NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

May 8, 2018

MATERIALS LABORATORY FACTUAL REPORT — Report No. 18-003

A. ACCIDENT INFORMATION

Place	:	Millersville, Pennsylvania
Date	:	July 2, 2017
Vehicle	:	Natural gas mechanical tapping tee assembly
NTSB No.	:	DCA17FP006
Investigator	:	Roger Evans (RPH)

B. COMPONENTS EXAMINED

Mechanical tapping tee assembly involved in the accident (206 Springdale Avenue); and two mechanical tapping tee assemblies that were not involved in the accident (from adjoining dwellings 201 and 202 Springdale Avenue).

C. DETAILS OF THE EXAMINATION

1.0 As-received

Figures 1 and 2 show photographs of the Permalock® mechanical tapping tee assemblies and pipe segments that were submitted to the Safety Board Materials Laboratory.[1] Each polyethylene tapping tee assembly joined a 2-inch IPS “Aldyl” polyethylene main to a 0.5-inch CTS nominal diameter polyethylene service pipe.[2] The 1-inch IPS outlet portion of each tee assembly was connected by a fusion weld to an excess flow valve and a Perfection Permasert® half-coupling was fused to the other end by Perfection at the factory. The other end of the Perfection Permasert half-coupling was connected to the service pipe. Gas service to the dwelling was supplied by UGI Utilities, Inc (UGI).

Table 1 shows the installation date of the tapping tee assembly involved in the accident (dwelling 206) and those of the tapping tee assemblies that were located on each side of the dwelling involved in the accident (dwellings 201 and 202), based on information provided by representatives of UGI. The tapping tee assemblies in the

[1] Permalock is a tradename for a mechanical tapping tee assembly that was manufactured by Perfection Corporation, later known as Elster-Perfection, and now currently owned by Honeywell.

[2] (a) IPS is a designation for Iron Pipe Standard. (b) Aldyl is a trademark name that refers to a finished polyethylene pipeline product manufactured by the DuPont chemical company using Dupont’s proprietary Alathon® polymer resin. The Aldyl product line was acquired from Dupont by the Uponor company in 1991. (c) CTS is a designation for Copper Tube Size.

adjoining dwellings were of the same model and vintage as the one involved in the accident. All were made from medium density polyethylene and have a flat cap.

2.0 General Description of the Permalock® Mechanical Tapping Tee Assembly

The Permalock® mechanical tapping tee assembly, also referred to as a bolt-on saddle service tee assembly, is made from polyethylene and incorporates an internal circular steel cutter assembly. The cutter assembly is comprised of two pieces, a cutter tool and a locking sleeve. The shaft portion of the cutter tool is inserted inside the hollow portion of the locking sleeve. Figures 3 and 4a show the cross section (cut-away view) of a Permalock® mechanical tapping tee assembly. The Permalock® written installation instructions for installing a tee assembly is show in figure 4b. The mechanical tapping tee assembly consists of an upper half (referred to as the tower or chimney portion) and a lower half (referred as the base portion) that fit together around the main. Four Nylon bolts, when tightened, cause the halves to fasten around the outer surface of a main. A bolt torque is not specified. The bolts are inserted through non-threaded holes at the four corners of the tower portion and screwed into threaded bolt holes at the corners of the base. An elastomer O-ring (referred to as a saddle O-ring) located at the base of the tower portion is compressed between the outer surface of the main and the base of the tower, forming a seal at the joint between the exterior of the main and the tower. When shipped from the manufacturer (Perfection), the cutter assembly is positioned at the upper portion of the tower.

2.1 Perfection Written Installation Instructions

The Permalock® tapping tee assembly is designed to be installed on a live main, a main that is in service at operating pressure. Each tee assembly shipment is supplied with a depth tube. The depth tube is made from a thin-walled piece of plastic material and is of a specified length, and ensures the cutter assembly (cutter tool and locking sleeve) have been installed to the specified depth. The depth tube is needed for the assembly installation because the installer cannot visually verify the point at which the cutter assembly contacts, penetrates, and engages the main. The depth tube provides a visual indication to an installer of the vertical travel distance of the cutter assembly.

At installation, the tower and base portions are fastened around the outer surface of the main using four Nylon bolts. Four Nylon bolts, when tightened, cause the halves to fasten around the outer surface of a main. The bolts are to be tightened until the corners of the tee assembly touch using a cross over tightening pattern. As indicated earlier, bolt torque is not specified. After installation of the bolts, the tee assembly is pressure tested to assess the compression of the saddle O-ring. The depth tube is inserted into the hollow portion of the tower, on top of the cutter assembly. A 5/16-inch hex wrench is attached to the top of the cutter tool portion. The wrench is turned clockwise causing the cutter tool and sleeve portions to be driven down. The circular cutter tool pierces a hole in the main. The pierced slug from the main is retained inside the hollow portion of the cutter tool. As the cutter tool progresses further down the pierced hole, the locking sleeve portion is designed to form threads into the pierced hole. The written instructions indicate to thread the cutter assembly until it becomes snug, and the top of the depth tube should be flush to 1/8 inch (0.13 inch) above the top of the tower. Although not specifically mentioned in the written instructions, at this point the outer lip (flange portion) of the locking sleeve should have made contact with the manufactured step (referred to as a stop) near the bottom end of the hollow tower (see figures 3 and 4a). Now, the locking sleeve secures the tower portion to the main. The next step is to open a gas path between the main and service pipe. To do this, the wrench is turned counterclockwise, an action that causes the cutter tool to separate (disengage) from the locking sleeve. The cutter tool is threaded upward until the top portion of the cutter tool is flush with the top of the tower. The cutter tool remains inside the tower portion for the duration of service. The depth tube is removed from the tower and discarded. A cap is manually screwed onto the top of the tower portion, hand tightened, until the cap contacts a molded-in-place stop (located on the outer surface of the tower).

2.2 Perfection Video Installation Instructions

Ester-Perfection produced a video titled “Perfection Permalock Tee Installation Instructions”, copyright dated 1996, that demonstrates the installation of a Permalock tee assembly. The video demonstration contains additional information that is not included in the written installation instructions. For example, the video demonstration states that the use of smaller length wrenches can allow the technician (installer) to feel the various phases of the installation. Longer wrenches tend to reduce the technician’s ability to feel the various phases of the installation. The length of the wrench in the video was not specified. When using of smaller length wrench, an installer should sense severe resistance on the handle of the wrench when the outer lip (flange portion) of the locking sleeve makes contact with the manufactured step (referred to as a stop) near the bottom end of the hollow tower. At this point the locking sleeve is attached to the main. To open a gas path between the main and service pipe an installer will turn the wrench handle counterclockwise, an action that causes the cutter tool to separate (disengage) from the locking sleeve. As another example, the video demonstration states that the installer should feel a sudden release (disengagement) on the handle of the wrench as the cutter assembly separates from the locking sleeve, additional information that is not included in the written instructions. The disengagement is audible. The video production was released about one year after the introduction of the locking sleeve feature and is not included with each tee assembly.

3.0 Safety Board Materials Laboratory Examination

Between August 8 and 10, 2017, the following individuals participated in the examination of the pipe segments at the Safety Board’s Materials Laboratory in Washington, D.C.:

Frank Zakar	Group Chairman	NTSB
Edward Komarnicki	Member	NTSB
Max Kieba	Member	PHMSA
Zaid Obeidi	Member	PHMSA

Joshua Arnold	Member	PHMSA
Robert Biggard	Member	Pennsylvania Public Utility Commission
Chester Wentz	Member	UGI Utilities
Mark Connors	Member	UGI Utilities
David Robison	Member	Honeywell – Global Gas Components

Follow-up work continued and was completed after departure of the group members.

3.1 Tee Assembly Involved in the Accident (206 Springdale Lane)

3.1.1 Visual Examination

Figures 5 through 8 show photographs of the tee assembly involved in the accident (also referred in this report as tee assembly from dwelling 206). Visual examination of the tee assembly involved in the accident revealed two of the four Nylon bolts fractured at the first full thread adjacent to the non-threaded shank portion. The fracture in each bolt corresponded to an area between 0.13 and 0.16 inch above the mating halves of the tee assembly, on the non-outlet side. The outlet side was facing the house. A gap was noted between the mating halves of the tee assembly on the non-outlet side (side that contained the fractured bolts). The gap measured in the vertical direction approximately 0.5 inch. The mating halves of the tee assembly on the side that contained the two intact bolts (outlet side) showed no evidence of a gap.

3.1.2 X-Ray Computed Tomography

Prior to disassembly, the submitted tee assemblies were inspected by the X-ray computed tomography (CT) method. The work was contracted to Chesapeake Testing, Belcamp, Maryland. A Nikon 225kV Micro-Focus XCT System was used for the work, providing a resolution of 120 micrometers (um). Figure 9 shows a cross section of the reconstructed CT image of the tee assembly from dwelling 206 involved in the accident and the tee assembly from dwelling 201 not involved in the accident. Inspection of the tee assembly from dwelling 206 revealed the locking sleeve remained attached to the cutter tool. The locking sleeve was not attached to the pipe wall. In comparison, inspection of the tee assembly from dwelling 201 revealed the cutter tool was in the upper portion of the tower and the locking sleeve was engaged with (attached to) the pipe wall, the specified locations of the cutter tool and locking sleeve after the installation is completed. The reconstructed X-ray CT images of the tee assembly from dwelling 202 was similar to that from dwelling 201. In all three submitted tee assemblies, the gas path between the main and outlet was open (allowed gas to flow into the service pipe). With exception of the two fractured bolts from the accident tee assembly, all the other submitted bolts showed no evidence of a fracture or crack. In preparation for the X-ray CT inspection, a saw cut was made through the main in areas located approximately 0.5 inch from each end of the tee assembly, and a saw cut was made through the outlet in an area located approximately 1.5 inch from the outer wall of the tower. The removal of the main and service pipe cut segments facilitated inspection of the tee assemblies.

3.1.3 Nylon Bolts

3.1.3.1 Nylon Bolt Specification

The Perfection engineering drawing 53935 for the Nylon bolt, revision F, specified polyamide, that conforms to requirements in Perfection engineering specification E-336, titled “Polyamide (Nylon) Screw Injection Molding Resin”. Engineering specification E-336, revision C, specified a 43% glass fiber-filled type 66 polyamide. The same engineering drawing and engineering specification for the bolt indicated the resin was to be made from DuPont Zytel Nylon resin, typical elongation values for the Nylon resin was 2.3% (dry) and 3.7% (50% relative humidity). The crystalline melting temperature for this Nylon 6/6 materials was 493 ºF (256 ºC). The same engineering specification indicated regrind levels during injection molding are not to exceed 25%, and mold release is not to be used for manufacturing the polymer material into the molded parts. In 2005, the bolt material was changed to Nylon 11, and the fiber glass content remained unchanged.

3.1.3.2 Examination of Nylon Bolts

The Nylon bolts were arbitrarily assigned a number between “1” and “4”, orientation as shown in figure 5. The length of a Nylon bolt measured approximately 2.5 inches. The combined length of the shank and threaded portions measured approximately 2 inches. The diameter of the non-threaded shank portion measured approximately 0.5 inch. Figure 10 shows a side view of the upper half portions of the fractured bolts. The mating thread fragments remained in the base. The two fractured bolts were located on the non-outlet side, corresponded to numbers “1” and “2”. The mating fractured portion of the bolts remained attached to the base. The intact bolts were located on the outlet side, corresponded to numbers “3” and “4”. The head portion of each bolt contained hexagonal recessed slots. The hexagonal slots of the four bolts showed evidence of vertical contact lines consistent with hexagonal slots that were in contact with an Allen key/wrench, and no evidence of slot deformation.

The two fractured bolts “1” and “2” were removed by hand from the tee assembly, with ease and no resistance. Both fractured bolts went through ultrasonic cleaning bath using a solution of dishwashing soap and water. The shank and thread portions of the fractured bolts “1” and “2” showed no visible evidence of elongation deformation (reduction in diameter cross section) in the general area of the fracture. On both bolts, the fracture occurred at the first full root of the thread, in an area adjacent to the non-threaded shank portion, and on a slight spiral plane that followed the root of the thread. On both bolts, the fracture extended around one complete revolution of the root portion of the spiral thread. The fracture face in the center portion of the bolt on one side of the fracture face extended approximately the length of one thread above the fracture plane, and appeared similar to a round cone. Figure 11 shows a photograph of the fracture face from bolt “2”. The fracture face of bolt “2” showed no evidence of a fracture origin or general direction of fracture propagation. The fracture face of bolt “1” showed fracture features that were similar to those of bolt “2”.

Scanning electron microscope (SEM) examination of bolt “2” revealed the fracture face contained evidence of fracture features on the polymer matrix (Nylon) and fiber portions (see figure 12). The Nylon matrix portion of the bolt exhibited evidence of fibrils that exhibited minor elongation. Many of the glass-fiber fracture faces showed evidence of a fracture propagation direction, but the direction of fracture propagation varied from fiber to fiber. The fracture face on the Nylon matrix and individual fibers showed no evidence of a pattern that identified a general direction of fracture propagation in the bolt. The origin of the bolt fracture could not be determined, because fracture patterns varied randomly within the Nylon matrix and direction of fracture propagation varied from fiber to fiber.

Nylon bolts were disassembled from tee assemblies associated with dwellings 201, 202, and 206. Visual and bench binocular microscope examination of the disassemble bolts revealed the threaded portions, as well as other portions of the bolts, contained no evidence of a crack.

3.1.3.3 Torque Testing of Nylon Bolts

Manufacturer (Perfection) written installation instructions are to be supplied with each delivered tee assembly. The manufacturer written instructions indicated that the attachment bolts are to be hand tightened with a 5/16-inch hex wrench (hex key), until corners touch using a cross over tightening pattern. A locking torque is not specified for the bolts.

Prior to disassembly of all the submitted tee assemblies, the release and locking torque for the bolts were measured. For the purpose of this report, a release torque is defined as the greatest measured torque value required to loosen the bolt. The locking torque is defined as the greatest measured torque value that is necessary to re-tighten the bolt to its original installed position. The results of the measured torque values are shown in table 2. The measured release torque values for all the bolts ranged between 15.1 inch-pounds (in-lbs) and 35.5 in-lbs, whereas, the measured locking torque values for all the bolts ranged between 13.6 and 38.8 in-lbs. The measured release and locking torque values for the bolts from dwelling 206 were near the upper end of measured torque values, when compared to those from all the tee assemblies.

3.1.3.4 Materials Testing of Nylon Bolts

3.1.3.4.1 FTIR Spectrometer Testing of Nylon Bolt from Dwelling 206

A sample of fractured bolt “2” from dwelling 206 was analyzed by Fourier Transform Infrared Spectroscopy (FTIR) to verify consistency with Nylon 6/6. The FTIR analysis was performed at the NTSB Materials Laboratory. The bolt sample was examined using FTIR spectrometer testing with a diamond attenuated total reflectance (ATR) accessory in accordance to American Society for Testing Materials E1252-98: *Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis*. The spectrometer was used to collect and process infrared wavelength absorbance spectra of each sample. The combination of functional groups that made up the spectrum for the bolt material was consistent with a polyamide. A spectral library search was perform using the bolt material spectrum. The search found a very strong match to Nylon 6/6. (see Appendices “A1” and “A2”).

3.1.3.4.2 Crystalline Melting Temperature of Nylon Bolts

Samples of bolts from the dwelling 206 and those not involved in the accident were analyzed by differential scanning calorimetry (DSC) to determine the crystalline melting temperature. The DSC work was contracted to NSL Analytical Services, Cleveland, Ohio. The testing included bolts from Permalock® mechanical tapping tee assemblies of the same model as the tee assembly from the accident that were manufactured in the range between 1995 and 2005. UGI submitted to the NTSB Materials Laboratory a tee assembly that was excavated from a dwelling located at 2253 Firmstone Street, Wilson Boro, Pennsylvania, as a result of a gas leak that stemmed from the tee assembly. Two bolts from the 2253 Firmstone Street tee assembly had fractured. The tee assembly from dwelling 2253 was manufactured in 1999. Bolts were also tested from two new tee assemblies (not installed) that were manufactured in 1995 and 2005. Bolts from tee assemblies manufactured in 2005 and thereafter were manufactured from Nylon 11.

Table B1 in Appendix B shows results of the crystalline melting temperature. The crystalline melting temperature of bolt samples from dwelling 206, dwelling 2253, and 1995 vintage tee assembly, measured approximately 261 ºC, consistent with the specified material Nylon 6/6. The crystalline melting temperature of Nylon 11 is typically between 185 ºC and 187 ºC.[3] The crystalline melting temperature of the bolt sample from the 2005 vintage tee assembly measured approximately 190 ºC, consistent that of Nylon 11 bolt materials manufactured 2005 and thereafter.

3.1.3.4.3 Fiber Content in Nylon Bolts

Samples of bolts from dwelling 206 and those not involved in the accident were analyzed to determine the ash content, per ASTM D 5630, titled “Standard Test Method for Ash Content in Plastics”. This test is used to determine filler material in plastics. The weight of a known amount of sample is weighed before and after combustion. The ash residue remaining (incombustible material) is considered the filler material. The incombustible material can be made up of glass fiber reinforcement and mineral. The testing was contracted to NSL Analytical Services. Table B2 in Appendix B shows the results of the testing. The ash content of each tested bolt was determined to be in the range between 40% and 43% by weight. For the purpose of this examination, the ash content in each bolt provides a rough estimate of the glass fiber reinforcement. The results of the testing are consistent with bolts having the specified amount of glass fiber reinforcement (43% by weight).

[3] According to A. Ravve, Principles of Polymer Chemistry, Table 6.4 Approximate Melting Points of Polyamides, p306, 1995, Plenum Press, New York, the crystalline melting temperature of Nylon 11 is 185 ºC -187 ºC and for Nylon 12 is 180 ºC.

3.1.3.4.4 GPC Testing of Nylon Bolts

Samples of Nylon bolts from the tee assembly involved in the accident and those not involved in the accident were analyzed by the Gel Permeation Chromatography (GPC) to determine the molecular size distribution, and this work was contracted to Jordi Labs, Mansfield, Massachusetts. The testing data was collected for information purpose. To describe the molecular weight distribution of a polymer numerically, three different molecular weight averages are commonly used. These are the number average molecular weight (M_n), the weight average molecular weight (M_w), and the Z average molecular weight (M_z). M_n provides information about the lowest molecular weight portion of the sample. M_w is the average closest to the center of the curve and M_z represents the highest molecular weight portion of the sample. Table C1 in Appendix C shows the results of the calculated molecular weight averages (M_N, M_W, M_Z, M_WM_N ratio). Polydispersity index (PDI) is the calculated M_WM_N ratio value. The PDI values of all the samples was in the range between 2.42 and 3.50.

3.1.4 Cutter Tool and Locking Sleeve

Figure 13 shows a side view of the tee assembly from dwelling 206 and the exposed inner wall of the main in the area where the cutter tool made a hole in the wall of the main. The cap was removed from the tower of each tee assembly. The distance between the top portion of the cutter tool and the top portion of the tower was measured and the results are shown in table 3. The pierced hole in the main showed no evidence of a locking sleeve, and only showed the bare wall of the main. When looking into the cut outlet portion of the tee assembly, the bottom end of the locking sleeve was located in an area near the upper side of the outlet port (see figure 14). A 5/16-inch hex wrench was inserted into top of the cutter tool and turned counterclockwise. The cutter tool for the tee assembly from dwelling 206 was retreated with the locking sleeve attached to the cutter tool, see figures 15 and 17(d). Figure 17 shows a photograph of several cutter assemblies in various states of disassembly. The locking sleeve from dwelling 206 was located approximately midway down the length of the non-threaded shank portion of the cutter tool. The threaded portion of the locking sleeve was not attached to the wall of the main, and the bottom hollow portion of the cutter tool contained a round cut-out portion of the wall portion of the main, referred to as a coupon. An effort was made to pull apart by hand the locking sleeve from the cutter tool portion. This effort did not separate the two pieces from one another. A weight was secured with stainless steel assembly wires to the locking sleeve. As much as 65 pounds of weight was used in an effort to separate the two pieces with no result. A hammer was used to impact the top ratchet portion of the locking sleeve. Several continuous hammer blows were required to cause separation of the two pieces.

Figure 16 shows a photograph of the exposed shank portion of the cutter tool after the removal of the locking sleeve. Visual examination of the disassembled cutter tool revealed the outer surface of the shank in isolated areas were covered with brown granular-like particles, consistent with soil particles (photograph on the left side of figure 16). The soil particles in several isolated areas were compacted. The cutter tool showed no evidence of mechanical damage. Perfection Corporation engineering drawing for the cutter tool specified type 12L14 steel assembly that is to be galvanized and treated with a yellow dichromate conversion coating. The ratchet (top) portion of the cutter tool is to be coated with molybdenum disulfide lubricant. X-ray energy dispersive spectroscopy (EDS) analysis at the Safety Board Materials Laboratory of the shank portion of the cutter tool produced a spectrum that contained major elemental peaks of zinc and minor elemental peaks of oxygen, carbon, silicon, and chromium, consistent with a shank that was galvanized and treated with dichromate (see Appendix D1). EDS spectrum of the granular-like particles on the shank surface of the cutter tool produced major elemental peaks of iron, silicon, and oxygen, and minor elemental peaks of zinc, carbon, manganese, chromium, titanium, calcium, potassium, sulfur, aluminum, magnesium, and nickel, consistent with soil particles (see Appendix D2). EDS spectrum of particles at the step portions of the ratchet contained major elemental peaks of molybdenum and sulfur, and minor elemental peaks of zinc, oxygen, and carbon (see Appendix D3). The major elemental peaks of molybdenum and sulfur in Appendix D3 are consistent with a molybdenum disulfide lubricant.

The locking sleeve is specified to be made from the same steel assembly material and coating as those specified for the cutter tool. The inner surface of the locking sleeve in isolated areas also were covered with brown granular-like particles, consistent with soil particles. The outer thread portion of the locking sleeve contained a white deposit. EDS analysis of the white deposit produced major elemental peaks of zinc and oxygen, and a minor elemental peak of carbon and iron (see Appendix D4). The major elemental peaks in Appendix D4 is consistent with galvanized coating. The locking sleeve showed no evidence of mechanical damage.

The size of the cutter tool and locking sleeve are specified in Perfection Corporation engineering drawing number 53778, revision D. The specified and measured size of the outer diameter of the cutter tool and inner diameter of the locking sleeve are shown in table 4. The measured outer diameter of the cutter tool and inner diameter of the locking sleeve were within specified size.

The shank portion of the cutter tool contained a slot for an O-ring (see figure 3). According to the engineering drawing for the cutter tool, the O-ring is specified as BUNA-N (Nitrile) that is to be coated with a silicone oil. Examination of the cutter tool revealed the slot and O-ring were covered with brown granular-like deposits, similar to soil particles. FTIR analysis of the cutter tool O-ring at the Safety Board Materials Laboratory produced a spectrum consistent with nitrile (see Appendices A3 and A4). The size of the O-ring for the cutter tool is specified in Perfection Corporation engineering drawing number 53778, Revision D, titled ‘Cutter Assembly Ratchet for 2”, 3”, 4” & 6” PMTT’. The measured size of the O-ring for the cutter tool is shown in table 5. The inside diameter and thickness of the O-ring for the cutter tool was within the size specified by the manufacturer, see table 5.

The cutter tool and locking sleeve showed no evidence of mechanical damage.

3.1.5 Identification Marks Found on the Tee Assembly

The cap portion of the mechanical tapping tee assembly from dwelling 206, on the top flat face portion, was marked with raised characters “Permalock®, P.C. HH, CAV.3, P.E.”, and the side of the tower portion of the tee assembly was marked in raised characters “PERFECTION”. The upper half portion of the tee assembly was marked with raised characters “2” I.P.S. HH, P.E., 2306/2406”, a dial indicator that pointed to a number that represented the month of manufacture “1”, and contained the last two digits of the year of manufacture “98”. This information indicated the upper half portion of the tee assembly was manufactured from medium density 2406 polyethylene (PE), in January 1998, by Elster-Perfection Corporation, currently a division of Honeywell Incorporated, under the brand name Permalock® tee. The base was marked “P.E.”, “CAV. 2”, with the month of manufacture “1” and the year of manufacture “98”. Although the base did not indicate the grade of polyethylene, the Elster Perfection engineering drawing for the base specified PE2306/2406, a material classification for medium density polyethylene (MDPE). The base was made by the same material, on the same date, and company, as the upper portion of the tee assembly.

3.1.6 Specification for the Tee Assembly Housing (Tower and Base Portions)

The Perfection engineering drawing for the upper half (tower) portion of the tee assembly specified Virgin Plexco medium density PE2406 per specification E-351. The Perfection engineering specification E-351, revision B, “unfilled medium density polyethylene screw injection molding resin - Plexco 2406 yellow pipe and fitting material” indicated this material is MDPE material that is typically used for tapping towers, and regrind material is not permitted. The Perfection engineering specification E-333, revision C, “Regrind unfilled Polyethylene Screw Injection Molding and Extrusion Resins” indicated this material is typically used for the base portion, shall meet the requirements of Plexco 2406 yellow pipe and fitting material, and regrind levels shall not exceed 25%.

3.1.7 Disassembly of the Tee Assembly from Dwelling 206

The tee assembly was disassembled from the pipe (see figure 18). The tee assembly showed no evidence of cracking. Two long curled fragments were found on the surface of the main. The longer curled fragment extended between the pierced hole made by the cutter tool and the outer face of the tee assembly. The shorter curled fragment was located near the base. The two curled fragments exhibited an orange-like color and texture that were similar to those of the main. The width of the curled fragments measured between 0.16 inch and 0.24 inch. The greatest width was nearly as large as the specified wall thickness of the main (0.216 inch - 0.242 inch). The length of the longer curled fragment measured approximately 6 inches, whereas, the length of the shorter curled fragment measured approximately 2.8 inches. The thickness of the curled fragments measured between 0.01 inch and 0.02 inch. The surface of both fragments exhibited a continuous longitudinal texture, as if the fragment was shaved from the wall of the main. FTIR testing of a sample from the main in the tee assembly at the Safety Board Materials Laboratory produced a spectrum that was consistent with polyethylene (see Appendices A5 through A7). The FTIR spectrum of a sample from the curled fragment also was consistent with polyethylene (see Appendix A7), similar to the FTIR spectrum from the main.

The saddle O-ring was found on top of the main (see figure 18). The saddle O-ring is specified as BUNA-N (Nitrile). According to manufacturer written installation instructions supplied with each tee assembly shipment, the main surface and saddle O-ring are to be lubricated with a silicone grease or leak test soap solution prior to installing the tower on to the main. The size of the saddle O-ring is specified in Perfection Corporation engineering drawing number 53942, Revision B, titled 'Contoured O-ring 2" IPS PMTT'. The measured size of the saddle O-ring is shown in table 6. The inside diameter of the saddle O-ring was within the size specified by the manufacturer (see table 6). Although only a thickness is specified for the saddle O-ring, the height and width of the O-ring were measured. The height of the saddle O-ring was slightly less than the specified thickness and the width of the saddle O-ring was slightly greater than the specified thickness. FTIR analysis of the saddle O-ring produced a spectrum consistent with nitrile, and two peaks associated with a molecular functional group often found in a class of surfactants (such as a detergent), see Appendices A8 and A9.

Detailed bench binocular microscope examination of the main from dwelling 206 revealed the pierced hole contained circumferential cut marks with no evidence of threads, see figures 19 and 20. The diameter of the pierced hole measured 0.71 inch (see table 7).

3.1.8 Pressure Testing of Tee Assembly Prior to Disassembly

At the Safety Board Materials Laboratory, the tee assembly from dwelling 206 was pressure tested with a continuous and uninterrupted supply of compressed shop air, prior to disassembly of the tee assembly. The pressure test was conducted to determine the amount of air that was leaking (flowing) out of the gap between the mating halves of the tee assembly. The ends of the main and service pipe were plugged with mechanical pipe plugs. The mechanical plug at one end of the main contained a pass-through port that allowed pressurized air to enter the main. The pressure and rate of air leak was measured with the VPFlowScope® in-line electronic flow meter, manufactured by Van Putten Instruments, Netherlands. The main was pressurized up to a pressure of 30 pounds per square inch gauge (psig). The pressure test terminated when the air compressor reached its operating limit. The measured pressure and flow rates are shown in table 8. The volumetric leak rate for air was converted to volumetric leak rate for natural gas, and the converted values are shown in table 8. At the time of the accident, the operating pressure of the main was approximately 56 psig.[4]

[4] According to representatives from UGI, a pressure monitoring point about 0.65 miles from the accident site showed a pressure of 56 psig. However, the exact pressure at the specific accident location did not have pressure monitoring.

3.2 Tapping Tee Assembly from 201 Springdale Lane

Figures 21 through 23 show close-up photographs of the tapping tee assembly from dwelling 201. Visual examination of the tee assembly from dwelling 201 revealed the four Nylon bolts were intact. This tapping tee assembly was manufactured by the same company and grade materials as those from 206 Springdale Lane. The tower portion of the tapping tee assembly was manufactured in January 1998, and the base was manufactured in June 1997, based on markings found on the tee assembly.

Figure 24 shows a side view of the tee assembly from dwelling 201 and the exposed inner wall of the main in the area where the cutter tool pierced a hole in the wall of the main. The cap was removed from the tower. The distance between the top portion of the cutter tool and the top portion of the tower was measured and the results are shown in table 3. When looking into the end of the main, the bottom end of the locking sleeve extended slightly beyond the inner wall of the main. When looking into the outlet port, the top end of the locking sleeve (ratchet portion) was located at the bottom side of the outlet port (see figure 25), consistent with a locking sleeve that remained attached to the main. The bottom end of the cutter was located approximately midway down the outlet port (see figure 25), consistent with the position of a cutter tool after retracted to the top of the tower. An Allen key was inserted on top of the cutter tool and turned counterclockwise. The cutter tool was removed from the tower. A #8 spiral flute screw extractor was dropped into the top of the tower, and the top portion of the extractor was tapped lightly with a hammer. The extractor was turned counterclockwise removing the locking sleeve and extractor from the tower. The locking sleeve was removed with the spiral screw extractor.

Visual examination of the disassembled cutter tool and locking sleeve revealed the surfaces were clean with no evidence of brown granular-like particles, with the exception that the threaded portion of the locking sleeve contained a brown stain in the area that corresponded to the intersection between the wall of the main and the bottom of the tower. The cutter tool and locking sleeve showed no evidence of mechanical damage. The measured outer diameter of the cutter tool and inner diameter of the locking sleeve were within specified size, see table 4. The size of the O-ring for the cutter tool was measured and found to be within the size specified by the manufacturer (see table 5).

Figure 26 shows a photograph of the disassembled tee assembly. The saddle O-ring was attached to the groove at the bottom of the tower. The measured size of the saddle O-ring is shown in table 6. The inside diameter of the saddle O-ring was within the size specified by the manufacturer (see table 6). A thickness was specified for the saddle O-ring. The height and width of the saddle O-ring were measured. The height of the saddle O-ring was slightly less than the specified thickness and the width of the saddle O-ring was slightly greater than the specified thickness.

Detailed bench binocular microscope examination of the main revealed the pierced hole contained threads that extended all around the pierced hole and through the wall, see figures 27 and 28. The diameter of the pierced hole with the threads measured 0.78 inch (see table 7).

3.3 Tapping Tee Assembly from 202 Springdale Lane

Figure 29 shows a photograph of the tee assembly from dwelling 202. Visual examination of the tee assembly revealed the four Nylon bolts were intact. The tower and base portions of the tapping were manufactured by the same company, grade material, and month of manufacture, as that from the 206 Springdale Lane, based on markings found on the tee assembly. When looking into the outlet port, the locking sleeve and cutter tool were in a position that was similar to that from the tee assembly associated with dwelling 201, consistent with a locking sleeve that was threaded to the main. The cutter tool and locking sleeve were extracted from the tee assembly. The surfaces of the extracted cutter tool and locking sleeve were clean with no evidence of granular-like particles, with the exception that the threaded portion of the locking sleeve contained brown stain material in the area that corresponded to the intersection between the wall of the main and the bottom of the tower. The size of the cutter tool and locking sleeve (see table 4), and the size of the cutter tool O-ring (see table 5), were within the size specified by the manufacturer. The measured size of the saddle O-ring is shown in table 6. The inside diameter of the saddle O-ring was within the size specified by the manufacturer (see table 6). A thickness was specified for the saddle O-ring. The height and width of the O-ring were measured. The height of the saddle O-ring was slightly less than the specified thickness the width of the saddle O-ring was slightly greater than the specified thickness.

Detailed bench binocular microscope examination of the main revealed the pierced hole contained threads that extended all around the pierced hole and through the wall, similar to that from dwelling 201. The diameter of the pierced hole with the threads in the main measured 0.78 inch (see table 7), consistent with the size of the pierced hole with threads for the tee assembly from dwelling 201.

3.4 Main

The mains were marked “2” IPS, SDR11, UPONOR ALDYL®, PE2406, CDA T04-040595, FOR GAS USE ONLY, ASTM 2513, ROTASONIC INSPECTED”. This information indicates the main is a 2-inch IPS nominal pipe, was manufactured from medium density “Aldyl” polyethylene, by Uponor Pipe, on April 5, 1995. The dimensions of the main were measured in accordance with ASTM D2513-87 “Standard Specification for Thermoplastic Gas Pressure Piping Systems” and ASTM D2122 “Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings.” Average outer diameter for the mains were measured with a circumferential wrap tape (which includes a factor of pi). The variation in the outer diameter was also determined using a caliper to determine ovality[5]. Representatives from UGI reported that the 2-inch main was manufactured and packaged as coil pipe. Thickness measurements on the 2-inch main

[5] Measured in a manner such that the maximum, A, and the minimum, B, diameter at various cross sections are obtained. Calculate the ovality, O, in percent as follows: O=[(A-B)/Average]x100

were made with a ball-flat micrometer and the eccentricity[6] was calculated. The specified size and measured values for the pipes are shown in tables 9 through 16. The cut end of each main that was associated with a tee assembly was marked with abbreviations for compass orientations of the main (see section 3.8 of this report). The compass abbreviations are used in tables 11 through 16. The measured size of the main was within the specified size. The calculated ovality and wall eccentricity for the main was within the range specified by ASTM D2513 and ASTM D2122. After the tower portion was removed from the main, the tilt angle between the center of a pierced hole was measured relative to the top dead center of the pipe. The location of the top dead center of a main and the approximate location of the center of a pierced hole was marked on the saw cut wall portion of a main. A compass was placed on the saw cut portion of the main and the tilt angle was read. The center of the pierced hole for each main was located approximately in a tilt angle that was similar to the tilt angle reported for each respective tee assembly shown in table 17.

As indicated earlier, FTIR analysis at the Safety Board Materials Laboratory of a sample removed from the main produced a spectrum consistent with polyethylene (see Appendices A5 and A6).

3.5 Service Pipe

The outer face of the service pipe from 201 and 202 dwellings were marked "½" CTS 0.090 IN. WALL, Plexco® Yellowpipe, PE2406, CEC, FOR GAS USE ONLY, ASTM 2513". This information indicates the pipe was manufactured as a 0.5-inch CTS pipe, with a 0.090-inch thick wall, from medium density polyethylene, by Performance Pipe (a division of Chevron Phillips Chemical Company LP, Plano, Texas).

The outer face of the service pipe from the 206 dwelling in area near the riser was marked "ASTM 2513, ½" CTS, SDR 7.0, UPONOR, UAC 2000, ROTASONIC INSPECTED", whereas, the outer face of the same pipe near the tapping tee assembly end was marked "PE2406-CEC, T01-041398, FOR GAS USE ONLY, IATMO ASTM D 2513". These marks indicate the service pipe for the 206 dwelling was manufactured as a 0.5-inch CTS nominal pipe, manufactured from medium density polyethylene, by Uponor Pipe (currently US Poly).

Tables 9 and 10 show the specified and measured values of the service pipes. The measured diameter of service pipes was within the size specified by ASTM D2513-87, and the thickness of the wall for all the service pipes was greater than specified by ASTM D2513-87.

[6] Wall Thickness Eccentricity Range - measure in a manner such that the maximum, A, and the minimum, B, wall thicknesses at single points of each cross section measured are obtained. Calculate the wall thickness eccentricity range, E, in percent for each cross section as follows: $E=[(A-B)/A]x100$

FTIR analysis at the Safety Board Materials Laboratory of a sample removed from the service pipe produced a spectrum consistent with polyethylene, (see Appendix A7).

3.6 Excess Flow Valve

An excess flow valve (EFV) was fused to the outlet of the tee and a Perfection Permasert® half coupling was fused to the other end by Perfection at the factory. A label was adhesively bonded to the EFV and was marked “UMAC Valve, Series 400SC, MAX W.P. 60 psi”. This information indicates that each EFV was manufactured by GasBreaker™, Tulsa, Oklahoma (a Division of Hubbell Gas Connectors and Accessories [HGCA]), and is rated for 60 psig. Visual examination of the external portion of the EFV showed no evidence of mechanical damage. The Perfection Permasert half coupling (1/2- inch CTS) fused to the end of the EFV was marked “PE 2406 CE, 0.090 wall”.

3.7 Sleeve for the Service Pipe

The ½-inch CTS service pipe for dwelling 206 was inserted into a 1-inch CTS polyethylene sleeve (jacket). The sleeve was marked “1” CTS, PE2406, FOR GAS USE ONLY and ASTM 2513”. The marks on the pipe indicated the pipe was manufactured from MDPE material as 1-inch CTS nominal pipe. A half foot segment was cut and submitted with the service pipe. The outside diameter of the sleeve measured approximately 1.1 inch and the thickness measured approximately 0.091 inch. The sleeve extended between the tee assembly and the riser portion adjacent to the house involved in the accident (dwelling 206). The exposed portions of the service pipes in the trench for dwellings 201 and 202 at the ends that contained the tee assembly showed no show evidence of a sleeve.

3.8 On-site

Figure 30 shows an overhead photograph of dwelling 206 after the accident. The main was located on a cul-de-sac and contained a slight curvature to accommodate the curvature of the cul-de-sac. The diameter of the street (asphalt) portion of the cul-de-sac that was located in front of dwelling 206 involved in the accident measured approximately 90 feet. The main was located approximately 48 feet from the center of the cul-de-sac. The outlet portion of each tapping tee assembly was facing away from the center of the cul-de-sac.

A trench approximately four feet by four feet was dug around each submitted tapping tee assembly to a depth that exposed each tapping tee assembly. The top of each service pipe was located approximately 3.3 feet below the ground. The main in the areas of the tee assemblies from dwellings 201, 202, and 206 showed no evidence of downward sagging. An inclinometer (slope dial gauge) was placed on the top surface of the main along the length of the main, and the inclinometer measured an angle of approximately zero degrees in the areas surrounding the tee assemblies. The main reportedly was operating at a pressure of approximately 56 psig, according to representatives from UGI. Each exposed tapping tee assembly was pressure tested with compressed air and the outer surface was coated with a soap solution. A tapping tee assembly would test positive for a leak if the outer surface produced soap bubbles. A leak test performed by UGI showed soap bubbles emanated from the tapping tee assembly that was installed in front of the 206 dwelling. No air leak was detected on the tapping tee assemblies that were installed in front of the 201 and 202 dwelling.

The main in the area of the tee assembly for dwelling 201 was located in a Southwest (SW) to Northeast (NE) orientation. The main in the area of the tee assembly for dwelling 202 was located in an East (E) to West (W) orientation. The main in the area of the tee assembly for dwelling 206 was located in a Southeast (SE) to Northwest (NW) orientation. The orientation directions were marked on the cut segments of the main, see figures 1 and 2, and correspond to those shown in figure 30.

An inclinometer was placed on the flat surface of the cap portion of each tee assembly, to measure the tilt angle of the cap relative to the horizon, see table 17. The outlet port of each tapping tee assembly was facing the house. For the purpose of this report, zero degrees indicates the axial length of the outlet port was level with the ground and parallel to the horizon. A positive angle value indicates the number of degrees that the outlet portion extended above the horizon, whereas, a negative angle value indicates the number of degrees that the outlet portion of the tee assembly extended below the horizon. The tilt angle for the cap on the tapping tee assembly for the 201, 202 and 206 dwelling measured zero degrees, 6 degrees, and 17 degrees, respectively.

The length of the service pipe for dwelling 206 in the area between the tee assembly and riser was excavated and exposed. A sleeve was installed over the entire length of the service pipe. The sleeve was yellow. The open end of the sleeve was located approximately one foot from the Perfection Permasert half coupling. The outside diameter and wall thickness of the sleeve measured approximately 1.1 inch and 0.091 inch, respectively. The sleeve was made from polyethylene based on the markings found on the pipe. With regards to the service pipe for dwellings 201 and 202, no evidence of a sleeve was found at the exposed end of the service pipe in the area of the excavated tee assembly. The length of the service pipe for dwellings 201 and 202 between the open trench and the riser was not exposed.

3.9 Curvature of the Main

Once at the Safety Board Materials Laboratory, Washington, D.C., measurements were made on each main segment to determine their curvature. Each main was cut approximately 2 feet on each side of a tee assembly. Each tee assembly was placed on a flat table such that the concave side of the main were facing the table. The distance between the outer wall of the pipe and the table was measured with a ruler (see figure 2). The distance between the outer wall of the main facing the table and the top surface of the table for the tee assemblies from dwellings 201, 202, and 206 measured 0.9-inch, 1 inch, and 1.3 inches, respectively. The length between the cut ends for each tee assembly measured approximately 50 inches.

The tee assembly for dwelling 206 was disassembled, and the arc length between the center of the pierced hole for the locking sleeve and the top dead center of the main measured approximately 0.35 inch. The angle between the top dead center of the pipe and the pierced hole for the locking sleeve was calculated to be 17 degrees, based on a radius for the main of 1.2 inches, same as the measured tilt angle in table 17.

Frank Zakar
Senior Metallurgist

Table 1 Tee Assembly Installation		
Dwelling	Installation Date (month/day/year)	Approximate Years in Service
201	11/12/1997	20
202	10/17/1998	19
206	06/23/1998	19

Table 2 Measured Torque Value for Bolts (Inch-Pounds)								
Dwelling	Bolt							
	1		2		3		4	
	Release	Locking	Release	Locking	Release	Locking	Release	Locking
201	29.1	31.8	22.2	29.0	35.5	38.8	22.3	25.3
202	22.4	27.3	15.1	13.6	24.4	25.7	20.7	23.8
206	Fractured				34.7	31.2	34.9	29.6

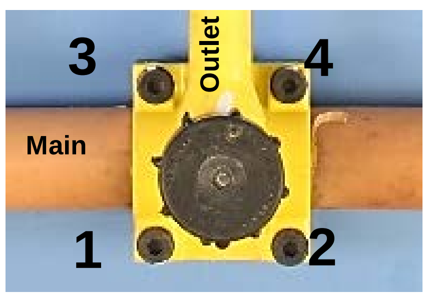


Table 3
Top Surface of the Cutter and Locking Sleeve Measured Relative to Top of Tower (Inches)

Dwelling	Cutter		Locking Sleeve
	Specified	Measured (top of cutter to top of tower)	Measured (top of locking sleeve to top of tower)
201	Flush to 1/8 inch above the top of the tower per manufacturer written instructions	0.06	3.19
202		0.03	3.21
206		0.04	Cutter remained attached to locking sleeve

Table 4
Cutter Assembly Dimensions (Inches)

Dwelling	Locking Sleeve Inside Diameter		Cutter Tool Outside Diameter	
	Specified	Measured	Specified	Measured
201	0.7935 - 0.7965	0.7945 - 0.7955	0.788 – 0.792	0.790
202		0.7945 – 0.7960		0.788
206		0.7940 – 0.7960		0.788

Table 5
Cutter Tool O-Ring Dimensions (Inches)

Dwelling	Thickness			Inside Diameter	
	Specified	Measured Width	Measured Height	Specified	Measured
201	0.067 - 0.073	0.072	0.071	0.605 - 0.684	0.630
202		0.071	0.070		0.640
206		0.072	0.071		0.630

Table 6
Saddle O-Ring Dimensions (Inches)

Dwelling	Thickness			Inside Diameter	
	Specified	Measured Width	Measured Height	Specified	Measured
201	0.205 - 0.215	0.21 - 0.24	0.18 - 0.19	1.323 - 1.343	1.34
202		0.21 - 0.22	0.18 - 0.19		1.32
206		0.21 - 0.22	0.18 - 0.19		1.33

Table 7 Size of Pierced Hole Found in the Main (Inches)			
Dwelling	**201 Springdale Lane**	**202 Springdale Lane**	**206 Springdale Lane**
Measured Diameter Of Pierced Hole	**0.78** **Pierced hole was threaded**	**0.78** **Pierced hole was threaded**	**0.71** **Pierced hole was not threaded**

Table 8 Pressure Leak Testing at 73 °F				
Applied Air Pressure	**Measured Volumetric Leak Rate in Air**		**Calculated Volumetric Leak Rate For Natural Gas**	
(PSIG)	**(CFM)**	**(CFH)**	**(CFM)**	**(CFH)**
10	6.4	384	8.3	498
14	8.9	534	11.5	690
20	9.1	546	11.7	702
25	10.9	654	14.1	846
30	11.7	702	15.1	906

Table 9
PE Tubing Outer Diameter (Inches)

Pipe	Specified	Method Of Measure	Measured		
			201 Springdale Lane	202 Springdale Lane	206 Springdale Lane
1/2-inch CTS Nominal Tubing Size	0.621 - 0.629	Caliper	0.625	0.626	0.626
2-inch IPS Nominal Pipe Size	2.369 - 2.381	Pi Tape	2.378	2.378	2.378

Table 10
PE Tubing Thickness (Inches)

Pipe	Specified	Method Of Measure	Measured		
			201 Springdale Lane	202 Springdale Lane	206 Springdale Lane
1/2-inch CTS Nominal Tubing Size	0.090-0.099	Caliper	0.094	0.095	0.093
2-inch IPS Nominal Pipe Size	0.216 - 0.242	Ball-Flat Micrometer	0.222-0.229	0.221-0.228	0.223-0.227

Table 11
Measured Outer Diameter for 2-Inch Pipe; SDR11; (Inches)
201 Springdale Lane

Location (clock position)	0 inch	12 inches	0 inch	12 inches
	from SW end of tee assembly		from NE end of tee assembly	
12:00	2.41	2.39	2.41	2.39
1:30	2.38	2.38	2.38	2.38
3:00	2.31	2.37	2.33	2.38
4:30	2.35	2.38	2.37	2.38
Average	2.36	2.38	2.37	2.38
Minimum	2.31	2.37	2.33	2.38
Maximum	2.41	2.39	2.41	2.39
Ovality[7] for 3-inch IPS or less not to exceed 5%, when supplied as coiled pipe	4.2 %	0.84 %	3.4 %	0.42 %

Table 12
Measured Wall Thickness for 2-Inch Pipe, SDR11, (Inches)
201 Springdale Lane

Location (clock position)	from SW end of tee assembly	from NE end of tee assembly
12:00	0.224	0.222
1:30	0.226	0.227
3:00	0.229	0.226
4:30	0.227	0.224
6:00	0.223	0.223
7:30	0.227	0.225
9:00	0.226	0.226
10:30	0.225	0.225
Minimum	0.223	0.222
Maximum	0.229	0.227
Wall eccentricity Max allowed is 12%	2.6 %	2.2 %

[7] Ovality applies only to coiled pipe. UGI Incorporated reported that the 2-inch diameter pipe was manufactured and packaged as coiled pipe. Ovality was calculated for information purposes.

Table 13 Measured Outer Diameter for 2-Inch Pipe; SDR11; (Inches) 202 Springdale Lane				
Location (clock position)	0 inch	12 inches	0 inch	12 inches
	from E end of tee assembly		from W end of tee assembly	
12:00	2.41	2.40	2.41	2.38
1:30	2.38	2.39	2.41	2.38
3:00	2.31	2.37	2.31	2.38
4:30	2.36	2.39	2.36	2.39
Average	2.37	2.39	2.37	2.38
Minimum	2.31	2.37	2.31	2.38
Maximum	2.41	2.40	2.41	2.39
Ovality for 3-inch IPS or less not to exceed 5%, when supplied as coiled pipe	4.2 %	1.3 %	4.2 %	0.4 %

Table 14 Measured Wall Thickness for 2-Inch Pipe, SDR11, (Inches) 202 Springdale Lane		
Location (clock position)	from E end of tee assembly	from W end of tee assembly
12:00	0.223	0.221
1:30	0.223	0.225
3:00	0.228	0.226
4:30	0.226	0.224
6:00	0.224	0.223
7:30	0.223	0.225
9:00	0.226	0.224
10:30	0.225	0.223
Minimum	0.223	0.221
Maximum	0.228	0.226
Wall eccentricity Max allowed is 12%	2.2 %	2.2 %

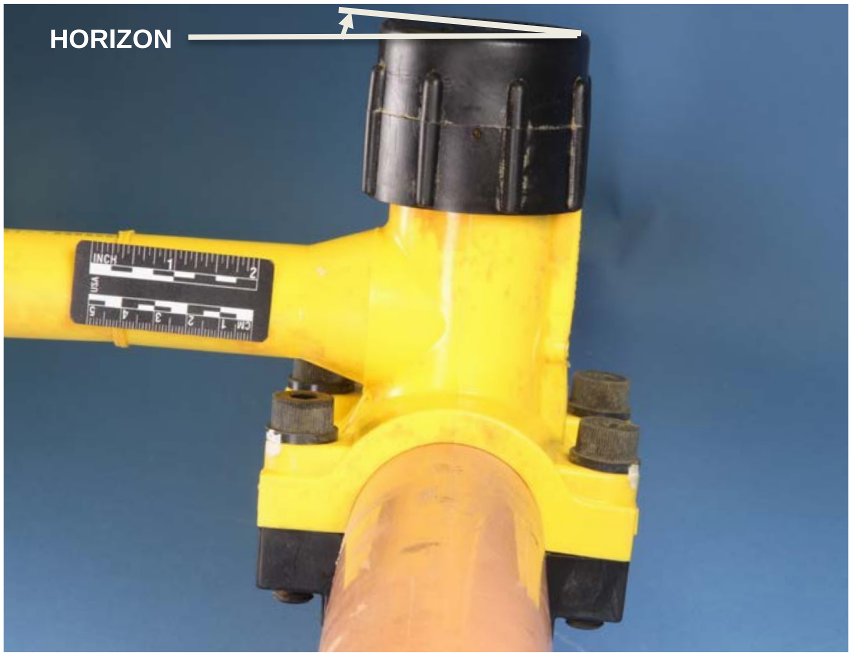
Table 15
Measured Outer Diameter for 2-Inch Pipe; SDR11; (Inches)
206 Springdale Lane

Location (clock position)	0 inch	12 inches	0 inch	12 inches
	from SE end of tee assembly		from NW end of tee assembly	
12:00	2.38	2.39	2.40	2.38
1:30	2.37	2.38	2.37	2.37
3:00	2.36	2.37	2.36	2.37
4:30	2.38	2.39	2.38	2.38
Average	2.37	2.38	2.38	2.38
Minimum	2.36	2.37	2.36	2.37
Maximum	2.38	2.39	2.40	2.38
Ovality for 3-inch IPS or less not to exceed 5%, when supplied as coiled pipe	0.84 %	0.84 %	1.68 %	0.42 %

Table 16
Measured Wall Thickness for 2-Inch Pipe, SDR11, (Inches)
206 Springdale Lane

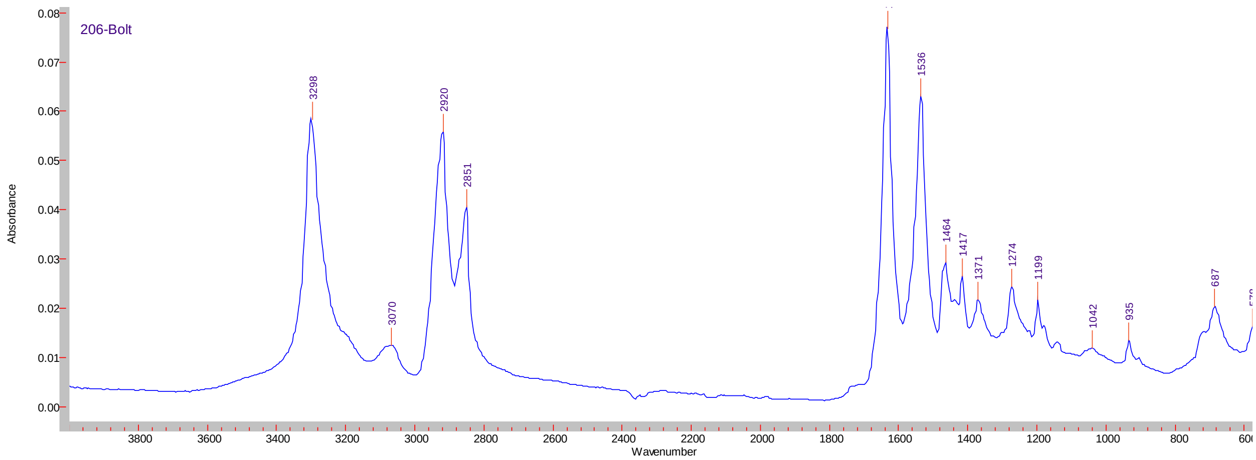
Location (clock position)	from SE end of tee assembly	from NW end of tee assembly
12:00	0.223	0.223
1:30	0.224	0.223
3:00	0.226	0.227
4:30	0.225	0.224
6:00	0.225	0.226
7:30	0.226	0.223
9:00	0.225	0.226
10:30	0.223	0.225
Minimum	0.223	0.223
Maximum	0.226	0.227
Wall eccentricity Max allowed is 12%	1.3 %	1.8 %

Table 17 Tilt Angle (Radial-Circumferential) in Degrees, Top Surface of the Cap Portion of the Tapping Tee assembly Relative to the Horizon, When Looking into the Main	
Dwelling	**Degrees**
201	**0**
202	**6**
206	**17**

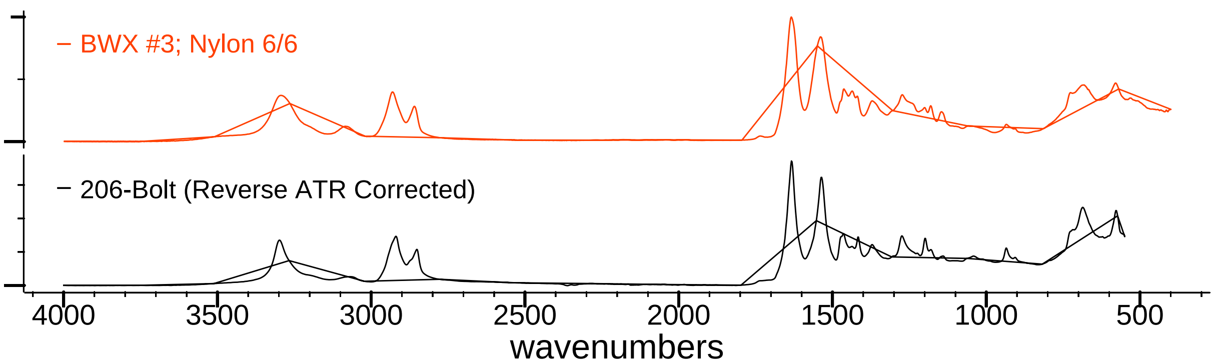


APPENDIX A

FTIR Spectra



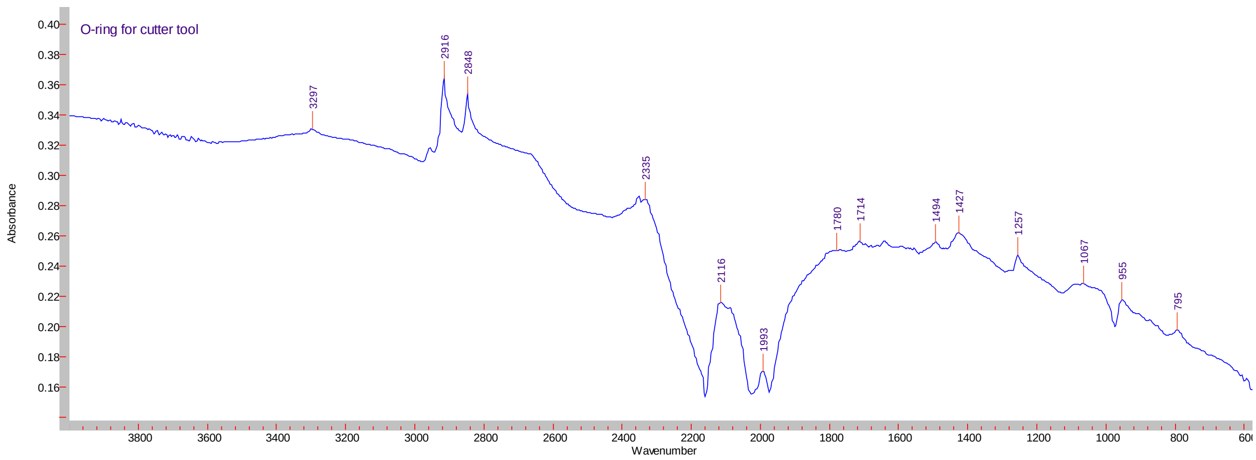
Appendix A1. FTIR spectrum of bolt "2" from dwelling 206 showing the identity of specific wavenumber peaks.



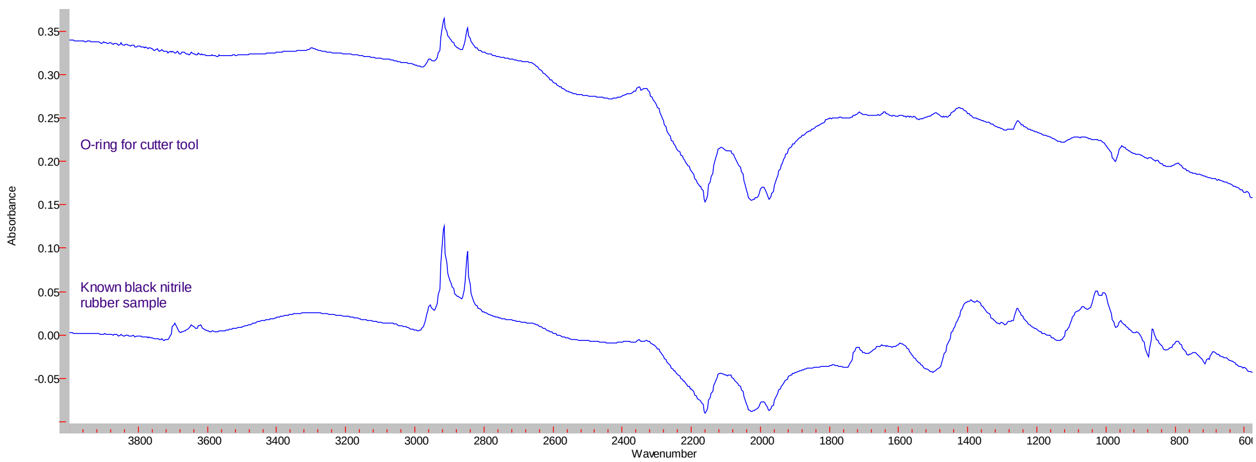
Appendix A2. FTIR spectrum of Nylon 6/6 library reference standard (top spectrum) is consistent with that of bolt "2" from dwelling 206 (bottom spectrum).

Notes regarding Appendices A1 and A2:

The BOLT sample from dwelling 206 spectrum contained the following combination of spectral peaks corresponding to particular functional groups found within the molecular structure of the bolt material. The presence of two peaks at ~3300 cm^{-1} and at ~3070 cm^{-1} is indicative of nitrogen-hydrogen (N-H) stretching bonds. The presence of a strong doublet peak between ~2900 $cm^{-1}$and ~2850 cm^{-1} is indicative of a carbon-hydrogen (C-H) single stretching bond. The presence of a single peak ~1640 cm^{-1} is indicative of a double bonded carbon-oxygen (C=O) group. The presence of a single peak ~1530 cm^{-1} is indicative of a nitrogen-hydrogen (N-H) bending bond. The presence of a single peak ~1371 cm^{-1} is indicative of a carbon-nitrogen (C-N) bond. The presence of a single peak ~935 cm^{-1} is indicative of a carbon-carbon=oxygen (C-C=O) group. This combination of functional groups is consistent with a polyamide. A spectral library search was perform using this spectrum. The search found a very strong match to Nylon 6/6.



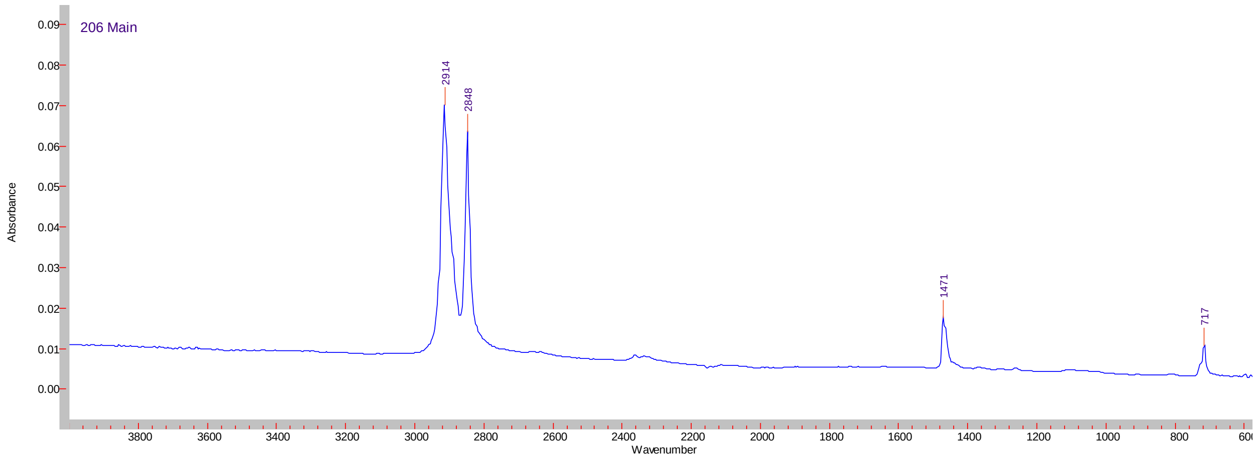
Appendix A3. FTIR spectrum of the cutter tool O-ring for the tee assembly from dwelling 206 showing the identity of specific wavenumber peaks.



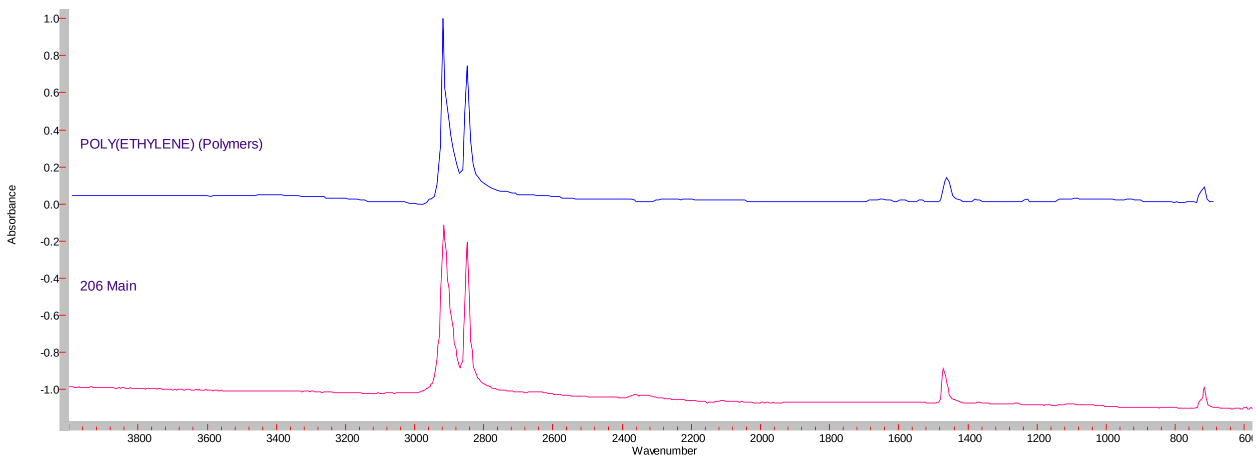
Appendix A4. FTIR spectrum of the cutter tool O-ring from dwelling 206 (top spectrum) is consistent with that from a sample of a known sample of black nitrile rubber (bottom spectrum).

Notes regarding Appendices A3 and A4:

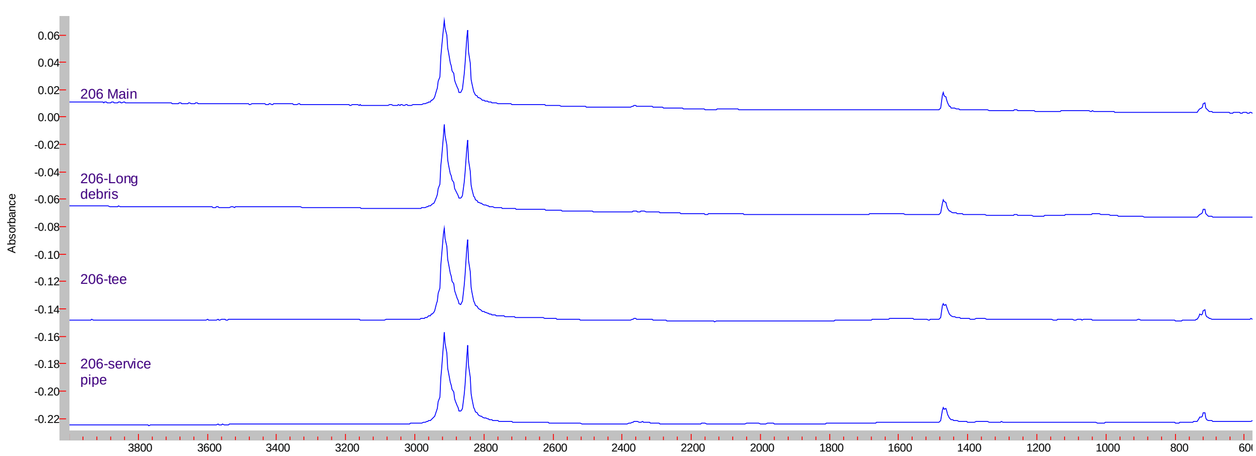
The samples identified as SADDLE O-RING and CUTTER TOOL O-RING shared matching spectra indicating that both samples were the same material. Both spectra contained the following combination of spectral peaks corresponding to particular functional groups found within the molecular structure of the material. The presence of a low broad peak between ~3100 cm^{-1} is indicative of a carbon-hydrogen (C-H) functional group that is double bonded to another molecule (most likely another carbon molecule). The presence of a strong doublet peak between ~2900 $cm^{-1}$and ~2850 cm^{-1} is indicative of a carbon-hydrogen (C-H) single stretching bond. The presence of a single peak ~2230 cm^{-1} is indicative of a triple bonded carbon-nitrogen (C≡N) group. The presence of a single broad peak ~2100 cm^{-1} is indicative of double bonded carbon=carbon (C=C) group (most likely in the form of elemental carbon). The presence of a single peak ~1990 cm^{-1} is indicative of another double bonded carbon group (alkene). The presence of a single peak ~1470 cm^{-1} is indicative of a $carbon-hydrogen_2$ ($C-H_2$) bending bond. The presence of a single peak ~950cm^{-1} is indicative of a $carbon-hydrogen_3$ ($C-H_3$) bending bond. A spectral library search was performed on both O-ring samples. The search found a match to acrylonitrile/butadiene copolymer (n-buta rubber or nitrile rubber).



Appendix A5. FTIR spectrum of the tee assembly main associated with dwelling 206 showing the identity of specific wavenumber peaks.



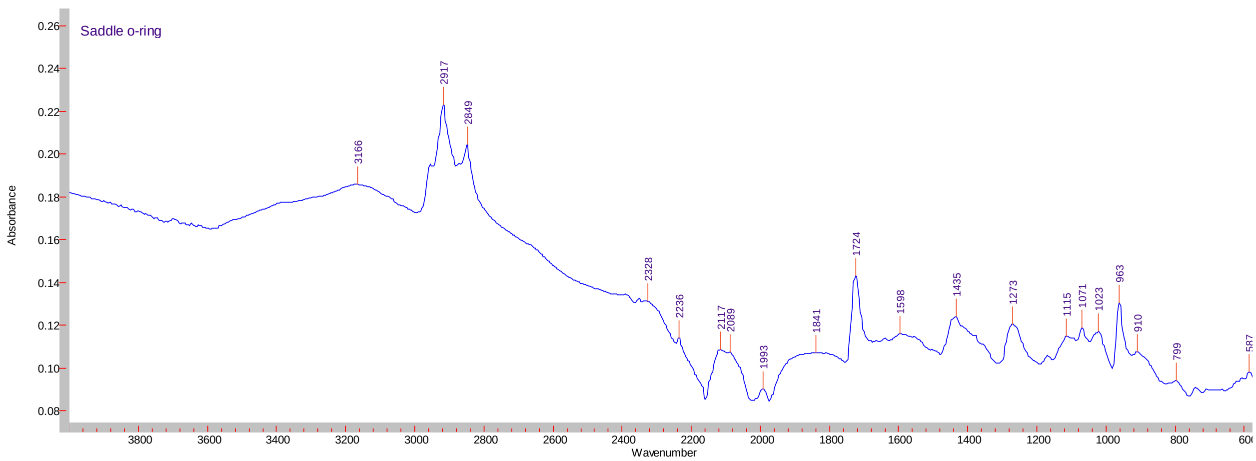
Appendix A6. FTIR spectrum of polyethylene library reference standard (top spectrum) is consistent with spectrum of that from the main (bottom spectrum).



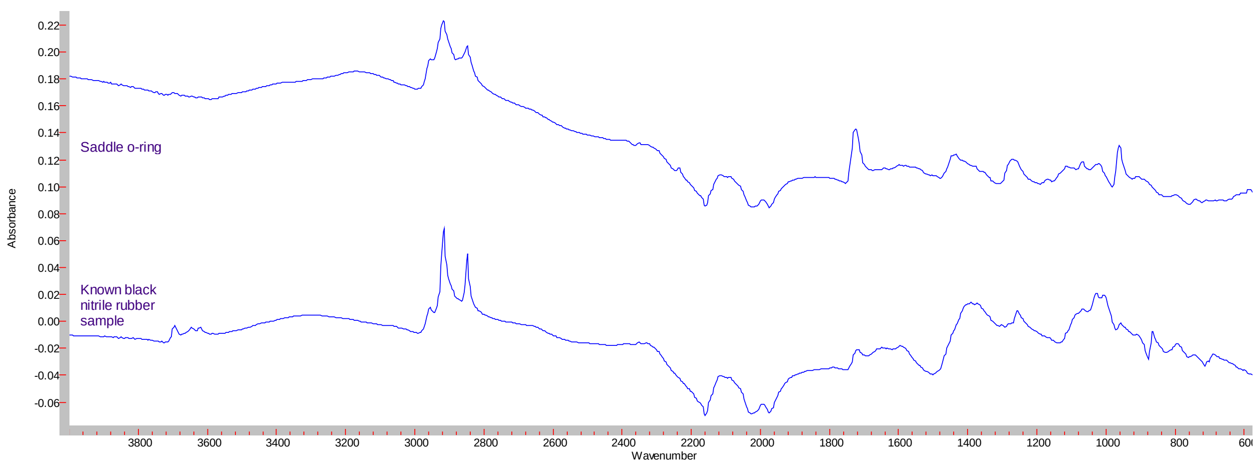
Appendix A7. FTIR spectra for the main, long curled debris found in the pierced hole of the main, tee assembly tower portion, and service pipe, all from dwelling 206 (from top to bottom spectrum, respectively). They are all similar and consistent with polyethylene.

Notes regarding Appendices A5 through A7:

The samples identified as MAIN, LONG DEBRIS, TEE and SERVICE PIPE shared matching spectra indicating that all four samples were the same material. The four spectra contained the following combination of spectral peaks corresponding to particular functional groups found within the molecular structure of this material. The presence of a strong doublet peak between ~2900 $cm^{-1}$and ~2850 cm^{-1} is indicative of a carbon-hydrogen (C-H) single stretching bond. The presence of a single peak ~1470 cm^{-1} is indicative of a carbon-hydrogen$_2$ ($C-H_2$) bending bond. The presence of a single peak ~700cm^{-1} is indicative of multiple carbon-hydrogen$_2$ ($C-H_2$) bending bonds. A spectral library search was performed on a representative spectrum for this group. The search found that the material in the four samples was a very strong match to polyethylene (PE).



Appendix A8. FTIR spectrum of the saddle O-ring for the tee assembly from dwelling 206 showing the identity of specific wavenumber peaks.



Appendix A9. FTIR spectrum for the saddle O-ring from dwelling 206 (top spectrum) is consistent with that of a known sample of black nitrile rubber (bottom spectrum).

Notes regarding Appendices A8 and A9:

The FTIR spectrum for the SADDLE O-ring was similar to the spectrum from the CUTTER TOOL O-ring, consistent with acrylonitrile/butadiene copolymer (n-buta rubber or nitrile rubber).

In the spectrum for the SADDLE O-RING sample, one peak was found that was not found in the CUTTER TOOL O-RING sample or the known sample. The presence of a single peak ~1700 cm^{-1} is indicative of double bonded carbon=oxygen (C=O) group. The presence of the a carboxy (C=O) group could indicate the presence of a foreign material on the surface of the O-ring. Carboxy groups are common in a wide variety of materials including materials containing carboxylic acids, esters and carboxylates (a class of surfactants).

APPENDIX B

Crystalline Melting Temperature
and
Fiber Content

Table B1
Crystalline Melting Temperature
Using Differential Scanning Calorimeter Method

Bolt Description, Vintage in Month/year	Specified Bolt Material	Typical Crystalline Melting Temperature (°C)	Measured Melting Point 1st Heating Scan (°C)	Consistent With Manufacturer Specification?
Bolt Exemplar Vintage 9/1995	Nylon 6/6	256	261	Yes
Accident Fractured Bolt “1” Dwelling 206 Vintage 1/1998	Nylon 6/6	256	261	Yes
Intact Bolt “4” Dwelling 2253 Vintage 2/1999	Nylon 6/6	256	261	Yes
Bolt Exemplar Vintage 1/2005	Nylon 11, for bolts manufactured in 2005 and thereafter	185-187	190	Yes

Table B2
Ash Content in Each Bolt
(Rough Estimate of the Glass Fiber Reinforcement)

Bolt Description, Vintage in Month/year	Specified Bolt Material	Specified Glass Fiber Reinforcement (Weight %)	Measured Ash Content After Ignition (Weight %)
Bolt Exemplar Vintage 9/1995	Nylon 6/6	43	43
Accident Fractured Bolt “1” Dwelling 206 Vintage 1/1998	Nylon 6/6	43	41
Intact Bolt “4” Dwelling 2253 Vintage 2/1999	Nylon 6/6	43	43
Bolt Exemplar Vintage 1/2005	Nylon 11	43	40

APPENDIX C

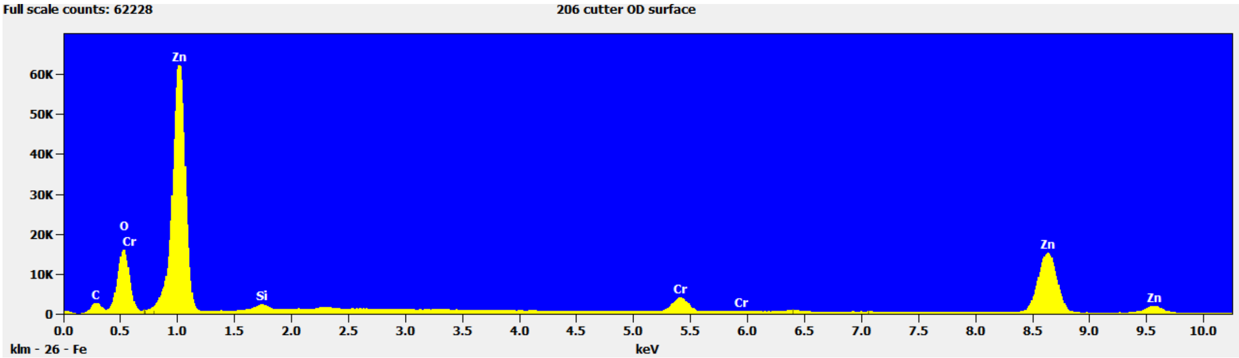
Molecular Weight Distribution

Table C1
Average Molecular Weight (Daltons)
Relative to polystyrene standards

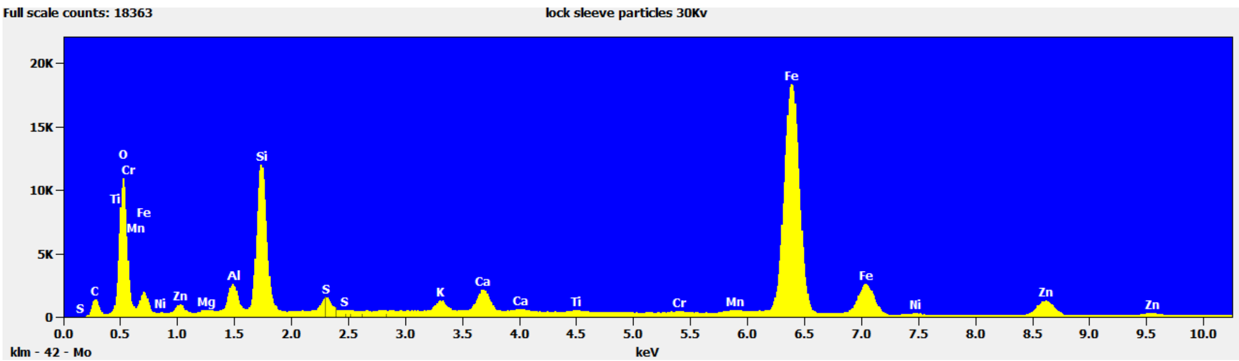
Bolt Description, Vintage in Month/year	M_n	M_w	M_z	M_w/M_n
Bolt exemplar Vintage 9/1995	13,347	38,815	114,136	2.91
Accident Fractured Bolt “1” Bolt Dwelling 206 Vintage 1/1998	9,176	31,041	84,197	3.38
Intact Bolt “4” Dwelling 2253 Vintage 2/1999	8,971	31,423	80,641	3.50
Bolt Exemplar Vintage 1/2005	9,117	22,070	50,084	2.42

APPENDIX D

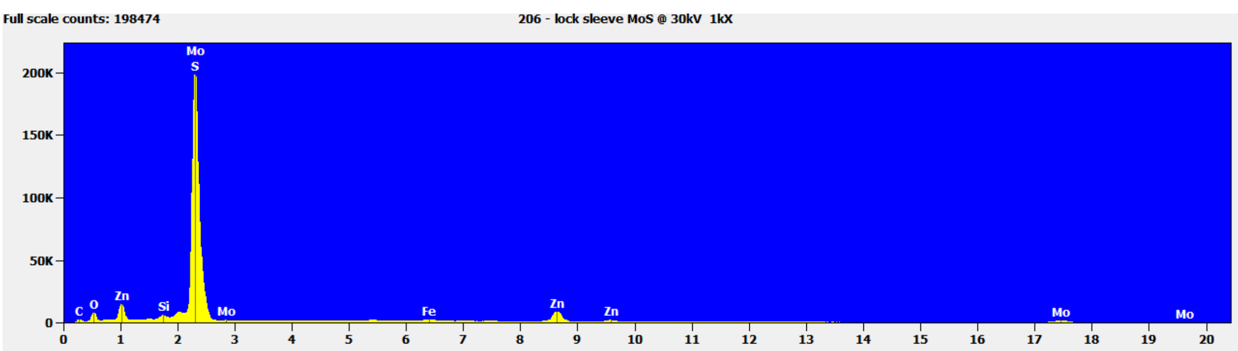
EDS Spectra



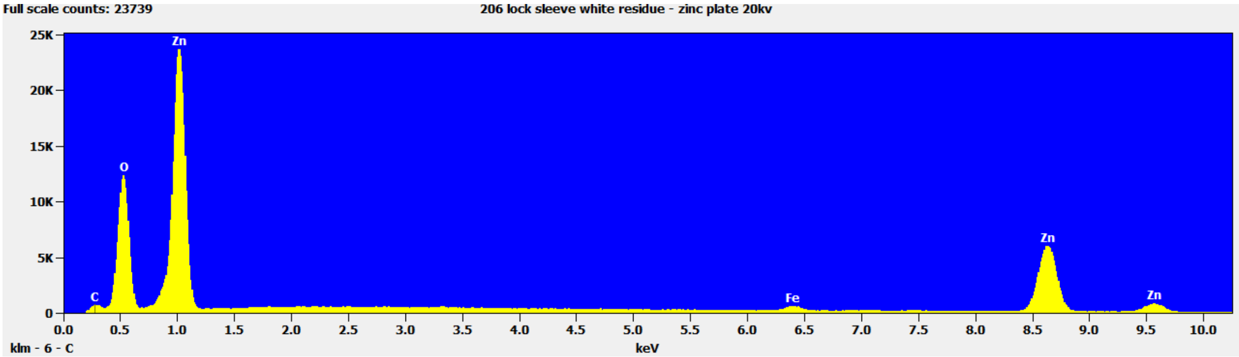
Appendix D1. EDS spectrum of the shank portion of the cutter tool from dwelling 206, showing major elemental peaks of zinc and minor elemental peaks of oxygen, carbon, silicon, and chromium.



Appendix D2. EDS spectrum of granular-like particles found on the shank portion of the cutter tool from dwelling 206 showing major elemental peaks of iron, silicon, and oxygen, and minor elemental peaks of zinc, carbon, manganese, chromium, titanium, calcium, potassium, sulfur, aluminum, magnesium, and nickel.



Appendix D3. EDS spectrum of molybdenum disulfide particles found on the ratchet surface of the cutter tool from dwelling 206, showing major elemental peaks of molybdenum and sulfur, and minor elemental peaks of zinc, oxygen, and carbon.



Appendix D4. EDS spectrum of the locking sleeve outer threads from dwelling 206 in an area that contained white deposits showing major elemental peaks of zinc and oxygen and minor elemental peaks of carbon, and iron. The major peak of zinc is consistent with the galvanized coating that was specified for the locking sleeve.

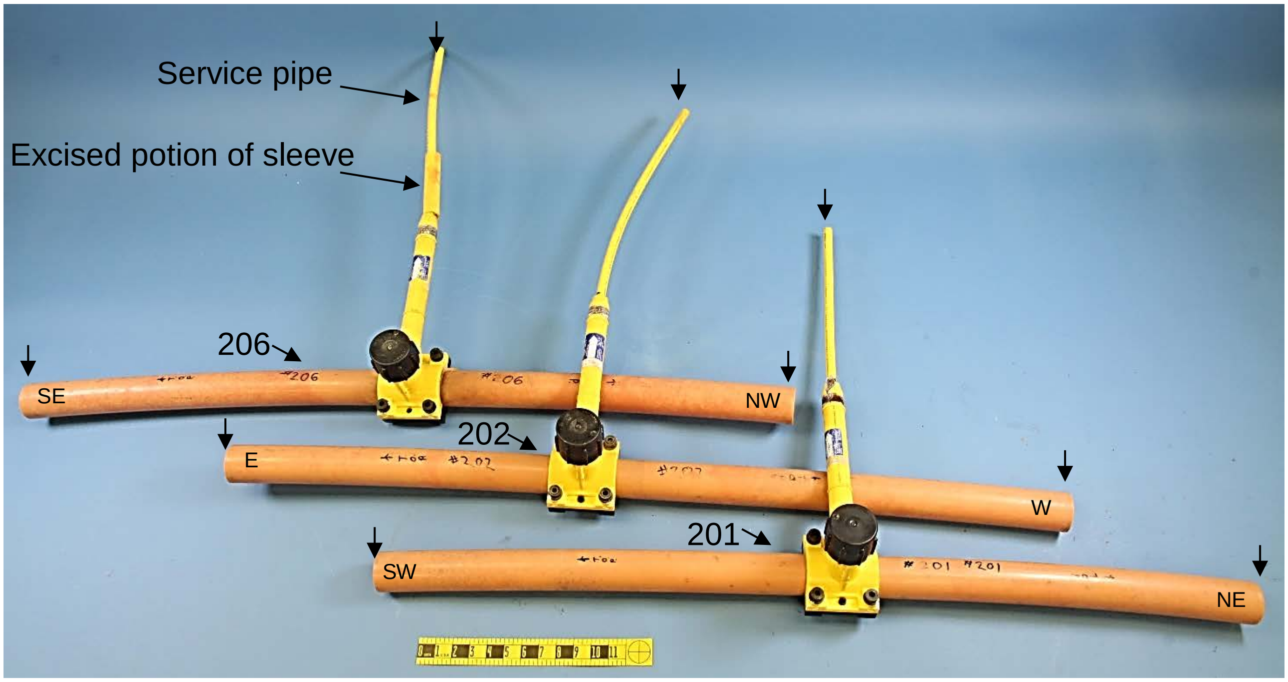


Figure 1. As-received Permalock® mechanical tapping tee assemblies from dwellings 201, 202, and 206, shown after brush cleaning with water. Arrows indicate cut portions of the pipes to facilitate transportation and handling. The position of the sleeve does not represent the sleeve's location as-found on the service pipe at the time of the accident.

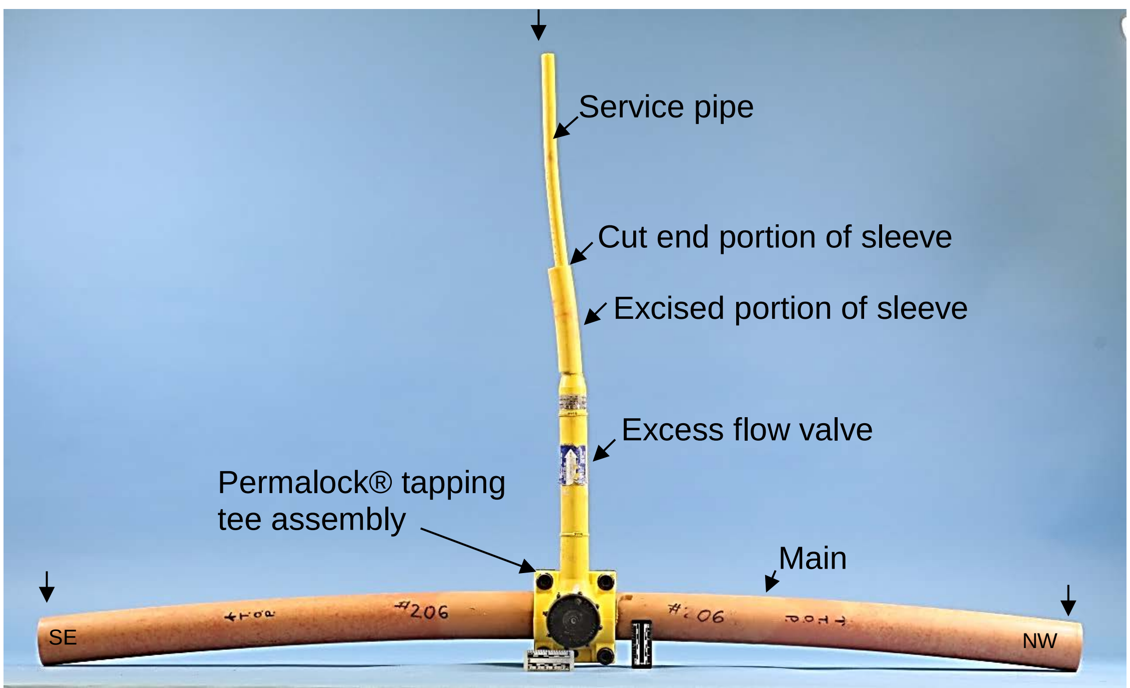


Figure 2. Close-up photograph of the Permalock® mechanical tapping tee assembly from dwelling 206. Arrows indicate cut portions of the pipes to facilitate transportation and handling.

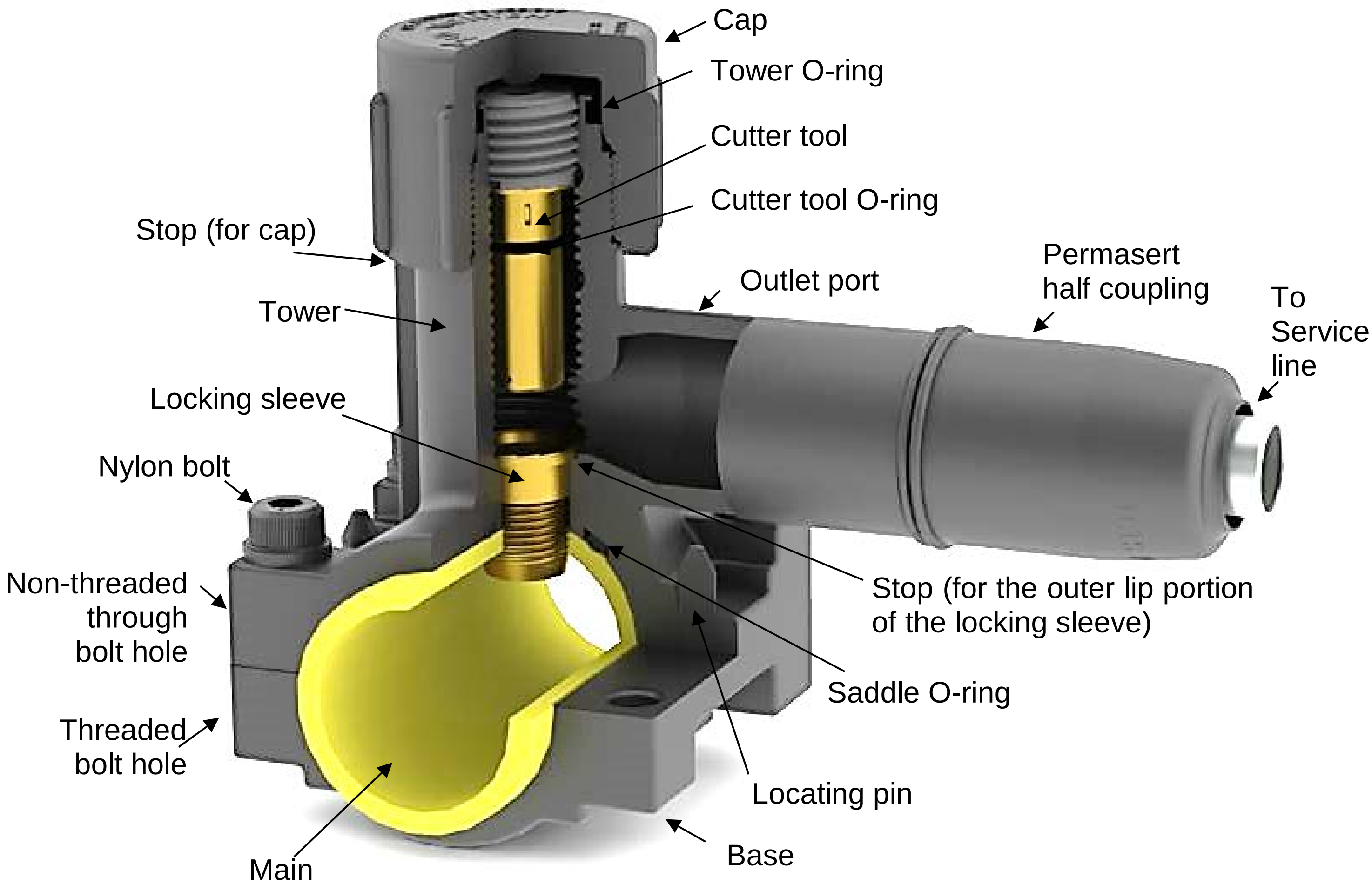


Figure 3. Diagram of a Permalock® mechanical tapping tee assembly that was not involved in the accident showing a partial cross section through the wall and the specified location of the cutter tool and locking sleeve after installation. For educational purposes only. The color of various portions of the assembly does not reflect those from the accident. The tee assembly involved in the accident contained an excess flow valve between the outlet port and Permasert half coupling that is not illustrated in this diagram. Courtesy of Elster-Perfection Corporation (currently Honeywell).

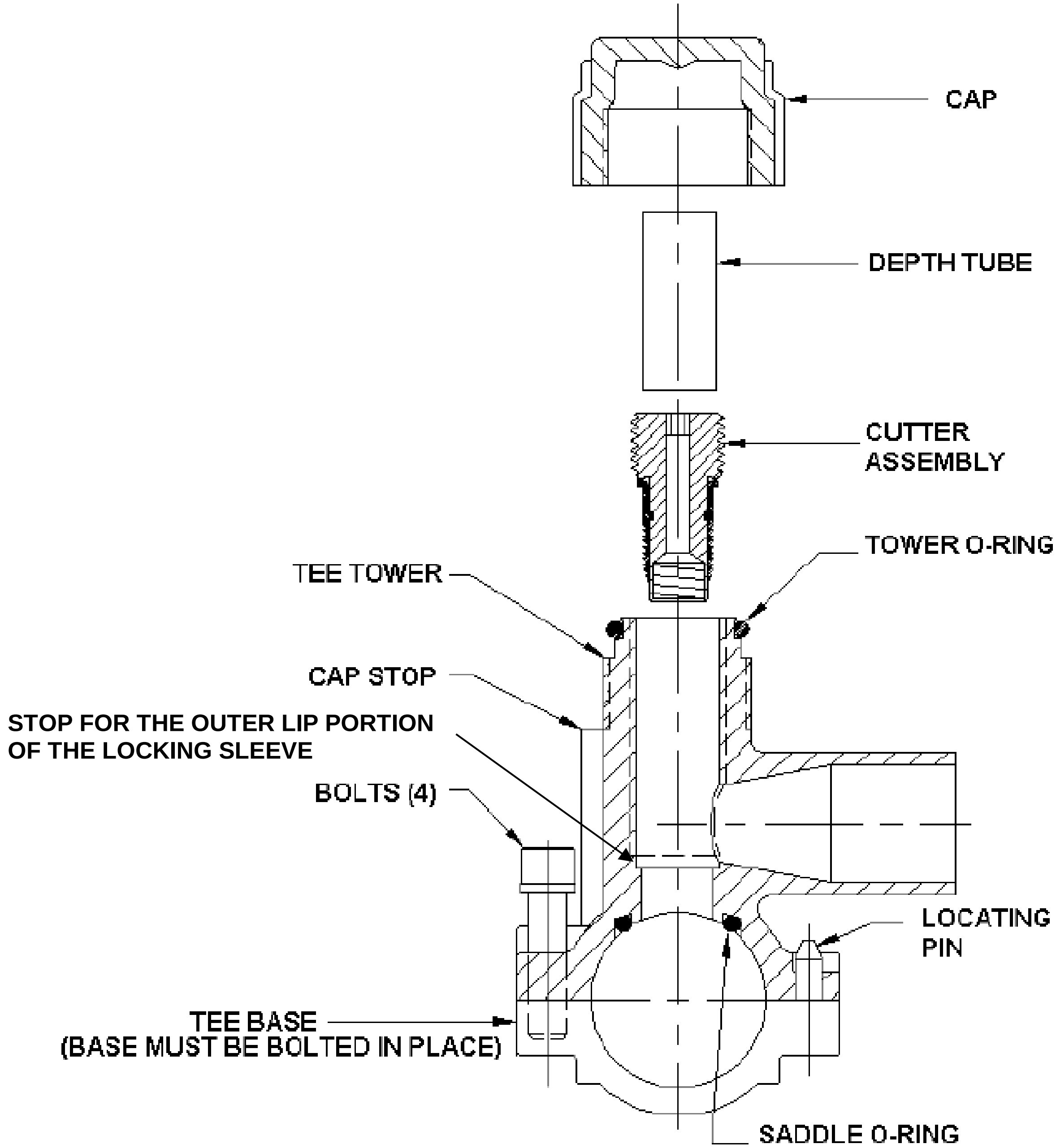


Figure 4a. Cross section diagram of a Permalock® mechanical tapping tee assembly. The cutter assembly is comprised of two pieces, a cutter tool portion that is inserted into a locking sleeve portion. The depth tube is plastic piece of thin-walled pipe that is supplied with the tee shipment from the factory and is used to verify correct installed depth of the cutter assembly. Source: Elster-Perfection Corporation (currently Honeywell).

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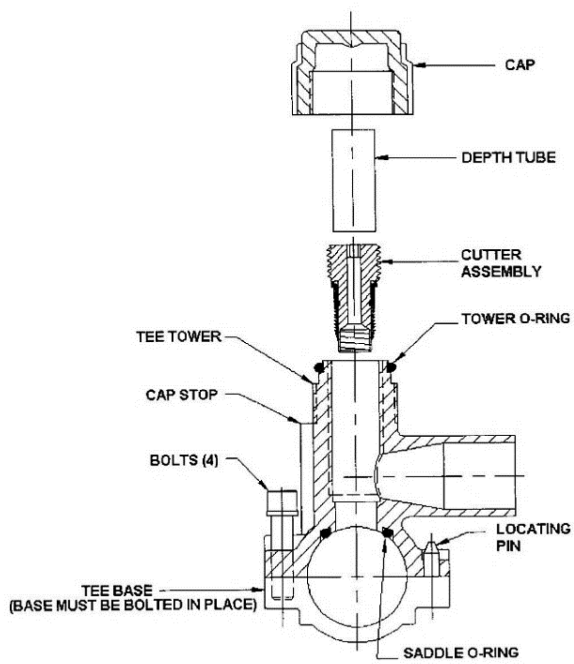
Sht. 1 of 2

Perfection Installation Instructions

PERFECTION PERMALOCK® TEE

U.S. PATENT NOS. 4,730,636 & 4,809,735
U.K. PATENT NOS. 2199271 & 2234693

1. Remove TEE ASSEMBLY and DEPTH TUBE from the bag (check tee for TOWER and SADDLE O-RINGS).
2. Clean surface of main where TEE is to be installed. Avoid areas that are gouged or damaged. Lubricate SADDLE O-RING and main surface with leak test soap solution or silicone grease.
3. Bolt TEE onto PE main and tighten until the corners touch using a cross over tightening pattern (a gap between the flanges in the locating pin area is acceptable).
4. Connect service to the TEE TOWER outlet.
5. Test tee/service assembly in accordance with your company's standard leak test procedures.
6. Place DEPTH TUBE on top of the CUTTER ASSEMBLY. Thread CUTTER ASSEMBLY downward using a 5/16" hex wrench. Continue threading the CUTTER ASSEMBLY downward until it becomes snug. The DEPTH TUBE will be flush to 1/8" above the top of the TEE TOWER.
7. Thread CUTTER upward (counterclockwise) until top of CUTTER is flush with the top of the TOWER. This will gasify the service
   (Discard the DEPTH TUBE at this point).
8. Install CAP on the tower, hand tighten to CAP STOP.



Note: This product is designed to be installed by qualified installers. Qualification training manuals are available by writing or calling the Gas Sales Department of Perfection Corporation.

Perfection
Corporation
A Subsidiary of American Meter Company
222 Lake Street
Madison, Ohio 44057-3189
Fax 440-428-7325
440-428-1171
www.perfectioncorp.com

Figure 4b. Written installation instructions for installing a Perfection Permalock® tee assembly to a main. Applicable to the tee assembly involved in the accident. Courtesy of Honeywell.

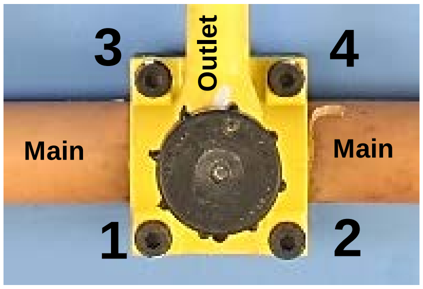


Figure 5. Photograph of the tee assembly from dwelling 206 that was involved the accident showing the top view, and identification numbers that were arbitrarily assigned to the Nylon bolts, “1” through “4”. The same bolt numbering system was used for each tee.

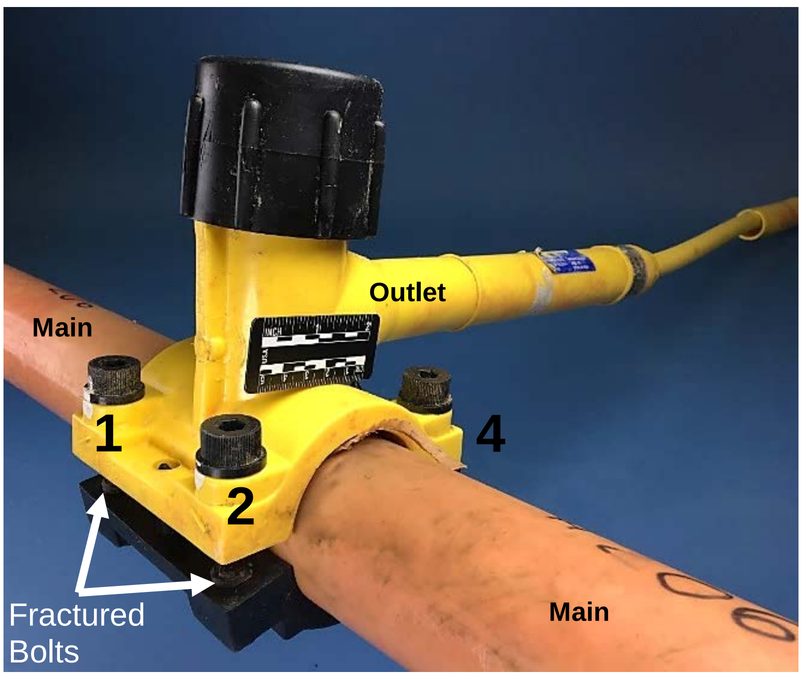


Figure 6. Photograph of the tee assembly from dwelling 206 showing fractured bolts “1” and “2”.

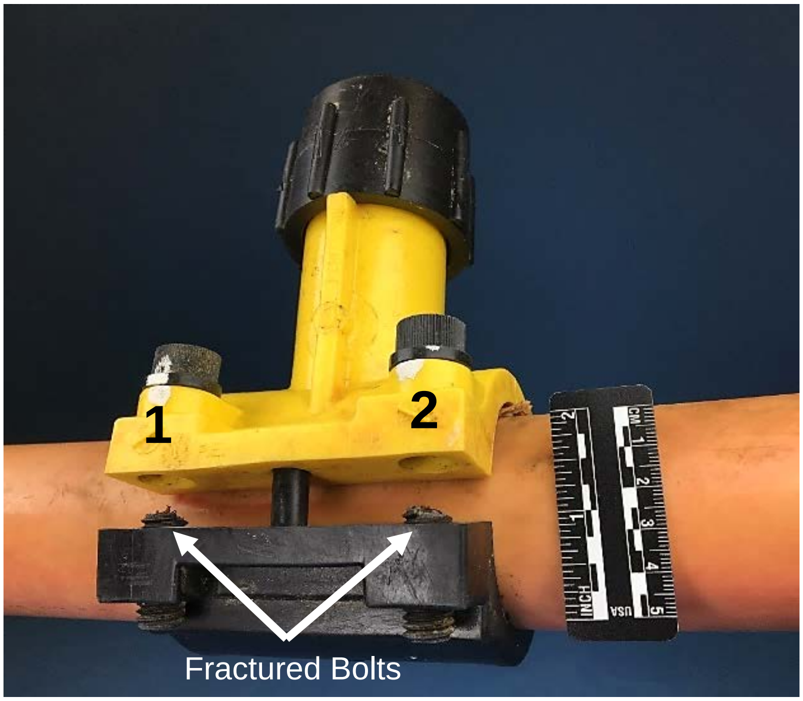


Figure 7. Another view of the tee assembly from dwelling 206 showing fractured bolts “1” and “2”.

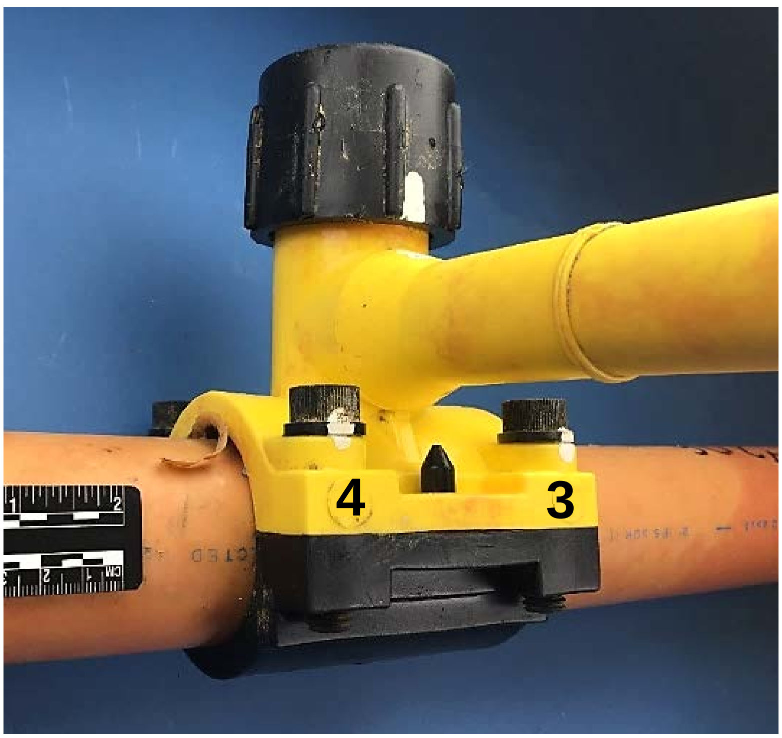


Figure 8. Photograph of the tee assembly from dwelling 206 showing intact bolts “3” and “4”.

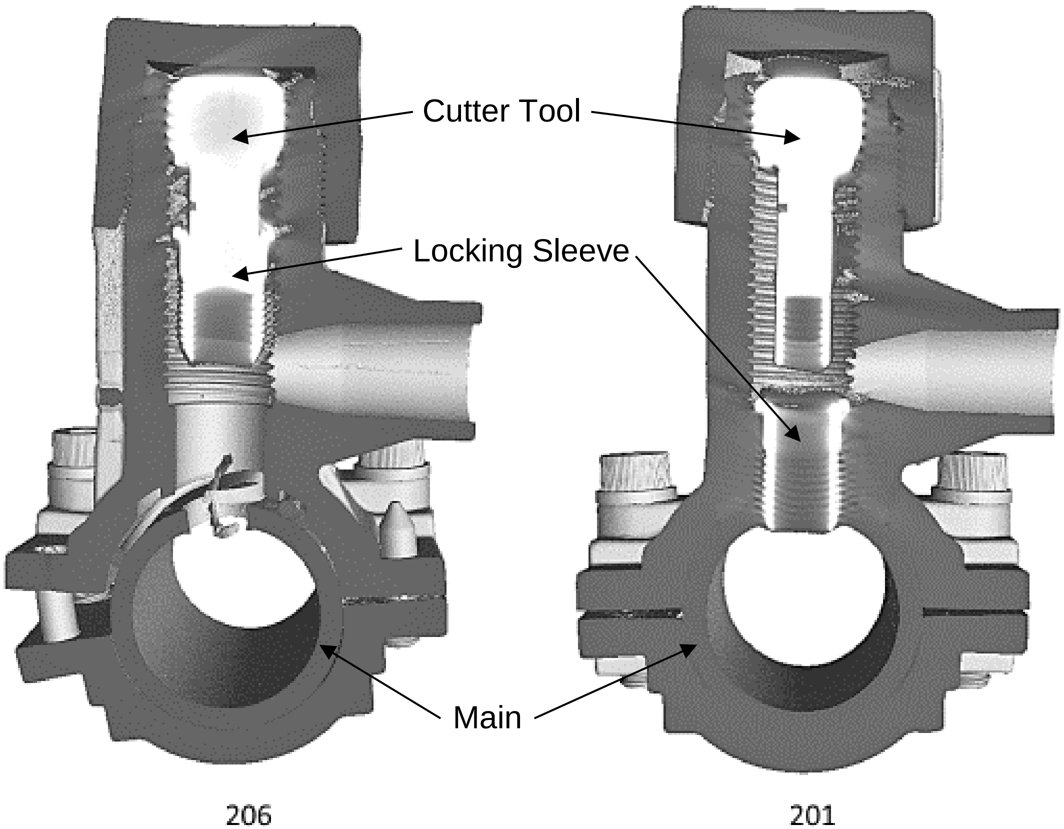


Figure 9. Reconstructed X-ray CT image of the tee assembly from dwelling 206 involved in the accident showing a locking sleeve that was not installed on the main (left side of page) and image of tee from dwelling 201 showing a locking sleeve that was attached to the main (right side of page). The locking sleeve in the dwelling 206 tee assembly remained attached to the cutter tool.

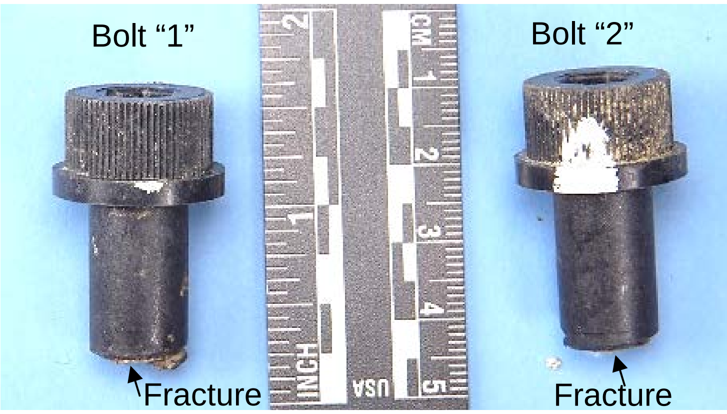


Figure 10. Photograph of fractured Nylon bolts "1" and "2" that were disassembled from the tee assembly involved in the accident (dwelling 206).

Figure 11. Fracture face of Nylon bolt "2" after ultrasonic cleaning.

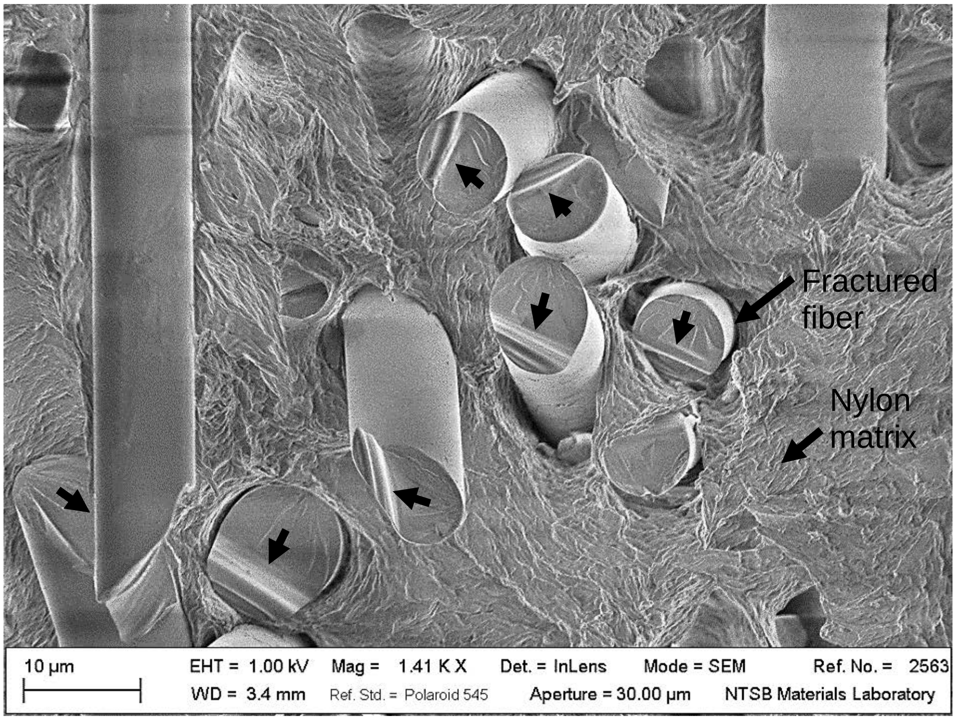


Figure 12. Scanning electron microscope (SEM) photograph of a portion of the fracture face from Nylon bolt “2” showing the matrix (Nylon) and the end of several fractured fibers. Arrows indicate general direction of fracture propagation on each fractured fiber.

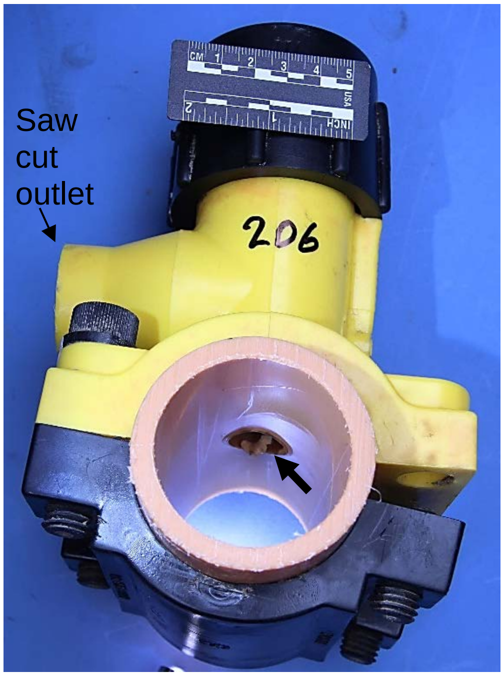


Figure 13. Photograph of the tee assembly from dwelling 206 showing the exposed inner wall of the main in the area where the cutter tool made a hole in the wall of the main. A curled fragment is sticking out of the pierced hole in the area indicated by an unmarked arrow. The wall of the pierced hole was bare and showed no evidence of a locking sleeve.

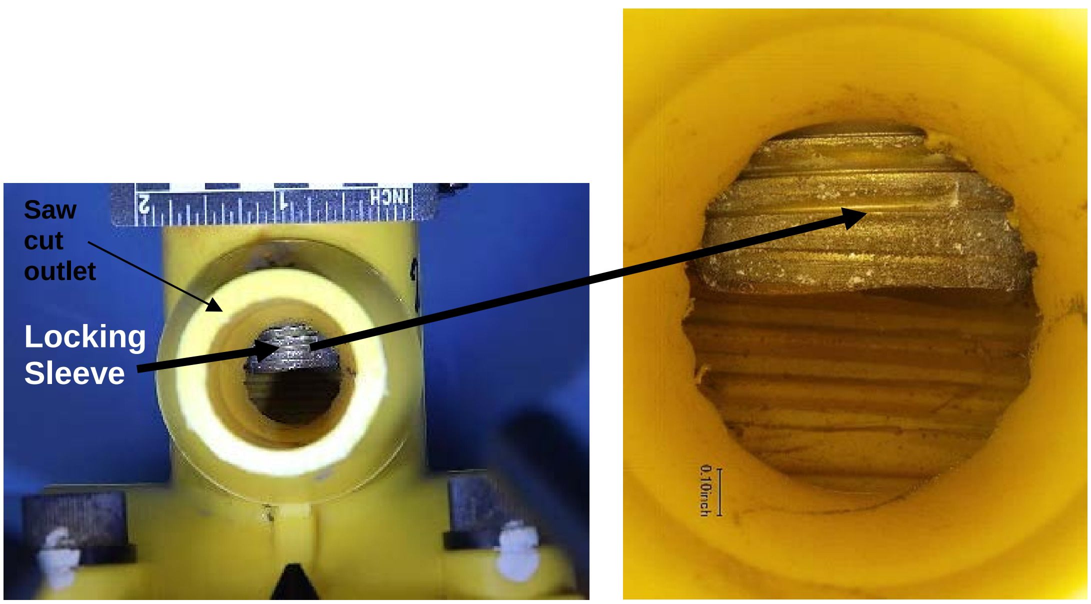
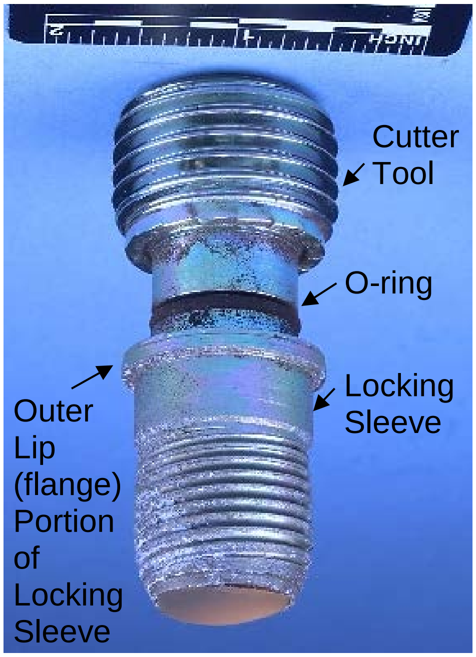


Figure 14. Photograph of a portion of the tapping tee assembly from dwelling 206 looking in the outlet port showing the bottom end of the locking sleeve that was in an area near the upper side of the outlet port (left side of page) and a close-up photograph of the same locking sleeve (right side of page).



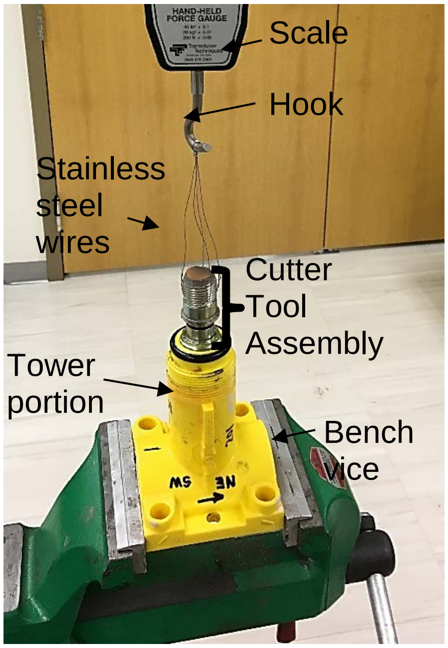
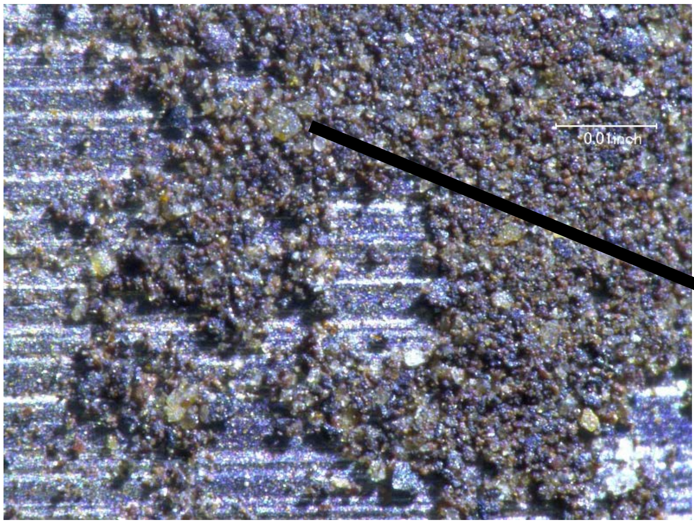


Figure 15. Photograph of the cutter tool assembly that was disassembled from the tapping tee assembly from dwelling 206 (left side of page). The locking sleeve remained attached to the cutter tool. Set-up used for attempting to separate the cutter tool from the locking sleeve (right side of page). The threaded-head portion of the cutter tool was inverted and installed into the tower portion, and the tee was secured to the bench vice.



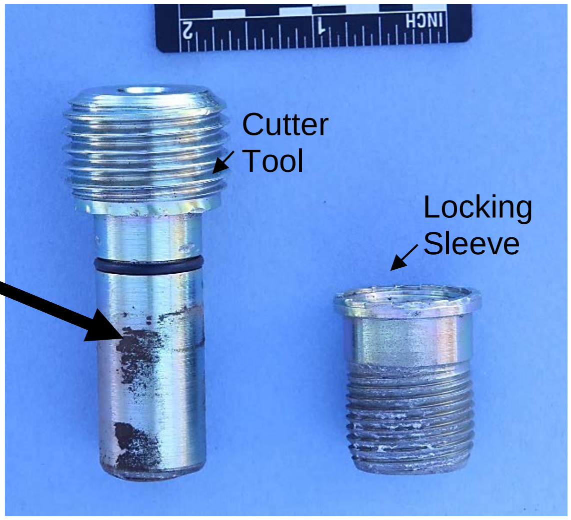


Figure 16. Photograph of the cutter tool from dwelling 206 after it was disassembled from the locking sleeve (right side of page), and photograph of soil particles that were found on the shank portion of the cutter tool (left side of page).

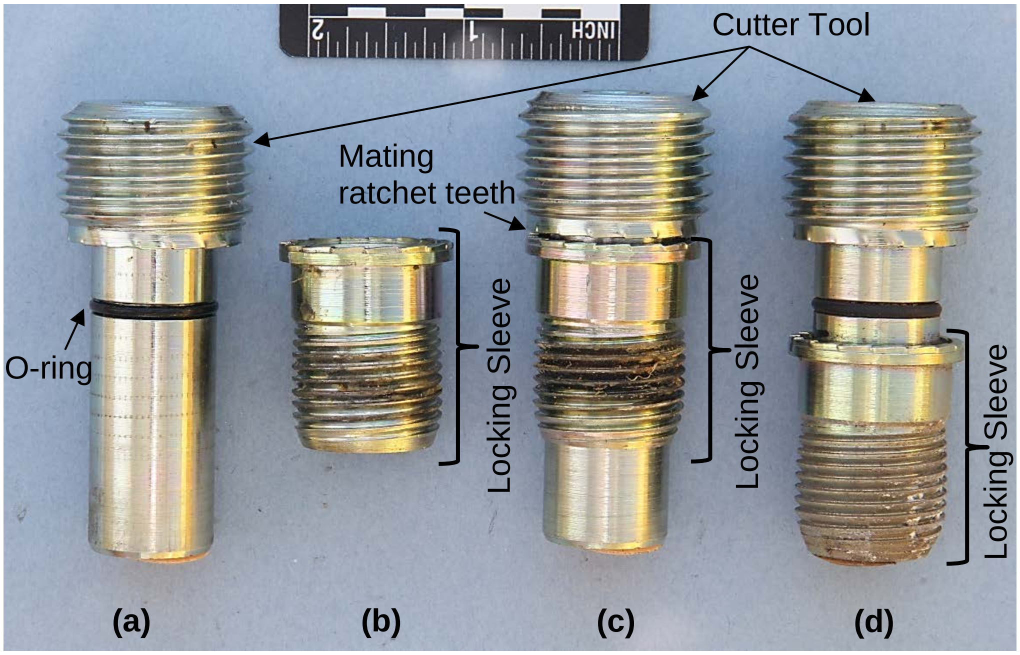


Figure 17. Photograph of cutter assemblies in different conditions of assembly showing (a) disassembled cutter tool from dwelling 201; (b) disassembled locking sleeve from dwelling 201; (c) cutter tool and locking sleeve from dwelling 202 that were re-assembled to simulate the unit prior to driving the cutter assembly into the main; and (d) cutter assembly (locking sleeve and cutter tool) in the condition when removed from the tee assembly associated with dwelling 206.

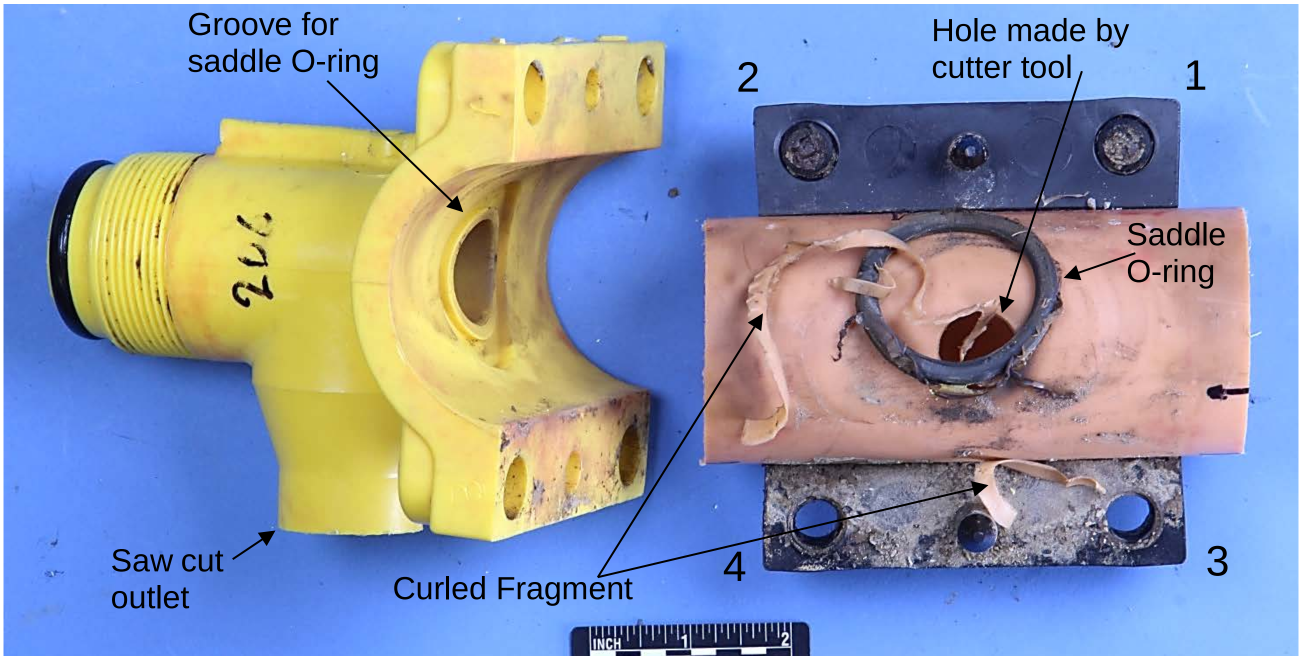


Figure 18. Photograph of the disassembled tee from dwelling 206 showing the top exposed surface of the main and pierced hole (made by the cutter tool).

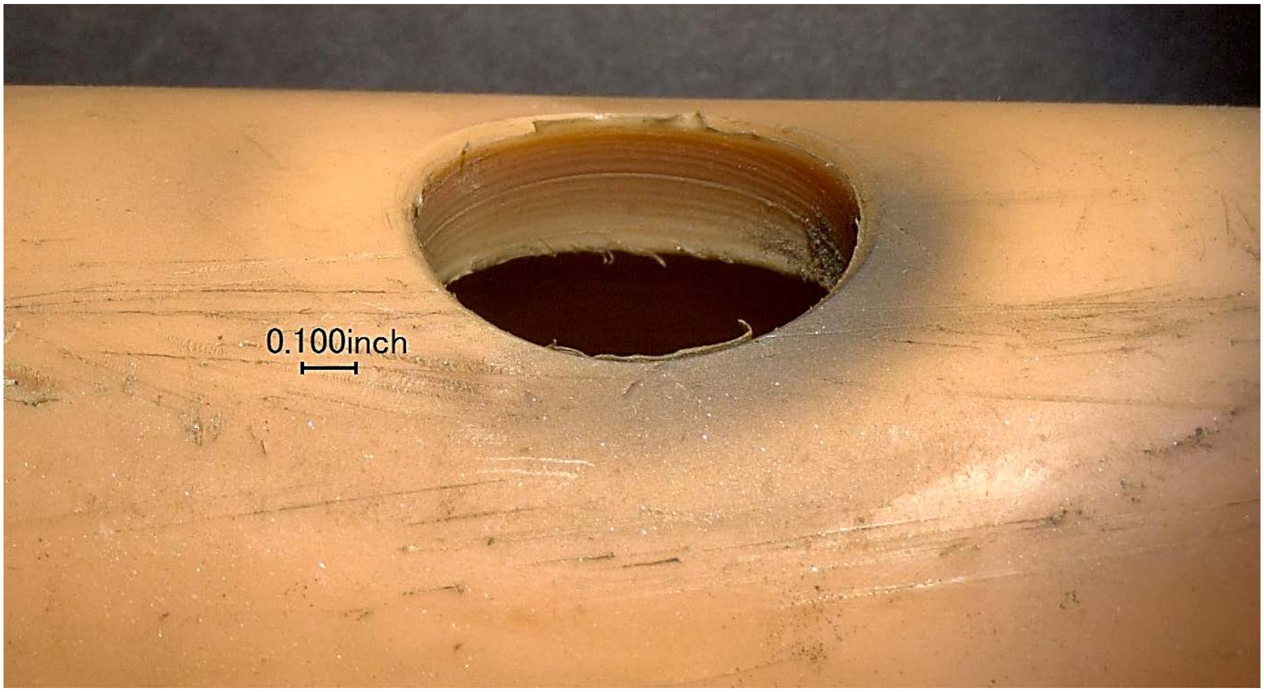


Figure 19. Photograph of the exposed outer top surface of the main after disassembly of the tee from dwelling 206 showing the pierced hole made by the cutter tool. Note the fine circular cut marks within the pierced hole and the absence of threads.

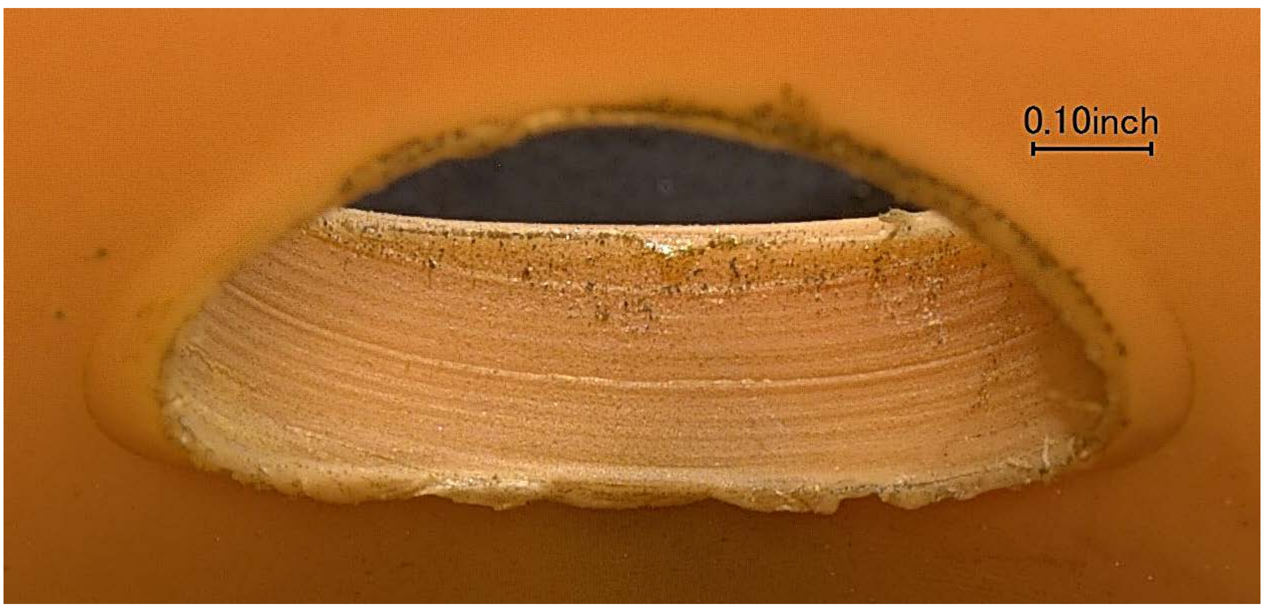


Figure 20. Photograph of the exposed inner surface of the main after disassembly of the tee from dwelling 206 showing the pierced hole made by the cutter tool. Note the fine circular cut marks within the pierced hole and the absence of threads.

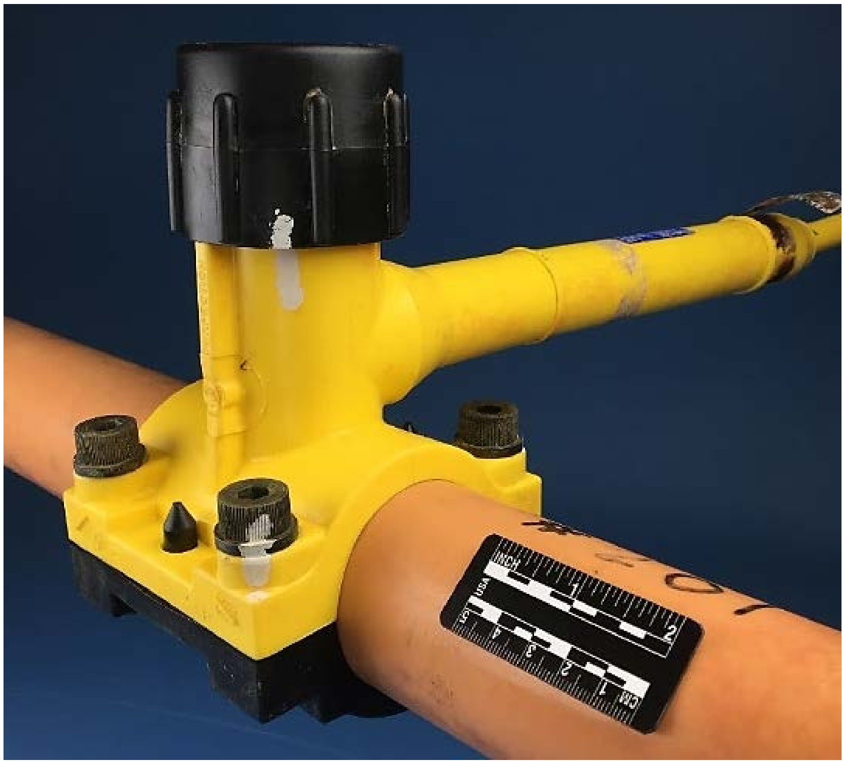


Figure 21. Photograph of the tee assembly from dwelling 201.

Figure 22. Photograph of the tee assembly from dwelling 201 showing a portion of the base.

Figure 23. Photograph of the tee assembly from dwelling 201 showing the side view.

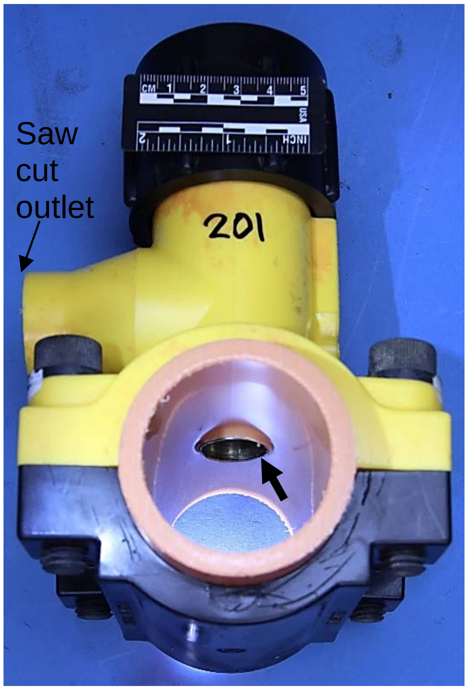


Figure 24. Photograph of the tee assembly from dwelling 201 showing the exposed inner wall of the main in the area where the cutter tool pierced the wall of the main. The bottom portion of the locking sleeve is visible in the pierced hole, in the area indicated by an unmarked arrow.

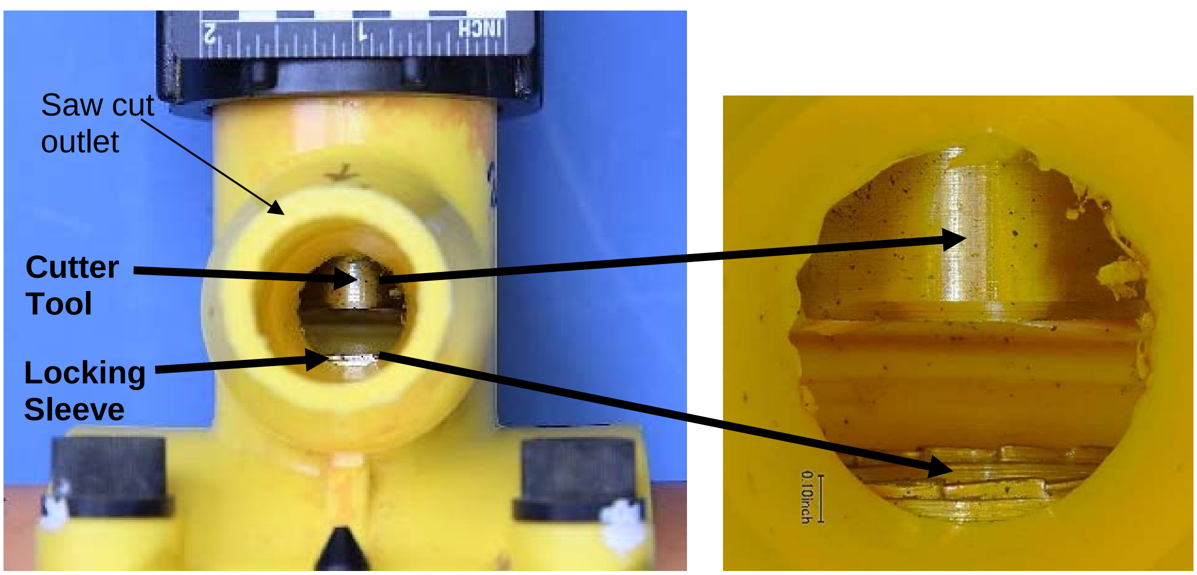


Figure 25. Photograph of a portion of the tapping tee assembly from dwelling 201 looking in the outlet port showing a portion of the cutter tool in the area near the upper side of the outlet port and upper portion of the locking sleeve at the lower side of the outlet port (left side of page); and a close-up photograph of the cutter tool and locking sleeve (right side of page).

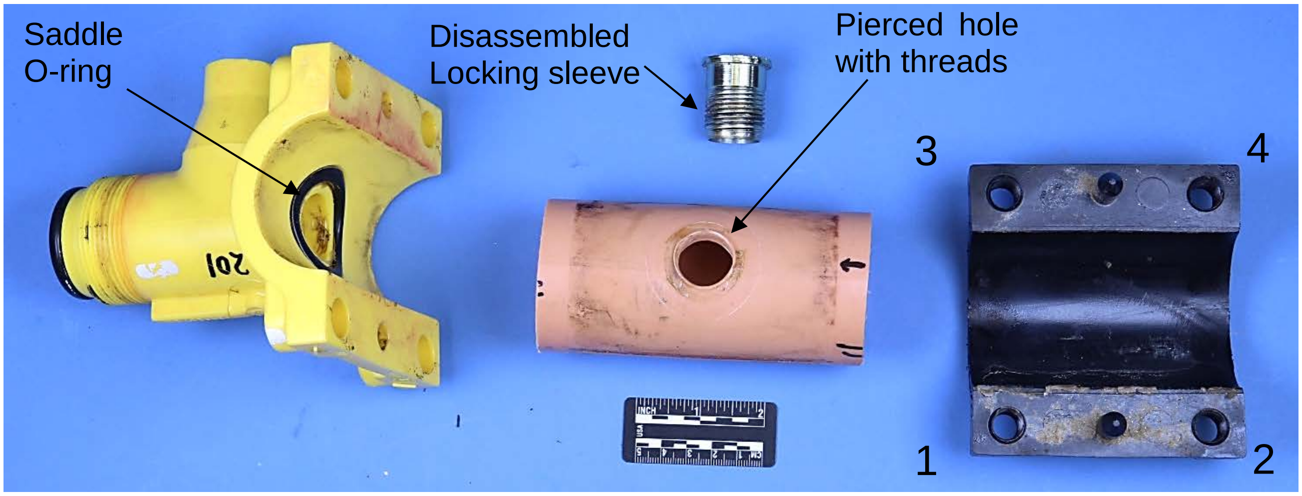


Figure 26. Photograph of the disassembled tee from dwelling 201 showing the top exposed surface of the main and pierced hole with threads (after removal of the locking sleeve).

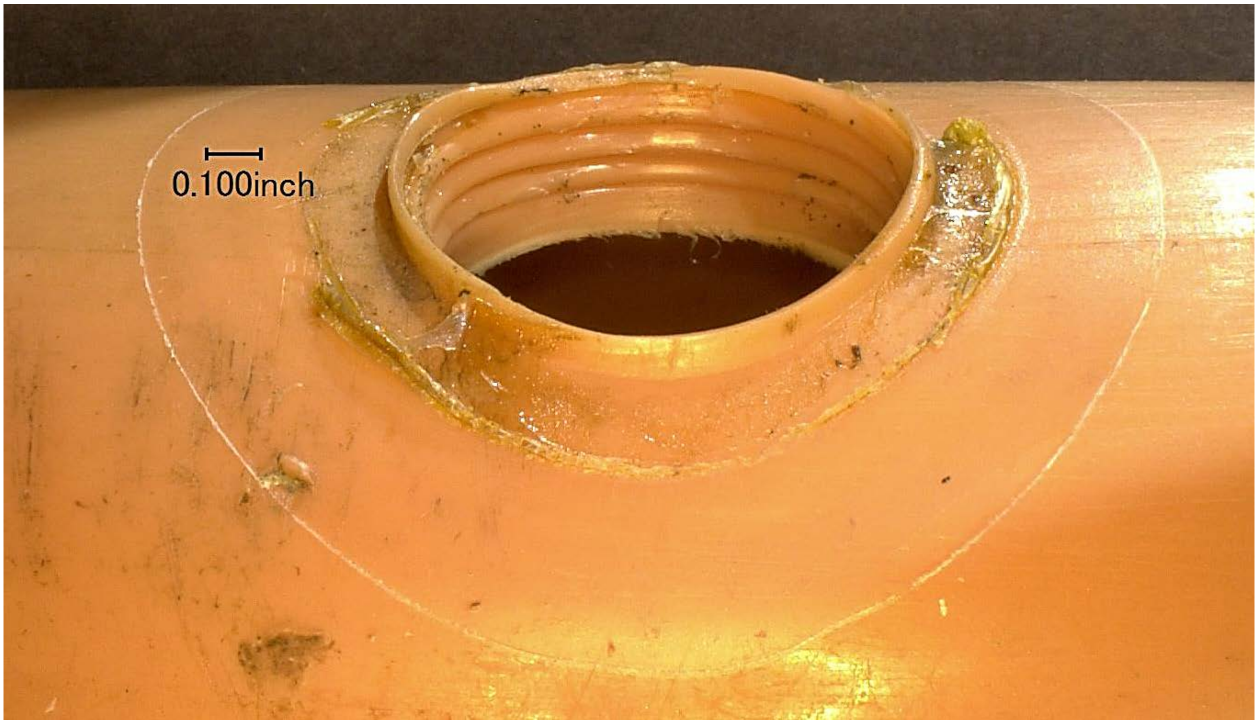


Figure 27. Photograph of the exposed outer top surface of the main after disassembly of the tee from dwelling 201 showing the pierced hole with threads (after removal of the locking sleeve).

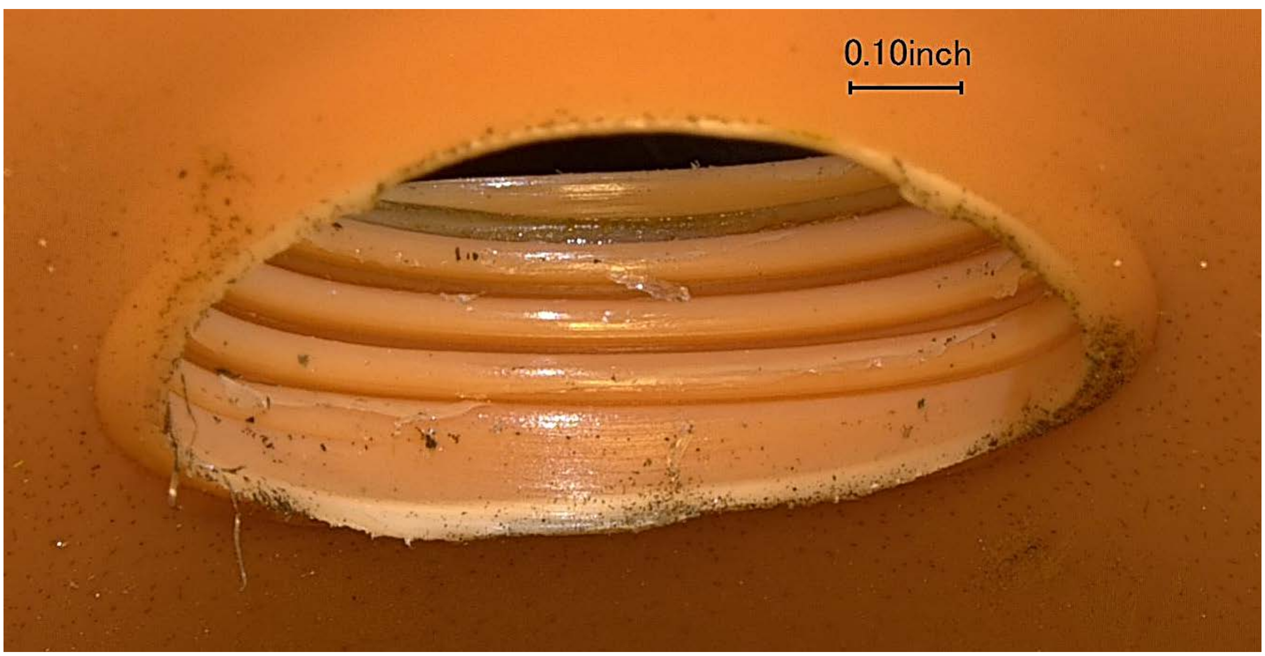


Figure 28. Photograph of the exposed inner surface of the main after disassembly of the tee from dwelling 201 showing the pierced hole with threads (after removal of the locking sleeve).

Figure 29. Photograph of the tee assembly from dwelling 202.

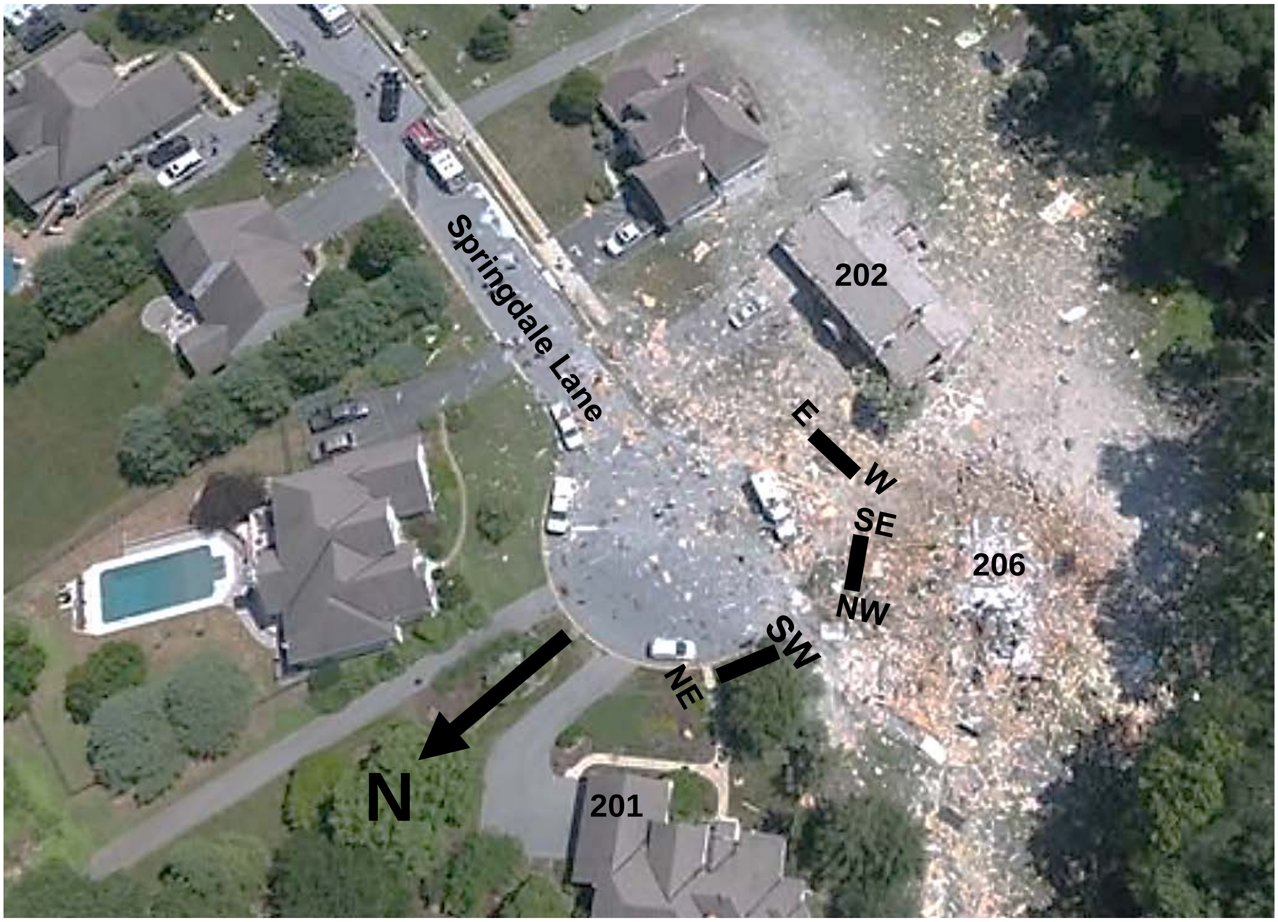


Figure 30. Overhead photograph of the house that was involved in the accident (206 Springdale Lane). Three four-foot long main segments each containing the tapping tee assembly for dwellings 201, 202, and 206, were removed from the accident site and transported to the Safety Board Materials Laboratory. The approximate location of removed gas main segments are indicated by a black line. The cut ends of the gas main segments were labeled with approximate orientation relative to the North (N) direction. For example, the gas main portion in front of dwelling 206 was oriented in the SE-NW direction.