, I mean a lot of the stations go back to the '50s and '60s. The new stations, we have the field engineers come out and draw them for us.

The M&R supervisor said that employees sometimes used older legacy recordkeeping systems to supplement newer isometric drawings of the regulator stations because critical information was missing from the new drawings. He described the documentation failures of the newer drawings, such the omission of valves, as "a deficiency on the engineers," although he said that it might not have been the fault of the engineers because "it wasn't clear enough when they explained to them what they wanted drawn."

He described the legacy recordkeeping system as "the old books," stating that "we call them our bibles." He said that even though employees "weren't supposed to have them anymore because they may not be current," during his tenure in his prior position in the field, he found them to sometimes be "more current than the new drawings."

Table 3 details the information associated with the sensing lines and the regulator stations including where it can be found and also includes other related documentation, such as the geographic information system (GIS) data. According to the director of field engineering, the GIS data did not provide project reviewers/approvers with sensing line location information at the time of the accident. These information sources were not in one location; hence, engineers would be required to visit multiple places to capture the true as-built configuration. M&R staff also had extensive institutional knowledge about sensing line locations.

Table 3. Sources of sensing line information and select regulator station documentation. Table courtesy of NiSource.

Document or source of information	Location	Description	Update interval	Responsible for updating
Critical Valve Book (contain sensing line information)	Lawrence Operations Center	Identifies the location of critical valves in relation to other system components, including regulator stations and sensing lines where applicable	As needed	Engineering
Work Done Files (contain sensing line information)	Lawrence Operations Center	Compilation by town and street of records and as-built sketches of work done on system, including sensing line installations, replacements, and relocations	As work is done	Distribution, Construction, Operations
Historical Maps (contain sensing line information)	Lawrence Operations Center	System maps predating implementation of GIS. Certain historical maps include sensing line locations	Historical	N/A

Document or source of information	Location	Description	Update interval	Responsible for updating
Capital Close Out Files (contain sensing line information)	Lawrence Operations Center	As-built drawings and other project documentation from inspector work order packets for capital projects, including as-built drawings of project sensing line installations, replacements, relocations	As projects are closed out	Construction/Capital Close Out
WMS (work management system) Docs (contain sensing line information)	WMS Docs Database	Electronic version of Capital Close Out files, including as-built drawings of project sensing line installations, replacements, relocations	As projects are closed out	Capital Close Out
M&R Regulator Books (contains sensing line information)	M&R Technician Vehicles	Books maintained for reference by M&R in the field. The books contain diagrams depicting the piping configuration around regulator stations, including the location of sensing lines	As needed	M&R
Regulator Station Inspection Record	Regulator Station	Record of station attributes, major components, station shut-off valve	As inventory changes	M&R
Regulator Station Inventory Record	Regulator Station	Record of station attributes, major components, station shut-off valve	As inventory changes	M&R
Station Isometric Drawing	Regulator Station	Depicts direction of flow through regulator station and sequence of major station components	As needed	Engineering
GIS Map Printout	Regulator Station	GIS record identifying location of regulator station's critical valve in relation to regulator station, station's inlet and outlet piping, and natural gas mains in the vicinity of station	As needed	Capital Close Out

1.6 Engineering Project Management

1.6.1 Staffing and Scope of Responsibilities

The field engineer assigned to the South Union Street project was based in the Lawrence Operations Center, and began work at CMA in July 2014, soon after graduating from college with a mechanical engineering degree. He was promoted from field engineer 1 to field engineer 2 in December 2016. He was responsible for developing and planning engineering modifications to the natural gas distribution system. He had about 1 year of experience when assigned to the South Union Street project in 2015, and he continued to work on that and other projects through 2018. He had worked as a field engineer with CMA for about 4 years when the accident occurred.

The field engineer had completed training from NiSource on various topics, including regulators, sensing lines, and company-wide NiSource Operational Notice (ON) 15-05; the latter discussed how sensing lines could be damaged by excavation close to a regulator station, and it highlighted the specific risk of overpressurization due to damage to sensing lines. However, he told NTSB investigators that sensing lines typically were not addressed in his work packages unless a project involved replacing a regulator station (such as in the 2014 work package) or vault. He could not recall if he had addressed sensing lines on previous projects. He added that he did

not know if the engineering department had access to sensing line information, although he believed that the M&R department did.

Field engineers are supervised by one of two leaders of field engineering (LFE), who both report to the manager of field engineering. There is one LFE for CMA's Brockton Operations Center and the other for CMA's Springfield and Lawrence Operations Centers. The LFE for the Springfield and Lawrence Operations Centers oversaw the South Union Street project. He began working for Bay State Gas Company (now CMA) as a co-op student on January 3, 1984. He was hired full time as an associate engineer in 1987 and worked within the engineering department until 2001. He then left the company and went into private consulting for 5 years. He came back to CMA in April 2007. He was promoted from field engineer to LFE in December 2013. In that capacity, his responsibilities included overseeing engineering projects in areas covering Springfield, Massachusetts, and Lawrence, Massachusetts. He had six full-time engineers who reported directly to him from the Springfield division and three engineers in the Lawrence Operations Center, where work packages for the South Union Street project were prepared.

The LFE earned a bachelor of science degree in mechanical engineering and a master of science degree in engineering management. He is licensed as a professional engineer (P.E.) in Massachusetts.

The field engineering group provides engineering support that includes the design of replacement projects, estimating, cost tracking, creation of tie-ins, and project management. For calendar year 2018, CMA established a goal to replace 58 miles of what was categorized as replacement pipe. The section of cast iron pipe related to the accident was part of this 58-mile scope.

In an interview, the LFE described the initiation of the South Union Street project. He said that as part of a natural gas system enhancement program, the field engineering department submits a 5-year pipe-replacement plan each year to the Massachusetts Department of Public Utilities (DPU). From there, the team develops a preliminary design to determine the project scope and prioritize tasks. After a preliminary estimate and preliminary design, the field engineering group meets with the construction group for a constructability review.

According to the LFE, once they finalize a plan:

> We make sure that we take a look at all of the material that's going to be installed and abandoned. We develop tie-in procedures, pressure-testing procedures. We make sure environmental concerns are addressed. And we actually have a checklist to go down to make sure that the protocol has been followed as far as constructability reviews, reviews of crews in the field—I mean, constructability reviews for the construction people so they understand the scope of the project.

The engineering review includes sign off by the LFE, the manager of field engineering, and the director of field engineering. During interviews with NTSB investigators, the LFE, and the manager and director of field engineering stated that their review did not include an evaluation of each step in the work package. The LFE stated, "I do not go through and actually—on every

single project look at every single step of the process." The LFE was not required or asked to review the work package and certify it under the standards of a Professional Engineer.

The director of field engineering indicated that he is responsible for approving projects with costs over $1 million, which included the South Union Street project. He said that his reviews typically were at a higher level, and he did not carefully review each step of work packages, particularly those that were routine in nature, as was the case with the work being done on the day of the accident. Moreover, he suggested that he would expect the managers of engineering to perform similar high-level reviews.

However, the director of field engineering indicated that he would expect the field engineers and the LFEs to work together to ensure that work packages were safely designed. He said that it was up to the LFE to assess the capabilities of each field engineer and provide the appropriate level of oversight based on their capabilities. He added that peer reviews, in which field engineers evaluated each other's work, were often used as well. However, he said that such reviews were informal and unstructured. He added that when field engineers were in the process of gathering information on a project, they looked at the documentation on the facilities that are in the scope of the work. He said that after the accident NiSource recognized that "we were short on readily available information around the sensing lines, the control lines."

1.6.2 Measurement and Regulation Department

The M&R department is responsible for maintaining the regulator stations in the CMA natural gas distribution system. On September 13, 2018, the M&R department consisted of 11 full-time technicians across Massachusetts, with 2 technicians in the Lawrence area who had more than 45 years of experience between them. The department is responsible for the regulator vaults, the regulators, and the sensing lines. CMA expects the M&R department to initiate work for existing sensing line maintenance. On capital projects, CMA expects the engineering department to work in coordination with M&R and the construction departments when sensing line work is needed.

The NTSB was provided an affidavit from the field engineer in which he stated that he discussed sensing line configurations in general with a member of the construction department during the design phase of the South Union Street project, and during the constructability review that took place on March 1, 2016. The field engineer also said that he contacted the M&R department to discuss sensing lines, though he no longer recalled "all the specifics of that conversation." The field engineer said that he concluded his discussion with the M&R department with the understanding that the engineering department did not need to do anything further regarding sensing lines on the South Union Street project. The affidavit did not reveal a plan to relocate the sensing lines. NiSource did not have a requirement to document conversations between the engineering and measurement and regulation departments regarding sensing lines.

NiSource provided the investigation with an e-mail, dated October 16, 2016, from the Lawrence construction leader to the M&R department. The Lawrence construction leader was involved in the South Union Street project and had signed the first constructability review for the project on March 1, 2016, (before sending the e-mail), and the second constructability review on January 6, 2017, (after sending the e-mail). However, the M&R department employee addressed

in the e-mail had left CMA and was not employed by the company at the time of the accident. The e-mail stated:

> We are working near the union st reg station. We are working on the low-pressure outlet and will be placing a tap fitting on the outlet and eventually moving the static lines to the new outlet piping. A new outlet valve will be installed. The shutdown of the pit will be scheduled for some time later. This is a notice that work in the area has started.

In addition, NiSource provided the NTSB with an affidavit from a contract inspector in its Lawrence Operations Center that stated that he discussed with the Lawrence construction leader the need to relocate the sensing lines before the existing cast iron main was abandoned.[22] The contract inspector said that the two agreed to discuss the relocation "in more detail, with input from others, once the project progressed further." He said that the construction crew, including the construction foreman, construction lead, and the NiSource local construction coordinator, also were aware of the need to relocate the sensing lines before the cast iron main was abandoned. Although several affidavits suggest there were conversations about sensing lines, and an e-mail exists that confirms that it was known that the sensing lines needed to be relocated, there is no evidence that a work order or formal plan was ever developed to address the issue.

In 2015, NiSource issued an operational notice, *Below Grade Regulator Control Lines: Caution When Excavating Near Regulator Stations or Regulator Buildings,* ON 15-05, requiring that M&R personnel be consulted on all future excavation work that was done within 25 feet of a regulator station with sensing lines, other communications and/or electric lines critical to the operation of the regulator station, or buried odorant lines. The ON provided that M&R personnel stand by the regulator station throughout the excavation if there was a risk that the excavation could damage any such line. The South Union Street project excavation work being performed on the day of the accident occurred over 2,000 feet away from the Winthrop Avenue regulator station and, thus, was beyond the 25-feet requirement in ON 15-05. The basis of the 25 feet in ON 15-05 is the assumption of a safe distance that encompasses the equipment associated with a regulator station, including sensing lines. According to the document:

> If a control line breaks, the regulator will sense a pressure loss, causing the valve to open further, resulting in an over pressurization on the downstream piping system, which may lead to a catastrophic event. The same result occurs if the flow through the control line is otherwise disrupted (e.g., control line valve shut off, control line isolated from the regulator it is controlling) (NiSource 2015).

As documented in the NTSB's November 14, 2018, Safety Recommendation Report on this accident, a former CMA employee informed NTSB investigators about a purported past policy or practice that CMA allegedly phased out, whereby M&R personnel stood by a regulator station when construction took place on its natural gas mains (NTSB 2018). During interviews with a NiSource employee and a former employee, investigators were told there were times in the past (at least 5 years earlier) when M&R personnel provided assistance while distribution system piping modifications were being tied over to live systems to minimize the risks associated with

[22] The affidavit was signed on May 2, 2019, 231 days after the accident.

overpressurization at natural gas mains. No documentation was found to support that such a policy or practice existed, except as outlined by ON 15-05. NiSource stated that no such policy or practice existed and; therefore, none was phased out or discontinued.[23]

1.7 Overpressure Protection

1.7.1 Overpressurization Protection Requirements

For low-pressure natural gas distribution systems, there is no requirement for a service regulator or protective device at the service location that would prevent the overpressurizing of customers' piping and appliances. Overpressure protection relies on the redundant worker and monitor regulators at the regulator stations where natural gas is introduced to the low-pressure natural gas distribution system.

Title 49 *CFR* 192.197 requires high-pressure natural gas distribution systems be equipped with a service regulator or protective devices at the service location that would prevent the overpressurizing of customers' piping and appliances. This is in contrast to the requirements for low-pressure natural gas distribution systems, where the pressure in the main is essentially the same as the pressure provided to the customer.

The American Society of Mechanical Engineers (ASME) sets forth guidelines for the safe design and construction of both high and low-pressure natural gas distribution systems. These guidelines, called The Code, include requirements for district regulator vaults, regulators, and control lines (ASME 2012).

Specifically, The Code states the following in section 845.3:

> (g) When a monitoring regulator, series regulator, system relief, or system shutoff is installed at a district regulator station to protect a piping system from overpressuring, the installation shall be designed and installed to prevent any single incident, such as an explosion in a vault or damage by a vehicle, from affecting the operation of both the overpressure protective device and the district regulator.[24]
>
> (h) Special attention shall be given to control [sensing] lines. All control lines shall be protected from falling objects, excavations by others, or other foreseeable causes of damage and shall be designed and installed to prevent damage to any one control line from making both the district regulator and the overpressure protective device inoperative.

Title 49 *CFR* 192.195 requires protection from the accidental overpressuring of natural gas distribution systems, and states that systems must have a pressure-relieving or pressure-limiting

[23] NiSource informed the NTSB that it had investigated this issue thoroughly, speaking with 18 field and supervisory employees from the construction and M&R departments at each of NiSource's operations centers—including the employees interviewed by the NTSB. NiSource also provided the NTSB with sworn affidavits from each of those employees regarding this issue.

[24] *Monitor regulators* are sometimes referred to as *monitoring regulators*.

device that meets the requirements outlined in 49 *CFR* 192.199 (g). Title 49 *CFR* 192.199 (g) states, "where installed at a district regulator station to protect a pipeline system from overpressuring, be designed and installed to prevent any single incident such as an explosion in a vault or damage by a vehicle from affecting the operation of both the overpressure protective device and the district regulator." The redundant worker and monitor regulators underground vault at the Winthrop Avenue regulator station met the overpressure requirements of 49 *CFR* 192 and the ASME guidelines.

1.7.2 Previous Overpressurization Accidents Investigated by the NTSB

Over the past 50 years, the NTSB has investigated several accidents that involved natural gas under high pressure entering low-pressure natural gas lines.[25]

On June 3, 1969, the NTSB investigated a natural gas pipeline overpressure incident in Gary, Indiana (NTSB 1969). The pipeline, owned by Northern Indiana Public Service Company (NIPSCO), which is the present-day NiSource, was overpressurized when an employee inadvertently opened a separation valve that allowed 20 psig gas to flow into a 0.25 psig system. The absence of any overpressure protection in the 0.25 psig system now subjected to the 20 psig resulted in a regulator diaphragm failure. Although operators recognized the error and closed the separation valve, the failed regulator allowed 20 psig gas into the natural gas distribution system. There were no fatalities; however, nine residents and five firefighters were injured. Seven homes were destroyed and several incurred damage. The property damage was about $350,000.

On November 6, 1969, a low-pressure natural gas distribution system in Burlington, Iowa, overpressurized when a bulldozer impacted one of 24 regulator stations on a 7,500-customer system (NTSB 1969a). The impact damaged the worker regulator. When the worker regulator was damaged, the monitor regulator activated; however, the monitor regulator failed to control the 55 psig inlet pressure to the required 0.25 psig as-designed setting. The Iowa Southern Utility Company estimated that the pressure reached 1.25 psig, which amounted to a four- to five-fold increase over the normal operating pressure. Although the sensing lines were bent in the mishap, their integrity to maintain pressure was not compromised. There were no fatalities, but two firefighters suffered minor injuries. There were no explosions, but six homes were totally destroyed; 42 other homes suffered fire damage. The Burlington Fire Department estimated the damages at $80,000.

On August 9, 1977, natural gas under high-pressure (20 psig) entered a Southern Union Gas Company low-pressure (6 ounces per square inch) natural gas distribution line and overpressured more than 750 customer service lines in a 7-block area in El Paso, Texas.[26] Flames from gas pilots and the burners of appliances burned out of control and caused fires in nearby flammable materials. The gas company was replacing a section of 10-inch cast iron low-pressure natural gas main and isolated it between two valves. The isolated sector contained the natural gas regulator pressure sensing control lines. When the pressure fell to 0 psig the natural gas regulators

[25] The reports cited in this section are available on http://www.ntsb.gov.
[26] For reference, 1 ounce per square inch, gauge equals 0.0625 psig which equals 1.73-inch w.c.

opened up to try to maintain the operating pressure and overpressured the rest of the affected system. The problem was corrected before any fatalities or major injuries resulted (NTSB 1978).

On May 17, 1978, a Columbia Gas of Ohio, Inc., construction crew in Mansfield, Ohio, mistaking an 8-inch low-pressure steel natural gas main for an 8-inch high-pressure steel natural gas main, drilled a small pilot bit hole through the wall of the low-pressure natural gas main and began to cut into the pipe wall with a large diameter bit.[27] The construction crew was making a "hot tap" to complete the final tie-in of an 8-inch, replacement natural gas main to the existing high-pressure natural gas distribution system.[28] The hot tap was to be made using a three-way tapping tee which had its side outlet welded to the live high-pressure replacement natural gas main and its bottom outlet mistakenly welded to the low-pressure natural gas main. When the 1-inch pilot bit on the tapping machine attached to the top outlet of the tee penetrated the wall of the low-pressure natural gas main, gas at 42 psig pressure from the high-pressure natural gas distribution system entered the 14-inch w.c. (about 1/2 psig pressure) low-pressure natural gas main and rapidly increased the pressure in the low-pressure natural gas system in a 4.8 square mile area of Mansfield. The Mansfield Fire Department began receiving reports of fires caused by excessively high appliance flames on natural gas appliances. There were no fatalities or injuries requiring hospitalization. Property damage to 16 houses resulted from the ignition of nearby combustibles by high-pilot flames; five of these houses were extensively damaged.

On January 28, 1982, in Centralia, Missouri, natural gas at 47 psig entered a low-pressure natural gas distribution system which normally operated at 11-inches w.c. (0.40 psig) after a backhoe bucket snagged, ruptured, and separated the 0.75-inch diameter steel pressure regulator control line at the Missouri Power and Light Company's district regulator station No. 1 (NTSB 1982). Because the regulator no longer sensed system pressure, the regulator opened and high-pressure natural gas entered customer piping systems, in some cases, resulting in high pilot light flames which initiated fires in buildings; while in other cases, the pilot light flames were blown out, allowing natural gas to escape within the buildings. Of the 167 buildings affected by the overpressurization, 12 were destroyed and 32 sustained moderate to heavy damage. Five occupants received minor injuries.

On September 23, 1983, natural gas pressure in the Boston Gas Company's distribution system in East Boston, Massachusetts, rapidly increased from 7-inches w.c. (about 0.25 psig) to more than 17-inches w.c. (about 0.6 psig).[29] The Boston Fire Department began receiving telephone calls about natural gas odors, high pilot lights, and fires. Natural gas company crews searching for the source of high-natural gas pressure found the district regulator vault at Bremen and Porter Streets (one out of four in the East Boston area) had been submerged in water following a broken water main. After the vault had been pumped out, inspection of the primary regulator

[27] For more information, see the NTSB letters, dated August 21, 1978, to Columbia Gas of Ohio (regarding NTSB Safety Recommendations P-78-45 through -49); Materials Transportation Bureau (regarding NTSB Safety Recommendations P-78-50 and -51); and American Gas Association (regarding NTSB Safety Recommendation P-78-52).

[28] *Hot tapping* is the method of making a connection to existing piping while the pipe is in service without interrupting the flow of natural gas.

[29] For more information, see the NTSB letter, dated April 9, 1984, to the Boston Gas Company regarding NTSB Safety Recommendations P-84-7 through -9.

showed that water had entered the regulator through leaks in a gasket and through the vent piping, filling the area above the regulator diaphragm, holding the regulator valve open and allowing natural gas pressure to increase in the distribution system. In addition, a dispatcher at the Boston Gas Company control center received an alarm about the substantial rise in pressure.[30] Many East Boston residents had been awakened to the sound and smell of blowing natural gas to see larger-than-normal natural gas pilot lights and natural gas appliance pilot flames in their homes. The Boston Fire Department responded immediately to telephone calls from the residents and began alerting and evacuating residents. The fire department turned off natural gas at customer meters and pursued fighting fires. A 1-square-mile section of East Boston was affected; one restaurant was destroyed by an explosion, two residences were destroyed by natural gas-fed fires, and other small fires occurred as a result of the natural gas overpressurization. No fatalities or injuries resulted from the accident.

On January 17, 1992, in the River West area of Chicago, Illinois, a crew from Peoples' Gas, Light and Coke Company (Peoples) was doing routine annual maintenance work on a monitor regulator at one of its regulator stations, when high-pressure natural gas at 10 psig entered a low-pressure natural gas distribution system (NTSB 1993). The natural gas escaped through appliances into homes and other buildings where it was ignited by several unidentified sources. The resulting explosion and fires killed 4 people, injured 4, and damaged 14 houses and 3 commercial buildings.

1.7.3 Previous NiSource Overpressurization Incidents

Over the past 15 years, there have been four overpressurization events and one near-miss within the NiSource network, not including this one on September 13.[31] NTSB did not investigate these incidents.

On March 1, 2004, a system with an inlet pressure of 50 psig and an outlet pressure of 13 inches w.c. was overpressurized to 4.5 psig when debris was lodged at the seat of the bypass valve in Lynchburg, Virginia.

On February 28, 2012, an operator error during an M&R station inspection resulted in accidental overpressurization in Wellston, Ohio. Over 300 customers were without service for 14 hours.

On March 21, 2013, a segment of pipe with a maximum allowable operating pressure (MAOP) of 1 psig was pressurized at over 2 psig in Pittsburgh, Pennsylvania. A work crew, under the direction of the local NiSource subsidiary, was making a tie-in and failed to monitor the pressure and flow of the existing low-pressure natural gas distribution system during the tie-in process. The pressure cycled from 12 inches w.c. up to 2 psig three times.

On August 11, 2014, a local NiSource crew in Frankfort, Kentucky, was excavating to repair a Grade 1 leak located on the outside of a regulator station building. The crew uncovered

[30] For more information, see the NTSB letter, dated November 27, 1984, to the Boston Gas Company regarding NTSB Safety Recommendations P-84-43 through -45.
[31] E-mail from NiSource to NTSB, March 25, 2019.

and narrowly missed hitting the 1-inch sensing line and tap located on the 8-inch outlet pipeline. The crew was unaware of the purpose of the 1-inch pipeline and called local M&R personnel. The M&R personnel advised the crew of the purpose of a sensing line and what would have happened had the line been broken.

On January 13, 2018, during the investigation of a service complaint, a pressure of 2 psig was discovered on a 14-inch w.c. natural gas distribution system in Longmeadow, Massachusetts. The cause was associated with debris accumulation on both the worker and monitor regulator seats at a regulator station. Once the debris was removed, the pressure returned to normal.

1.8 Pipeline Safety Management Systems

On July 25, 2010, a 30-inch diameter pipeline owned and operated by Enbridge Incorporated ruptured and released more than 840,000 gallons of crude oil into nearby wetlands and a creek that flowed into the Kalamazoo River in Marshall, Michigan. Unaware that the pipeline had ruptured, Enbridge employees continued pumping oil into the ruptured pipeline for 17 hours until a local utility worker discovered the oil and contacted the company (NTSB 2012).

The rupture was caused by fatigue cracks that grew and coalesced from crack and corrosion defects under disbonded polyethylene tape coating. Contributing to the accident were weak regulations for assessing and repairing crack indications as well as ineffective oversight of pipeline integrity management programs, weak pipeline control center procedures, and a low level of public awareness. As a result of the Marshall, Michigan, investigation, the NTSB made the following safety recommendation to the American Petroleum Institute (API):

> Facilitate the development of a safety management system standard specific to the pipeline industry that is similar in scope to your Recommended Practice 750, *Management of Process Hazards*. The development should follow established American National Standards Institute requirements for standard development. (P-12-17)

In response to this recommendation, API developed a recommended practice (RP), titled *Pipeline Safety Management Systems,* which was sanctioned by the American National Standards Institute (ANSI).[32] The API document, known as API RP-1173, exceeded the NTSB's intent in issuing the recommendation to facilitate the development of a safety management system (SMS) standard specific to the pipeline industry. In addition, API, which represents commercial concerns throughout the oil and natural gas industry, addressed safety culture and other safety-related issues in its API RP-1173 (API 2015). As a result, on October 22, 2015, the NTSB classified Safety Recommendation P-12-17 "Closed—Exceeds Recommended Action."

API formed a stakeholder group consisting of oil and natural gas pipeline operator personnel and trade association staff, other federal and state agency personnel, and safety experts representing the public. The group met monthly, surveyed the public, and developed actionable guidelines for the pipeline industry to work toward a goal of continuous safety improvement. The API RP-1173 established a pipeline safety management system (PSMS) framework for

[32] A *recommended practice* is a voluntary pipeline industry consensus standard.

organizations that operate hazardous liquids and natural gas pipelines under the jurisdiction of the US Department of Transportation.

In 2015, the pipeline industry completed the development of the PSMS framework, designed specifically for pipeline operators. It is a product of a collaboration between pipeline operators, state and federal regulators, and other stakeholders. Participants include API, the Association of Oil Pipe Lines, the American Gas Association, the American Public Gas Association, the Interstate Natural Gas Association of America, and the Canadian Energy Pipeline Association.[33] Since the availability of API RP-1173, many oil and natural gas companies have been aligning with its guidance and building PSMSs that suit their companies' situations and goals. To facilitate the continued success and use of PSMS guidance, the developers of API RP-1173 prepared a PSMS maturity model for companies to gauge the status of their PSMS build out. (See figure 9.) Five levels of maturity were defined in the maturity model (MM): planning (level 1), developing (level 2), implemented (level 3), sustaining (level 4), and improving (level 5). The "plan, do, check, act" cycle and; therefore, the full safety benefits of PSMS are realizable in levels 4 and 5.

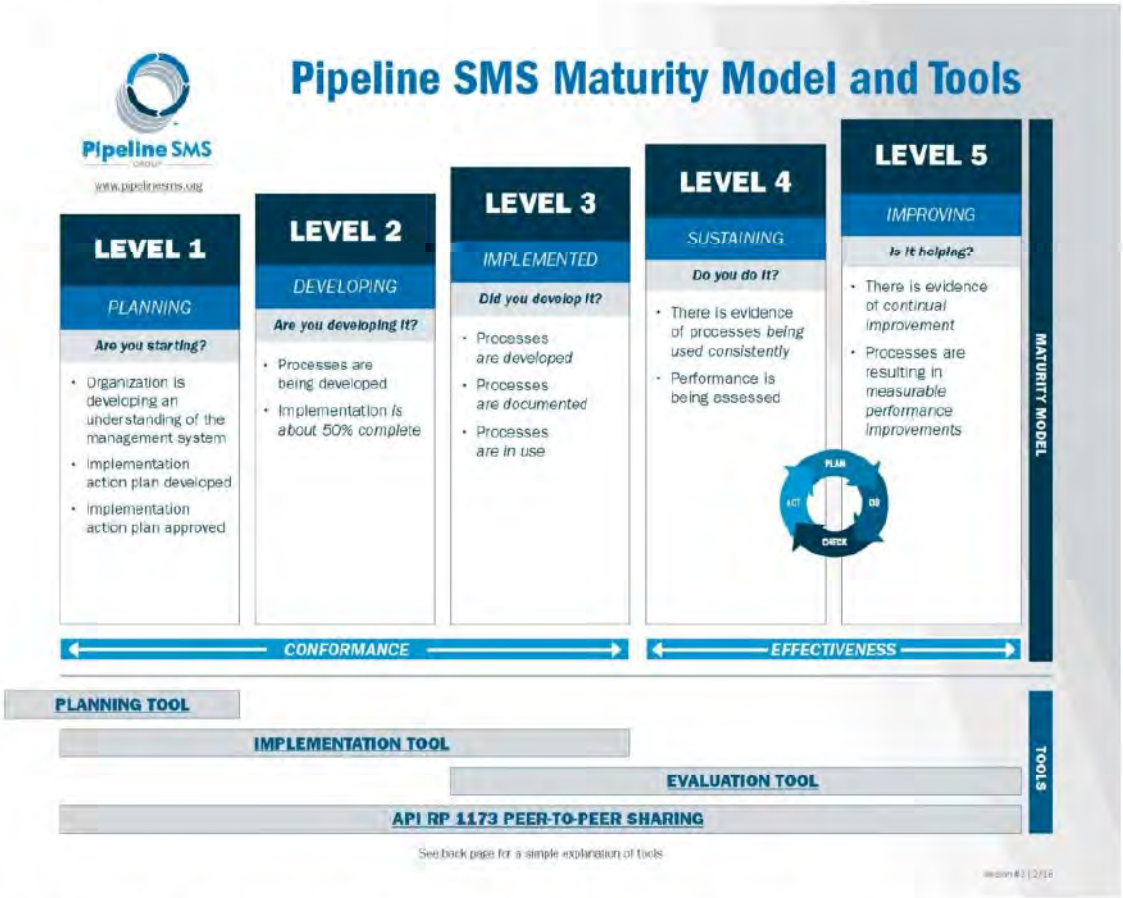

Figure 9. Pipeline SMS maturity model. Graphic courtesy of Pipelinesms.org.

[33] For more information, see https://pipelinesms.org.

NiSource began its SMS efforts several years prior to the overpressurization, as evidenced by the company being listed as a participant in the American Gas Association's (AGA) SMS project. Interviews with NiSource executives revealed that they had initiated SMS development in 2015 and accelerated efforts since the accident. NiSource employees indicated that they were excited about SMS development, but were still early in the process. They had not yet determined how they were going to assess the maturity of their SMS.

NiSource was among the first natural gas utility companies to embrace API RP-1173 for its operations when it was implemented at its subsidiary, Columbia Gas of Virginia, in 2015. Its initial efforts at Columbia Gas of Virginia began before the Merrimack Valley overpressurization. NTSB investigators interviewed senior executives at NiSource to better understand the status of its PSMS development and implementation efforts.

The director of pipeline safety for NiSource Corporate Services said that both he and the NiSource board of directors were excited about the deployment of PSMS. After the accident, he indicated that he had another opportunity to discuss the PSMS with the board, at which point PSMS efforts were "very much encouraged to move even faster," and NiSource has now accelerated implementation of PSMS in all its companies. When investigators asked about the maturity of the PSMS, he indicated that the maturity measures had not "been defined," though there was "certainly a lot of discussion" taking place on the topic, additional resources have been added to accelerate PSMS implementation, and there is not an "endpoint" because it involves a process of continual improvement.

He also said that NiSource, as well as third parties, would be involved in safety oversight. He indicated there would be checks and balances and stated that the "governance piece is really good." However, he also indicated that "the auditing process is yet to be defined." He said that NiSource is trying to get the primary elements of PSMS in place by the end of 2019.

NTSB investigators also spoke with a NiSource senior vice president about the implementation of PSMS. Direct reports to this senior vice president include the vice president of safety, the vice president of training, and the vice president of environmental. The senior vice president indicated that the initial plans for PSMS were a "sequential deployment" on a state-by-state basis. He said that he believed that a "generic gap analysis kind of at the (natural) gas segment level" had been performed. He added that NiSource was in the process of "really deploying and building safety management systems around the recommended practice [API RP-] 1173." He also indicated that gap analyses had been performed for Virginia and Indiana, and that NiSource is undertaking them in other states, including Massachusetts. The senior vice president indicated that many gaps had been improved upon, if not closed. When they began their effort, they performed a gap analysis based on the 10 elements within the API-1173 standard and determined that NiSource's Virginia-based safety programs were about 58 percent in agreement with the 10 elements. Relating to API-1173 implementation, Virginia was intended to be the pilot state for implementation; at the time of the accident, API-1173 implementation had yet to be

implemented in Massachusetts. Following the accident, CMA was ordered by the Massachusetts DPU to adopt API-1173.[34]

1.9 Professional Engineer Review and Approval

Professional engineer (P.E.) approval and stamping of drawings is a required practice for engineering projects to assure the safety of the public throughout the United States. P.E.s must be licensed by the state in which they practice. Although licensing laws vary state to state, they contain similar requirements for education and experience. To be licensed as a P.E., an engineer must earn a 4-year degree in engineering from an accredited engineering program, pass the Fundamentals of Engineering examination, complete 4 years of progressive engineering experience under the guidance of a licensed P.E., and pass the Principles and Practice of Engineering examination.

Projects requiring P.E. approval and stamping include, but are not limited to, roadways, bridges, tunnels, dams, and building structural design. Industrial exemptions allow utilities to perform engineering work related to public safety without the approval and stamp of a licensed P.E. In many cases, this exemption creates a loophole because there is no requirement to have work performed by an engineer at all. The P.E. who approves and stamps the project documents must be in responsible charge of the project.[35] This assures that all aspects of the project are performed under the supervision and direction of a qualified engineer. However, 31 states exempt public utilities from this requirement even though proper design is necessary for public safety. Prior to the overpressurization of the CMA natural gas system in Merrimack Valley, Massachusetts was one of those states that exempted utilities.

At the time of the accident, two NiSource employees who held P.E. licenses were involved with the South Union Street project: the LFE and the director of field engineering. Their employment roles required both employees to review and sign off on the South Union Street project, but there was no requirement to stamp the construction documents. Neither the LFE nor the director of field engineering was in responsible charge of the project. Therefore, none of the construction documents were issued with P.E. stamps.

The documents prepared for the South Union Street project were signed by a degreed engineer who had an engineer-in-training certificate, which is held by individuals preparing to take the P.E. examination. However, he was not yet eligible to take the P.E. examination because he had not satisfied the work experience requirement.

On November 14, 2018, the NTSB issued Safety Recommendation P-18-5 to the Commonwealth of Massachusetts that addressed the removal of a P.E. licensure exemption for such public utility work, along with a corresponding Safety Recommendation P-18-6 issued to NiSource, the parent company of Columbia Gas of Massachusetts, recommending P.E. approval

[34] Commonwealth of Massachusetts Department of Public Utilities Consent Order, D.P.U. 18-PL-03, November 30, 2018.

[35] *Responsible charge* refers to the degree of control an engineer is required to maintain over engineering decisions made personally or by others over whom the engineer exercises supervisory direction and control authority.

of natural gas pipeline projects within NiSource (NTSB 2018).[36] As described more fully in section 2.1, Massachusetts acted to satisfy Safety Recommendation P-18-5 less than 2 months after it was issued. Subsequent to this recommendation, the NTSB contacted two independent organizations seeking expert information on the current state of P.E. license oversight and the industrial exemptions among the United States and territories for major infrastructure projects.

The National Council of Examiners for Engineering and Surveying (NCEES) is a national nonprofit organization dedicated to advancing professional licensure for engineers and surveyors. NCEES develops, administers, and scores the examinations used for engineering and surveying licensure in the United States. It also facilitates professional mobility and promotes uniformity of licensure processes in the United States through services for its member licensing boards and licensees, including engineering and surveying examinations, examination preparation materials, records programs, and credentials evaluations.

The National Society of Professional Engineers (NSPE) is a professional association representing licensed P.E.s in the United States, in 53 state and territorial societies and over 500 local chapters (NSPE 2019). In August 2016, NSPE compiled a published report that documented the language of the individual states, including Washington, DC, pertaining to laws and regulations that govern the P.E. oversight of major infrastructure project practices and reviewed the industrial exemption provisions, as allowed by those laws and regulations. Currently 31 states have exemptions and 19 states and the District of Columbia do not. The State of New York is in the process of removing the exemption. Table 4 outlines the P.E. industrial exemption by state.[37]

Table 4. P.E. industrial exemption for infrastructure project practices.

State	Exempt (Yes or No)	If Yes, action required for change
Alabama	Yes	Amend statute
Alaska	Yes	Amend statute
Arizona	Yes	Amend statute
Arkansas	Yes	Amend statute
California	Yes	Amend statute
Colorado	Yes	Amend statute
Connecticut	Yes	Amend statute
Delaware	No	
District of Columbia	No	
Florida	Yes	Amend statute
Georgia	Yes	Amend statute
Hawaii	No	
Idaho	Yes	Amend statute
Illinois	Yes	Amend statute
Indiana	No	
Iowa	Yes	Amend statute
Kansas	No	
Kentucky	Yes	Amend statute
Louisiana	Yes	Amend statute
Maine	Yes	Amend statute
Maryland	Yes	Amend statute

[36] NTSB Safety Recommendation P-18-6 (Urgent).
[37] Data for this chart was submitted by NCEES.

CORRECTED COPY

State	Exempt (Yes or No)	If Yes, action required for change
Massachusetts	No	Legislation passed and signed into law
Michigan	No	
Minnesota	Yes	Amend statute
Mississippi	Yes	Amend statute
Missouri	Yes	Amend statute
Montana	Yes	Amend statute
Nebraska	Yes	Amend statute
Nevada	Yes	Amend statute
New Hampshire	No	
New Jersey	No	
New Mexico	No	
New York	Yes	Amend statute[a]
North Carolina	Yes	Amend statute
North Dakota	No	
Ohio	No	
Oklahoma	No	
Oregon	No	
Pennsylvania	Yes	Amend statute
Rhode Island	No	
South Carolina	Yes	Amend statute
South Dakota	Yes	Amend statute
Tennessee	No	Amend statute
Texas	Yes	Amend statute
Utah	Yes	Amend statute
Vermont	No	
Virginia	Yes	Amend statute
Washington	No	
West Virginia	No	
Wisconsin	No	
Wyoming	Yes	Amend statute

[a] Legislation proposed.

1.10 Government Oversight

1.10.1 Federal Oversight

Federal pipeline safety statutes allow for states to assume safety authority over intrastate natural gas pipelines, hazardous liquid pipelines, and underground natural gas storage through certifications and agreements with the Pipeline and Hazardous Materials Safety Administration (PHMSA) under Title 49 *United States Code* 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 and underground natural gas storage safety through their state legislatures. If states do not participate in the pipeline safety programs, the inspection and enforcement of these intrastate pipeline facilities would be PHMSA's responsibility.

To support states participating in the pipeline safety programs, PHMSA certifies and provides grants to states to reimburse up to 80 percent of the total cost of the personnel, equipment, and activities reasonably required by the state agency for conducting its pipeline safety program during a given calendar year (PHMSA 2019).

1.10.2 Massachusetts Oversight

1.10.2.1 Massachusetts Department of Public Utilities

The Massachusetts DPU is a state-level adjudicatory agency overseen by a three-member commission. It is responsible for the oversight of investor-owned electric power, natural gas, and water utilities in Massachusetts. In addition, the DPU develops alternatives to traditional regulation, monitors service quality, regulates safety in the transportation and natural gas pipeline areas, and oversees the siting of energy facilities. The mission of the DPU is to ensure that customers of the covered utilities receive reliable and economical service, along with protecting the public from natural gas pipeline-related accidents and ensuring that residential ratepayers' rights are protected (Commonwealth of Massachusetts 2019).

The pipeline safety division of the DPU is an enforcement office, ensuring that operators of natural gas distribution companies, municipal natural gas departments, steam distribution companies, and other intrastate operators are following state and federal regulations governing safety. The pipeline safety division investigates natural gas incidents and determines the cause of those incidents, which is intended to improve public safety and prevent similar incidents. Incident investigations have resulted in new safety regulations for abandoned service lines, cast iron pipe, and liquefied natural gas plants. The DPU regulates pipeline safety within the Commonwealth of Massachusetts; however, pipelines that cross state boundaries (interstate) are regulated by PHMSA. The DPU also tests commonwealth natural gas meters for accuracy and leaks. After passing the test, each meter is marked with a stamp, showing that it is approved for use (Commonwealth of Massachusetts 2019a).[37] PHMSA audits the DPU annually and gives it a proficiency score based on its actions to ensure that operators comply with federal requirements. The proficiency score influences funding levels that DPU receives from PHMSA. In the 2017 audit, the DPU scored 112 points out of a possible 115, for an overall state rating of 97.5. Past DPU actions involving CMA violations are listed in appendix C.[38] Enforcement action by DPU on this accident is pending.

1.10.2.2 Massachusetts Executive Office of Public Safety and Security

The Commonwealth of Massachusetts Executive Office of Public Safety and Security oversees several agencies that deal with emergency response. According to its website, the Executive Office of Public Safety and Security "is responsible for the policy development and budgetary oversight of its secretariat agencies, independent programs, and several boards which aid in crime prevention, homeland security preparedness, and ensuring the safety of residents and visitors in the Commonwealth." (Commonwealth of Massachusetts 2019b).

[37] Massachusetts Code 220 *Code of Massachusetts Regulations* 69.00, "Procedures for the Determination and Enforcement of Violation of Safety Codes pertaining to Pipeline Facilities, Transportation of Natural Gas, and Liquified Natural Gas Facilities" is the guidance for the DPU enforcement actions.

[38] E-mail from NiSource to NTSB, May 13, 2019.

2 Postaccident Actions

2.1 NTSB Safety Recommendation to Commonwealth of Massachusetts

At the time of the accident, a Massachusetts P.E. stamp was not required on any utility system construction, operations, or maintenance projects as local natural gas distribution companies in the state had a utility exemption from requiring a P.E.'s stamp. On November 14, 2018, the NTSB issued a safety recommendation report, *Natural Gas Distribution System Project Development and Review*, in response to this accident and the events that followed (NTSB 2018). According to the report:

> The Commonwealth of Massachusetts' exemption for the requirement of registered Professional Engineer (P.E.) to perform industrial and public utility work limits the opportunities for competently trained and experienced engineers to uncover system design and work process deficiencies. By eliminating the exemption, especially for systems involving inherently dangerous materials such as natural gas distribution systems, companies, workers, and the public are provided greater safety assurance that competent and qualified engineers, who are ethically bound to work only on projects within the scope of their expertise, will review, assess, and execute the requisite work activities according to best engineering practices and with expected safeguards.

As a result of this investigation, the NTSB issued Safety Recommendation P-18-5 to the Commonwealth of Massachusetts

> Eliminate the professional engineer licensure exemption for public utility work and require a professional engineer's seal on public utility engineering drawings. (P-18-5)

Less than 2 months after the safety recommendation was issued, on December 28, 2018, Bill H.5005, requiring that licensed P.E.s review and approve engineering plans developed by or on behalf of natural gas companies, to ensure the safe construction, operation, and maintenance of natural gas infrastructure, was passed by the Massachusetts House of Representatives. The act applies to engineering work or services on natural gas distribution systems that could pose a material risk to public safety, as determined by the DPU, performed by or on behalf of a natural gas company. Moreover, the act requires any engineering plans or specifications for engineering work or services that could pose a material risk to public safety, developed by or on behalf of a natural gas company, to bear the stamp of approval of a licensed P.E.[39] After the Massachusetts Senate passed the act, it was signed by the governor on December 31, 2018, as Chapter 339 of the Acts of 2018. This new law included an emergency preamble and took effect immediately. Because it required natural gas work that might pose a material risk to the public be reviewed and approved by a certified P.E., Safety Recommendation P-18-5 is classified "Closed—Acceptable Action."

[39] See https://malegislature.gov/Bills/190/H5005. Accessed on May 25, 2019.

2.2 NTSB Urgent Recommendations to NiSource

In the November 14, 2018, safety recommendation report, *Natural Gas Distribution System Project Development and Review,* the NTSB also issued four urgent recommendations to NiSource (NTSB 2018). While the engineering design package for the South Union Street project underwent a constructability review, the review did not identify the impact on pressure regulation and control. The NiSource field engineer who developed the engineering plans told NTSB investigators he developed them without reviewing engineering drawings that documented the regulator sensing lines.

Because a comprehensive constructability review, which would require all departments to review each project, along with the seal of approval from a registered P.E., likely would have identified the omission of the regulator sensing lines, thereby preventing the error that led to the accident, the NTSB issued urgent Safety Recommendation P-18-6 to NiSource:

> Revise the engineering plan and constructability review process across all your subsidiaries to ensure that all applicable departments review documents for accuracy, completeness, and correctness, and that the documents or plans be sealed by a professional engineer prior to commencing work. (P-18-6) (Urgent)

In response to this recommendation, NiSource developed and implemented a new Gas Standard (GS 2810.050) detailing the stakeholder reviews that are required for design capital projects or projects where pipeline facilities are installed or replaced. The Gas Standard details the steps in project design and execution when additional stakeholder input is necessary to ensure safe work performance. With this Gas Standard, the use of an enhanced Constructability/Safety Review form is required across the organization to provide additional assurance that all applicable departments review project plans prior to the start of work.

Since January 1, 2019, NiSource requires that all relevant construction documents for complex projects are being sealed by a P.E. prior to the start of construction. In meetings with the NTSB, NiSource discussed that there were potentially large numbers of routine main extensions involving standard tie-ins, emergency main replacements requiring standard tie-ins, or new and replacement service lines, and that completing all of these standard designs would delay implementing this recommendation beyond what is appropriate given its urgent classification. Therefore, although NiSource agreed that construction work that could pose a material risk to public safety needed P.E. review and approval prior to commencing construction, NiSource developed criteria for when review by a P.E. is not necessary. In GS 2810.050, NiSource defines complex projects requiring that documents or plans be sealed by a P.E. as follows:

- Plans for installation or replacement of transmission-class pipelines or distribution mains with an MAOP equal to or greater than 200 psig
- Plans for the installation of or replacement of distribution mains with more than two tie-ins
- Plans for the installation of pipelines requiring a temporary bypass

- Projects which involve a change in system pressure
- Plans for the installation of distribution services requiring the interruption of natural gas flow to the adjacent transmission lines and/or distribution main
- Plans for nonstandard new points of delivery and district regulator stations
- Plans for regulator station work that require an interruption of natural gas flow on the inlet or outlet transmission lines and/or distribution mains

The development and implementation of GS 2810.050, including the requirement that construction documents and plans be sealed by a P.E., satisfies Safety Recommendation P-18-6 which is classified "Closed—Acceptable Action."

NiSource engineering plans used during the construction work did not document the location of regulator sensing lines. The NTSB believes that had accurate alignment sheets with comprehensive system information been prominently available and required within the toolsets used by the engineers, and diligently reviewed for completeness and technical/safety risks by engineering supervisors, the work package and construction activity plans would have accounted for the regulator sensing lines and prioritized their relocation before abandoning the cast iron main. As a result, the NTSB made the following urgent safety recommendation to NiSource:

> Review and ensure that all records and documentation of your natural gas systems are traceable, reliable, and complete. (P-18-7) (Urgent)

In its May 10, 2019, letter, NiSource responded it had completed locating, marking, and mapping control (regulator-sensing) lines at all 2,072 low-pressure regulator runs across its system. NiSource said that these facilities are depicted in isometric drawings and are visible in its GIS. In addition, NiSource contracted with a third-party natural gas engineering firm to verify the assets required to safely operate its low-pressure natural gas systems and ensure these assets are clearly indicated on relevant maps and records. On July 22, 2019, Safety Recommendation P-18-7 was classified "Closed—Acceptable Action."

NTSB investigators found that NiSource did not use management of change (MOC) procedures for managing maintenance and construction changes to pipeline operations. The company did not conduct separate risk assessments for each construction project, critical components of a PSMS program. MOC procedures require an analysis of implications, among several other elements. Additionally, a risk identification and assessment are necessary to establish the appropriate prevention and mitigation measures to reduce the likelihood of consequences should an incident occur. CMA failed to perform such an analysis and failed to establish appropriate controls to mitigate the risks of the work that was being performed. Had NiSource adequately performed MOC, it could have immediately addressed the issue and mitigated the

consequences of the event. Therefore, the NTSB issued Safety Recommendation P-18-8 to NiSource:

> Apply management of change process to all changes to adequately identify system threats that could result in a common mode failure. (P-18-8) (Urgent)

In response, NiSource improved its MOC process by developing and using Gas Standard 1680.010, "Tie-Ins and Tapping Pressurized Pipelines," and NiSource now requires the use of a written tie-in plan template. As part its PSMS development activities, NiSource initiated asset review and probabilistic risk assessments that focus on improving risk analysis, identification, and mitigation. NiSource also developed and implemented an MOC procedure for its construction employees and contractors that details the steps needed to ensure safety on a project during a change in personnel. These activities satisfy Safety Recommendation P-18-8 which is classified "Closed—Acceptable Action."

NTSB investigators also determined that had NiSource adequately performed system engineering management throughout its project work, the safety risk of an overpressurization likely would have been identified, along with appropriate mitigations implemented before undertaking the construction activities. For example, with recognition for potential overpressurization to the unprotected low-pressure distribution lines, mitigations could have been used, such as pressure relief valves, temporary slam-shut valves, or personnel positioned at critical points along the system and prepared to manually intervene by closing valves. NiSource failed to adopt and execute an appropriate system engineering management approach to this work and, consequently, neglected to perform important engineering reviews based on thorough system-level information which, consequentially exposed the company, its workers, and the public to the unexpected, albeit foreseeable through proper engineering practices, overpressurization. The NTSB issued Safety Recommendation P-18-9 to NiSource:

> Develop and implement control procedures during modifications to gas mains to mitigate the risks identified during management of change operations. Gas main pressures should be continually monitored during these modifications and assets should be placed at critical locations to immediately shut down the system if abnormal operations are detected. (P-18-9) (Urgent)

In a May 2019 letter, NiSource said that it has made "significant" enhancements to its tie-in and tapping procedures, including risk assessments, thorough checklists, and the development of contingency plans. NiSource also said that it was installing automatic pressure-control equipment and remote monitoring devices on every low-pressure natural gas distribution system across its operating area. These revisions satisfied Safety Recommendation P-18-9, which on July 22, 2019, was classified "Closed—Acceptable Action."

2.3 NiSource Emergency Preparedness and Response Actions

In early 2019, and as part of the company's SMS implementation, NiSource commissioned a cross-functional emergency preparedness and response team, led by a senior vice president for emergency preparedness, to enhance emergency preparedness activities and emergency response capabilities. The project is integrating improved preparedness plans and drills covering a broad

range of potential scenarios and levels of emergency with well-defined roles and clear responsibilities.

Key outcomes of the project include:

- A single emergency response plan (ERP) across the natural gas segment
- Consistent definitions for incident levels from less severe to the most severe
- Implementation of a single incident command system and structure regardless of incident level
- Consistent use of incident command system processes and terminology
- Enhanced training (computer-based, classroom and independent study) for all employees with roles in the ERP and incident command system
- Emergency drills in the third and fourth quarters to build familiarity with the plan, processes, and terminology

In addition to creating consistency across the NiSource natural gas segment, these efforts enhance consistency with key external partners who have used the incident command system for a number of years. A comprehensive project plan is guiding the team's work and remains on track. Key milestones achieved through the first half of 2019 included:

- Successfully completing classroom training and certification in Federal Emergency Management Agency ICS 100, 200, and 700 modules
- Reviewing and analyzing existing corporate and operating company emergency and crisis communications plans, as well as the corporation's business continuity plans
- Completing best practice visits with industry peers and internally
- Conducting more than 20 internal critical function interviews with individuals who spent significant time supporting Merrimack Valley restoration efforts
- Finalizing the first draft of the natural gas segment incident command structure in early April and the first draft of the natural gas segment ERP in late April

NiSource reported that its emergency preparedness response team is engaged with its technical training department to build comprehensive and individualized plans for those employees with emergency response roles. Concurrently, the team is working to develop comprehensive drills and exercises to test the plan, identify gaps, and make the necessary adjustments to strengthen overall company preparedness.

The NiSource corporate affairs and legal teams are working to develop a crisis communications "playbook" to support crisis response efforts. An ongoing assessment by

NiSource corporate affairs is the first phase of the effort. They plan to incorporate the crisis communications plans, processes, protocols and materials into the natural gas segment of the Emergency Preparedness and Response Plan.

2.4 Industry Actions

On November 26, 2018, AGA released a technical document titled *Leading Practices to Reduce the Possibility of an Over-Pressurization Event*, a document that serves as a resource for natural gas utilities to help avoid an overpressurization incident in a natural gas system (AGA 2018).

Following this natural gas accident, the AGA had information about the role of overpressurization that allowed the AGA to work to identify practices and procedures that can help avoid a similar accident in the future.

There are several leading practices included in the document:

- Design practices, including common overpressure protection designs and equipment
- Operating procedures and practices, including system monitoring, records, and damage prevention
- Human factors, including MOC, OQ, and field oversight
- Management of the risk of an overpressurization event, including addressing overpressurization under the operator's distribution integrity management plan

General practices the AGA considers key to managing the risk of an overpressure event include:

- Looking for opportunities to work with all stakeholders to proactively upgrade utilization pressure systems
- Defining risk criteria for overpressure events

This AGA document was developed with input from stakeholders and experts across the industry, with the focus on developing leading practices that can be used to help prevent overpressurization events.

3 Analysis

3.1 Exclusions

On the day of the accident, the crew that performed the last tie-in on the South Union Street project included one full-time CMA employee, who was a construction coordinator, and a contracted four-member utility construction crew, consisting of a foreman, a truck driver, and two laborers. The CMA employee had several years' experience running utility construction crews and had worked on multiple occasions with the contracted crew. All crewmembers were trained and qualified in accordance with OQ. In addition, a representative from the local police department was present for traffic control.

The type of instructions provided on the day of the accident were of the same format, layout, and overall content as that of the previous 12 tie-ins performed on the South Union Street project; but unique to this work was abandoning the cast iron main. The work package consisted of a computer-aided design drawing with item numbers on it that matched a project execution set of instructions. A review of the work performed by the contractor showed no deviations from the work instructions. Postaccident testing of the regulators from the Winthrop Avenue regulator station determined that they functioned as designed with no deficiencies.

Therefore, the NTSB concludes that none of the following were factors in this accident: the training and qualification of the construction crew, the use of alcohol or other drugs, or the condition and operability of the regulators at the Winthrop Avenue regulator station.

3.2 Overpressurization Protection for Low-Pressure Natural Gas Systems

The low-pressure natural gas distribution system in Merrimack Valley met the requirements for overpressure protection contained in 49 *CFR* 192.195 *Protection against accidental overpressuring* and 49 *CFR* 192.197 *Control of the pressure of gas delivered from high-pressure distribution systems*. At each of the 14 regulator stations feeding natural gas into the low-pressure natural gas distribution system, there were two regulators installed in series to control the natural gas flow from the high-pressure natural gas distribution system. The worker regulator and the monitor regulator were set to limit the pressure to the mains and then to the customer to a maximum safe value. However, a review of accidents investigated by the NTSB over the past 50 years (section 1.7.2) and prior NiSource incidents (section 1.7.3) demonstrate that this scheme for overpressure protection can be defeated in several ways. Three of the NTSB investigations (Gary, Indiana, June 3, 1969; Mansfield, Ohio, May 17, 1978; and Chicago, Illinois, January 17, 1992) detailed how operator error resulted in high-pressure gas being introduced into the low-pressure natural gas distribution system through an interconnection. In three other NTSB investigations (Burlington, Iowa, November 6, 1969; Centralia, Missouri, January 26, 1982; and East Boston, Massachusetts, September 23, 1983), outside force damage in or near the regulator vaults damaged equipment, resulting in high-pressure gas being introduced into the low-pressure natural gas distribution system through the regulators. The remaining NTSB investigation (El Paso, Texas, August 9, 1977) was nearly identical to this accident in Merrimack Valley because

it occurred when a cast iron main with sensing lines attached was isolated as part of a pipe replacement project.

In this accident, when the cast iron main with the sensing lines attached was isolated from the distribution system and abandoned in place, both regulators responded to the decreasing pressure, detected by the sensing lines, by fully opening. Both regulators were disabled simultaneously by the single event of isolating the cast iron main, which eliminated the redundancy of using dual regulators. In this accident and the earlier accidents discussed above, the overpressure occurred as the result of a single failure. In engineering analyses, such a situation is referred to as a common mode failure. Therefore, the NTSB concludes that the multiple overpressurization accidents investigated by the NTSB over the past 50 years demonstrate that low-pressure natural gas distribution systems that use only sensing lines and regulators as the means to detect and prevent overpressurization are not optimal to prevent overpressurization accidents. Thus, the NTSB recommends that PHMSA revise 49 *CFR* Part 192 to require overpressure protection for low-pressure natural gas distribution systems that cannot be defeated by a single operator error or equipment failure.

For regulator sensing lines, CMA only considered excavation damage as a risk to be mitigated. In engineering design, there are several methods available to assess and mitigate risk. A failure modes and effects analysis (FMEA) is a generally accepted and recognized engineering practice to identify and assess potential failures, including common mode failures. FMEA methodology is a structured and systematic technique for assessing and mitigating risks. FMEA was initially applied in the 1950s to understand and prevent malfunctions. Its use has continued to influence engineering design of systems and it has been expanded into several forms: risk assessment for design, functionality, and process failures; as well as criticality analyses of engineered systems. The NTSB concludes that a comprehensive and formal risk assessment, such as an FMEA, would have identified the human error that caused the redundant regulators to open and overpressurize the system. Although PHMSA rulemaking could take several years, it has other mechanisms to quickly communicate and encourage best safety practices. Therefore, the NTSB recommends that PHMSA issue an alert to all low-pressure natural gas distribution system operators of the possibility of a failure of overpressure protection; and the alert should recommend that operators use an FMEA or equivalent structured and systematic method to identify potential failures and take action to mitigate those identified failures.

3.3 CMA Engineering Processes

Early in the investigation, after determining that the contractors followed the instructions they were provided, it became apparent that there were deficiencies in several of NiSource's engineering processes. About 2 months after the accident, NTSB released a safety recommendation report, *Natural Gas Distribution System Project Development and Review*, which issued several urgent safety recommendations to NiSource (NTSB 2018). The following sections build on that report regarding records and documentation, constructability reviews, and risk management.

3.3.1 Records and Documentation

The field engineer responsible for the South Union Street Project largely relied on GIS to develop work packages. He also had access to isometric drawings containing schematics of the pipes in the regulator vaults as well as the piping and valve configurations. Sensing lines, however, were not included in the isometric drawings or GIS.

The field engineer told investigators that he did not know if the engineering department had access to sensing line information, though he believed that the M&R department did. According to NiSource, information about sensing lines for the Winthrop Avenue regulator station was available in hard-copy records in the Lawrence Operations Center. However, when investigators asked NiSource in an e-mail exchange about the instructions that NiSource provides employees with respect to how to find information about sensing lines, NiSource did not provide an answer; rather, it asserted that "CMA Engineering, Construction, and M&R personnel know how to obtain information about sensing line locations."[40] Moreover, an M&R manager suggested that locating accurate and up-to-date information about sensing lines was challenging because there was a shortage of information and confusion regarding what recordkeeping system would be used. The available evidence suggests that although the field engineer would have likely been able to seek out sensing line information, these data were not easily accessible electronically.

NiSource's director of engineering told investigators that the GIS was the company's centralized record system and that a goal of the system was to integrate data from various sources. That is, the company was taking data from old cabinets and binders and making it available electronically to all interested stakeholders. The director of engineering recognized that, at the time of the accident, there was a shortage of readily available information about the sensing lines. NiSource reported it has addressed the lack of sensing line data in the GIS after the accident.

An e-mail provided by NiSource showed that at least one employee, the Lawrence construction leader, knew that the sensing lines needed to be relocated. Moreover, an affidavit provided by NiSource suggested that other employees were aware of the need to relocate the sensing lines. However, NiSource stated in its submission for this accident investigation that after the South Union Project was delayed in 2016:

> There was a nearly complete turnover in project personnel. CMA did not effectively transfer the knowledge its 2016 construction personnel had about the status of the project sensing lines to its 2018 construction personnel.

Thus, according to NiSource, the successful execution of the South Union Street project was contingent upon employees remembering to transfer knowledge. In its evaluation of the probable cause of the accident, the company pointed to the city of Lawrence's "unprecedented suspension of project work," a 1 1/2-year delay, as a contributing factor. A delay in construction does not justify a catastrophic accident. However, NiSource does point to a true system defect in its list of contributing factors: "The project work order package did not explicitly address sensing line locations or their relocation."

[40] E-mail from NiSource to NTSB, May 31, 2019.

NiSource displayed an informal, unstructured approach for documenting this critical project step for the South Union Street project. The lack of documentation made it impossible to pinpoint the exact nature of the joint failure between the engineering, M&R, and construction departments to develop a formal plan for relocating the sensing lines. It is likely that more robust documentation and recordkeeping would have resulted in the sensing line issue being formally addressed prior to the work package being released to construction. As it was, the relocation of the sensing lines was not directed in an orderly top-down manner, but rather, NiSource relied on institutional knowledge. When the appropriate employees were not at the correct place at the correct time due to a project delay, there was no documentation to refer to for preventing a critical project step from being omitted. Therefore, the NTSB concludes that CMA's inadequate planning, documentation, and recordkeeping processes led to the omission of the relocation of the sensing lines for the South Union Street project. Furthermore, the NTSB concludes that the abandonment of the cast iron main without first relocating the sensing lines led to the system overpressurization, fires, and explosions.

Although there was a 2-year delay from the time the work order was developed until the time of the accident, NTSB investigators could find no evidence that the delay contributed to the accident. Had this work order been executed 2 years earlier, the system would have been overpressurized just as it was on September 13, 2018. The NTSB concludes that the delay between the development of the initial project work order and its execution had no impact on this accident.

3.3.2 Constructability Review

The engineering plans were included in the project package that was circulated for a constructability review. Constructability reviews are recognized and accepted as a necessary engineering practice for the execution of construction services. They are intended to provide structured reviews of construction plans and specifications to ensure functionality, sustainability, and safety—ensuring there are no shortcomings, inefficiencies, conflicts, or errors. Constructability reviews are essential in the engineering management of projects for verifying that all stakeholders have knowledge about and input into a work project.

Nonetheless, the constructability review process did not detect the omission of the need to relocate the sensing lines. Part of the failure of the process was likely due to the absence of a review by a critical department. Despite there being at least two constructability reviews for the South Union Street project, the M&R department did not participate. CMA requires the engineering department and the construction department to approve all projects, but the land services department and the M&R department are only required to review the packages on an "as-needed basis" as determined by the project engineer. The M&R department maintains the regulator stations, and with the project requiring the relocation of the sensing lines, the department should have been included. A review from someone in the M&R department may have resulted in the detection of the omission of a work order to relocate the sensing lines. The basis for the "need" is not described, nor are examples provided in the NiSource constructability review guidance.

There are several other factors that suggest an overall lack of robustness of the review process. The Lawrence construction leader signed all three reviews, but never objected to the lack of a work order to relocate the sensing lines, even though he had e-mailed the M&R department regarding the need to relocate the sensing lines between the first and second review. In addition,

the only indication of a third review is the set of signatures (dated December 14, 2017) on the paperwork for the second review (originally signed January 6, 2017). NiSource did not provide any additional documentation for the third review. This calls into question the thoroughness of the third review. The NTSB concludes that the CMA constructability review process was not sufficiently robust to detect the omission of a work order to relocate the sensing lines. After the accident, NiSource has been working to improve its constructability review process.

3.3.3 Engineering Risk Assessment

NiSource's ON 15-05 requires that M&R personnel be consulted on all excavation work that is performed within 25 feet of a regulator station with sensing lines, and for other specified work. This notice resulted from a near-miss incident in 2014, where excavation work almost struck sensing lines near a regulator.

The work being performed on the South Union Street project on the day of the accident did not occur within 25 feet of the Winthrop Avenue regulator station; therefore, ON 15-05 did not apply directly to the work. NiSource's ON 15-05 can be read in its entirety in appendix E.

Although the risk mitigations mandated in ON 15-05 did not apply, the language of the notice revealed that NiSource was aware that a catastrophic overpressurization of downstream piping would occur if flow should be disrupted through a segment of piping with active sensing lines for any reason. However, the controls implemented in the notice were only intended to prevent sensing lines from being struck during excavation.

More robust risk management was needed in the planning of the South Union Street project with respect to the analysis of the impact on the system, as discussed in NTSB Safety Recommendation Report PSR-18/02 (NTSB 2018). Moreover, as discussed earlier, broader risk management was needed with respect to overpressurization to the system in general. That is, engineering controls should have been implemented considering the vulnerability of the system to a common mode failure during the construction project. After the accident, NiSource has worked to improve its risk management processes and is installing automatic pressure-control equipment. Therefore, the NTSB concludes that NiSource's engineering risk management processes were deficient.

3.4 Professional Engineer Review and Approval

The NTSB recognizes that a P.E. license is a valued credential, especially for engineering projects affecting public safety. The P.E. license conveys that the holder maintains and demonstrates technical competency and imposes continuing education requirements in most states. Moreover, P.E. licensees are bound to a code of ethics for engineers, which creates a duty to hold public safety, health, and welfare paramount and to perform services only in the areas of their competence, among several other obligations. P.E. licensees are also personally accountable for the work they approve and stamp and must exercise responsible charge over all aspects of the work. As shown in table 4 of this report, 31 states have an industrial exemption for P.E. licensure. The NTSB concludes that requiring a licensed professional engineer to stamp plans would illustrate that the plans had been approved by an accredited professional with the requisite skills,

knowledge, and experience to provide a comprehensive review. Therefore, the NTSB recommends that those 31 states with an industrial exemption for natural gas infrastructure projects remove the exemption so that all future natural gas infrastructure projects require licensed professional engineer approval and stamping.

3.5 Emergency Response

3.5.1 Public Safety Answering Points

The PSAPs in each municipality were inundated with emergency calls, especially during the first hour after the accident. Each PSAP had alternate and final PSAPs as backup resources, to handle the overflow of incoming calls. The Lawrence PSAPs, which had the highest number of calls for aid from people affected by the overpressurization, reported that the number of incoming calls declined after the first hour of the event through midnight on September 13, 2018. The NTSB found no evidence that the high number of emergency calls delayed critical reports of damage nor requests for emergency assistance. Therefore, the NTSB concludes that the municipal PSAPs had available and ready resources to handle the large number of distress calls requesting emergency services.

3.5.2 Emergency Responder Communications

Radio communications among emergency responders was necessary for effective deployment and reassignment of emergency personnel and resources across the area affected by the natural gas overpressurization. Responding units from fire, police, and medical departments needed to coordinate activities, share situation-specific status information, and communicate instructions when required to move to new locations.

Each fire department had one radio channel for intradepartmental communications. In addition, some fire departments had radios capable of interdepartmental communications, allowing direct communications with other fire departments during the emergency response. ICs from each of the three municipalities reported to NTSB investigators that there was a high volume of "chatter" on the radio due to many responders and agencies using the single interdepartmental channel, making it difficult to understand and exchange information. NTSB investigators were told that the mix of radios used by the responding departments also created challenges because not all radios were interoperable. As a result, not all fire departments could directly access other departments.

When the 15 task forces were activated across the state, additional communication resources were included. On September 13, Communication unit leaders were sent to the overpressure accident. Communication unit leaders are responsible for developing communications plans in accordance with the Massachusetts Tactical Channel plan and assessing what resources are needed to maintain communications during an accident. Communication plans were developed for the Merrimack Valley natural gas accident through the operational period from September 13 through September 16. However, the first communication plan was not implemented until around 7:05 p.m., 3 hours after the fires began. Local fire departments needed additional tactical radio channels within the first 2 hours of the accident, when most emergency calls were

made. The NTSB concludes that the field radio communications used across fire departments on September 13 lacked adequate interoperability and availability to ensure that emergency responders had efficient means of interdepartmental and intradepartmental communications.

Statewide Communications Interoperability Plans (SCIP) are comprehensive plans to enhance and maintain emergency communications between multiple jurisdictions in the event of natural disasters, acts of terrorism, or other man-made disasters. Massachusetts issued its first SCIP in 2007 and noted that home rule poses challenges to radio interoperability because towns were given the authority to determine their own needs (Commonwealth of Massachusetts 2015). The SCIP identified six critical strategic initiatives that Massachusetts needed to put into place to achieve optimum communications interoperability, including the development of funding sources to support the program. The northeast region of Massachusetts, including Merrimack Valley, does have a regional communications system, but the SCIP suggested that the region needed greater interoperability and moment-to-moment sharing of information.

Massachusetts' SCIP was last updated in 2015 and outlined a multi-jurisdictional and multidisciplinary statewide strategic plan to enhance interoperable and emergency communications. The purpose of the updated SCIP was to provide a strategic plan for directing and aligning resources for interoperable and emergency communications at both state and local levels, as well as expanding existing systems for voice communications for sufficient capacity and coverage for first responders. The plan discusses critical elements to achieve successful interoperable communications such as developing standard operating procedures and upgrading technology. However, no guidance is provided on how to coordinate and implement a plan for emergency responders to effectively communicate during a multi-jurisdictional incident.

The Federal Emergency Management Agency (FEMA) developed "how-to" guides to assist state and local governments in developing effective hazard mitigation planning. This guidance helps local governments develop and implement multi-jurisdictional hazard mitigation plans to help assess and identify vulnerabilities within and across communities and formulate strategies to mitigate the consequences of such events (FEMA 2006).

The communications difficulties experienced by emergency responders in the multi-jurisdictional response to the overpressurization indicate that communications interoperability is still a problem in Massachusetts, despite the communication resources available to local jurisdictions, as outlined in the 2015 SCIP. The NTSB concludes that the communications issues during the September 13 overpressurization illustrate the need for emergency planning for a multi-jurisdictional response. Therefore, the NTSB recommends that the Commonwealth of Massachusetts Executive Office of Public Safety and Security develop guidance that includes a component for effective communications when deploying mutual aid resources within the first hours of a multi-jurisdictional incident.

3.5.3 NiSource Emergency Coordination with Municipal Responders

The ICs from Lawrence, North Andover, and Andover each told NTSB investigators that they attempted to reach CMA through dispatch, but they did not receive information from the company until hours later. They acknowledged that CMA likely was overwhelmed with

emergency calls, but they emphasized that responders needed to know in a timely manner about the company's response efforts and about which natural gas service sites were impacted.

The *NiSource Emergency Manual* states that when an overpressurization of the system occurs, there "may be a need" to communicate with local government officials and emergency management agencies as well as fire and police departments. The manual states that it is "imperative for all entities involved to remain informed of each other's activities." The manual states that the IC, in this case, the FOL, is required to establish appropriate contacts for communications purposes throughout the accident (NiSource 2018). However, during the initial hours of the event, the IC did not establish these requisite communication contacts because he was involved with shutting down the natural gas system. Moreover, although CMA representatives went to emergency responder staging areas and emergency operations centers, NTSB investigators were told that representatives could not address many of the questions from the emergency responders because they were not prepared with thorough and actionable information.

The NTSB concludes that the CMA IC faced multiple competing priorities, such as communicating with affected municipalities, updating the emergency responders, and shutting down the natural gas distribution system, which adversely affected his ability to complete his tasks in a timely manner.

The CMA ERP describes a detailed communications plan in which its director of government affairs (or designees) would be posted with the MEMA emergency operations center (EOC), who must have access to the CMA emergency coordinator, the CMA president, and the CMA vice president/general manager. According to the plan, appropriate maps and outage reports would be made available to these staff for the purpose of informing the EOC officials. MEMA officials and the state fire marshal stated that NiSource took too long to provide maps of the low-pressure system. They emphasized that emergency response officials needed street maps showing the layout of the natural gas system to understand where the affected customers were located. They also emphasized that emergency response officials needed updates on CMA's progress to shut down the natural gas system. The officials stated that CMA did not provide this requested information, either during the initial hours following the overpressurization or afterward, and that the absence of information from CMA impeded its public safety decision-making.

Without understanding the nature or extent of the overpressurization or the company's success in restoring control of the natural gas distribution system, emergency response officials and ICs had to make decisions to preserve public safety despite a lack of critical information. For example, decisions were made to evacuate thousands of people from homes and businesses and to shut down electricity throughout the region, including nonaffected neighboring areas. Because emergency officials did not have accurate information with respect to the affected area, they evacuated and shut down electricity in an area larger than necessary.

The evacuations led to major traffic congestion, which slowed CMA and NG technicians responding to the areas in and surrounding the accident location. The traffic issues were handled by the Massachusetts State Police, who were stationed at major intersections within an hour following the overpressurization. Travel delays on public roads and confusion caused by the uncertainty of the natural gas explosions and fires existed for hours following the overpressurization.

When electricity was shut off to the cities and towns, state and local officials had to manage a number of complex public safety issues, such as sustaining critical services in hospitals and critical-care facilities, police and fire departments, water and sewer treatment plants, and ensuring the security of numerous facilities, as well as maintaining orderly evacuations without traffic lights. State and local government and emergency response officials coordinated with NG, the electric utility company, to ensure that sensitive populations and critical infrastructure were prepared before shutting down the electric power. State and local police provided security to some facilities without electric power.

The lack of timely, thorough, and actionable information on the circumstances of the overpressurization evacuations and electricity shutdowns were conducted in areas where they were not needed, straining resources and further complicating the response. The NTSB concludes that CMA was not adequately prepared with the resources necessary to assist emergency management services with the response to the overpressurization. Therefore, the NTSB recommends that NiSource review its protocols and training for responding to large-scale emergency events, including providing timely information to emergency responders, appropriately assigning NiSource emergency response duties, performing multi-jurisdictional training exercises, and participating cooperatively with municipal emergency management agencies.

4 Conclusions

4.1 Findings

1. None of the following were factors in this accident: the training and qualification of the construction crew, the use of alcohol or other drugs, or the condition and operability of the regulators at the Winthrop Avenue regulator station.

2. The multiple overpressurization accidents investigated by the National Transportation Safety Board over the past 50 years demonstrate that low-pressure natural gas distribution systems that use only sensing lines and regulators as the means to detect and prevent overpressurization are not optimal to prevent overpressurization accidents.

3. A comprehensive and formal risk assessment, such as a failure modes and effects analysis, would have identified the human error that caused the redundant regulators to open and overpressurize the system.

4. Columbia Gas of Massachusetts' inadequate planning, documentation, and recordkeeping processes led to the omission of the relocation of the sensing lines for the South Union Street project.

5. The abandonment of the cast iron main without first relocating the sensing lines led to the system overpressurization, fires, and explosions.

6. The delay between the development of the initial project work order and its execution had no impact on this accident.

7. The Columbia Gas of Massachusetts constructability review process was not sufficiently robust to detect the omission of a work order to relocate the sensing lines.

8. NiSource's engineering risk management processes were deficient.

9. Requiring a licensed professional engineer to stamp plans would illustrate that the plans had been approved by an accredited professional with the requisite skills, knowledge, and experience to provide a comprehensive review.

10. The municipal public safety answering points had available and ready resources to handle the large number of distress calls requesting emergency services.

11. The field radio communications used across fire departments on September 13 lacked adequate interoperability and availability to ensure that emergency responders had efficient means of interdepartmental and intradepartmental communications.

12. The communications issues during the September 13 overpressurization illustrate the need for emergency planning for a multi-jurisdictional response.

13. The Columbia Gas of Massachusetts incident commander faced multiple competing priorities, such as communicating with affected municipalities, updating the emergency responders, and shutting down the natural gas distribution system, which adversely affected his ability to complete his tasks in a timely manner.

14. Columbia Gas of Massachusetts was not adequately prepared with the resources necessary to assist emergency management services with the response to the overpressurization.

4.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the overpressurization of the natural gas distribution system and the resulting fires and explosions was Columbia Gas of Massachusetts' weak engineering management that did not adequately plan, review, sequence, and oversee the construction project that led to the abandonment of a cast iron main without first relocating regulator sensing lines to the new polyethylene main. Contributing to the accident was a low-pressure natural gas distribution system designed and operated without adequate overpressure protection.

5 Recommendations

5.1 New Recommendations

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

To the Pipeline and Hazardous Materials Safety Administration:

Revise Title 49 *Code of Federal Regulations* Part 192 to require overpressure protection for low-pressure natural gas distribution systems that cannot be defeated by a single operator error or equipment failure. (P-19-14)

Issue an alert to all low-pressure natural gas distribution system operators of the possibility of a failure of overpressure protection; and the alert should recommend that operators use a failure modes and effects analysis or equivalent structured and systematic method to identify potential failures and take action to mitigate those identified failures. (P-19-15)

To the States of Alabama, Alaska, Arizona, Arkansas, California, Colorado, Connecticut, Florida, Georgia, Idaho, Illinois, Iowa, Kentucky, Louisiana, Maine, Maryland, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New York, North Carolina, Pennsylvania, South Carolina, South Dakota, Texas, Utah, Virginia, and Wyoming:

Remove the exemption so that all future natural gas infrastructure projects require licensed professional engineer approval and stamping. (P-19-16)

To the Commonwealth of Massachusetts Executive Office of Public Safety and Security:

Develop guidance that includes a component for effective communications when deploying mutual aid resources within the first hours of a multi-jurisdictional incident. (P-19-17)

To NiSource, Inc.

Review your protocols and training for responding to large-scale emergency events, including providing timely information to emergency responders, appropriately assigning NiSource emergency response duties, performing multi-jurisdictional training exercises, and participating cooperatively with municipal emergency management agencies. (P-19-18)

5.2 Previously Issued Recommendations

On November 14, 2018, the National Transportation Safety Board issued the following safety recommendations:

To the Commonwealth of Massachusetts:

> Eliminate the professional engineer licensure exemption for public utility work and require a professional engineer's seal on public utility engineering drawings. (P-18-5)
>
> This recommendation is classified "Closed—Acceptable Action" in section 2.1 of this report.

To NiSource, Inc.:

> Revise the engineering plan and constructability review process across all of your subsidiaries to ensure that all applicable departments review construction documents for accuracy, completeness, and correctness, and that the documents or plans be sealed by a professional engineer prior to commencing work. (P-18-6) (Urgent)
>
> This recommendation is classified "Closed—Acceptable Action" in section 2.2 of this report.
>
> Review and ensure that all records and documentation of your natural gas systems are traceable, reliable, and complete. (P-18-7) (Urgent)
>
> This recommendation is currently classified "Closed—Acceptable Action."
>
> Apply management of change process to all changes to adequately identify system threats that could result in a common mode failure. (P-18-8) (Urgent)
>
> This recommendation is classified "Closed—Acceptable Action" in section 2.2 of this report.
>
> Develop and implement control procedures during modifications to gas mains to mitigate the risks identified during management of change operations. Gas main pressures should be continually monitored during these modifications and assets should be placed at critical locations to immediately shut down the system if abnormal operations are detected. (P-18-9) (Urgent)
>
> This recommendation is currently classified "Closed—Acceptable Action."

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ROBERT L. SUMWALT, III
Chairman

JENNIFER HOMENDY
Member

BRUCE LANDSBERG
Vice Chairman

Date: September 24, 2019

Appendix

Appendix A. The Investigation

The National Transportation Safety Board (NTSB) was notified about 4:00 p.m. local time on September 13, 2018, of an overpressurization of a low-pressure natural gas distribution system that occurred in the city of Lawrence and the towns of Andover and North Andover in Massachusetts that resulted in fires or explosions at over 60 locations. Columbia Gas of Massachusetts (CMA) owns and operates the natural gas distribution system in these jurisdictions.

Local emergency response officials urged all residents with homes serviced by CMA to evacuate, impacting about 146,000 residents. CMA isolated and depressurized the system to prevent further incidents. Electrical power in the area was shut off to minimize potential ignition sources. One person was killed and at least 10 people were injured in the event.

NTSB Board Chairman Robert L. Sumwalt, III, Board Member Jennifer Homendy, an investigator-in-charge, and 18 other staff launched to the accident scene.

Parties to the investigation included the Pipeline and Hazardous Materials Safety Administration (PHMSA); the Massachusetts Department of Public Utilities (DPU); the Massachusetts State Police; NiSource, Inc.; and CMA.

Appendix B. NiSource Safety Management System Plan

Figure 10. NiSource Safety Management System Plan Part A.

Figure 11. NiSource Safety Management System Plan Part B.

Appendix C. Enforcement Actions

Table 5. Massachusetts DPU enforcement actions for the 5 years previous to the accident. Data courtesy of the Massachusetts DPU.

Violation Date	PHMSA 192 Code Sections	Fine	Location	Description
March 7, 2012	192.13(c) 192.227 192.455 192.461 192.605	$7,500	55 Arthur's Place Bridgewater	Buried steel portion of transition fitting on a 2" plastic main had no cathodic protection; records did not indicate transition fitting or name of welder
July 26, 2012	192.13(c) 192.361(a) 192.375	$15,000	100 Union Street Attleboro	Shallow cover on service and outlet piping; transition fitting used as service riser, and exposed transition fitting
June 24, 2012	192.13(c) 192.605(a) 192.615(a)(2) 192.615(b)(2) 192.805(h) 192.727(a) 192.727(b) 220 *CMR* 107.04	$20,000	390 Fall River Avenue Seekonk	Shallow cover on service and outlet piping; transition fitting used as service riser, and exposed transition fitting
November 23, 2012	192.13(c) 192.605(a) 192.615(a)(3) 192.615(a)(5) 192.615(a)(7) 192.615(b)(2) 192.615(b)(3) 192.805(b) 192.805(d) 192.805(e) 192.805(h) 199.101 199.105(b) 199.202 199.225(a) 199.107(a) 40.277	$170,000	453 Worthington Street Springfield (leak)	CMA tech failed to follow proper procedures during leak investigation; during abnormal operating condition, CMA did not check other buildings in area per procedures; CMA did not properly evaluate tech's conduct; call center response to caller was inadequate, did not follow script; CMA did not follow its anti-drug and alcohol plans for testing
November 23, 2012	192.13(c) 192.481(a) 192.491(c) 192.605(a) 192.723(a) 192.723(b)(1) 192.805(h)	$150,000	453 Worthington Street Springfield (ignition)	CMA failed to show that it monitored service lines for atmospheric corrosion; provided insufficient evidence that it performed atmospheric corrosion inspections per procedures; insufficient evidence re leak surveys in business district; insufficiently calibrated leak detection equipment; personnel not properly requalified for leak investigation and surveys

Violation Date	PHMSA 192 Code Sections	Fine	Location	Description
May 1, 2012	192.13(c) 192.605(a) 192.615(a) 192.615(b) 192.727(a) 192.727(b) 220 *CMR* 107.04	$125,000	36 Maple Avenue Seekonk	Improper abandonment of service; failed to report leak and fire to Division; CMA integration center personnel failed to act after reports of fire from four employees; insufficient procedures; inadequate communications with Fire Dept; insufficient public awareness plan
November 17, 2012	192.13(c) 192.605(a) 192.615(a)(5) 192.615(a)(7) 192.615(b)(2) 192.615(b)(3) 192.703(a) 192.703(b) 192.703(c) 192.805(b) 192.805(e) 192.805(h) 220 *CMR* 101.06(21)(e)	$100,000	189 Washington Street Canton	CMA personnel failed to classify leak persuant to CMA's (natural) gas standard; supervisor did not have current operator qualifications necessary to classify leaks; CMA did not check guilding foundations in area
February 4, 2015	192.13(c) 192.605(a) 192.805(b) 192.805(h) 192.807(a) 192.805(b)	$35,000	335 Washington Street Taunton	Unqualified employee (service outage) attempted to install Trident Seal on leak; no mention of Trident Seal in procedures
February 15, 2016	192.201(a)(2)(i) 192.739(1) 192.195(b)(2) 192.603(b) 192.13(c) 192.605(b)(1)	$75,000	West Water Street Taunton	Overpressurization; MAOP exceeded; distribution system not designed to prevent accidential overpressuring; CMA failed to protect regulators from dirt and debris; failed to maintain records retesting, maintenance, inspection

Appendix D. Constructability Safety Review

CAPITAL DESIGN JOB ORDER CHECKLIST
For use by Columbia Engineering Team

Job Order Number: 16-0349062-00

Design to Build - Build as Designed

Constructability / Safety Review

- € **Project Scope** ✓
- € **Route and Drawings**
  - Special Considerations
  - Primary Construction Method(s)
  - Permits
  - ROW and Staking Requirements
- € **Tie-in Locations, Designs, and Sequencing** Re-email due to 2016 work
- € **Material** ACTION: REDUCERS & VALVES check P/A
  - Special Fittings
  - All Estimated Materials
  - Long Lead-time Items
  - Other
- € **Units for Estimate** ✓ Add 6" BAG TIE IN
  - Labor
  - Fill
  - Restoration/Paving
  - Survey Requirements
  - Service Replacements/Tie-overs
  - Tie-ins
  - Traffic Control
  - Shoring
  - Test Holes
  - Meter Move-outs
- € **Duration** ✓
  - Working Hours
  - Who is on Jobsite
  - Number of Crews
  - Special Conditions
- € **Land Services Requirements (permits, private ROW, etc.)** ✓
- € **Safety** ✓ 2 police
  - Excavation Safety
  - Tie-in Locations
  - Traffic Control
  - Operability/Damage Prevention
- € **Field Visit Needed?** (☐ Yes / ☒ No)

Page 1 of 2 Last updated: 7/30/14

CAPITAL DESIGN JOB ORDER CHECKLIST
For use by Columbia Engineering Team

Constructability / Safety Review

Job Order Number: 15-084906Z-00

Comments/Adjustments

-
-
-
-
-
-
-
-

For Engineering: [redacted] 12/14/17 Date: 1/6/17

For Construction: [redacted] 12/14/17 Date: 1/6/17

For M&R: _____ Date: _____
(M&R only needs to sign when applicable)

For Land Services: _____ Date: _____
(Land Services only needs to sign when applicable)

* To be filed in WMSDocs Workspace(s)

Appendix E. NiSource Operational Notice ON 15-05

The following is NiSource's Operational Notice *Below Grade Regulator Control Lines: Caution When Excavating Near Regulator Stations or Regulator Buildings.*

NiSource
Distribution Operations

Operational Notice

Issue Date: 09/02/2015	**Below Grade Regulator Control Lines: Caution When Excavating Near Regulator Stations or Regulator Buildings**	Notice Number: **ON 15-05**
Supersedes: N/A		Page 1 of 3

Companies Affected:

☑ NIPSCO	☑ CGV	☑ CMD
	☑ CKY	☑ COH
	☑ CMA	☑ CPA

Purpose

This Operational Notice has the following objectives.

1. Bring awareness to Company and Contractor employees regarding the existence and importance of regulator control lines, other communications and electric lines that help to provide critical sensing information for the accurate monitoring and control of outlet pressure into the Company's piping systems, and buried odorant lines.
2. Set forth required actions for future Company excavations.

A Near Miss

A Company crew was excavating to repair a Grade 1 leak located on the outside of a regulator station building. They uncovered and narrowly missed hitting the 1-inch control line and tap located on the 8-inch outlet pipeline. The crew was unaware of the purpose of the 1-inch pipeline and called local M&R personnel. The M&R personnel advised the crew of the purpose of a control line and what would have happened if the line had been broken.

What is a Control Line?

Many regulators require external control lines, which sense the outlet pressure of the regulator. Based on the pressure sensed through the control line, the regulator valve will open or close to control the downstream pressure at the set point of the regulator. Regulators requiring control lines are found at City Gate/Town Border/Point of Delivery (POD), District Plant Regulator and Customer Measurement & Regulator (M&R) stations.

In accordance with existing gas standards, the current location for a control line tap is above grade on the outlet leg of the regulator setting downstream of the outlet valve. Aboveground control lines consist of stainless steel tubing (typically 3/8" or ½" diameter) and extend from the control line tap to a port on the regulator body. However, on certain installations some control line taps are located further downstream on the buried outlet piping based on the regulator manufacturer's recommendations, smoother operation of the regulator, or previous control line installation standards or practices. Control lines that extend to a below grade connection, normally a Continental or Mueller punch tee, transition above grade from stainless steel tubing to coated 1-inch steel pipe as required by our design standards.

Figure 1 is a schematic drawing showing a regulator setting with control lines extending below grade.

What Happens if a Control Line Breaks?

If a control line breaks, the regulator will sense a pressure loss, causing the valve to open further, resulting in an over pressurization of the downstream piping system, which may lead to

NiSource
Distribution Operations

Operational Notice

Issue Date: 09/02/2015	Below Grade Regulator Control Lines: Caution When Excavating Near Regulator Stations or Regulator Buildings	Notice Number ON 15-05
Supersedes: N/A		Page 3 of 3

Required Actions

General Excavation Requirements

Required state law excavation practices shall be followed, such as vacuum excavation (preferred method) or hand digging (if vacuum excavation in not reasonably available) within the tolerance zone of a marked (or known) facility.

City Gate/Town Border/POD Stations or District Plant Regulator Stations

Pre-excavation meetings with the plant/distribution or contract crew and M&R personnel shall be conducted for Company planned excavations within the footprint of a City Gate/Town Border/POD Station or a District Plant Regulator Station and/or within 25 feet of a station building or fence. Available as-built station drawings and/or electrical blueprints shall be reviewed for locations of buried conduits, control lines, and/or odorant lines. Known buried control lines, electric and communication lines, and odorant lines shall be located prior to excavation.

As a result of the near miss that occurred and what could have happened, any Company excavations within the footprint of a City Gate/Town Border/POD Station or a District Plant Regulator Station and/or within 25 feet of a station building or fence shall only proceed with M&R personnel standing by throughout the excavation, unless all control lines, other communications and electric lines critical to the operations of the station, and odorant lines, are verified to be located completely above ground.

Customer M&R Stations

Any Company excavations within 25 feet of a Customer M&R Station with control line(s), other communications and/or electric lines(s) critical to the operations of the station, or buried odorant lines, shall only proceed after a consultation with M&R personnel. The M&R personnel shall stand by throughout the excavation if there is a risk of damaging a control line, other communications or electric lines critical to the operation of the station, or a buried odorant line.

Next Steps (Leadership Actions)

NiSource Leadership will determine the feasibility of other Damage Prevention opportunities to identify situations where 3rd party excavators are digging within 25 feet of a City Gate/Town Border/POD Station or District Plant Regulator Station, so that excavations planned near these Company facilities require consultations and/or on-site monitoring.

[redacted]

CORRECTED COPY

a catastrophic event. The same result occurs if the flow through the control line is otherwise disrupted (e.g., control line valve shut off, control line isolated from the regulator it is controlling).

Other Communications and Electric Lines Critical to the Operations of Regulators

Other lines if damaged, such as telemetry sensing lines and electric lines to equipment at the City Gate/Town Border/POD, District Plant Regulator or Customer M&R station, may also result in pressure monitoring and control issues, which may lead to a catastrophic event.

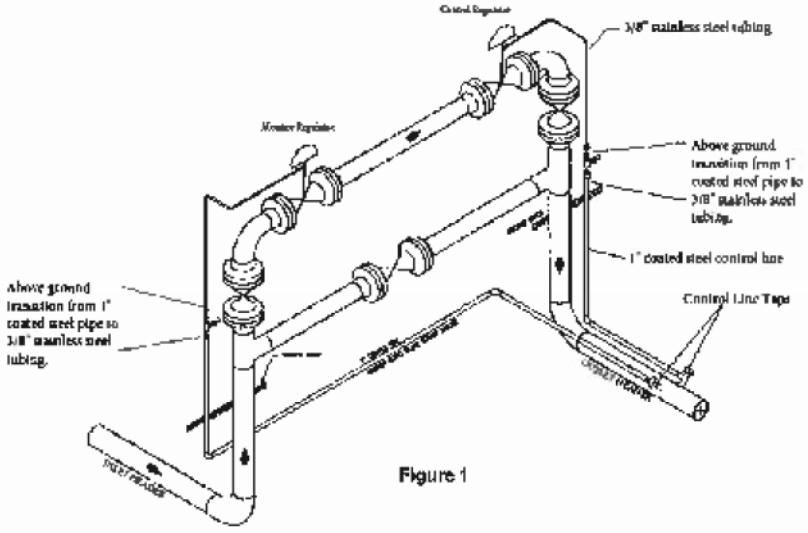

Figure 1

In Massachusetts, it is common to have closed looped systems, where the remote terminal unit (RTU) is continuously reading and controlling pressure at a valve that is acting as a regulator. The cables providing the signals to and from the RTU often run below ground through conduits within the existing footprint of the station, and if the cables or pressure sensing taps are damaged, this may result in pressure monitoring and control issues, which may lead to a catastrophic event.

Buried Odorant Lines

Occasionally, buried odorant lines, which transport odorant from an odorizer to an injection point into the downstream piping system, exist within the footprint of a City Gate/Town Border/POD Station. If an odorant line is damaged causing an odorant spill, the clean-up and impact on the public may be costly. Although odorizers are typically located at City Gate/Town Border/POD Stations, buried odorant lines may also exist at odorizers located at other sites, such as District Regulator Stations or Customer M&R Stations.

References

AGA (American Gas Association). 2018. *Leading Practices to Reduce the Possibility of a Natural Gas Over-Pressurization Event.* (Washington, DC: AGA).

American Council of Engineering Companies of Massachusetts. 2019. "DPU Issues Inquiry for Regulation Development: MA Passes Law Requiring Professional Engineers on Natural Gas Projects." Accessed May 25, 2019. https://www.acecma.org/about/news/massachusetts-passes-law-requiring-professional-engineers-on-natural-gas-projects-2340.

API (American Petroleum Institute). 2015. *Pipeline Safety Management Systems.* API RP-1173. (Washington, DC: API).

ASME (The American Society of Mechanical Engineers). 2012. *Gas Transmission & Distribution Piping.* ASME B31.8. (New York: ASME).

Coester, Adam. 2004. "Dillon's Rule or Not?" *National Association of Counties Research Brief.* Vol. 2, no. 1. (Washington, DC: National Association of Counties).

Commonwealth of Massachusetts. 2019. "About the DPU." Accessed June 30, 2019. https://www.mass.gov/about-the-dpu.

----. 2019a. "Pipeline Safety Information." Accessed March 19, 2019. https://www.mass.gov/pipeline-safety-information.

----. 2019b. "Executive Office of Public Safety and Security." Accessed July 9, 2019. https://www.mass.gov/orgs/executive-office-of-public-safety-and-security.

----. 2018. "Governor Baker Declares State of Emergency Regarding Incidents in Lawrence, Andover and North Andover." Accessed June 20, 2019. https://www.mass.gov/news/governor-baker-declares-state-of-emergency-regarding-incidents-in-lawrence-andover-and-north.

----. 2015. "Statewide Communications Interoperability Plan." Accessed July 15, 2019. https://archives.lib.state.ma.us/handle/2452/208169?show=full.

FEMA (Federal Emergency Management Agency). 2006. *Multi-jurisdictional Mitigation Planning.* FEMA 386-8. (Washington, DC: Department of Homeland Security, Federal Emergency Management Agency).

Kirby, J.G., Cannalte, R.P., Hicks, D.K., and Japel, E.J. 1989. *Constructability and Design Reviews: Analysis and Recommendations for Improvement.* US Army Corps of Engineers Constructional Engineering Research Library Technical Report, P-89/15 (Washington, DC: US Army Corps of Engineers).

MEMA (Massachusetts Emergency Management Agency). 2018. *MEMA Reports*, "Special Edition Covering August – October 2018." Vol. 17, no. 7. (Framingham, Massachusetts: MEMA).

NCEES (National Council of Examiners for Engineering and Surveying). 2019. "Advancing Licensure for Engineers and Surveyors." Accessed July 14, 2019. https://ncees.org/.

NiSource, Inc. 2018. *NiSource Emergency Manual*. (Merrillville, Indiana: NiSource).

----. 2015. *Below Grade Regulator Control Lines: Caution When Excavating Near Regulator Stations or Regulator Buildings*. ON 15-05. (Merrillville, Indiana: NiSource).

NSPE (National Society of Professional Engineers). 2019. "Champion, Guide, Advance, Unite." Accessed July 14, 2019. https://www.nspe.org/.

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

----. 2018. *Natural Gas Distribution System Project Development and Review (Urgent)*. PSR-18/02. (Washington, DC: NTSB).

----. 2012. *Enbridge Incorporated Hazardous Liquid Pipeline Rupture and Release, Marshall, Michigan, January 25, 2010.* PAR-12/01. (Washington, DC: NTSB).

----. 1993. *Over-Pressure of Peoples Gas Light and Coke Company Low-Pressure Distribution System, Chicago, Illinois, January 17, 1992.* PAR-93/01-SUM. (Washington, DC: NTSB).

----. 1982. *Missouri Power and Light Company Natural Gas Fires, Centralia, Missouri, January 28, 1982.* PAR-82/03. (Washington, DC: NTSB).

----. 1978. *Pipeline Accident Reports – Brief Format.* PAB-78/01. (Washington, DC: NTSB).

----. 1969a. *Low-Pressure Natural Gas Distribution System, Burlington, Iowa, November 6, 1969.* PAR-70/01. (Washington, DC: NTSB).

----. 1969. *Low-Pressure Natural Gas Distribution System, Gary Indiana, June 3, 1969.* (Washington, DC: NTSB).

PHMSA (Pipeline and Hazardous Materials Safety Administration). 2019. "State Programs Overview." Accessed June 13, 2019. https://www.phmsa.dot.gov/working-phmsa/state-programs/state-programs-overview.