Failure Analysis Associates

Exponent®

Carmel Gas Incident

Exponent

Carmel Gas Incident

Prepared for

Sumeet Singh
Pacific Gas and Electric Company
6111 Bollinger Canyon Road
San Ramon, CA 94583

Prepared by

Exponent
149 Commonwealth Drive
Menlo Park, CA 94025

April 2014

Doc. no. 1401752.000 - 6877

Contents

	Page
Limitations	**iv**
Executive Summary	**v**
Background	**1**
Construction Job Documentation	1
Incident Description	4
Description of Incident Site	**5**
House and Property Layout	6
Site Inspections	9
Assessment of Potential Ignition Sources	18
Description of Evidence Collected	**22**
Meter and Regulator Set from the Incident House	22
Section of the Gas Service Line and Riser to the Incident House	23
Section of Steel Gas Main along Redacted	26
Section of Plastic Gas Main inside the Steel Main	26
Inspection of Sewer System	**31**
Sewer Video Inspection Findings	34
Sewer Main on Redacted West of Manhole	34
Sewer Main on East of Manhole	36
Sewer Main on Redacted South of Manhole	36
Sewer Main on North of Manhole	39
Residence's Sewer System	39
Sewer Lateral Excavation	43
Plumbing Traps	46
Gas Migration Test	**49**
Analysis of Gas Migration and Ignition	**59**

Root Cause Analysis **61**

Conclusions **66**

Appendices

Limitations

At the request of PG&E, Exponent has conducted an investigation of the gas leak and subsequent explosion on March 3, 2014 in Carmel-by-the-Sea (Carmel), California.

Exponent investigated specific issues relevant to this incident, as requested by the client. The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein is at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

Exponent has no direct knowledge of, and offers no warranty regarding, the condition of concealed construction or subsurface conditions beyond what was exposed during our investigation. Comments regarding concealed construction or subsurface conditions are professional opinions, derived in accordance with current standards of professional practice based on our geologic and engineering experience and judgment.

The findings presented herein are made to a reasonable degree of scientific and engineering certainty. We have made every effort to accurately and completely investigate all areas of concern identified during our investigation. If new data becomes available or there are perceived omissions or misstatements in this report regarding any aspect of those conditions, we ask that they be brought to our attention as soon as possible so that we have the opportunity to fully address them.

Executive Summary

Pacific Gas and Electric (PG&E) has retained Exponent Failure Analysis Associates (Exponent) to conduct a failure analysis investigation of a gas leak and subsequent explosion on March 3, 2014 in Carmel-by-the-Sea (Carmel), California.

Background

In the late morning on March 3, 2014, a PG&E welding crew was in the process of performing work in a bell hole near the intersection of Redacted in Carmel-by-the-Sea (Carmel), California. After tapping a line stopper fitting on a steel pipe, the crew removed the tapping tool and found a steel coupon and a plastic coupon inside it, indicating that the steel line was inserted with plastic pipe. Approximately 15 to 30 minutes later, an explosion occurred at an adjacent unoccupied house located at the southwest corner of Redacted Redacted (subject house).

Site Inspections

Exponent's initial site inspection of the house after the explosion, on March 4, 2014, revealed extensive damage to the first floor areas that were visible from the perimeter of the property. All exterior walls of the first floor had been blown out and the roof had been torn into pieces and scattered in the surrounding area. Only some of the interior walls remained in place. Debris was scattered across the property and in nearby trees. Exponent performed additional site inspections in the month of March.

Ignition Source

As part of the investigation, Exponent performed an assessment of potential ignition sources for the incident. The potential ignition sources identified include a water heater, furnace, kitchen stove, kitchen refrigerator, bedroom ceiling fan, and other electrical components. Each potential ignition source was assessed.

Based on our analysis, the most likely ignition source was the continuous pilot flame of the kitchen stove.

Sanitary Sewer System

In the vicinity of the subject residence, the sanitary sewer system[1] for the city of Carmel consists of sewer pipes along Redacted with sewer laterals for the adjacent residences. Exponent investigated potential gas migration paths to the residence. One potential gas migration path was natural gas travelling though the sewer system and entering the residence through the sewer lateral and internal waste water system.

Along Redacted approximately 50 feet west of the manhole at Redacted, a sewer lateral break tap[2] at the sewer main was observed. The sewer main and sewer lateral are in close proximity to the gas service tee.

Approximately 8 feet from the tap at the sewer main, the sewer lateral had a joint offset and opening. More than 50 percent of the cross-sectional area of the sewer lateral pipe was offset, exposing a relatively permeable sand backfill around the pipe. The vertical distance between the top of the sewer lateral offset and the bottom of the gas main at the service tee was approximately 30 inches. Given this configuration, natural gas released into the soil near the location of the gas service tee had a short downward path through the soil, into the sewer system. Natural gas traveling upwards through the soil near this location encountered a relatively low permeability soil layer capped by the pavement above the gas main. This migration pathway was verified with a gas migration test.

Gas Migration and Ignition

To investigate the likely gas migration path from the release site to the subject residence, a gas migration test was performed at the site. The gas migration test consisted of injecting helium

[1] In this report "sewer" refers to the sanitary sewer (not storm sewer).

[2] Break tap refers to lateral-to-main connection performed by creating an opening in the sewer main after it was manufactured (i.e., connection not from a factory-manufactured tap).

gas through the annular space between the plastic gas main and the 2-inch steel pipe partially encasing it on Redacted

The gas migration test results indicate that the most likely helium gas migration path was through the annular space between the plastic gas main and the steel pipe encasing it along Redacted Redacted exiting the annular space near the gas service tee location, traveling through the soil and then entering the sewer system through two likely locations: 1) the dislocated sewer lateral plastic segment near the gas service tee, and 2) apparent openings in the tap of the sewer lateral at the sewer main on Redacted Once inside the sewer system, gas traveled towards the subject residence, and exited at multiple locations inside and just outside the main floor of the residence: sewer vents and sewer drains, including the toilet. The subject residence had been reportedly unoccupied for over one year, and water seals of plumbing traps were likely ineffective, providing a direct communication path between the sewer system and living space. The water valve for the bathroom toilet was also found in the closed position.

Based on Exponent's site inspection, interviews with individuals that witnessed the incident, the inspection of the sewers, and the helium gas migration testing, the following sequence represents the most likely gas migration and ignition events.

Gas leak: Inspection of the 2-inch gas main and inserted 1¼-inch plastic piping shows that there was a hole created in the plastic pipe after the Save-a-valve was tapped. This hole resulted in a pressurized natural gas release from the plastic pipe. The gas leak at this location may have started when the Save-a-valve was welded onto the steel pipe, before the Save-a-valve was tapped. A second hole was introduced into the plastic pipe when an M/2 line stopper fitting was tapped a short time after the first tapping operation. This second hole caused additional gas to leak.

Flow through annular space: The released natural gas traveled through the annular space between the inserted plastic pipe and the steel pipe in both directions (east and west) along Redacted Redacted, away from the plastic pipe leak. Upon reaching the end of the 2-inch steel pipe, the gas exited the annular space and flowed into the soil.

Flow through soil: The pressurized natural gas exited the annular space in close proximity to openings in the sewer system at the intersection of Redacted, and near the sewer service lateral. The pressurized natural gas likely traveled through the soil, into the sewer pipe openings (dislocated sewer lateral for the incident house).

Flow through the sewer system: Helium testing showed that pressurized gas released from the annular space may enter the openings in the sewer system. Gas entering the sewer system found uninterrupted paths through the system, including sewer main and sewer lateral.

Flow into the house: Because the house was reportedly unoccupied for an extended period prior to the incident, it is likely that some of the plumbing traps had dried out, rendering the water seal in the trap ineffective.[3] This allowed for a direct pathway into the living space from the sewer system. The results of the helium gas migration test and a fire photograph provided by PG&E provide support to the toilet being the most likely entry path for large volumes of natural gas entering the house on the day of the incident.

Accumulation and ignition: Based on the high concentration of helium measured at the toilet during the helium testing, and a fire photograph provided by PG&E, it is likely that the natural gas entering the house was well above the lower flammability limit. Based on the evaluation of potential ignition sources, including the kitchen stove, the ignition source was likely the stove pilot light.

Root Cause Analysis

Exponent personnel reviewed the initial documentation and defined the following problem statement for the root cause analysis.

"On March 3, 2014, while tapping into an existing 2" steel line, gas was released, entered a residence and ignited causing an explosion."

[3] The water valve for the bathroom toilet was also found in the closed position.

The analysis was performed through a review of records and followed up with interviews with key personnel involved in the various incidents and management processes. All documents identified during the analysis were catalogued and all interviewed personnel identified.

The data collection effort was focused on retrieving the job folder for the installation of the plastic insert of the 2-inch line on Redacted. In spite of the extensive data collection and review effort, the installation job folder has yet to be located.

A Timeline and Causal Analysis Diagram were developed as part of the root cause analysis. The resulting root cause was determined to be:

> ***Inadequate verification of system status and configuration when performing work on a live line.***

Recommended Corrective Actions

Based on the root cause, the following actions are recommended to prevent recurrence of the problem:

1. Develop or revise existing procedures to require positive verification of the expected system status and configuration when working on a pipeline. These procedures should emphasize that plat maps should not be considered "as-builts" and are not to be used in lieu of other means of positive verification.

2. Develop or revise existing procedures to require, as part of the design process, further investigation (e.g., field verification) of the system configuration when estimating a job for which "as-builts" are not available.

3. With this event in mind, review the current process for receiving, approving and storing job folders, including "as-builts," to assure that all job folders will be adequately filed and the necessary mapping changes made in a timely manner.

4. Develop and implement a process for a more detailed pre-job briefing, including a discussion of what can go wrong and who is responsible for taking what action if it does go wrong, and ensuring that the appropriate equipment is available to handle potential emergencies.

Note that this Executive Summary does not contain all of Exponent's technical evaluations, analyses, conclusions, and recommendations. Hence, the main body of this report is at all times the controlling document.

Background

In the late morning on March 3, 2014, a PG&E welding crew was in the process of performing work in a bell hole near the intersection of Redacted in Carmel-by-the-Sea (Carmel), California. After tapping a line stopper fitting on a steel pipe, the crew removed the tapping tool and found a plastic coupon inside it. At this point, the workers realized that the steel pipe was inserted with plastic pipe and the plastic pipe had been punctured by the tapping operations. Approximately 15 to 30 minutes later, an explosion occurred at an adjacent unoccupied house located at the southwest corner of Redacted (subject house).

Construction Job Documentation

The work being conducted on the day of the incident was part of PG&E job 30921135. The work included a tie-in to connect a new plastic gas distribution line on Redacted to an existing line on Redacted The new line being installed was intended to replace a section of Aldyl-A pipe on Redacted that was installed in 1972. The distribution plat sheet for the area in question is shown in Figure 1.

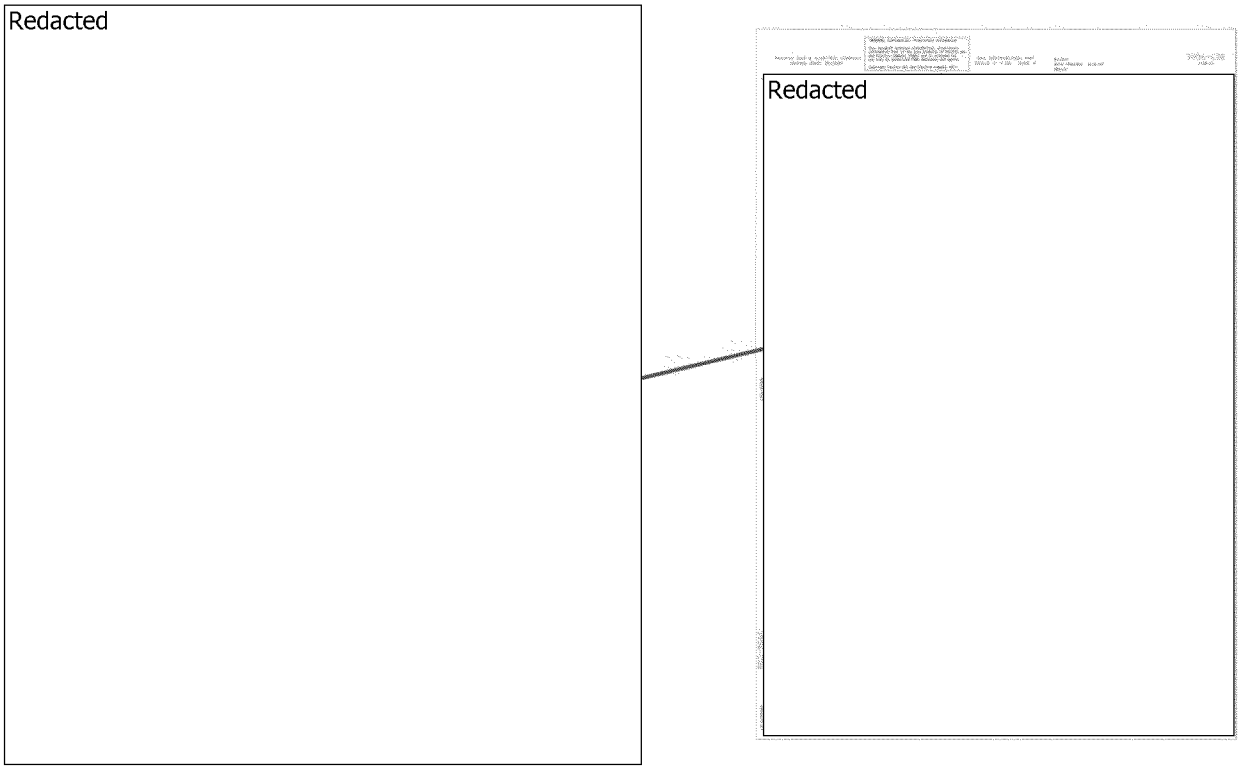


Figure 1. Annotated distribution plat sheet for the subject area. Subject house and bell hole labels and outline added by Exponent.

Figure 2 shows portions of a construction drawing[4] from job 30921135. The document is labeled as "Issued for Construction" and dated August 26, 2013.

[4] Issued for construction drawings for job 30921135. Revision 0, sheet 5 of 6, updated August 26, 2013.

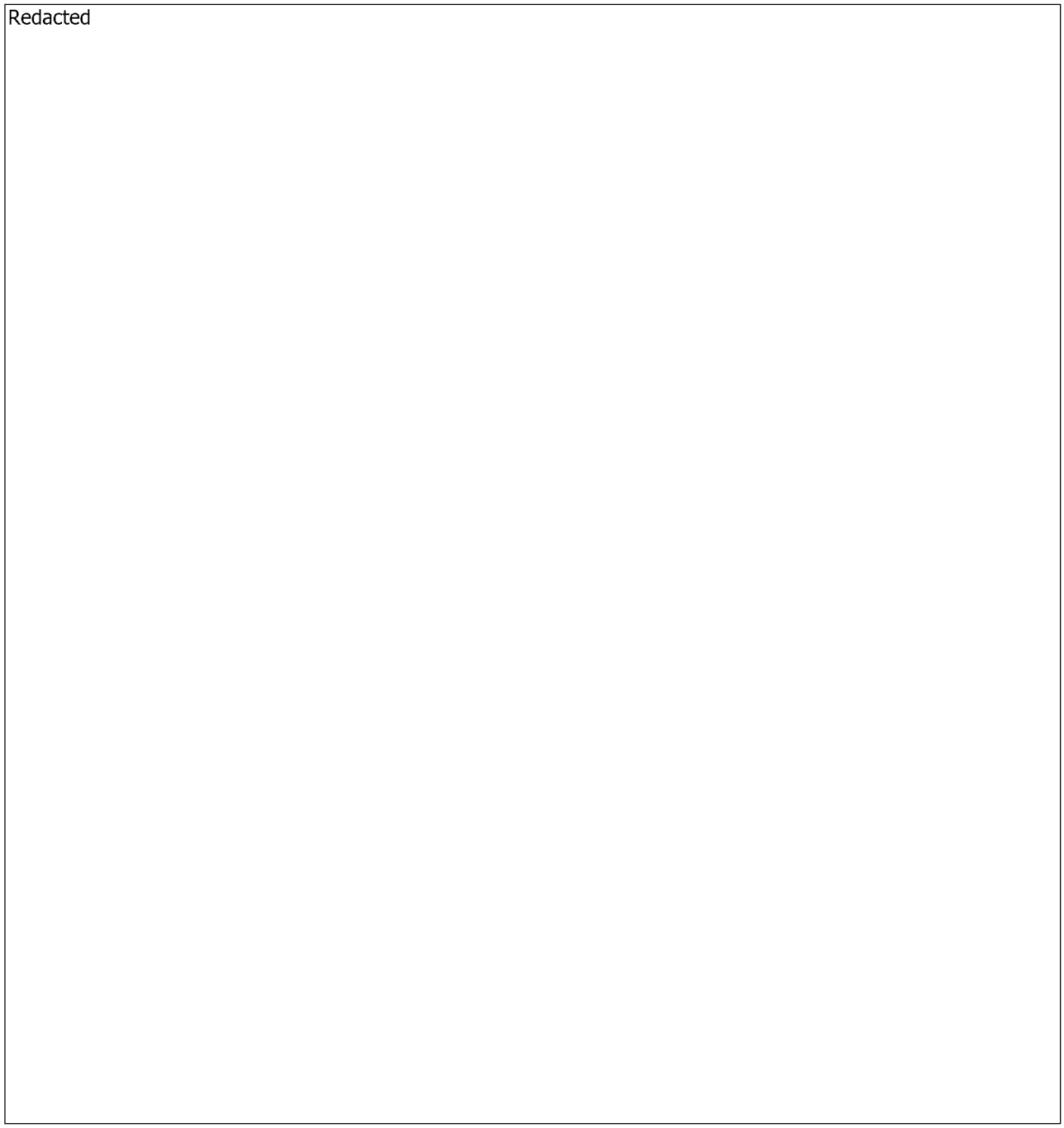


Figure 2. Annotated portion of construction drawing showing subject area. Red annotations added by Exponent. Source: Construction drawing for job 30921135.

The construction drawing shows that the job intended to tie into an existing pressure control fitting located on the steel distribution line on Redacted The job also intended to install a transition fitting where the pipe material transitioned from steel to plastic.

Incident Description

On the day of the incident, a PG&E welding crew was working on the subject gas line. The following timeline summarizes Exponent's best understanding of the relevant times leading to and immediately following the subject explosion.

~8:30-9:00 a.m.	Welding crew arrived at job site
~10:00-10:15 a.m.	Welding crew installed and tapped a save-a-valve
~10:15-10:35 a.m.	Welding crew installed and tapped M/2 line stopper
10:38 a.m.	Field Inspector called Gas Division Supervisor to report gas leak[5]
11:15 a.m.	Explosion
11:16 a.m.	Field Inspector called Division Supervisor to inform him of explosion[5]
11:17 a.m.	Field Inspector called 911[5]
11:18 a.m.	Explosion reported to FD[6]
11:23 a.m.	FD arrived on scene[6]
11:25 a.m.	Event reported to PG&E[7]
11:38 a.m.	PG&E response personnel arrived[7]
11:45 a.m.	Gas flow stopped by squeezing main on either side of leak area[7]

During and immediately after the explosion, the PG&E welding crew at the site reported hearing a quick, loud bang and seeing pieces of the house falling down in the surrounding area. The workers did not report seeing a fireball, and did not report seeing a fire in the house immediately after the explosion. They reported seeing a small fire in the house several minutes after the explosion. Upon arrival, the fire department observed a building skeleton that was missing its roof and walls, and building debris was spread across the roadway, trees, and power lines.[8] The fire department deployed a hose line to extinguish a small fire in the demolished structure.[9]

---

5 Reported to Exponent by PG&E per cell phone call history, pg 1.

6 Monterey Fire Department NFIRS report, FDID 27060, Incident number 14-0001163.

7 PG&E A-Form, dated 3/3/14, leak number 07-14-70371-B.

8 Monterey Fire Department NFIRS report, FDID 27060, Incident number 14-0001163, pg 2.

9 *Ibid.*

Description of Incident Site

The incident site is located in Carmel-by-the-Sea, approximately ¾ of a mile east of the Carmel Bay, and approximately ¼ of a mile west of Cabrillo Highway (Highway 1) (Figure 3). The incident site is located in a residential area of Carmel near the southwest corner of the intersection of Redacted (Figure 4).

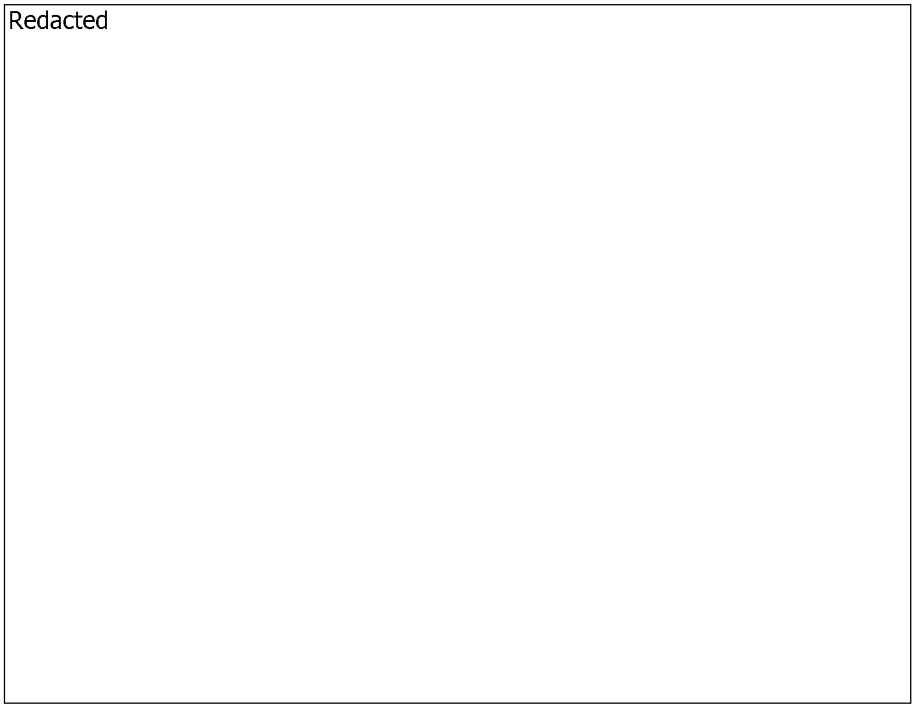


Figure 3. Incident site location (indicated by arrow). Image source: Google Earth.

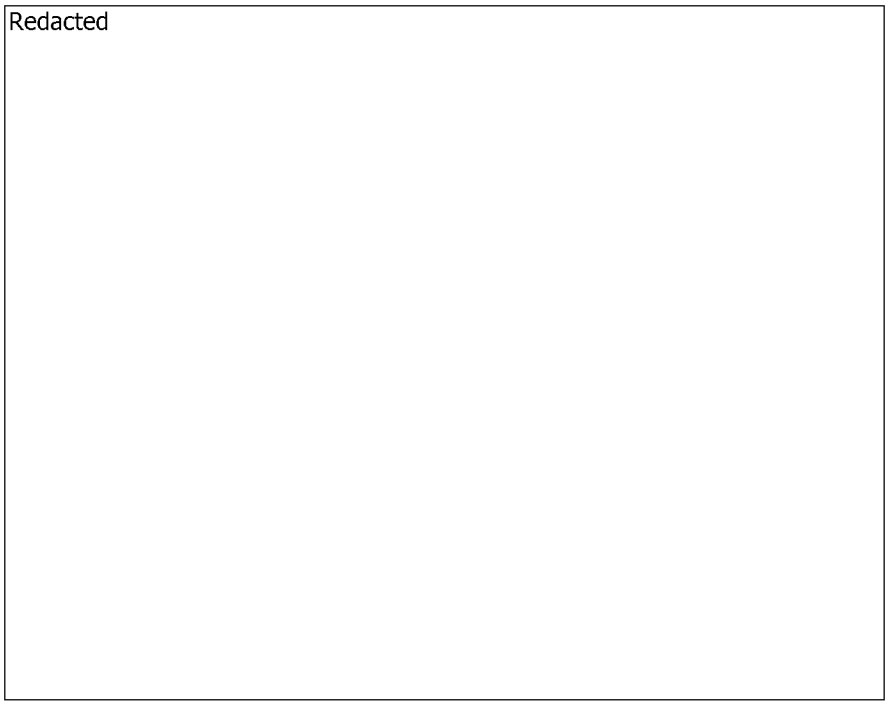


Figure 4. Incident site location. Image source: Google Maps.

House and Property Layout

The incident house was a single-story, single family, wood-frame structure built on a sloping site located at the southwest corner of the intersection of Redacted in Carmel-by-the-Sea, California.[10] According to public records, the house was built in 1943 and has 530 square feet of living space. The house consisted of two levels: an unfinished basement/garage and a main floor. The main floor had five rooms: kitchen, living room, bedroom, bathroom, and a utility or laundry room, and there was an elevated deck off the bedroom (Figure 5). The foundation consisted of stone walls that enclosed a basement underneath the structure. Primary framing for the floor consisted of 2" × 8" joists spanning from north to south, supported on the north and south ends by the stone walls, and the center is supported by a girder running east to west. Exterior finishes consisted of wood shake on top of sheathing. Interior walls consisted of batt and board partitions. Asphalt shingles on top of paper on wood sheathing comprised the roof.

[10] Site location given in geographical terms, since houses in Carmel, California typically do not have actual addresses.

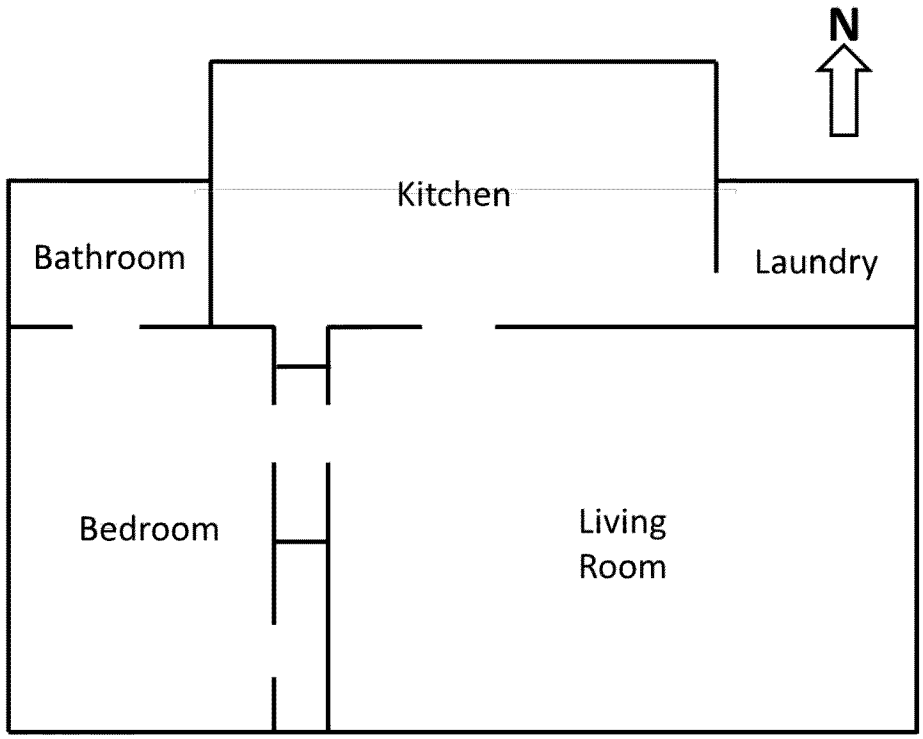


Figure 5. Sketch of incident house approximate main floor plan.

Two pre-incident photos of the exterior of the house are shown in Figure 6 and Figure 7. Neighbors reported that the house had been unoccupied for an extended period of time.

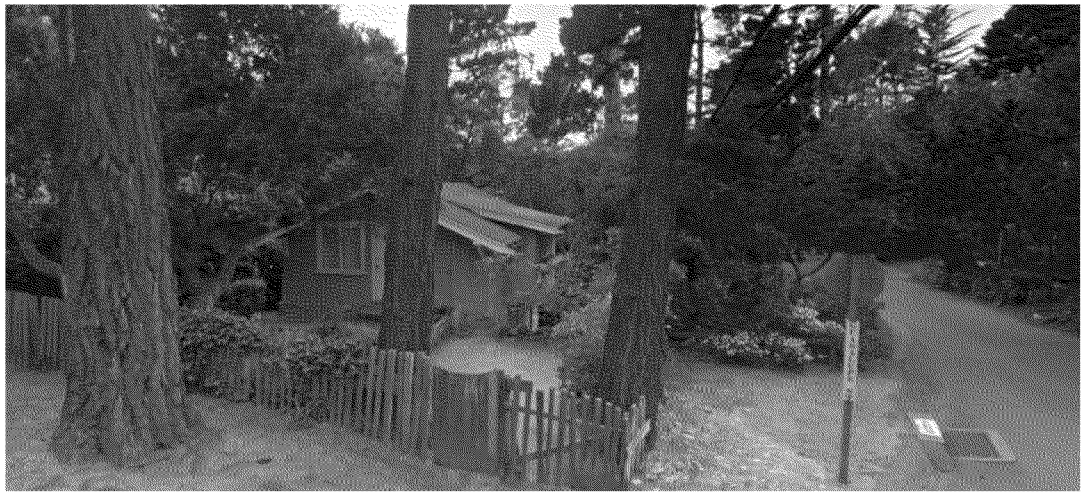


Figure 6. Pre-incident photo of the house, looking West down Redacted Source: Google Maps street view.

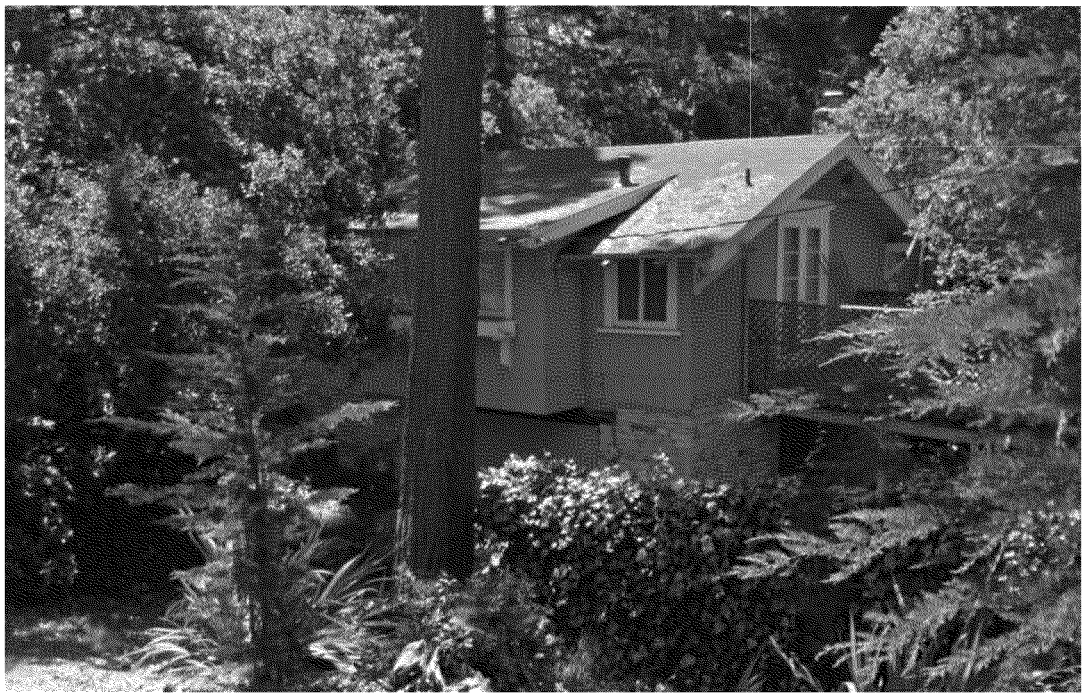


Figure 7. Pre-incident photo of the house, looking southeast from Redacted Source: Google Maps street view.

The subject house had an underground gas service line and sewer service lateral on the north side of the structure connecting the house to gas and sewer mains on Redacted The building electric service and meter was on the northwest corner of the house. The approximate layout of the gas, electric, and sewer service lines is shown in Figure 8.

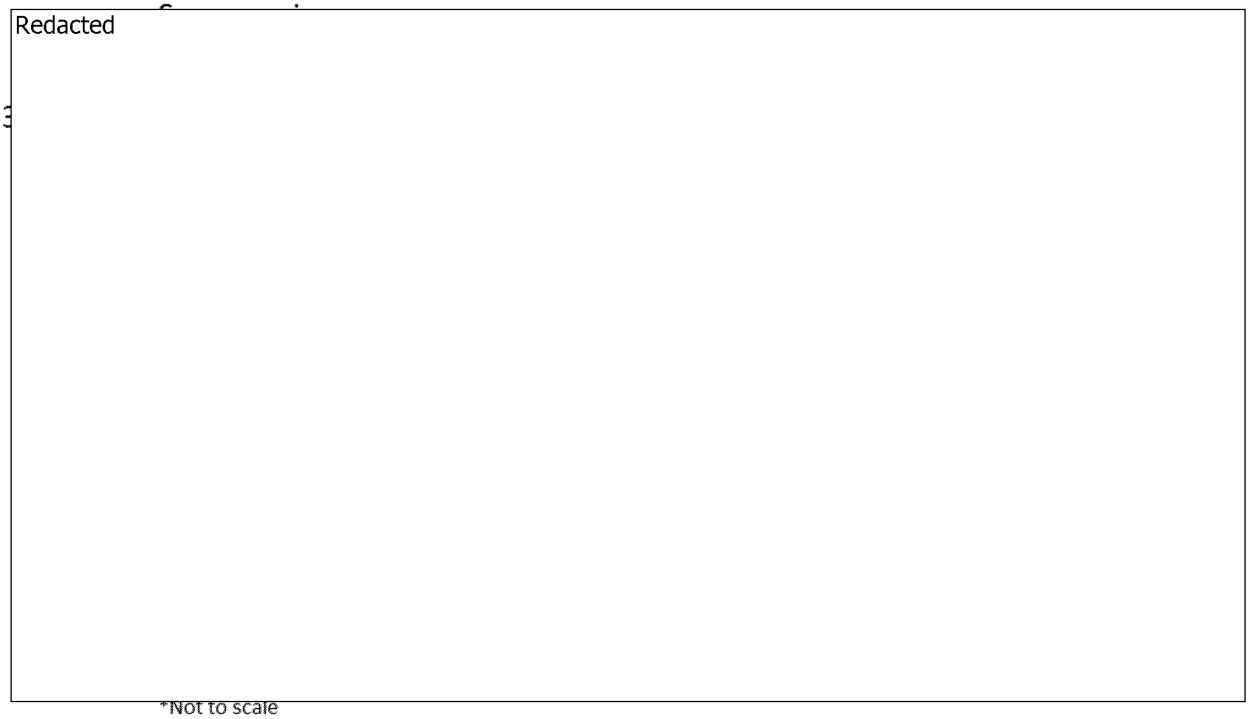


Figure 8. Sketch of utility services at incident house. Bell hole where PG&E crew was performing work prior to the incident is to the top, right (northeast) in the above sketch (refer to Figure 1 and Figure 2).

Site Inspections

Exponent's initial site inspection of the house after the explosion, on March 4, 2014, revealed extensive low-order and high-order damage to the first floor areas that were visible from the perimeter of the property.[11] All exterior first floor walls of the subject residence had been blown out and the roof had been torn into pieces and scattered in the surrounding area. Only

[11] Low and high order damage is defined in NFPA 921 as follows:

"Low-Order Damage. Low-order damage is characterized by walls bulging out or laid down, virtually intact, next to the structure. Roofs may be lifted slightly and returned to their approximate original position. Windows may be dislodged, sometimes without glass being broken. Debris produced is generally large and is moved short distances. Low order damage is produced when the blast load is sufficient to fail structural connections of large surfaces, such as walls or roof, but insufficient to break up larger surfaces and accelerate debris to significant velocities."

"High-Order Damage. High-order damage is characterized by shattering of the structure, producing small debris pieces. Walls, roofs, and structural members are broken apart with some members splintered or shattered, and with the building completely demolished. Debris is thrown considerable distances, possibly hundreds of feet. High-order damage is the result of relatively high blast loads."

some of the interior walls remained in place (Figure 9 and Figure 10). Debris was scattered across the property and in nearby trees.

Figure 9. Incident house looking West from the entryway. Photograph by Exponent on March 4, 2014.

Figure 10. Incident house looking West into the laundry room. Roof section on right side of picture. Photograph by Exponent on March 4, 2014.

Exponent's interior inspections of the subject house[12] discovered limited evidence of fire inside the house. Some of the paint on the walls of the living and bedrooms had signs of high temperature (blistering), but very few signs of sustained flame impingement (Figure 11 and Figure 12). Some of the debris showed a small amount of charring. The bathroom was the only place where clear signs of sustained fire were observable. There was a distinct fire pattern on the South wall next to the toilet and on the toilet bowl, toilet seat, and tank (Figure 13 through Figure 15). PG&E provided Exponent with a photograph taken shortly after the explosion (Figure 16). The photograph shows flames in the bathroom, matching the location of the observed fire patterns.

[12] Exponent first entered the house on March 5, 2014.

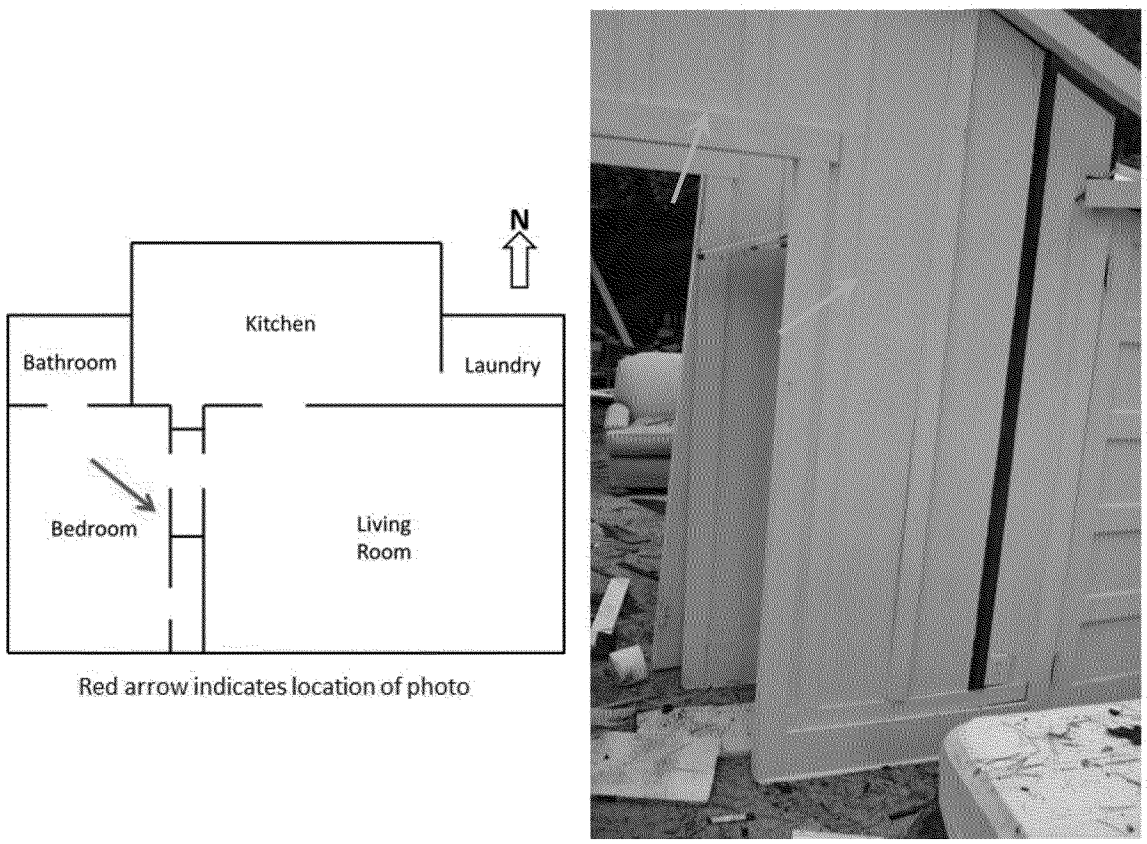


Figure 11. Interior walls and furniture. An unburned couch in the living room is visible in the background and the corner of an unburned mattress is visible in the foreground. Yellow arrows indicate some areas of wall blistering. Photograph by Exponent on March 6, 2014.

Figure 12. Close-up of the paint blistering on bedroom wall and door. Photograph by Exponent on March 7, 2014.

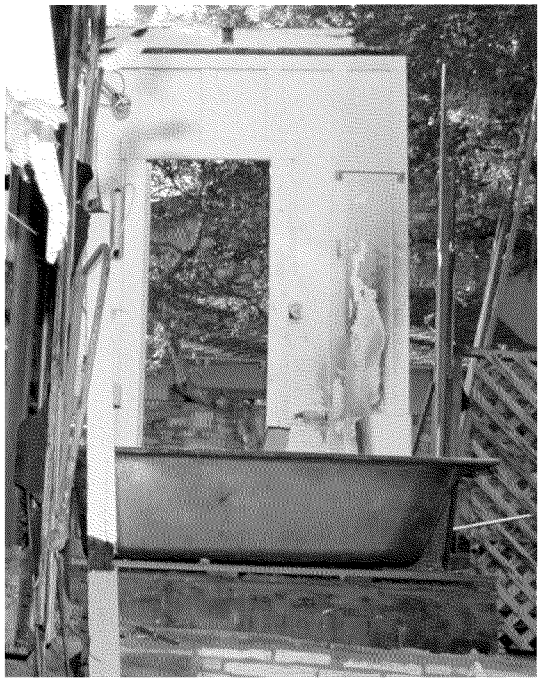


Figure 13. Fire pattern on bathroom wall, looking South from Redacted Photograph by Exponent on March 7, 2014.

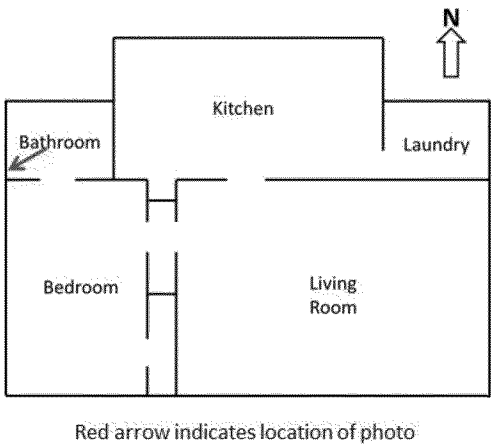


Figure 14. Bathroom toilet. Photograph by Exponent on March 6, 2014.

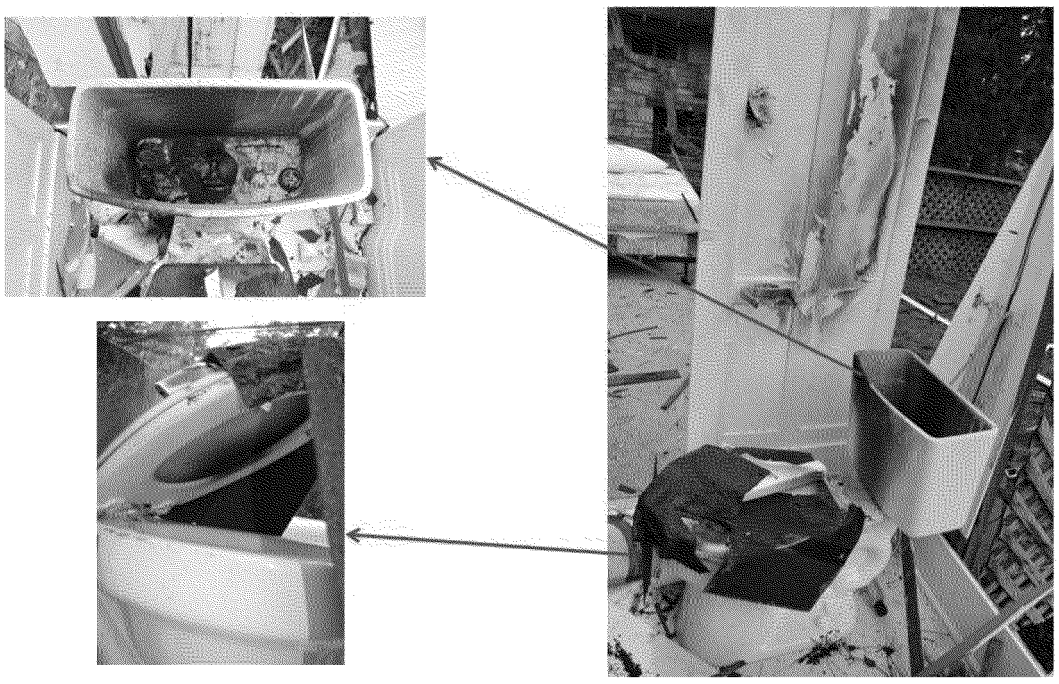


Figure 15. Damage to bathroom toilet. Burn marks below toilet seat and melted components inside toilet tank. Photographs by Exponent on March 6, 2014.

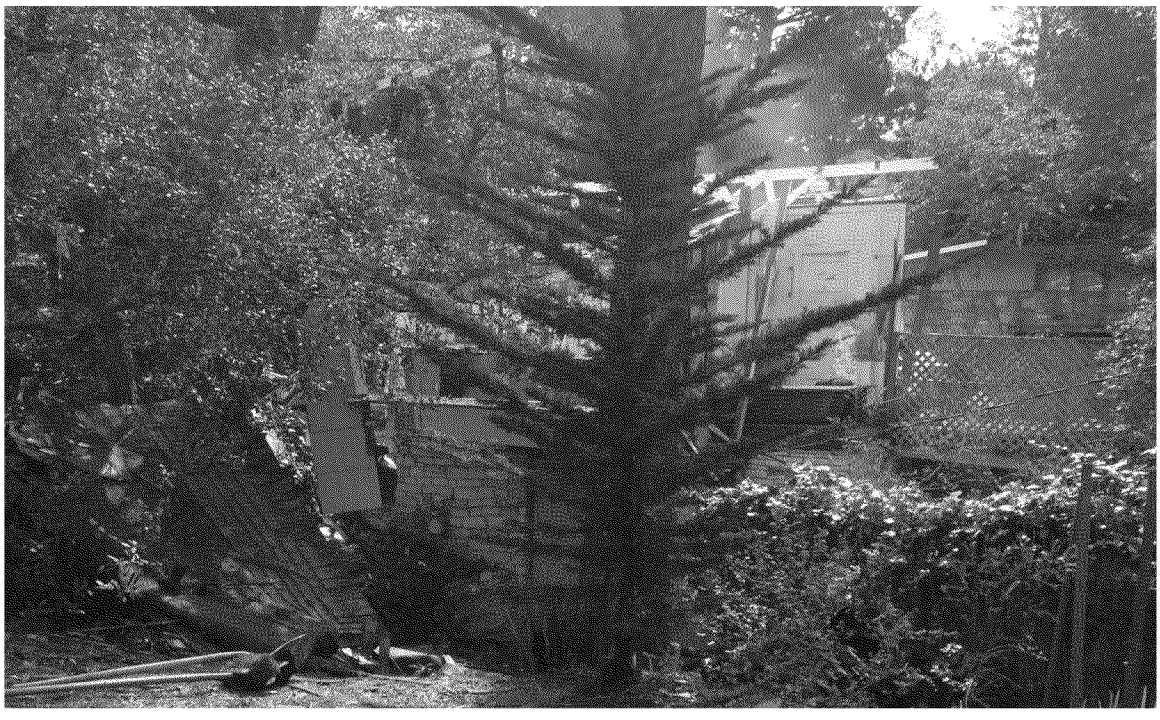


Figure 16. Photograph taken shortly after the explosion showing flames over bathroom toilet. Photograph provided to Exponent by PG&E.

The basement area showed limited damage compared to the main floor. The perimeter walls did not show evidence of damage from the recent explosion and the windows' glasses were undamaged. The ceiling finishes had collapsed in several areas and two of the wooden beams showed longitudinal cracks (Figure 17).

An Exponent engineer deemed the first floor of the structure unsafe due to recent damage to joists and girder framing. Shoring of the first floor from the basement level was recommended in order to continue inspection on the first floor. Recommendations were also made to remove falling hazards from trees, neighboring bushes, and cantilevered portions of the structure.

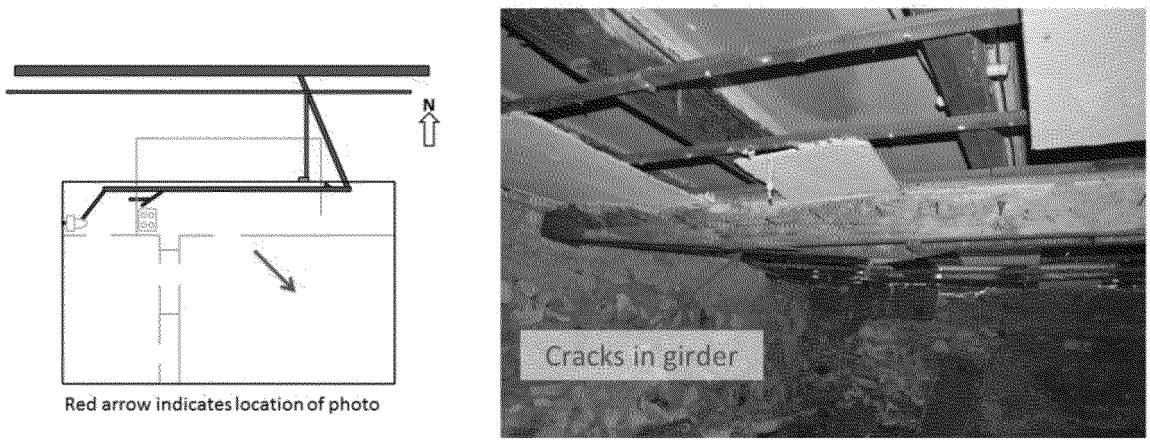


Figure 17. Incident house basement. Ceiling girder with multiple longitudinal cracks. Photograph by Exponent on March 5, 2014.

The sewage system of the house was visually inspected from the basement and through the remaining walls. Some of the sewage vent pipes had been blown off; inspection of the vents revealed the presence of debris inside them (Figure 18 and Figure 19).

Figure 18. Sewer vent pipe (broken off) in the laundry room. Vent pipe likely broken off during the explosion. Photograph by Exponent on March 7, 2014.

Figure 19. Vent pipe (broken off) in the bathroom. Vent pipe likely broken off during the explosion. Photograph by Exponent on March 7, 2014.

Assessment of Potential Ignition Sources

As part of the investigation, Exponent performed an assessment of potential ignition sources. The potential ignition sources identified are the gas fired appliances in the house (water heater, furnace, and stove), kitchen refrigerator, bedroom ceiling fan, and other electrical components. Each potential ignition source was assessed and the conclusions are described below.

Water heater: The house water heater was located in the basement. The appliance gas shut-off valve for the water heater was found in the open position and the thermostat was found in the off position. Fuel-fired appliances can act as a competent ignition source when they are operational. Based on the thermostat being set to the off position, it is unlikely that the water heater was the ignition source for the incident explosion.

Furnace: The house furnace was located in the basement, near the ceiling. The appliance shut-off valve for the furnace was found in the closed position. Based on the closed appliance shut-off valve, it is unlikely that the furnace was the ignition source for the incident explosion.

Stove: A kitchen stove was present in the subject house. The location of the stove is shown in Figure 20. The appliance shut-off valve for the stove was found in the open position and the stove was equipped with a continuous pilot flame (Figure 21). Based on these facts, the stove cannot be ruled out as a likely ignition source for the incident explosion.

*Kitchen refrigerato*r: A refrigerator was present in the kitchen of the subject house. The refrigerator was found with the power cord unplugged from the wall receptacle. Based on this fact, it is unlikely that the refrigerator was the ignition source for the incident explosion.

Bedroom ceiling fan: The bedroom of the subject house was equipped with a ceiling fan. The fan showed very little signs of thermal damage, and had no visible indicators of unusual electrical activity. Based on these facts, it is unlikely that the fan was the ignition source for the incident explosion.

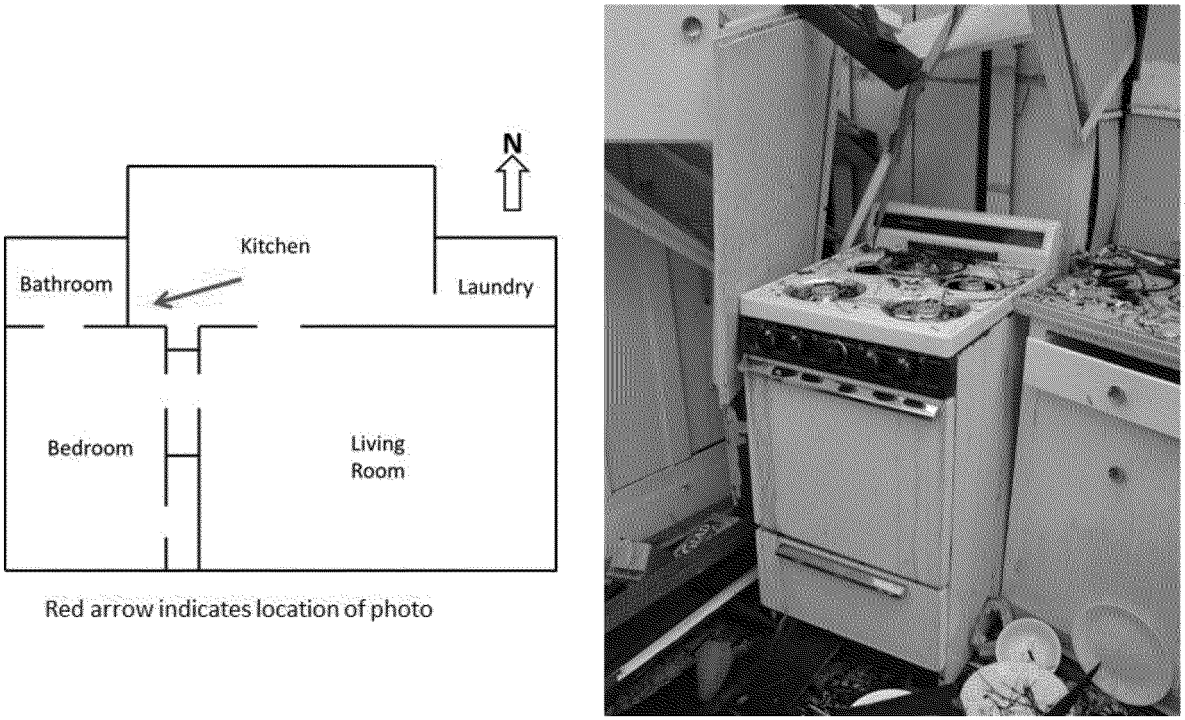


Figure 20. Location of kitchen stove. Photograph by Exponent on March 6, 2014.

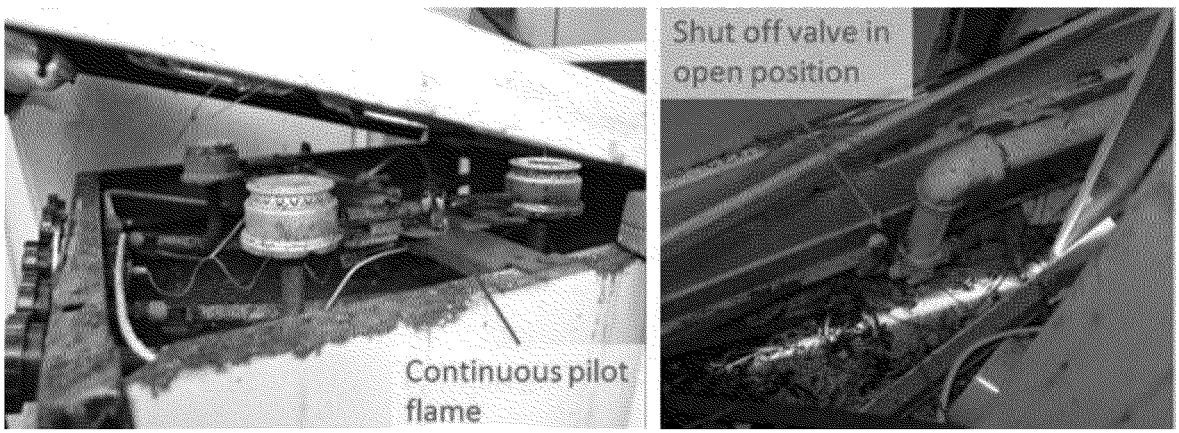


Figure 21. Kitchen stove components. Photographs by Exponent on March 6, 2014.

Other electrical components: The building had other electrical components, including wiring, light fixtures, and switches. The light switch in the bathroom was melted and showed signs of thermal damage. The visible damage appeared to be the result of an external fire exposure located near the toilet. No visible indications of unusual electrical activity were observed. A cursory examination was performed of the rest of the building's electrical system and no visible

signs of unusual electrical activity were observed. Based on these facts, it is unlikely that one of the building's other electrical components was the ignition source for the incident explosion.

Based on this analysis, the most likely ignition source was the continuous pilot flame of the kitchen stove.

Description of Evidence Collected

As part of the incident response activities, PG&E personnel collected several items from the scene on March 3, 2014. These items were taken into evidence and stored at the PG&E Potrero Substation evidence storage unit in San Francisco, CA. The items collected were:

1. Meter and regulator set from the incident residence
2. Section of gas service line and riser to the incident house
3. Section of steel gas main along Redacted
4. Section of plastic gas main inside the steel main

On March 10, 2014, Exponent inspected these items at the storage unit at the PG&E Potrero Substation. The paperwork for the evidence chain of custody was reviewed during this visit and appeared to be complete, and in accordance with standard procedures. The following sections provide a description and key observations of each the above-mentioned items.

Meter and Regulator Set from the Incident House

The regulator and meter set (Figure 22) had been removed just downstream of the service riser shut-off valve. The meter was equipped with a SmartMeter module. No functional tests were performed during the inspection.

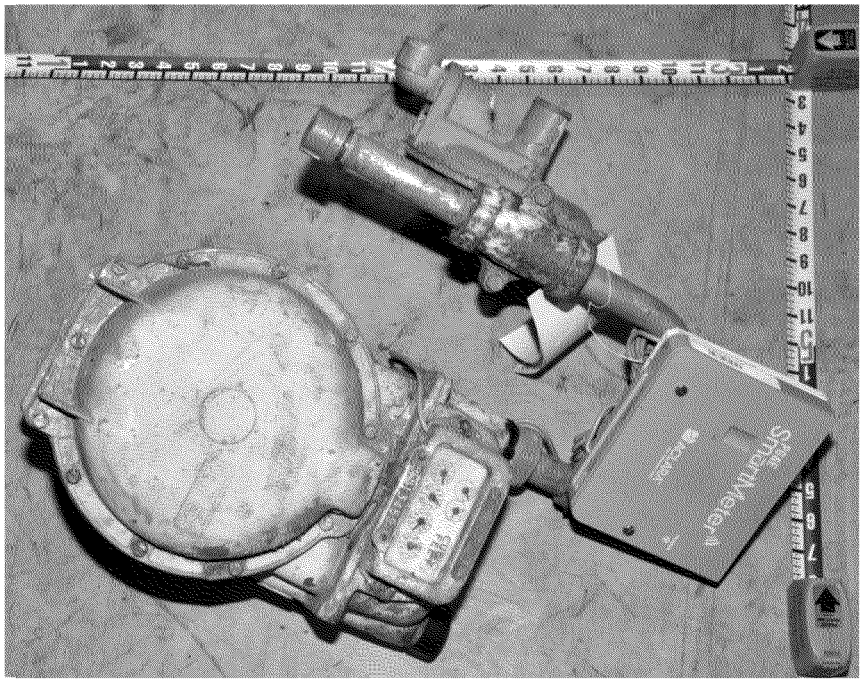


Figure 22. Regulator meter set removed from incident house. Photograph by Exponent on March 10, 2014.

Section of the Gas Service Line and Riser to the Incident House

The steel ¾-inch gas service line and riser are shown in Figure 23. The steel line is approximately five feet in length and inserted with a ½-inch plastic line (Figure 24). The line segment terminates in a service head adapter kit and service riser shut-off valve. According to the PG&E leak repair report, the service riser shut-off valve was turned to the closed position during the incident response operations.

Figure 23. Portion of the gas service line to incident house. Photograph by Exponent on March 10, 2014.

Figure 24. Close-up of the cut end of the gas service line. Photograph by Exponent on March 10, 2014.

The service head adapter seals the annular space between the ¾-inch steel pipe and the ½-inch plastic pipe. The service head adapter was lacking identifying markings, but appears to be similar to a Perfection ¾" × (½" PE) × ¾" Extended Service-Head Adapter. The two service head adapters are shown in Figure 25.

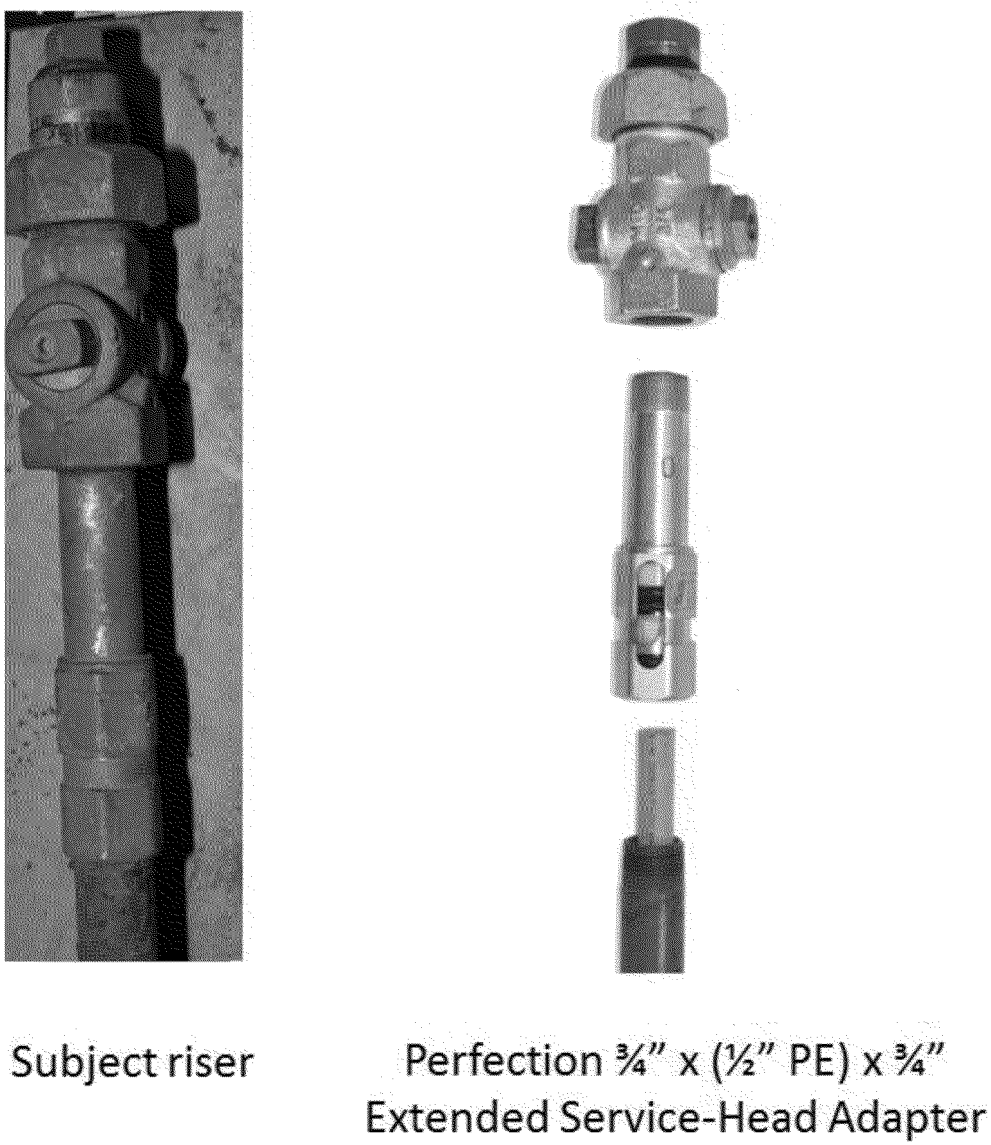


Figure 25. Service head adapter. Sources: Photograph by Exponent on March 10, 2014, service head adapter image from PG&E Gas Methods and Procedures document Service-Head Adapter Photo Identification.

The inserted plastic pipe from the service line had a date code that read "052697," indicating a date of manufacture of May 26, 1997. The inserted plastic service line is shown in Figure 26.

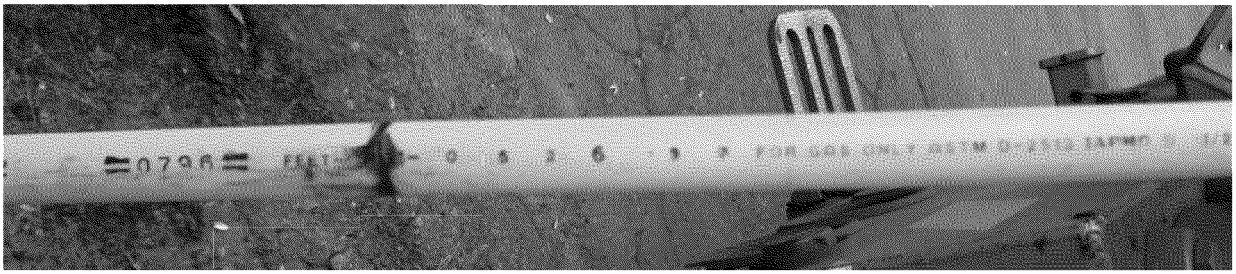


Figure 26. Inserted plastic service line. Photograph source: PG&E.

Section of Steel Gas Main along Redacted

A three-foot long section of the 2-inch steel main running along Redacted was removed from the bell hole at the intersection of Redacted (Figure 27). The steel pipe segment has two welded fittings that were installed on March 3, 2014; one is a 1-inch Save-a-valve fitting and the other is a 2-inch M/2 line stopper fitting. There were no obstructions either in the main pipe or the two fittings.

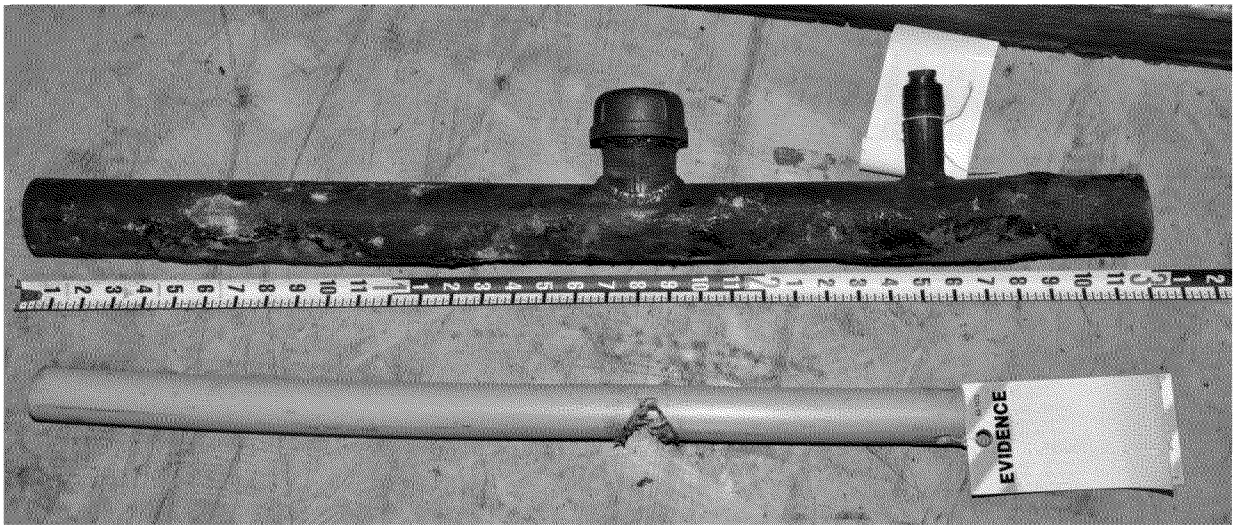


Figure 27. Portion of the gas main along Redacted Steel pipe (top) with welded fittings and plastic pipe insert. Photograph by Exponent on March 10, 2014.

Section of Plastic Gas Main inside the Steel Main

A section of the inserted 1¼-inch yellow plastic pipe retained along with the section of 2-inch steel gas main (Figure 27). When inserted, an annular space could be observed between the two

pipes (Figure 28). The plastic line segment has two perforations that correspond to the Save-a-Valve and M/2 fittings (Figure 29). There are some markings printed along the exterior of the pipe. A portion of the writing is associated with the fabrication date; in this particular piece only the year is visible, 1997 (Figure 30).

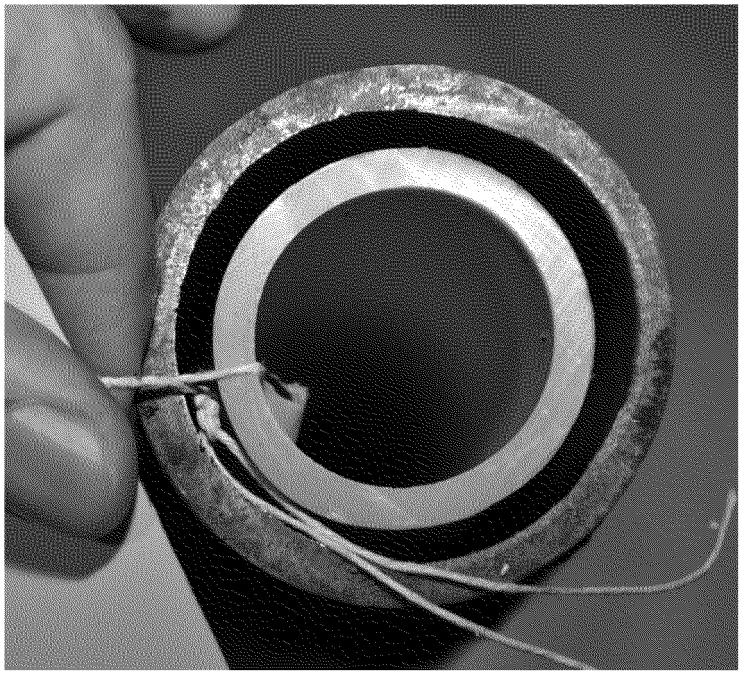


Figure 28. Plastic gas line inserted into steel line. Photograph by Exponent on March 10, 2014.

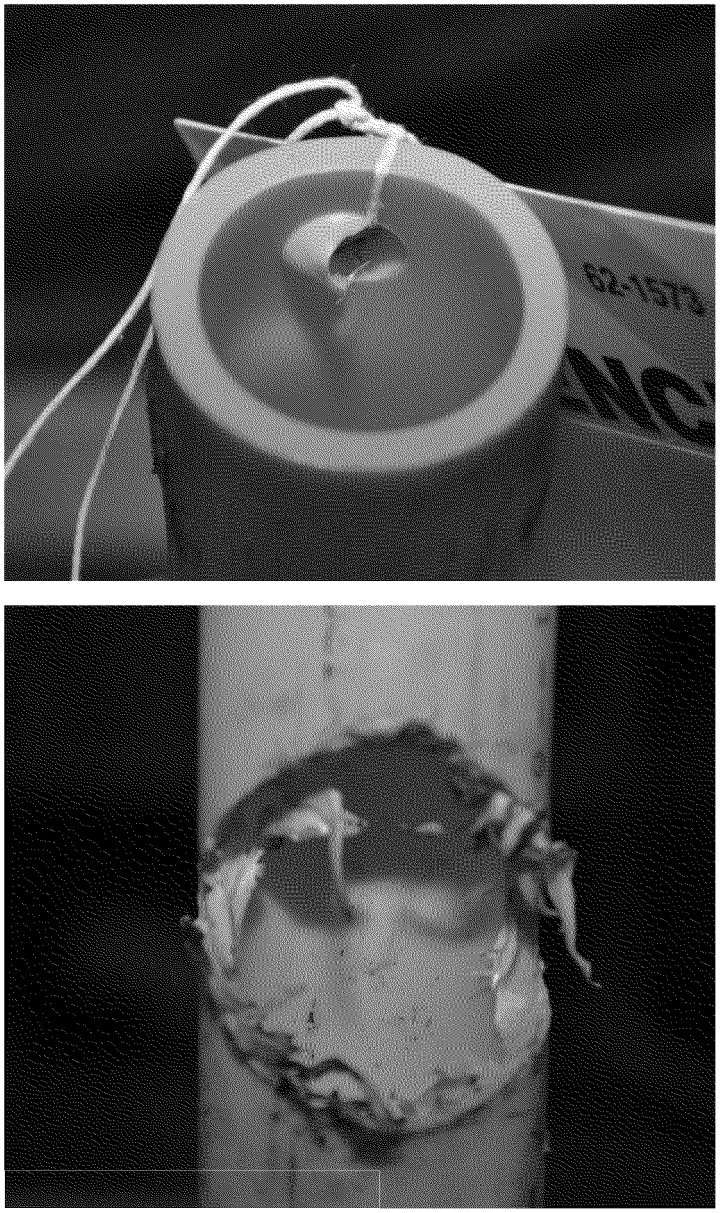


Figure 29. Perforations in plastic gas line: Save-a-Valve fitting (top) and M/2 fitting (bottom). Photographs by Exponent on March 10, 2014.

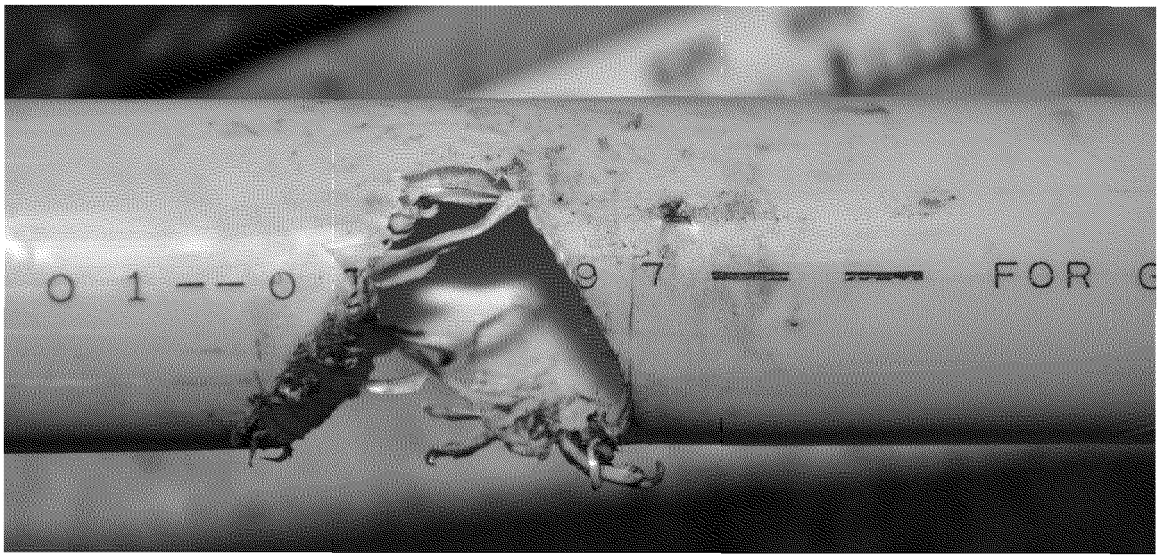


Figure 30. Close-up of the visible portion of the date code on the plastic pipe. Photograph by Exponent on March 10, 2014.

An additional portion of the gas main along Redacted was taken into evidence by PG&E. Exponent did not inspect this item, but PG&E provided multiple pictures to Exponent. The additional item corresponds to the west side gas main portion where the line had been squeezed after the incident (Figure 31). The writing on the photographs shown to Exponent indicates that the plastic pipe had a complete manufacturing date code of July 17, 1997 (Figure 32).

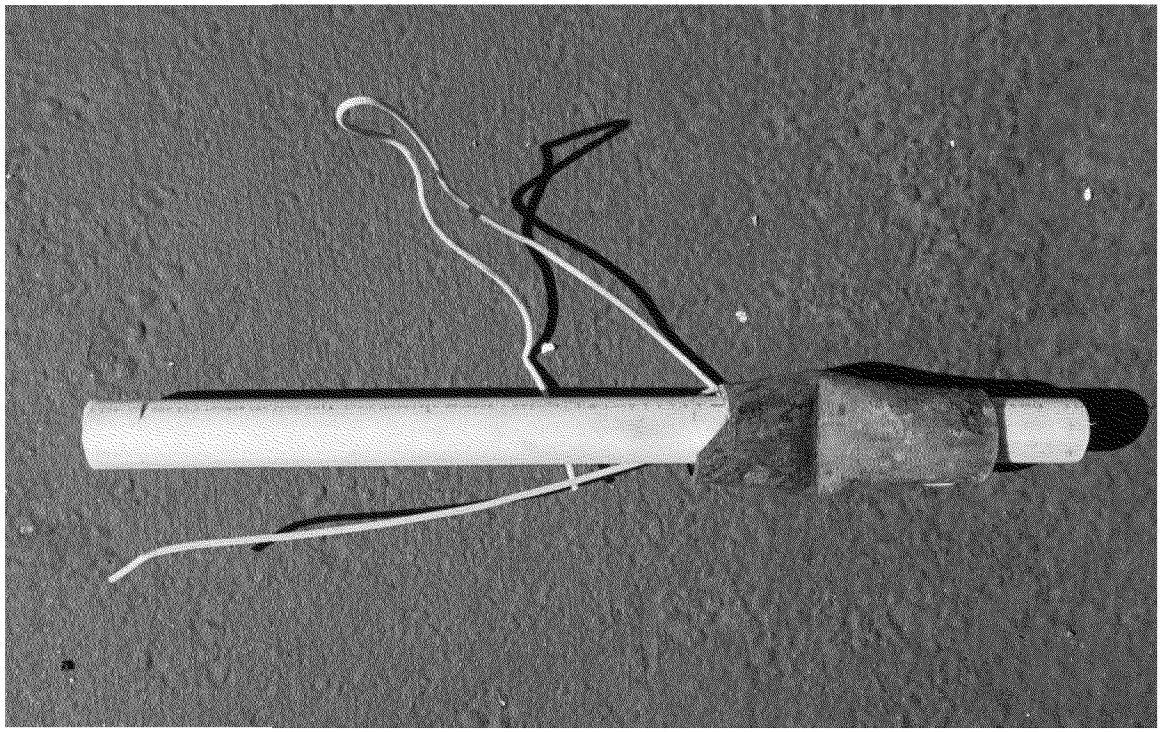


Figure 31. West-side squeeze point of the gas main along Redacted Yellow tracer wire is visible. Photograph provided by PG&E.

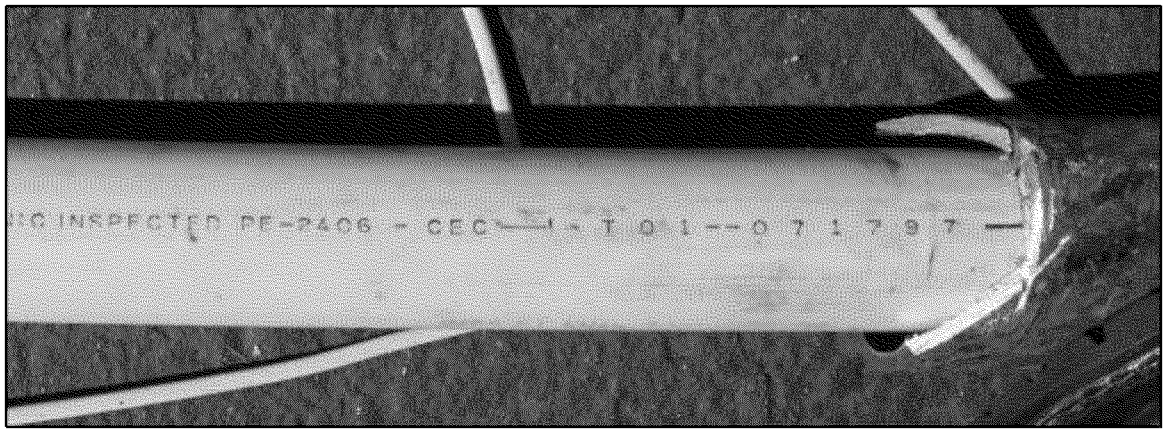


Figure 32. Close-up of the complete manufacturing date code of the plastic gas main. Photograph provided by PG&E.

Inspection of Sewer System

In the vicinity of the subject residence, the sewer system for the City of Carmel consists of sewer pipes along Redacted (Figure 33), with sewer laterals for the adjacent residences. According to Frontline Energy Services (FES), the sewer mains in Carmel are typically flushed and cleaned approximately every six months and the sewer main system was last videoed by others in December 2013.[13] Exponent did not receive documentation of damage to pipes identified by those videos in this area of the sewer system.

Exponent investigated potential gas migration paths to the residence. One potential gas migration path was natural gas travelling though the sewer system and entering the residence through the sewer lateral and internal waste water system. This section summarizes Exponent's findings related to the evaluation of potential gas travel paths through the sewer system.

To document the conditions and configuration of the sewer system, video inspection of the sewer pipes in the vicinity of the site was performed on March 11 and 12, 2014. Frontline Energy Services (FES) oversaw contractors conducting the video/CCTV inspections of sewer mains and laterals and documented the inspection's findings. Exponent was present during portions of the video inspections of March 11 and reviewed a report presented by FES summarizing the findings of their video inspection in this area.[14] Figure 34 shows the approximate area video inspected as part of this investigation.[15]

---

[13] Reportedly, information on the December 2013 video inspection and flushing schedule was provided to FES by way of discussion with the Sanitary Water District. Exponent understands that FES did not perform the December 2013 video inspection of this sewer pipe.

[14] FES, "Crossbore Sewer Safety Inspection Status Report," dated March 18, 2014.

[15] FES indicates that their scope included "Sewer main on Redacted a minimum 200 feet North and a minimum of 120 feet South of the intersection with Redacted " However, Exponent understands that as part of this investigation, FES did not video record the pipeline on Redacted north of Redacted

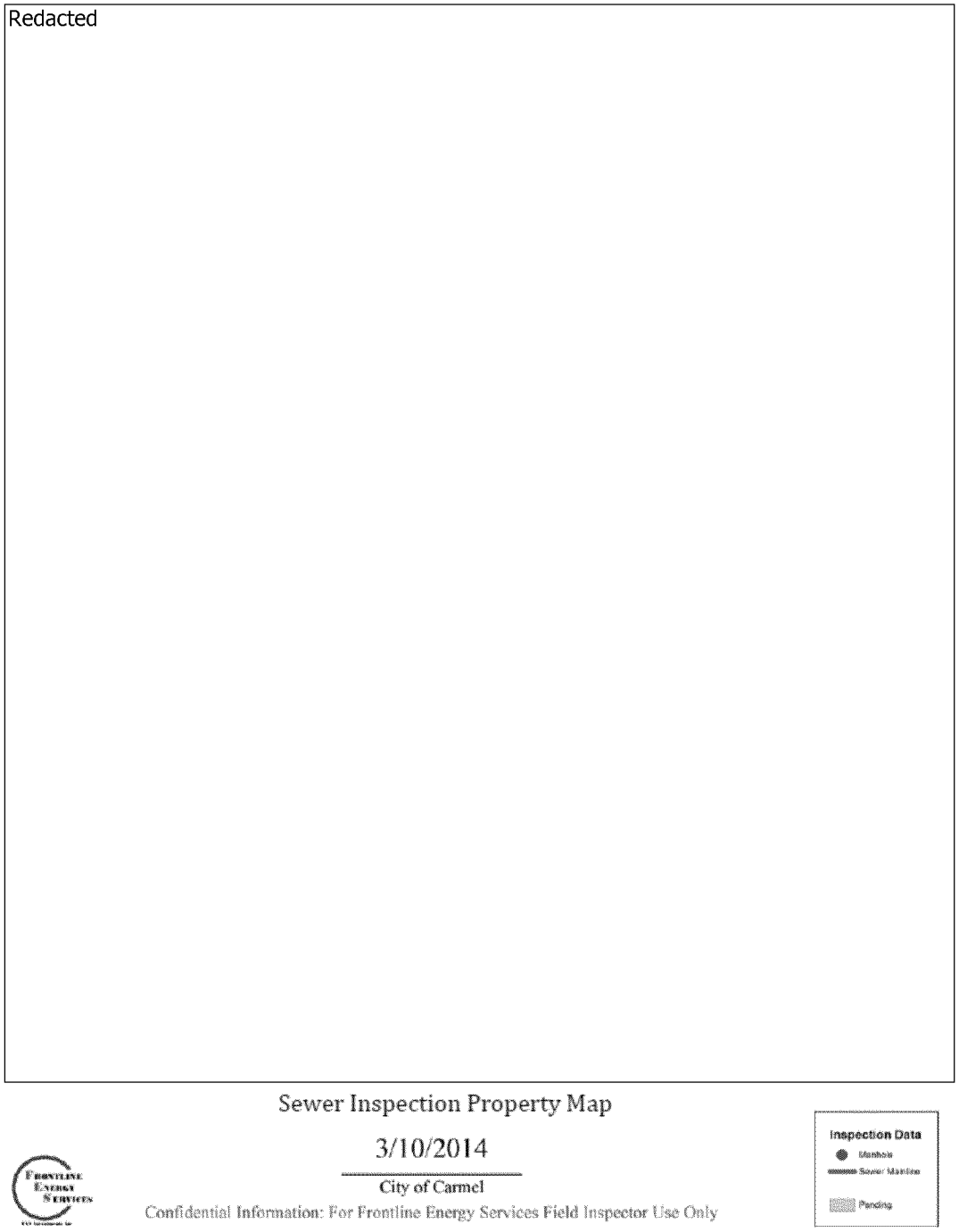


Figure 33. GIS reference map included in FES (March 18, 2014) report.

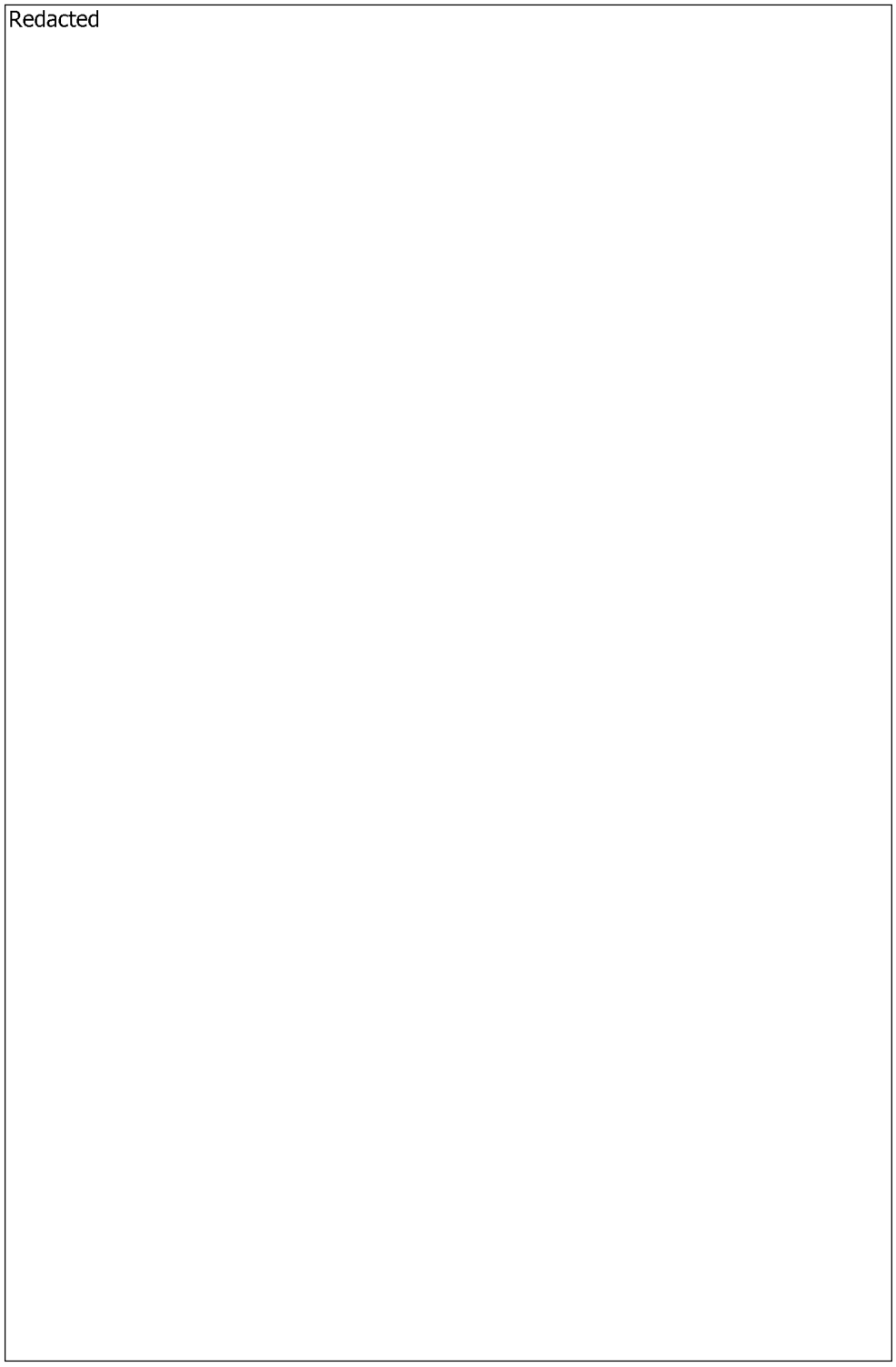


Figure 34. Area of sewer video inspections. Red box and line indicate areas video inspected on March 11, 2014. Orange box indicates other areas video recorded by FES on March 12, 2014 as part of this investigation. Map Source: Google Maps.

Sewer Video Inspection Findings

This section summarizes findings from the sewer video inspections that are considered relevant to the explosion investigation at the subject residence. Additional findings are documented in the FES (March 18, 2014) report.

As shown in Figure 34, the sewer main and laterals on Redacted east and west of the manhole at the intersection with Redacted was video inspected on March 11, 2014. The same figure shows that portions of the sewer main and laterals on Redacted were video inspected on March 12, 2014. The sewer system (Figure 33) in the vicinity of this intersection consists of three pipes, approximately 8 inches in diameter, discharging to the manhole and one pipe, approximately 12 inch in diameter, capturing the discharge. The approximately 12-inch diameter sewer main is located along Redacted west of the subject manhole.

Sewer Main on Redacted West of Manhole

The sewer main west of the manhole along Redacted (toward the subject residence) consisted of an unlined clay pipe, with an approximate diameter of 12 inches. The sewer main had a number of taps.[16] None of the taps allowed full access of the lateral with the lateral-launch camera and, thus, the laterals were not video inspected in their entirety.

The sewer main along Redacted was in general good condition. No collapse or significant damage to the sewer pipe was observed. Longitudinal cracks along the pipe were observed near the manhole at Redacted The portions of the lateral's factory taps that were video inspected showed the taps were capped.

Along Redacted approximately 50 feet west of the manhole at Redacted a break tap was observed. This was the first lateral entry point from the aforementioned manhole. Figure 35 shows the street marking for the location of the sewer lateral and the asphalt patch performed

[16] Factory taps are manufactured into the sewer main for potential connection of sewer laterals (unlike break taps, which are made after the manufacturing process is complete). Factory taps along Redacted were not used. Apparent service lateral connections to the various residences were done through break taps.

by PG&E for the gas service line. As shown in this figure, the sewer line is in close proximity to the gas service tee.

Figure 35. Relative location of cold asphalt patch for gas service tee (dashed yellow lines) and sewer lateral tap connection to sewer main (green arrow) for subject residence. Residence is to the left in photograph. Photograph by Exponent on March 11, 2014.

Gaps around the sewer lateral (at the break tap) and the sewer main were observed. The lateral was an approximately 4-inch cast iron pipe for the subject residence. As shown in Figure 36, the sewer lateral had debris accumulated around its interior perimeter and showed clear evidence of lack of recent use, including presence of spider webs, dryness and deterioration.

As shown in Figure 36, approximately 8 feet from the tap at the sewer main, the sewer lateral had a joint offset and opening. The green painted dot marked inside the left side of the cold asphalt patch shown in Figure 35 indicates the approximate location of this joint offset. More than 50 percent of the cross-sectional area of the pipe was offset, exposing the backfill around the pipe. The lateral-launch camera was unable to continue beyond this joint offset.

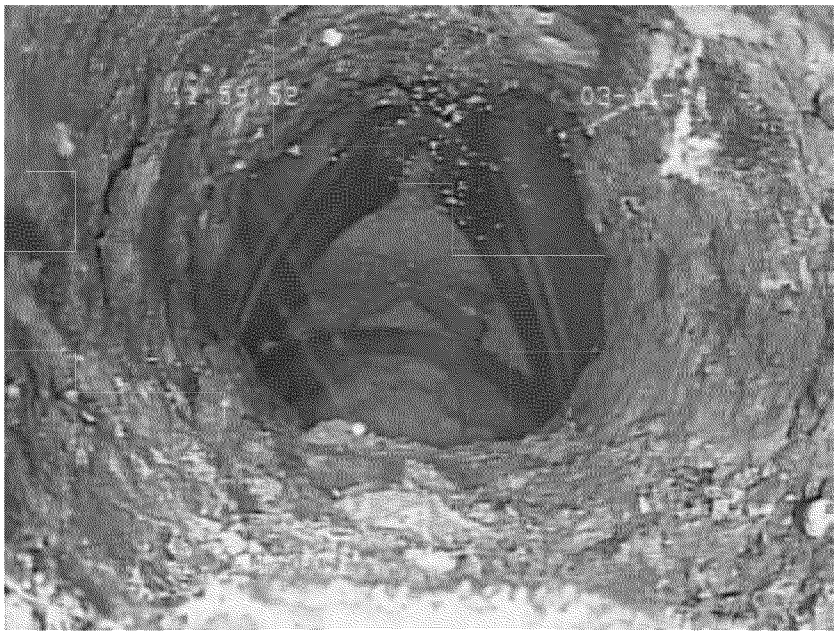


Figure 36. Sewer lateral conditions approximately 5 feet from tap with sewer main. Deterioration, spider webs and debris in cast iron pipe in area closest to camera. Separation and dislocation of lateral away from camera. Source: FES.

Video of the remainder of the sewer lateral was attempted from the interior of the residence, and is discussed later.

Sewer Main on Redacted East of Manhole

The sewer main east of the manhole along Redacted consisted of an unlined clay pipe, with an approximate diameter of 8 inches. The sewer main was generally in good condition. FES reports that the entire main east of the intersection was video inspected and "found to be clear of obstructions."[17]

Sewer Main on Redacted South of Manhole

The sewer main south of the manhole along Redacted consisted of an unlined clay pipe, with an approximate diameter of 8 inches. A collapse was observed approximately 1½ to 2 feet

[17] FES, "Crossbore Sewer Safety Inspection Status Report," dated March 18, 2014. The FES report incorrectly identifies this section of the sewer main to be west of the intersection between Redacted

south of the manhole (Figure 37). Standing water was observed in the collapsed area. The area of the observed collapse appears to be aligned with the storm pipe system.

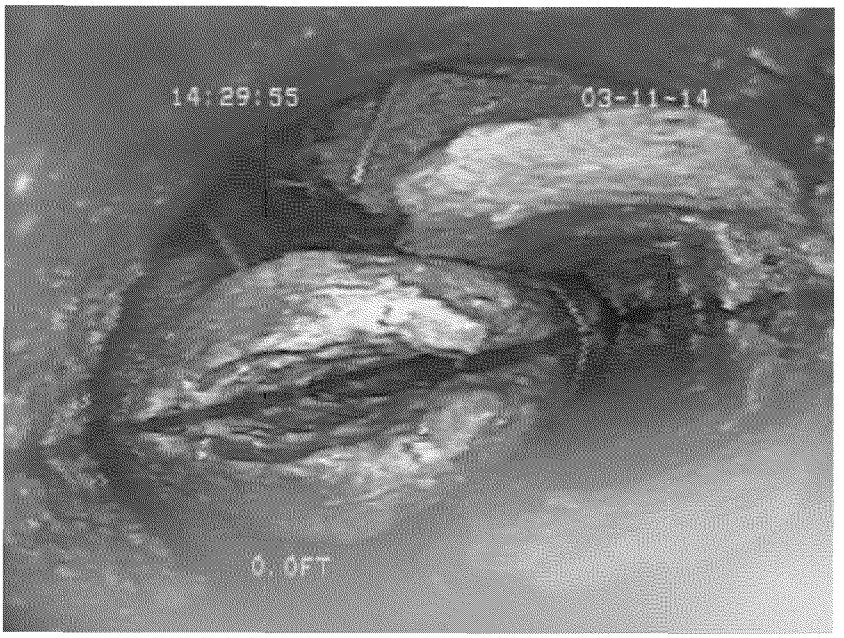


Figure 37. Collapse of sewer main along Redacted south of manhole. Standing water at bottom. Source: FES.

Figure 38. Underground utilities in the vicinity of subject residence (indicated by white arrow). Green arrows indicate sewer line flow directions into manhole (only one line discharging towards Redacted in the western direction). Blue dashed lines indicate likely alignment of storm drain pipes inside pavement trench marks. Red oval indicates approximate location of collapsed sewer pipe.

Because of the pipe collapse, the video inspection could not progress south from the manhole. Video inspection of this portion of the main was later performed on March 12, 2014, "completing a 200 ft. traverse of the full segment."[18] The video inspection reportedly showed no lateral connection between the sewer main and the subject residence.[19] Thus, the only identified sewer lateral for the residence is the one connecting to the sewer main on Redacted

FES reported that inside the main, "the collapsed main obstruction …[was] underwater through 6 ft. of sagging line."[20] According to information relayed to FES, the collapse had not been

[18] FES, "Crossbore Sewer Safety Inspection Status Report," dated March 18, 2014.

[19] "The lateral located 32 feet up the main South from MH 710 and oriented in the direction of the subject property was found to be blocked by root intrusion, and the lateral appeared to be capped." (FES, March 18, 2014).

[20] FES, "Crossbore Sewer Safety Inspection Status Report," dated March 18, 2014.

identified in the December 2013 video inspection of the sewer system performed on behalf of the City of Carmel. Reportedly, the video camera for this sewer main was launched from the south and may have videoed the typical maximum camera cable length of approximately 200 feet; thus, the video may have stopped a few feet short of the subject manhole. Exponent has not reviewed the reported December 2013 video documentation of the sewer system.

Sewer Main on Redacted North of Manhole

The sewer main north of the manhole along Redacted consisted of a lined pipe, with a restricted diameter of approximately 8 inches. FES concluded that "Push camera and structure access will be necessary to inspect this main North of the intersection and the laterals on it."[21] Exponent understands FES did not perform a video inspection of this pipe as part of this investigation.

Residence's Sewer System

At the subject residence, because of the sewer lateral joint offset near the sewer main, video of the sewer lateral was attempted from the interior of the residence. The selected entry point for the video was a toilet, which was removed to allow the push camera to enter the sewer pipe (Figure 39).

The push camera video recorded the sewer drain system from the toilet toward the sewer main. The following summarizes characteristics of the sewer pipe between the toilet and the vicinity of the sewer main:

- Sewer line below toilet was an approximately 4-inch cast iron pipe (Figure 40).
- Various pipe connections occurred inside the house. The connections were for other sewer pipes and vents (Figure 41).
- Sewer pipe exited the residence approximately 23 feet from the toilet (distance measured along the sewer pipe). The sewer pipe at the wall's residence exterior was approximately 1¼ feet below ground.

[21] FES, "Crossbore Sewer Safety Inspection Status Report," dated March 18, 2014.

- Conditions of the sewer lateral pipe changed for a pipe section between approximately 27½ and 35 feet from the toilet. At a distance of approximately 27½ feet from the toilet, the sewer pipe was approximately 1.1 feet below ground.
- Approximately 51 feet from the toilet, an offset in the cast iron lateral was observed. A dislocated joint with an apparently white plastic pipe was observed at this location (Figure 42). The sewer lateral depth at this location was approximately 4¼ feet below ground.
- An approximately 5-foot segment of the plastic pipe was videoed until another joint dislocation was encountered and the push camera could not continue (Figure 43).
- No plumbing traps were found along the entire videoed drain line segment.

Figure 39. Toilet removed to allow for insertion of sewer push camera. Photograph by Exponent on March 11, 2014.

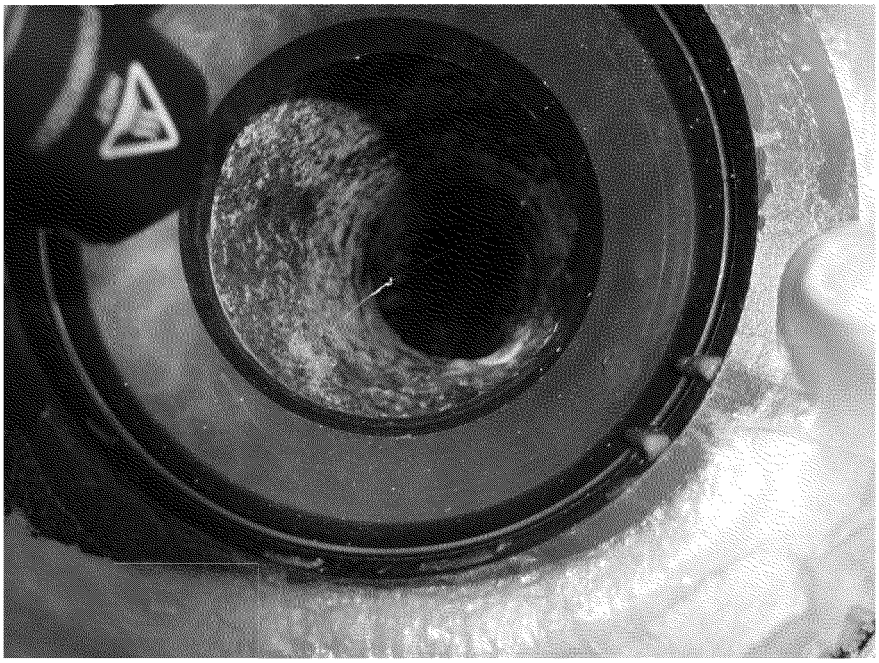


Figure 40. Sewer pipe riser below toilet. Cast iron pipe is dry, spider webs are visible. Photograph by Exponent on March 11, 2014.

Figure 41. Multiple connections to building sewer system inside residence. Arrow indicates tub plumbing trap. Photograph from inside residence's basement. Photograph by Exponent on March 11, 2014.

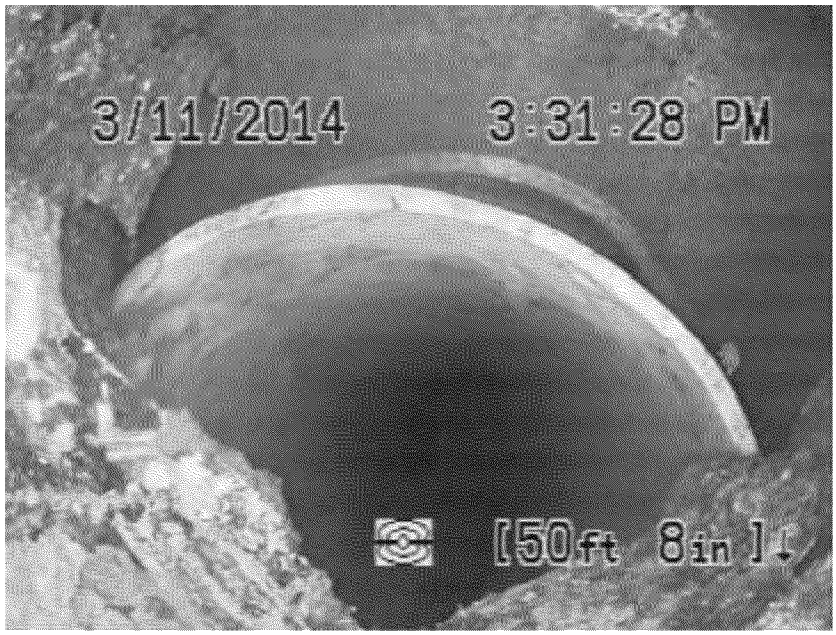


Figure 42. Dislocated joint between an apparently white plastic pipe and cast iron sewer lateral. Source: FES.

Figure 43. Sewer lateral joint offset at connection between white plastic pipe segment (green arrow) and apparent cast iron pipe (yellow arrow). Source: FES.

Sewer Lateral Excavation

To confirm the video-identified offset and presence of plastic segment in the sewer lateral at the residence, an excavation was performed to expose the section of the sewer lateral in the vicinity of the gas service line tee.

The approximate area previously excavated by PG&E on the day of the explosion (Figure 35) was re-excavated. The depth of excavation continued until a portion of the sewer lateral was exposed (Figure 45). As shown in Figure 46, the presence of a white plastic segment of sewer lateral, and an offset of the pipe, was confirmed by the excavation. The date of installation of the plastic segment in the sewer lateral is unknown. According to statements by Redacted of Fire Cause Analysis, the homeowners stated that they have not performed sewer replacement/ repair work since they purchased the property in 1999.

Figure 44 shows a schematic configuration of the sewer and gas systems in the vicinity of the excavation.

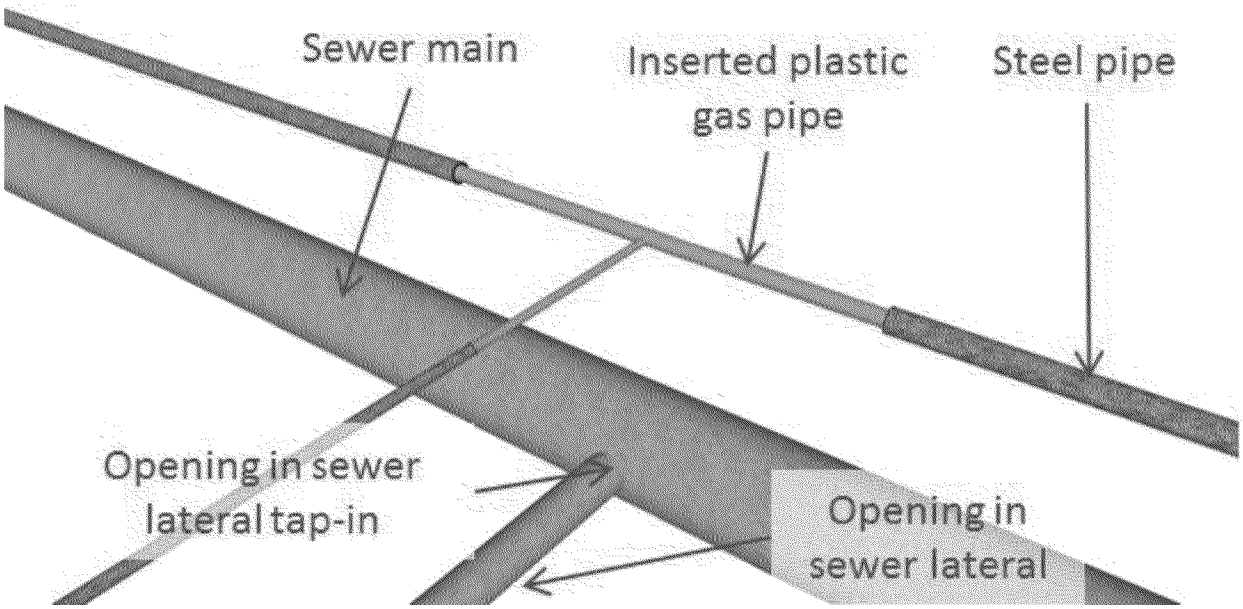


Figure 44. Schematic configuration of the sewer and gas systems in the vicinity of the excavation. Figure not to scale.

Figure 45. Excavation to expose sewer lateral at subject residence in the vicinity of gas service tee. Yellow arrow indicates gas main along Reda Redacted Red arrow indicates gas service line. Green arrow indicates sewer lateral. Photograph by Exponent on March 21, 2014.

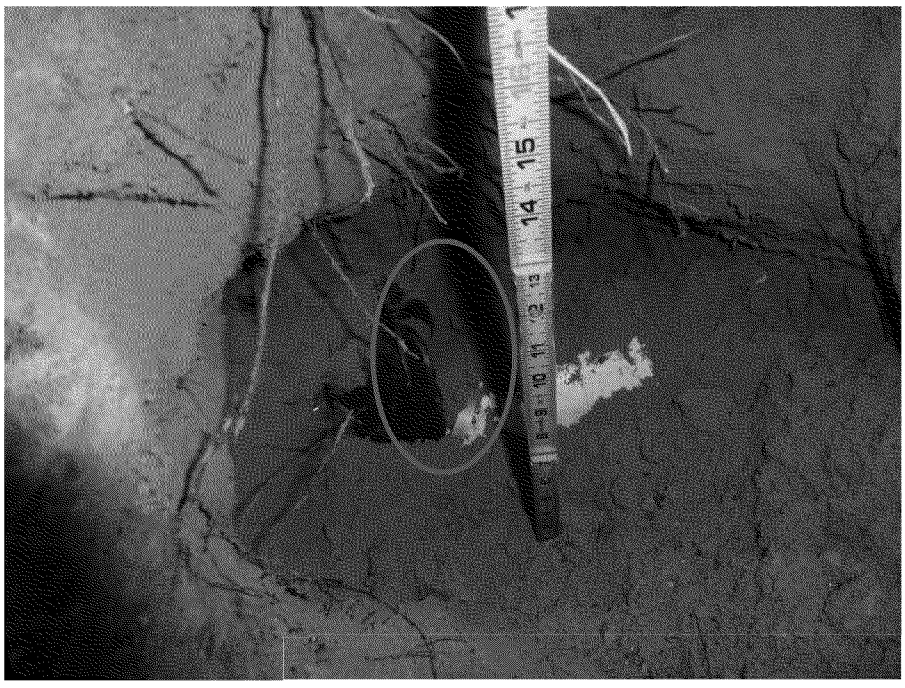


Figure 46. Sewer lateral offset joint (green oval), and white plastic segment of sewer lateral. Sand backfill surrounding sewer lateral. Photograph by Exponent on March 21, 2014.

Figure 47. End of annular space in gas main along Redacted (yellow oval) in vicinity of sewer lateral offset joint (green arrow). Photograph by Exponent on March 21, 2014.

The excavation revealed the following configuration for the sewer lateral and gas lines:

- Approximate depth to top of gas main at service tee: 24 inches
- Approximate depth to top of sand backfill for sewer lateral: 36 inches
- Approximate depth to top of sewer lateral: 53 inches to 55 inches

Based on the above measurements, the vertical distance between top of the sand backfill above sewer lateral and the bottom of the gas main at service tee was approximately 11 inches. Therefore, there was a shorter path for the gas to travel downwards towards the permeable sand backfill than upwards, towards the base of pavement (~21 inches). In addition, due to the rainfall preceding the explosion[22], the shallow soil not covered by asphalt pavement likely had

[22] NOAA (National Oceanic and Atmospheric Administration) rainfall records for stations near the site indicate that over three inches of cumulative rainfall were recorded in the five days prior to the explosion. NOAA station at Monterey Regional Airport, approximately 4 miles northeast of the site (Monterey NWSFO Station - GHCND:USC00045802); and Monterey 1.1 SSW Station approximately 2.5 miles northeast of the site (GHCND:US1CAMT0030).

higher water content than the deeper soil, reducing its relative permeability. Finally, the pavement above the gas main created a relatively low permeability cap above the gas main and portions of the service line.[23]

Plumbing Traps

Plumbing traps are curved sections of pipe installed to contain water and provide a barrier to sewer gases entering living space. The water seal trap on any plumbing fixture or plumbing drain line must be filled with water to be effective. At the subject residence, traps were observed in all lines leading to, or in, all plumbing fixtures present.[24] Some of these plumbing fixture traps are shown in Figure 48 and some of the plumbing line traps are shown in Figure 41.

[23] Redacted

[24] At the time of Exponent's visits, no laundry equipment was present in the presumed laundry room. A vertical sewer line riser was present. The type of connection from this riser to the laundry equipment is unknown.

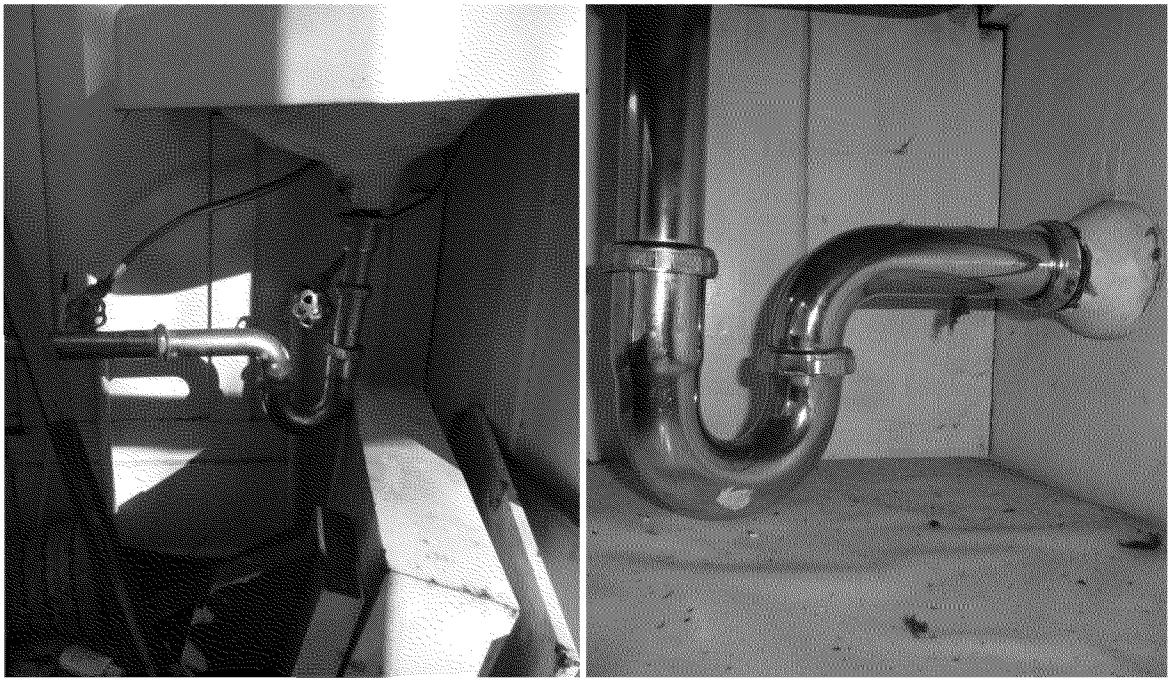


Figure 48. Plumbing traps at bathroom sink (left) and kitchen sink (right). Photographs by Exponent on March 11, 2014.

As previously noted, there was no plumbing trap in the sewer drain line section video recorded from the toilet towards the sewer main on Redacted. The only trap along this sewer line path was the integral trap in the toilet fixture. Figure 49 documents this trap.

It is Exponent's understanding that the residence had been unoccupied for over one year. When plumbing fixtures are not used for extended periods of time the plumbing traps can lose their water seal through evaporation. On March 6, 2014, Exponent observed a low water level in the bathroom toilet bowl (Figure 50). The exact water level conditions of the toilet at the time of the explosion are unknown. As noted earlier, the fire department deployed a hose line to extinguish a small fire in the demolished structure,[25] and it is likely that the water observed in the toilet bowl was introduced at the time the small fire was being extinguished.

[25] Monterey Fire Department NFIRS report, FDID 27060, Incident number 14-0001163 , pg 2.

Figure 49. Toilet drain trap. Photograph by Exponent on March 11, 2014.

Figure 50. Low water level in the bathroom toilet bowl three days after explosion. Photograph by Exponent on March 6, 2014.

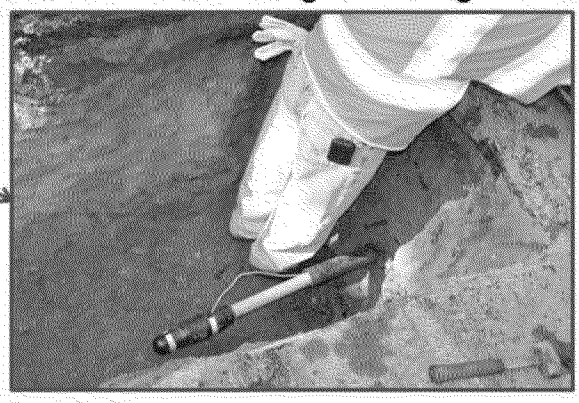
Gas Migration Test

To investigate the likely gas migration path from the release site to the subject residence, on March 21, 2014, a gas migration test was performed at the site. This section summarizes the result of the gas migration test, and details of the testing protocol and procedures are summarized in Appendix A.

The gas migration test consisted of injecting helium gas through the annular space between the plastic gas main and the 2-inch steel pipe partially encasing it on Redacted. Helium injected through the annular space was allowed to travel through the area while helium concentrations were monitored at selected site locations during the test. The helium injection point near the location of the plastic pipe was punctured on the day of the explosion (Figure 51). The nineteen helium monitoring points are listed in Table 1 and shown graphically in Figure 52 for the area outside the subject residence, in Figure 53 at the residence's basement and in Figure 54 for the residence's first floor. Figure 55 through Figure 57 show example monitoring points for the tests.

Redacted

Prior to adding test fitting



Test fitting in place

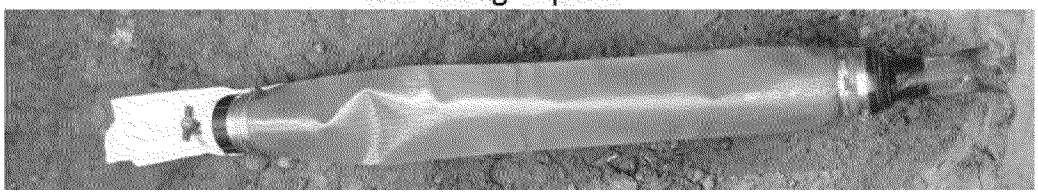


Figure 51. Annotated D-Plat 3956-C08 showing helium injection point and test fitting. Photographs by Exponent on March 21, 2014.

Monitoring Point	
ID	**Description**
1	~10' from IP
2	~20' from IP
3a	At ST (~29' from IP) - pavement
3b	At ST (~29' from IP) - soil
4	~10' from ST
5	~20' from ST
6	toe of garden retaining wall
7a	~4' from basement wall
7b	outside of basement wall
19	manhole Redacted

Maximum measured helium concentration in all tests:

Green: Not detected
Yellow <1%
Orange: >1%
Red: ~100%

Redacted

Figure 52. Helium test monitoring points and results outside of residence.

Monitoring Point	
ID	Description
8	cleanout next to water heater
9	near center of basement, over soil
10	void in basement slab

Maximum measured helium concentration in all tests:

Green: Not detected
Yellow <1%
Orange: >1%
Red: ~100%

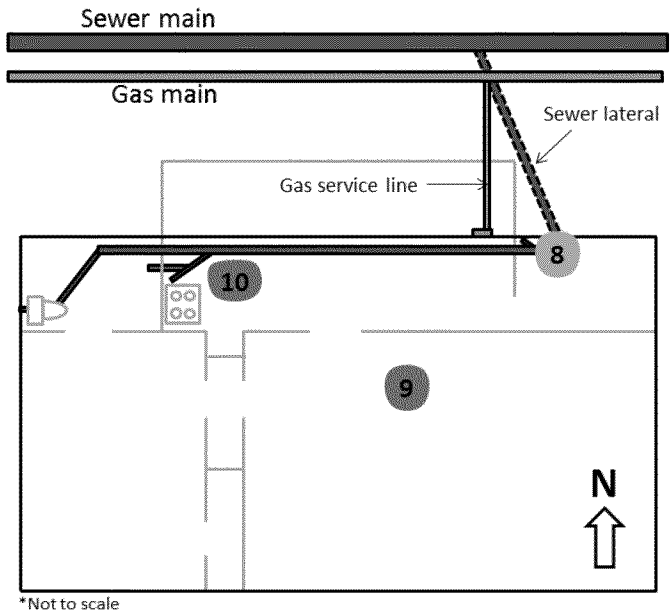


Figure 53. Helium test monitoring points and results at the residence's basement.

Monitoring Point	
ID	Description
11	laundry room vent
12	kitchen sink
13	bathroom sink
14	bathtub drain
15	Toilet
16	toilet vent
17	toilet tank
18	bathroom vent

Maximum measured helium concentration in all tests:

Green: Not detected
Yellow <1%
Orange: >1%
Red: ~100%

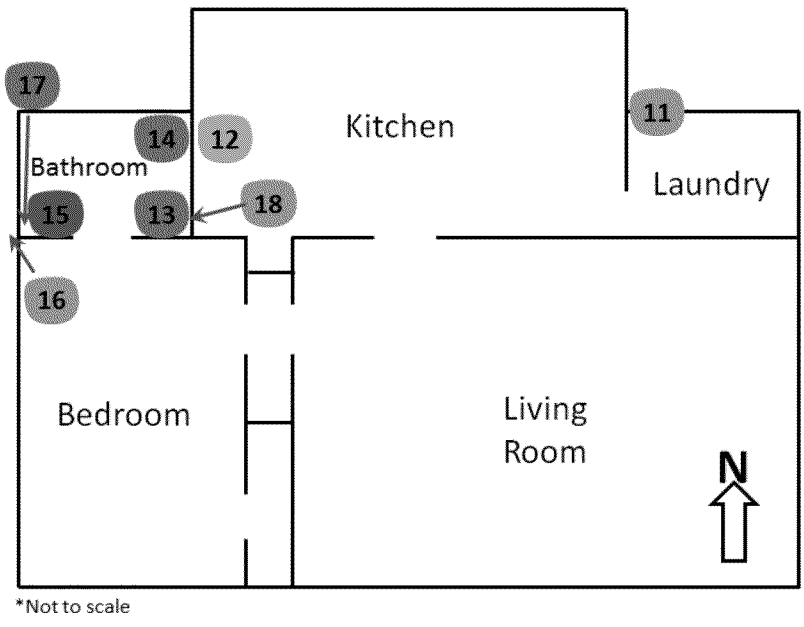


Figure 54. Helium test monitoring points and results at the residence's first floor.

Figure 55. Example monitoring points outside of residence. Monitoring point #3 (left) near excavation performed by PG&E at gas service tee for residence. Monitoring point #19 (right) at sewer manhole near the intersection of Red Redacted Photographs by Exponent on March 21, 2014.

Figure 56. Example monitoring points at the residence's basement. Monitoring point #8 (left) by the cleanout next to water heater. Monitoring point #9 (right) near center of basement, over soil. Photographs by Exponent on March 21, 2014.

Figure 57. Example monitoring points at the residence's first floor. Monitoring point #15 (left) at the toilet. Monitoring point #18 (right) at bathroom vents. Photographs by Exponent on March 21, 2014.

Table 1. Helium gas migration test results

		Conditions:	AS-IS CONDITIONS						EXCAVATE & RECOMPACT TOP ~8 INCHES				TOILET REMOVED				EXPOSE SEWER LATERAL & RECOMPACT			
			Test 1		Test 2		Test 3		Test 4a		Test 4b		Test 5a		Test 5b		Test 6A		Test 6B	
		Start:	9:26		9:58		10:06		11:59		12:02		13:28		13:34		16:26		16:33	
		Pressure:	~ 6 psi		~ 10 psi		~ 35 psi		~ 10 psi		~ 15 psi		~ 15 psi		~ 48 psi		~ 15 psi		~ 20 psi	
	ID	Monitoring Point Description	% meas.	time	% meas.	time	% meas.	time	% meas.	time	% meas.	time	% meas.	time	% meas.	time	% meas.	time	% meas.	time
															Hose Fail @13:36					
Outside of House	1	~10' from IP	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	~20' from IP	0.10 - 0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3a	At ST (~29' from IP) - pavement	2.5 - 0.44	-	-	-	-	-	0.00	12:00	1.2	12:03	14+	13:29	-	-	3.0+	16:27	-	-
	3b	At ST (~29' from IP) - soil	25+	9:29	-	-	2.0+	10:15	0.00	12:00	0.42	12:03	-	-	0.40	13:42	8.0+	16:27	-	-
	4	~10' from ST	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	5	~20' from ST	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	16:36
	6	toe of garden retaining wall	*0.04*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	16:35
	7a	~4' from basement wall	*0.15*	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	0.04	16:35
	7b	outside of basement wall	*0.09*	-	-	-	0.00	10:12	-	-	0.00	12:05	-	-	0.00	13:41	-	-	0.00	16:32
	19	manhole Redacted	-	-	-	-	-	-	-	-	-	-	0.00	13:29	28.00	13:44	-	-	6.00	16:53
Basement	8	cleanout next to water heater	*0.13*	-	-	-	0.00	10:11	-	-	trace	12:06	trace	13:33	trace	13:38	-	-	0.03	16:38
	9	near center of basement, over soil	*0.15*	-	-	-	0.00	10:10	-	-	0.00	12:07	0.00	13:33	0.00	13:39	-	-	0.00	16:38
	10	void in basement slab	*0.10*	-	-	-	0.00	10:12	-	-	0.00	12:05	-	-	-	-	-	-	0.00	16:39
First Floor	11	laundry room vent	*0.00*	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	8.7	16:46
	12	kitchen sink	*0.19*	9:37	0.00	10:04	-	-	-	-	-	-	-	-	-	-	-	-	0.03	16:45
	13	bathroom sink	0.00	9:42	0.00	10:02	0.00	10:09	-	-	-	-	-	-	-	-	-	-	0.00	16:45
	14	bathtub drain	0.00	9:41	0.00	10:04	0.00	10:08	-	-	-	-	-	-	-	-	-	-	0.00	16:43
	15	toilet	0.00	9:41	0.00	10:01	0.00	10:08	-	-	0.00	12:07	0.00	13:30	0.00	13:37	-	-	100	16:42
	16	toilet vent	0.00	9:42	0.00	10:00	0.00	10:08	-	-	0.00	12:09	-	-	-	-	-	-	1.2	16:41
	17	toilet tank	0.00	-	0.00	10:02	0.00	10:08	-	-	0.00	12:08	eliminated		eliminated		eliminated		eliminated	
	18	bathroom vent	-	-	0.00	10:03	0.00	10:09	-	-	-	-	-	-	-	-	-	-	8.0	16:44

Notes: IP: Injection Point; ST: Gas Line Service Tee.
Italic indicates suspect reading due to need of sniffer recalibration.
Yellow highlight indicates detected helium.
Test 1: sniffer recalibrated at 9:39; ran out of helium at 9:37.
Tests 3: a hole created by escaping helium was found close to point 3b.
Test 4b: pressure was increased to ~48 psi at 12:10. Hose clamp failed at 12:11. No measurements were made after the pressure increase.
Test 6B: ran out of helium at 16:45.

Table 1 summarizes the results of the helium gas migration test. As shown in the table, the injection pressure was varied between different testing stages. As the tests progressed, relevant times during the test were documented (e.g., initiation of injection, time of change in injection pressure, etc.). Helium concentration measurements and time of measurement at selected monitoring points were recorded throughout the tests.

Field conditions were varied for the six helium path migration tests. As described in Appendix A, the initial test was performed with field conditions undisturbed from those existing prior to initiation of the gas migration tests. Each subsequent test was designed in an attempt to simulate conditions closer to those present at the site immediately prior to the explosion. The tests included the following field conditions (additional testing details as summarized in Appendix A):

- Tests 1 through 3 were with "As-is" conditions (i.e., no field modifications taking place on the day of the test). Test injection pressures varied. During Test 3, a pinhole formed through the soil near the gas service tee, causing release of helium gas into the air.

- Test 4: In an attempt to bring soil conditions closer to those present before the gas service tee excavation was performed by PG&E on the day of the explosion, the shallowest eight inches (approximately) of soil above the gas service tee were excavated, re-compacted in place and paved with an asphalt cold patch (Figure 58). Other field conditions were as described for Test 1.

- Test 5: To test the condition of dry toilet bowl on the day of the explosion, the toilet was removed, and helium measurements were taken directly at the toilet sewer riser (Figure 59). Other field conditions were as described for Test 4.

- Test 6: After the excavation to expose the sewer lateral was completed (as described earlier), the excavation was backfilled and the shallowest two feet (approximately) above the gas service line were re-compacted and moisture conditioned. Moisture condition included the addition of water to allow for increased soil compaction and to increase the water content of the shallow soil layers (NOAA rainfall records for stations

near the site[26] indicate that over three inches of cumulative rainfall were recorded in the five days prior to the explosion. However, no rainfall was recorded at these stations in the two weeks prior to the gas migration test). Other conditions were as described for Test 5.

Figure 58. Excavation (left) and re-compaction (right) near gas service tee. Photographs by Exponent on March 21, 2014.

[26] NOAA station at Monterey Regional Airport, approximately 4 miles northeast of the site (Monterey NWSFO Station - GHCND:USC00045802); and Monterey 1.1 SSW Station approximately 2.5 miles northeast of the site (GHCND:US1CAMT0030).

Figure 59. Monitoring point #15 after removal of the toilet. Photograph by Exponent on March 21, 2014.

As summarized in Table 1 and Figure 52 through Figure 54, the results of the helium gas migration test conclusively show that, when helium gas is released near the location where the puncturing of the plastic pipe occurred on March 3, 2014, the gas can enter the sewer system in the vicinity of the subject residence. Once inside the sewer system, helium gas can travel through the sewer system and be released into the living space of the subject residence.

The gas migration test results indicate that the most likely helium gas migration path was as follows:

1. Gas travels through the annular space between the plastic gas main and the steel pipe encasing it along Redacted
2. Gas exits annular space near gas service tee location.

3. Gas travels through soil in all directions. In the up vertical direction, the gas encounters a relatively impermeable seal formed by moist soil (silty sand to clayey sand) and asphalt pavement. Thus, gas travels mainly in the horizontal and downward directions.

4. Gas reaches backfill for the sewer lateral composed of relatively high permeability sand.

5. Gas travels through backfill for the sewer lateral and enters sewer system through two likely locations: 1) dislocated sewer lateral plastic segment near gas service tee, and 2) apparent openings in tap of sewer lateral at the sewer main on Redacted

6. Gas travels through sewer system along the Redacted sewer main and through the sewer lateral towards the subject residence

7. Gas exits at multiple locations inside and just outside first floor of residence: sewer vents and sewer drains, including toilet. Toilet sewer drain is largest opening in sewer system inside the house. The subject residence had been reportedly unoccupied for over one year, and water seals of plumbing traps were likely ineffective, providing direct connection between the sewer system and living space.

Analysis of Gas Migration and Ignition

Based on Exponent's site inspection, interviews with individuals that witnessed the incident, the inspection of the sewers, and the helium gas migration testing, the following steps represent the most likely gas migration and ignition events.

Step 1 – Gas leak. Inspection of the 2-inch gas main and inserted 1¼-inch plastic piping shows that there was a hole created in the plastic pipe after the Save-a-valve was tapped. This hole resulted in a pressurized natural gas release from the plastic pipe. It is estimated that this occurred between 10:00 a.m. and 10:15 a.m. The process of welding the Save-a-valve onto the steel pipe may have created a smaller hole in the plastic pipe and resulted in an earlier starting point for the gas release.[27] A second hole was introduced into the plastic pipe when an M/2 line stopper fitting was tapped a short time after the first tapping operation. This second hole caused additional gas to leak.

Step 2 – Flow through annular space. The released natural gas traveled through the annular space between the inserted plastic pipe and the steel pipe in both directions (east and west) along Redacted away from the plastic pipe leak. Upon reaching the end of the 2-inch steel pipe, the gas exited the annular space and flowed into the soil.

Step 3 – Flow through soil. The pressurized natural gas exited the annular space in close proximity to openings in the sewer system at the intersection of Redacted Redacted and near the sewer service lateral. The pressurized natural gas likely traveled through the soil and into the sewer pipe openings (dislocated sewer lateral for the incident house and sewer lateral tap into the sewer main, as well as collapsed section of sewer main on Redacted In both locations, pavement located above the openings in the annular space acted as a relatively impermeable cap, impeding most of the escaping gas from traveling up and out of the ground.

[27] Shop testing reportedly conducted by PG&E showed that it is possible to create a hole in a plastic pipe that is inserted into a steel pipe by welding fittings onto the steel pipe.

Step 4 – Flow through the sewer system. Helium testing showed that pressurized gas released from the annular space may enter the openings in the sewer system. Helium gas entering the sewer system found uninterrupted paths through the sewer system, including the sewer main and sewer lateral. It is likely that the escaping natural gas followed a similar path.

Step 5 – Flow into the house. Because the house was reportedly unoccupied for an extended period prior to the incident, it is likely that some of the plumbing traps had dried out, rendering the water seal of the trap ineffective. This allowed for a direct pathway into the living space from the sewer system. It is likely that one or more of these traps (including the bathroom toilet) allowed gas to enter the house. The photograph shown in Figure 16 provides evidence of fire in the bathroom (Figure 13 through Figure 15) and the results of the helium gas migration test provide support to the toilet being the most likely entry path for large volumes of natural gas into the house on the day of the incident.

Step 6 – Accumulation and ignition. Based on the high concentration of helium measured at the toilet during the helium testing, and the fire photograph shown in Figure 16, it is likely that the natural gas entering the house was well above the lower flammability limit. The density of natural gas is less than the density of air, which would have caused this natural gas to rise and accumulate high in the living space on the first floor. Eventually the gas layer would have descended and encountered a competent ignition source. Based on the evaluation of potential ignition sources, including the kitchen stove, the ignition source was likely the stove pilot light. Due to the lack of fire damage in the house (except in the bathroom, as previously described), the fact that no witnesses reported a fireball, and the short bang sound reported, it is likely that the gas-air mixture was well mixed and within the flammability limits.

Root Cause Analysis

Problem Statement

The problem statement provides the focus of the root cause analysis to ensure that the appropriate issues are addressed. Exponent personnel reviewed the initial documentation and defined the problem statement for the root cause analysis. The problem statement developed for performing this root cause analysis is:

> ***"On March 3, 2014, while tapping into an existing 2" steel line, gas was released, entered a residence and ignited causing an explosion."***

Approach

The root cause analysis was performed in accordance with a structured approach for root cause and failure analysis. The objective of the analysis was to identify the root cause of the gas leak and subsequent explosion, and to recommend corrective actions to prevent recurrence. The description of the tasks performed is provided below.

Data Collection

The analysis was performed through a review of records and followed up with interviews with key personnel involved in the various incidents and management processes. All documents identified during the analysis were catalogued and all interviewed personnel identified.

The data collection effort was focused on retrieving the job folder for the installation of the plastic insert of the 2-inch line on Redacted In performing the data collection and analysis tasks, Exponent staff conducted the following activities:

1. Reviewed all documents provided by Distribution Integrity Management Program (DIMP) and logged the source location. The log of these documents is located in Appendix B.

2. Targeted examination of the Gas Pipeline Replacement Program (GPRP) based on division and time frame. The GPRP records examined are located in Appendix C.
3. Conducted independent search of Monterey and Salinas offices for relevant job documents. The records searched in these locations are listed in Appendix D.
    a. Mapping Folders
    b. Leak Survey/Maps Logs
4. Examined PC Leaks, the database used to store leak information prior to IGIS.
5. Examined production mapping backlog.
6. Contacted current and former PG&E employees that worked in the division during the 1997-2000 time frame. The list of interviewees is provided in Appendix E.
7. Compared Carmel map/plat to Leak Repair job files and Gas Service Records.
8. Examined procedures for welding and installation of Save-A-Valve and Line Stopper.
9. Independent review of IGIS for relevant documents.
10. Independent review of SAP/JTM for job financials.
11. Examined Corrective Action Program (CAP) items related to inaccurate maps.
12. Examined Event Reports related to inaccurate maps.
13. Examined Mapping Correction Transmittals.

The objectives of the data collection activities were two-fold. First, the job records search was a targeted search to uncover the installation job of the 1¼-inch plastic pipe inside the steel main in the 1997-2000 year range. The time frame was based on the manufacturing date of the pipe, 1997 as shown on Figure 26, and the maximum time plastic pipe is stored in the warehouse (up to three years). Second, the data collection and interview activities were utilized to prepare the timeline of the incident. This provides the framework for identifying initiating events, as well as providing input into the root cause analysis in the subsequent sections.

In spite of the extensive data collection and review effort, the installation job folder has yet to be located. As a result, we were not able to determine why the inserted plastic pipe was not reflected on the plat maps. Therefore, the root cause analysis focused on the installation activities.

Development of the Event Timeline

The activities on the timeline leading up to the explosion are primarily based on the interviews of individuals present at the event.

The initiating events identified from the timeline formed the starting point for the root cause analysis that follows. The incident timeline is located in Appendix F and the initiating events are highlighted in red font.

Based on the Carmel Gas Leak and Explosion Timeline, there are two events that precipitated the gas leak and subsequent explosion. These are:

- Welders did not access the pipe using the existing PCF on the east side of the street, as specified on the drawing. (Note: The existing PCF was not excavated.)
- Plat map indicated the pipe was 2-inch steel & did not show the internal plastic line.

Performance of Root Cause Analysis

The root cause analysis is performed in a structured sequence of steps that lead to identification of the root cause and any contributing causes. When a significant event occurs, the root cause analysis examines the apparent cause (such as material failure or human error), as well as programmatic and management causes that failed to prevent the incident. The root cause analysis was performed in the following steps:

- Identification of initiating events from the timeline, as described above.
- Causal analysis: This step included the causal analysis for each of the identified initiating events. The causal analysis results in identifying the cause of each initiating event. These are identified as contributing causes.

- Root cause analysis: The root cause analysis was performed based on eliminating a contributing cause and re-assessing the event timeline. If the removal of a contributing cause prevented the occurrence of the problem, this cause was considered a root cause.
- Validation of the root cause: After completion of the root cause analysis, validation was provided by review with key participants.

The outcome of this effort was the identification of a single root cause. This information formed the basis for developing recommended corrective actions.

Root Cause

The previous section provided an analysis of the existing conditions, timeline of events, and characterization process to identify the initiating events. They consist of actions taken relative to performance of defined procedures and processes or potential deficiencies in the procedures and processes. The root cause analysis was performed for these initiating events through the following steps:

- A Causal Analysis Diagram was developed using the initiating events as the starting points.
- A root cause analysis is performed to identify the root cause and contributing causes (if any) relative to the problem statement. The analysis removes each cause and then determines if the event described by the problem statement would have been prevented. If the answer is "yes", the root cause has been determined.

This section provides the results of the root cause analysis and the identified root cause.

A Causal Analysis Diagram, located in Appendix F, considers the two aforementioned initiating events in the problem statement with the resulting root cause being:

Inadequate verification of system status and configuration when performing work on a live line.

Development of Corrective Actions

The desired outcome of a root cause analysis is to identify corrective actions to prevent recurrence of the problem. Effective corrective actions are those that address the root cause, are implementable by the organization, are cost effective, and are consistent with company business goals and strategies.

Based on the root cause, the following actions are recommended to prevent recurrence of the problem:

1. Develop or revise existing procedures to require positive verification of the expected system status and configuration when working on a pipeline. These procedures should emphasize that plat maps should not be considered "as-builts" and are not to be used in lieu of other means of positive verification.

2. Develop or revise existing procedures to require, as part of the design process, further investigation (e.g., field verification) of the system configuration when estimating a job for which "as-builts" are not available.

3. With this event in mind, review the current process for receiving, approving and storing job folders, including "as-builts," to assure that all job folders will be adequately filed and the necessary mapping changes made in a timely manner.

4. Develop and implement a process for a more detailed pre-job briefing, including a discussion of what can go wrong and who is responsible for taking what action if it does go wrong, and ensuring that the appropriate equipment is available to handle potential emergencies.

Conclusions

In the late morning on March 3, 2014, a PG&E welding crew was in the process of performing work in a bell hole near the intersection of Redacted in Carmel-by-the-Sea (Carmel), California. After tapping a line stopper fitting on a steel pipe, the crew removed the tapping tool and found a plastic coupon inside it. Approximately 15-30 minutes later an explosion occurred at an adjacent unoccupied house located at the southwest corner of Redacted Redacted (subject house).

Exponent performed an investigation of the explosion. As part of the investigation, Exponent performed an assessment of potential gas migration paths and ignition sources for the incident. Based on our analysis, once the gas was released due to the tapping operation, the most likely migration path was through the annular space between the inserted plastic pipe and steel pipe, through the soil, into the sewer pipe openings and sewer system and then into the house, mainly through the toilet. The most likely ignition source was the continuous pilot flame of the kitchen stove.

A Timeline and Causal Analysis Diagram were developed as part of the root cause analysis. The resulting root cause was determined to be:

> ***Inadequate verification of system status and configuration when performing work on a live line.***

Based on the root cause, the following actions are recommended to prevent recurrence of the problem:

1. Develop or revise existing procedures to require positive verification of the expected system status and configuration when working on a pipeline. These procedures should emphasize that plat maps should not be considered "as-builts" and are not to be used in lieu of other means of positive verification.

2. Develop or revise existing procedures to require, as part of the design process, further investigation (e.g., field verification) of the system configuration when estimating a job for which "as-builts" are not available.

3. With this event in mind, review the current process for receiving, approving and storing job folders, including "as-builts," to assure that all job folders will be adequately filed and the necessary mapping changes made in a timely manner.

4. Develop and implement a process for a more detailed pre-job briefing, including a discussion of what can go wrong and who is responsible for taking what action if it does go wrong, and ensuring that the appropriate equipment is available to handle potential emergencies.

Appendix A

Gas Migration Evaluation Scope of Work, Testing Protocol and Signature Page

Gas Migration Evaluation Scope of Work, Testing Protocol and Signature Page

Exponent completed the following tasks for the gas migration evaluation:

1. Performed reconnaissance visits to the explosion site and nearby areas
2. Researched and compiled weather data for Carmel-by-the-Sea for February and March 2014
3. Attended selected sewer pipe video inspections performed by others
4. Developed testing protocol for gas migration test, included in this appendix
5. Attended and documented results of the gas migration test
6. Observed excavation by PG&E during gas migration testing on the gas service tee and the sewer lateral near the sewer main for the subject residence
7. Analyzed the information obtained from Tasks 1 through 6, above
8. Discussed initial findings with PG&E staff
9. Prepared relevant sections of this report

Redacted

Helium Test Protocol

Test Date: Friday, March 21, 2014

Introduction

Helium was used as a tracer gas for testing at the site. Helium has been used successfully as a tracer gas in part due to its physical properties. It is neither toxic nor flammable and is an inert gas. Helium, as natural gas, is lighter than air.

A Gas Testing Contractor (Scan Tech) performed the Helium injection and gas detection test.

Exponent observed the test.

This testing protocol describes the site preparation and testing methodology followed during the gas migration testing performed at the site on March 21, 2014.

Site Description

Nomenclature used in this testing protocol:

Residence: House where the incident occurred.

Sewer Lateral: Based on the information reviewed to date, Exponent understands there is only one sewer lateral to the Residence. The Sewer Lateral exits the Residence along the north side of the Residence.

Lateral-Main Connection: Connection of the Sewer Lateral to the sewer main on 3rd Avenue.

Service Line: ½-inch plastic gas service line, which enters the Residence along its north side.

Gas Main: 1¼ -inch plastic gas main line along Redacted. The Gas Main is partially encased inside a 2-inch steel pipe.

Service Tee: Connection of the Service Line to the Gas Main.

Release Location: Location where puncture of Gas Main occurred on March 3, 2014.

Site Preparation before Test Date (Wednesday, March 19, 2014)

1. PG&E made preparations to allow for the helium test to be conducted safely.
2. PG&E installed fitting and injection port to the end of the 2-inch steel pipe that surrounds the Gas Main.

Test Procedure (Friday, March 21, 2014)

1. Using wire staff marking flags and white spray painting, Exponent marked monitoring points, outside the Residence, in the Residence's basement and Residence's first floor.
2. Scan Tech provided helium for the entirety of the test, and the helium leak detection equipment.[28]
3. Between tests, basement doors at the Residence were closed.
4. Background concentrations of helium were measured near the Release Location, near Service Tee, near the Service Line riser, at the Residence basement, at the location of all sewer drains and sewer vents. All background measures showed undetected helium.
5. Helium was injected through the PG&E-installed fitting at the Gas Main, near the Release Location.
6. Helium injection pressure was maintained constant during each testing stage.
7. The injection pressure was varied between different testing stages. The helium injection pressure was documented. Relevant times during the test were documented (e.g., initiation of injection, time of change in injection pressure, etc.).
8. Helium concentration and time of measurement was monitored and recorded at selected monitoring points.

[28] Scan Tech used a Marks Products Helium Leak Detector Model 9822. This device is a portable leak pinpointing instrument that uses helium as a tracer gas. The instrument can detect the percentage of helium from 0.01 to 100 percent.

9. Once measurements were recorded and documented, helium injection was stopped. During some of the tests, helium in the tank was depleted. During some relatively high injection pressure tests, the injection fitting failed. Time of occurrence of these events was documented.

10. Line was de-pressurized after each test.

Prior to performing the gas migration test, some of the conditions present at the site immediately prior to the explosion were modified by activities which took place following the explosion. The following list summarizes relevant changes to the field conditions that took place following the explosion:

1. House explosion: Damage to the residence as a result of the explosion caused important changes to the pre-explosion conditions. Some of those changes that could potentially affect the results of the gas migration test included debris accumulation in the sewer drains and vents.

2. Excavation at gas service tee: PG&E performed an excavation at the gas service tee to disconnect the service line from the residence. The gas meter and riser near the residence were also removed by PG&E. The excavation was backfilled with the excavated soil and the pre-existing pavement was replaced with an asphalt cold patch (Quikrete).

3. Weather-related changes: Moisture condition of the soil was changed as a result of changing weather. NOAA (National Oceanic and Atmospheric Administration) rainfall records for stations near the site[29] indicate that over three inches of cumulative rainfall were recorded in the five days prior to the explosion. No rainfall was recorded at these stations in the two weeks prior to the gas migration test.

4. Water in toilet: At the time of Exponents observations and documentation of the toilet conditions (on March 6, 2014), the toilet bowl had low water. After reportedly not being used for over one year, it is likely that the toilet bowl had dried out, rendering ineffective

[29] NOAA station at Monterey Regional Airport, approximately 4 miles northeast of the site (Monterey NWSFO Station - GHCND:USC00045802); and Monterey 1.1 SSW Station approximately 2.5 miles northeast of the site (GHCND:US1CAMT0030).

a water seat of the trap. Water in the toilet may have been introduced by while extinguishing a small fire inside the residence, as discussed in the report.

A total of six tests were performed on the system. As described below, the initial test was performed with conditions undisturbed from those existing prior to initiation of the tests. Each subsequent test was designed in an attempt to simulate conditions closer to those present at the site immediately prior to the explosion. The tests were conducted as follows (listed in chronological order):

- Test 1: "As-is" conditions were maintained, with no field modifications taking place on the day of the test. Helium was injected at a relatively low pressure of approximately 6 pounds per square inch (psi).

- Test 2: Conditions as described for Test 1, with the exception of an increase in helium injection pressure to approximately 10 psi.

- Test 3: Conditions as described for Test 1, with the exception of an increase in helium injection pressure to approximately 35 psi. During Test 3, a pinhole formed through the soil near the gas service tee, causing release of helium gas into the air.

- Test 4: In an attempt to bring soil conditions closer to those present before the gas service tee excavation was performed by PG&E on the day of the explosion, the shallowest eight inches (approximately) of soil above the gas service tee were excavated, re-compacted in place and paved with an asphalt cold patch. Other field conditions were as described for Test 1.

    - Test 4a: Helium was injected at approximately 10 psi.

    - Test 4b: Approximately three minutes after initiation of the test, with no evidence of a pinhole forming through the soil at the location where it had been previously formed during Test 3, the injection helium pressure was increased to approximately 15 psi.

- Test 5: To test the condition of dry toilet on the day of the explosion, the toilet as removed, and helium measurements were taken directly at the toilet sewer riser. Other field conditions were as described for Test 4.
    - Test 5a: Helium was injected at approximately 15 psi.
    - Test 5b: Approximately six minutes after initiation of the test, with no evidence of a pinhole forming through the soil at the location where it had been previously formed during Test 3, the injection helium pressure was increased to approximately 48 psi (approximate pressure of the gas main at the time of the explosion). Approximately two minutes after initiation of Test 5b (i.e., after increasing the injection pressure), the fitting at the injection point failed due to the high pressure.
- Test 6: To confirm conditions observed during video inspection of the sewer lateral at the residence, an excavation was performed to expose the section of the sewer lateral in the vicinity of the gas service line tee. The excavation was backfilled and the shallowest two feet (approximately) above the gas service line were re-compacted and moisture conditioned. Moisture condition included the addition of water to allow for increased soil compaction and to increase the water content of the shallow soil, as were likely the conditions prior to the explosion, due to the precedent rainfall, as previously discussed. Other conditions were as described for Test 5.
    - Test 6a: Helium was injected at approximately 15 psi.
    - Test 6b: Approximately seven minutes after initiation of the test, with no evidence of a pinhole forming through the soil at the location where it had been previously formed during Test 3, the injection helium pressure was increased to approximately 20 psi.

Appendix B

List of DIMP Provided Documents

List of DIMP Provided Documents

Document	Description	Source Location
1972 Map-LE52913_1.pdf	Drawing: Job 468902. 1972 main replacement on Redacted	Monterey Service ctr. file
1972 Map-LE52913_2.pdf	Duplicate Drawing: Job 468902. 1972 main replacement on Redacted	Monterey Service ctr. file
A-Form_Day of Incident.pdf	A-form 03/03/14 for leak on 1 1/4" PL (2" stl) @ Redacted	IGIS
Detailed Map-3rd Guadalupe.pdf	Plat view of incident area with customer connections	PG&E's Gas plat data base GIS
Gas Event Carmel 030314 revised 030514 Photos.pdf	Incident summary with maps and photos from GO-DIM	Redacted (DIMP) provided this document
Redacted Weld Qual & Int Notes.pdf	WQ Redacted	Redacted (CAP team) interviewed and provided notes
GSR's-Reda (19010).pdf	GSRs 2007/8 west of incident on 3rd	Record is located in the Monterey office
Redacted SR's.pdf	GSRs 1972-2013 on Redacted north and south of R, both sides of road	from SAP - PM# 30921135
Job Estimate-30921135.pdf	Trenching job estimate/report 8/26/13	from SAP - PM # 30921135
Leak Survey A-Forms.pdf	Leak Survey A-forms 1995-2013, blocks north and west of incident	Received these from Mapping in Salinas
Leak Survey Map (1995-2013).pdf	Leak Survey Map (1995-2013)	Received these from Mapping in Salinas
Redacted Weld Qual.pdf	WQ Redacted	Learning roster
Nearby Job Estimates of Interest.pdf	Job Estimates 1997-2000 for incident surrounding area	These as-builts are located at the Monterey office
Plat Map 3956-C08.pdf	Plat of incident area showing stl pipe	PG&E's Gas plat data base GIS
Pre 1973 Aldyl-A Leak Cluster Review.pdf	Survey of locations containing Aldyl A in surrounding blocks	from SAP - PM # 30921135
Records Overview.docx	List of records obtained in the causal evaluation by PGE	Redacted (CAP team) put this together to track the records collected
Redacted Weld Qual.pdf	WQ Redacted	Learning roster
Redacted OQ & Weld Qual.pdf	WQ and OQ Redact	Learning roster
TD-4461P-20.pdf	As-Built Process for Distribution Mains and Services	Located in the technical information library (TIL)
USA Documentation.rtf	USA ticket	IRTH.net
USA Documentation-2.rtf	USA ticket	IRTH.net

Document	Description	Source Location
USA Photos.rtf	USA ticket photos	IRTH.net
3956-C08 091808.pdf	Plat map	PG&E's Gas plat data base GIS
3956-C08 040103.pdf	Plat map	PG&E's Gas plat data base GIS
3956-C08 033109 W Iso Steel.pdf	Plat map	PG&E's Gas plat data base GIS
WO47212 86 Redacted A.pdf	Carmel work permit application	Redacted
WO47212 86 Redacted .pdf	WO47212 job estimate package	Redacted
GM 472156 72 Redacted .pdf	As-built docs for GM472156	Redacted
4376H 70 Redacted pdf	As-built docs for 4376-H	Redacted
GM 467458 72 Redacted .pdf	As-built docs for GM467458	Redacted
SO 19010 cut off 050207 .pdf	GSR Redacted	Redacted
Incident Report.pdf	Monterey Fire Department report	Monterey Fire Department
20140312090606.pdf	GSR Redacted	Redacted
inspector notes.docx	Redacted interviews with Reda inspector and PGE field engineers	Redacted
PGE typed interview notes Reda docx	Redacted interview notes with crew onsite during incident	Redacted
phone list Red notes.docx	A list of former PGE employees in the Carmel area during the 1997-2000 with Redacted notes for contacting them	Redacted
Tie in notes Carmel.docx	An image of the tie-in directions from the job package	Redacted
30921135ConDWGD.pdf	Job package 30921135	Redacted
CPA 3956-39 CPA Leak Log 2012.pdf	Leak repair logs for Carmel Area	Redacted
CPA 3956-39 CPA Map 2012 upper orig.JPG	Leaks repairs on plat map	Redacted
CPA 3956-39 read sheets 2012.pdf	Cathodic protection logs	Redacted
Gas ER Data Dump-Final.xls	Event reports prior to CAP	Redacted
Copy of Carmel_CAP Data Request.xlsx	CAP request similar to incident	Redacted
Copy of REFINED_GE_DATA.xlsx	Financial project pull	Redacted
PCleaks Extract Map 3956 Plat C08.xlsx	PC leaks database pull based upon plat map location	Redacted
Copy of TD 2004-12-31 employee listing.xls	List of full time employees working in Monterey and Salinas	Raymond Thierry
700189&7001870CAP_Event_262637_Final_Report_20140319152803.342_X.pdf	Mountain View internal event incident review	Redacted – Sr. Gas Dist. Engineer
CAP 262637 Mountain View event 073013.pdf	Mountain View Event CAP report	Redacted
Copy of CAP Mapping Data Request_3-4-14.xlsx	CAP reports based on mapping errors	Redacted
Copy of CarmelMainsHistory.xlsx	List of mains listed, both plastic and steel, during time of interest	Raymond Thierry

Document	Description	Source Location
Copy of GPRP Boxes w JFN.xlsx	GPRP with searchable jobs	Raymond Thierry
Copy of ORD 225 1995-2000.xls	Order Costs 1995-2000	Raymond Thierry
FW Carmel Redacted Records Search.msg	Salinas Records search effort	Redacted

Appendix C

GPRP Central Coast Records Reviewed

GPRP Central Coast Records Reviewed

Distrpk	Division	District	Diameter	Material	Year Completed	Repl. Document
114583	Central Coast	Coast	2	Steel	1998	6016005
114660	Central Coast	Coast	2	Steel	1998	6003458
114981	Central Coast	Coast	2	Steel	1998	6007275
115082	Central Coast	Coast	2	Steel	1998	6012572
115115	Central Coast	Coast	2	Steel	1998	6008987
115185	Central Coast	Coast	2	Steel	1998	6003457
115198	Central Coast	Coast	2	Steel	1998	6012379
115216	Central Coast	Coast	4	Steel	1998	6003456
115228	Central Coast	Coast	4	Steel	1998	6008523
115321	Central Coast	Coast	2	Steel	1998	6012467
115331	Central Coast	Coast	2	Steel	1998	6003431
115343	Central Coast	Coast	2	Steel	1998	6007276
115389	Central Coast	Coast	2	Steel	1998	6012571
115417	Central Coast	Coast	2	Steel	1998	6007273
115436	Central Coast	Coast	2	Steel	1998	6014602
115476	Central Coast	Coast	2	Steel	1998	6012470
115568	Central Coast	Coast	2	Steel	1998	6008440
115609	Central Coast	Coast	2	Steel	1998	6003460

Appendix D

Monterey and Salinas Office Document Search

Monterey and Salinas Office Document Search

Monterey Historical Mapping Record Search

Job Number	Location	Year
GM 1507326	Carmel	1995
GM 1506153	Carmel Valley Ranch	1995
GM 1325732	Carmel Valley	1995
GM 10372250	Carmel	1995
PM 30231311	Carmel	2001
PM 30200840	Carmel	2001
PM 30175569	Carmel	2001
PM 30169553	Carmel	2000
PM 30154593	Carmel	2000
PM 30126168	Carmel	2000
PM 30119701	Carmel	2000
PM 30091150	Carmel	1999
PM 30083775	Carmel	1999
GM 4840880	Carmel	1990
GM 4018503	Carmel	1991
GM 4018529	Carmel	1993
GM 4018602	Carmel	1992
GM 4204020	Carmel Valley	1994
GM 4226213	Carmel	1982
PM 30070653	Carmel	1996
30428647	Monterey	2005
3047153	Carmel	2005
30522243	Carmel	2006
30469528	Monterey	2005
30434092	Monterey	2005
30483942	Monterey	2006
30440511	Monterey	2005
30434092	Monterey	2006
30447602	Monterey	2006
30461120	Monterey	2006
3046310	Monterey	2010
30466201	Monterey	2006
30467823	Monterey	2006
30475387	Monterey	2006
30483950	Monterey	2006
30491719	Monterey	2006
30493938	Monterey	2006
30493939	Monterey	2006
30494001	Monterey	2006
30500922	Monterey	2006
30532610	Monterey	2007
30508805	Monterey	2006
30422243	Monterey	2007
30547803	Monterey	2007

Job Number	Location	Year
30581626	Monterey	2007
30587642	Monterey	2007
30658478	Monterey	2008
30662414	Monterey	2009
30715810	Carmel	2009
30715811	Carmel	2009
30714915	Monterey	2009
30726344	Carmel Valley	2009
30726349	Monterey	2009
30739718	Monterey	2009
30739740	Monterey	2009
30747321	Monterey	2009
30849080	Carmel Valley	2011
30483950	Monterey	2006
WO 04587A	Carmel	1994
WO 04551A	Carmel Valley	1994
WO 04552A	Carmel Valley	1994
WO 45515A	Monterey	1993
WO 45775A	Monterey	1994
WO 45524A	Monterey	1994
WO 43713A	Carmel	1993
WO 43704A	Monterey	1993
WO 43697A	Monterey	1993
WO 43722A	Monterey	1993
WO 43562A	Carmel	1993
WO 43651A	Monterey	1993
WO 43642A	Carmel	1993
WO 43633A	Monterey	1993
WO 43544A	Carmel	1993
WO 43526A	Carmel Valley	1993
WO 43517A	Monterey	1993
WO 41822A	Carmel	1991
WO 41430A	Monterey	1993
WO 41378A	Carmel Valley	1993
WO 41369A	Carmel	1993
WO 41314A	Monterey	1992
WO 41305A	Monterey	1992
WO 41225A	Carmel	1992
WO 41029A	Monterey	1992
WO 41298A	Carmel	1992
WO 41270A	Carmel	1992
WO 41252A	Carmel	1992
WO 41243A	Carmel	1992
WO 41234A	Monterey	1992
WO 41181A	Monterey	1992
WO 41074A	Monterey	1992
WO 41038A	Monterey	1991
WO 40930A	Monterey	1991
WO 41001A	Monterey	1991

Job Number	Location	Year
WO 40976A	Monterey	1991
WO 40912A	Monterey	1991
1001913	Carmel	1997
1001793	Carmel	1997
1001613	Monterey	1998
1001673	Carmel	1998
A150674	Carmel	1995
1006481	Carmel Valley	1998
8002017	Monterey	1995
1000360	Carmel	1997
2001183	Monterey	1996
G81369	Carmel	1999
G81965	Carmel	1996
G87140	Carmel	1997
G81965	Carmel	1997
G87095	Carmel	1997
G92340	Carmel	1997
G92619	Carmel	1997
G94078	Seaside	1997
G95503	Monterey	1997
A150674	Carmel	1996
G97361	Carmel	1996
G98479	Carmel	1999
GM 447116	Carmel	1968
GM 466052	Carmel	1971
GM 467458	Carmel	1971
GM 468244	Carmel	1972
GM 468901	Carmel	1972
GM 468902	Carmel	1972
30270621	Carmel	
30259401	Monterey	
30281572	Carmel Valley	
30287771	Carmel	
30300562	Carmel	
30300565	Carmel	
30318563	Carmel Valley	
30331224	Carmel Valley	
30340164	Carmel	
30357179	Carmel Valley	
30375503	Carmel	
30348688	Pacific Grove	
40024920	Carmel Valley	
40029722	Carmel	
40287322	Monterey	
4955159	Carmel	
4955035	Carmel	
4955019	Carmel	
4955001	Carmel	
4840997	Carmel	

Job Number	Location	Year
4840989	Carmel	
4840971	Carmel	
4840880	Carmel	
4840799	Carmel	
4840740	Carmel	
4840666	Carmel	
4840658	Carmel	
4840500	Carmel	

Salinas Historical Records Search

Emergency Shut Down Zone Binder
Looking for any valves in the Redacted area in Carmel
Looked through the following tabs:
CC-MY3-C1
CC-MY3-C2
Location of the valves in Carmel:
Redacted Reg Station at Redacted
Redacted and Redacted . Reg Station
and Reg station
Redacted

Request for Calculation/Planning Binder			
Date	**To**	**From**	**Subject**
8/4/1993	Redacted	Redacted - Gas Planning	RFC - Shutdown foam Street 10" Main
9/18/1992	Redacted	Redacted - Gas Planning	Oak Grove GPRP
5/4/1992	Gas Distribution	Redacted - Coast & Coast Valleys Gas Planning	RFC - Pipeline Replacement Project in Carmel
12/17/1991	Service Planning	Redacted - Coast & Coast Valleys Gas Planning	RFC - Abandon Main on Redacted Redacted
10/17/1991	Service Planning	Redacted - Coast & Coast Valleys Gas Planning	RFC - Oak Grove Pipeline Replacement Project

Date	To	From	Subject
12/12/1990	Planning	Redacted	Redacted Project
2/13/1998	Redacted		Redacted
8/28/1997	Redacted	Redacted	Main Insert at Redacted and Redacted
4/14/1992	Redacted	Redacted	Redacted ; New Laundry
10/23/1996	Redacted	Redacted	Redacted

Main Abandonment Records

Job	Year	Location
PM 30420781	2005	Redacted
PM 30244121	2002	
PM 40436057		
PM 30447602	2007	
PM 30238898	2002	
PM 30425186	2005	
PM 30349192	2004	
PM 30365763	2005	
PM 30349192	2004	
PM 30349192	2004	
PM 30365765	2005	
PM 30425184	2005	
PM 30271097	2004	
PM 30236402	2003	
PM 30357223	2006	
PM 30357226	2006	
PM 30234447		
PM 30188308	2001	
PM 30271097	2004	
PM 30357178		
PM 30188301	2001	
PM 30236402	2003	

Job	Year	Location
5G94046	1999	Redacted
PM 30071778	2001	
PM 30279538	2002	
PM 30315814	2003	
PM 30278533	2002	
PM 307785		
PM 30502821	2006	
PM 30269501	2002	
PM 30426920	2005	
PM 30357223	2006	
PM 30077175	2002	
PM 30479490	2006	
PM 30077175	2002	
PM 30277499	2002	
GM 4152873		
Not Found		
Not Found		
PM 30443084	2006	
PM 30287771	2006	
PM 30522243	2003	
PM 30299964	2003	

Job	Year	Location
PM 30467823	2006	Redacted
PM 30467823	2006	
PSRS8911	2000	
PM 40029722	2000	

Salinas Mapping Storage Files
G00004-G31820
G41824-G33149
G03170-G15721
G05743-G18030
PM 30072372-30077074
PM 30077077-30119210
PM 30121552-30177698
4226239-4361838
4361846-4535175
4535183-4552220
4552246-4552626

Leak A-Form Binders (year)
1996
1998
2001
2002

Appendix E

List of Interviewees

List of Interviewees

Redacted, PG&E Supervisor GC Central Coast

Redacted Construction Inspector

Redacted, Underground Construction Superintendent of Construction

Redacted, PG&E Journeyman/Welder

Redacted, PG&E Apprentice Welder

Redacted, PG&E Gas Mapping Supervisor for San Jose, Central Coast, and Cupertino

Redacted, PG&E Foremen/Plastic Welder

Redacted, PG&E Apprentice Welder

Redacted, PG&E Journeyman Welder

Redacted, PG&E Gas Supervisor Monterey

Redacted, PG&E Manager, Estimating

Redacted, PG&E Retired

Redacted, PG&E Retired

Redacted, PG&E Retired

Redacted PG&E Retired

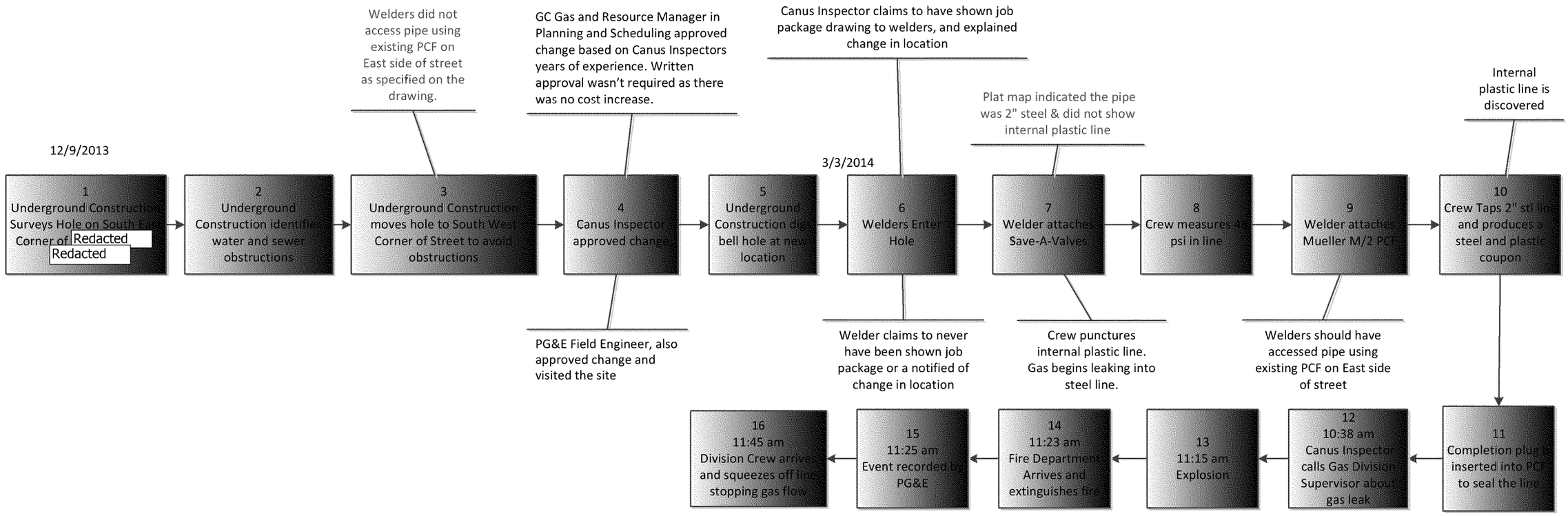
Redacted, PG&E Retired

Appendix F

Carmel Gas Leak and Explosion Timeline

Carmel Gas Leak and Explosion Root Cause Diagram

Carmel Gas Leak and Explosion Timeline



Carmel Gas Leak and Explosion Root Cause Diagram