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

March 25, 2017

MATERIALS LABORATORY FACTUAL REPORT Report No. 16-097

A. ACCIDENT INFORMATION

Place	:	Silver Spring, Maryland
Date	:	August 10, 2016
Vehicle	:	Washington Gas service pipe and gas regulator assemblies
NTSB No.	:	DCA16FP003
Investigator	:	Ravi Chhatre

B. COMPONENTS EXAMINED

Two gas pressure regulator assemblies and associated pipe pieces that were disassembled from the basement located at 8701 Arliss Street.

C. DETAILS OF THE EXAMINATION

1.0 As-received Pipe Segments

Figures 1 and 2 show photographs of the as-received gas pressure regulator assemblies and associated pipe pieces. The following is a detailed description of the submitted pieces:

(a) A nominal 2-inch inside diameter (ID) service pipe of which approximately a 40-inch segment was installed underground and a 14-inch segment was installed inside the basement containing the service valve. The service pipe transitioned into a nominal 1-inch ID inlet pipe by means of a reducer coupling. The inlet pipe fractured from the reducer coupling. A plug was installed at the reducer coupling end to allow on-site pressure testing of the service pipe. The plug remained attached to the reducer coupling.

(b) Two gas pressure regulator assemblies, 1-inch ID inlet pipe, a nominal 2-inch ID stand pipe and union assemblies.[1]

(c) Three round plates.

(d) Vent pipe that separated from the two gas regulator assemblies. This vent pipe is connected by approximately 25-inches, 58-inches, and 62-inches segments.

[1] A union assembly is similar to a coupling and serves as an attachment between two external threaded pipes and nipples. It also allows the convenient disconnection of pipes and nipples for maintenance or fixture replacement.

(e) Exemplar service pipe segment that was cut from 8701 Arliss Street and an exemplar service pipe segment that was cut from 8703 Arliss Street, length of each is about 12 inches.

The gas pressure regulator assemblies involved in the accident are referred as the "upper" and "lower" pressure regulator assemblies. Visual examination of the submitted pieces revealed the union assembly for the lower gas regulator assembly separated in the area indicated by arrows "X1" in figures 1 and 2. The vent port for each gas regulator assembly involved in the accident was manufactured with internal threads. A threaded nipple[2] separated from the vent port of the upper gas regulator assembly, in the area indicated by arrow "X2" in figures 1 and 2. Gas flowed in the general direction indicated by arrows in figure 3. The gas pressure regulator assemblies, service pipe segments and attachment hardware that run up to the gas meters are owned and have been maintained by Washington Gas since the installation date.

2.0 Safety Board Materials Laboratory Group

The following individuals participated in the examination of the pipe pieces and gas regulator assemblies on October 24, 2016 at the Safety Board's Materials Laboratory in Washington, D.C.:

Frank Zakar	Group Chairman	NTSB
Edward Komarnicki	Member	NTSB
Kelly Emeaba	Member	NTSB
Douglas Staebler	Member	Washington Gas
John Clementson, II	Member	Public Service Commission of Maryland
Lt. William Olin	Member	Montgomery County Fire Rescue Services

The following individuals participated on the second day session:

Frank Zakar	Group Chairman	NTSB
Edward Komarnicki	Member	NTSB
Kelly Emeaba	Member	NTSB
Jacob Waller	Member	Washington Gas

Work continued on the gas regulator assemblies and associated pipe segments after the party members departed from the laboratory examination.

3.0 Exemplar Gas Pressure Regulator Assembly

Photographs in Appendix 1 show different views of an exemplar mercury-containing gas pressure regulator assembly (not involved in the accident).[3] Marks found on the external portion of the exemplar gas regulator assembly facilitated the identification of the gas

[2] Threaded nipple is a fitting, consisting of a short piece of pipe, usually provided with an external thread at each end, for connecting two other internal threaded fittings.
[3] NTSB Materials Laboratory Factual Report 16-098 provides further information regarding exemplar gas regulator assemblies (not involved in the accident). Exemplar gas regulator assemblies were disassembled from buildings that were adjoined the building involved in the accident.

regulator assemblies involved in the accident. Details in this section of the report will show that the gas regulator assembly involved in the accident was made by the Reynolds Gas Regulator Company, and was of the same vintage and model as that from the exemplar gas regulator assembly.

Examination of the exemplar gas regulator assembly revealed it contained a body and a top cover. The top cover and body of the exemplar pressure regulator assembly contained markings that extended above the surface and exhibited a rough external texture consistent with a casting. Markings on the top cover indicated the manufacturer of the pressure regulator assembly as “Reynolds Gas Regulator Co”, “Anderson IN”, established (“EST”) in “1892”, and was an “HP Type”. The bottom portion of the body contained markings “R-8150-1” that extended above the surface, consistent with the casting number for the body portion. A metal tag that contained an impression marking “I-55” was installed between the top cover and the body, indicating the regulator assembly was manufactured in 1955. Another metal tag was attached by a screw to the top cover and contained the marking “ORIG. I-M-30”, indicating the model number of the regulator.

The top cover for the upper and lower gas regulator assemblies were destroyed from exposure to heat from a fire, and information regarding the manufacturer and model had perished with this destruction. Both gas regulator assemblies from the accident contained multiple marks that helped with identification of the assemblies. The upper gas pressure regulator assembly involved in the accident contained a metal tag indicating that it was model number “ORIG. I-M-30”. The body of the two gas pressure regulator assemblies involved in the accident exhibited the size and shape, body casting number “R-8150-1”, and metal identification tag indicating the year of manufacturer (“I-55”), that were the same as those from the exemplar gas pressure regulator assembly. The shape and size of the gas regulator assemblies from the accident and identification marks found on these assemblies are consistent with mercury-containing gas regulator assemblies that was manufactured by Reynolds Gas Regulator Company.

Alloy analysis was performed on various parts of the accident gas regulator assemblies with a hand-held alloy analyzer, unless otherwise noted in this report.[4] The body was determined to be made from a ferrous alloy, top cover and both metal tags was determined to be made from an aluminum alloy, according to analysis performed by an alloy analyzer at the NTSB Materials Laboratory.

3.1 General Construction

At the time this report was prepared, the manufacturer of the gas pressure regulator that was involved in the accident was no longer in business and a cross section of the gas regulator assembly that was involved in the accident was not available for display. For educational purpose and illustration, Appendix 2A shows a cross section diagram and internal parts of a typical non-mercury containing gas pressure regulator assembly. The principals of operation between the gas regulator assembly involved in the accident and the

[4] General classification of materials (whether a ferrous or aluminum alloy) in this report were determined at the NTSB Materials Laboratory with the use of a Thermo Scientific Niton XL3t-980 X-ray fluorescence (XRF) portable alloy analyzer, unless otherwise noted.

one shown in Appendix 2A are the same in that both assemblies utilize an internal spring mechanism that presses against the diaphragm, in combination with an orifice and disc, to control pressure at the outlet end.

As shown in Appendix 2A, the internal parts of a gas regulator assembly consist of an orifice, disc (also referred as a valve seat), stem, lever, pusher post, flexible diaphragm, rigid diaphragm plate, and spring mechanism. The orifice is a tapered tube with a fixed size aperture that permits gas to enter the internal chamber of the gas regulator assembly. The flat portion of the disc facing the orifice contains an elastomer liner. The flexible diaphragm can be made from leather or an elastomer. The outer edges of the diaphragm are attached to a sealing surface at the outer edges (periphery) of the body. When the top cover is attached to the body, the outer edges of the diaphragm are hermitically sealed between the outer edges of the top cover and the outer edges of the body. The flexible diaphragm is installed between the diaphragm plate and the pusher post. The diaphragm plate is located below the diaphragm and spring pressure is applied directly to the rigid diaphragm plate. The orifice and disc work together and as a unit are referred as a valve.

The gas regulator assembly from the accident is different from the one shown in Appendix 2A in that the gas regulator from the accident was not manufactured with a relief valve spring, lower spring seat, and vent port spring shown in Appendix 2A. The gas regulator involved in the accident was manufactured with an internal reservoir that was filled with mercury in the area adjacent to the vent port (instead of a vent port spring as shown in Appendix 2A).

3.2 General Operation

For the purpose of explaining the general operation of a gas regulator assembly refer to the cross section diagram in Appendix 2B. In general, the gas regulator assembly operates in the following manner. Gas enters the inlet port. When there is no downstream demand for gas, the disc is pressing against the orifice. In this scenario, gas does not flow downstream. When downstream demand for gas increases the pressure under the diaphragm decreases. This action causes the diaphragm to move downward and the lever to pivot in a manner such that the stem and disc move away from the orifice, resulting in the gap between the orifice and disc. As the disc moves away from the orifice, gas flow into the regulator increases. In contrast, when downstream demand decreases, the pressure under the diaphragm increases. This causes the disc to move closer to the orifice and results in a reduced gas flow. The size of the gap between the orifice and disc determines the amount of gas that passes through the outlet.

Mercury-containing gas regulator assemblies are installed in a manner such that the internal diaphragm and saucer-like body portion of the assembly is oriented parallel to the ground (horizon). This alignment is necessary to assure that mercury stays within the reservoir (a cylinder cup). A set screw on the top potion of the cover can be adjusted to regulate the tension on the spring and, in turn, this tension adjustment regulates the outlet pressure. To increase the outlet pressure setting of the regulator assembly, the adjusting screw is turned clockwise, and vice-versa. In the event of an overpressure[5], gas inside the regulator assembly will pass through the mercury reservoir and out the exit port.

Appendix 2C shows a composite cross section diagram of a mercury-containing gas regulator assembly that was made by the Reynolds Gas Regulator Company, 1938 edition; designed nearly 20 years earlier than the one involved in the accident. The Reynolds gas regulator assembly involved in the accident used toggle links that were similar to the ones used in the Reynolds 1938 edition.

The body portion of the Reynolds mercury-containing gas regulator assembly that was involved in the accident was manufactured with a 2-inch diameter inspection port (see Appendix 1). The port was located on the side of the body and it can be used for inspecting the internal orifice and disc mechanism. A threaded plug is screwed on to the port. The port portion contains the internal thread and the plug contains the external thread. Appendix 3 shows a photograph of the disc and orifice portions from an exemplar Reynolds gas regulator assembly, when viewed through the 2-inch inspection port after removal of the plug. The stem portion of the gas regulator assembly is square in cross section. The disc can be disassembled from the stem by removing a cotter pin.[6]

4.0 Gas Regulator Assemblies from the Accident Site

This section covers the examination of the lower and upper gas regulators and associated pieces from the accident site.

4.1 Lower Regulator Assembly

4.1.1 Visual Examination

Figures 1, 2, 3, 5, and 9 show photographs of the lower gas regulator assembly. The top cover for the lower gas regulator assembly was attached to the body and it was severely deformed from exposure to heat from a fire. The spring was laying on its side and encased in the solidified top cover. Attachment screws and corresponding nuts for the top cover were intact and attached to the body. The attachment screws were disassembled from the body and the top cover was removed. Visual examination of body after the top cover was removed revealed the diaphragm plate was intact and attached to the pusher post. The flexible diaphragm was consumed by heat of the fire. The diaphragm plate was disassembled from the pusher post. The toggle links were intact and attached to the pusher post. The plug on the side of the body was attached to the 2-inch diameter port. The plug was disassembled in order to view the internal chamber of the body. View through the open 2-inch diameter port revealed the disc, and outer portion of the orifice were covered by dust or debris. The dust or debris was brush cleaned with a bristle brush. The exposed square-shaped stem, cotter pin, disc and orifice were intact (see figure 4). An attempt was made to move the diaphragm plate in the vertical (up and down) orientation. This exercise did not cause

[5] When pressure inside of the gas regulator exceeds a level (limit), limit set by the gas regulator manufacturer in combination with the control adjustments that can be made by a trained representative of the gas company, the excessive pressure exits through the vent port.

[6] Refer to NTSB Materials Laboratory Factual Report No. 16-098 for additional detail regarding the construction of the disc.

movement the diaphragm plate, toggle links, or the disc. The bottom portion of the disc and orifice were encased by a solidified metal globule that prevented movement of the diaphragm plate and toggle links.

Mercury is stored in a cylinder cup. The cup was attached by screw threads to the body portion of the gas regulator assembly. The cup was disassembled (unscrewed) from the body portion. Visual examination of disassembled cup revealed inner chamber of the case contained no evidence of a liquid pool of mercury.

4.1.3 Union Assembly for the Lower Gas Regulator Assembly

As indicated earlier, the union assembly for the lower gas regulator assembly separated in the area indicated by arrows "X1" in figures 1, 2 and 5. The union assembly is comprised of three components – the nut which has been referred as the retaining nut or "collar; the male part of the union which has been referred as a "tail piece", male spherical component, or insert; and the female part of the union which has been referred as the mating socket component. The female part of the union has the external threads, which mate to the union nut. For the purpose of this report, the three components will be referred as the nut, insert, and mating external threaded socket (see figure 5). The union assembly separation was between the external threaded socket portion and the nut portion.

According representatives from Washington Gas, the material for the union assembly is specified as malleable iron, and the threads were specified as tapered with the exception of the nut. Washington Gas' experience has shown that the nut uses straight threads. The same representatives indicated that the union assembly is specified to be manufactured in accordance to ASME B16.39. ASME B16.39 states that all threads are tapered in accordance to ASME B1.20.1; that is, ¾-inch FNPT ends engage with a pipe of 1.05 inch OD, with 14 threads per inch. The thread pitch is specified as 0.07142857 inch. The change in thread diameter is specified as 0.00446 inch per turn of thread. Vintage records from Washington Gas indicate the union head/nut thread size was likely 1-1/4 inch NPT (11.5 threads per inch, and pitch diameter at the beginning of the external thread of 1.55713 inches). The search of Washington Gas records revealed the dimensions for the union nut were not specified but, as indicated earlier, their experience has shown that the nut uses straight threads. Washington Gas' experience indicated that pipe fittings with the exception of union nut use tapered pipe threads.

Visual examination of the union assembly revealed the surfaces of the nut, insert, and external threaded socket portions exhibited a rough texture consistent with casting product. The nut, insert and external threaded adapter were determined to be made from a ferrous alloy, according to alloy analysis performed at the NTSB Materials Laboratory. The nut, insert, external threaded socket and associated pipe segments were covered with brown iron oxide and metal splatter-like deposits as shown in figure 5. The metal splatter-like deposits exhibited a light and dull luster, similar to the appearance of aluminum or zinc. The metal splatter-like deposits were determined to be made from an aluminum alloy or zinc, according to analysis performed by an alloy analyzer at the NTSB Materials Laboratory. The union insert and union external threaded socket contained several tool marks at the tool engagement areas (such as the hexagonal flats). The tool marks were in the form of several longitudinal impression marks (such as teeth marks from a pipe wrench) that were oriented parallel to the axial length of the union assembly. The tool marks were covered with iron oxide, similar to the color and texture of the iron oxide found on the external parts of the union assembly.

The union external threaded socket was attached to the vent port by an elbow and threaded nipple. The mechanical connections between the vent port and the union external threaded socket were firm. The union insert was connected to the vent pipe by a threaded nipple and a pipe tee. The mechanical connections between the vent port and the union external threaded socket were firm.

Reference marks were made with a black marker or thin grinding wheel (tip of a cut-off wheel) along the longitudinal axis of the pipe segments, elbows, threaded nipples and union assembly parts to indicate position of the parts relative to each other prior to disassembly. The nut, insert and external threaded socket portions were disassembled from their respective threaded nipples and cleaned by immersing them in a solution of EVAPO-RUST®, a commercial soak type rust remover. Figure 5 shows a photograph (lower side of page) of the disassembled nut, insert and external threaded socket portions after cleaning. Each disassembled piece was examined with a bench binocular microscope.

4.1.3.1 Union External Threaded Socket

The external threads of the external threaded socket contained five threads, indicated by arrows "1" through "5" in figure 6. External thread arrowed "1" was a partial thread, whereas, those arrowed "2" through "5" were full threads. The crown portion of the first two full external threads arrowed "2" and "3" showed evidence of minor deformation that extended for the most part all around the socket. Metal deformation was found in the general direction indicated by arrows in figure 6. The NTSB Materials Lab could not determine when these deformation marks occurred. The external threads contained two dents, between arrows "D" in figure 6, one of which intersected the crown portion of the next to the last external thread arrowed "5". The dents were parallel to each other. The external threaded socket showed no evidence of major deformation.

4.1.3.2 Union Nut

The nut contained seven internal threads, indicated by arrows "1" through "7" in figure 7. Internal thread arrowed "1" and "7" were partial threads, whereas, those arrowed "2" through "6" were full threads. The crown portion of the first three internal threads arrowed "1" through "3" showed evidence of minor deformation on one side of the nut. The crown portion of the first thread indicated by arrow "1" in figure 7 on the diametrically opposite side showed evidence of minor deformation only on an isolated area. Metal deformation was in the general direction indicated by an arrow in figure 7. The NTSB Materials Lab could not determine when these deformation marks occurred.

4.1.3.3 Union Insert

The ball portion of the union insert (a sealing surface) and mating sealing surface on the union external threaded socket showed no evidence of mechanical damage.

4.1.3.4 X-ray CT of the Disassembled External Threaded Socket and Nut

The disassembled external threaded socket and mating nut from the union assembly of the lower gas regulator assembly were subjected to X-ray computed tomography (CT) scan. X-ray CT scanning was contracted to Chesapeake Testing in Belcamp, Maryland. A Nikon Metrology 450 kV micro focus X-ray tube was used to inspect the lower gas regulator assembly. Each CT volume was evaluated using the Volume Graphics Studio Max software package to reconstruct a three-dimensional image of the separated threads. The software package has the capability to take the external surface of a cylinder and unroll/unwind the surface, so that the external surface that extends all around the cylinder is virtually spread out and represented on a flat plane. Appendix 4 show virtual reconstructed images of the external threads of the external threaded socket that were unrolled and spread out on a flat plane. Appendix 5 show a virtual reconstruction images of the mating nut that was unrolled and spread out on a flat plane.

4.1.4 Re-assembly of the Union Assembly

The union insert, nut and external threaded socket portions were reassembled by hand. The nut was manually rotated by hand and hand pressure was used to tighten the nut. The assembly remained intact and could not be pulled apart by hand. Figure 8 shows a photograph of the union assembly for the lower gas regulator assembly (after re-assembly). The union assembly for the lower pressure regulator assembly contained a gap between the nut and mating threads on one side of the assembly, in the area between arrows “M” in figure 8. In comparison, the union assembly for the upper regulator assembly contained a gap between the nut and the mating threads that was minor (see area between arrows “N” in figure 8) compared to that on the lower gas pressure regulator assembly.

4.2 Upper Gas Regulator Assembly

Figures 1, 2, 3, and 9 show photographs of the upper gas regulator assembly. Detailed examination of the upper gas regulator assembly revealed the top cover melted and solidified remnants of the aluminum top cover were found between the diaphragm plate and body (see figure 9). The diaphragm plate was intact and attached to the pusher post. The flexible diaphragm was consumed by the fire and no trace of it was visible. The diaphragm plate was disassembled from the pusher post in order to expose the toggle links. The toggle links were intact and attached to the pusher post. The plug had melted and was not present. Solidified portions of the plug were found around the circumference of the 2-inch diameter port. The exposed orifice and disc portions of the valve mechanism were encased in solidified metal (see figure 10). The solidified metal was determined to be made from an aluminum alloy, according to analysis performed by an alloy analyzer at the NTSB Materials Laboratory. Although the plug for the upper gas regulator assembly melted and was not present, the plug for the lower gas regulator was intact. The plug from the lower regulator assembly was determined to be made from an aluminum alloy, according to analysis performed by an alloy analyzer at the NTSB Materials Laboratory.

An attempt was made to move the diaphragm plate in the vertical (up and down) orientation. This exercise did not result in movement of the disc. The disc and orifice were fully encased in an aluminum alloy solidified globule that prevented movement of the diaphragm plate and toggle links. The cup for the mercury reservoir was unscrewed from the body portion. Visual examination of disassembled cup revealed the inner chamber of the cup contained no evidence of a liquid pool of mercury.

4.2.1 Union Assembly for the Upper Gas Regulator Assembly

The vent port of the upper regulator assembly contained internal threads. A threaded nipple separated from the vent port of the upper gas regulator assembly, in the area indicated by arrow “X2” in figures 1, 2 and 11. The bottom end of the threaded nipple showed evidence of bending deformation relative to the length of its axis. The bending deformation was in the general direction indicated by an arrow in figure 11. The length of the deformed end measured approximately 0.22 inch. The bending deformation extended through approximately four threads. Each of the four threads showed evidence of severe bending deformation that was toward the exit port. The exposed threaded nipple and union assembly were covered with brown iron oxide. The first four threads on the vent port showed thread damage that coincided with those on the nipple (see figure 12).

As indicated earlier, a union assembly contains a nut, insert, and external threaded socket portion. The insert portion was located above the nut and the external threaded socket portion was located below the nut portion (see figure 11). An attempt was made to rotate the nut by hand. The nut was firmly attached to the external threaded socket and it could not be rotated by hand relative to the external threaded socket. The nut, external threaded socket and threaded nipple rotated together as a unit, relative to the insert portion. The insert portion was firmly attached to the threaded nipple above it and, in turn, the threaded nipple was firmly attached to the elbow. The external portions of the union assembly showed no evidence of a crack.

The union assembly was scanned by X-ray CT. Review of the reconstructed image of the union assembly showed that the threads for the external threaded socket and mating nut were intact (see Appendix 6). The external threaded socket was fully inserted into the nut, with the exceptions noted earlier regarding the ability to rotate the nut and external threaded socket relative to the insert portion.

Prior to disassembly, the union assembly was tested with compressed air at the Safety Board Materials Laboratory. The union assembly was pressurized with a continuous and uninterrupted supply of compressed air at a pressure range between 0.1 psig and 20 psig. The corresponding rate of air leak was measured with a flow meter. The lower end of the nipple (indicated by arrow X2 in Appendix 6) was fitted with a pipe internal plug and the other end was fitted with a pipe internal plug that contained a bypass port. The bypass port was used to allow compressed air to enter the union assembly. The pressure entering the union assembly was controlled by a pressure regulator and monitored with a pressure gage and flow meter.[7] Leak testing of the union assembly revealed a stream of air was leaking from the joint between the union nut and the mating external threads on the external threaded socket portion. Table 1 shows the applied pressure and corresponding volumetric leak rate in air that was leaking from the joint between the union nut and the mating external threads

[7] Pressure and flow were measured with a VPFlowcope® in-line electronic flow meter, manufactured by Van Putten Instruments, Netherlands.

on the external threaded socket portion. The volumetric leak rate in air was converted to a volumetric leak rate at standard conditions as if the pipe segment was tested with natural gas. The same test was conducted with the plug removed from the lower end of the nipple, so that compressed air can flow out of the lower (open) end of the nipple. Table_1 also shows the results of the leak test with a plug removed from the lower end of the nipple.

The union assembly was taken apart. Examination of the disassembled union assembly revealed the ball end of the union insert and the mating portion that mates with the ball portion showed no evidence of damage. The exposed external threads on the socket and mating threads showed no evidence of damage.

5.0 Fracture of the One-Inch ID Inlet Pipe

The one-inch ID inlet pipe fractured at the threaded end in the area adjacent to the reducer coupling. A thread remnant from the one-inch inlet pipe remained attached to the mating threads of the reducer coupling. The inlet pipe portion between the fractured end and approximately 4 feet below the fractured end exhibited a blue/gray tint, consistent with a ferrous metal that was exposed to heat from a fire. A pipe internal plug was found inserted into the open end of the reducer coupling. The pipe internal plug was inserted on-site by the gas company into the open end of the reducer coupling, in order to conduct pressure testing and prevent gas from escaping from the reducer coupling end.

The upper threaded end portion was excised from the of the one-inch inlet pipe. The exposed fracture face at the upper end of the threads was cleaned by immersing in EVAPO-RUST®. Bench binocular microscope examination of the excised piece revealed the fracture face and outer face all around the pipe was covered with blue/gray oxide scale. The fine fracture features on the face of the fracture were obliterated from exposure to heat from a fire. The fracture faces were on a slant plane consistent with overstress separation. Saw cut operations typically leave gouge marks that are oriented parallel to each other. The fracture face showed no evidence of saw cut marks.

The reducer coupling was disassembled from the two-inch diameter service pipe and the pipe plug was disassembled from the bottom end of the reducer coupling. The bottom end of the reducer coupling retained a thread fragment from the fractured one-inch inlet pipe. The reducer coupling and attached thread fragment from the inlet pipe were cleaned by immersion in EVAPO-RUST®. Bench binocular microscope examination of the reducer coupling revealed the thread remnant from the one-inch inlet pipe fractured at the root radius portion of the thread. The fracture face of the thread remnant contained a rough texture on slant planes consistent with overstress separation in ferrous alloys, with no evidence of a pre-existing fracture, such as fatigue, through-the-wall corrosion, or saw cut marks.

6.0 Threaded Nipple that Leads to a Pipe Tee for the Lower Row Gas Meters

The threaded nipple, indicated by arrow “Q” in figures 1, 2, 13, and 14, led to a pipe tee for the lower row of gas meters. Magnifying glass examination of the threaded nipple “Q” revealed the separated face contained parallel texture features consistent with a saw cut that extended through the diameter portion of the thread (see figure 15).

7.0 Pipe tee that Leads to the Upper Row Gas Meters

The pipe tee indicated by arrow “R” in figures 1, 2, 13, and 14 led to the upper row of gas meters. The pipe tee contained internal threads. Magnifying glass examination of the internal threads revealed the crown portions contained evidence of deformation damage (see figure 16). The crown portion of the threads showed evidence of deformation that was toward the open (exposed) end.

8.0 Vent Pipe

The external portion of the vent pipe segments showed no evidence of gouge or dent damage. To facilitate the inspection, the vent pipe segments were disconnected (disassembled) from the elbows in the areas indicated by arrows “K1” and “K2” in figure 1. The cap at the bottom of the drip leg was disassembled from the vent pipe. The internal portion of the vent pipe segments was inspected with an Olympus model iPlexLX video scope, hereafter referred as borescope. The flexible fiber optic probe portion was inserted into the pipe segments. The borescope inspection revealed the internal portion of the vent pipe contained no evidence of an obstruction.

9.0 Pipe Thickness and Diameter Measurements

Table 2 shows the measured size (outside dimeter, inside diameter, and wall thickness) of various pipes. Table 3 shows the diameter of pipes and schedule thickness values.[8] The measured sizes of the pipes are consistent with Schedule 40 pipe sizes.

10.0 Analysis for Evidence of Mercury

Residues were collected from various parts of the gas regulator assemblies and associated pipe pieces and they were analyzed by X-ray energy dispersive spectroscopy (EDS) analysis for evidence of mercury. Residues were collected from inside the mercury cup and the 2-inch diameter inspection port for each gas regulator assembly; the vent port for the upper regulator assembly; inside of the body for the upper regulator in the area between the diaphragm and mercury cup; the bottom end of the diaphragm plate for the lower regulator assembly; passage that leads to the mercury cup for lower regulator assembly; screen at the outside portion the vent pipe; internal surface of the vent pipe in the area approximately 2 feet from the outside open end of the vent pipe; inside the cap that was installed at the drip leg for the vent pipe, external treads on the union external threaded socket, flats on the union external threaded socket and mating union nut. The EDS spectrum for each residue typically contained elemental peaks of carbon, oxygen, magnesium, aluminum, silicon, sulfur, potassium, calcium, titanium, and iron (see typical EDS spectrum in figure 17). The intensity (height) of each elemental peak varied from sample to sample. The EDS spectrum for each residue showed no evidence of an elemental peak for mercury.

[8] Table from www.McNichols.com

11.0 2-inch ID Service Pipe – Cut Segments

A 2-inch ID service pipe segment, about 12 inches, was cut from the accident site. Another 2-inch ID service pipe segment, about 12 inches, was cut from the residence located at 8703 Arliss Street. Visual examination of both pipe segments revealed the internal and external surface showed no evidence of corrosion damage. The OD of the bare portions of the 2-inch ID service pipe segments measured approximately 2.38 inch, each, and the thickness of these pipe segments measured approximately 0.165 inch,

12.0 Round Plates

Three round plates were submitted for examination (see figure 1). The plates were not marked with identification information. The three round plates showed no evidence of a crack or corrosion damage that penetrated the wall. The diameter of each diaphragms plate measured approximately 6.2 inches.

The upper and lower gas regulator assemblies from the accident were disassembled and each assembly contained one diaphragm plate. The size of the diaphragm plate from the upper and lower gas regulator assembly each measured approximately 5.6 inches, smaller than any of the three individually submitted round plates. The three round plates did not originate from the accident gas regulator assemblies.

13.0 Deformation Damage

As indicated earlier, mercury-containing gas regulator assemblies are installed in a manner such that the internal diaphragm and saucer-like body portion of the assembly is to be oriented parallel to the ground (horizon). When visually examined, the body portion of the gas regulator assemblies exhibited general deformation relative to each other and several pipe segments. The alignment of the round, saucer-like, body portion of the upper and lower gas pressure regulator assemblies was not parallel to the ground (horizon). The east end of the saucer-like portion of each gas pressure regulator assembly was tilted down relative to the horizon, in the general direction indicated by angles "A" and "B" in figure 13.

The bottom portion of the inlet pipe was deformed relative to the top portion. The bottom end of the inlet pipe showed bending deformation that was toward the east, in the general direction indicated by angle "C" in figures 13 and 18. The threaded nipple that leads to a pipe tee for the lower row gas meters is indicated by arrow "Q" in figures 1, 2, 13, and 14. The length of the nipple was facing east and exhibited bending deformation that was up relative to the horizon, in the general direction indicated by angle "D" in figure 13.

The vent pipe assembly was placed next to the gas pressure regulators so that the horizontal (lateral) segments of the pipes were facing the east-west direction; the vertical segment of the pipes was facing up; and the threaded nipple, arrowed "Q" in figures 1, 2, 13 and 14 was facing east. The straight pipe extension was placed over the vent port for the upper gas regulator assembly and the orientation of the separated union joint parts for the lower gas regulator assembly were examined. In this reconstruction, the union insert in general was facing southeast, represented by angle "G" in figure 14. An imaginary line was projected between the open end of the union insert and the open end of the union external threaded socket portion of the union assembly in figure 14. Visual examination revealed the open end of the union external threaded socket was not aligned with the open end of the union insert portion of the union assembly. The angle between the imaginary line and the open end of the union external threaded socket portion is indicated by angle “F” in figure 14.

The vent pipe contained a pipe tee indicated by arrow “W” in figures 1, 13, 18 and 19 in the area next to the union assembly for the upper regulator assembly. An imaginary line was projected along the length of the vent pipe in the area indicated by a solid black line in figure 19. Examination revealed the vent pipe in the area below pipe tee arrowed “W” in figure 19 exhibited bending deformation, indicated by dashed line in figure 19, relative to the vent pipe portion above pipe tee arrowed “W” in figure 19. The angle between the imaginary line and the portion that exhibited bending deformation is indicated by angle “H” in figure 19. The bottom end of the vent pipe was deformed west, relative to the pipe portion above pipe tee arrowed “W” in figure 19.

14.0 Other Observations

The outer surface of the gas regulator assemblies, pipe segments, and nipples that led to the gas regulator assemblies contained no evidence of corrosion damage that penetrated the wall of these respective pieces.

Frank Zakar
Senior Metallurgist

FIGURES

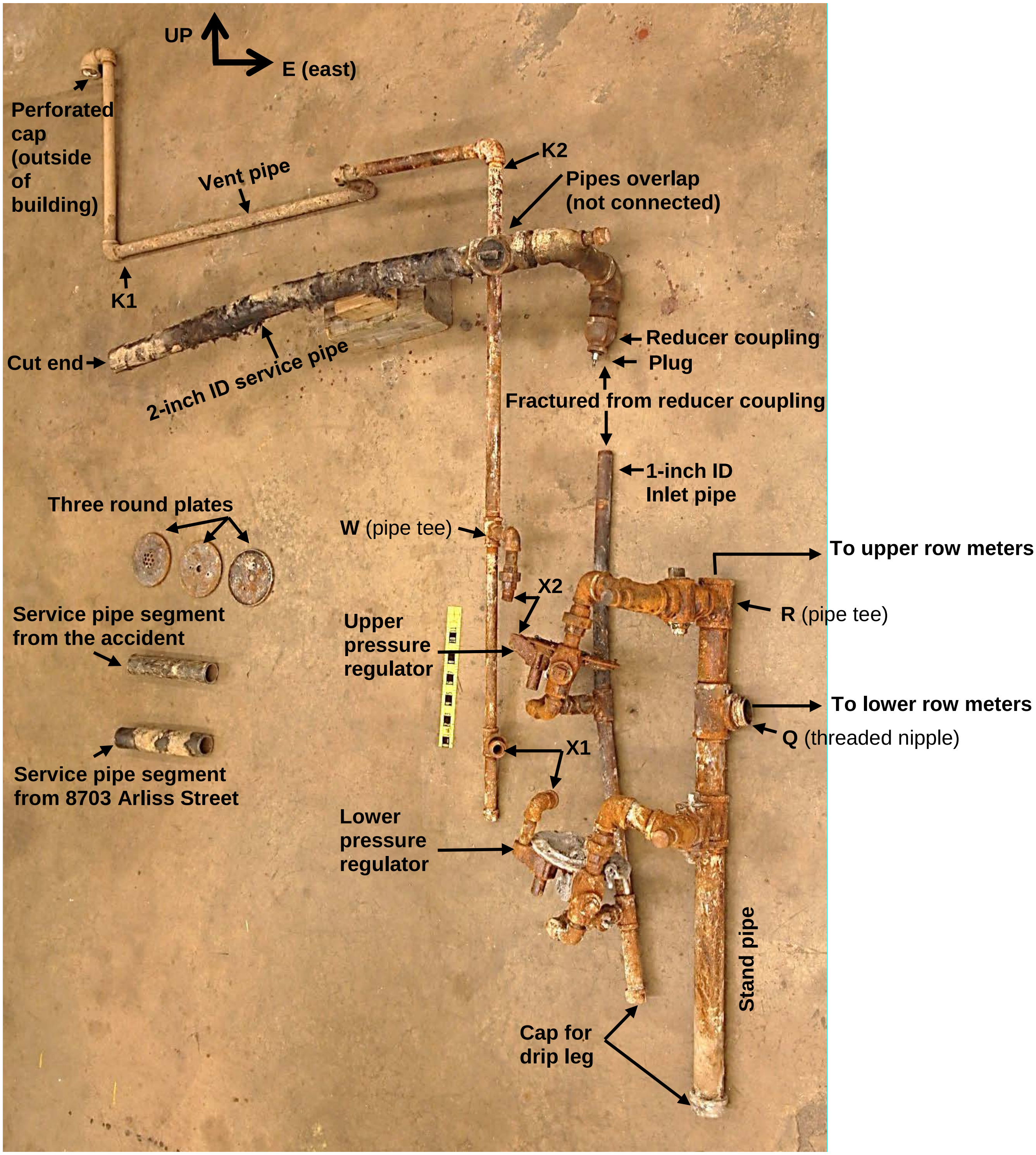


Figure 1. Photograph of the two as-received natural gas pressure regulator assemblies and associated pipes, relative to each other as if installed. The regulator assemblies separated from the vent pipe in the areas indicated by arrows “X2” and “X1”. The up and east (E) orientations are indicated in the photograph. Vent pipe segments were disassembled at NTSB Materials Lab at the elbow locations in areas indicated by arrows “K1” and “K2”.

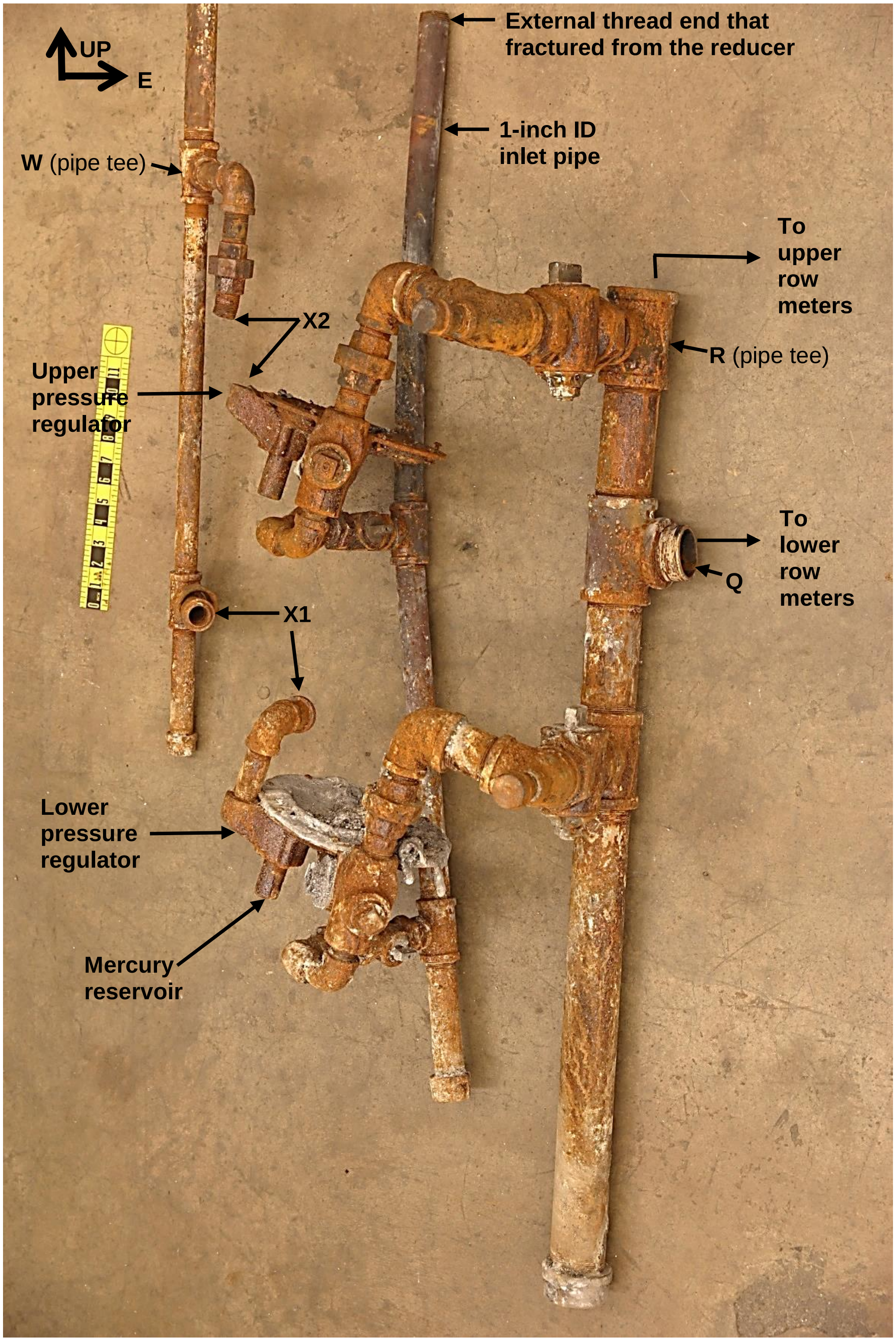


Figure 2. Close-up photograph of the two natural gas pressure regulator assemblies.

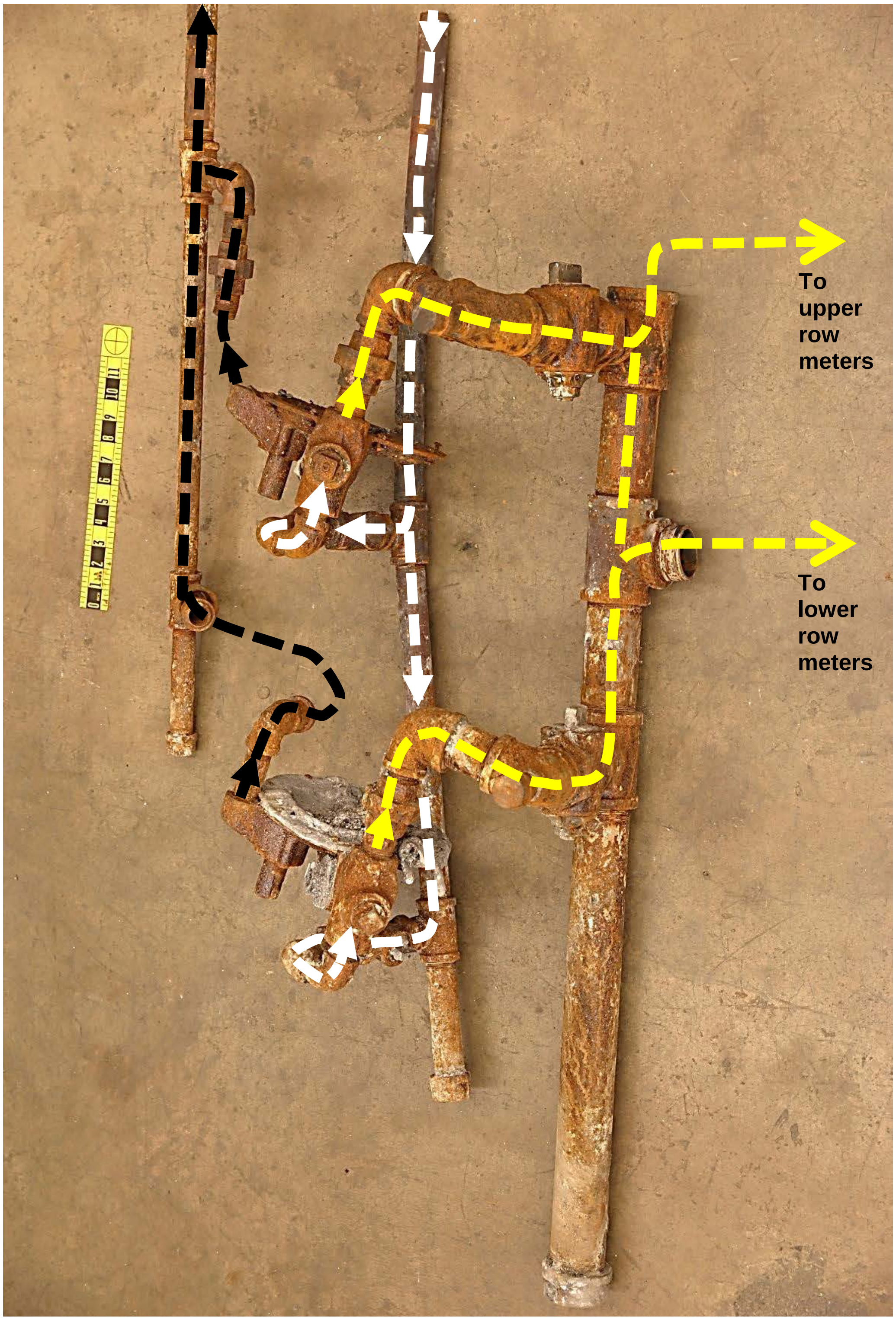


Figure 3. Same photograph as in figure 2 showing the general direction of gas flow during normal operation. Arrows indicate the general direction of gas flow. Gas flow from the service line is indicated by white dashed lines. Gas (reduced pressure) from the gas regulator assembly is indicated by yellow dashed lines. When intact and in the event of excess gas pressure within the regulator assembly, gas would exit the vent port and flow through the vent pipe in the general direction indicated by black dashed lines. Photograph shows all possible gas flow combinations.

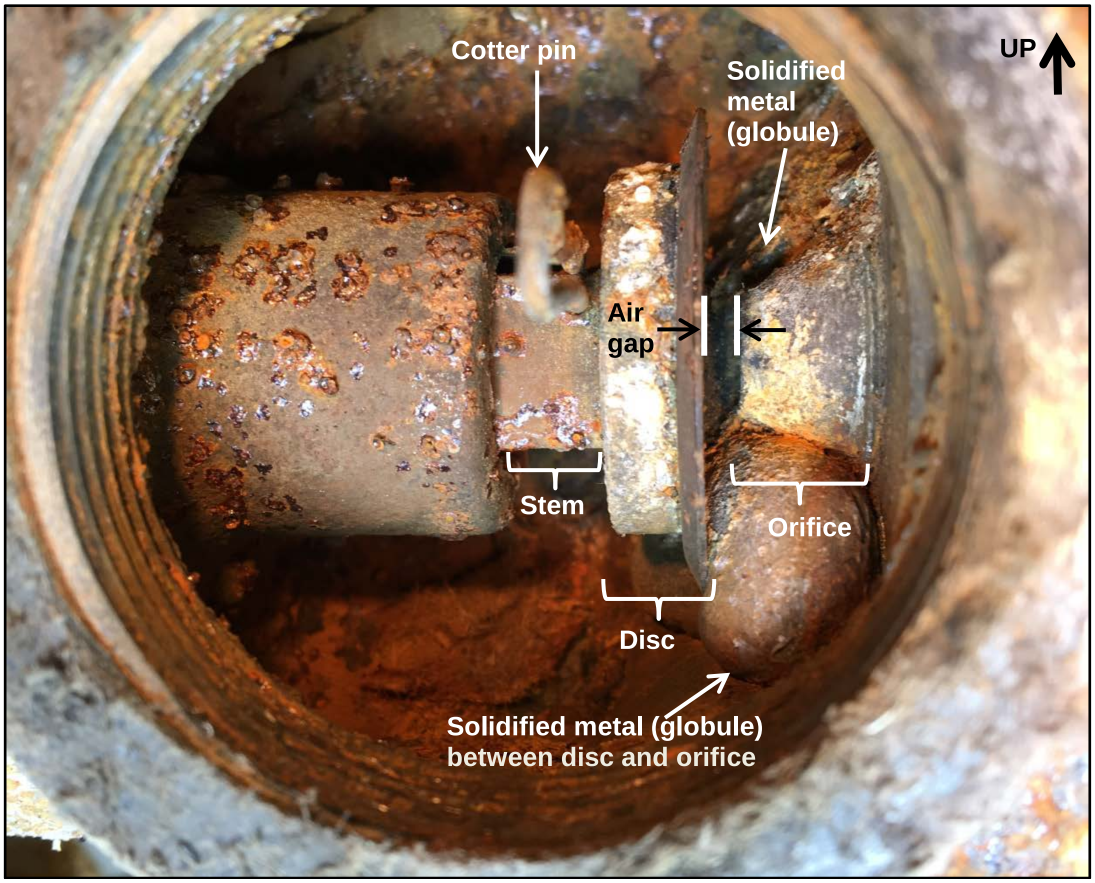
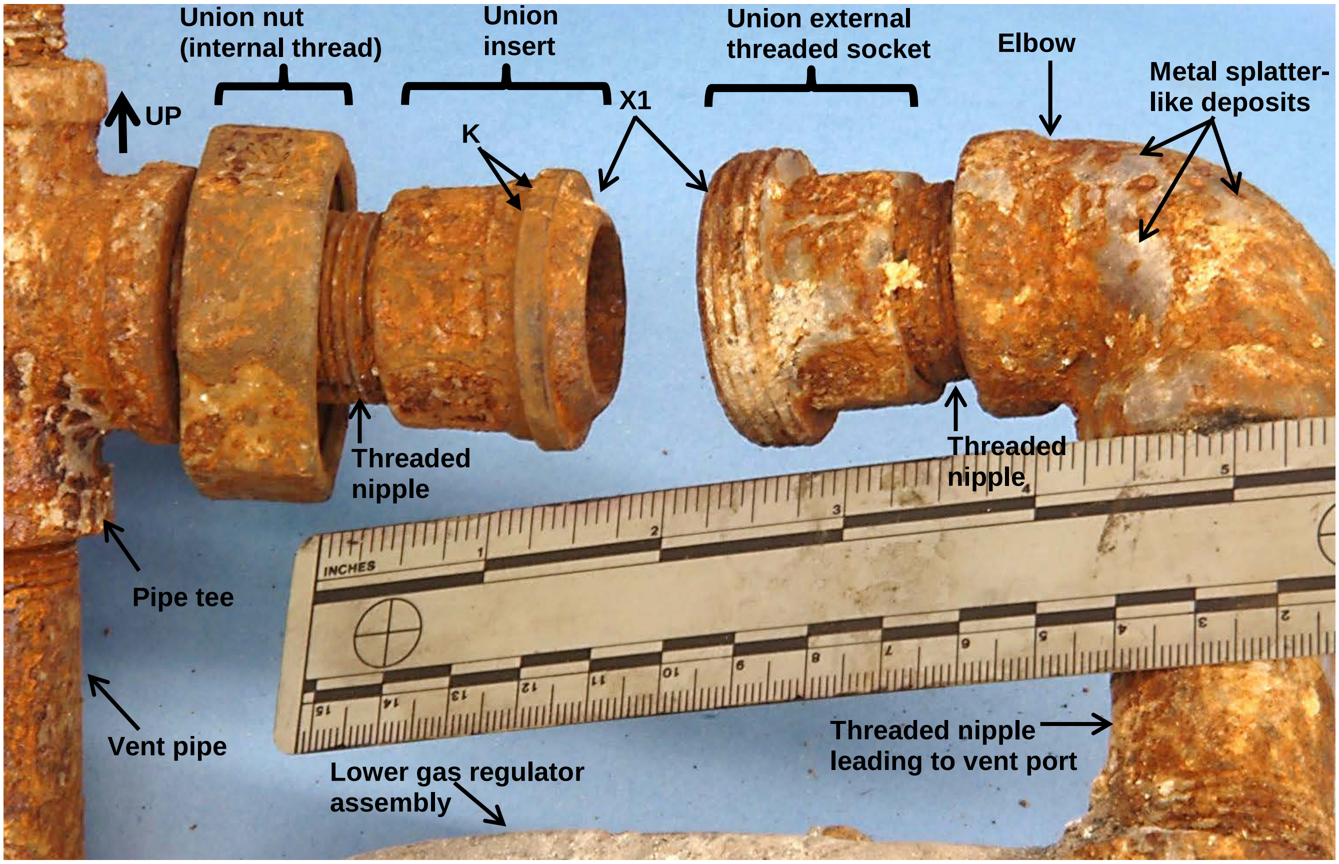


Figure 4. View through the 2-inch diameter internal threaded side port of the lower gas regulator assembly after disassembly of the plug, after cleaning the internal cavity with a soft bristle brush.



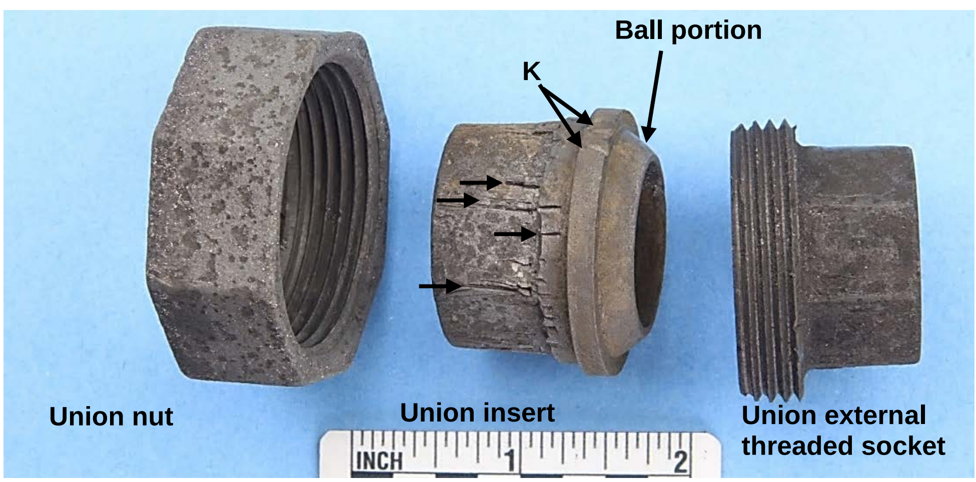
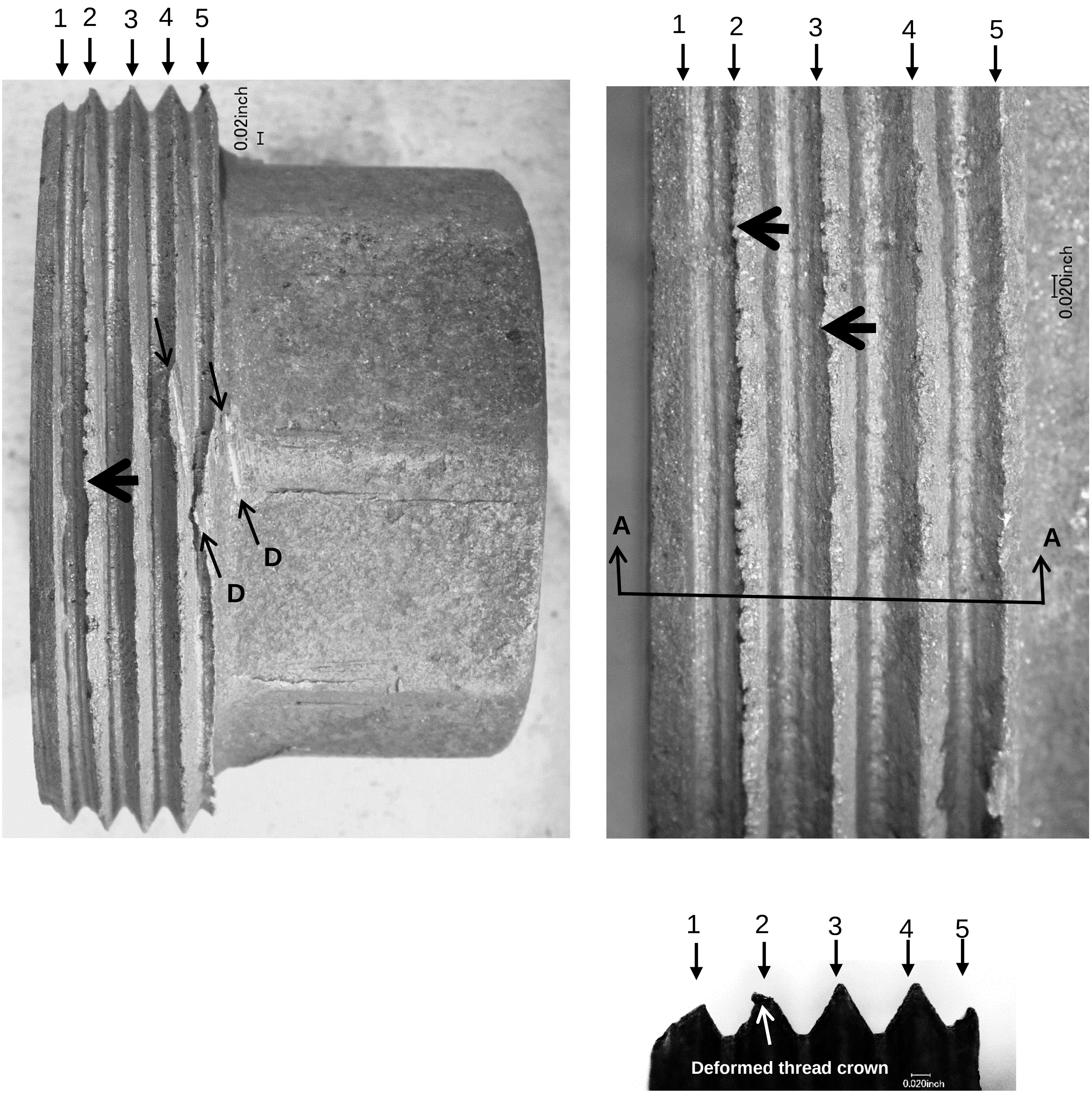


Figure 5. Photograph on upper side of page shows the union assembly for the lower gas regulator assembly that separated in the area indicated by arrows “X1”. Parts were intentionally aligned next to each other at the NTSB Materials Laboratory for the purpose of describing the different parts of the union assembly. Photograph on the lower side of the page shows the disassembled lower union assembly (union nut, union insert and external threaded socket) after cleaning with EVAPO-RUST®. Unmarked arrows indicate tool marks from a pipe wrench that was used at the NTSB Materials Laboratory to disassemble the union assembly. Arrows “K” indicate tool marks that were present prior to disassembly and cleaning.



Side Profile “A-A”

Figure 6. View of the disassembled union external threaded socket from the lower gas regulator (left upper corner of page); close-up photograph of the external threads (right upper right corner of page); side profile of external threads (lower right corner of page). Crown portion of the threads were randomly numbered “1” through “5”. For the purpose of this report, thread “1” is the first thread. Minor deformation was found on the crown of the threads in the area indicated by unmarked arrows in the two upper photographs. Direction of metal flow is indicated by the unmarked arrows. Parallel dent marks are indicated by arrows “D”.

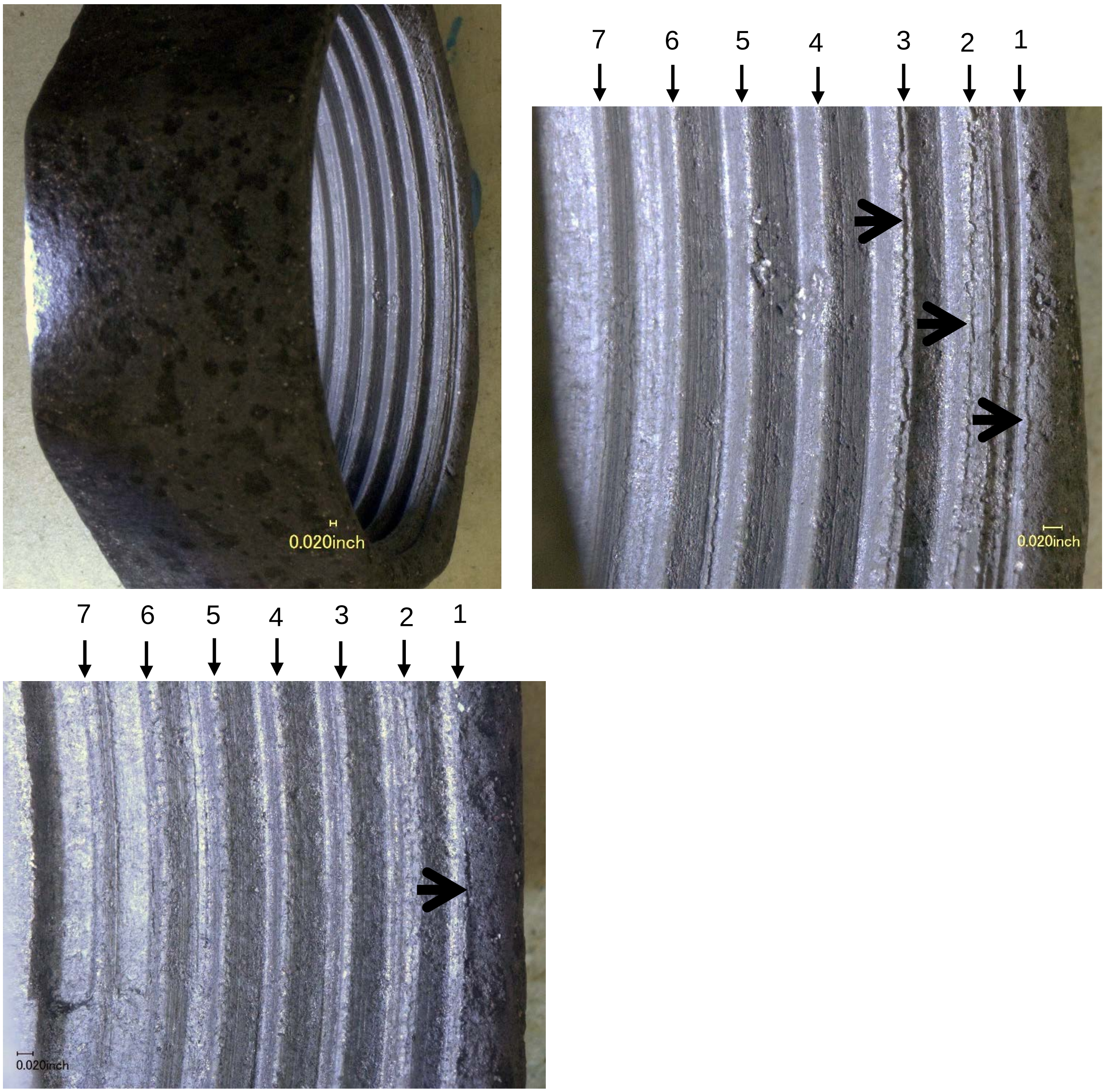


Figure 7. Photographs of the nut showing the internal threads (upper left corner of page); close-up view of the internal threads (upper right corner of page); and close-up of internal threads on the diametrically opposite side (lower left corner of page). Crown portion of the threads are randomly numbered “1” through “7”. Minor deformation was found on the crown of the first three threads in the area indicated by unmarked arrows, and on the crown of the first thread in the diametrically opposite side. Direction of metal flow is indicated by arrow. For the purpose of this report, thread “1” is the first engaging thread.

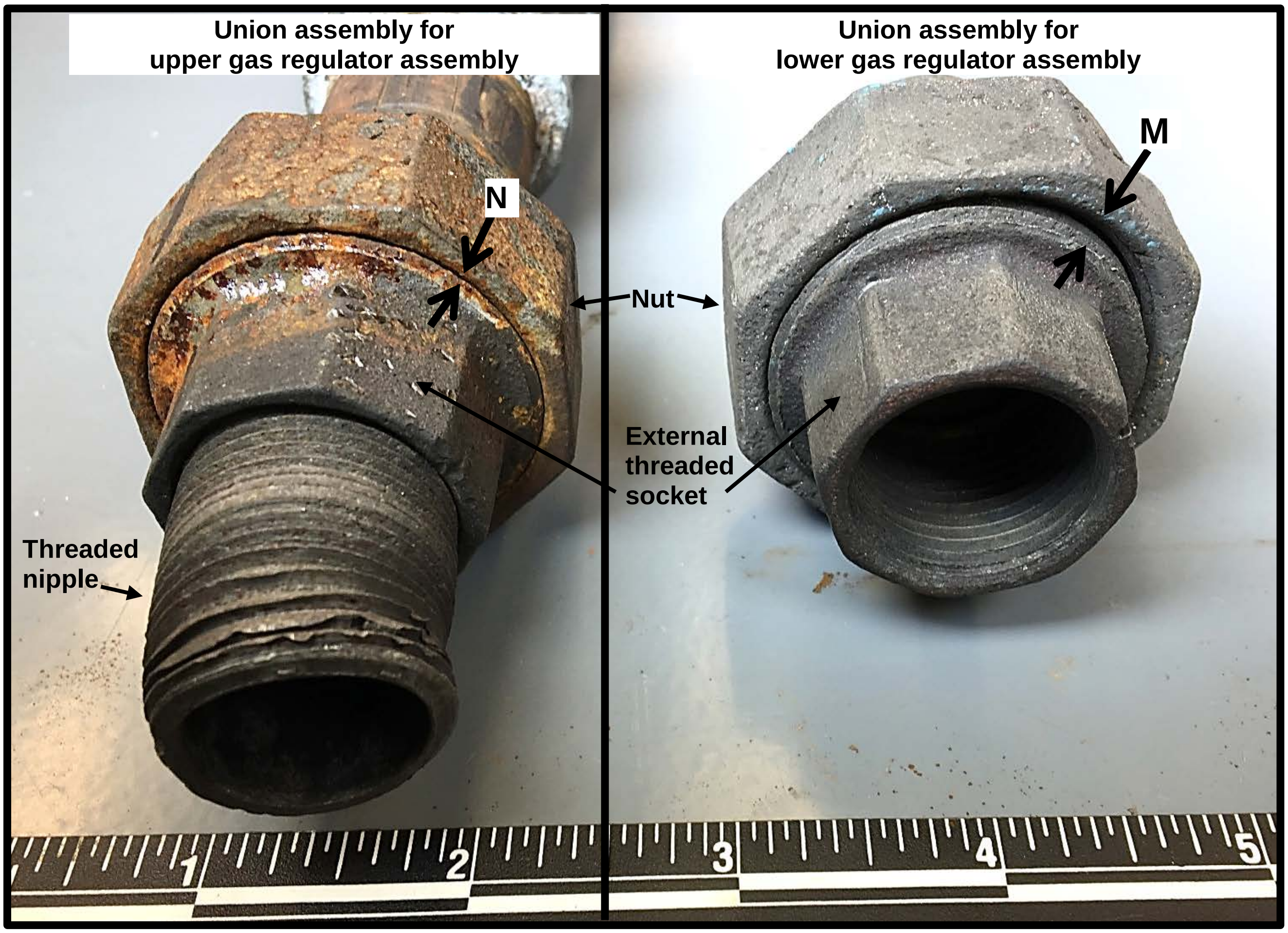


Figure 8. Photograph of the union assembly for the upper and lower gas regulator assemblies when placed next to each other for comparison (after the union assembly for the lower gas regulator was re-assembled). Note the gap between the nut and mating threads on the union assembly for the lower gas regulator assembly in the area between arrows “M”, compared to same respective area on the other assembly (between arrows “N”).

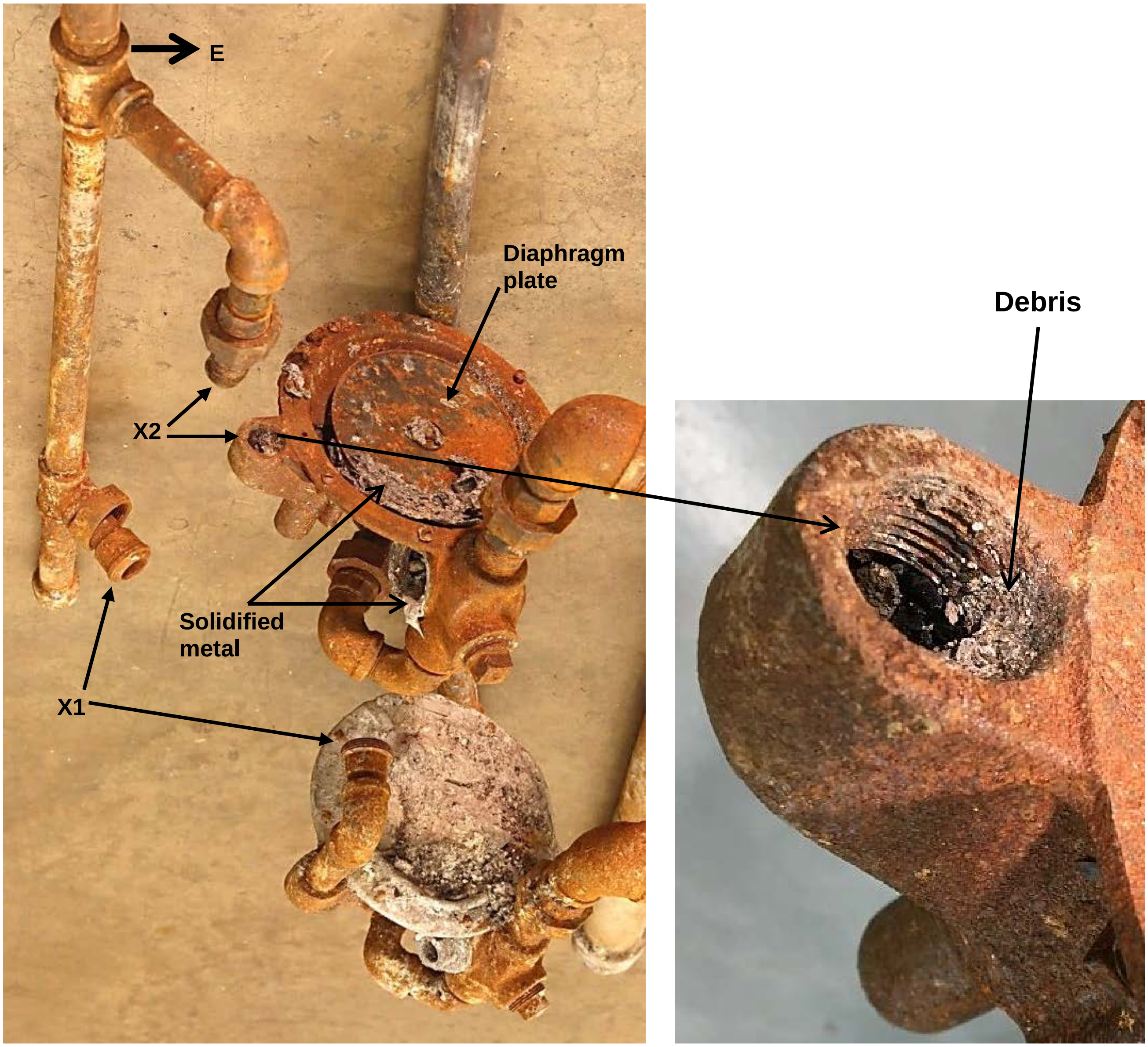


Figure 9. View of the internal threaded portion at the vent port of the upper gas regulator assembly.

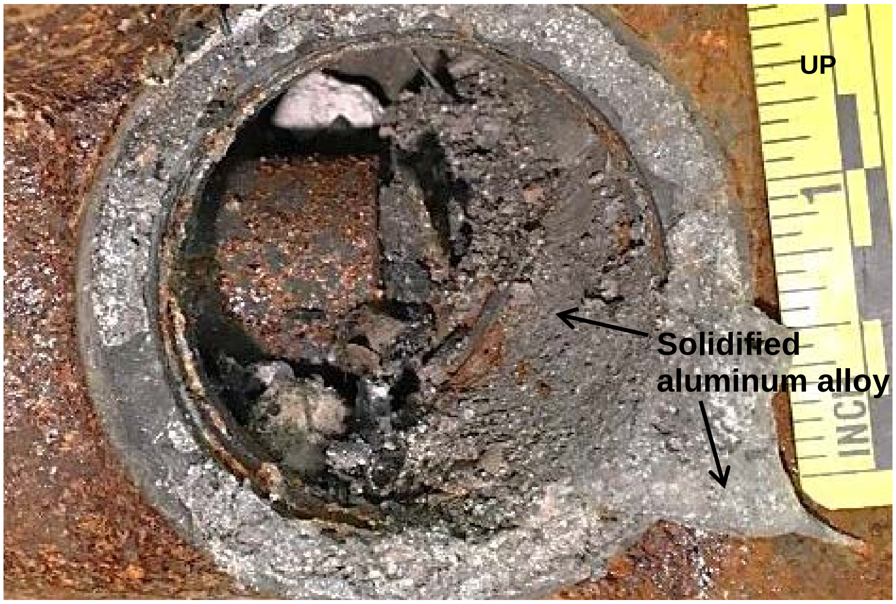


Figure 10. View through the 2-inch diameter side port of the upper gas regulator assembly showing solidified aluminum alloy that encased the orifice and disc portions.

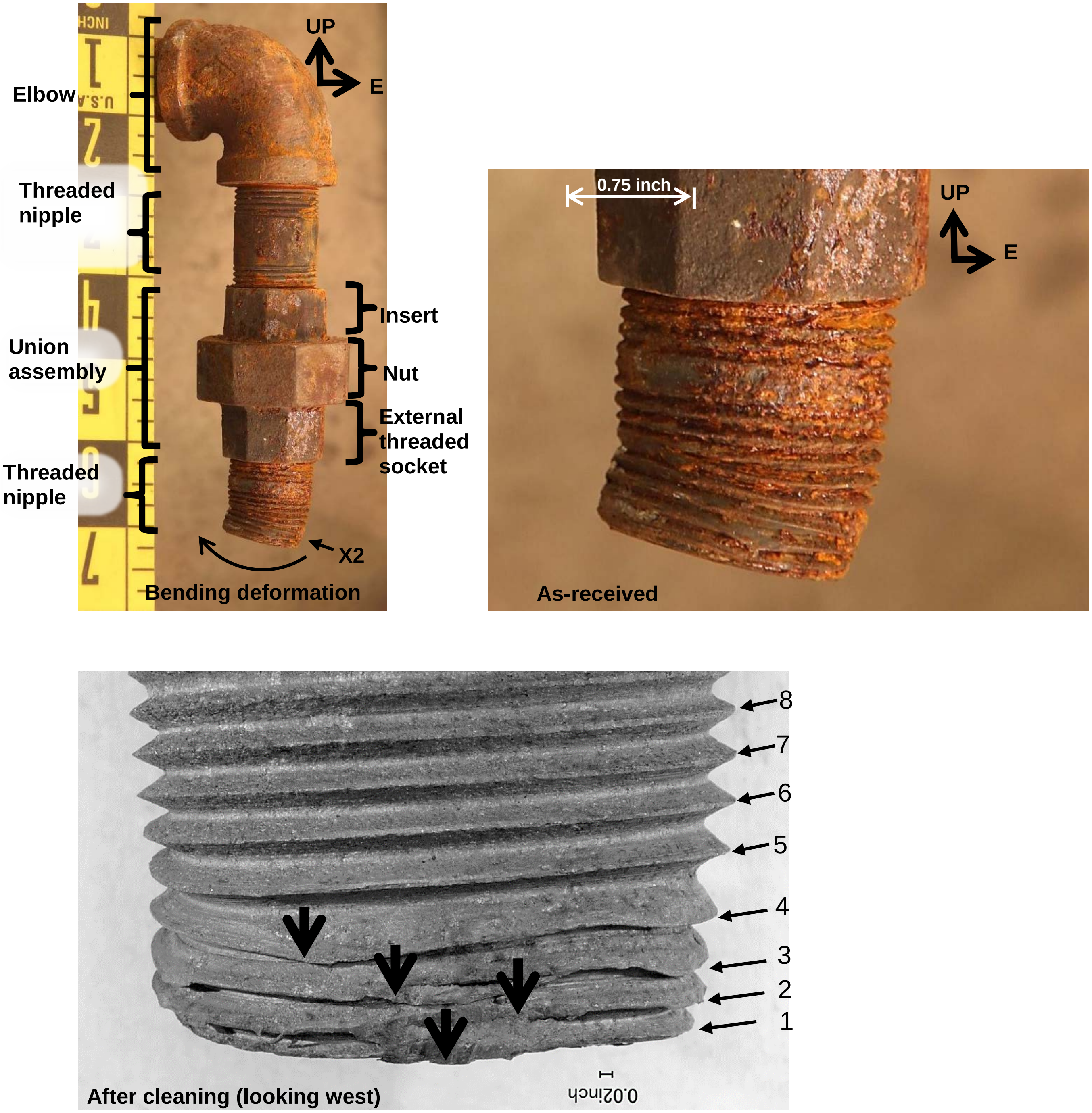


Figure 11. View of the exposed external threaded pipe that separated from the vent port for the upper regulator assembly. The mating internal threads are shown in figure 12. Crown portion of the first eight threads were randomly numbered “1” through “8”. For the purpose of this report, thread “1” is the first engaging thread. Bending deformation was found on the first four threads in the areas indicated by unmarked arrows, and also in the direction indicated by the respective arrows. For the purpose of this report, thread “1” is the first engaging thread.

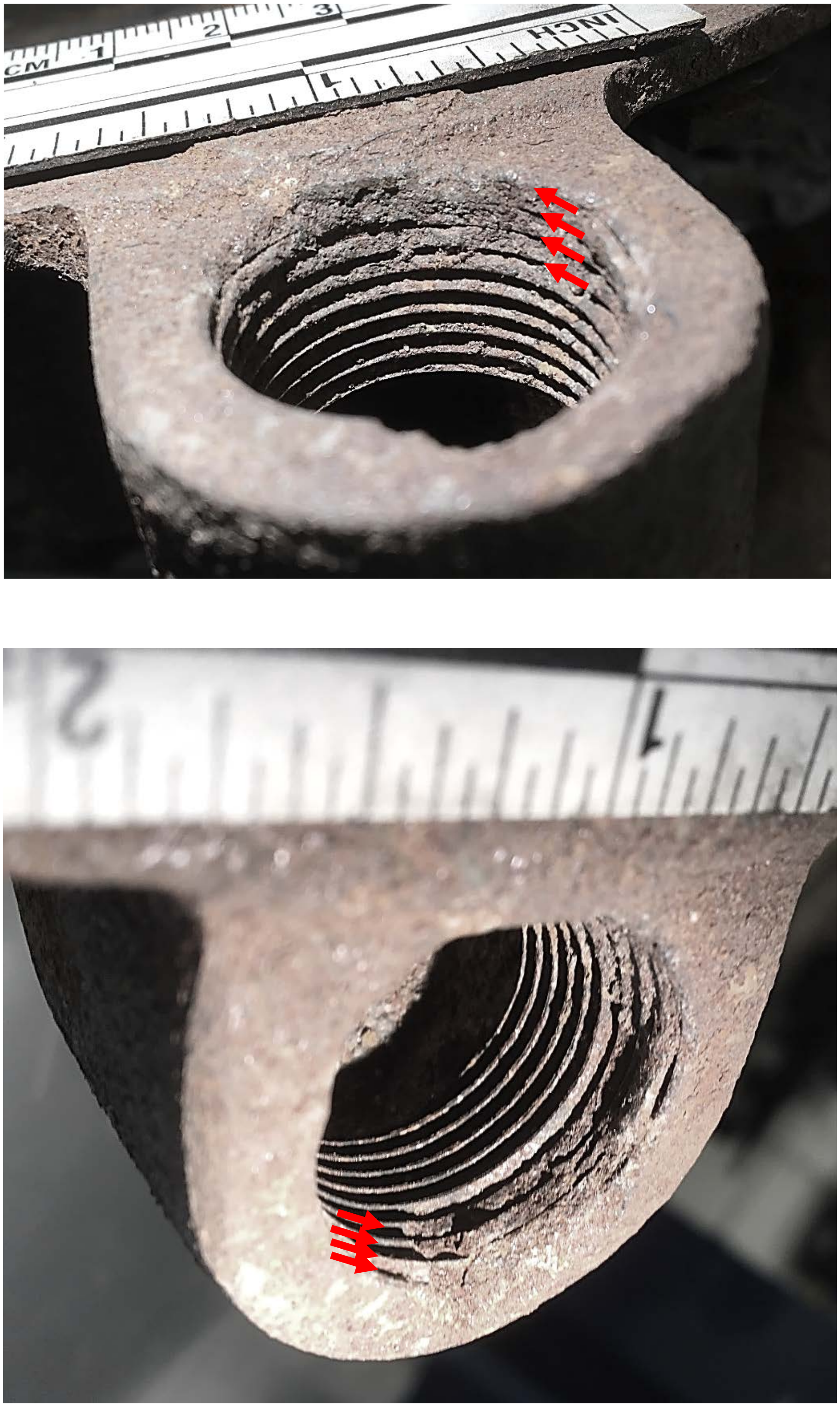


Figure 12. Views looking into the vent port of the upper gas regulator assembly, after brush cleaning with methanol, showing mechanical damage to the first four threads adjacent to the opening of the vent port, areas indicated by arrows.

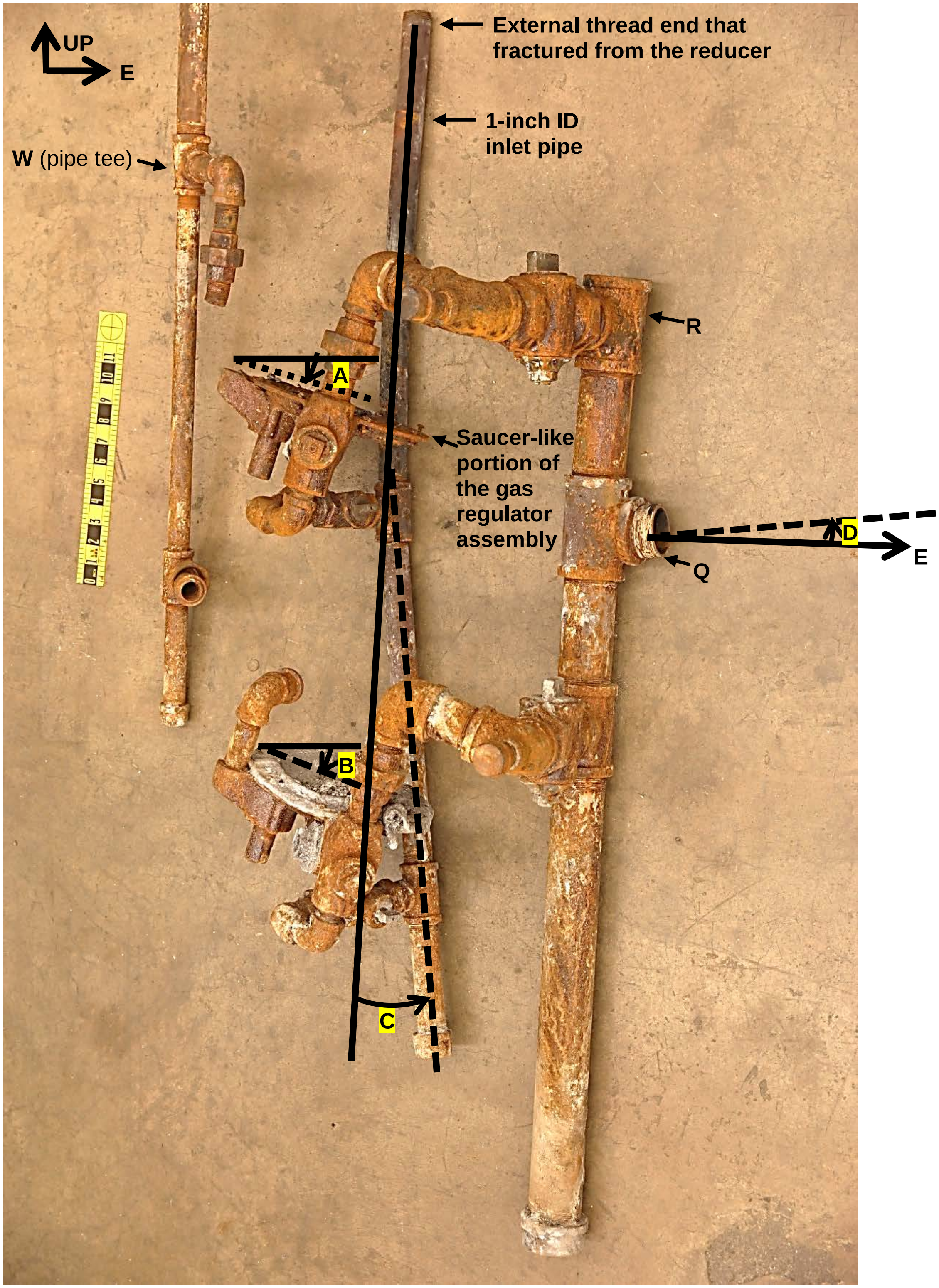


Figure 13. Side view of the upper and lower pressure regulator assembly.

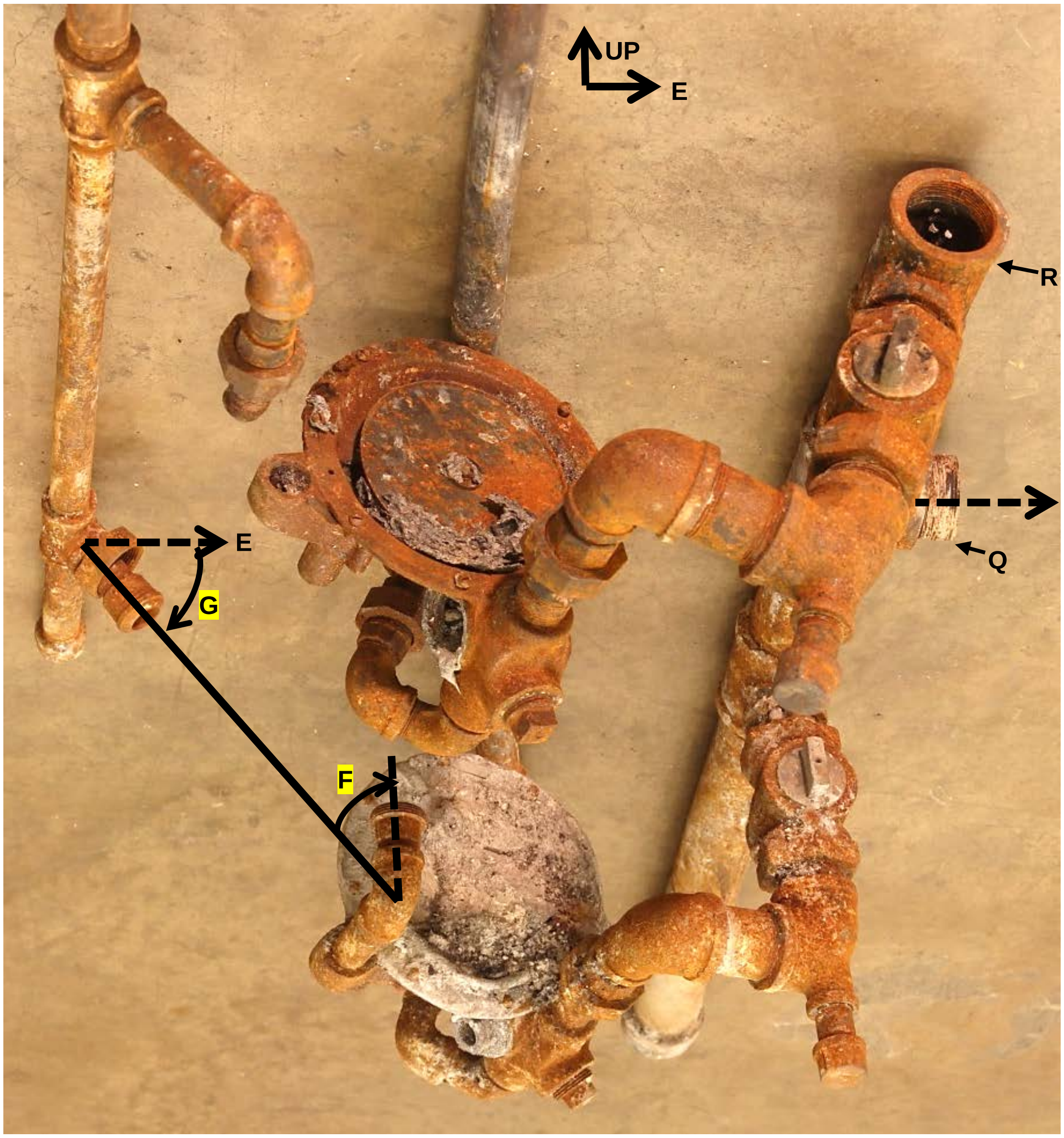


Figure 14. View looking down at the upper and lower pressure regulator assembly. East is indicated by “E”.

Figure 15. The threaded nipple, indicated by arrow "Q" in figures 1, 2, 13, and 14 that led to a tee for the lower row of gas meters showing saw cut features that extended through the entire diameter.

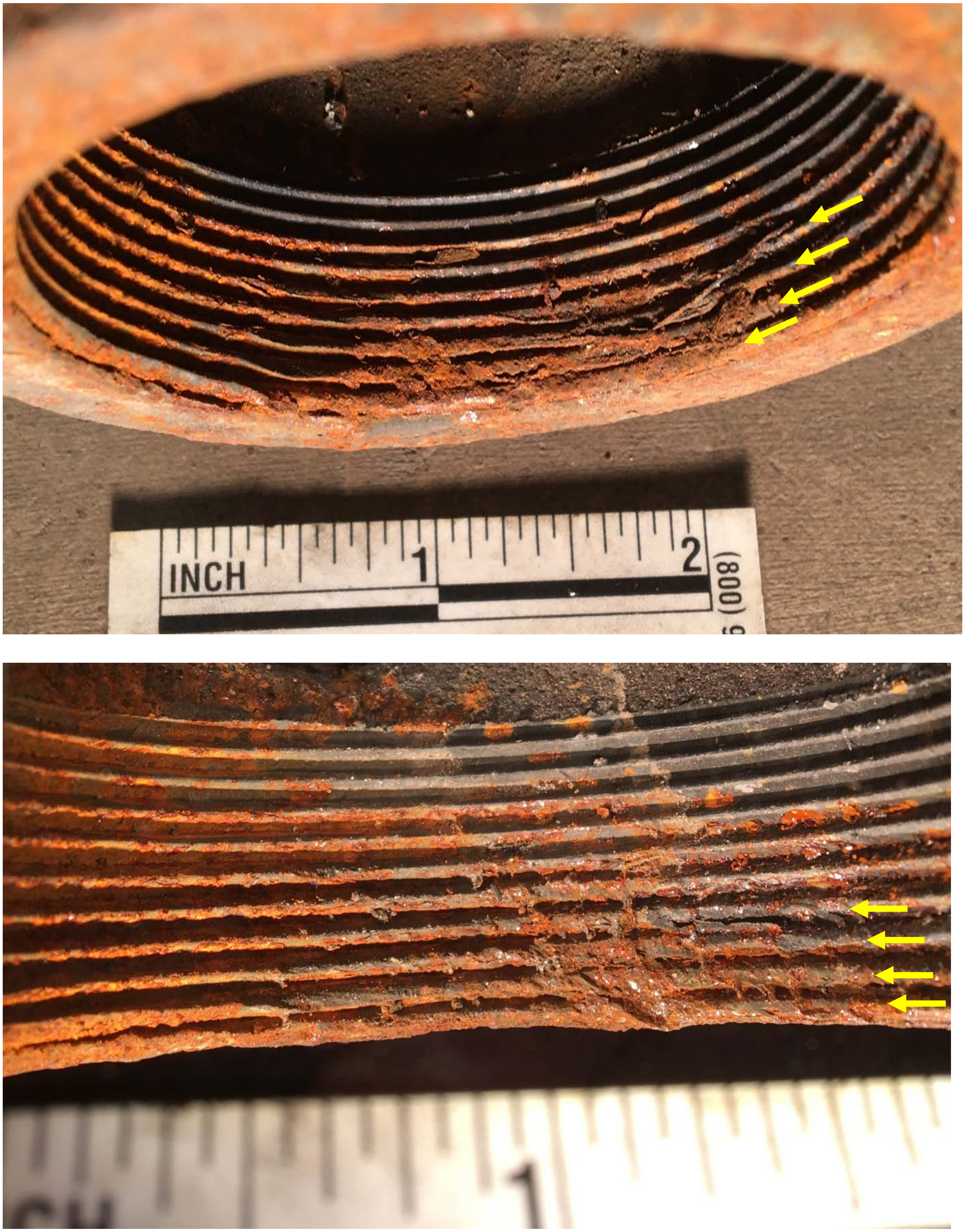


Figure 16. Views looking inside of the pipe tee indicated by arrow “R” in figures 1, 2, 13, and 14 that leads to the upper row of gas meters. Photograph at the bottom of the page shows the diametrically opposite side. The first four threads adjacent to the opening in the areas indicated by arrows exhibited thread deformation damage.

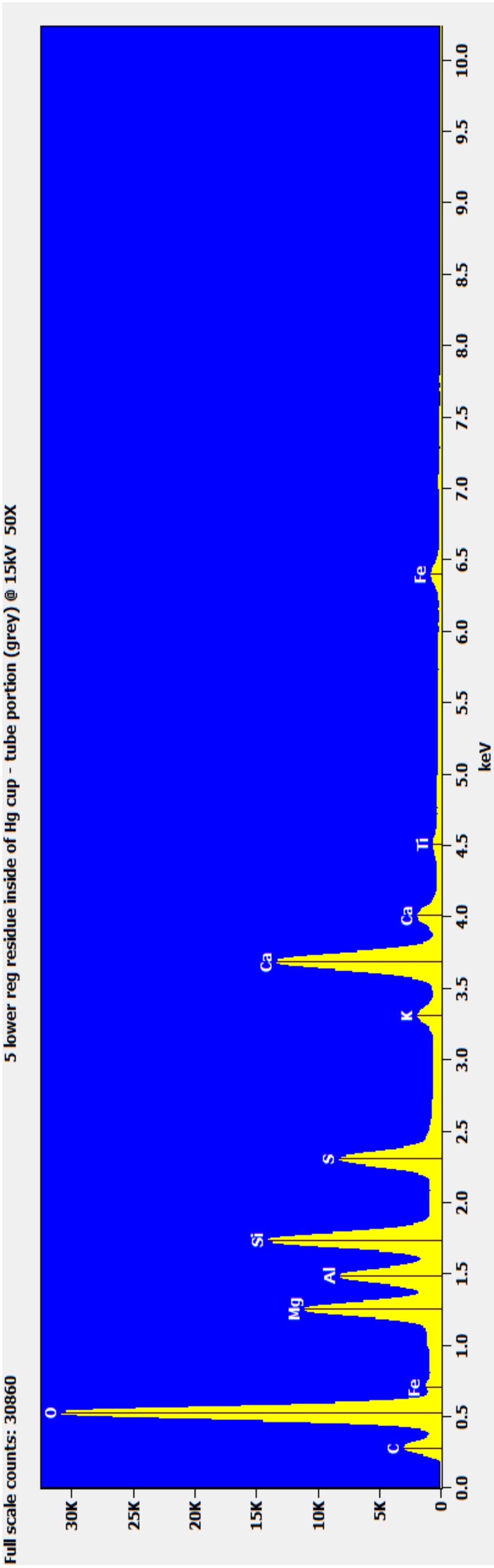


Figure 17. EDS spectrum of a typical residue that was found inside of the mercury cup for the lower regulator assembly.

Figure 18. View looking up at the upper and lower pressure regulator assembly.

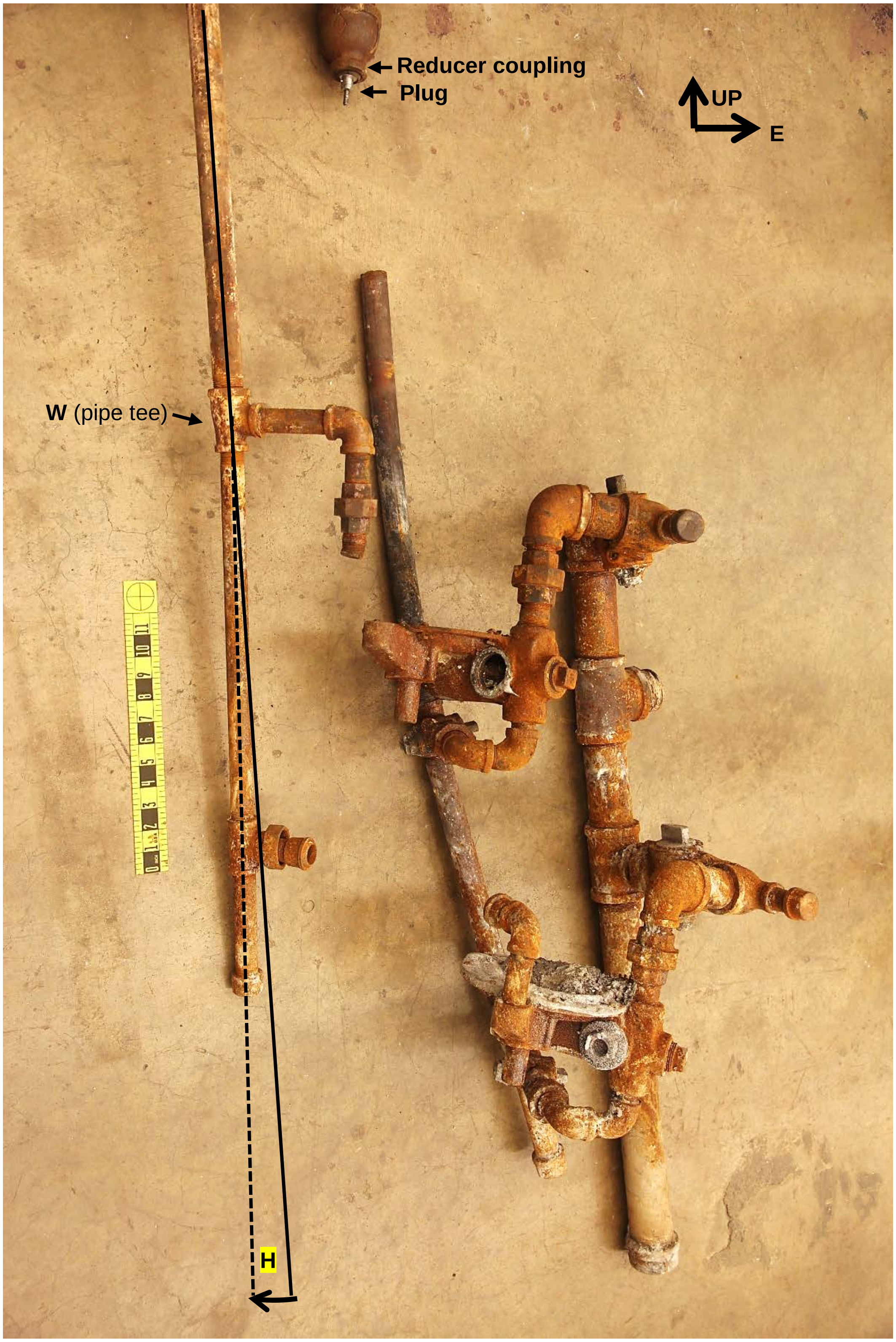
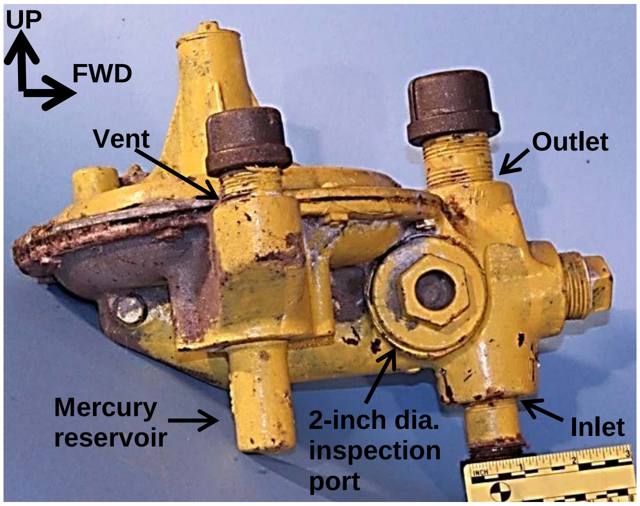
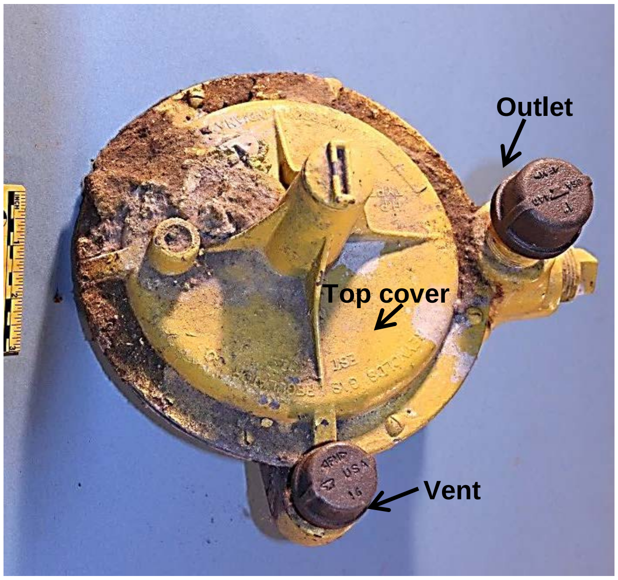


Figure 19. Another side view of the vent pipe.

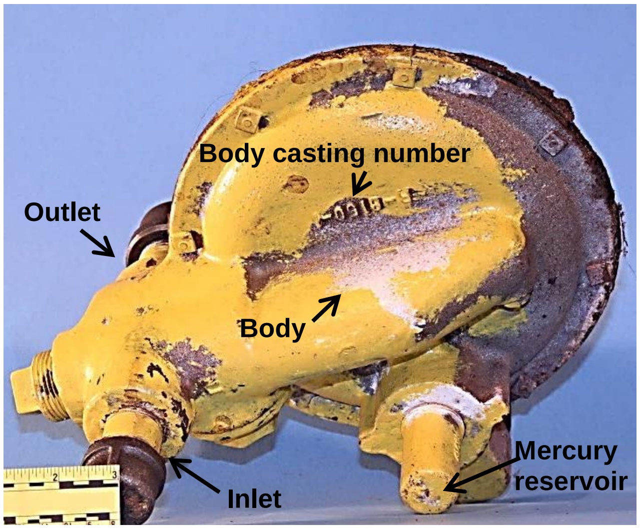
APPENDICES



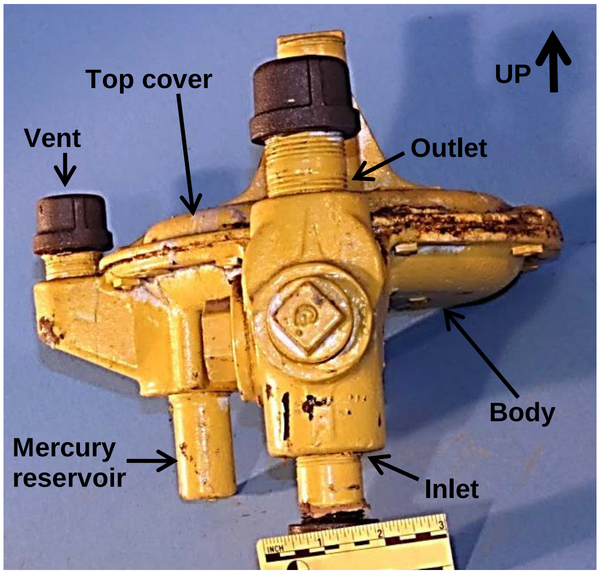
Side view showing 2-inch dia. inspection port and mercury reservoir



Top side

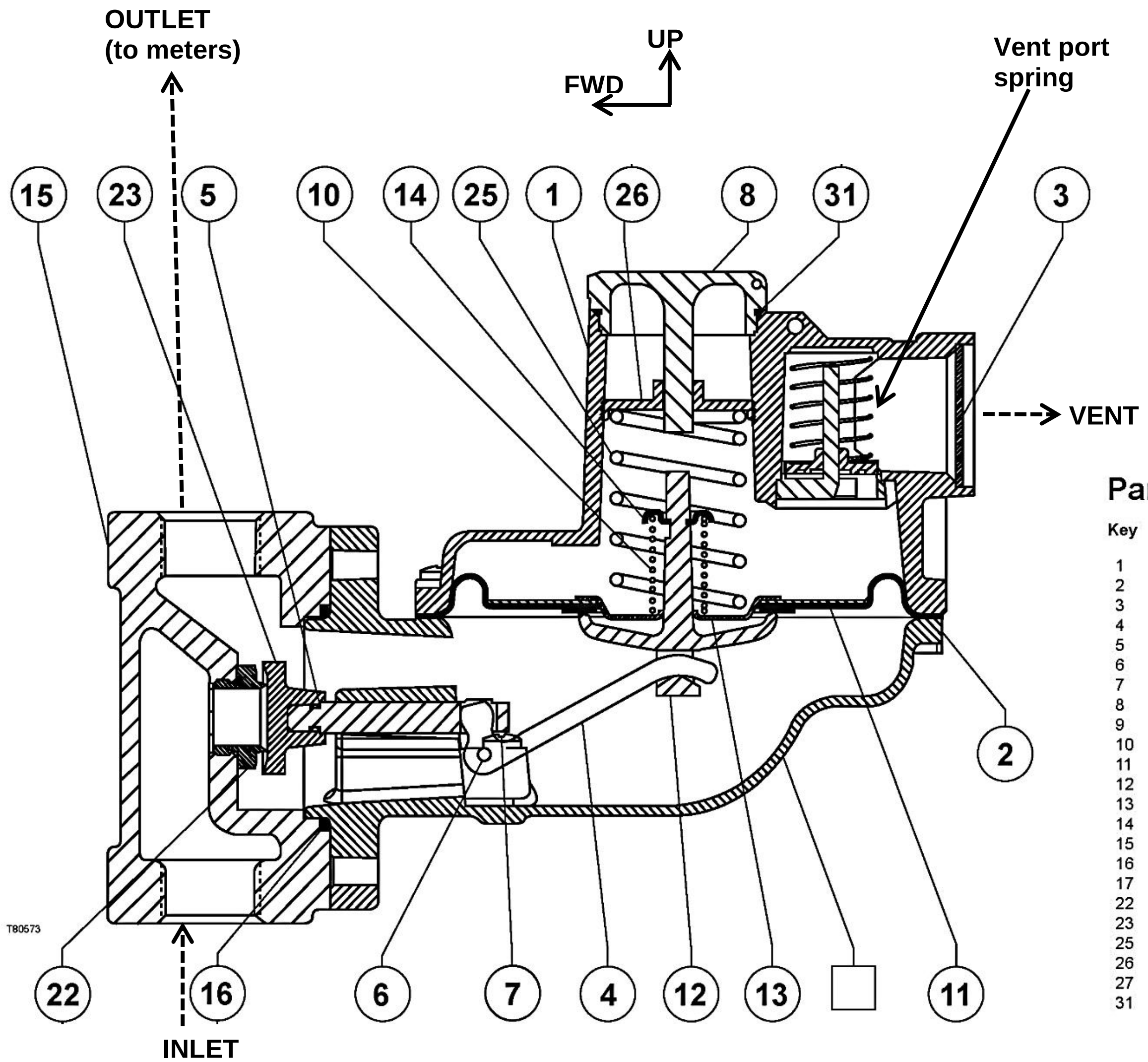


Bottom side



Another side view

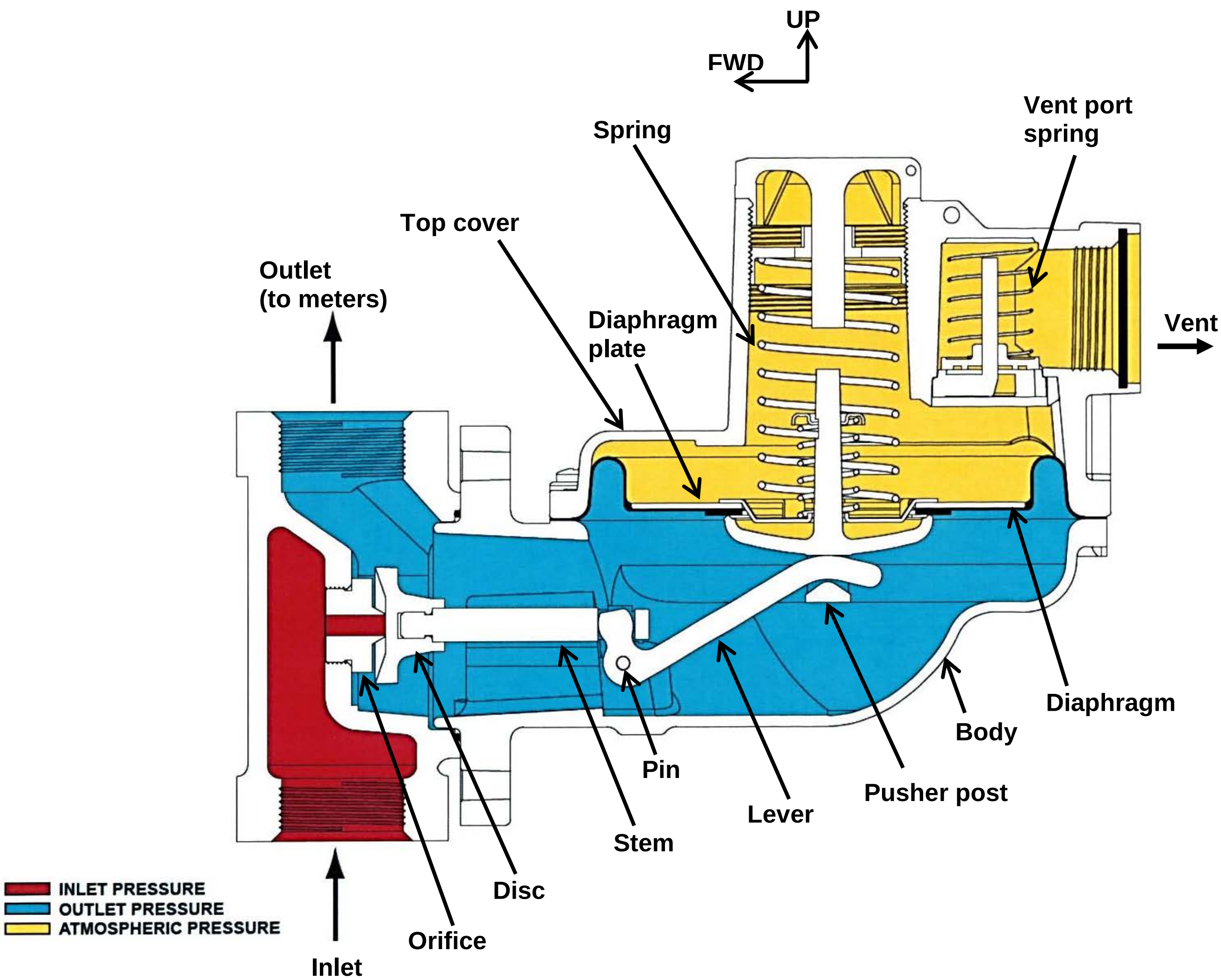
Appendix 1. Multiple views of an exemplar mercury-containing natural gas pressure regulator assembly that was not involved in the accident. The inlet, exit and vent ports were capped after disassembly to prevent accidental leakage of mercury. This exemplar gas regulator assembly was disassembled from the residence at 8642 Piney Branch Road. The forward end of the assembly is indicated by "FWD"



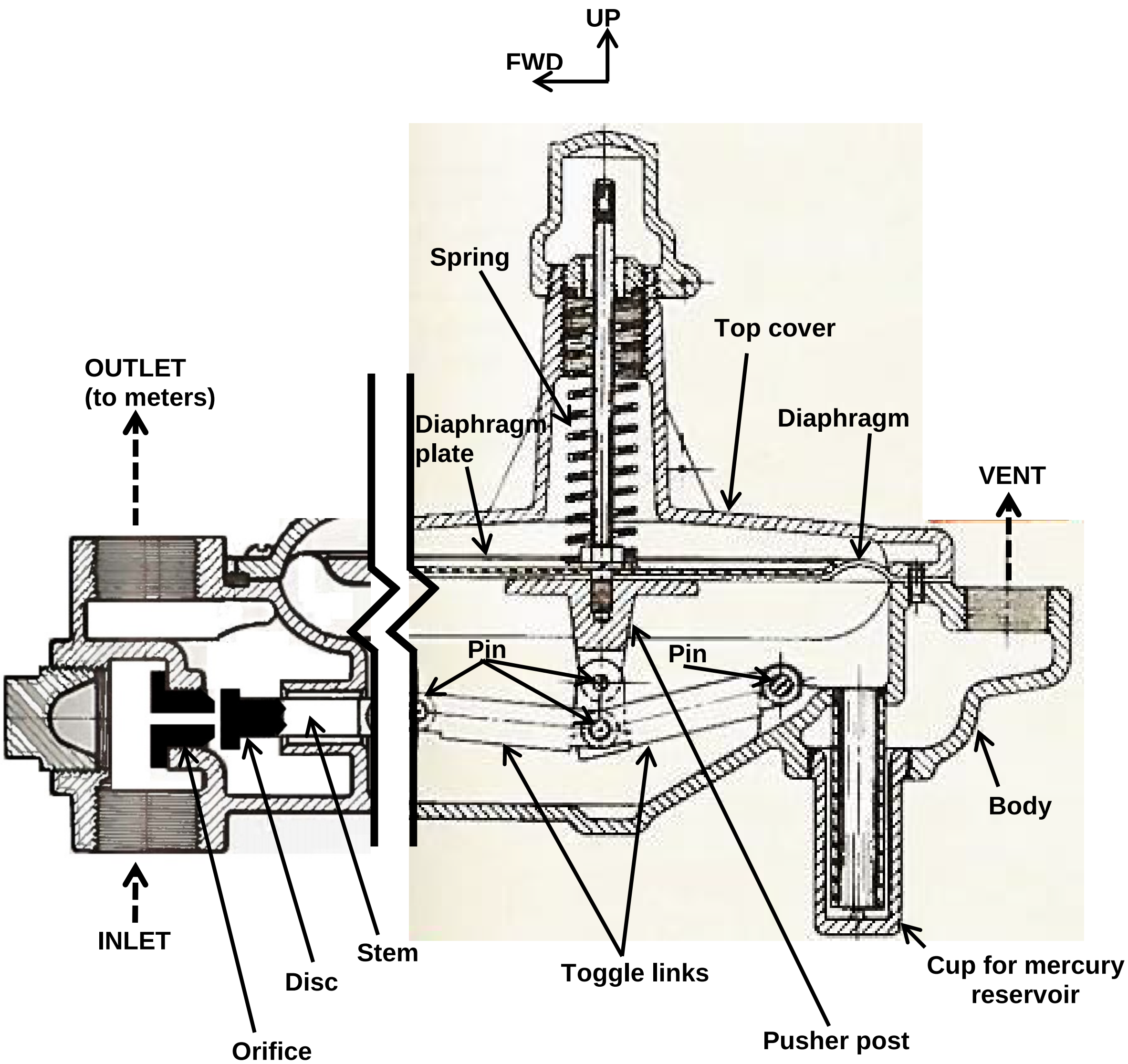
Parts List

Key	Description
1	Spring Case Assembly
2	Lower Casing
3	Screen
4	Lever
5	Stem
6	Straight Pin
7	Machine Screw (2 required)
8	Closing Cap
9	Machine Screw (8 required)
10	Relief Valve Spring
11	Diaphragm
12	Pusher Post
13	Lower Spring Seat
14	Relief Spring Retainer
15	Body
16	O-Ring
17	Cap Screw (2 required)
22	Orifice
23	Disc
25	Spring
26	Adjusting Screw
27	Information Label
31	Closing Cap O-Ring

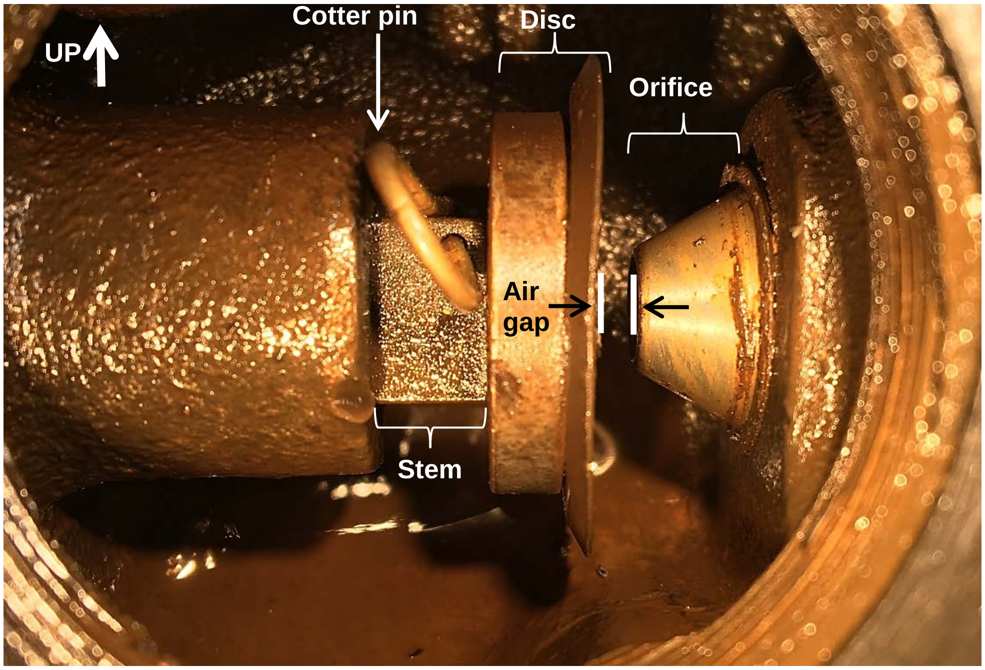
Appendix 2A. Cross section diagram of a typical non-mercury-containing gas pressure regulator assembly showing the internal parts. The model shown is an Emerson Type HSR pressure-reducing regulator that was not involved in the accident. This diagram is used for education/illustration purpose. For the purpose of this report, the portion of the assembly that contains the inlet and outlet are referred as the forward (FWD) end. Source: Emerson Instruction Manual; Emerson Process Management Regulator Technologies, Inc.; www.fisherregulators.com



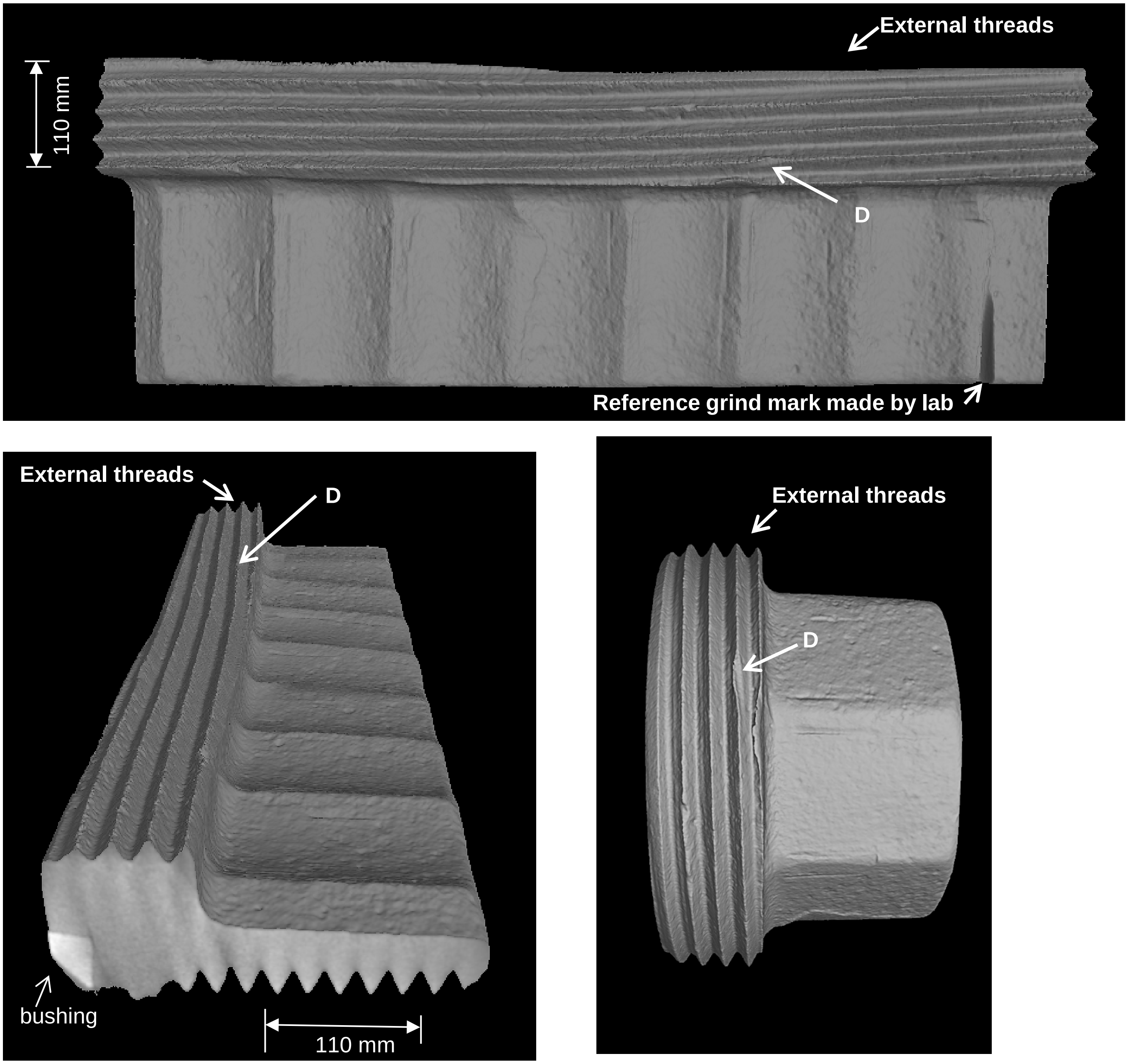
Appendix 2B. Same cross section as in Appendix 2A with the exception that various pressure chambers were color-coded. The model shown is an Emerson Type HSR pressure-reducing regulator that was not involved in the accident. The diagram is used for education/illustration purpose. Source: Emerson Process Management Regulator Technologies, Inc.



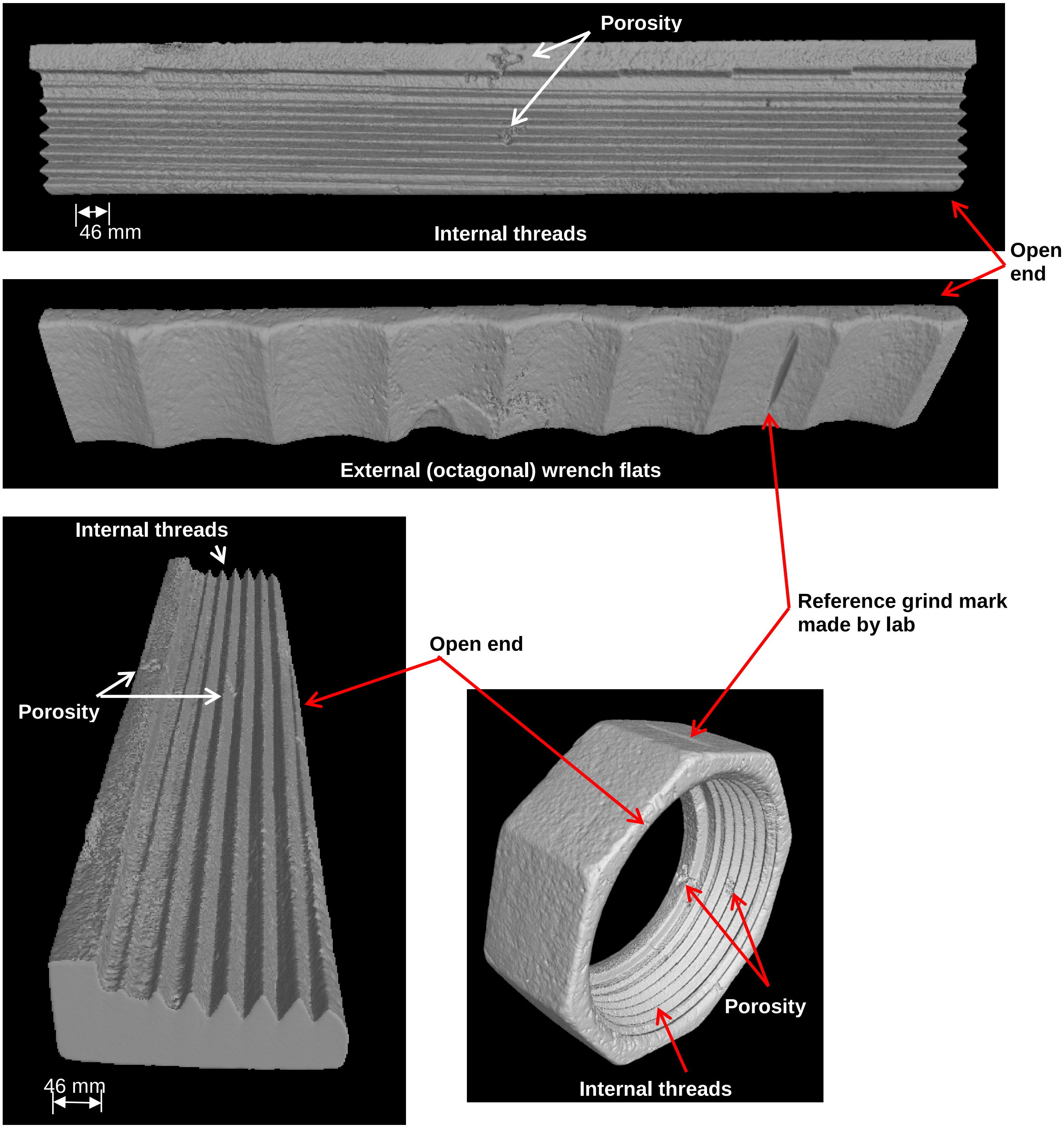
Appendix 2C. Composite cross section diagram of a Reynolds model 30 mercury-containing gas pressure regulator assembly that was not involved in the accident showing the internal parts. This diagram is used for education/illustration purpose. The gas regulator involved in the accident contained a mercury reservoir (cup); toggle links; one spring; diaphragm, and a diaphragm plate that were similar to the ones shown in this diagram. The top cover in this diagram has a restraint design for the upper portion of the spring that is different from the one involved in the accident. Cosmetic changes were made to highlight the orifice and disc portions. Source: Excerpts from Reynolds Gas Regulator Catalog, 1938 edition.



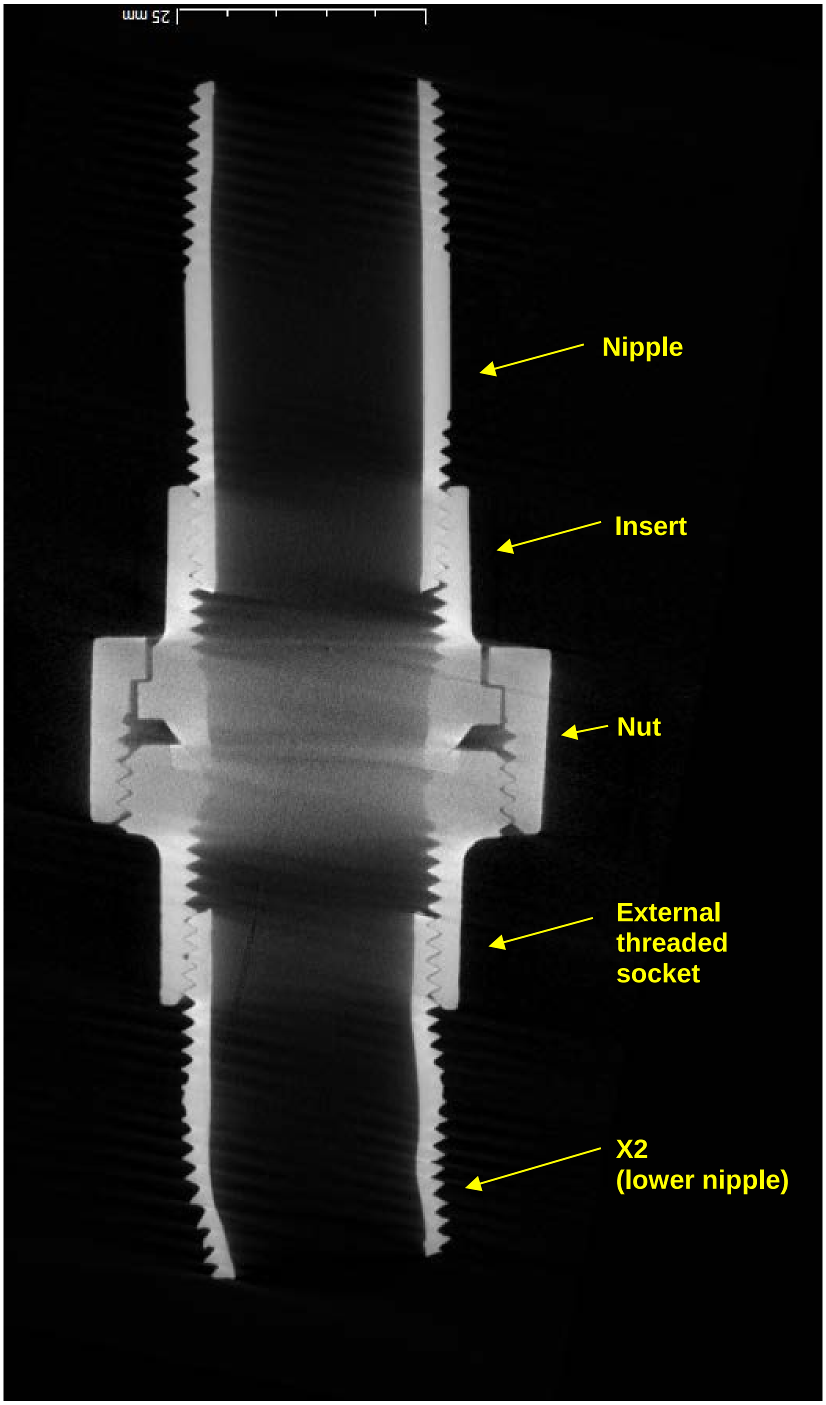
Appendix 3. View through the 2-inch diameter internal threaded side port of an exemplar gas regulator assembly after disassembly of the 2-inch diameter plug, showing the internal mechanisms in the area of the dis and orifice. Parts were not cleaned. This gas regulator assembly is from the residence at 8674 Piney Branch Road.



Appendix 4. X-ray CT reconstructed images of the union external threaded socket from the lower pressure regulator assembly. The image on the upper side of the page shows the external threads that were virtually unrolled on a flat plane; the image on the bottom left side of the page shows an oblique view of the flat unrolled external threads and a cross section through the threads at one end of the threads; and the image on the bottom right shows the entire side view of the external threaded socket. The external and internal threads were intact. “D” indicates one of the diagonal dents in figure 6.



Appendix 5. X-ray CT reconstructed images of the union nut from the lower pressure regulator assembly. The image at the upper side of the page shows the internal threads that were virtually unrolled on a flat plane, image in the center of the page shows virtual unrolled view of the external wrench flats; the image at the bottom left side of the page shows an oblique view of the flat unrolled internal threads with a cross section at one end of the threads; and the image at the bottom right side of the page shows the entire nut. The threads were intact.



Appendix 6. X-ray image showing the cross section of the union assembly for the upper gas regulator assembly.

TABLES

Table 1.
Pressure Leak Testing[9],
Union Assembly for the Upper Regulator Assembly,
Leak was Found at the Joint between
the Nut and External Threaded Socket

Applied Air Pressure (PSIG)	With pipe plug attached to the nipple lower end		With pipe plug removed from the nipple lower end	
	Measured Volumetric Leak Rate in Air (CFM)	Calculated Volumetric Leak Rate for Natural Gas (CFM)	Measured Volumetric Leak Rate in Air (CFM)	Calculated Volumetric Leak Rate for Natural Gas (CFM)
0.1	0.4	0.5	0.4	0.5
0.2	0.6	0.7	0.6	0.7
0.5	0.9	1.1	0.9	1.1
1.0	1.1	1.3	1.2	2.4
2.0	1.4	1.7	1.5	1.8
5.0	2.1	2.5	2.4	2.9
10	3.0	3.6	3.4	4.1
20	4.6	5.5	5.5	6.6

[9] Pressure testing conducted at 63°F.

Table 2 **Inside and Outside Diameters, and Wall Thickness** **(all values are in inches)**			
Description	Measured Outside Diameter	Measured Inside Diameter	Measured Wall Thickness
3/4-Inch ID Vent Pipe Segment (located below pipe tee “W” in figure 1)	1.05	0.81	0.135
1-Inch ID Vent Pipe Segment (located above pipe tee “W” in figure 1)	1.34	1.05	0.138
1-Inch ID Inlet Pipe	1.30	1.05	0.130
2-Inch ID service Pipe	2.38	2.07	0.165

TABLE 3
Outside and Inside Diameters, & Wall Thickness Dimensions For Given Pipe Sizes
(all values are in inches)

Nominal Pipe Size	O.D.	Schedule 40 Thickness		Schedule 10 Thickness		Schedule 5 Thickness	
		I.D.	Wall Thickness	I.D.	Wall Thickness	I.D.	Wall Thickness
3/4	1.050	0.824	0.113	0.884	0.083	0.920	0.065
1	1.315	1.049	0.133	1.097	0.109	1.185	0.065
1-1/4	1.660	1.380	0.140	1.442	0.109	1.530	0.065
1-1/2	1.900	1.610	0.145	1.682	0.109	1.770	0.065
2	2.375	2.067	0.154	2.157	0.109	2.245	0.065
2-1/2	2.875	2.469	0.203	2.635	0.120	2.709	0.083
3	3.500	3.068	0.216	3.260	0.120	3.334	0.083
3-1/2	4.000	3.548	0.226	3.760	0.120	3.834	0.083
4	4.500	4.026	0.237	4.260	0.120	4.334	0.083
6	6.625	6.065	0.280	6.357	0.134	6.407	0.109
8	8.625	7.981	0.322	8.329	0.148	8.407	0.109

Nominal pipe size (NPS) is a North American set of standard sizes for pipes. Specific pipe is identified by the pipe diameter and another non-dimensional number for the wall thickness referred as the schedule (for example – “2-inch diameter pipe, Schedule 40”). Pipe Schedule is the term used to describe the thickness of a pipe. The OD of a pipe is the same for all Schedules in a particular nominal pipe diameter. OD is the outside diameter and ID is the inside diameter. Source:www.McNichols.com